NCEconomics

FINAL REPORT

ACT Healthy Waterways: Economic Analysis

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1 EXECUTIVE SUMMARY

The ACT's Environment, Planning and Sustainable Development Directorate engaged Natural Capital Economics (NCEconomics) to undertake an *ex-post* economic evaluation of the ACT Healthy Waterways program.

The ACT is currently undergoing increased urbanisation that is leading to negative outcomes, including increased risk of pollution to waterways and water bodies. Monitored waterways in the ACT are in either 'poor' or 'fair' condition.[1] Poor water quality has serious consequences yet there is insufficient motivation and capabilities for individual polluters to take appropriate action on their own. Given that there is a market failure, the ACT Government has invested in infrastructure projects, the H2OK program, and research and monitoring projects to reduce pollution of waterways.

ACT Healthy Waterways program aimed at improving water quality in the ACT and downstream into the Murrumbidgee River system by reducing total suspended solids, total nitrogen and total phosphorous through water quality control infrastructure, encouraging behavior change, and improving data and knowledge.

Infrastructure projects included wetlands, raingardens, ponds, gross pollutant traps and waterway restoration. These assets also create additional ecosystem services such as enhanced amenity, physical activity and recreation for residents, urban cooling, and enhanced biodiversity. NCE's economic evaluation assessed all investments and the ecosystem services they created using an ecosystem services valuation framework. The identified key ecosystem services were water quality regulation, enhanced amenity, avoided loss of and/or enhanced recreation opportunities, urban cooling and contribution to biodiversity.

NCE's key economic evaluation method was a cost–benefit analysis and we also undertook a cost-effectiveness analysis for each asset, and a regional economic impact assessment.

The cost–benefit analysis shows the program has present value benefits of $127 million and present value costs of $76 million. Therefore, the project has net present value of $50 million and benefit–cost ratio of 1.66 ('most likely' estimates). Sensitivity analyses indicate the net present value ranges from $24 million to $126 million and the benefit–cost ratio ranges from 1.3 to 2.6. These results indicate that the program was economically viable as the benefits of the program outweigh the costs.

Table ES1. ACT Healthy Waterways costs and cost–benefit analysis results*

Description	Value
Present value of benefits	$127 m
Present value of costs	$76 m
Net Present Value	$50 m
Benefit–cost ratio	1.66

*There are some minor rounding errors

On average, the program assets were found to be generally cost-effective at managing total nitrogen and total suspended solids. Program assets had an average cost-effectiveness of $303 per kilogram while the benchmark assets were $474 per kilogram of total nitrogen. Similarly, the program assets had an average cost-effectiveness of $2 per kilogram while the benchmark assets were $3 per kilogram of total suspended solids. However, they were less cost-effective for managing total

[1] Reports may be accessed at: http://www.act.waterwatch.org.au/chip.html

phosphorous. ACT Healthy Waterways assets had an average cost-effectiveness of $1,827 per kilogram while the benchmark assets were $1,188 per kilogram of total phosphorous.

Overall, the direct gross regional product impact over the three years of construction is estimated at $46.8 million, broken down over the three years as:

- $11.7 million for 2018, with flow-on impacts of $22.3 million
- $4.1 million for 2019, with flow-on impacts of $7.9 million
- $0.3 million for 2020, with flow-on impacts of $0.6 million.

The direct employment impact was estimated at 153 full-time equivalents across the ACT and Queanbeyan regions.

NCE has developed recommendations to guide program budget allocation, monitoring and evaluation mechanisms, and evaluation of ecosystem services from similar future initiatives.

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1 INTRODUCTION

1.1 Background

The ACT's Environment, Planning and Sustainable Development Directorate engaged Natural Capital Economics (NCEconomics) to undertake an *ex-post* economic evaluation of the ACT Healthy Waterways program to estimate the value-for-money in investing in the ACT Healthy Waterways Program.

1.2 Government intervention

Government intervention can be used to change the behaviour of businesses and individuals, to address market failures and to achieve social and environmental benefits that would not otherwise be delivered. The ACT is currently undergoing increased urbanisation that is leading to negative outcomes, including increased risk of pollution to waterways and water bodies. Annual reports produced by the Catchment Health Indicator Program show that a majority of monitored waterways in the ACT are in either 'poor' or 'fair' condition (compared to 'good' or 'excellent').[2] In economics, this type of pollution is referred as an 'externality problem' that arises because of absence of fully defined property rights. This means that individual actions of residents, property developers and other stakeholders leads to pollution in waterways and water bodies, yet the consequences are experienced by others who are not necessarily responsible for the pollution (e.g. downstream water users).

Poor water quality has serious consequences on the waterways and water bodies within the ACT (and downstream) yet there is insufficient motivation and capabilities for individual polluters to take appropriate action on their own. The consequences of the poor water quality impact the environment and economy. Therefore, there is an evident market failure in managing and mitigating pollution loads in waterways and water bodies. Given the market failure, the ACT Government, together with the Australian Government, invested in the ACT Healthy Waterways program.

1.3 ACT Healthy Waterways investment components

The ACT Healthy Waterways program aimed at improving water quality in the ACT and downstream into the Murrumbidgee River system by reducing total suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP) via constructing water quality control infrastructure, encouraging behavior change, and improving data and knowledge.

There were two phases of investment within the ACT Healthy Waterway Program:

- Phase 1 provided baseline information, focusing on data collection (water quality monitoring), analysis and modelling of potential improvements from water quality interventions. Phase 1 also provided the rationale for Phase 2.
- Phase 2 started in 2016 and involved three broad investment components: infrastructure projects, behaviour change and social initiatives, and research and monitoring projects. These three components are discussed in detailed below. This assessment is of the Phase 2 investment.

Infrastructure projects

Infrastructure projects were undertaken to construct wetlands, ponds, raingardens, gross pollution traps and to restore waterways. The purpose of these projects is to enhance water quality and waterway health in priority catchments and locations downstream. However, additional ecosystem services are also provided by these projects. For example, an urban wetland provides benefits such as water filtration, urban cooling, habitat for plant and animals, enhanced amenity, and flood water

[2] Reports may be accessed at: http://www.act.waterwatch.org.au/chip.html

storage. Therefore, in addition to water quality improvement benefits, other benefits that are delivered by these infrastructure projects.

Behaviour change and social initiatives

Contaminated stormwater runoff from streets, residential properties, development sites and commercial and industrial sites significantly contribute to pollution of urban waterways. Community awareness is an important factor towards improving waterway health.

Behaviour change and social initiatives were undertaken under the *H2OK: Keeping our Waterways Healthy Program* (H2OK program) aimed at improving community waterway literacy and capacity with the intent to reduce the risks to waterways from residents' actions (e.g. reducing litter entering waterways from households).

Capacity building was supported by demonstration sites around the ACT and nearby NSW regions, including significant consultation and surveying to understand how the community interacts with waterways and the impediments to behaviour change. The H2OK program also funded the ACT Waterwatch program, which engages communities with the environment through monitoring and caring for catchments as well as education and awareness of catchment health issues.

The objective of the H2OK program was to achieve a reduction in both current and future risks to waterway condition. Benefits of the H2OK program are realised when communities change their behaviour and minimise waterway pollution actions and establish pollution-mitigating infrastructure on private properties.

Research and monitoring projects

Two research projects were undertaken as part of the ACT Healthy Waterways. In-lake treatments that could improve water quality and reduce the number of closures caused by blue-green algae were assessed, alongside the relationships between pond depth and water quality. The program also funded the Upper Murrumbidgee Waterwatch Program. Other projects were on monitoring of water quality as well as improvements of water monitoring practices.

2 METHODOLOGY

Key points

- To capture these benefits derived from ACT Healthy Waterways, NCE used an ecosystem services valuation framework. Ecosystem services are the benefits people obtain from the natural environment. The benefits identified were then described and quantified to inform an economic assessment.

- Three complementary economic assessment methods were used to evaluate ACT Healthy Waterways: cost–benefit analysis, cost-effectiveness analysis and a regional economic impact assessment.

- Cost-benefit analysis (CBA) was used to provide a detailed and comprehensive analysis of the whole ACT Healthy Waterways Program. A broad suite of benefits was identified, scoped and valued within an ecosystem services framework. A project is deemed economically beneficial when the NPV is greater than $0 and the BCR is greater than 1.

- Cost-effectiveness analysis (CEA) was used to benchmark the relative efficiencies of infrastructure projects in reducing pollutant loads. CEA is a way to benchmark the effectiveness of pollutant removal given the cost of different assets funded under the program. The CEA compared the present value of costs against the estimated pollution load reductions per pollutant. However, CEA does not consider other socio-economic benefits attributable to the assets, for example amenity benefits associated with a constructed wetland.

- An economic impact assessment was also undertaken to estimate attributable gross regional product and employment impacts. The input-output economic impact estimation approach was used to measure the economic impact from the capital expenditure on 20 infrastructure assets. The contribution of the infrastructure assets to employment was also calculated.[3]

- Given the variability and uncertainty in some of the underlying assumptions and data sources, significant sensitivity analysis was undertaken. A range of values was estimated using Monte-Carlo simulations with 20,000 iterations to identify the 90 per cent confidence interval for each estimated ecosystem service benefit.

2.1 Evaluation framework

Ecosystem services are the benefits people obtain from the natural environment. To capture these benefits derived from ACT Healthy Waterways, NCE used an ecosystem services valuation. The current best practice framework for this approach is outlined in the Common International Classification of Ecosystem Services (CICES).

The CICES has been developed by the European Environment Agency to as part of a revision of the *System of Environmental Economic Accounting: Experimental Ecosystem Approach* (SEEA:EEA), currently being led by the United Nations Statistical Division (UNSD). In Australia, development of the SEEA:EEA has had input and is endorsement by various Australian Government departments, including the

[3] The economic impact assessment using multipliers was undertaken for infrastructure projects only.

Australian Bureau of Statistics, the Bureau of Meteorology, and the Department Agriculture and Water Resources, among others.

The CICES ecosystem services are categorised into three broad types:[4]

1. *Provisioning services*: all the products obtained from ecosystems (e.g. raw water).
2. *Regulating services*: benefits obtained from the regulation of ecosystem processes (e.g. regulation of water quality, air quality, climate and erosion).
3. *Cultural services*: related to non-material benefits, for instance recreation, aesthetic experiences, and spiritual enrichment.

The conceptual framework of CICES is based on the cascade model shown in Figure 1. This model shows cause–effect relationships for how changes to the environment lead to changes in social and economic systems. The ecosystem services framework starts with the concept of ecosystem assets — defined as spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. An example of an ecosystem asset is a river ecosystem.[5] The extent and condition of these assets are influenced by pressures (e.g. reductions in vegetated riparian zones or increases in impermeable surfaces nearby) and policy interventions aimed at alleviating these pressures (e.g. revegetating riparian zones or construction of wetland systems). The functioning of ecosystem assets generates a range of 'services' that contribute to human wellbeing.[6] These services are known as ecosystem services and they are the 'final' outputs from ecosystems that most directly affect the wellbeing of people. [7] Services, in the cascade, give rise to goods and benefits, as in the case of improved amenity values when property price premiums are achieved and the 'production boundary' is crossed.

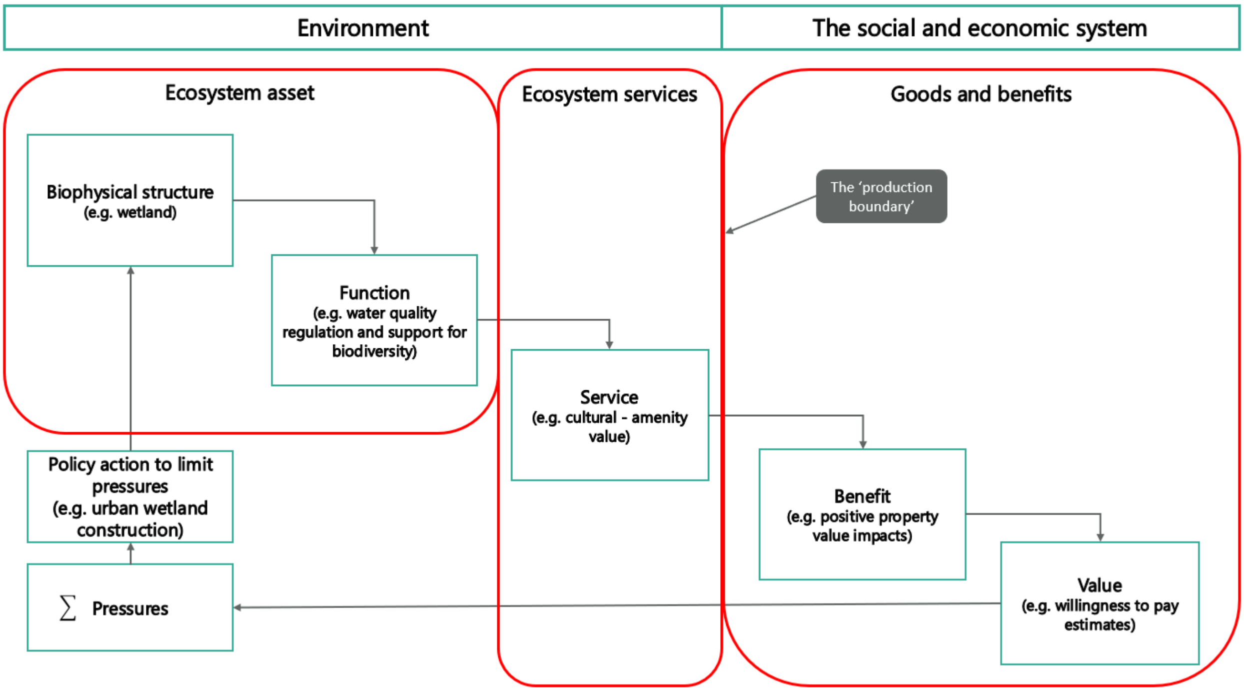


Figure 1. The cascade model of ecosystem services

Source: adapted from Potschin and Haines-Young (2016)

[4] All these three ecosystem services are underpinned by the 'supporting services' (FAO, 2019).

[5] Ecosystem assets are characterised in terms of *extent* and *condition*.

[6] CICES defines ecosystem services as the 'contributions that ecosystems (i.e. living systems) make to human well-being'.

[7] Haines-Young, R. and M.B. Potschin (2018): Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. Available from www.cices.eu.

The ecosystem services valuation was used to identify the ecosystem services which were then investigated further for benefits estimation. The benefits were then used to inform the cost-benefit analysis as well as the cost-effectiveness analysis. The regional economic impact assessment was done outside of the ecosystem services valuation and the results are not included in the either the cost-benefit analysis or the cost-effectiveness analysis.

Earlier frameworks such as the Millennium Ecosystem Assessment (MA, 2005), list *supporting services*. as fourth ecosystem service. The CICES acknowledges the importance of the supporting service but does not include into the key categories. According to Potschin and Haines Young (2018) the CICES's focus is to identify the final outputs from ecosystems that might form the basis of valuation and assessment. Therefore, the CICES classifies services located at the interface of the biophysical and socioeconomic component in Figure 1. While, the valuation will be informed by the final services it is important to note that these final services are underpinned by the supporting services and without these supporting services the final services will not be realised.

2.2 Economic evaluation approaches

Our key economic evaluation method was a cost–benefit analysis (CBA); however, we also undertook a cost-effectiveness analysis and an economic impact assessment.

Cost–benefit analysis of the whole program

A CBA was used to evaluate the economic benefits attributable to the ACT Healthy Waterways program against the costs of implementing the program. An appraisal period of 30 years and a 7% discount rate was used as per the Office of Best Practice Regulation (2014) and Infrastructure Australia (2018) guidelines. The CBA approach is outlined in Figure 2. Within the CBA framework, two primary decision rules are used:

- Net present value (NPV): NPV assesses the net benefits (benefits less costs) over the full life cycle of the project. The key decision rule is that a project has demonstrated it is economically beneficial if the NPV is > $0.
- Benefit-cost ratio (BCR): BCR is the ratio of benefits to costs (benefits divided by costs). The key decision rule is that a project has demonstrated it is economically beneficial if the BCR is >

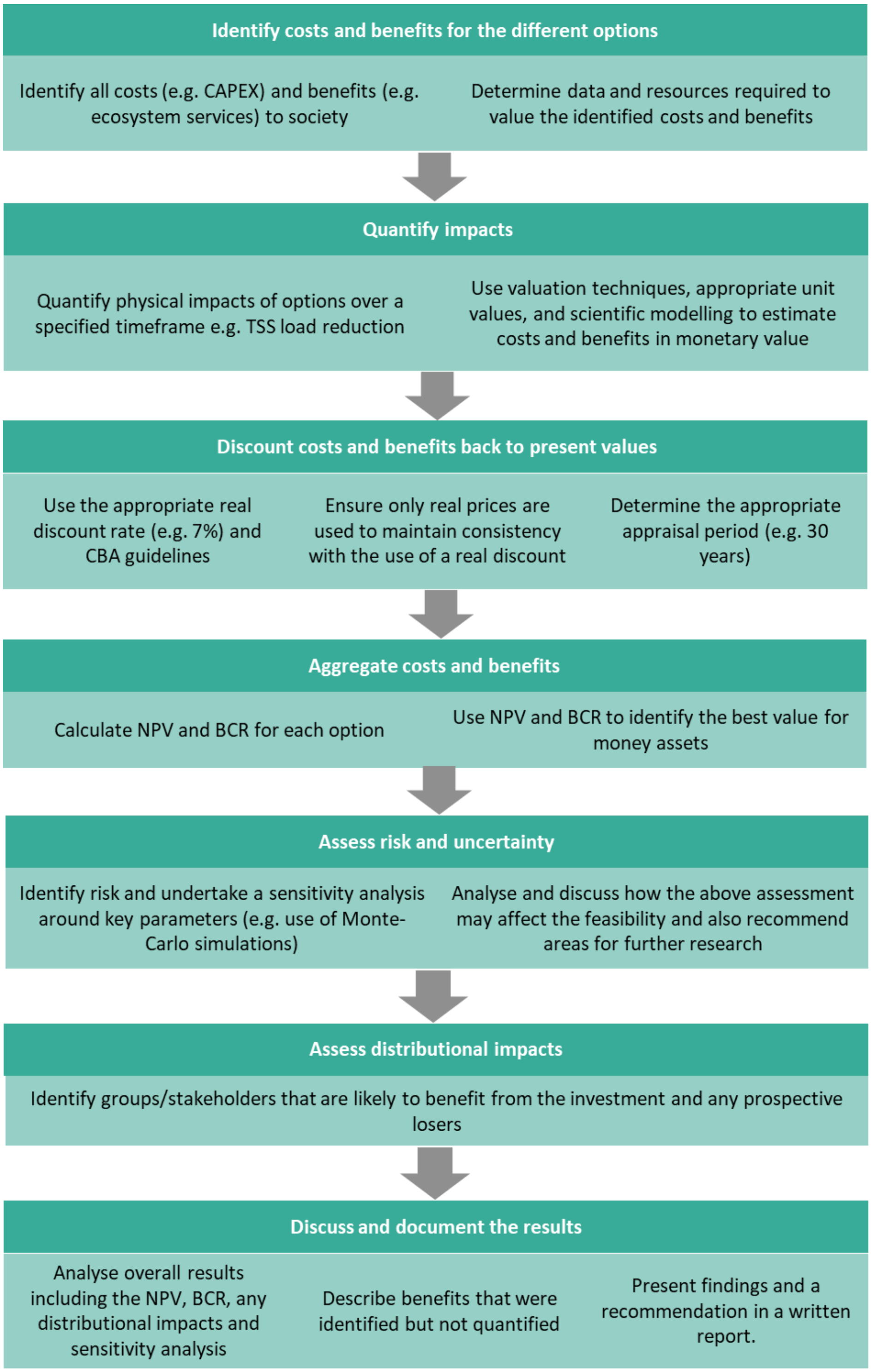


Figure 2. The cost–benefit analysis process

Cost-effectiveness analysis of infrastructure projects

The type of asset, surrounding land configuration and size will affect its efficacy (performance) in reducing waterway pollution. Therefore, in addition to the CBA, we used the cost information and the pollution abatement rates to undertake a cost-effectiveness analysis (CEA) for each of the infrastructure assets.

The CEA results enable assets to be ranked by their efficacies in reducing pollution loads, given their cost. A CEA also provides a way to compare the current assets' cost-effectiveness against industry benchmarks.

Economic impact estimation

An economic impact analysis was undertaken to estimate the regional economic and employment impacts. Typically, this estimation uses an Input–Output (I-O) approach (Miller and Blair, 2009). Sophisticated economic impact analysis can also be undertaken using computable general equilibrium (CGE) modelling. Both of these economic impact analysis approaches assess how the economy will respond to a policy or a major project. While a CGE is the superior approach of the two, it was outside the scope of this assessment and, therefore, the I-O approach was used.

The I-O analysis was undertaken using the AURIN Economic Impact Tool. Input data for the I-O estimation is the annual direct capital expenditure for the 20 program assets.[8] All expenses were counted as construction sector costs in the ACT and Queanbeyan (NSW) regions. Key outputs from this assessment are the contribution to the Gross Regional Product (GRP) and the estimated contribution to employment. GRP is a measure of the net contribution of an activity to the regional economy. It is calculated as the value of output less the cost of goods and services used in producing the output (or as the sum of all incomes earned in wages by households, gross operating surplus earned by firms and taxes earned by the government). The contribution to GRP will be less than the actual construction cost.

2.3 Sensitivity analysis

Several assumptions were made in undertaking the economic evaluation. Given the uncertainty of some on the key input parameters, ranges of these inputs were included in the modelling process to create lower, middle and upper bounds. Consequently, a range of values for the costs and benefits are provided for each quantified ecosystem service benefit in the results section as well as for the reported investment criteria (BCR and NPV). A range of values was estimated using Monte-Carlo simulations with 20,000 iterations to identify the 90 per cent confidence interval for each estimated ecosystem service benefit.

[8] See Appendix A for the descriptions of all 20 infrastructure assets

3 ASSESSMENT OF THE INVESTMENT PORTFOLIO

Key points

- The program included 20 infrastructure projects covering construction of ponds, wetlands, raingardens and restoration of waterways. The benefits assessed for each of the assets were:
  - water quality improvement (avoided abatement costs)
  - enhanced amenity
  - enhanced recreation and physical activity stimulation
  - urban cooling
  - enhanced biodiversity.
- Behaviour change initiatives in the H2OK project were designed to reduce the risk of pollutants entering the waterways.
- The ongoing research and monitoring projects are designed to enhance the efficiencies of the interventions and investments over time.

3.1 Infrastructure projects

The ecosystem services of 20 infrastructure assets were analysed. Figure 3 shows the location of the infrastructure projects across the ACT and in nearby New South Wales. Detailed information about each asset, including its location, aerial imagery (before and during construction), timeframes, footprint area, pollutant load reductions and a summary of the ecosystem services assessment is in Appendix A.

Figure 3. Infrastructure asset locations across the ACT and New South Wales

Table 1 is a summary of the identified ecosystem service benefits by infrastructure asset. Five key benefits from ecosystem services were identified from an assessment of the infrastructure projects: water quality improvements (avoided abatement costs); enhanced amenity; enhanced recreation and physical activity stimulation; urban cooling; and enhanced biodiversity. These services are within the ‘cultural and regulation services’ categories of the Common International Classification of Ecosystem Services (CICES, 2018), which is currently the guiding global ecosystem services classification guideline.

Table 1. Identified benefits from ecosystem services by infrastructure asset

Project code and type	Water quality improvement	Enhancement amenity	Enhanced recreation and physical activity stimulation	Urban cooling	Enhanced biodiversity
FW012 — Wetland	✓				✓
FW019 — Wetland	✓	✓	✓	✓	✓
FW025 — Wetland	✓				✓
LM013 — Wetland	✓	✓	✓	✓	✓
TG008 — Raingarden	✓	✓			✓
TG010 — Raingarden	✓	✓			✓
TG011 — Wetlands	✓	✓	✓		✓
TG012 — Waterway restoration	✓	✓	✓		✓
TG017 — Raingarden	✓		✓		✓
TG029 — Raingarden	✓	✓			✓
TG030 — Pond	✓	✓		✓	✓
UM001 — Waterway restoration	✓				✓
UM004 — Raingarden	✓	✓	✓	✓	✓
WB004 — Wetland	✓	✓	✓	✓	✓
WB009 — Wetland	✓	✓	✓		✓
WB010 — Waterway restoration	✓	✓	✓		✓
YA001 — Waterway restoration	✓				✓
YA002 — Waterway restoration	✓	✓		✓	✓
YA016 — Raingarden	✓	✓	✓	✓	✓
YA020 — Pond	✓	✓	✓	✓	✓

✓ = identified benefit

3.2 Behaviour change projects

The H2OK program was a key education initiative of behaviour change projects funded through the ACT Healthy Waterways Program designed from July 2016 to July 2019. The aim of H2OK was:

> 'to reduce pollutants entering [the region's] waterways by engaging with the community and teaching people better ways to keep pollutants out of our water'. (ACT Government, 2019).

H2OK was intended to influence behaviour that would lead to improvements in the health of waterways in the ACT and surrounding regions including Queanbeyan, Cooma and Yass. H2OK was considered to be particularly important because it is currently understood that the biggest cause of water pollution in lakes and waterways is from contaminated urban stormwater run-off from streets, houses, development sites, retail and industrial sites. A community perceptions survey (Schirmer 2016) showed that many people engage in behaviours that are detrimental to the health of waters, such as putting grease and other contaminants down household drains and blowing garden litter into street drains, among others.[9]

More specifically, H2OK intended to enhance awareness of stormwater within the ACT, explain the human impact on the health of the region's waterways and create a connection between an individual's actions and the quality and quantity of stormwater run-off.

The H2OK program comprised a multi-pronged approach that included six activities:

1. a print, radio and online media campaign
2. a social media campaign
3. drain stencilling
4. roadshows and education events
5. bus tours of demonstration sites
6. tours of the demonstration sites.

3.3 Research and monitoring projects

Seven studies were undertaken as part of the research and monitoring component of ACT Healthy Waterways. The type of projects varied from cultural heritage assessments to research programs to address key knowledge gaps associated with poor water quality in the ACT's lakes and waterways. The list of reports is in Appendix C.

Research outputs and outcomes

The research and monitoring component of the ACT Healthy Waterways provides valuable knowledge and understandings that are key to addressing previously existing knowledge gaps. Importantly, reducing these gaps leads to better decision making, and improved ecological and economic outcomes for the waterways and water bodies.

The research and monitoring projects mainly focused on the health of Lake Tuggeranong. The investigations examined issues stemming from excessive nutrient concentrations that result in a proliferation of blue-green algae (BGA). Excessive BGA is a problem for the health of in-lake living organisms, as well as impacting on other ecosystem services such as water-based recreation (e.g. rowing). A study completed by the Institute of Applied Ecology (Reich et al., 2017) noted that very little is known about dissolved oxygen in Lake Tuggeranong, the amount of sediment in the lake, and the amount of phosphorous that is bioavailable. All of these problems cause algal blooms. The findings from another report undertaken by the Institute of Applied Ecology (Ubrihien et al., 2018) highlight the complexity of algal blooms in Lake Tuggeranong, finding that the lake is receiving large loads of nutrients from external sources as well as large amounts of nutrients released from in-lake sediment under certain conditions. Although these studies did not definitively determine the solution to nutrient issues, they did improve knowledge about the processes influencing poor water quality events. This work will improve decision making and, therefore, the societal benefit derived from the lake.

Extensive cultural heritage assessments were undertaken at the sites of two wetlands (FW012 and FW025) and a site for waterway restoration (YA001). These assessments provided further information

[9] See Appendix B for a summary of survey results from the Schirmer's (2016) *Water quality and the community* report.

on whether works could be carried out at each site. Where significant cultural heritage was identified, the works were scaled down or redesigned to preserve the cultural heritage of the sites. Bowen (2016) concluded that several Aboriginal sites were noted as existing within a four-kilometer radius of YA001, FW012 and FW025, attesting to Aboriginal use of the general landscapes. However, site FW025 had been significantly disturbed and had no Aboriginal heritage was discovered. The assessments at YA001 water restoration site revealed in-situ and sub-surface Aboriginal archaeological material given its proximity to Yarralumla Creek, nearby to previously identified stone artefacts. A desktop analysis for FW012 revealed the works had only a very low potential to disturb any Aboriginal cultural heritage (Bowen 2016). With this in mind, no Aboriginal archaeological protection plan, Aboriginal heritage excavation permit, or any form of sub-surface test excavation investigation was recommended for sites FW012 or FW025. However, a program of controlled archaeological excavation at certain locations at site YA001 was recommended given that this site was likely to impact Aboriginal archaeology.

Future research impacts

The research and monitoring outputs funded under ACT Healthy Waterways provides important information for current and future decision making on pollution abatement works in the ACT region, particularly within the Tuggeranong Catchment. It is anticipated that further investment on pollution will be funded and the Directorate has identified a range of 'no regrets' investments in the catchment that they will be investing in. These future investments include community education, works on irrigated open space, and upgrades to gross pollutant traps. The Directorate estimates that further investment in the order of $1 million to $10 million will be made on these activities. Furthermore, there may be more targeted investment into the catchment coming from the findings from another year of research currently underway in the catchment. As such, NCE is confident there will be an efficiency dividend[10] from this research and monitoring.

[10] An efficiency dividend in this case means applying some efficiency gains associated with access to reliable and up to date research information leading to more efficiency outcomes for future programs targeted at waterway health in the ACT.

4 PROGRAM COSTS AND BENEFITS

Key points

- The analysis incorporates all capital, operating, maintenance and other project costs such as the H2OK project, research and monitoring, and overall project administration costs.
- Operating and maintenance costs for individual assets were estimated from previous studies. While these estimated costs are reasonable, one downside is that it is hard to compare cost-effectiveness for the same asset type (e.g. wetlands) at different locations.
- The analysis presented in this report incorporates all capita, operations and maintenance and other project costs such as the H2OK project, research and monitoring, and overall project administration costs.
- A comprehensive suite of benefits was included in the analysis. To the extent possible, benefits were quantitatively assessed. Where quantification was not possible, benefits were qualitatively assessed. Therefore, the aggregate quantitative estimate is conservative.
- The annual value of pollution abatement benefits attributable to the infrastructure projects is $7.8 million (most likely estimates, in 2019 Australian dollar value). This estimate is based on the avoided cost of the most expensive pollutant load for each of the 20 infrastructure assets.
- While quantifying the impacts of improvements in water-sensitive behaviours and reductions in waterway pollution will require further investigation, there are indications that the H2OK program is making ACT residents more conscious of the impact of their behaviour on water quality. This consciousness is leading some residents to act on this knowledge in deliberate ways, contributing to making ACT residents 'water sensitive citizens' (Dean, et al., 2016b). The benefits of behaviour change are estimated at $56,600 per annum over five years (most likely estimate).
- The infrastructure assets have a longer life than the 30-year appraisal period, thus a residual value was estimated and adjusted to 2019-dollar values for each asset. The estimated value was then used to capture the remaining value as a benefit. This value was estimated to be 40% of the individual assets' CAPEX. ACT Healthy Waterways assets were estimated to have cumulative value of $2.7 million at the end of the 30-year appraisal period.
- Based on previous studies, the value of additional visits to Lake Burley Griffin and Lake Tuggeranong due to fewer closure days due to reduced BGA blooms is estimated to be $573,800 per annum (most likely estimate).
- A conservative approach was taken to estimate the property price impacts of enhanced amenity due to the construction of assets. For example, no benefits were assumed for assets located in areas that are already dominated by vegetated and natural open spaces including water bodies. It is estimated that there is property price impact of $1.7 million per annum from 10 assets ('most likely' estimate).
- The ACT Healthy Waterways assets have contributed to enhanced biodiversity through increased quality and quantity of native vegetation and water bodies. However, it was not possible to estimate the marginal improvements in biodiversity to support a quantitative economic valuation. Thus, the biodiversity benefit was not quantified.

- Urban cooling benefits are relatively small, largely due to the small size of the individual assets as well as the location of the assets relative to dwellings. Of the three case studies assessed, two were found to have a combined annual benefit of $980 for 51 households ('most likely' estimate).

- The benefits of the infrastructure assets created by the ACT Healthy Waterways program to passive and active recreation are acknowledged. However, these were not quantified due because the urban assets are located in existing recreation spaces that are already catering for recreation through provision of facilities such as pathways, benches and other social amenities.

4.1 Program costs

The Directorate supplied the costs incurred in the program:

- capital expenditure (CAPEX) data associated with all infrastructure investment activities from the program
- ongoing total operating and maintenance costs (OPEX) for all assets
- non-infrastructure costs (i.e. research, monitoring, behavior change and program management costs).

Capital expenditure

Table 2 provides a summary of total CAPEX data for each asset. For the purposes of the CBA, these estimates were allocated across the 2017–2019 period based on the aggregate pattern of expenditure from the ACT Budget papers.

Table 2. Infrastructure investment asset capital cost

Project code and name	CAPEX ($)
FW012 — Wetland	2,356,832
FW019 — Wetland	4,474,431
FW025 — Wetland	1,525,232
LM013 — Wetland	2,826,425
TG008 — Raingarden	2,656,074
TG010 — Raingarden	2,158,309
TG011 — Wetlands	3,859,144
TG012 — Waterway restoration	2,060,549
TG017 — Raingarden	3,548,018
TG029 — Raingarden	2,770,383
TG030 — Pond	2,810,093
UM001 — Waterway restoration	2,555,331
UM004 — Raingarden	1,462,480
WB004 — Wetland	4,081,280
WB009 — Wetland	3,197,708
WB010 — Waterway restoration	1,390,437
YA001 — Waterway restoration	1,732,418
YA002 — Waterway restoration	1,541,137
YA016 — Raingarden	1,892,989
YA020 — Pond	2,619,058
Total	**51,518,328**

Operating and maintenance expenditure

Total OPEX data for program assets was provided by the Directorate at a program level. This data assigned the total OPEX to individual assets on an annual basis over the 30-year appraisal period. Further information was then sought from previous studies on similar assets undertaken by Alluvium, Melbourne Water and Bligh Tanner Consulting as reported in Alluvium (2017). The costs listed in Table 3 were used as annual OPEX values. When we applied these costs to the individual assets, the aggregate range of estimates is consistent with the program-level estimates provided by the Directorate. The data provided by the Directorate indicates an annual range of $494,000 to $1.6 million. Our estimated annual OPEX values range from $700,000 to $1.1 million. Therefore, we are confident that the unit values sourced from Alluvium (2017) are appropriate for use in estimating the operating costs for the individual infrastructure projects.

Table 3. Annual operating cost per asset

OPEX per m2	Low	Most Likely	High
Wetland	$1.68	$2.10	$2.63
Raingarden	$4.19	$5.24	$6.55

Source: Alluvium (2017)

OPEX for ponds and waterway restoration were assumed to be the same as those for wetlands. The cost range in Table 3 was used as input to a sensitivity analysis using Monte-Carlo simulation process to capture the variability in the estimated annual operating costs. Figure 4 shows that the 5th and 95th percentile for the total OPEX are $0.77 million and $0.99 million. Therefore, there is 90% probability that the OPEX cost is more than $0.77 million and less $0.99 million

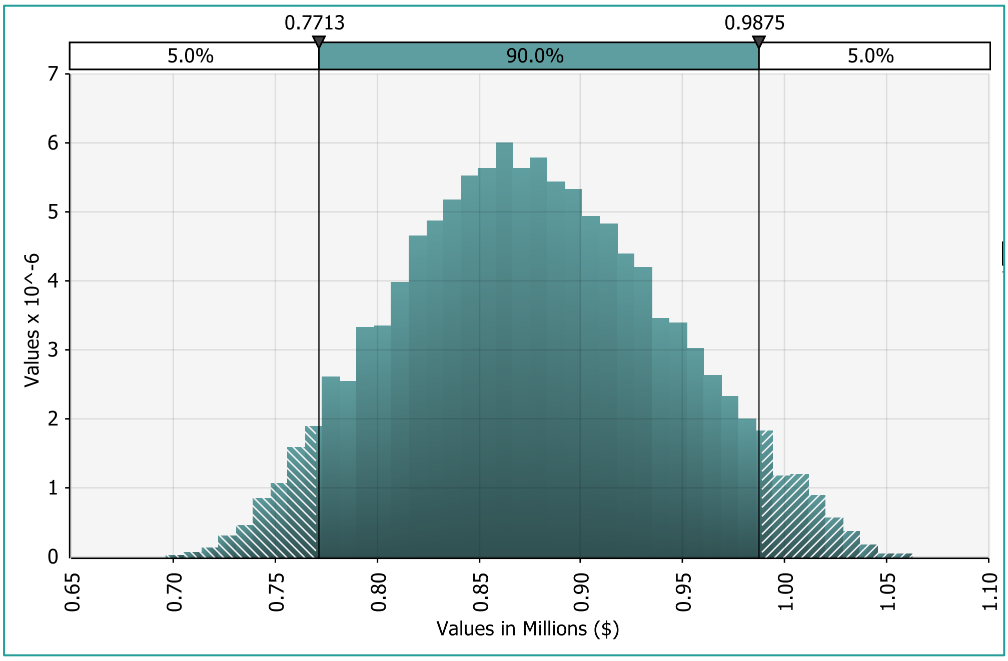


Figure 4. OPEX Monte-Carlo simulation results

Other project costs

Further costs were also provided by the Directorate. These costs were the annual non-construction costs of ACT Healthy Waterways. The total non-construction costs were estimated as $7.3 million over eight years ending 2021. These costs include program management, the H2OK program, and research and monitoring projects.

All costs were included in the analysis to estimate program costs and the life-cycle costs for the infrastructure investments.

4.2 Program benefits

After a comprehensive assessment of all investment assets and projects funded within the ACT Healthy Waterways program, further information was sought to inform the benefit estimation process for the identified ecosystem services. A literature review established unit values for benefit-transfer estimation of the biophysical changes stemming from the program. While all benefits from each of the infrastructure assets relate to the avoided costs of pollution management and were able to be quantified, only a proportion of the assets had amenity benefits that were quantified, and no biodiversity benefits were quantified. A detailed quantitative assessment of the urban cooling impacts was undertaken for three of the assets.

A review of the design reports was undertaken to investigate any significant negative impacts from the construction of the assets. These design reports indicated that care was taken to ensure the new assets did not lead to adverse outcomes for local communities and wildlife. For example, the constructed designs improved or did not worsen flood risks. In some cases, extensive cultural heritage assessments were undertaken at the sites (e.g. wetlands FW012 and FW025, and a site for waterway restoration YA001). These assessments were undertaken to provide further information on whether works could be carried out as per the designs. Where cultural heritage was identified, the works were scaled down or redesigned to preserve the cultural heritage of the sites. Therefore, it is assumed that there were no material disadvantages from the works undertaken through the ACT Healthy Waterways investment.

Table 4 provides a summary of the identified key ecosystem service benefits by infrastructure asset. *Q* signifies that a benefit was identified and quantified. A tick (✓) indicates that a benefit has been identified but its economic value was not estimated.

Table 4. Identified ecosystem service benefits by infrastructure asset

Project code	Water quality improvement	Enhancement amenity	Enhanced recreation and physical activity stimulation*	Urban cooling	Enhanced biodiversity
FW012 — Wetland	Q		Q		✓
FW019 — Wetland	Q	Q	Q	✓	✓
FW025 — Wetland	Q		Q		✓
LM013 — Wetland	Q	Q	Q	✓	✓
TG008 — Raingarden	Q	✓	Q		✓
TG010 — Raingarden	Q	✓	Q		✓
TG011 — Wetlands	Q	✓	Q		✓
TG012 — Waterway restoration	Q	Q	Q		✓

Project code	Water quality improvement	Enhancement amenity	Enhanced recreation and physical activity stimulation*	Urban cooling	Enhanced biodiversity
TG017 — Raingarden	Q		Q		✓
TG029 — Raingarden	Q	✓	Q		✓
TG030 — Pond	Q	Q	Q	✓	✓
UM001 — Waterway restoration	Q		Q		✓
UM004 — Raingarden	Q	Q	Q	✓	✓
WB004 — Wetland	Q	Q	Q	✓	✓
WB009 — Wetland	Q	Q	Q		✓
WB010 — Waterway restoration	Q	Q	Q		✓
YA001 — Waterway restoration	Q		Q		✓
YA002 — Waterway restoration	Q	Q	Q	✓	✓
YA016 — Raingarden	Q	✓	Q	✓	✓
YA020 — Pond	Q	Q	Q	✓	✓

✓ = identified benefit, Q=identified and quantified benefit, *Only the lake access related recreation benefits were quantified

Avoided pollution abatement costs

An avoided-cost approach was used to estimate the benefits of pollution load reductions. Data from previous studies on efficacies and cost of abatement actions were used. Assessments previously undertaken by Alluvium (2017) and Water by Design (2010, 2014) provide estimated efficacies and costs of urban water quality management actions. The following assets were identified as alternative management actions to manage waterway health in the ACT: streetscape raingardens, WSUD tree pits, grass swales, cartridge filters, end-of-pipe bioretention systems, wetlands and stormwater harvesting. A description of each of the assets is in Table 5.

Table 5. Management actions to mitigate polluted stormwater runoff

Management action	Description
Streetscape raingardens	Small bioretention systems within land lots or along streets. Four variations were included based on size (e.g. small or big) and whether land costs are included.
Street trees	Street trees that are passively irrigated by stormwater runoff from the road kerb. There were two variations: 'with' or 'without' formal biofiltration soil filter.

Management action	Description
Grass swale	Roadside grass swale. There were two variations: an inexpensive version in lieu of an underground piped drainage or a complementary grass swale in addition to a piped drainage system.
Cartridge filters	A manufactured stormwater treatment device that uses fine filtration and activated media to remove particulate and soluble pollutants.
Raingarden	A system designed to filter stormwater through a vegetated, soil-based filter. Four variations were included based on size (small or big) and whether includes land costs.
Wetland	A constructed system made up of densely vegetated shallow marsh system designed to detain and improve the quality of stormwater runoff.

Source: adapted from Water by Design (2014) and Alluvium (2017)

All abatement costs were adjusted to 2019-dollar values and used as an indicator of avoided costs or comparable costs of pollution management. An average cost ($) per kilogram for each of the pollutants was estimated based on various alternative and practical actions for pollution reduction. These were then used as the range of unit benefits in the CBA and CEA modelling. These unit costs are based on the CAPEX, OPEX and total load reductions over a 30-year period as expressed in Equation 1.[11]

$$X = \frac{C + \sum_{i}^{n} A_i / (1+r)^i}{\sum_{i=1}^{n} P} \qquad \textbf{Equation 1}$$

Where:

X = abatement cost per unit of pollution ($/kg)

C = capital cost of pollution abatement action ($)

A = annual operating costs of abatement action ($)

r = discount rate

P = annual amount of pollution abated (kg)

i = year

n = period of analysis

By not discounting the pollution load over time we expect a lower BCR than when the loads are also discounted. The relationship between X and the benefit-cost ratio is expressed in Equation 2

$$BCR = \frac{X+Y}{Project\ costs} \qquad \textbf{Equation 2}$$

Where:

X = abatement cost per unit of pollution ($/kg) as per Equation 1

Y = all other quantified benefits from the ACT Healthy Waterways program

Project costs = Discounted ACT Healthy Waterways program costs

Table 6 shows the range of values used to estimate the avoided pollution abatement costs. For example, the average annual cost per kilogram of achieving a reduction in total nitrogen is $474, but this cost can range from $258 to $853, depending on the abatement action and efficacy levels.

[11] This equation applies a discount rate to future costs but does not apply a discount rate to future pollution loads Hall (2012).

Table 6. Annual unit abatement cost by pollutant ($/kg), adjusted to 2019-dollar values

Pollutant	Low	Most Likely	High
TN	258	474	853
TP	702	1,188	2,065
TSS	1	3	5

The pollutant with the *highest* abatement value was used as measure of the avoided cost given that an asset will achieve with concurrent load reductions for TSS, TN and TP. For example, while the avoided abatement costs were estimated for each pollutant for asset FW012, only the highest-cost pollutant (i.e. TSS) was used to estimate the benefit. This approach avoids significant double counting where the total avoided abatement value for pollutant is aggregated. Table 7 shows the total estimated avoided abatement cost for each asset and pollutant.

Table 7. Annual estimated avoided abatement cost by pollutant ($)

Project code	Asset type	TN	TP	TSS	Avoided cost ($pa)	Benefit estimation pollutant
FW012	Wetland	42,660	34,452	49,500	49,500	TSS
FW019	Wetland	663,600	380,160	900,000	900,000	TSS
FW025	Wetland	237,000	142,560	210,000	237,000	TN
LM013	Wetland	600,084	290,050	410,730	600,084	TN
TG008	Raingarden	225,624	73,656	138,780	225,624	TN
TG010	Raingarden	410,958	122,602	237,330	410,958	TN
TG011	Wetlands	2,066,640	912,384	1,371,000	2,066,640	TN
TG012	Waterway restoration	109,020	39,204	144,000	144,000	TSS
TG017	Raingarden	351,234	123,077	169,200	351,234	TN
TG029	Raingarden	181,068	30,769	108,900	181,068	TN
TG030	Pond	56,880	53,460	84,000	84,000	TSS
UM001	Waterway restoration	123,240	53,460	150,600	150,600	TSS
UM004	Raingarden	213,300	74,844	154,800	213,300	TN
WB004	Wetland	179,646	95,515	146,700	179,646	TN
WB009	Wetland	81,860	60,279	107,310	107,310	TSS
WB010	Waterway restoration	81,955	41,580	77,070	81,955	TN
YA001	Waterway restoration	-	-	396,900	396,900	TSS
YA002	Waterway restoration	-	-	291,600	291,600	TSS
YA016	Raingarden	308,109	109,376	182,397	308,109	TN
YA020	Pond	808,236	274,246	419,077	808,236	TN
Total		**6,692,766**	**2,906,922**	**5,804,662**	**7,842,532**	

Additional benefits attributable to the behavior change program

Additional pollution reductions are expected from behavior change actions as a result of the ACT Healthy Waterways program. An evaluation of the progress being made by H2OK found that all six

H2OK activities were likely to have increased the number of people actively contemplating the impact of their behaviours on stormwater contamination (Mosaic Insights, October 2018). However, the same evaluation concluded that although the activities with the widest reach (the media campaigns) were likely to bring the link between individual behaviour and stormwater into individual consciousness, no evidence indicated that this shift led to lasting behaviour change. Among the program activities, the activities with the smallest reach (the demonstration sites) were the most likely to produce a lasting change where participants actively maintained behaviours, reducing stormwater pollution and quantity (Mosaic Insights, 2018).

Preliminary results from a post-program evaluation of the H2OK program indicate that 7.2% of the 639 respondents reported knowing more about water as a result of their engagement with H2OK; 2.5% have thought about doing something different from their current water management behaviours; and 2.6% reported to have taken action. Actions and behaviour changes by respondents often referred to not putting oil or grease down the drain, sweeping leaves more effectively, ensuring that no organic matter goes into drains and waterways, and maximising the efficiency of the household's water use. Such behaviour changes are likely to lead to reductions in stormwater pollution and hence lower pollution loads in lakes and waterways.

However, it is not possible to ascertain whether the final sample size in the post-program evaluation survey will be comparable with that of the baseline survey undertaken in 2016. However, applying the preliminary findings of the most recent survey to the results of the 2016 survey indicates that as many as 122 people (2.6% of the 2016 sample of 4,701) may have acted to avoid negative stormwater outcomes. Using the same logic, the H2OK program may have also contributed to greater knowledge of waterway health for up to 338 individuals captured in the survey sample. Overall, greater knowledge about water has been empirically 'associated with adoption of water-saving and pollution-reduction behaviours and support for both alternative water sources and rain-gardens' in Australia (Dean et al., 2016). As such, it is reasonable to assume that all efforts to enhance individuals' knowledge about water, such as the activities comprising H2OK, have the capacity to increase pollution-reduction behaviours. However, validating such an assumption requires further investigation that engages the original sample to track changes to the behaviours reported in the 2016 community survey combined with in-depth, individual interviews to qualitatively measure the influence of H2OK initiatives on behaviour change.

It is also possible to assess potential impacts of H2OK on individual behaviours by evaluating evidence from a cognate program in NSW and from academic research. In the early 2000s, the NSW Government funded its Urban Stormwater Program, which similarly placed a strong emphasis on behaviour-change through its Urban Stormwater Education Program (USEP) as a means of reducing the negative impacts of stormwater (NSW EPA, 2001). Similar to H2OK, USEP used the media to change people's behaviour, although with a higher budget of $4 million, its campaign used mass media as well as social media and had a larger reach. These initiatives led to measured increases in people's efforts to reduce behaviours that would pollute stormwater:

- 20% of people changed their behaviour to reduce negative impacts on stormwater
- almost 40% of people said they made an effort to keep sand and soil out of drains through actions such as cleaning gutters and drains
- 90% of people could identify something they did to reduce stormwater pollution
- 2.1 million people reported changes in their behaviour to avoid actions that would pollute stormwater.

Although the evaluation report for the NSW initiative did not investigate whether such changes were maintained, it does indicate real improvements in individual behaviours that could be quantified with evaluation data reporting on the baseline behaviours. If the H2OK campaign has a similar impact on

ACT as the USEP campaign had, it would equate to up to 136,900 ACT residents[12] changing their behaviour to avoid actions that would pollute waterways. However, given the difference in the campaigns, this approach was deemed not to be appropriate. For example, only 2.6% of the surveyed ACT residents reported to have acted based on the H2OK behaviour change program, considerably smaller than the 32.3% from the NSW USEP campaign. Thus, the preliminary post-program survey results were deemed more appropriate and used to estimate the likely outcome of H2OK program.

Our valuation of the behaviour change outcomes relied on the H2OK post-program survey and the estimated contribution of households to stormwater pollution in the ACT region. Residential areas contribute to diffuse waterway pollution. For example, a study by Fashae et al., (2019) found that residential areas tend to have considerably higher contribution to total suspend solids in waterways. The study found that residential areas had an average total suspend solids of 223mg/l compared to vegetated (97.0 mg/l) and commercial (71.8 mg/l) landuse types (Fashae et al., 2019). Thus, in urban areas stormwater runoff tends to carry pollutants from garden fertilisers, chemicals, and soils from gardens. These fertilisers and herbicides are easily dissolved in stormwater runoff and have high phosphate and nitrogen content (Toor et al. 2017).

It is common for fertilisers and herbicides to be used to care for and manage lawns and gardens. If not managed well, stormwater runoff from residential areas will transport sediments, pesticides, herbicides, nitrogen, and phosphorous to waterways and lakes. The H2OK program promoted changes to behaviour to mitigate households' contribution to waterway health improvement. This contribution was quantified in a conservative way given the uncertainties around behaviour change programs. Table 8 provides a summary of assumptions and variables used to estimate the benefit attributable to the H2OK program.

Table 8. Summary of assumptions for estimating benefits of behaviour change

Variable	Assumption	Source/comment
Number of households changing their behaviour	2.6%	Based on the preliminary post-program evaluation survey results
Number of households in Canberra	110,550	ABS 2016 Census survey
Average household contribution to pollutant load ($/year)	TSS = 71.00 (+/-50%) TP = 0.15 (+/-50%) TN = 1.00 (+/-50%)	These estimates were calculated using MUSIC. The MUSIC scenario is based on a 1ha urban block (mixed zoning). MUSIC gives an impervious fraction of 0.6. The outflow of pollutants was estimated at 709 kg/year for TSS, 1.44 kg/year of TP and 10.1 kg/year for TN. It was assumed that 30% of the 1ha is roads and the pollutant loads were assigned to the remaining 7,000m^2 block that was estimated to hold 10 houses. It is expected that the estimated values will vary depending on wetness and type of rainfall events experienced.
Benefit timeframe	5 years from 2017	A review of the H2OK program indicated that a high risk of dis-adoption for any new adopters. Thus, it

[12] To arrive at this figure, we calculated that 2.1 million people in the NSW USEP campaign evaluation reported changes in their behaviour to avoid actions that would pollute stormwater. This represented 32.3% of the total resident population of NSW in the year 2000 (6,568,902) (ABS, 2002). Similarly, 32.3% of the ACT's 2018 resident population of 423,800 (ABS, 2018) is 136,887.

Variable	Assumption	Source/comment
		was assumed that the changes attributed to the ACT Healthy Waterways program will last a conservative five years.
Assumed reduction in pollutants load	5% (+/-50%)	NCEconomics conservative estimate

Asset life and residual value

Design reports were used to estimate the asset life for each of the 20 infrastructure assets. These design reports indicated that all 20 assets will have an estimated 50-year asset life. Given that the CBA appraisal period is 30 years, a residual value was calculated based on the remaining 20 years of asset life based on the core elements of the assets such the stormwater pipe and structures, gross pollutant traps, sediment forebay and structures, sediment basins, culverts and stormwater drainage infrastructure, inlet and outlet structures. A straight-line asset consumption approach was used to be consistent with the broader water industry approach to asset management. This approach infers that the residual value of each asset at the end of the 30-year assessment period is 40% of the CAPEX. This residual value at the end of the 30 years was discounted and included as a benefit for each asset. ACT Healthy Waterways assets were estimated to have cumulative value of $2.7 million at the end of the 30-year appraisal period.

Avoided lake closures (lake-based recreation)

BGA blooms impact on water quality at Lake Burley Griffin and Lake Tuggeranong. These blooms often lead to the closure of both lakes, substantially affecting their use for water-based and land-based recreation. Improved water quality in the lakes is a direct benefit resulting from the investment in the ACT Healthy Waterways Program. It is estimated that in the last eight years, Lake Burley Griffin was closed due to 'high to extreme' BGA levels for an average of 76 days a year, while Lake Tuggeranong was closed 102 days a year on average. Given these closures often occur in the summer months when recreational demand is at its peak, the negative economic consequences of closures are significant.

A study undertaken by HydroNumerics (2015) estimates that due to the ACT Healthy Waterways Program there is likely be a reduction in the number of lake closure days by 7% at Lake Burley Griffin and 26% at Lake Tuggeranong. The reduction in lake closure days will results in an economic benefit as more recreation visits will be achieved at both sites.

An earlier study on visitation data indicates that that Lake Burley Griffin has, on average, 1.89 million visits per year and Lake Tuggeranong has 198,500 visits per year (Aither, 2015). The Aither (2015) report also estimated that a blue-green algal bloom would lead to a decline of 90% for visitors who engage in water-based activities and 30% decline for those engaging in land-based activities. The avoided decline in visits over a year was calculated based on this information. It was estimated that for each day the lake is closed, there is average decline in visitation numbers of 3,099 for Lake Burley Griffin and 196 for Lake Tuggeranong.

The value of a lake visit was estimated to be $26 (adjusted to 2019-dollar values) per person per visit. This value is based on findings from Lansdell and Gagadharan (2003) that was undertaken to estimate the value of a similar major urban park with a significant water feature — Albert Park in Melbourne.[13] The estimated value of a visit was used along with the avoided lake closures to estimate the benefit of reductions in BGA-related lake closures

[13] Albert Park is located within 3km of Melbourne's Central Business District. The park has lake and it caters for both water-based and land-based activities similar to those available at both Lake Burley Griffin and Lake Tuggeranong.

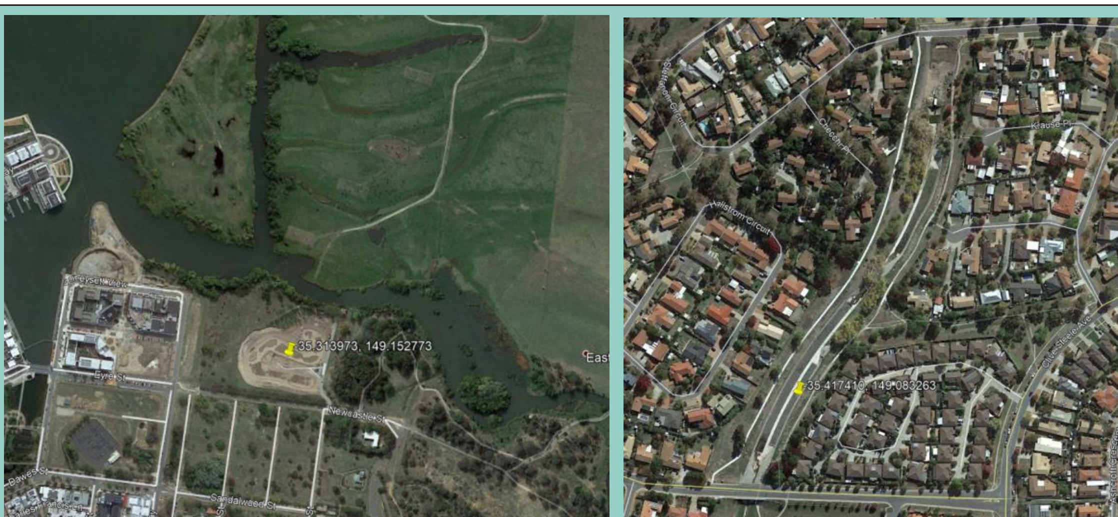
Improved amenity and local recreation

Previous research has shown that urban residents have a preference for residing in close proximity to natural and vegetated spaces. Past studies such as Pandit et al. (2014), Polyakov et al. (2017), Tapsuwan et al. (2009), and Thomy et al. (2016) have found there is a price premium attached to properties located nearby natural assets such as restored and healthy waterways, lakes, and wetlands. While proximity to these assets is a driver of price uplift, the attributes of the assets (e.g. native vegetation, waterbody, natural waterways, and accessibility) are also key drivers of the amenity benefits. ACT Healthy Waterways assets include the construction of ponds, wetlands, raingardens and waterway restoration works. Many of these assets are located in areas that are already functioning as recreation spaces such as public open spaces. Several park benches and some limited shared pathways were included with some of the assets. These facilities are likely to contribute to enhanced recreation amenity as well as stimulate more people to engage with their local outdoor areas for both recreation and exercise purposes.

An assessment of whether there was benefit likely to accrue to local communities was undertaken. Several factors were considered before a proceeding with an economic valuation of a given benefit for each of the assets. For example, for an asset to be considered as leading to property price premiums the following considerations were undertaken:

- Is the asset located in close proximity to properties (i.e. no farther than 500 m)?
- Do construction works provide a significant amenity change to the location (e.g. a small pond next to a large lake would be considered not to have material impact property prices. Or, a widening of a 100m pathway segment in a location with multiple and connected pathways would be considered not enough to stimulate significant physical activity that could be quantified and valued in an economic sense).
- Are the benefits material and is there data available to inform the attributable impact from the asset? In some cases, the benefits were not quantified as the assets were assumed to led to immaterial benefits and/or there was no sufficient data to estimate the attributable marginal impact for a given asset.

An assessment of the design report, asset location and aerial imagery was undertaken to identify assets where material amenity improvement impacts were most likely to be captured. Figure 5 provides an illustration of two assets: (a) FW012 is a wetland located nearby a larger waterbody and away from residential houses; (b) TG012 is a waterway restoration sites with several properties along the waterway. Amenity impacts were quantified for TG012 but not for FW012 as this asset is away from properties and is located in close proximity to a relatively larger waterbody. Assets where the amenity enhancements benefits were identified and quantified are shown in Table 4 (above).



a) FW012 – Wetland b) TG012 – Waterway restoration

Figure 5. Aerial imagery for two assets assessed for amenity impacts on property values

Source: Google Earth (2019)

Several assets were found to contribute to enhanced neighborhood amenity through increased native vegetation, addition of water bodies and naturalisation of stream banks. A benefits-transfer approach was used to estimate the marginal impact of these improvements on nearby property values. Key data was sourced from:

- Cooperative Research Centre for Water Sensitive Cities (CRCWSC) developed INFFEWS Value tool (Wetland Value Function) (Iftekhar et al., 2019).
- Valuing urban riparian corridors: The interaction of riparian buffers and channel condition and their influence on property prices (Thomy, 2016).
- Suburb median house and unit price (CoreLogic, 2019).
- Cadastral data from the ACT Geospatial Data Catalogue (actmapi-actgov.opendata.arcgis.com/) and NSW Spatial Services (maps.six.nsw.gov.au/).

Biodiversity

Urban wetlands have both an ecological (regulating ecosystem service) and social service (cultural ecosystem service) functions. One of the key functions of an urban wetland is providing habitat for plants and animals. Within CICES 5.1, this function is categorised as 'regulation and maintenance of biological conditions'. Similarly, ponds, and raingardens contribute to enhanced biodiversity as they function as habitat for aquatic birds and plants. These assets serve as 'stepping stones' that facilitate movement of species through the landscape (Hassall, 2014). Additionally, all infrastructure assets created as part of the ACT Healthy Waterways program included the addition of or replacement of non-native plants with native vegetation. Thus, all assets were deemed to contribute to an enhanced biodiversity.

Non-market valuation studies such as Morrison (2002) and Bennett et al. (2008) have shown that people have a significant willingness-to-pay to increase biodiversity (e.g. birds, native vegetation). For example, Bennett et al. (2008) found that households are willing to pay $5.56 (2006 AUD) to increase native vegetation by 1% along rivers and while Blamey et al. (2000) found that $1.69 (1997 AUD) to avoid loss in non-threatened species.

Based on the literature and an assessment of the individual assets, the ACT Healthy Waterways Program has contributed to enhanced habitats and biodiversity. It is also evident that people place a value on biodiversity. However, a quantitative assessment was constrained by data limitations. Therefore, it was not possible to estimate the marginal improvements in biodiversity to support a quantitative economic valuation. Consequently, the biodiversity related benefits were not estimated.

Urban cooling[14]

Several ponds, wetlands, raingardens and vegetation planting were included in the ACT Healthy Waterways Program. These new assets have an impact on nearby ambient temperatures. Vegetation and urban water bodies play an important role in reducing urban temperatures (Qiu, 2013). Such temperature reduction provides for outdoor human thermal comfort around the assets, as well as lower temperatures at nearby dwellings or workplaces. The cooling benefits captured by people is dependent on a number of variables, including local environmental conditions, the design and placement of the systems, and the nature of the surrounding urban landscape (Coutts et al., 2012).

To understand the temperature changes from the ACT Healthy Waterways activities, three sites across the ACT were selected and the Air-temperature Response to Green/Blue-Infrastructure Evaluation Tool (TARGET) was used to calculate spatial temperature differences.[15] TARGET is used to calculate the

[14] See Appendix C for a detailed discussion in the modelling of the urban cooling benefits

[15] TARGET was developed by Broadbent et al., (2019) for the Cooperative Research Centre for Water Sensitive Cities (CRC WSC).

surface temperature, the air temperature, and a measure of human thermal comfort for the desired spatial locations and specific measurements for a representative hot day. It can be used on a range of scales from the street level to a city-wide scale. A high spatial resolution of $3m^2$ was chosen for the assessment of sites due to their relatively small size.

Three sites (FW019, UM004, and WB004) were assessed by simulating modelling 'before' and 'after' intervention scenarios. The 'before' intervention scenario was based on information from Google Earth Pro aerial images to gauge vegetation density and estimate the cooling impact. The intervention case was then modelled based on Google Earth Pro images as well as design guidelines for each of the sites. The intervention case was modelled to represent the finished product and this enabled the calculation of the difference in temperature before and after the intervention.

A previous study found that Melbourne and Sydney households were willing to pay $47 and $57, respectively, for a 2˚C drop in summer temperature (Brent et al., 2017). There are several benefits associated with lower temperatures particularly in the event of extreme heat and heatwave events. These benefits include reduced mortality (Nicholls et al., 2008), avoided public healthcare service costs (Molla, 2015), avoided cooling costs, and avoided loss of labour productivity (Zander et al., 2014). The willingness-to-pay estimates from Brent et al. (2017) were used to capture the quantified cooling benefits from the three case study assets (see Table 9). The willingness to pay values from Brent et al. (2017) were adjusted to 2019 dollars and used to estimate the urban cooling benefit. Table 9 provides a summary of the input data and results for the estimated urban cooling. The total number of homes affected was 51, and the temperature reductions were less than 1˚C. The FW019 wetland had a relatively high maximum temperature reduction of 7˚C at the asset location but no nearby homes were found to benefit from this cooling effect. Thus, no benefit was calculated for this asset. While the high temperature reductions at the asset are not quantified, these reductions do play a role in providing outdoor thermal comfort for people recreating or travel past the asset. The estimated urban cooling benefits are conservative and indicative. It is expected that larger assets and those located closer to homes and workplaces will lead to higher benefits associated with lower mortality, morbidity, productivity and energy savings. These additional benefits were not estimated in this case due to relatively small size of assets, assets locations and limited resources.

Table 9. Annual urban cooling benefits for three case-study assets

Asset code	Asset type	Cooling at the asset (˚C)	Cooling at nearby homes (˚C)	Number of households	Estimated benefit, $ pa
FW019	Wetland	7	-	0	N/A
UM004	Raingarden	3	0.8	30	$682
WB004	Wetland	7	0.5	21	$298
Estimated annual cooling benefits (3 assets, only)				**51**	**$980**

Recreation and enhanced physical activity

ACT Healthy Waterways assets were constructed to accommodate multiple uses, including supporting outdoor recreation for local and visiting communities. Additional pathways, park benches and viewing platforms contribute to enhanced passive and active engagement with outdoor areas. The ACT Healthy Waterways assets are located along waterways and within existing open space areas that are already actively used for outdoor recreational activities such walking and cycling.

In previous economic studies (e.g. Lansdell and Gagadharan, 2003), recreation unit values are commonly quantified using travel cost methods. These methods account for the cost and time it takes for a visit to a given site. For example, Parks Victoria and DELWP (2015) reported that the value of a visit to an urban park in Victoria is $9 (2014 AUD).[16]

Attractive and accessible local open space assets are used by communities for active recreation. This is important as physically inactive people are at a higher risk of mental illness, obesity, cardiovascular diseases, type 2 diabetes and cancer (WHO 2016). Increased active recreation, particularly by people who were previously physically inactive, could lead to lower poor health and mortality. Medibank Private (2008) estimated that the cost to the Australian economy due to physical inactivity was $13.8 billion per annum.

Given the location and nature of ACT Health Waterways assets it is difficult to attribute additional recreation and physical activity to the individual assets. Therefore, while the contribution of these assets to recreation and increased physical activity are acknowledged, these benefits were not quantified.

Other benefits

Other non-asset specific benefits identified from the ACT Healthy Waterways program were a contribution to an efficiency dividend through an improved understanding of water quality impacts on lakes (e.g. BGA blooms on Lake Burley Griffin and Lake Tuggeranong) from the program's investment in research, monitoring and evaluation.

[16] While there are some more recent travel cost studies in Australia, the focus tends to be on assets such as national parks, dams and lakes which are dissimilar to a typical urban open spaces.

5 RESULTS

Key points

- The ACT Healthy Waterways is estimated to have a net present value of $50 million and a benefit–cost ratio of 1.66. Thus, the program is found to be economically viable.

- Sensitivity analysis shows that the ACT Healthy Waterways economically viable even under the worst-case scenario for the quantified benefits. The 5th percentile for the benefit cost ratio is 1.3. This reflects that there is a 5% chance that the BCR is less than 1.3. Given the fact that some benefit streams have not been quantified and included in this CBA, the estimated benefits should be considered as conservative.

- The main drivers of variability in the estimated investment criteria (BCR and NPV) are the assumed discount rate, avoided abatement costs, and property premium values.

- After accounting for an outlier project (UM001 — waterway restoration project), the program assets are relatively more efficient than the benchmark values achieved elsewhere. Fourteen of the 18 assets designed to manage TN were more cost-effective than the benchmark.

- On average the ACT Healthy Waterways program assets were found to be less cost-effective than the average benchmark values for reducing TP. Eight of the 18 assets designed to manage TP were found to be more cost-effective than the benchmark.

- On average the ACT Healthy Waterways program assets are more cost-effectiveness in reducing TSS loads than the benchmark cost-effectiveness. Fifteen of the 20 assets designed to manage TSS were found to be more cost-effective than the benchmark.

- The direct Gross Regional Product (GRP) impact of the construction and establishment phase is estimated at $16.1 million and the flow-on GRP impact is $30.1 million.

- It is estimated that the ACT Healthy Waterways Program will lead to a direct employment impact of 152 FTEs and 250 FTEs flow-on employment impact across the ACT and Queanbeyan regions between 2018 and 2020.

5.1 Overview

Overall, a conservative approach was taken to estimate the total benefits associated with the ACT Healthy Waterways program. The benefits quantified in this analysis are: avoided abatement costs, property price impacts, residual asset values, lake-based recreation, urban cooling and behaviour change benefits (see Table 10).[17]

Table 10. A list of the quantified benefits, valuation approach and key data source

Benefit	Underlying valuation approach	Unit value source	Key data source
Water quality improvement	Avoided abatement cost	Average costs of water quality management actions	Alluvium (2017) MUSIC Modelling Post-program survey

[17] Employment and regional economic impacts are discussed separately in Section 5.5

Benefit	Underlying valuation approach	Unit value source	Key data source
Amenity	Hedonic property valuation	Benefit-transfer	• CoreLogic (2019) • Iftekhar et al. (2019) • Thomy et al. (2016) • ACT Geospatial Data Catalogue actmapi-actgov.opendata.arcgis.com/ • NSW Spatial Services actmapi-actgov.opendata.arcgis.com/
Recreation	Travel cost method	Benefit-transfer	• Aither (2015) • Lansdell and Gagadharan (2003) • HydroNumerics (2015)
Urban cooling	Willingness to pay estimate	Benefit-transfer	• Brent et al. (2017) • TARGET modelling

5.2 Cost–benefit analysis

The CBA analysis was undertaken over a 30-year appraisal period and a 7% discount rate. The total investment costs of $107 million included CAPEX and OPEX over the appraisal period, and non-construction costs including management, research and behavior change investments. The operating and maintenance costs include money already spent plus estimated future costs.

CBA results indicate that the program has a present value of benefits of $126 million and present value of cost of $76 million (see Table 11). Thus, the project has net present value of $50 million and a benefit–cost ratio of 1.65 (all 'most likely' estimates). These results indicate that the program is economically viable as the benefits of the program outweigh the costs.

Table 11. ACT Healthy Waterways costs and CBA results ($ million)

Description	Value
Appraisal period (years)	30
CAPEX, undiscounted	$76 m
OPEX, undiscounted	$24 m
Non-construction costs, undiscounted	$7 m
Whole-of-life costs, undiscounted	$107 m
Cost–benefit analysis of discounted monetary costs and benefits	
Present value of benefits	$127 m
Present value of costs	$76 m
Net Present Value	$50 m
Benefit–Cost Ratio	1.66

*There are some minor rounding errors

The estimated benefits are dominated by the water quality improvements as measured through avoided abatement costs from the 20 infrastructure assets ($96.3 million). The second largest benefits are from amenity improvements captured via property price premiums ($20.5 million). Additional recreation access at Lake Burley Griffin and Lake Tuggeranong leads to $7.1 million of recreation value, while residual value of the assets, behaviour change and urban cooling benefits[18] are relatively lower at $2.7 million, $300,000 and $12,000, respectively. Figure 6 shows the breakdown of estimated present value of benefits by benefit type.

[18] Urban cooling benefits are based on a detailed assessment of two wetlands and a raingarden.

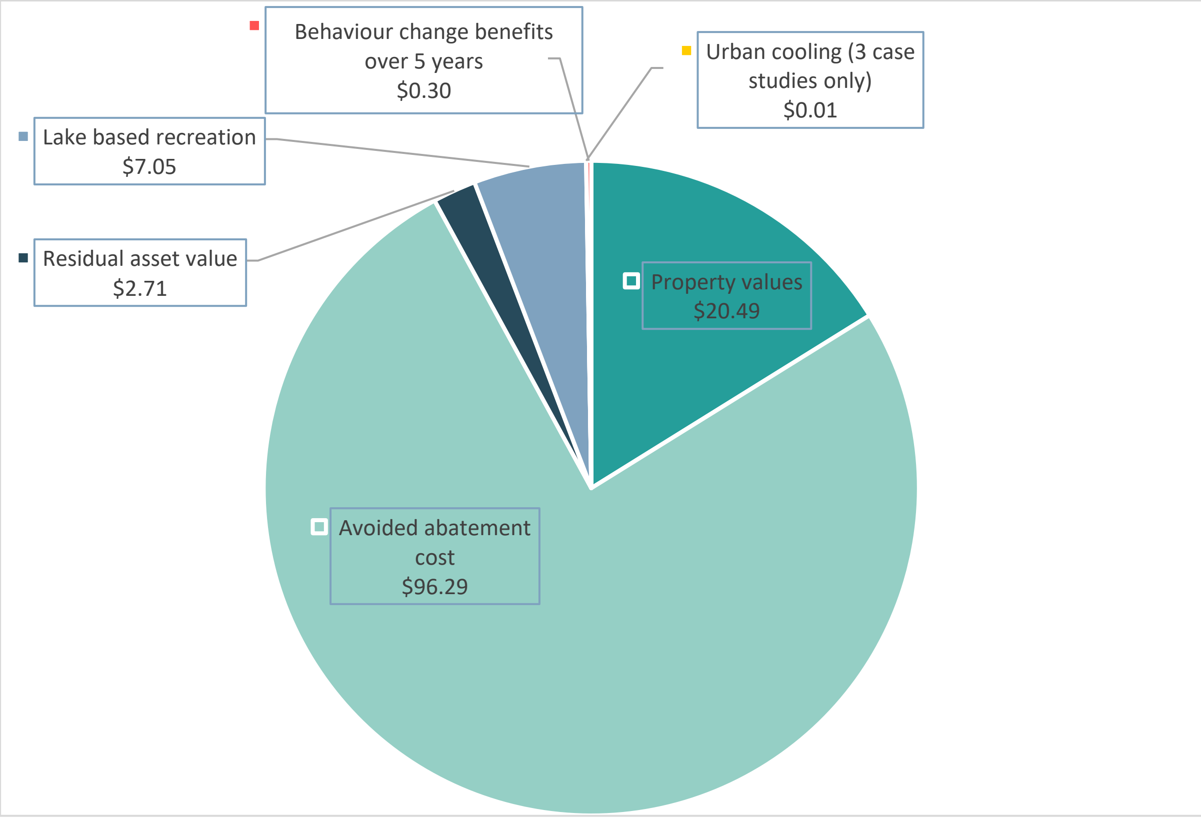


Figure 6. Breakdown of estimated present value of benefits by benefit type ($ million)

5.3 Sensitivity analysis

The CBA used input data parameters and assumptions that have a degree of risk or uncertainty. [19] Therefore, rather than point-estimates, a range was used for some key input parameters in the model to inform a Monte-Carlo analysis. While the most likely NPV is $50 million, Figure 7 shows that NPV is estimated to range from $24.4 million (5th percentile) to $125.7 million (90th percentile). Similarly, Figure 8 shows that the estimated benefit–cost ratio ranges from 1.3 to 2.6.

[19] The focus is on the benefits within the sensitivity analysis. Sensitivity analysis is not required for the capital costs as they are historical costs (and known) for an ex-post CBA.

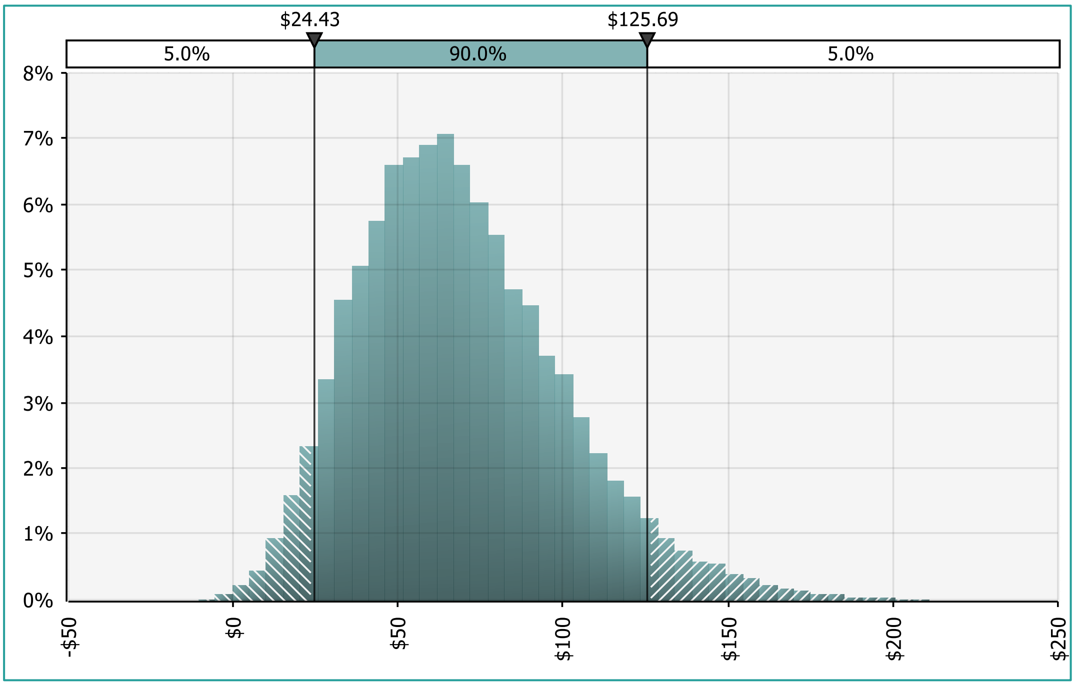


Figure 7. Estimated Net Present Value for the ACT Healthy Waterways program

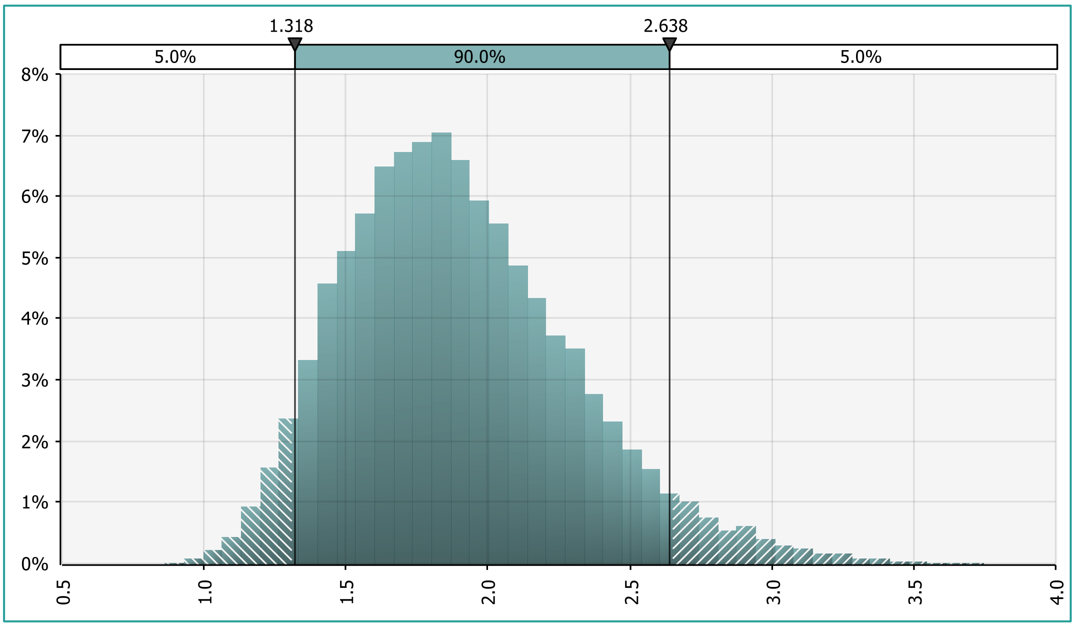


Figure 8. Estimated benefit–cost ratio for the ACT Healthy Waterways program

A further investigation of the key drivers of variability in the investment criteria was undertaken. Figure 9 shows the top 10 key drivers of uncertainty. The discount rate has the highest effect on the variability of the estimated investment criteria, followed by the avoided cost of pollution control for both TN and TSS, and then the value of a visit to the lake. Other key drivers include the number of days the lakes are closed and hence avoided number of days a lake is closed due to BGA bloom, the wetland OPEX, and then estimated impact on nearby property values.

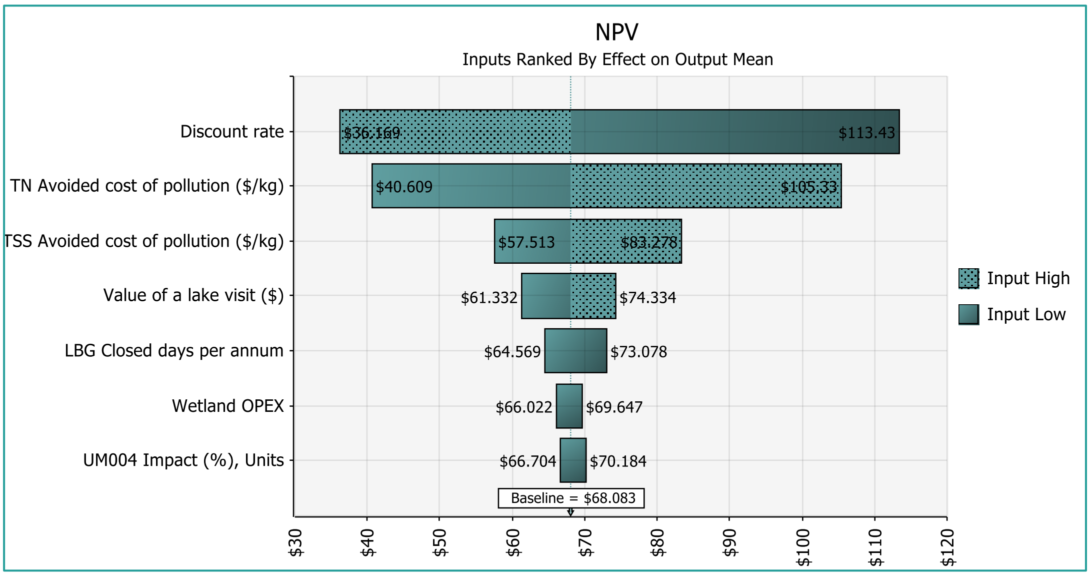


Figure 9. Inputs ranked by their effect on present value of benefits ($ millions)

5.4 Cost-effectiveness analysis

All assets were assessed for their cost-effectiveness for reducing pollution loads for TN, TP, and TSS. The present value of costs for each of the assets was divided by the estimated load reductions between years 2021–2049. The estimated additional load reductions were assumed to start after completion of the asset's establishment phase. All assets are expected to reach the end of establishment phase in 2020 or early 2021.

The CEA was undertaken to provide information on the relative cost-effectiveness of the different program assets in mitigation pollutant loads. Furthermore, the average cost-effectiveness of the program assets was compared to the average cost-effectiveness reported for mitigating the same pollutants in the Water by Design (2014) and Alluvium (2017) reports. The average cost-effectiveness of the raingardens, street trees, grass swales, cartridge filters, and wetlands from Water by Design (2014) and Alluvium (2017) were used as the benchmark values for each of the pollutants. Table 12 provides the average program assets and benchmark assets cost-effectiveness values.

Table 12. Average cost-effectiveness of the program assets and benchmark values by pollutant ($/kg)

	TN	TP	TSS
Program assets	303	1,827	2.1
Benchmark value	474	1,188	3.0

Figure 10 shows the TN abatement cost-effectiveness ($/kg) for each of the assets. UM001, which was a waterway restoration project along the Molonglo River, is relatively very inefficient in reducing total nitrogen load.[20] UM001 was estimated to cost $9,801 per kg of TN and the next least efficient asset was FW012 (wetland) at $1,096 per kilograms of TN. The average cost-effectiveness of the ACT Healthy Waterways asset (*ACT HWS Average 1* is $303/kg)[21] is lower than the benchmark value ($474/kg). Another way to account for the outlier is to estimate the median cost-effectiveness ($223/kg), which is also lower than the benchmark value. Including the outlier leads to a higher cost-effectiveness value for the program assets (see Average 2 in Figure 10).

[20] UM001 project consisted primarily of riparian plantings along the Molonglo River. As much of these plantings are above the waterline, they will have limited impacts on water quality (as predicted by MUSIC models). Instead, the majority of the benefits will accrue through improved riverbank health and stability, and improved in-stream aquatic processes that are not simulated or quantified by MUSIC, hence the underestimation of the performance of this asset

[21] This estimate excludes the UM001 outlier project.

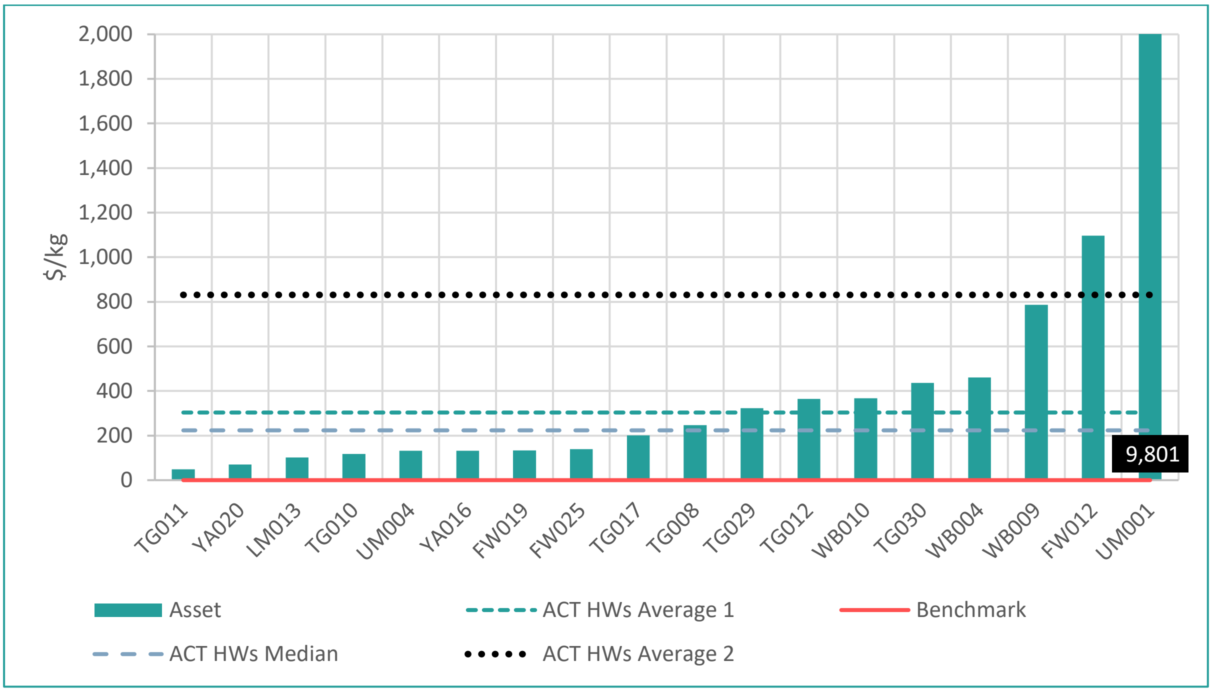


Figure 10. Cost-effectiveness for total nitrogen ($/kg)

Unlike the TN cost-effectiveness results, the ACT Healthy Waterways program assets were found to be, on average, less effectives than the benchmark assets for reducing TP. The average cost-effectiveness for the program assets is $1,827 per kilogram of TP while the benchmark value is $1,188 per kilogram. However, eight of the 18 program assets designed to capture TP are more efficient that the benchmark average values (see Figure 11).

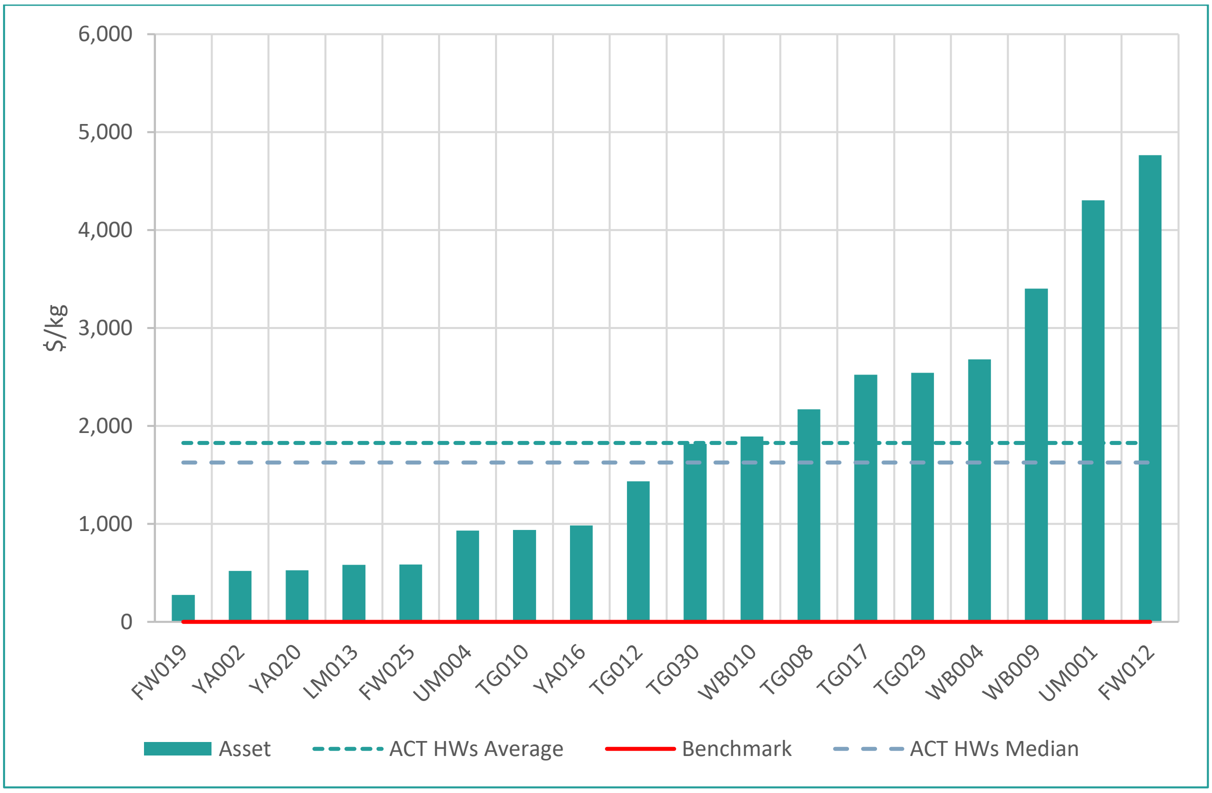


Figure 11. Cost-effectiveness for total phosphorous ($/kg)

On average the ACT Healthy Waterways program assets were found to be more cost-effective in reducing TSS loads than the benchmark assets (see Figure 12). The average program cost-effectiveness was $2.1 per kilogram, while the benchmark value was $3 per kilogram. Only 5 of the 20 assets were found to be less cost-effective than the benchmark value.

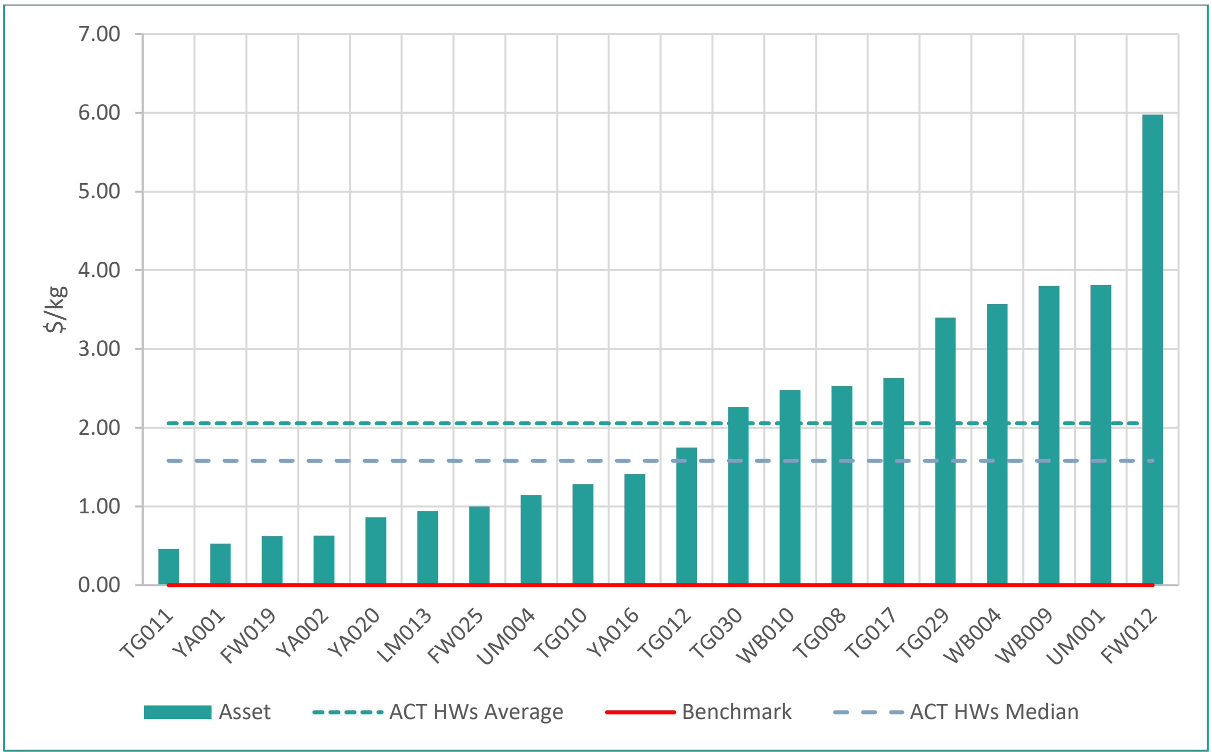


Figure 12. Cost-effectiveness for total suspended solids ($/kg)

5.5 Regional economic impact analysis

The Australian Urban Research Infrastructure Network (AURIN) economic impact tool was used to estimate impact from construction projects in the ACT (19 projects) and Queanbeyan (1 project). The assessment was region- and industry-specific. The ACT direct capital expenditures were $36.5 million in 2018, $12.5 million in 2019 and $1.04 million in 2020. In Queanbeyan direct capital expenditures were $0.8 million in 2018 and $0.7 million in 2019. The estimated total direct impacts for the ACT and Queanbeyan region were $11.7 million, $4.1 and $0.3 million for years 2018, 2019 and 2020, respectively. Table 13 shows that the flow-on impacts are $22.3 million, $7.9 million and $0.6 million for years 2018, 2019 and 2020, respectively, respectively. Overall the GRP impact over the three years construction and establishment is estimated at $46.8 million.

Table 13. Gross Regional Impact ($million) by region and year

Impact on gross regional product	ACT			Queanbeyan		All regions		
	2018	2019	2020	2018	2019	2018	2019	2020
Direct	11.4	3.9	0.3	0.3	0.2	11.7	4.1	0.3
Flow-on	21.8	7.5	0.6	0.5	0.4	22.3	7.9	0.6
Total	**33.2**	**11.4**	**0.9**	**0.7**	**0.6**	**33.9**	**12.0**	**0.9**

Figure 13 shows the distribution of the GRP impact by industry sectors. The highest impact is in the construction.

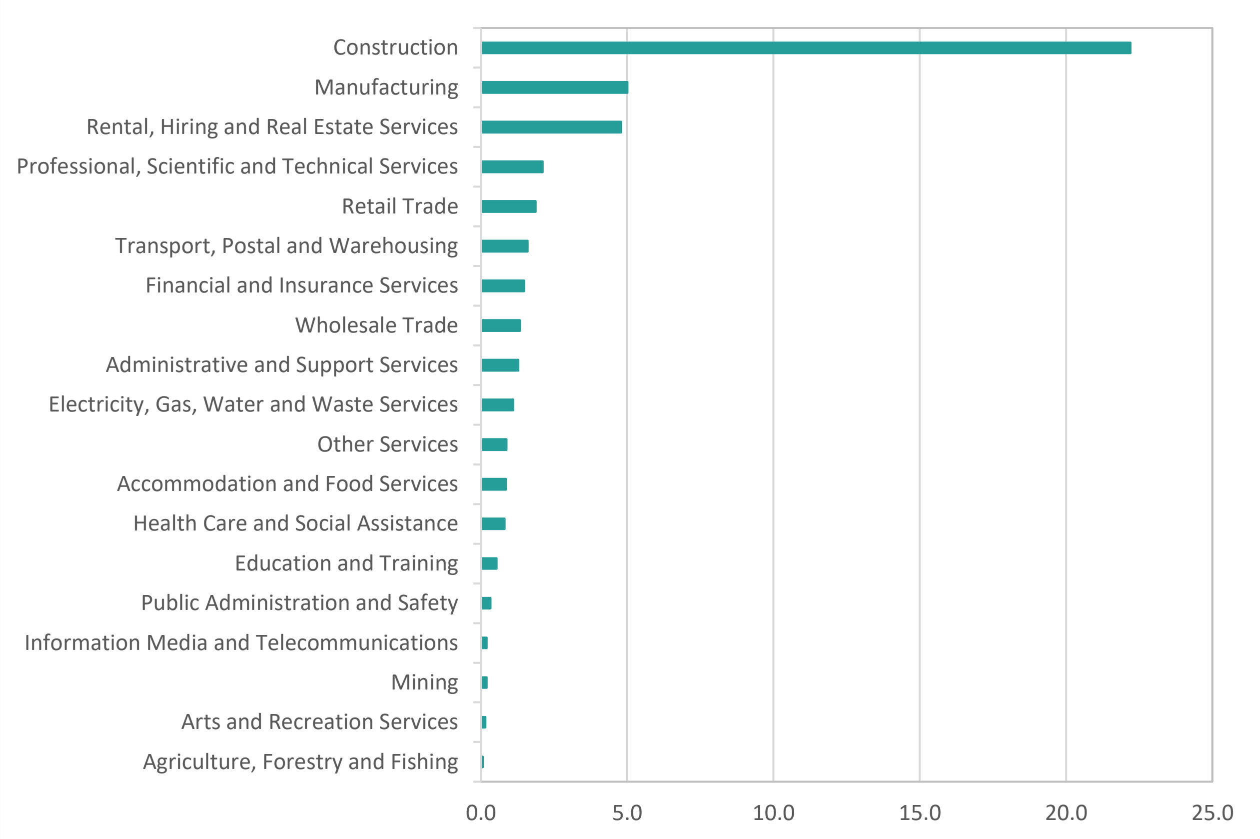


Figure 13. Distribution of GRP impact by industry sector

Table 13 shows there is a direct employment impact across the ACT and Queanbeyan regions as a result of the ACT Healthy Waterways program. Similarly, flow-on employment impacts are estimated in Table 14. An estimated 95% of the FTEs impacts are realised in 2018 and 2019. The highest employment impact is from the construction industry with an estimated 210 FTEs over the three-year construction and establishment period (see Figure 14).

Table 14. Employment Impact (FTE) by year and region

Impact on gross regional product	ACT			Queanbeyan		All regions		
	2018	2019	2020	2018	2019	2018	2019	2020
Direct	108	37	3	2	2	110	39	3
Flow-on	177	61	5	4	3	181	64	5
Total	284	98	8	6	5	290	103	8

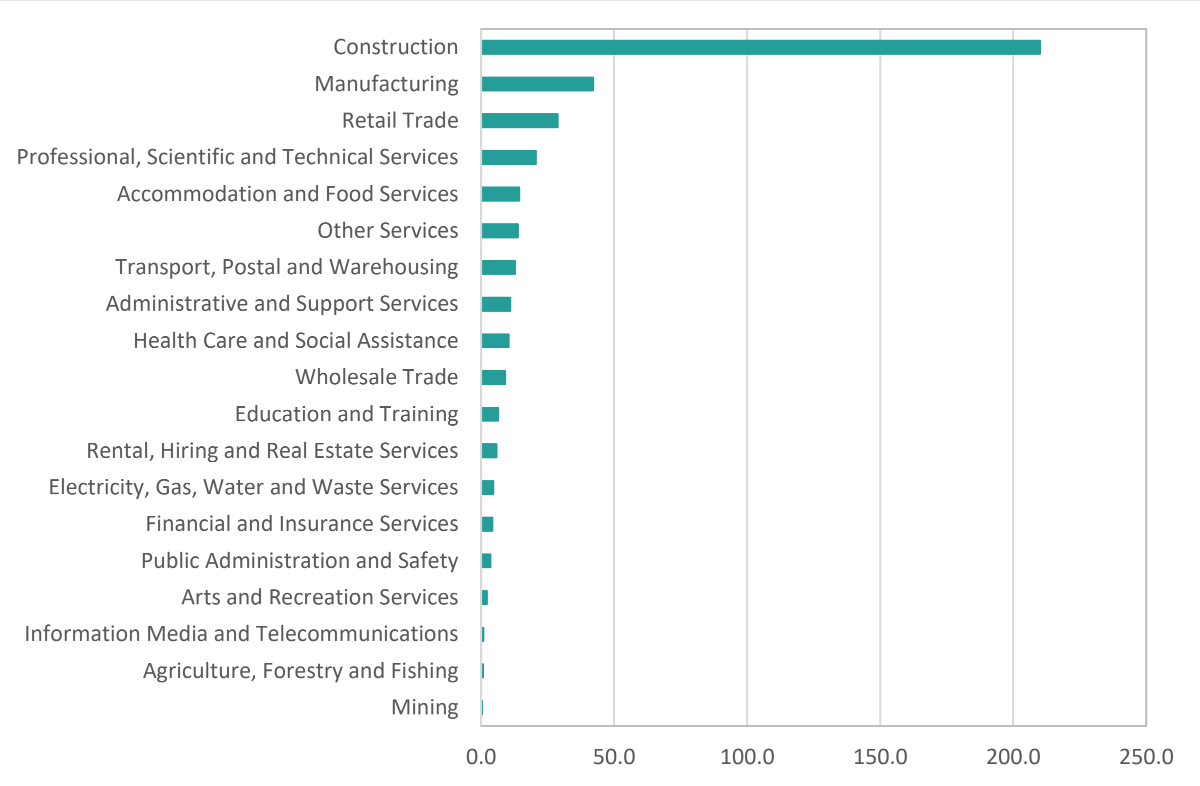


Figure 14. Distribution of total employment (FTE) impact by industry sectors

6 CONCLUSIONS

An economic assessment of the ACT Healthy Waterways program indicate that the program is economically viable. and present value of cost of $76 million. Thus, the project has net present value of $50 million and benefit-cost ration of 1.66 (all most likely estimates). Sensitivity analyses were undertaken using Monte-Carlo simulation and the results indicate that the net present value ranges from $24 million to $126 million and the benefit-cost ratio range from 1.3 to 2.6. These results indicate that the program is economically viable as the benefits of the program outweigh the costs.

On average, the ACT Healthy Waterways program assets were found to be more cost-effective at managing total nitrogen and total suspended solids. However, they were on average relatively less cost-effective for managing total phosphorous.

The regional economic impact analysis results indicate the direct gross regional product contribution from the program's funding of construction activities region is $11.7 million, $4.1 and $0.3 million for years 2018, 2019 and 2020, respectively. flow-on impacts are $22.3 million, $7.9 million and $0.6 million for years 2018, 2019 and 2020, respectively, respectively. Overall the GRP impact over the 3 years construction and established is estimate at $46.8 million. The direct employment impact was estimated at 153 across the ACT and Queanbeyan regions.

7 RECOMMENDATIONS

The following recommendations are made to help improve the knowledge of urban stormwater benefits and their economic values. These recommendations are also designed to provide better guidance on program budget allocation, setting up monitoring and evaluation mechanisms, and the evaluation of ecosystem services from similar initiatives.

Recommendation 1

Some assets were found not to be cost-effective (for example the UM001 — waterway restoration). Other assets had a relatively poor cost-effectiveness across all three pollutants (for example FW012 — wetland and TG030 — pond).

NCE recommend that a cost-effectiveness analysis is undertaken before construction as a justification for funding. If an asset is consistently not cost-effective for all pollutants, such a justification could be that the asset leads to other key ecosystem services such as amenity enhancement, contributions to natural habitat and biodiversity, among other benefits.

Recommendation 2

In some instances, data on the actual amount spent or budgeted for specific activities or assets was not available. For example, while the Directorate provided a total budget for operating and maintenance of all constructed assets, the data was not disaggregated to individual assets. Disaggregated operating and maintenance costs would allow a more robust cost-effectiveness analysis that considers individual assets' location and other factors that might affect the operating and management of the individual assets.

NCE recommend that future planning for similar programs considers both CAPEX and annual OPEX individual assets.

Recommendation 3

The ACT has some landmark lakes that attract significant visitations from local residents and visitors. Visitors engage in both active and passive recreation, while others attend specific events hosted on the lakes.

NCE recommends that a primary study surveying visitors be undertaken to gauge the impact of lake closures on planned events and general recreational visitation. This work could estimate consumer surplus through a travel cost valuation method, leading to more robust and bespoke assessment of the economic benefit of avoided lake closures. This data is important given that the unit value of a lake visit is one of the key drivers in the estimated net present values.

Recommendation 4

While initial evidence from an assessment of the H20K initiative suggested some modest behaviour change is likely to have been achieved, there was not enough information to gauge how the objectives of the behaviour change were achieved in relation to waterway pollution reduction.

NCE recommends that any future iterations of programs seeking to influence behaviour should include evaluation approaches that measure behaviour change across the same variables measured in any baseline survey for a more rigorous evaluation of change.

Recommendation 5
Behaviour change results from the NSW Urban Stormwater Education Program indicate significant behaviour change outcomes from a mass media campaign.

NCE recommends that the ACT Government consider including a mass media campaign into H20K to further the reach and potential impact of the initiative.

Recommendation 6
An assessment of the H2OK initiative (Mosaic Insights, 2018) indicated that demonstration sites are likely to lead to longer-lasting behaviour changes.

NCE recommends that the ACT Government considers strategies to increase the public's access to demonstration sites.

Recommendation 7
Due to environmental factors, urban cooling benefits of infrastructure projects are dependant on asset placement. Results from this study indicate that, ideally, assets should be placed to the north of properties so that northerly winds can spread the cooling effect to the south in the direction of properties.

NCE recommends that the location of assets relative to houses in closely considered to maximise cooling benefits.

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APPENDIX A — SUMMARY OF INFRASTRUCTURE PROJECTS

FW012: Wetland

Brief description

Asset FW012 is a wetland located in the suburb of Kingston on the banks of Jerrabomberra Creek and about half a kilometer from Lake Burley Griffin. Works at this site also included relocation of pedestrian and cyclist pathways to separate riparian vegetation from human traffic. The total asset footprint area is 1.0ha. Figure 15 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 15. FW012 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 15 provides key project timelines, asset footprint area and total capital costs.

Table 15. FW012 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
29/10/2018	14/05/2019	16/05/2021	1.0	2,356,832

Biophysical impacts

The FW012 wetland will have a waterbody are of 0.66ha. Another 0.31 ha will be planted with native vegetation. Along, with two other ACT Healthy Waterways wetland projects in the area, this wetland will improve the stormwater pollution filtration of the existing Jerrabomberra wetlands. The wetland will also support improvements in provisioning of habitat for native animals and birds found in the wetlands area. Table 16 shows the estimated additional annual pollution load reductions for the new wetland.

Table 16. FW012 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	16,500	29	90

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions. The wetland is also expected to have a positive contribution to the biodiversity within the wetlands area. No material aesthetic, recreation, climate regulation benefits are assumed for this asset as it is located within 100m of Jerrabomberra Creek and Lake Burley Griffin is also within 350m.[22]

FW019: Wetland

Brief description

Asset FW019 is a wetland located in a pre-existing low-flow path of the Jerrabomberra Creek adjacent Mills Creek Oval in the suburb of Narrabundah. The works involved construction of the wetland, ponds, a gross pollutant trap, a sediment forebay, landscaping and improvements to existing shelter and seating areas. Figure 16 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 16. FW019 aerial images before and during construction

Source: Google Earth Pro (2019)

Table 17 provides key project timelines, asset footprint area and total capital costs.

Table 17. FW019 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
6/08/2018	20/05/2019	30/04/2021	1.94	4,474,431

Biophysical impacts

The FW019 wetland has a footprint of approximately 1.94ha, a waterbody area of 1.45ha and a volume of 2,800m^3. It has a water storage of 5,900m^3 for extended detention depth and short detention of volume of 8,000m^3. This 420m long wetland includes a chain of four open water ponds with an average depth of 1.2m. Works at the site also include construction of a sediment forebay.

[22] There are three big blocks adjacent to the open space where the wetland is located – check what the proposed development plans for those blocks are

Improvement works were undertaken to plant native vegetation and enhance the facilities around the wetland. Pest willow trees were removed and replaced with more suitable and native tree species. The native vegetation was planted over 0.69ha around the wetland. Facility improvements included improvements to an existing unsealed track and construction of a concrete path around the wetland. Table 18 shows the estimated annual pollution load reductions for the wetland.

Table 18. FW019 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	300,000	320	1,400

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions and improvement in aesthetics. Other important benefits include support for biodiversity, potential urban cooling benefits for nearby residential properties and stimulation of outdoor passive and active recreation.

FW025: Wetland

Brief description

Asset FW025 includes two long and narrow wetlands located within the Jerrabomberra Wetlands in the suburb of Fyshwick. The two wetlands have a combined footprint area of 1.34ha. Figure 17 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 17. FW025 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 19 provides key project timelines, asset footprint area and total capital costs.

Table 19. FW025 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
8/10/2018	4/06/2019	nd	1.34	1,525,232

nd=no data

Biophysical impacts

The two wetlands connect to an existing wetland that currently receives minimal stormwater inflow. Thus, in addition to the additional functions of the new wetlands, the existing wetland is also utilised for added benefits in control of waterway pollution. A waterbody area of 0.78ha and another 0.30ha of native vegetation were added through this project. The asset location has several walking paths, these paths will be upgraded from grass trails to decomposed gravel trails to minimise on-going maintenance costs. A circuit path was completed through and around the wetland, connecting to the existing boardwalks and tracks. The landscape works included macrophyte planting as part of the extended wetland system, terrestrial batter planting, dryland grassing, decking, street furniture and signage location. Table 20 shows the estimated annual pollution load reductions for the wetland.

Table 20. FW025 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	70,000	120	500

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions. The inclusion of new paths and improved connectivity to existing pathways is likely to enhance recreational activity in the area. No material aesthetic, climate regulation benefits are assumed for this asset as it is located within the Jerrabomberra Wetlands area where there are multiple other substitutes assets for cultural benefits.

LM013: Wetland

Brief description

Asset LM013 is a wetland located south of Cotter Rd in the suburb of Duffy. The new asset has a footprint area of 2.08ha. The site works include stormwater pipes, stormwater structures, GPT, trash racks and landscaping. Figure 18 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 18. LM013 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 21 provides key project timelines, asset footprint area and total capital costs.

Table 21. LM013 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
20/11/2017	22/06/2018	26/02/2021	2.08	2,619,058

Biophysical impacts

The wetland waterbody area is 0.84ha. The wetland sediment basin has a volume 600m^3 and the wetland has volume of 2,400m^3 at normal wetland level. The basin and wetland have a surface area of 740m^2 and 5,640m^2, respectively. An estimated 0.88ha of was planted with native vegetation. Rock seats and jetties were installed as low cost and durable facilities for seating and viewing the wetland. There were no other additional facilities linked to recreation that were installed as part of this project.

The asset includes a wetland and GPT for water quality regulation and landscape works to the open space with the added interest and appeal generated by the diversity of low water margin vegetation, a large pond of open water and a rock viewing platform into an otherwise largely open area of slashed dry grass setting. Improvement works were undertaken to plant native vegetation to contribute to nutrient stripping and sediment capture. Table 22 shows the estimated annual pollution load reductions for the wetland.

Table 22. LM013 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	136,910	244	1,266

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions, biodiversity and aesthetics for nearby residents. Other benefits include contribution to enhanced outdoor activity as the wetland is located near an existing walking path and potential urban cooling benefits for nearby residents.

TG008: Raingarden

Brief description

Asset TG008 is a raingarden[23] and a GPT. The asset is located in Wanniassa suburb within the Tuggeranong district. This site works included a construction of a raingarden, a GPT, stormwater drainage infrastructure, and landscaping. Figure 19 shows an aerial image of the asset location before and during construction works.

[23] Raingardens are also known as bioretention systems.

a) Before construction b) During construction

Figure 19. TG008 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 23 provides key project timelines, asset footprint area and total capital costs.

Table 23. TG008 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
14/05/2018	13/05/2019	30/04/2021	0.60	2,656,074

Biophysical impacts

The raingarden area is 0.60ha and it is made up of 3 separate segments. The three segments were designed to fit into pre-existing site constraints and topography. An estimated 0.45ha of area will be planted with native vegetation.

The asset area is bounded by a 2.5m wide main pathway and there are also some minor pathways. Landscape works include macrophyte planting as part of the extended bioretention system, open space tree planting, shrub planting, dryland grassing, concrete paving, and a bench. The planted open space trees are *Casuarina cunninghamiana*. These trees match existing species on site, provide additional shade amenity to the perimeter of the bioretention system and also provide a buffer to existing water storage tanks. Table 24 shows the estimated annual pollution load reductions for the raingarden.

Table 24. TG008 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	18,990	52	468

Ecosystem services assessment

The identified key ecosystem services contribution from the raingarden is water quality regulation through pollutant load reductions and aesthetics for nearby residents. Other benefits include potential contribution to enhanced outdoor activity experience for local residents as the raingarden is located near some multiple shared paths.

TG010: Raingarden

Brief description

Asset TG010 is a raingarden located adjacent to the Isabella Lake in the suburb of Isabella Plains. The site works included construction of stormwater pipes, stormwater structures, trash racks, landscaping and an update to an existing GPT. Figure 20 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 20. TG010 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 25 provides key project timelines, asset footprint area and total capital costs.

Table 25. TG010 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
24/11/2017	25/10/2018	26/02/2021	0.90	2,158,309

Biophysical impacts

The raingarden area is 0.90ha. A new concrete path was constructed over the raingarden to connect to a viewing platform overlooking the adjacent Isabella Lakes. Some seats were installed at locations that encourage viewing of the lake and the raingarden. Informal rocks were also arranged to create an interactive 'rock jetty' and location for installing interpretive signage.

An estimated area of 0.98ha will be planted with native vegetation. The trees planted in the open space are predominantly *Casuarina cunninghamiana*. These trees match existing species on site, they are a source of additional shade amenity to the perimeter of the raingarden, they provide a buffer to the sediment forebay as well as some screening and shade for local residents. Smaller species of *Melaleuca pallida* were planted to the north of the bioretention system adjacent to the grass swale. Table 26 shows the estimated annual pollution load reductions for the raingarden.

Table 26. TG010 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	79,110	103.2	867

Ecosystem services assessment

The identified key ecosystem services contribution from the raingarden is water quality regulation through pollutant load reductions and aesthetics for nearby residents. Other benefits include potential contribution to aesthetic value. It is assumed that the impact on property values is immaterial given that there is more significant natural asset, is the Isabella Lake, located in the same area. Other key benefits will include contribution to enhancing the habitat for fauna and biodiversity of the area's fauna. According to Canberra Nature Map, 45 bird species have been sighted in the area (Canberra Nature Map, n.d.)

TG011: Wetlands

Brief description

Two wetlands were constructed at Isabella Pond in the suburb of Monash. Onsite works included construction of the two wetlands, one on the south and the other on the north of the pond, retaining walls, supporting earthworks and associated works within Isabella Pond. Figure 21 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 21. TG011 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 27 provides key project timelines, asset footprint area and total capital costs.

Table 27. TG011 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
24/11/2017	18/04/2019	26/02/2021	7.5	3,859,144

Biophysical impacts

The new wetlands have a footprint area of 7.5ha. Additional facilities in the area included construction of a pathway system and some landscaping works. Aquatic, ephemeral and terrestrial plants were planted in the asset area. An estimated 1.56ha around the wetlands were planted with native vegetation. The new wetlands provide biodiversity improvements through attraction of birds and other native wildlife. Four benches were installed to provide seating areas for viewing of the wetlands. Table 28 shows the estimated annual pollution load reductions for the wetlands.

Table 28. TG011 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	457,000	768	4,360

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions. Other important benefits include contribution to aesthetic values,[24] biodiversity and enhancement of recreation. The wetlands are located in close proximity to residential properties that are likely to benefit from enhanced aesthetics.

TG012: Waterway restoration

Brief description

Asset TG012 includes three constructed vegetated swales along a floodway in Monash. These swales are constructed along a section of a floodway downstream of a triple 1800 mm diameter stormwater outlet to the west of Krause Place down to Charleston Avenue, Monash. Site works included modification of an existing silt trap, construction of a shared path and introduction of native tree species. Figure 22 shows an aerial image of the asset location before and during construction works.

a) Before construction   b) During construction

Figure 22. TG012 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 29 provides key project timelines, asset footprint area and total capital costs.

Table 29. TG012 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
19/03/2018	25/03/2019	27/03/2021	0.33	2,060,549

Biophysical impacts

The restoration site footprint area is 0.33ha with a waterbody area of 0.23ha. Exotic trees were removed and replaced with 60 native trees. Other landscape works include introduction of macrophyte plants as part of vegetated treatment zones to the sides of the existing concrete channel, dryland grassing, and street furniture (benches). The planting layout is designed to create a pattern of alternating planting bands along the treatment area. This provides unity and variety and ensures water can flow through a diversity of species bands from channel inlet diversions to the outlet. Established vegetation is to be dense and uniformly distributed to prevent stormwater flows meandering between plants, to withstand minor and major design flows, to create a uniform root zone for maximum

[24] There are some multi-residential dwelling on the RHS of the works.

treatment, prevent clogging and to restrict access to the treatment area thereby improving public safety. A 470m shared path was constructed on the west side of the waterway along the waterway from Corlette Street to a Bus Stop located at Charleston Street. This footpath is in addition to another pre-existing 2m wide path on the eastern side of the waterway. Table 30 shows the estimated annual pollution load reductions for the waterway restoration works.

Table 30. TG012 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	48,000	33	230

Ecosystem services assessment

The identified key ecosystem services contribution from the swales is water quality regulation through pollutant load reductions and aesthetics for nearby residents. However, it is worth noting that the naturalised waterway segment is located within less than a kilometer from three other key assets, which are: Lake Tuggeranong, Isabella Pond and Isabella Lake. Thus, the aesthetic benefits are considered positive but not significant. Other benefits include potential contribution to enhanced outdoor activity and walking to public transport due an additional half a kilometer footpath connecting residents to a bus stop.

TG017: Raingarden

Brief description

Asset TG017 is a raingarden located in Gowrie suburb. Construction work includes construction of the raingarden, stormwater drainage infrastructure, landscape and planting to the raingarden and surrounding area, concrete paths and sealed access tracks around the treatment asset, erosion and sediment control. Figure 23 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 23. TG017 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 31 provides key project timelines, asset footprint area and total capital costs.

Table 31. TG017 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
1/10/2018	20/05/2019	2021	0.61	3,548,018

Biophysical impacts

The raingarden area is 0.61ha. An estimated 0.55ha of land will be planted with native vegetation. The planting layout is natural and informal in appearance and designed to ensure water can flow through a diversity of species from inlet zones to the bioretention outlets. A GPT and sediment forebay are proposed in the stormwater source upstream of the raingarden to reduce sediments transferred to the raingarden and facilitate efficient ongoing maintenance. Landscape works include macrophyte planting as part of the extended bioretention system, open space tree planting, shrub planting, dryland grassing, concrete paving, street furniture, boulder placement and terracing and signage location. The site is bounded to the west by an existing footpath within the floodway. A new footpath is proposed to connect the access track to the new seating area located on the northern side of the asset. Table 32 shows the estimated annual pollution load reductions for the raingarden.

Table 32. Average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	56,400	103.6	741

Ecosystem services assessment

Pollution abatement and enhancement of biodiversity. This raingarden is located in an existing and well vegetated (bigger) park area. Other benefits may include improved recreational experience through provision of seats and enhanced aesthetics for local residents. Given the greener neighbourhood, the property impacts are deemed immaterial.

TG029: Raingarden

Brief description

Asset TG029 involved the construction of two raingardens located in the Tuggeranong Creek catchment area in the suburb of Fadden. Site works included construction of two raingardens, stormwater drainage infrastructure, landscape and planting to the bio retention and surrounding area, erosion and sediment control, and concrete paths and sealed access tracks through and around the treatment asset. Figure 24 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 24. TG029 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 33 provides key project timelines, asset footprint area and total capital costs.

Table 33. TG029 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
14/05/2018	15/04/2019	27/03/2021	0.68	2,770,383

Biophysical impacts

The raingarden area is 0.68ha. No new paths or facilities were constructed; however, street benches were provided. An existing path was increased from a width of 2.5m to 4m over a 160m length. Other llandscape works included macrophyte planting as part of the extended bioretention system, open space tree planting, shrub planting, dryland grassing, concrete paving, boulder placement and terracing and signage location.

The area planted with native vegetation is 0.48ha. The planting layout is banded in pattern, designed to ensure water can flow through a diversity of species from inlet zones to the bioretention outlets. The banded planting pattern also gives the asset an interesting aesthetic character and allows for plant spread. The planting focuses on dense, uniform littoral vegetation planting to prevent stormwater flows meandering between plants, to withstand minor and major design flows, to create uniform and deep root zones for maximum treatment and to restrict access to the bioretention system and therefore increase public safety. Table 34 shows the estimated annual pollution load reductions for the raingardens.

Table 34. TG029 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	36,300	25.9	382

Ecosystem services assessment

Pollution abatement and enhancement of biodiversity are the key ecosystem services from the raingarden. This raingarden is located in existing and very well vegetated bigger park area. Given the green asset location, the property impacts and contribution to recreation are deemed immaterial.

TG030: Pond

Brief description

Asset TG030 is a pond located in the Tuggeranong Creek catchment area in the suburb of Kambah. Site works included construction of the pond, stormwater drainage infrastructure, landscape including planting to the pond and surrounding area, and concrete paths. Figure 25 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 25. TG030 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 35 provides key project timelines, asset footprint area and total capital costs.

Table 35. TG030 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
14/05/2018	27/05/2019	2021	0.31	2,810,093

Biophysical impacts

The TG030 pond has a footprint area of 0.31ha, a water bod area of 0.31ha of 3,000m^3. The asset will include a pond, a GPT and 60m^3 sediment forebay for water quality regulation and also create a more appealing landscape to the open space with the added interest and appeal generated by the vegetation and street furniture. Some improvement works were undertaken to plant native trees over a 0.29ha area. Additional works included improvement of paths connecting the pond viewing area with existing local pathways and the nearby Kambah shops. Seating areas (including benches and rocks) were placed at strategic locations around the pond to provide viewing points. Table 36 shows the estimated annual pollution load reductions for the pond.

Table 36. TG030 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	28,000	45	120

Ecosystem services assessment

Pollution abatement and enhancement of biodiversity are the key ecosystem services that will accrue from the construction on this pond. This pond is located in existing open space with connected pathways. Given the asset location, the property impacts and contribution to recreation are deemed immaterial.

UM001: Waterway Restoration

Brief description

Asset UM001 is a waterway restoration along Molonglo River in the suburb of Oaks Estate. Works at the site include installation of rock chutes, stock exclusion fencing, weeds removal, pest control and revegetation along Molonglo River and at the confluence of both the Molonglo River and the Queanbeyan River. Figure 26 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 26. UM001 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 37 provides key project timelines, asset footprint area and total capital costs.

Table 37. UM001 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
4/02/2019	10/04/2019	2021	9.25	2,555,331

Biophysical impacts

The waterway restoration has asset footprint of 9.25 ha. Native vegetation was planted over 9ha around the asset, this included open space trees, shrubs and dryland grassing. Revegetation works were included to achieve approximately 10m of a riparian buffer around the river. Table 38 shows the estimated annual pollution load reductions for the waterway restoration works.

Table 38. UM001 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	46,256	41	18

Ecosystem services assessment

The works will reduce the amount of erosion on the banks while also improving the site's aesthetics. An increase in biodiversity and a reduction in weeds should encourage native plants, birds, aquatic species and other animals.

UM004: Raingarden

Brief description

Asset UM004 is a raingarden, in the suburb of Queanbeyan. Construction works included construction of raingarden, stormwater drainage infrastructure, construction of a flow diversion swale, reshaping of the existing floodway, and erosion and sediment control works. Figure 27 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 27. UM004 aerial images before and during construction

Source: Google Earth Pro (2019)

Table 39 provides the key project timelines, asset footprint area and total capital costs.

Table 39. UM004 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
22/11/2018	6/06/2019	30/04/2021	0.36	1,462,480

Biophysical impacts

The raingarden has a footprint of approximately 0.36ha. Native vegetation was planted over 0.33ha around the asset, including open space trees, shrubs and dryland grassing. The planting layout is natural and informal in appearance and designed to ensure water can flow through a diversity of species from inlet zones to the bioretention outlets. The informal planting pattern gave the asset a desirable naturalised aesthetic character. The planting focused on dense, uniform littoral vegetation planting to prevent stormwater flows meandering between plants, to withstand minor and major design flows, to create uniform root zone for maximum treatment and to restrict access to the raingarden and therefore increase public safety.

Landscape works included macrophyte planting as part of the extended raingarden system, concrete paving, street furniture, boulder placement and terracing. An existing path ran diagonally through the location of the raingarden. This path was relocated a short distance to the east to allow a continuous raingarden in the open space area and optimise the available area. In order to extend the longevity of the raingarden system a GPT is proposed immediately upstream. Table 40 shows the estimated annual pollution load reductions for the raingarden.

Table 40. UM004 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	51,600	63	450

Ecosystem services assessment

The identified key ecosystem services contribution from the raingarden is water quality regulation through pollutant load reductions and aesthetics for nearby residents. Other benefits include potential contribution to biodiversity, enhanced outdoor activity experience for local residents as the rain garden is located near some multiple shared paths.

WB004: Wetland

Brief description

Asset WB004 is a wetland in the suburb of Melba. Works at WB004 that included the construction of two wetlands, a sediment basin, stormwater pipes/culverts, stormwater structures, a GPT, landscaping and provision for seats. Table 41 provides key project timelines, asset footprint area and total capital costs.

Table 41. WB004 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
1/08/2018	30/05/2019	2021	2.16	4,081,280

Biophysical impacts

The wetland has asset footprint of 2.16ha and a waterbody area of 1.11ha. Native vegetation was planted over 0.97ha around the asset. The wetland provides water quality improvement with potential nutrient stripping and sediment entrapment by plantings, plus limited assisting of flood retardation. Multiple seats are provided adjacent the southern wetland offering good wetland viewing location integrated into the landscape. There are no new formal pedestrian or cycle facilities proposed for this asset. Figure 28 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 28. WB004 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 42 shows the estimated annual pollution load reductions for the wetland.

Table 42. WB004 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	48,900	80.4	379

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions and biodiversity enhancement. No material aesthetic, climate regulation benefits are assumed for this asset as it is located within a greater and connected open space area where there are multiple other substitutes assets for cultural benefits.

WB009: Wetlands

Brief description

Asset WB009 includes two wetlands located in the suburb of Evatt. Onsite works included the construction of the wetlands, a sediment basin, stormwater pipes/culverts, stormwater structures, a GPT, landscaping, a footpath and viewing jetty. Table 43 provides key project timelines, asset footprint area and total capital costs.

Table 43. WB009 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
1/08/2018	30/05/2019	2021	1.60	3,197,708

Biophysical impacts

The wetland has an asset footprint of 1.60ha, and waterbody area of 0.7ha. Native vegetation was planted over 0.90ha around the asset, revegetation works included open space trees, shrubs and dryland grassing. Multiple rock 'seats' and a bench seat were used in the viewing area as a natural and low-cost durable seating options to offer good wetland viewing location integrated into the landscape. Recreation facilities included a rock jetty located next to the southern wetland with approximately 50m of an access path connecting it to the existing shared path. Figure 29 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 29. WB009 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 44 shows the estimated annual pollution load reductions for the wetland.

Table 44. WB009 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	35,770	50.7	172.7

Ecosystem services assessment

The identified key ecosystem services contribution from the wetland is water quality regulation through pollutant load reductions and biodiversity enhancement. Additional climate regulation and aesthetic benefits are assumed for this asset. However, these are deemed immaterial as the wetland is located within a connected and vegetated open space area where there are multiple other substitutes assets for cultural benefits.

WB010: Waterway Restoration

Brief description

WB010 works involved waterway restoration in suburb of Florey. Intervention works included replacing an existing concrete channel with a vegetated channel, rock linings and the construction of a riffle/detention pool. Other works include landscaping the riparian buffer. Figure 30 shows an aerial image of the asset location before and during construction works.

a) Before construction

b) During construction

Figure 30. WB010 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 45 provides key project timelines, asset footprint area and total capital costs.

Table 45. WB010 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
17/07/2018	23/05/2019	2021	1.23	1,390,437

Biophysical impacts

The waterway restoration has asset footprint of 1.23ha and waterbody area of 0.181 ha. Native vegetation was planted over 1.04ha around the asset, including channel plantings, dryland grassing, retardation basin plantings and tree retention. Concrete banks were removed from 550m segment of the drainage channel and replaced with rock linings, soil and plants. The channel was designed to be wider and have a more natural meandering shape. The floodway and northern retardation basin provide water quality improvement with potential nutrient stripping and sediment entrapment by plantings. A 200m^2 detention basin was also added to the asset area. Despite a water quality focus the project site area provides an appealing landscape to the open space. The added appeal is likely to be generated from the increase in diversity of vegetation and landform (into an otherwise largely wooded area of dry grass setting and tree groups). There are no new formal pedestrian or cycle facilities for this asset. There is already an existing pedestrian pathway and a playground area adjacent to the waterway. Table 46 shows the estimated annual pollution load reductions for the restored waterway.

Table 46. WB010 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	25,690	35	172.9

Ecosystem services assessment

The identified key ecosystem services contribution from the waterway restoration is water quality regulation through pollutant load reductions and aesthetics for nearby residents. Other benefits include enhanced outdoor activity experience for local residents as the restoration works are located adjacent to an existing pedestrian pathway.

YA001: Waterway Restoration

Brief description

Asset YA001 is a waterway restoration in the suburb of Yarralumla, which includes the repair of heavily eroding banks of the creek with gabions, reno mattress and reinforced planting. Figure 31 shows an aerial image of the asset location before and during construction works. A survey of the area revealed that the remaining valley fills had potentially high scientific significance. Alluvial deposits dating back to 1840s formed a significant part of the upper bank stratigraphy. The initial survey and a comparison of alluvium at YA001 with valley floor and creek alluvial geomorphological sites listed for their assessed heritage values in the ACT and on the Southern Tablelands suggested the locations at YA001 have potentially some of the highest heritage values reported for alluvium valley floor sequences in the ACT (Barham and Lillis, 2017). Furthermore, background searches identified that the southern part of YA001 had already been identified as a site of geological interest and significance in the most recent published guide to Geological Sites in the Canberra Region.[25]

[25] See Finlayson (2008) A Geological Guide to Canberra Region and Namadgi National Park. Compiled by D.M. Finlayson with contributions from R.S. Abell. D.L. Strusz, P. Wellman, M.J. Rickard; D. Clark; K. McCue; K.S.W Campbell, K.G. Mc Queen, B. Pillans. Published by Geological Society of Australia (ACT Division)

a) Before construction b) During construction

Figure 31. YA001 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 47 provides key project timelines, asset footprint area and total capital costs.

Table 47. YA001 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
22/03/2019	28/06/2019	No establishment	0.18	1,732,418

Biophysical impacts

The waterway restoration has asset footprint of 0.18 ha. Native vegetation was planted over 0.18ha around the asset. As part of the works within the select areas along the creek select existing trees will need to be removed to facilitate the stabilisation of the creek embankments with new gabion walls. It is proposed 30 new native tree plantings within select areas along the creek will be planted. There are no new formal pedestrian or cycle facilities proposed for this asset. There were no other additional facilities linked to recreation that were installed as part of this project. Table 48 shows the estimated annual pollution load reductions for the waterway restoration works.

Table 48. YA001 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	132,300	NA	NA

Ecosystem services assessment

This site is of cultural and indigenous heritage significance. Thus, works around the site were designed to preserve the heritage status of the site. Further work was undertaken under the ACT Healthy Waterways to provide important information that guided the current works and is likely to be valuable information to the government and other land managers in the area.

The identified key ecosystem services contribution from the actual restoration works include water quality regulation through pollutant load reductions (particularly in the management of TSS). While the restored segments contribute to other ecosystem services (such as biodiversity) these are deemed as immaterial given the small-scale nature and location of the restored waterway segment.

YA002: Waterway Restoration

Brief description

Asset YA002 is a waterway restoration in the suburb of Curtin. Project works included the repair of heavily eroded banks, the construction of rock riffles, weed control and landscaping. Existing concrete was removed and replaced with a vegetated channel, sections of rock linings and a riffle pool. Figure 32 shows an aerial image of the asset location before and during construction works.

a) Before construction   b) During construction

Figure 32. YA002 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 49 provides key project timelines, asset footprint area and total capital costs.

Table 49. YA002 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
11/01/2019	3/05/2019	No establishment	0.02	1,541,137

Biophysical impacts

The waterway restoration area has a footprint of 0.02ha. Native vegetation was planted over 0.02ha around the asset, this included open space trees, shrubs and dryland grassing. The restoration works provides water quality improvement with potential nutrient stripping and sediment entrapment by plantings, plus limited assisting of flood retardation. Multiple rock 'seats' were used to function as natural rock viewing platforms. Table 50 shows the estimated annual pollution load reductions for the restored waterway.

Table 50. YA002 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	97,200	NA	NA

Ecosystem services assessment

The identified key ecosystem services contribution from the restored waterway is water quality regulation through pollutant load reductions and aesthetics for nearby residents. While the restored segments contribute to other ecosystem services (such as recreation amenity and biodiversity) these are deemed as immaterial given the small-scale nature and location of the restored waterway segment.

YA016: Raingarden

Brief description

Asset YA016 is a raingarden located in the suburb of Curtin. Construction works included the construction of a raingarden, stormwater pipes, stormwater structures, a GPT and landscaping. Figure 33 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 33. YA016 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 51 provides key project timelines, asset footprint area and total capital costs.

Table 51. YA016 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
15/03/2018	27/11/2018	19/12/2020	0.54	1,892,989

Biophysical impacts

The raingarden has an asset footprint area of 0.54ha. Three bioretention basins were constructed to provide water quality improvement with potential nutrient stripping and sediment entrapment by plantings, plus limited assisting of flood retardation. Native vegetation was planted over 0.20ha around the asset, this included open space trees, shrubs and dryland grassing. While water quality is the dominant focus the project the raingarden creates an appealing landscape to the open space with the added interest and appeal generated by the diversity of low vegetation in an area largely made up of mown grass and trees. A bench seat was provided to offer a raingarden viewing location integrated into the landscape. A 250m length of existing cycle way has been widened from a width of 2.5m to 4m as part of this project. Table 52 shows the estimated annual pollution load reductions for the raingarden.

Table 52. YA016 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	60,799	92.1	650

Ecosystem services assessment

The identified key ecosystem services contribution from the raingarden is water quality regulation through pollutant load reductions, biodiversity enhancement and aesthetics for nearby residents. Other benefits include potential contribution to enhanced outdoor activity experience for local residents as the raingarden is located near multiple shared paths.

YA020: Pond

Brief description

Asset YA020 is a water quality control pond located in an open space in the suburb of Mawson. The works included construction of a pond, a sediment basin, some stormwater pipes, a gross pollutant trap, maintenance access tracks, landscaping and adjustment to an existing footpath.[26] Figure 34 shows an aerial image of the asset location before and during construction works.

a) Before construction b) During construction

Figure 34. YA020 aerial images before and during construction
Source: Google Earth Pro (2019)

Table 53 provides key project timelines, asset footprint area and total capital costs.

Table 53. YA020 summary of timeframe, size and capital cost

Site work commencement	Civil works completion	End of establishment period	Asset footprint (ha)	CAPEX ($)
15/03/2018	27/11/2018	19/12/2020	2	2,619,058

Biophysical impacts

The pond footprint area is 2.0ha, has a waterbody area of 0.7ha and a volume of 6,540m^3. The asset will include a pond and GPT for water quality regulation and also create a more appealing landscape to the open space with the added interest and appeal generated by the diversity of low water margin vegetation, a large pond of open water and the rock viewing platform into an otherwise largely open area of slashed dry grass setting. Improvement works were undertaken to plant native vegetation to contribute to nutrient stripping and sediment capture. Vegetation was planted over a 1.0ha area around the asset. There were no new pedestrian or cycle facilities proposed for YA020 but there is a small 30m access path linking an existing shared path to a rock viewing platform. Two bench seats and multiple rock seats were integrated into the landscape to create viewing platforms for the pond. Table 54 shows the estimated annual pollution load reductions for the pond.

Table 54. YA020 average pollutant load reduction (kg/yr)

Pollutant	TSS	TP	TN
Amount	139,692	231	1,705

[26] There are no new pedestrian or cycle facilities proposed for YA020.

Ecosystem services assessment

The identified key ecosystem services contribution from the pond is water quality regulation through pollutant load reductions. Other important benefits include contribution to aesthetic values[27] and enhancement of recreation. The new asset borders residential properties on the east side. These nearby properties are likely to benefit from improvements to a nearby open space through enhanced views and urban cooling benefits.

[27] There are a few multi-residential dwellings on the RHS of the works.

APPENDIX B — INVESTMENT IN BEHAVIOUR CHANGE

Behaviour change activities within the ACT Healthy Waterways Program were funded through the H2OK program. The H2OK program set out to encourage positive behaviour-change among ACT residents with the aim of reducing stormwater run-off into the region's waterways.

A comprehensive community survey conducted in 2016 established that rural and urban ACT residents engage in a range of behaviours across four categories that can either improve or deteriorate the water quality in ACT waterways and downstream areas. These four categories were:

- Maintenance of drains within and outside the home.
- Gardening.
- Watering.
- Nature strip management.

This survey was important to establish a baseline of behaviours that might affect water quality in the ACT and downstream regions. This survey had sample of 4,701 respondents. The results from the survey are summarised into the four categories below.

Maintenance of Drains

Table 55 provides a summary of behaviours related to drains within and outside a home. These results are based on sample of 4,701 respondents. Results indicate that more than half of the respondents pour cooking oil down the drain and 15% believe that fertiliser and other chemicals from their homes enter nearby stormwater drains as a result of their actions and/or stormwater runoff.

Table 55. Results on prevalence of drains-related behaviours within and outside the home

Behaviour 1: items put into drains within the home	Proportion of sample engaging in the behaviour (%)
Cooking oil	52
Food scraps	49
'Flushable' wipes	24
Cosmetics and soap	17
Medications	14
Paint	13
Behaviour 2: items entering drains outside the home	**Proportion of sample engaging in the behaviour (%)**
Soil and dirt to nearby drains because of stormwater runoff	68
Soil and dirt to nearby drains because of resident actions	54
Leaves	45
Detergents and cleaning agents	42
Fertiliser	15
Chemicals (e.g. pesticides)	14
Grass cutting	16
Oil and paint	11

Gardening

Table 56 provides a summary of behaviours related to management of leaves and grass clippings as well as fertiliser and pesticides related behaviours. From the 4,701 respondents, 865 reported that they mulched their garden beds and 80% raked leaves. Under half of the respondents (48%) took grass clippings to the waste/tip while 7% raked or blew these onto the streets. Fertiliser application was sometimes applied on the ground before or during a rain event by 48% of the respondents and only 3% perform this when it is dry.

Table 56. Results on prevalence of behaviours associated with leaves, grass clippings, fertiliser and pesticides management

Behaviour 1: Leaves and grass clippings	Proportion of sample engaging in the behaviour (%)
Mulching garden beds	86
Raked leaves	80
Composted leaves and grass clippings	75
Left leaves where they fell	70
Left grass clippings on the lawn	53
Took grass clippings to green waste/tip	48
Used leaf blower	38
Raked or blew grass clippings onto the street	7
Behaviour 2: Fertilisers and pesticides	**Proportion of sample engaging in the behaviour (%)**
Regularly apply fertiliser on the ground before/during rain events	6
Sometimes apply fertiliser on the ground before/during rain events	45
Used fertiliser on their gardens when it is dry or there has been little rain	3
Sometimes used fertiliser on their gardens when it is dry or there has been little rain	35
Regularly used pesticides on their gardens when it is dry or there has been little rain	2
Sometimes used pesticides on their gardens when it is dry or there has been little rain	32
Regularly used pesticides in the garden before or during rain events	1
Sometimes used pesticides in the garden before or during rain events	9

Watering

Table 57 provides a summary of behaviours related to management of watering behaviours. Survey respondents primarily watered their gardens using a hose (23% regularly and 62% sometimes). However, many respondents used sprinklers (13% regularly and 44% sometimes) or drippers (23% regularly and 26% sometimes). In terms of water sources, 22% of respondents regularly used tank water to water their garden, with 13% sometimes doing so; 11% regularly use 'grey water' (e.g. reused from bath, washing machine), with 21% sometimes doing so, and; 4% regularly use other water sources, e.g. bore water, with 3% sometimes doing so.

Other watering behaviour recorded by the survey include that 13% of respondents regularly wash their cars at home, with 53% sometimes doing so, and 1% of respondents regularly use the hose to clean windows or driveway, with 42% sometimes doing so.

Table 57. Results on prevalence of behaviours associated with garden watering and car washing

Behaviour 1: Garden watering and car washing behaviour	Proportion of sample engaging in the behaviour (%)
Regularly watered gardens using a hose	23
Sometimes watered gardens using a hose	62
Regularly watered gardens using sprinklers	13
Sometimes watered gardens using sprinklers	44
Regularly watered gardens using drippers	23
Sometimes watered gardens using drippers	26
Regularly used tank water for gardens	22
Sometimes used tank water for gardens	13
Regularly used grey water for gardens	11
Sometimes used grey water for gardens	21
Regularly used other sources of water for gardens (e.g. bore water)	4
Regularly used other sources of water for gardens (e.g. bore water)	3
Regularly wash cars at home	13
Sometimes wash cars at home	53
Regularly use hose to clean windows or driveways	1
Sometimes use hose to clean windows or driveways	42

Nature Strip

More than half of respondents (56%) indicated that they regularly or sometimes raked leaves from their nature strip; 21% regularly or sometimes left lawn clippings on the nature strip; 16% used a leaf blower to blow leaves from the nature strip; 9% used fertiliser on their nature strip, and; 10% used pesticides on their nature strip.

Barriers to Implementing Action

The survey also investigated the barriers to composting, taking leaves/clippings to green waste facilities, installing water tanks, mulching garden beds and landscaping gardens to reduce water flows – all actions with the capacity to reduce the volume and/or improve the quality of stormwater runoff. For composting, the primary barriers were high cost, lack of time and/or equipment, lack of knowledge and lack of space. For taking leaves/clippings to green waste facilities, the lack of a suitable car/trailer and low priority were the main barriers. For installing water tanks, the barriers were a lack of interest and high cost. For mulching garden beds, there were few barriers reported, although among the small barriers reported were lack of interest and low priority. Lastly, for landscaping gardens to reduce water flow, cost, lack of knowledge and low priority were the main barriers.

APPENDIX C — REPORTS CREATED AS PART OF THE ACT HEALTHY WATERWAYS PROGRAM

- Barham T. & Lillis E. (2017). Geomorphology at Yarralumla Creek - YA001 Supplementary Report Results of additional fieldwork as part of the Geomorphic Assessment of Potential Archaeological Deposits at YA001, Navin Officer Heritage Consultants Pty Ltd.
- Bowen, A. (2016). ACT Healthy Waterways Basin Priority Project: Fyshwick Wetland FW12, Fyshwick Pond FW25 (statement of heritage effect) and Yarralumla Creek YA001, ACT (cultural heritage assessment). Bowen Heritage Management.
- eWater (2018). Data and modelling management strategy advice.
- Reich, J., and Fiona Dyer (2017). In-lake research trials supporting literature summary: Part 1 Lake Tuggeranong. Institute of Applied Ecology.
- Reich, J., and Fiona Dyer (2017). In-lake research trials supporting literature summary: Part 2 Jerrabomberra Wetlands. Institute of Applied Ecology.
- Ubrihien, R., Dyer F., Foster, S., Thompson, R., Allan, H., Orwin, D., Bray, J., Clear, R. and Y. Cross (2018). Lake Tuggeranong Research Project (interim report): preliminary findings from stage 1 and recommendations for stage 2. Institute of Applied Ecology.
- Ubrihien, R., Dyer F., Foster, S., Thompson, R., Allan, H., Orwin, D., McGrath, K., Clear, R., Cross, Y. and A. Tschierschke (2018). Urban ponds research project (interim report): preliminary findings.

APPENDIX D — URBAN COOLING MODELLING

The Air-temperature Response to Green/blue-infrastructure Evaluation Tool (TARGET)

To understand the temperature changes from the ACT Healthy Waterways activities, we have selected three sites across Canberra and used The Air-temperature Response to Green/blue-infrastructure Evaluation Tool (TARGET) to calculate spatial temperature differences. It is used to calculate the surface temperature, the air temperature and a measure of human thermal comfort for the desired spatial location and specific measurements for a representative hot day. It can be used on a range of scales from the street level to the city-wide scale. A high spatial resolution of $3m^2$ was chosen for the assessment of sites due to their relatively small size.

TARGET is designed to be a simple model that balances a realistic representation of urban surfaces with computational efficiency. TARGET uses spatial grids to collate information for modelling. Every spatial grid point contains information about each of the following nine variables: roof, road, concrete, water, trees, dry grass, irrigated grass, building height, road width. These nine variables are based on the characteristics of the area being simulated including differences between water bodies, residential areas, and parks.

The meteorological data required to run TARGET are:

- air temperature (˚C)
- relative humidity (%)
- wind speed (ms^{-1})
- atmospheric pressure (hPa)
- incoming shortwave radiation (Wm^{-2})
- incoming longwave radiation (Wm^{-2}).

TARGET simulation was undertaken for three days, January 29th to 31st 2017 as a heatwave occurred on these days with maximum temperatures reaching 38˚C at 2:30pm on January 30.

Several ponds, wetlands, raingardens and vegetation planting were included in the ACT Healthy Waterways Program. These new assets have an impact on nearby ambient temperatures. Vegetation and urban water bodies play an important role in reducing urban temperatures (Qiu, 2013). Such temperature reduction provides for outdoor human thermal comfort around the assets as well as lower temperatures at nearby dwellings/workplaces. The cooling benefits captured by people is dependent on a number of variables, including local environmental conditions, the design and placement of the systems and the nature of the surrounding urban landscape (Coutts et al., 2012).

Three sites (FW019, UM004 and WB004) were assessed by simulating modelling: 'before' and 'after' intervention scenarios. The 'before' intervention scenario was based on information from Google Earth Pro aerial images to gauge vegetation density and estimate cooling impact. The intervention case was then modelled based on Google Earth Pro images as well as design guidelines for each of the sites. The intervention case was modelled to represent the finished product and will enable us to calculate the difference in temperature before and after the intervention.

Air temperature, relative humidity, wind speed and atmospheric pressure data were derived from the Canberra Airport Bureau of Meteorology weather station at a half hourly resolution.[28] The incoming shortwave radiation and incoming longwave radiation data are derived from the ERA5 reanalysis dataset, which is a global spatial dataset that assimilates weather observations into a weather forecasting model to produce highly accurate global weather observations. Reanalysis is the research

[28] We acknowledge the CRC for Water Sensitive Cities for supplying this data.

best practice source for meteorological data when good quality weather station data is unavailable or uncommon variables (such as incoming longwave radiation) are required.

Spatial heat maps showing temperatures at each of the sites before and after the ACT Healthy Waterways activities are provided in Figure 35 to Figure 37. The prevailing wind at the modelled time is from the north-west indicating that the downstream cooling effect would be experienced towards the south-east of the wetlands and raingarden.

Figure 35 shows a heat map illustration of the temperature difference before and after the construction of a wetland (FW019).

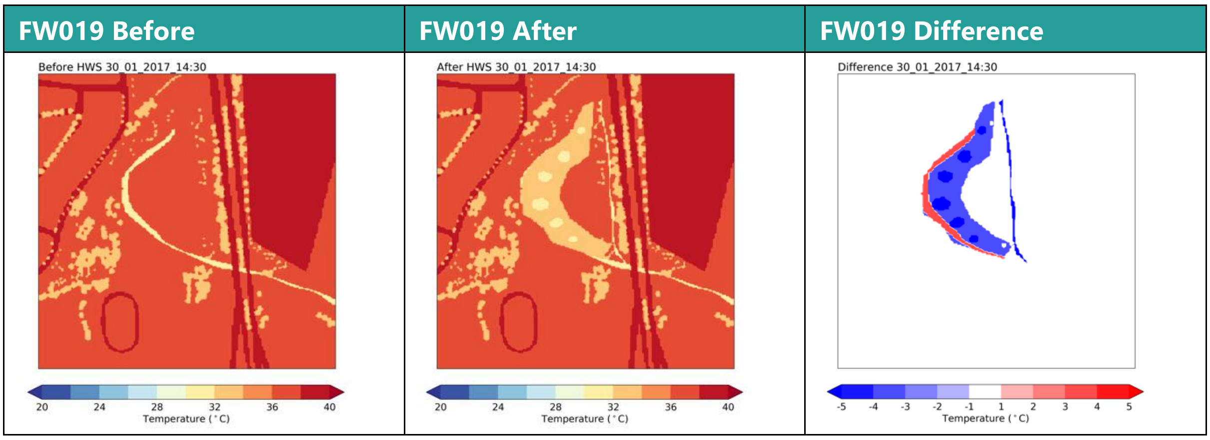

Figure 35. Urban cooling results for FW019

It is estimated that the addition of the wetland reduces the spatial average temperature by 1.0˚C at 2:30pm on January 30th 2017 (the representative summer day used for this case study). The maximum difference in temperature occurs at the wetland itself where the temperature is 7˚C lower than before the asset was constructed as dry unirrigated grass is replaced with open water and marshlands. The warming on the western side of the wetland is due to the slight difference in where the new waterbody is, as it has moved east slightly in construction. Hence, the original location of the waterbody is now designated as grasslands in the model showing a temperature increase from water to dry grass. This cooling air over the wetland will extend several hundred metres beyond the wetland due to the prevailing wind from the north-west. However, there are no houses within 500m south-east of the wetland and hence the cooling effect is unlikely to affect any houses.

Figure 36 shows a heat map illustration of the temperature difference before and after the construction of a raingarden (UM004).

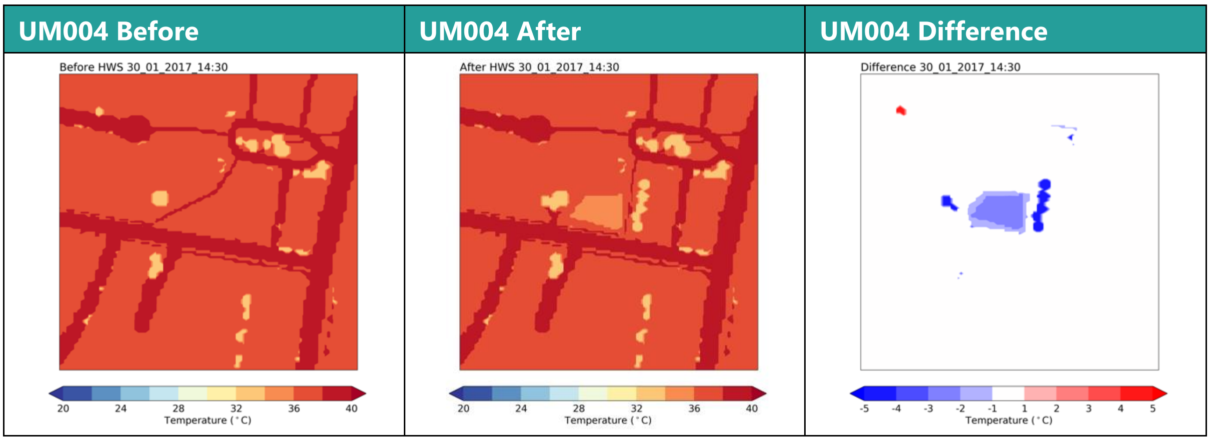

Figure 36. Urban cooling results for UM004

For this raingarden, across the area modelled using TARGET the addition of the raingarden reduces the spatial average temperature by 0.8˚C at 2:30pm on January 30th 2017. The maximum difference in temperature occurs at the raingarden where the temperature is 3˚C lower than before the asset was constructed as dry unirrigated grass is replaced with the raingarden. This cooler air over the raingarden will extend into the surrounding residential area due to the local wind effects, reducing the temperature of 30 houses in the downwind (south-east) area.

Figure 37 shows a heat map illustration to show the temperature difference before and after the construction of a wetland (WB004).

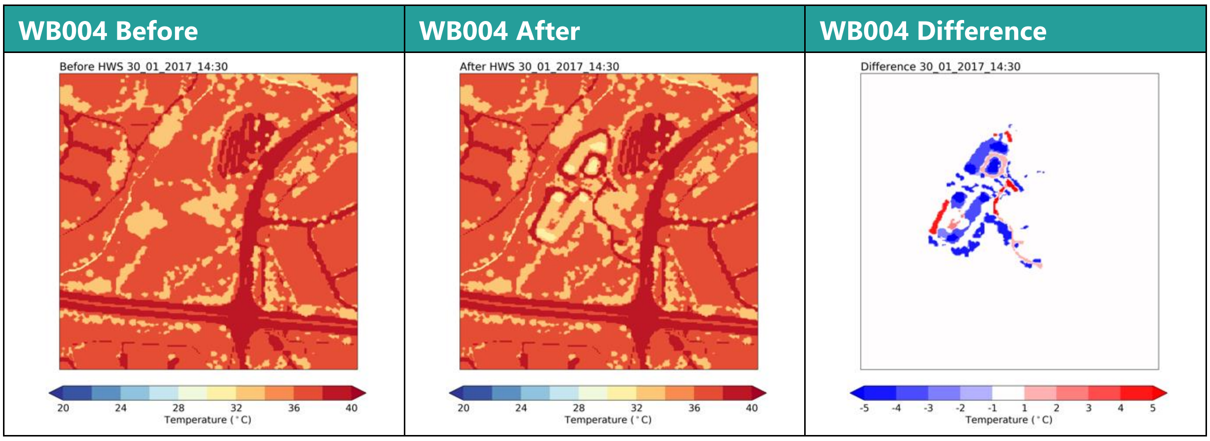

Figure 37. Urban cooling results for WB004

The wetland reduces the spatial average temperature by 0.5˚C at 2:30pm on January 30th 2017. The difference in temperature occurs at the wetland itself where the temperature is 7˚C lower than before the Program as dry unirrigated grass is replaced with open water and marshlands. The small areas of warming throughout wetland are due to trees being removed in the construction of the wetland, where the tree is replaced with dirt and gravel. This results in a smaller cooling result than FW019. This cooling air over the wetland will extend several hundred metres beyond the wetland into the residential area due to the local wind effects, reducing the temperature of 21 houses in downwind (south-east) area. It is likely the road to the south of the wetland will cause the cooler air from the wetland to mix with the hotter air from dry grass and roads, reducing the distance that the cool air can proliferate from the wetland.

These wetlands and raingardens contribute to temperature lowering and thus minimise the severity and frequency of extreme heat at the asset and the proximate areas. In general, extreme heat and heatwaves are estimated by using the 90th percentile of summer maximum temperatures as thresholds. According to the Canberra Airport weather station 90th percentile of summer maximum temperature is 35.2˚C (based on data from 2009 to 2018). On average, there were 11 days per year of extreme heat over 10 years (2009 – 2018). However, the number of extreme heat days is expected to rise due to climate change.

A previous study found that Melbourne and Sydney households were willing to pay $47 and $57, respectively, for a 2˚C drop in summer temperature (Brent et al., 2017). There are several benefits associated with lower temperatures particularly in the event of extreme heat and heatwave events. These include mortality (Nicholls et al., 2008), avoided cooling costs, and avoided labour productivity (Zander et al., 2014).

The willingness-to-pay estimates from Brent et al. (2017) were used to capture the quantified cooling benefits from the three case study assets. The willingness to pay values from Brent et al. (2017) were adjusted to 2019 dollars and used to estimate the urban cooling benefit. Table 58 provides a summary of the input data and results for the estimated urban cooling. The total number of homes affected was 51, and the temperature reductions were less than 1˚C. The FW019 wetland had a relatively high temperature reduction of 7˚C at the asset location but no nearby homes were found to benefit from this cooling effect. Thus, no benefit was calculated for this asset. While the high temperature reductions at the asset are not quantified, these reductions do play a role in providing outdoor thermal comfort for people recreating or travelling past the asset. The estimated urban cooling benefits are conservative and indicative. It is expected that larger assets and those located closer to homes and workplaces will lead to higher benefits associated with lower mortality, morbidity, productivity and energy savings. These additional benefits were not estimated in this case due to relatively small size of assets, asset locations and limited resources.

Table 58. Annual urban cooling benefits for three case-study assets

Asset code	Asset type	Cooling at the asset (˚C)*	Cooling at nearby homes (˚C)	Number of households	Estimated benefit, $ pa
FW019	Wetland	7	-	0	N/A
UM004	Raingarden	3	0.8	30	$682
WB004	Wetland	7	0.5	21	$298
Estimated annual cooling benefits (3 assets, only)				**51**	**$980**

*This is the largest temperature cooling outcome at the asset location