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Maximising the Value of Natural Capital in a Changing Climate Through the Integration of Blue-Green Infrastructure

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ABSTRACT

Australia's natural capital is under growing cumulative pressure from land use change and intensive agriculture, fishery, forestry, and urban sprawl. This consequently reduces the benefits and services that it provides. This paper firstly assessed how current trends of land-use change have an impact on the natural capital loss in South Victoria, Australia during 2006-2016. Then in order to increase natural capital inherent value and to ensure that natural capital is multifunctional, a system of Blue-Green Infrastructure is designed within the current natural capital of Tarwin Lower, in Victoria. Given that natural capital area is declining in Australia, incorporating designed elements into existing natural capital to create multifunctional natural capital, enables maximising the supply and value of ecosystem services in order to meet the demands of a growing population. Here, three ecosystem services (stormwater abatement, water quality improvement, and water supply services) were compared in terms of existing natural capital or with integrated Blue-Green Infrastructure elements to create multifunctional natural capital system. The results indicate that planning Blue-Green Infrastructure will enhance multiple aspects of regional sustainability and resilience in the Tarwin catchment and will maximise the multifunctionality of the natural capital. Finally, the paper simulates the cost-benefit analysis for the implementation of Blue-Green Infrastructure to show that it is a cost-effective and sustainable solution to cope with the current demographic, economic and agricultural trends, which affect natural capital. This paper confirms that in order to provide ecosystem services for extra demands of growing inhabitants, Blue-Green Infrastructure networks require to be extended in the Victoria State of Australia to compensate natural capital and ecosystem service losses due to the regional and urban development.

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KEYWORDS

Blue-green infrastructure, Natural capital loss, Ecosystem services, Sustainable development goals, Land-use change, Climate change.

INTRODUCTION

The emergence of the notion of 'natural capital' in recent years has lead to a recognition that environmental systems play an important role in defining a society's social well-being and economic output – providing services and resources, and absorbing wastes and emissions [1].

Natural capital is the most important of the forms of capital [2, 3] [manufactured capital (such as buildings and machines), human capital (such as people, their knowledge and skills), social capital (such as trust, norms and institutions) and natural capital (such as ecosystem services and minerals)] since it delivers the essential conditions for human being, delivering clean water, food, air, and basic resources and delivers the ecosystem services that are necessary to human wellbeing [4].

However, natural capital is disappearing or being fragmented all over the world [5, 6]. Despite the assumed growing demand for natural capital as the population grows, we are actually seeing it being fragmented and destroyed due to urbanisation or conversion to agricultural land [5, 6]. This reduces the benefits that it provides. The degradation and fragmentation of natural capital have disrupted essential environmental processes such as carbon sequestration, food provision, wildlife habitat, and water regulation that support quality of life, economic prosperity, and social well-being [6, 7].

Land-use change, mostly caused by agricultural activity, population growth, and urbanization, is recognised as one of the primary causes of loss of natural capital [8, 9]. This is because the common land uses (agriculture, urbanisation) are valued more highly than those land-uses associated with natural capital [10]. Several studies have reported the high rate of land use changes in developed and developing countries and have debated their consequences and causes [11, 12]. The majority of these land use changes occurred due to urban and regional development [13, 14].

The loss of natural capital is evident in Australia [15]. Almost 44% of Australia's woodland and forests have been cleared since human settlement [15] and a large proportion of wetlands have been destroyed or degraded due to agricultural areas, urban expansion, and the associated construction of flood protection measures such as levees [16]. More recently, the conversion of greenfield sites into rural and urban development have caused substantial pressures on the extent of the natural capital in southern, eastern and south-western Australia [15, 16] and continue to pose major problems for environmental managers.

Governments (various levels) in Australia have tried to arrest the loss of natural capital by the development and implementation of policies to protect, conserve, and regenerate its value, such that decisions to retain it in the face of competition with other land-uses can be defended. These include compensation schemes such as conservation banking, direct compensation to landowners, tradable habitat rights, insurance schemes, and tax relief mechanisms [17]. These payment methods need a willing buyer-seller market planning and well-defined property right. Despite these efforts, natural capital and consequently ecosystem service loss continues and some ecologists have questioned the efficiency of these efforts and the actual level of concern about natural capital and ecosystem service loss [18, 19]. Three key reasons are to blame [17]:

- "Information failure" is one reason why conservation investment finance is still unsuccessful. Despite increasing overall awareness of conserved environment advantages, there is a lack of detailed information at scales helpful for stakeholders and environmental managers on how people benefit from particular services;

- "Institutional failure" is the second reason. The beneficiaries of ecosystem service provision are usually distant and different from those who gain from ecosystem transformation. Local socio-ecological contexts, including institutions and property rights, are usually not given adequate consideration in conservation plans so that equity and validity concerns inhibit uptake;
- Thirdly, due to the public good characteristics of many profits and their lack of prices, "market failure" occurs. Furthermore, markets usually reward short-term values of natural resources (exaggerating the real opportunity costs of conservation) to the detriment of long-term environmental health and human well-being.

Therefore, due to the mismanagement of natural capital, its real value is not considered in socio-economic strategies despite its fundamental importance for human's well-being. One solution may be to ensure that the inherent multifunctionality of natural capital is retained through good planning and also accounted for in estimates of the value of natural capital to society. For example, individual nature reserves that are spatially isolated each have a value solely as nature reserves. But, if they are connected as a system of nature reserves, they potentially have new emergent properties such as providing flood control, biodiversity corridors and many other functions that they cannot perform individually. These connected systems can be designed using well-known engineering and biological principles and the added value to society of the emergent properties can be estimated. Therefore, 'multifunctional natural capital' is an important new concept that could help to solve the problem of declining natural capital in the face of competing land uses and population growth.

These connected systems can be achieved via a network of natural and semi-natural reserves. Water reservoirs and their related (natural) open spaces established along streams can regulate the river system, and prevent floods during extreme rainfall events. Wetlands and ponds can provide wildlife habitat (nature conservation), water treatment, and can clean the polluted water from nutrients and fertilizers that are mostly washed away from agricultural lands and which result in algae blooms in streams. In addition, they provide habitat for the wetland crops, such as biofuel production and reed, and provide areas for recreational purposes. Vegetated areas such as forests and woodlands provide carbon sequestration, regulate water flows and prevent soil from erosion. This network of the blue and green bodies is necessary to provide a wide range of advantages to the environment and people. As biodiversity supports the environmental services [20], guaranteeing the long-term persistence of habitat and species that provide main environmental services is conceivably, a practical strategy.

Blue-Green Infrastructure (BGI) is an interconnected network of natural and designed landscape components, including water bodies and green and open spaces, which provide multiple functions such as water storage for irrigation and industry use, flood control, wetland areas for wildlife habitat or water purification, among many others [21, 22]. Several developed and developing countries have already capitalized on this approach to achieve a range of economic, socio-cultural and environmental benefits [23].

Considering the natural ecosystem as infrastructure [24], in this paper, the land use and natural capital changes that occurred during 2006-2016 in the South Victoria and surrounding areas are evaluated. This:

- Gives us a view about natural capital changes in the regional context of Australia;
- Helps us to consider the land use effects of continuous development in regional and urban parts of Australia;
- Predicts future environmental behaviour in a spatially explicit manner.

Moreover, it allows the evaluation of future land use change impacts on ecosystem service supply considering a reference scenario. Those circumstances that can be tailored to underpin more informed decisions associated with natural capital management are reported and opportunities for more ecosystem services for the same area are identified. It is also shown how strategic, adaptive and multifunctional design of natural capital enables more ecosystem benefits based on a holistic understanding of the complex interrelations and dynamics of social-ecological systems. A method is presented to design the integration of BGI into existing natural capital and estimate the value of the resultant multifunctional natural capital. Lastly, this paper evaluates the cost and benefits of a designed BGI system in the study area.

Natural capital and ecosystem services

Ecosystem benefits and flows of natural capital ecosystem services are valued in Victoria using an Ecosystems Services Accounting (ESA) approach [25]. The ESA was developed by the State Department of Environment, Land, Water and Planning (DELWP) and Parks Victoria in order to identify and measure the ecosystem services delivered by Victoria's natural capital system, including the ecological and social advantages, according to international best practice [25]. In this approach, most of the amenities delivered by natural capital systems are considered as public goods and therefore the benefits are not reflected in market transactions. As such, it was necessary to establish a monetary value for individual ecosystem services based on a wide-ranging review of recent data, literature, and application of ecological evaluation methods.

For example, the ecosystem service flows of stormwater abatement, water quality improvement, and water supply provided by the natural ecosystem and their associated advantages in monetary terms are summarised in Table 1 [25]. These three (of many) components are highlighted because they are good examples of natural capital benefits that can be designed for multifunctionality and will be the focus of deeper analysis later.

Table 1. Summary of ecosystem flows and advantages of ecosystem services in Victoria, Australia [25]

Ecosystem service	Quantity of ecosystem service flow	Annual benefits (AUD) – welfare gains compared to surrounding land use	Other measures of economic activity	Hectares modelled	Level of confidence in flow quantities/monetary values
Water supply	Water run-off of 3,392 gigalitres (from nine highest yielding parks)	-	Value of water of AUD 244 million p.a. for supply (imputed)	896,367	Higher/Medium
Water purification (non-metro parks)	4,165 tonnes of sediment p.a. entering regulated rivers (preventing release of 47,000 tonnes from the counterfactual)	Avoided value of lost storage in regulated rivers (net of water yield reduction): AUD 50 million p.a.	-	368,732	Higher/Higher
Flood protection	34,372 ML of stormwater p.a. going into Melbourne's waterways (avoiding 40,000 extra stormwater from the counterfactual)	Avoided infrastructure costs to deal with additional stormwater: AUD 46 million p.a.	-	64,212	Higher/Higher

Market-based methods have been used for changes in water availability measured with corresponding supply costs or entitlement prices to water corporations in order to value the water supply services. Even though water market-based values are available, prices charged for abstraction do not reflect the real and full value of water. Water prices normally cover the infrastructure, operations, and maintenance, together with the energy costs of clean water allocation and wastewater treatment. These costs thus largely reflect the value of capital inputs on the supply aspect instead of the water itself [25].

To value the water purification services of natural ecosystem, market-based methods have been used according to the replacement cost method and the cost of new water treatment infrastructure to cope with the extra nitrogen or sediment.

Valuation of stormwater and flood regulation is based on the per hectare avoided cost of flood detention or retarding basin storage. The cost is related to the hydraulic constituent of water's developer contribution charges, which reflects the cost of on-site infrastructure that transports or postpones flood comprising stream/river protection works as well.

METHODS

This section covers the land use changes that occurred in southern Victoria during 2006-2016, problem description, and the introduction of multifunctionality to Natural Capital (BGI). Details on each step have been provided in the following sections.

Defining land use changes in southern Victoria

Changes in land use were evaluated in the South Victoria regions and surroundings (Figure 1).

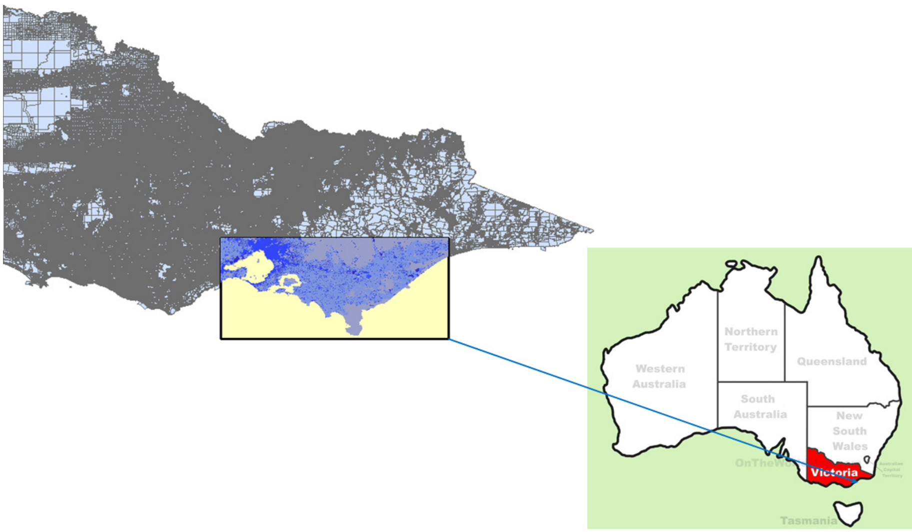

Figure 1. Location of South Victoria in Australia

The spatial analysis relied on two land use datasets of 2006 and 2016. The Victorian Land Use Information System (VLUIS) dataset has been used, and the land use data has been obtained from the Valuer-General Victoria. The land use descriptions and codes have been revised according to the Australian Valuation Property Classification Codes (AVPCC). The AVPCC includes nine main classifications:

- Residential;
- Commercial;
- Industrial;
- Extractive industries;
- Primary production;
- Infrastructure and utilities;
- Community services;
- Sports heritage and culture;
- National parks, conservation areas, forest reserve and natural water reserves.

There are two other classes, which were defined as Urban Void (V) and Unclassified private land (U). Urban voids refer to all areas in the urban context, whose designs and functions have not yet been decided upon conclusively and they are one of the main signs of urbanisation. Each of the main classifications was divided into different secondary and tertiary sub-classes [26].

By comparing the 2006-2016 shapefiles, it was possible to detect the land use changes during the 10-year period in the southern regions of Victoria. Table 2 illustrates the changes occurred during the ten years of the main classes. Figure 2 and Figure 3 show the distribution of different classification in the study area in 2006 and 2016, respectively.

Table 2. Changes occurred in land uses (primary classifications) during 2006-2016, southern Victoria, Australia

Land use type (primary categories)	2006 [ha]	2016 [ha]	Increase-decrease [ha]
Residential	296,503.5	265,293.7	−31,209.8
Commercial	15,114.1	4,173.6	−10,940.5
Industrial	21,471.5	9,194.9	−12,276.6
Extractive industries	13,883.6	11,761.6	−2,122
Primary production	1,292,013	1,125,249	−166,764
Infrastructure and utilities	15,803.4	43,748.3	27,944.9
Community services	532.1	11,160.8	10,628.7
Sport heritage and culture	7,081.1	12,759.5	5,678.4
National parks, conservation areas, forest reserve and natural water reserves	1,183,070	1,147,187	−35,883
Urban Void (V)	145,684.1	337,664.3	194,622.1
Unclassified private lands (U)	3,403,06.3	199,681	−140,625.3

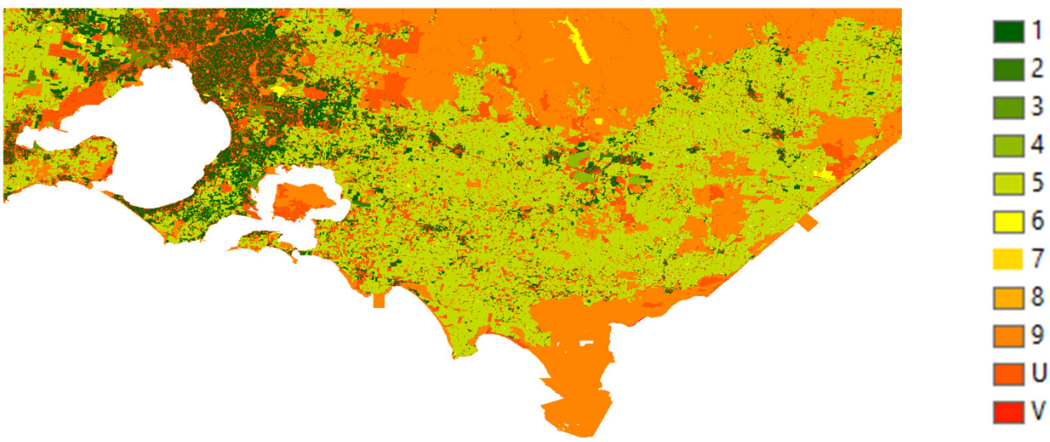

Figure 2. Spatial pattern of land use 2006, southern Victoria, Australia

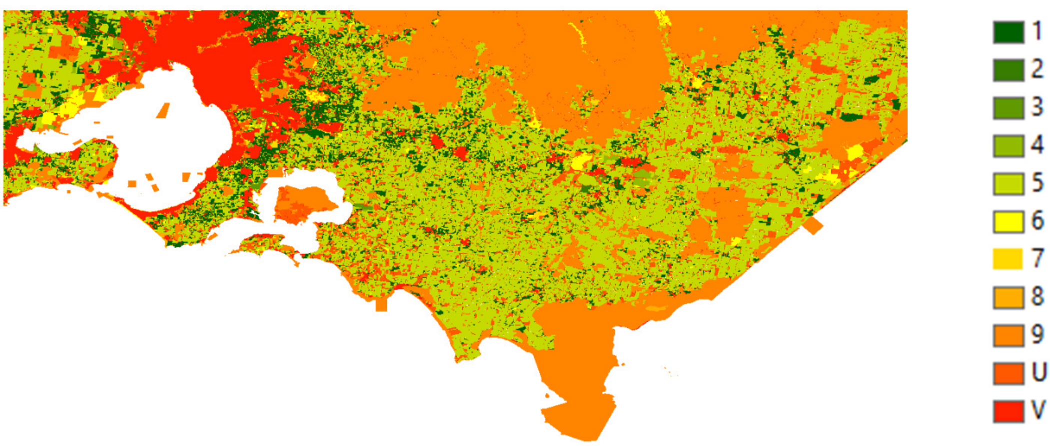

Figure 3. Spatial pattern of land use 2016, southern Victoria, Australia

It is important to mention that there is about 5% difference in the total coverage area in 2006 and 2016. According to VLUIS metadata, which is based on the state cadastral parcel layer, this difference is because of overlapping polygons due to subdivision and realignments of the cadastre [26]. This data layer is dynamic and therefore at any one time can have overlapping polygons [in particular this overlapping occurred in unclassified private lands (U)].

Here, the total coverage area of the natural capital (class 9 – National parks, conservation areas, forest reserve and natural water reserves) in southern Victoria was reported. Based on the results of Table 2, the decrease of the total natural capital area by almost 36,000 hectares (3%) during 2006-2016, shows a fall of ecosystem services in 2016 while at the same time the demand for ecosystem services increases by population growth. According to the Australian Bureau of Statistics (ABS) [27], Victoria experienced the highest population growth rate amongst other states by the growth of 1.1 million people (22.1%) during 2006-2016. In order to provide ecosystem services for extra demands of growing inhabitants, two things need to be considered: the first includes minimizing or stopping the conversion of natural capital to other artificial land uses, which is almost inevitable due to urbanisation and agricultural development. The second is the strategic design of natural capital (multifunctional natural capital) as to get more ecosystem benefits via a more holistic understanding of the complex interrelations and dynamics of social-ecological systems. Here, the impacts of multifunctional natural capital via a designed BGI system in a case study were analysed as a proof of concept and the costs and benefits of the designed system were reported.

Problem description

As a means of exploring the concept of multifunctional natural capital, its potential benefits in a case study of Victoria, Australia were explored. The case study is part of the Tarwin catchment (Tarwin Lower) located in the South Gippsland region in Victoria, Australia (Figure 4). Tarwin Lower is a good case study because:

- It has already suffered significant land-use driven reductions in natural capital over time and there is very little left [25];
- Agriculture is intensifying in the region and therefore there is every reason to suspect that the trend of declining natural capital will continue and exacerbate other problems (specifically nutrient run-off) [25];
- It is a highly flood-prone area that needs a solution.

The Tarwin catchment has experienced destructive flood events at a higher frequency in the past 25 years (1990, 1997, 2001, 2007, March 2011, May 2012, June 2012 and July 2016) which caused millions of dollars damage to people, infrastructures, properties, and environment. Significant floods had normally happened in this area, every 10 to 20 years. However, during 2011-2013, there have been three major flood events [28]. As climate change intensifies the frequency and magnitude of flooding more destructive floods are likely to happen in this area in the future [29]:

- Nutrient runoff is a serious problem, which needs a solution. Cumulative data from 1975 to 1997 show that nitrogen and phosphorus levels in the Tarwin catchment exceed recommended levels by State guidelines, particularly downstream of intensive agriculture and residential areas [30]. Elevated levels of phosphorus and nitrogen contribute to significant water quality deterioration in the Tarwin catchment as they are potential to cause toxic blue-green algal blooms;
- Due to the effects of the climate change, previous drought periods, changes in South Gippsland water's operation as a result of the drought, and landscape developments, the raw water demand for South Gippsland region in increasing every year [31]. For example, the average raw water demand in Tarwin River/Meeniyan in 2012 was estimated to be 65 ML/yr;

Flooding, nutrient run-off, and water supply will all become bigger problems due to climate change. As such, it is an ideal site to examine whether multifunctional natural capital can address some of the problems and therefore achieve a higher societal value, thus increasing the chances that the decline in natural capital can be stopped.

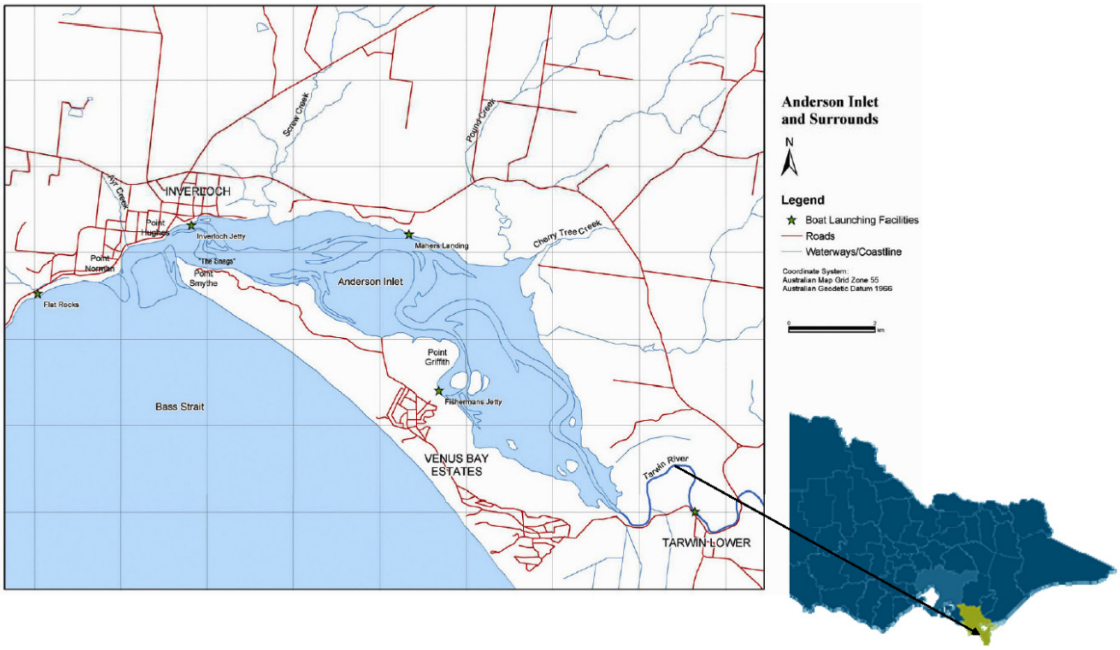

Figure 4. Location of the Tarwin River in South Victoria [32]

Introducing multifunctionality to Natural Capital (Blue-Green Infrastructure)

BGI planning is implemented according to a variety of guidelines or principles [33, 34], all with the common aim to promote ecological services in the communities [35]. BGI development is also considered a melting pot for innovative planning methods in the field of environment conservation and blue and green space management [36].

Here, a method is presented to design the integration of BGI into existing natural capital and estimate the value of the resultant multifunctional natural capital. BGI planning was used by integrating regional-scale approaches to systematically identify ecosystem service trade-offs, synergies, and 'hotspots' associated with BGI and its siting in order to highlight the multifunctionality of BGI.

Figure 5 depicts the typical steps for designing multifunctional natural capital via BGI. To analyse the impacts/benefits of the designed multifunctional natural capital (BGI) system on ecosystem services, its performance was evaluated with the help of Model for Urban Stormwater Improvement Conceptualisation (MUSIC) [37]. To provide a reliable method for simulation, a meteorological template was created in MUSIC using relevant data of rainfall, evapotranspiration, and time steps (orange colour).

When the climate-related data was introduced into the model, the source nodes were determined to specify the properties of the contributing catchments. This included defining land use type, establishing catchments, introducing rainfall run-off parameters, and defining pollutant generation parameters (grey colour).

To evaluate the impacts of the designed system, three MUSIC models were created:

- With current natural capital (current situation, blue colour);
- Without natural capital (green colour);
- With a designed multifunctional natural capital (BGI) system (purple colour).

After defining the BGI components, four criteria were considered:

- Location;
- Size;
- Connectivity;

- Physical configuration of BGI components to design the multifunctional natural capital via the BGI system (purple colour).

Lastly, the performance of each MUSIC model [with current natural capital, without natural capital, and with a designed multifunctional natural capital (BGI) system] was tested on three ecosystem services of water supply, water purification, and flood mitigation (yellow colour).

The model was designed to facilitate spatial planning at a regional scale and was applied to Tarwin Lower as a proof of concept. In the Tarwin Lower example, the analysis looked at three benefit criteria (abate stormwater, secure water quality improvement, and supply water for the drought periods) to compare performance. But, it should be noted that the model is generalizable and can be applied to other catchments or regions where appropriate data is available.

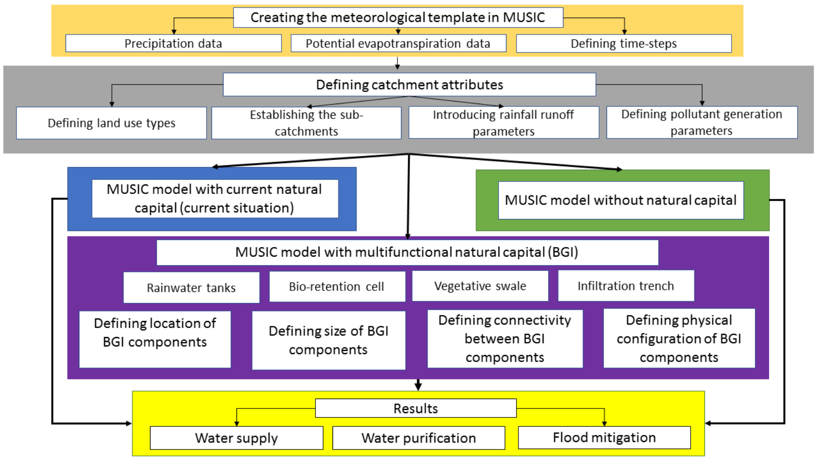

Figure 5. The typical steps for designing multifunctional natural capital via BGI [orange: creating the meteorological template in MUSIC, grey: defining catchment attributes, blue: creating MUSIC model with current natural capital (current situation), green: creating MUSIC model without natural capital, purple: creating MUSIC model with multifunctional natural capital (BGI), yellow: comparing the results of three MUSIC models on water supply, water purification, and flood mitigation]

The meteorological template was created for Tarwin Lower using continuous rainfall data per 6 minutes for the year 2012 (one of the wettest years on record), the measured mean monthly potential evapotranspiration for the Tarwin catchment, and a suitable definition of storm hydrograph movement through BGI components, which was specified by selecting the 6-minute time-steps (Figure 6).

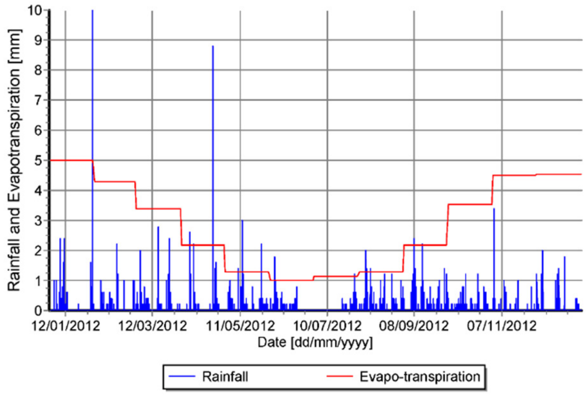

Figure 6. Rainfall and evapotranspiration data for the year 2012, Tarwin catchment, Victoria, Australia

To define the catchment attributes, the area for each sub-catchment was defined and inserted in the appropriate source node (in hectares). The location, extent, and the imperviousness ratio of the sub-catchments were specified. Also, rainfall run-off and pollutant generation parameters were determined in MUSIC.

Rainfall run-off parameters are impacted by the type of the soil and were produced via the interplay of the MUSIC Rainfall Run-off model, rainfall, and evapotranspiration (Table 3).

Table 3. Rainfall run-off parameters for the Tarwin catchment, Victoria, Australia

Impervious area properties	
Rainfall threshold [mm/day]	1.00
Pervious area properties	
Soil storage capacity [mm]	120
Initial storage [% of capacity]	25
Field capacity [mm]	80
Infiltration capacity coefficient – a	200
Infiltration capacity coefficient – b	1.00
Groundwater properties	
Initial depth [mm]	10
Daily recharge rate [%]	25.00
Daily baseflow rate [%]	5.00
Deep seepage [%]	0.00

Run-off pollutant parameters were produced stochastically by assuming a constant mean concentration or from a well-defined mean and standard deviation. The study area comprises five types of land use: grazing modified pasture (cattle), grazing modified pasture (other livestock), rural living, conservation environment, and roads. Table 4 illustrates Dry Weather Concentration (DWC) and Event Mean Concentration (EMC) of the nutrients according to the different land uses. Land use type is considered as the main parameter for changes in nutrient and sediment delivery to the BGI components. Data were collated by South Gippsland Water for Total Suspended Solid (TSS), Total Nitrogen (TN), and Total Phosphorus (TP).

Three MUSIC models [with current natural capital (current situation), without natural capital, and with a designed multifunctional natural capital (BGI) system] were created to compare their impacts on water supply, water treatment, and flood mitigation.

Figure 7 shows the current natural capital (green regions) located in the study area.

Table 4. DWC and EMC of TSS, TP, and TN for different land uses in the Tarwin catchment, Victoria, Australia

Land use type		log10 TSS [g/m^3]		log10 TP [g/m^3]		log10 TN [g/m^3]	
		Base flow	Storm flow	Base flow	Storm flow	Base flow	Storm flow
Agricultural (cattle)	Mean	1.000	2.300	−1.090	−0.301	−0.500	0.342
	Std. Dev.	0.130	0.310	0.130	0.300	0.130	0.260
Agricultural (other livestock)	Mean	1.000	2.200	−1.397	−0.301	−0.500	0.342
	Std. Dev.	0.130	0.310	0.130	0.300	0.130	0.260
Rural residential	Mean	1.000	2.041	−1.000	−0.602	−0.522	0.301
	Std. Dev.	0.170	0.320	0.190	0.250	0.120	0.190
Road	Mean	1.000	2.000	−1.000	−0.522	−0.522	0.362
	Std. Dev.	0.170	0.320	0.190	0.250	0.120	0.190
Conservation environment	Mean	0.699	1.602	−1.699	−1.046	−2.096	−0.046
	Std. Dev.	0.130	0.200	0.130	0.220	0.130	0.240

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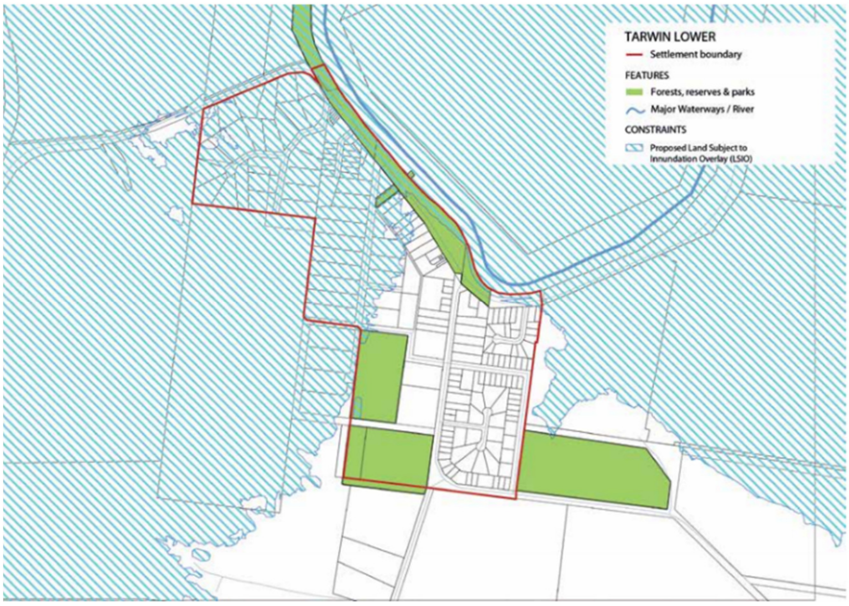

Figure 7. Natural capital located in the study area [38]

Tarwin Lower is a rural residential including natural capital zones facing numerous resilience challenges such as ageing infrastructure and high vacancy rates. Yet the Tarwin catchment natural capital, farms, and extensive vacant land also present an opportunity for regional transformation, and BGI is a primary redevelopment strategy. But are natural capitals in the Tarwin catchment being strategically planned where ecosystem service benefits are maximised and needed most? BGI spatial planning analysis was used to answer this question, comparing the designed modelled with the current natural capital across the Tarwin catchment.

As mentioned above, to design the multifunctional natural capital (BGI) system within the current natural capital, four criteria were considered:

- Location;
- Size;
- Connectivity;
- Physical configuration of BGI components.

Four BGI components (bio-retention cell, rainwater tank, infiltration trench, and vegetative swale) among many others were chosen based on their applicability in a regional context, efficacy, and aesthetic suitability.

In order to define the best location for the BGI components, different GIS shape-files (Gippsland flood-ways, Gippsland land-use land-cover, Gippsland soil, and Gippsland plan- overlay) were integrated with the Digital Elevation Model (DEM) layer. These layers provide information about areas prone to flood, current land-use and land-cover, type of the soil, soil permeability and drainage rate, and others.

Based on the soil layer shape-file information, the dominant soil type in the region is aeric and aquic podosols and extratidal hydrosols. The drain-rate fluctuates between very poor, poor and moderate level while perm-rate fluctuates between very slow, slow and moderate. The DEM layer signifies the surface level and slope.

The rainwater tanks were located on parts of the study area with the lowest elevation based on the information provided by the DEM layer. The gravity conveys the stormwater into the rainwater tank (storage component). Regardless of surface characteristics, slope is one of the most important factors to consider. Moreover, a number of these tanks were located in floodplain zones. The floodplain zones were identified using the flood-way layer to determine the best location to capture rainfall run-off directly.

The bio-retention cell and infiltration trench were located where the soil permeability value and soil moisture retaining capacity is very low so as to reinforce the rainfall infiltration process. The soil characteristics were fully covered by soil shape-file layer.

The vegetated swale was located in the areas that connect less permeable and high permeable zones. This was to ensure that they convey the stormwater from less permeable to the storage component or high permeable regions of the study area. The Gippsland land-use land-cover and plan-overlay layers provide us with the further indication of where the vegetative swale could best be located.

Size of each BGI component within the natural capital was set based on their applicability in a regional context. The area of the bio-retention cell was set at 2,000 m^2, the area of the infiltration trench was set at 1,000 m^2, the area of the vegetative swale was set at 1,000 m^2, the area of each tank was set at 50 m^2, and the volume of the tank 250 m^3 (250,000 L). Compared with the size of each natural capital in the study area (7.04, 4, 3.44, 1.64, and 0.52 ha), the occupied size of the BGI components in natural capital is negligible. Therefore, BGI has the benefit of taking little space and therefore having little impact in terms of space. As such, there are no significant implications on land-use by the introduction of BGI to regional and rural areas and natural capital.

Regarding connectivity, it is proposed that rural residential sites including roads will drain to the swale component prior to discharge to the bio-retention and infiltration trench before discharging to the rainwater tank. The agricultural farms will drain to the bio-retention prior to discharge to the infiltration trench before discharging to the rainwater tank. The conservation environment will directly drain to the rainwater tank.

Finally, the physical configuration of the BGI components was defined in MUSIC as shown in Tables 5-8, respectively.

Table 5. Rainwater tank properties

Inlet properties		
High flow by-pass [m^3/s]	100	
Low flow by-pass [m^3/s]	0	
Individual tank properties		
Number of tanks	5	
Storage properties		
Volume below overflow pipe [m^3]	250	
Depth above overflow [m]	0.10	
Surface area [m^2]	25	
Initial volume [m^3]	0.00	
Outlet properties		
Overflow pipe diameter [mm]	112	
Advanced properties		
	K [m/yr]	C^* [g/m^3]
TSS	400	12.000
TP	300	0.130
TN	40	1.400

Table 6. Bio-retention cell properties

Inlet properties		
Low flow by-pass [m^3/s]	1.500	
Storage properties		
Extended detention depth [m]	0.35	
Surface area [m^2]	3,500.00	
Filter and media properties		
Filter area [m^2]	1,000.00	
Unlined filter media perimeter [m]	14.00	
Saturated hydraulic conductivity [mm/hr]	150.00	
Filter depth [m]	0.60	
TN content of filter media [mg/kg]	800	
Orthophosphate content of filter media [mg/kg]	55.0	
Outlet properties		
Overflow weir width [m]	2.00	
Advanced properties		
Weir coefficient	1.70	
Number of Continuous Stirred-Tank Reactor (CSTR) cells	3	
Porosity of filter media	0.350	
Horizontal flow coefficient	3.0	
	K [m/yr]	C^* [g/m^3]
TSS	8,000	20.000
TP	6,000	0.130
TN	500	1.400

Table 7. Vegetative swale properties

Inlet properties			
Low flow by-pass [m^3/s]	0		
Storage properties			
Length [m]	500.0		
Bed slope [%]	1.00		
Base width [m]	2.0		
Top width [m]	5.0		
Depth [m]	0.30		
Vegetation height [m]	0.100		
Exfiltration rate [mm/hr]	0.00		
Calculated swale properties			
Mannings N	0.094		
Batter slope	1:5		
Velocity [m/s]	0.372		
Hazard	0.112		
Cross sectional area [m^2]	1.05		
Swale capacity [m^3/s]	0.391		
Advanced properties			
Number of CSTR cells	10		
	K [m/yr]	C^* [g/m^3]	C^{**} [g/m^3]
TSS	8,000	20.000	14.000
TP	6,000	0.130	0.130
TN	500	1.400	1.400

Table 8. Infiltration trench properties

Inlet properties		
High flow by-pass [m^3/s]	100	
Low flow by-pass [m^3/s]	0	
Storage properties		
Extended detention depth [m]	0.3	
Surface area [m^2]	1,000	
Exfiltration rate [mm/hr]	0.50	
Filtration properties		
Filter area [m^2]	1,000.00	
Filter depth [m]	2.0	
Filter median particle diameter [mm]	1.00	
Saturated hydraulic conductivity [mm/hr]	1,000.00	
Depth below underdrain pipe [% of filter depth]	0.0	
Outlet properties		
Overflow weir width [m]	2.00	
Advanced properties		
Weir coefficient	1.70	
Number of CSTR cells	3	
Void ratio	0.3	
	K [m/yr]	C^* [g/m^3]
TSS	8,000	20.000
TP	6,000	0.130
TN	500	1.400

It should be pointed out that MUSIC uses the Universal Stormwater Treatment Model (USTM) to calculate the treatment processes that take place in most of the treatment devices. When a parcel of water carrying materials such as suspended solids, phosphorus, or nitrogen enters a treatment measure such as a bio-retention cell, the water quality of the parcel begins to change. Several physical processes are involved, and detailed behaviour can be very complex. But the overall effect is that contaminant concentrations in the parcel tend to move by an exponential decay process towards an equilibrium value for that site at that time. This behaviour can be described by the first order kinetic (or k-C^*) model, in which C^* is the equilibrium value or background concentration, and k is the exponential rate constant.

The water quality performance of a treatment measure may depend upon the inflow rate. In particular, stormflow and baseflow may be handled very differently. Baseflows may be confined to a distinct low flow channel or pipe, while stormflows potentially occupy the whole area of the treatment measure. To allow for this, the package recognises two separate background concentrations in treatment measures that do not consist of a permanent pool, thus allowing for a better description of the low flow operating conditions in these measures.

C^* parameter has been redefined to be the event background concentration, which applies at higher flows when the extended detention storage is in use. The new parameter C^{**} becomes the baseflow background concentration, which applies when flows are

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largely confined to a low flow channel. Where a permanent pool is present, only a single background concentration (C^*) applies. The C^{**} feature can be disabled by setting it to have the same value as C^*.

Figures 8-10 depict the designed Tarwin catchment MUSIC model with the multifunctional natural capital (BGI) system, with current natural capital, and without natural capital respectively. To check the benefits of natural capital on ecosystem services, it is assumed that in the system without natural capital, the study area includes rural residential and agricultural zones only.

Figure 8. Study area with the designed multifunctional natural capital (BGI) system

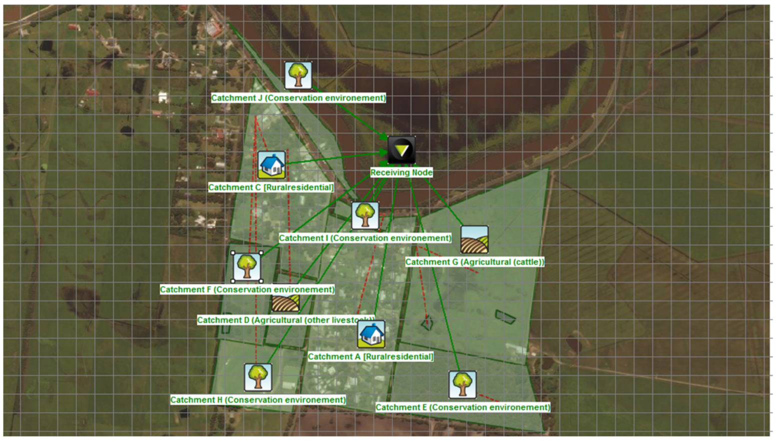


Figure 9. Study area with current natural capital

Figure 10. Study area without natural capital

RESULTS AND DISCUSSION

To evaluate the ecosystem services (water supply, water purification, and flood mitigation) the results of the three models were compared. Table 9 and Table 10 illustrate the changes occurred in sediment loads, runoff, and water supply for models with current natural capital and with multifunctional natural capital (BGI), and also with and without current natural capital respectively.

While Table 9 and Table 10 highlight the importance of multifunctional natural capital (BGI) system and natural capital in providing different ecosystem services respectively, Table 9 also provides initial evidence that designing about only 0.1% of the current natural capital area as BGI can maximise stormwater abatement by 16%, water quality improvement by 94.4%, and water supply reuse services by 100%. Here 100% means current natural capital in Tarwin Lower cannot secure water supply for reuse purposes by itself although they will reduce runoff by stormwater infiltration into the soil. BGI components such as rainwater tanks, ponds, and wetlands enable storing stormwater (by storage component or detention storage zone), which can be reusable for other purposes such as irrigation in the regional context or toilet flushing for urban areas.

Also, the results indicate that there are priorities for placing BGI in natural capital. Although the area of sub-catchments I (0.52 ha) and J (1.64) are smaller than sub-catchments E (7.04 ha), H (4 ha), and F (3.44 ha), sub-catchments I and J have higher priorities for BGI implementation (Figure 8). This is due to being located very close to the river, and also being located in lower elevation where gravity will convey water directly to those sub-catchments. The former reason makes those two sub-catchments very important because of their role in improving stormwater quality prior to discharge to the river and the latter reason highlights their importance because of runoff capture and flood mitigation.

Table 9. Ecosystem service differences with current natural capital and with multifunctional natural capital (BGI) system

	Model with current natural capital	Model with multifunctional natural capital (BGI) system	Decrease/increase	Decrease/increase [%]
Sediment loads [kg/yr]	37,560	2,118	−35,442	−94.4
Reused supplied [ML/yr]	0	42	+42	+100
Rainfall runoff [ML/yr]	326	274	−52	−16

Table 10. Ecosystem service differences with and without current natural capital

	Model without natural capital	Model with current natural capital	Decrease/increase	Decrease/increase [%]
Sediment loads [kg/yr]	56,048	37,560	−18,488	−33
Reused supplied [ML/yr]	0	0	0	0
Rainfall runoff [ML/yr]	392	326	−66	−17

The results show that planning BGI will enhance multiple aspects of regional resilience and sustainability in the Tarwin catchment where BGI could be strategically sited to maximise multifunctionality. The analysis provides a replicable and comprehensive method for designing future BGI so that it exploits environmental and social resilience. Moreover, it signifies a spatial planning method for complementary ecosystem service priorities and evaluating competing for a specific landscape.

Using the MUSIC-link model, which forms part of the standard MUSIC interface (accessed using the MUSIC-link tab in the main interface) and choosing the assessing authority, the validation report showed that the results were within an allowable range.

Cost-benefit analysis

Based on the results of Table 1, the sum of the benefits of applying the BGI components based on only three ecosystem services of water supply (reused supplied), water purification (reduction in sediment loads), and flood mitigation (reduction in rainfall runoff) was estimated AUD 100,525 per year. It is important to note that for water supply service the value of water was considered as the value of benefits, and for flood regulation service, the benefits of the stormwater retention services of Victoria's metropolitan natural ecosystem was considered due to the complication of peak flows valuation and modelling for non-metropolitan regions.

Using the MUSIC life cycle cost tool, the life-cycle cost of each BGI components was calculated. All cost approximations are based on functions that result from costing data collected from around Australia in 2003-2004. The information originated from all six Australian States, including major cities and regional areas. It included descriptions of the BGI's design/type, unusual characteristics (e.g. unusual construction costs or disposal costs), expected life cycle/span, catchment area, area of the treatment zone, cost elements, data quality and how cost elements vary over time (e.g. maintenance costs). The cost approximations demonstrated were inflated to the base costing year specified in the costing properties (year 2017).

The MUSIC life cycle cost of BGI components is tabulated in Tables 11-14, where:

- The life cycle cost: The sum of all discounted costs over the life cycle of the BGI measure (expressed in dollars relevant to a base date);
- Equivalent annual payment: The life cycle cost of the BGI measure (AUD) divided by the specified life cycle of BGI measure (years);
- Life cycle: The functional life of the BGI measure (in years);
- Total acquisition cost: The cost of defining the need for BGI measure (e.g. preliminary feasibility studies), all design costs and construction costs including overheads but not Goods and Services Tax (GST) or costs associated with using the land (where relevant);
- Annual establishment cost: The cost required to ensure that the BGI measure is properly established where that establishment cost is not included in the total acquisition cost;
- Typical annual maintenance cost: The annual cost of typical, frequent maintenance activities, including all costs associated with inspections, training, administration, and waste disposal (but not GST);
- Renewal/Adaptation cost: The cost of unusual and/or infrequent restoration activities (sometimes called 'corrective maintenance'), including all overheads but not GST;
- Renewal period: The period between infrequent renewal/adaptation costs;
- Decommissioning cost: The cost of removing the BGI measure and fully restoring the site at the end of the BGI's useful life;
- Annual inflation rate: A rate used in the life cycle costing module to convert real costs to a new base date;
- Discount rate: The rate (%) used to discount all future costs back to a base date.

Table 11. Costing inputs for vegetative swale

Life cycle [yrs]	50
Acquisition cost [AUD]	202,841
Annual maintenance cost [AUD]	13,840
Annual establishment cost [AUD]	0
Establishment period [yrs]	0
Renewal/adaptation cost [AUD]	5,122
Renewal period [yrs]	1
Decommissioning cost [AUD]	102,413
Real discount rate [%]	5.5
Annual inflation rate [%]	2
Costing results for swale	
Life cycle cost of swale [AUD 2017]	529,644
Equivalent annual payment cost of the asset [AUD 2017/year]	10,593
Equivalent annual payment per m^3/s maximum flow reduction [AUD]	7,393.99
Equivalent annual payment/ML flow reduction/year	invalid
Equivalent annual payment/kg TSS/year [AUD]	0.52
Equivalent annual payment/kg TP/year [AUD]	475.87
Equivalent annual payment/kg TN/year [AUD]	203.49
Equivalent annual payment/kg gross pollutant/year [AUD]	1.25

Table 12. Costing inputs for bio-retention cell

Life cycle [yrs]	50
Acquisition cost [AUD]	262,591
Annual maintenance cost [AUD]	15,508
Annual establishment cost [AUD]	0
Establishment period [yrs]	0
Renewal/adaptation cost [AUD]	6,631
Renewal period [yrs]	1
Decommissioning cost [AUD]	132,581
Real discount rate [%]	5.5
Annual inflation rate [%]	2
Costing results for bio-retention	
Life cycle cost of bio-retention [AUD 2017]	645,057
Equivalent annual payment cost of the asset [AUD 2017/year]	12,901
Equivalent annual payment per m^3/s maximum flow reduction [AUD]	9,758.95
Equivalent annual payment/ML flow reduction/year [AUD]	1,625.85
Equivalent annual payment/kg TSS/year [AUD]	0.21
Equivalent annual payment/kg TP/year [AUD]	125.57
Equivalent annual payment/kg TN/year [AUD]	18.31
Equivalent annual payment/kg gross pollutant/year [AUD]	1.23

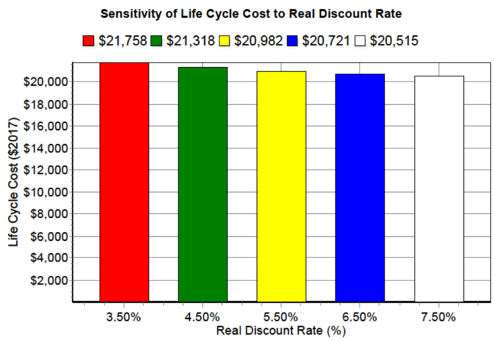
Table 13. Costing inputs for rainwater tank

Life cycle [yrs]	50
Acquisition cost [AUD]	19,000
Annual maintenance cost [AUD]	116
Annual establishment cost [AUD]	0
Establishment period [yrs]	0
Renewal/adaptation cost [AUD]	0
Renewal period [yrs]	1
Decommissioning cost [AUD]	259
Real discount rate [%]	5.5
Annual inflation rate [%]	2
Costing results for rainwater tank	
Life cycle cost of tank [AUD 2017]	20,982
Equivalent annual payment cost of the asset [AUD 2017/year]	420
Equivalent annual payment per m^3/s maximum flow reduction	Invalid
Equivalent annual payment/ML flow reduction/year [AUD]	10.27
Equivalent annual payment/kg TSS/year [AUD]	1.99
Equivalent annual payment/kg TP/year [AUD]	211.14
Equivalent annual payment/kg TN/year [AUD]	22.59
Equivalent annual payment/kg gross pollutant/year [AUD]	0.23

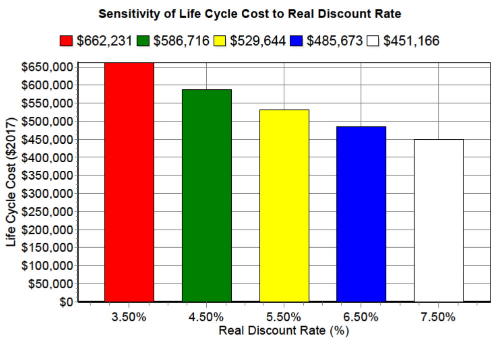
Table 14. Costing inputs for infiltration trench

Life cycle [yrs]	50
Acquisition cost [AUD]	139,800
Annual maintenance cost [AUD]	13,980
Annual establishment cost [AUD]	0
Establishment period [yrs]	0
Renewal/adaptation cost [AUD]	5,732
Renewal period [yrs]	1
Decommissioning cost [AUD]	48,930
Real discount rate [%]	5.5
Annual inflation rate [%]	2
Costing results for infiltration trench	
Life cycle cost of infiltration trench [AUD 2017]	475,333
Equivalent annual payment cost of the asset [AUD 2017/year]	9,507
Equivalent annual payment per m^3/s maximum flow reduction [AUD]	4,928.50
Equivalent annual payment/ML flow reduction/year [AUD]	32,784.33
Equivalent annual payment/kg TSS/year [AUD]	1.36
Equivalent annual payment/kg TP/year [AUD]	136.75
Equivalent annual payment/kg TN/year [AUD]	46.97
Equivalent annual payment/kg gross pollutant/year [AUD]	11.39

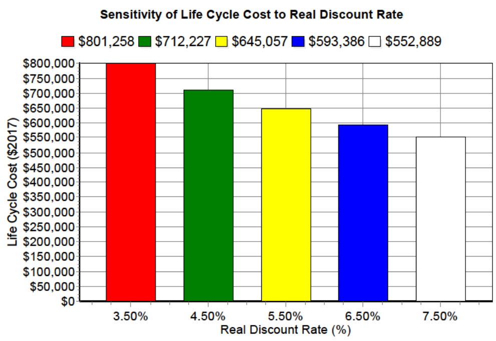
It is important to note that the current default value for the 'real discount rate' in MUSIC's life cycle costing module is 5.5% per year ±2% (at April 2005). Ideally, it is better to determine a rate that is current by contacting experienced local stormwater asset managers or agencies who routinely specify discount rates for the water industry. As this study was a proof-of-concept, a generic real discount rate was used that was informed by a sensitivity analysis. The sensitivity analysis looked at five values across the estimated life cycle cost of four BGI elements (Figures 11a-d). This can be important when evaluating options with substantially different temporal distributions of costs.



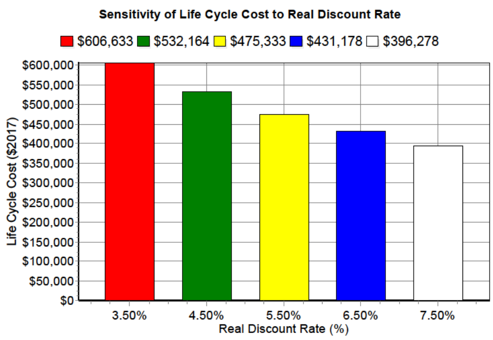
(a)



(b)



(c)



(d)

Figure 11. Sensitivity analysis to check the choice of real discount rate effects on the estimated life cycle cost for different BGI components: rainwater tank (a); vegetated swale (b); bio-retention cell (c) and infiltration trench (d)

While the lifecycle cost of the designed BGI network was estimated AUD 2,284,588, the benefit of the BGI network for 50 years was estimated AUD 5,026,250, which is more than twice as the lifecycle cost of the system. It is important to mention that for calculating the benefits of the BGI components, only three ecosystem services were considered. It is obvious that the benefits would be greater if more ecosystem services were included. Additional ecosystem servies that would be useful to consider are: coastal asset protection, climate regulation (carbon storage), carbon sequestration (from revegetation), habitats for species (intermediate service), maintenance of nursery populations, social cohesion and sense of place, amenity, and recreation opportunities. Considering these ecosystem services, together with the associated tests and experiments to incorporate them into the model, have been left for the future due to lack of data and time.

The results of the multifunctional natural capital (BGI) modelling suggest that current natural capital in Tarwin Lower is not purposefully planned to maximise multiple ecosystem service benefits. As this study has demonstrated, if it was being planned more holistically to support social-environmental sustainability in Tarwin Lower, the value of ecosystem services would be vastly different. A more integrated and strategic plan can help to certify that multiple ecosystem services are provided to areas of Tarwin Lower that need them most.

Table 2, indicates a significant growth in Urban Void, infrastructure and utilities, and community services followed by decreasing rate of national parks, conservation areas, forest reserve and natural water reserves. It is concluded that to compensate natural capital and ecosystem service losses due to urban and regional development and to provide extra demands of growing inhabitants for reserves, considerable efforts should be made in the development of multifunctional natural capital (BGI) networks. This needs smarter planning for available lands and an indication that investments in BGI will provide multi-functions for the community as a whole.

Two key findings can be achieved from this research. First of all, multifunctional natural capital (BGI) improves the supply of multiple ecosystem services at Australia's regional scale. Areas, where more BGI components are extended, deliver more benefits. BGI influences the capability of the environment to supply services at different scales also it provides the links, which attach environments together, enabling the flow of environmental processes, and finally, ecosystem services.

The second and more significant finding of this research is, given that natural capital area is declining in Australia, incorporating designed elements into existing natural capital to create multifunctional natural capital (BGI), maximises the supply and value of ecosystem services in order to meet the demands of a growing population.

CONCLUSIONS

This paper has presented a generalizable spatial planning method that integrates three commonly cited benefits of BGI (abate stormwater, secure water quality improvement, and supply water for the drought periods) to make current natural capital a multifunctional natural capital system in Tarwin Lower. Due to its holistic approach, BGI planning is considered to be more effective and able to handle more complexity than traditional planning for nature conservation or natural capital. This method can help stakeholders, planners, and local communities in classifying 'hotspots', evaluating possible spatial tradeoffs, and eventually assisting decision-makers to design BGI strategies that integrate a broader range of environmental and socio-economic benefits and local resilience priorities.

The approach developed here was applied to a specific case study but is generalizable to any regional hydrological system. Provided that data is available, the approach can be applied rapidly. The key input data required to run the models are publically available (rainfall threshold, soil type and soil drainage parameters, etc.) and other parameters (such as locally relevant pollution levels) are readily acquired in Australia from local water authorities. Furthermore, the approach could be expanded in the future to include additional ecosystem services.

Our findings suggest that the current natural capital do not provide the maximum ecosystem services and the results revealed why a strategic spatial planning process is needed in order to maximise the benefits. Therefore, policies now should dictate that as a community, we should invest in natural capital restoration and planning to achieve biodiversity objectives. This needs a substantial change from traditional biodiversity conservation goals, to a holistic land management approach that integrates smart urban and regional planning with viable populations of native fauna and flora.

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