WATERWAY TRIAGE: INVESTMENT STRATEGIES TO LIMIT POLLUTION AND MAXIMIZE VALUE

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ABSTRACT

Triage, typically, is an approach to rapid assessment of a natural disaster or crisis and delivery of emergency aid when resources are limited. The same philosophy is also used in environmental conservation and can be applied to managing waterway health by recognizing the unique needs of each section of the waterway and matching it with the most appropriate treatment strategy. This strategic approach can improve the net gains when compared to the current approach in Queensland, Australia. In Queensland, all new development is required by legislation to reduce stormwater pollutant loads discharging to the creek (in Brisbane, for example, total suspended solids needs to be reduced by 80%, total phosphorus by 60% and total nitrogen by 45%). Whilst these simple targets have driven millions of dollars of investment throughout the state and are a much-needed step to limiting our ecological impact, recent research by Healthy Land and Water (HLW) suggests that there is room for improving the way we deal with risk and distribute resources to protect our waterway assets. The current approach places no incentive to avoid or minimize pollution and other waterway threats, it does not adjust pollution controls to match the downstream waterway condition and it provides no opportunity to invest in waterway restoration or conservation efforts. To address these issues HLW have created Strategic Waterways, a tool for categorizing and prioritizing waterway investments based on triage principles. The tool uses a risk-benefit model to assess, diagnose and then plan the treatment of various waterway ailments. It allows for nine unique strategies to managing waterway value where previously there has been only one or two. This paper discusses three applications of the Strategic Waterways tool to support decision-makers including: how GIS can be used to rapidly assess very large areas of catchment; a methodology (triage) for prioritizing project sites and setting initial project budgets and a methodology for monitoring the state of the waterway and catchment. This tool can empower waterway managers to build a balanced portfolio of waterway investments to create the biggest possible ecological return on investment.
Keywords: management, pollution, prioritization, risk, stormwater, strategy, values, waterways

1 INTRODUCTION

The typical strategy for managing stormwater pollution for new housing estates in Queensland is to filter stormwater runoff via a bioretention basin (vegetated sand filter beds) before it discharges to the receiving waterways. This is a useful way to reduce potential environmental harm; however, the process does not typically consider the existing health condition of the downstream waterway [1] or the extensive legacy issues across our urban waterways [2]. It also does not allow for hazard minimization or waterway improvement or value creation strategies [3, 4]. Pollution reduction is relevant to waterway health; however, it should not be the stormwater industry's sole focus.

Waterway health monitoring [5] suggests that more effort is required to ease other types of waterway pressures and address emerging pressures such as urban densification and climate change (Fig. 1). If these pressures continue to build, then they may exceed the ecosystem carrying capacity and certain ecosystem services may fail or diminish despite our best efforts at minimizing stormwater pollution.

As an industry, we need to improve our waterway management practices if we are to achieve the objectives of the legislation under the Environmental Protection (Water) Policy [7] to 'protect and enhance water values'.

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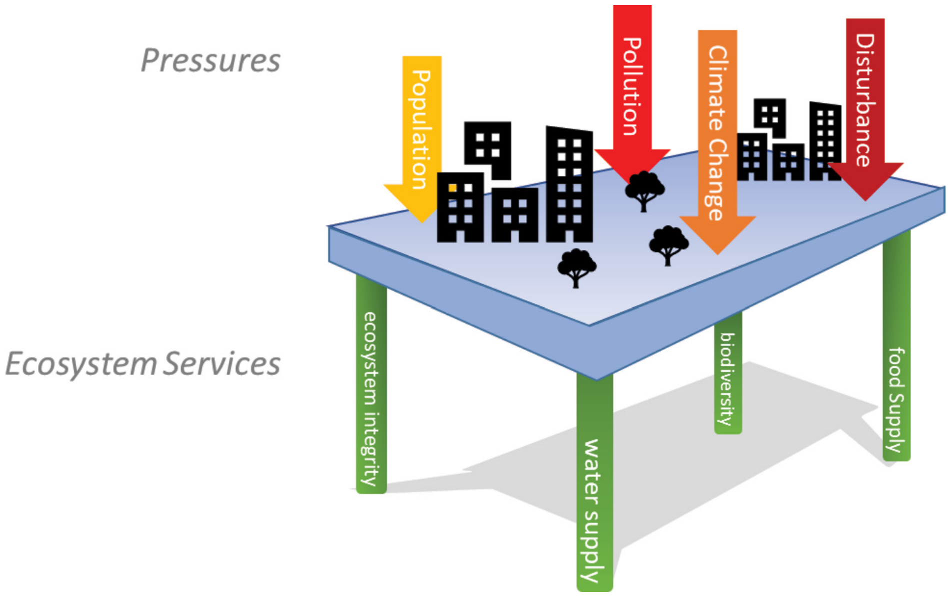


Figure 1: Ecosystem carrying capacity [6].

More can be achieved by taking a strategic approach to waterway management. This involves directing proportionate and appropriate effort and investment to locations where it can create the biggest impact. In circumstances where there is limited environmental funding, this approach to maximize ecological and social return on investment (ROI) is imperative.

1.1 Methodology for understanding the problem

Healthy Land and Water (HLW) have previously assessed and documented the state of waterway management in Queensland in 2014 and again in 2017 [8, 9]. More recently, HLW and Alluvium undertook an extensive review of scientific literature [1] throughout Queensland and internationally focusing particularly on the hydrologic and water quality impacts of urban development on waterways. The team also held eight half-day workshops with industry leaders and key councils across the state [2] to gather insight into the current stormwater management practices across the State. Further stakeholder feedback on our published findings [10] revealed that strategic catchment planning is a high priority for local councils.

1.2 Target audience

HLW's Strategic Waterways tool will be useful for a variety of decision-makers in local governments including waterway and catchment managers and planners, stormwater drainage engineers, asset managers, budgeting and finance. This highly adaptable tool can potentially be used to assess many other types of engineering risks, such as safety, bushfire and heat risk, natural areas management and flood management.

2 IDENTIFIED ISSUE: INEFFICIENT ALLOCATION OF FUNDING

The current approach of allocating funding to waterways in Queensland is too simple and can be compared to a game of checkers or droughts (Fig. 2). Using the analogy of a checkerboard, the landscape can be broken up into grid squares, lighter grids represent high risk zones and shaded grids represent an opportunity to enhance waterway value. Since all the pieces of a checkers game are played on the risk squares, all opportunities squares are ignored.

This is similar to current investment in the landscape where waterway enhancement opportunities are often overlooked in favour of risk mitigation. In checkers all the pieces are of equal value. Similarly, investment in stormwater treatment is distributed at approximately the same rate per square meter regardless of catchment waterway condition or risk. To spend money irrespective of the project site's position within the catchment or the magnitude of the waterway risk is an ineffective way of managing risk and an inefficient way to distribute resources.

3 PROPOSED SOLUTION

To diversify the portfolio of activities funded and improve our ecological ROI, HLW has created a new decision support tool to improve waterway condition called Strategic Waterways [3 ,4, 12, 13 & 14].

The Strategic Waterways approach unlocks many alternative ways to address catchment risks and opportunities. In this way it can be compared with a game of chess (Fig. 3), with pieces (i.e. projects) specific to risks and those specific to opportunity and those that address both. There are also pieces of lesser importance (i.e. pawns) that can be traded for larger opportunities elsewhere (i.e. offsets).

The Strategic Waterways decision support tool has a 5-step process:

- Step 1 - Condition assessment – *What is the current health status of the waterway?*
- Step 2 - Diagnosis – *What is causing poor waterway health?*
- Step 3 - Treatment strategy – *What treatment options should be used?*
- Step 4 - Triage – *Which sections of the waterway has the highest priority?*
- Step 5 - Monitoring – *How effective is our strategy?*

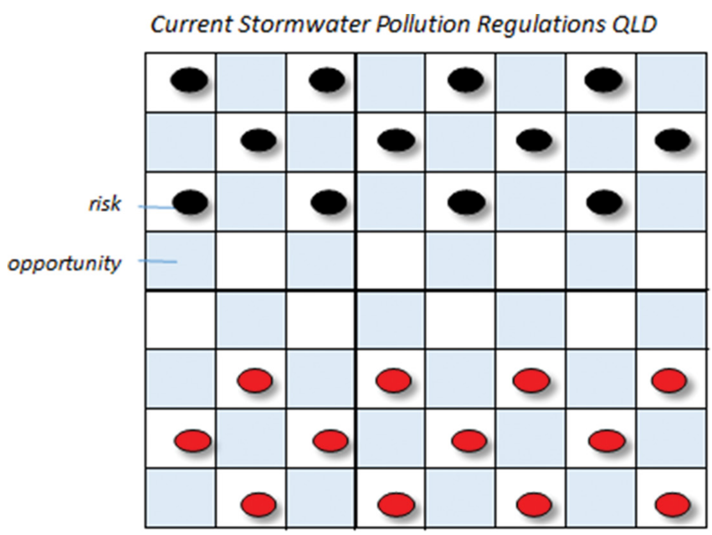


Figure 2: Is it time to change how we play the game?

Figure 3: Strategic Waterways provides more ways to address risk and opportunity.

3.1 Step 1: condition assessment

Strategic Waterways provides users with a questionnaire about hazards 'Red', values 'Green' and needs 'Blue'. A score of 0 indicates a low score and 250 indicates a high score. It then classifies a given waterway with a 'RGB' colour code [12]. Since 'RGB' colour coding can visually represent a diverse range of colours the system is quite versatile. Details of the colour coding system are outlined below:

- 'Red' indicates how hazardous the catchment is
- Where a hazard overlaps with a value it forms a risk ('Yellow')
- 'Green' indicates how valued the catchment/waterway is
- Where a value overlaps with a need it forms an opportunity ('Cyan')
- 'Blue' indicates where there is the opportunity to recover or enhance value
- Where a hazard can fulfil a need it forms a game changer ('Magenta')

The 'RGB' colour coding system means it is easy to visualize the combination of waterway hazards, values and needs and once a 'RGB' colour code is determined (Fig. 4) this helps diagnose what the waterway actually needs (Step 2), and a corresponding treatment strategy can be assigned (Step 3). The scoring can also be used to triage and prioritize actions (Step 4) as well as monitor and keep track of improvement strategies (Step 5).

The Strategic Waterways [12] questionnaire and user guide can be downloaded for free from: www.waterbydesign.com.au/resources

3.2 Step 3: treatment strategies

Once a waterway diagnosis has been undertaken, a waterway manager can start to assign an appropriate treatment strategy for each section of the waterway. For some pristine waterways,

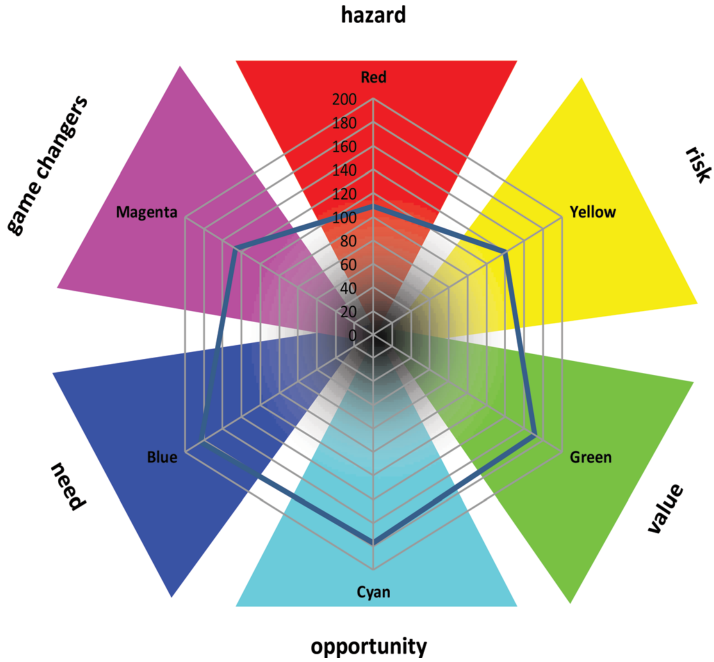


Figure 4: Diagnosing catchment hazards, values and needs (Step 2).

this strategy will focus on conservation, whereas for others the focus may be on hazard reduction. The nine treatment strategies to improve waterway management [14] include:

1. Value conservation
2. Value protection
3. Hazard minimization
4. Value creation
5. Risk mitigation
6. Value reconnection
7. Game changers
8. Strategic offsets
9. Minimum requirements

Further detail for each of the nine strategies is provided in Table 1 below.

Figure 5 shows the indicative distribution and relative position of each of the nine categories across the waterway health continuum. The majority of project sites will fall under risk mitigation or offsets categories. A smaller number of project sites on the edges of the bell curve will have a higher than normal chance to create or protect waterway value. The Strategic Waterways tool uses categorization and triage to find these significant project sites.

The nine strategies detailed above represent a marked improvement in the number of options available to stormwater managers under current Queensland stormwater quality regulations. Taking this nuanced management approach will account for the unique condition, pressures and prospects of each waterway and allow for better investment than standard approaches [14].

Table 1: Nine strategies to improve waterway management.

Strategy	Strategy Aims	Qualifying Criteria	RGB Colour Code
1. Value conservation	To maintain existing values. To manage potential threats. To inspire further conservation action.	Waterways and catchments are in pristine condition, e.g. National Parks.	‘Green’ R=0 G=200 to 250 B=0
2. Value protection	To maintain existing waterway values. To manage potential threats. To permit a low-impact form of development	Waterways have high value scores. Small portions of the catchment may already be cleared of vegetation and have development potential.	‘Mid Green’ R=0 G=150 to 200 B=0
3. Hazard minimization	To control hazards at their source.	Catchments with high-pollutant loads, e.g. commercial or industrial areas.	‘Red’ R=150 to 250 G=0 B=0
4. Value creation	To meet the immediate needs of the community and the local ecology.	Catchments where there is little to harm in the way of existing waterway value. Opportunities to create new value, e.g. flood ways.	‘Blue’ R=0 G=0 B=150 to 250
5. Risk mitigation	To reduce harm to waterways through hazard mitigation.	Sites where a hazard flows to an area of high value forming a critical vulnerability, e.g. development upstream of fishing zones.	‘Yellow’ R=150 to 250 G=150 to 250 B=0

Table 1: *(Continued)*

Strategy	**Strategy Aims**	**Qualifying Criteria**	**RGB Colour Code**
6. Value reconnection	To expand this value spatially. To link to other value regions. To improve complimentary value sets due to synergies.	Waterways must have a section with high value and opportunity to expand or improve value, e.g. reconnection of waterway habitat via a fish way.	'Cyan' R=0 G=150 to 250 B=150 to 250
7. Game changers	To use a waterway hazard to fulfil a community or ecological need.	Sites need to produce a suitable form of waterway hazard. There needs to be a mechanism to convert this hazard into a useful product. There must also be a particular demand for the product close by.	'Magenta' R=150 to 250 G=0 B=150 to 250
8. Strategic offsets	To redirect finance to areas where they will have a much bigger impact.	The donor site should not discharge to a high value waterway. It should be relatively stable. Adjacent waterways should have limited prospects for future recovery.	'Grey' R=50 to 100 G=50 to 100 B=50 to 100
9. Minimum requirements	To provide just the minimum amount of investment to prevent public safety risks and to avoid total sterilization of the waterway.	Every waterway should have a minimum amount of funding available to avert emergencies, e.g. unblocking culverts, preventing fish kills, etc.	'Charcoal' R=0 to 50 G=0 to 50 B=0 to 50

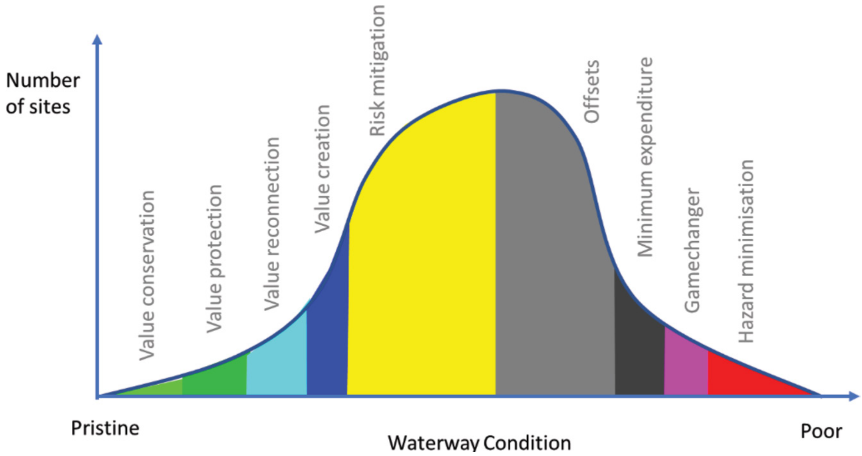


Figure 5: Indicative distribution of categories across the catchment.

This paper will now discuss three key applications of Strategic Waterways methodology including: 1. GIS mapping, 2. funding prioritization and distribution and 3. monitoring

4 GIS MAPPING

It is possible to apply the Strategic Waterways colour coding system to very large areas of terrain using GIS mapping tools thus reducing the assessment time considerably. This could be considered a rapid or shortlisting process to allow more focused effort on critical points within the catchment. This approach is very useful for councils with large spatial data sets. Where a local government has limited or patchy data then a significant step of data acquisition must first be undertaken.

Initially, three primary GIS layers (Red = Hazard, Green = Value, Blue = Needs) are created from questionnaire data produced in Step 1 of the tool. From there, primary layers can be combined to form secondary layers (Cyan = Opportunity, Yellow = Risk, Magenta = Game changers). Combination of all three layers will result in a tertiary layer or RGB colour.

It is anticipated a grid based (raster) system is used for each of the prime layers (e.g. 100x100m grids). Collating these 3 prime layers alone will be a significant advancement for the industry and aid decision-makers. Each prime layer will be constructed from numerous sublayers (as many as practical – the current questionnaire allows for 25 sublayers each worth 10 points). Input from local experts will decide which sublayers get used, how they are weighted and the packing methodology of each prime layer (it may need to be adjusted depending on data availability for each council area).

Once the three primary layers are established, GIS scripts can be programmed to allow Red, Green and Blue prime layers to be combined into a single RGB heatmap to aid decision-makers and communicate to the broader industry. Combined RGB heatmaps can then be analysed with algorithms to identify high priority sites and generate a ranked short list of project sites.

For a number of test sites there would need to be a validation (ground truthing) process to determine the level of trust in the mapping product. The is also opportunity to explore machine learning options to improve accuracy of the GIS mapping system.

This approach of combining layers aims to find the confluence between hazard, value and needs. It is this confluence point that is of special significance and investment in these key

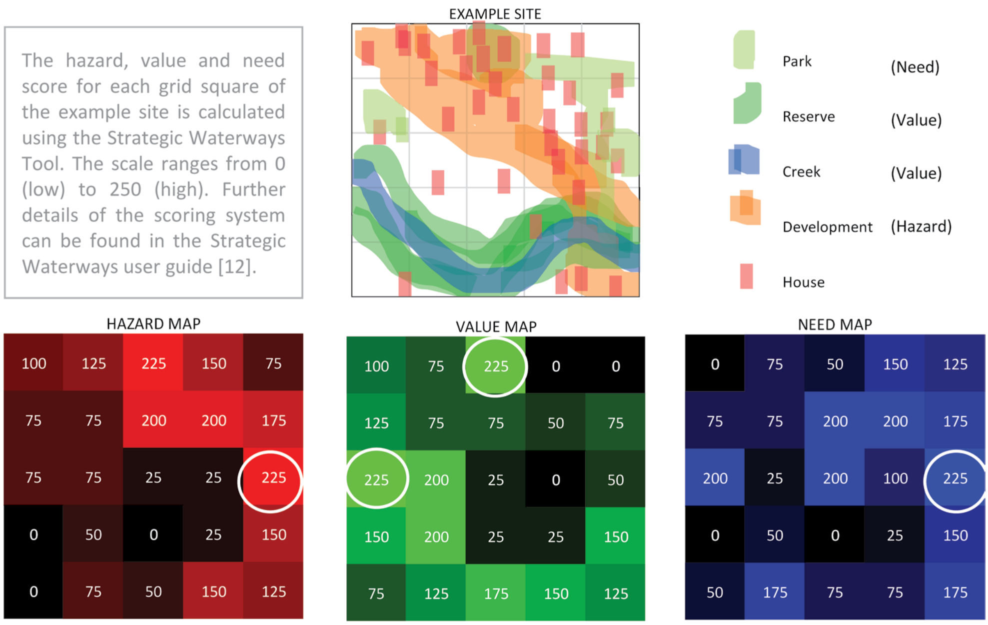


Figure 6: GIS mapping of waterways using the Strategic Waterways approach.

locations can either reduce waterway deterioration or magnify waterway enhancements compared with traditional investment approaches. Figure 6 shows how this can work for an example development site with a waterway and nature reserve.

5 FUNDING DISTRIBUTION - METHOD 1: SIMPLE

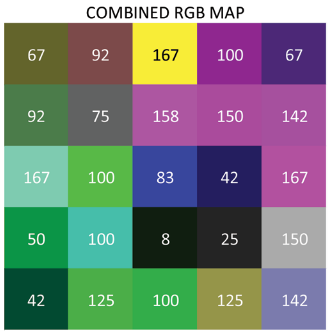
Once catchment risk has been mapped using the Strategic Waterways RGB colour coding system, it is simple to identify hotspots in the catchment where funding is most needed. The question then becomes how many key projects can be funded and how much funding can be provided to each. To improve upon the existing system of distributing funding and to help find better ways to invest in our waterways and create beneficial impact we explore two distribution approaches: 1. Simple method and 2. Triage method.

The first distribution method is described mainly as intermediate step but can still be used by small local government entities wishing to spend a fixed sum of money. The second distribution method can be used by larger councils with a mix of private and public investment.

In the simple method for distributing funding (Fig. 7), the catchment is broken into grids (e.g.100 x 100 m grids), and funding is allocated according to catchment importance (based on the average score calculated in Step 1). A brief methodology to determine which grid squares are given funding is outlined below:

1. Calculate average score for each grid square = (Value + Hazard + Need)/3
2. Set a funding threshold score (in this case the threshold score is 75)
3. Allocate a dollar spend per point (in this case the spend is $232 per point)
4. Assign project type based on colour category (e.g. cyan, yellow etc.).

This simple methodology would be an improvement from the current approach in Queensland as it directs money to high risk/value/need parts of the landscape. It is acknowledged



		total spend	$ 500,000	
$ -	$ 21,236	$ 38,610	$ 23,166	$ -
$ 21,236	$ -	$ 36,680	$ 34,749	$ 32,819
$ 38,610	$ 23,166	$ 19,305	$ -	$ 38,610
$ -	$ 23,166	$ -	$ -	$ 34,749
$ -	$ 28,958	$ 23,166	$ 28,958	$ 32,819

Figure 7: Simple method for funding distribution (based on the example site in Fig. 6).

that while some parts of the catchment are left unfunded these will tend to be low in existing value low in hazard and low chance of recovery. The simple method can be improved upon considerably by taking a strategic approach (Method 2) as detailed in the following section.

6 FUNDING DISTRIBUTION - METHOD 2: TRIAGE

Triage is an approach to delivering emergency aid in response to disasters when resources are limited. The same philosophy can be applied to waterway management by recognizing the unique needs of each part of the catchment and matching it with the most appropriate treatment strategy [11]. This strategic approach can improve the net gains when compared to the simple distribution method or the current approach in Queensland.

Different strategies will have a different cost-benefit, and they need to be applied at the correct location to gain the biggest benefit. Costs include capital and operational expenditure as well as non-financial costs. The benefit usually includes waterway health improvements but could also include economic gains. Table 2 below provides indicative and relative cost-benefits of each approach to assist in prioritization of strategies. Also shown below are the criteria for each strategy which be used to create a rationalized strategy map (Fig.8).

Using the example illustrated in Fig 6, it is possible that some grid squares will qualify for more than one strategy, so before money can be distributed there is an intermediate step to set the strategy precedents (Table 2). This precedence needs to be carefully considered as it may determine which projects get funded and which projects are unfunded. A guide for determining category precedents is presented below:

1. Protect conservation sites St1, St2 (determine via green score)
   These sites require protection from development pressures
2. Fund high impact projects St7, St6 (determine via magenta score and cyan score)
   These are the projects that deliver the best ROI
3. Determine offset sites St8, St9 (determine via RGB score)
   These sites will help to fund high impact projects
4. Determine remaining categories St3, St4, St5
   These categories are important projects but are easier to confirm via a process of elimination (determine via red score, blue score and yellow score)

Table 2: Indicative cost-benefit of each strategy.

Strategy	Criteria	Description	Cost	Benefit	Precedence
ST1	G>200	Value conservation	0	1	1
ST2	G>150	Value protection	-3	1	2
ST3	R>150	Hazard minimization	-1	1	8
ST4	B>150	Value creation	-4	3	7
ST5	Y>150	Risk mitigation	-2	2	9
ST6	C>150	Value reconnection	-2	3	4
ST7	M>150	Game changers^	-3	4	3
ST8	RGB<100	Strategic offsets#	+2	-2	6
ST9	RGB<50	Min requirements#	+2	-2	5

^resource recovery (e.g. recycled water sales) can improve the cost/benefit of game changers
#offsets provide initial cash instead of cost however these areas will be subject to a negative benefit due to diversion of funding.

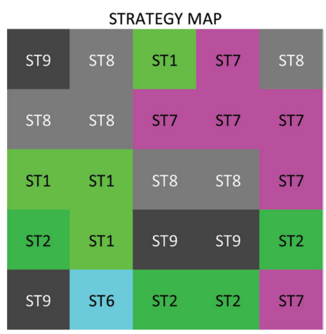


Figure 8: Rationalized strategy map (based on example in Fig. 5).

From the above rules, an algorithm can be created to quickly sort priority projects. Once a shortlist has been produced there will need to be substantial effort to validate or 'ground truth' the projects to ensure feasibility. This could also include investigations into community and political support for the projects.

6.1 Allocating funding

Using the threshold scores and precedents shown in Table 2, a rationalized strategy map can be created (Fig. 8) assisting the process of distributing funds amongst the 9 project classes. An algorithm is then used to distribute money among the potential investment sites. Figure 9 below shows how a strategy map can guide spending on projects throughout the catchment.

ST1 sites are assumed to be conservation zones that will not be developed. ST2 and ST5 are assumed to be funded by private development. The strategic investments (ST4, ST6 and ST7) can be funded by councils by using developer contributions to stormwater offsets schemes. ST8 and ST9 sit within an offset scheme and contribute funding to other sites.

It is noted that the catchment downstream of an offset will have reduced funding and therefore there will be a negative impact on the local waterway. However, the funding derived

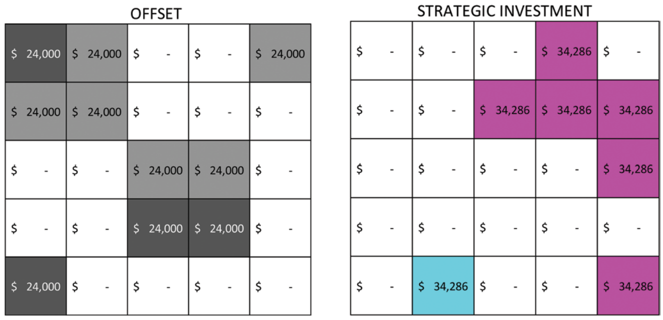


Figure 9: Allocation of funding using a strategic approach.

from the offset can be reinvested in strategic locations (hotspots), and this would likely more than make up for any minor losses in these waterways with offsets. The example below shows how private developer money collected from offsets can be distributed to high impact projects at no cost to the local council.

7 MONITORING WATERWAY HEALTH

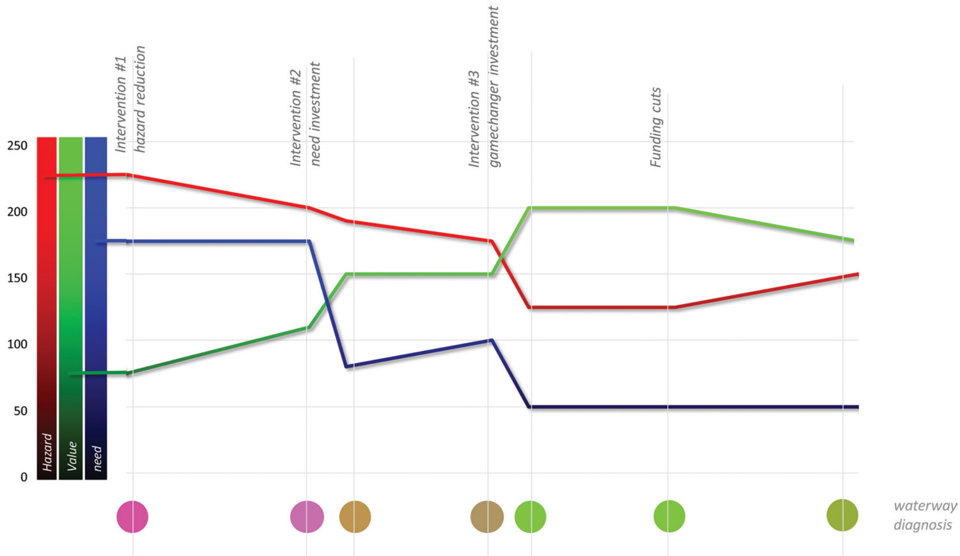
HLW have been monitoring the condition of the waterways across Brisbane for 20 years and publicizing the results in a report card. This report card has helped to consolidate political support for waterway investments [5]. Typically, the report card provides an A to F rating for each waterway. This is great for showing the current state of the waterway it does not however show the potential risk, opportunity or importance of a given waterway.

The Strategic Waterways colour coding system can be used to monitor and track the long-term health of our waterways with a lot more nuance than an A to F rating. The RGB code will give an instant indication of hazards, values and needs. This visualization can help communicate the benefits of waterway investments. In the example below (Fig. 10), the waterway is assessed and given a RGB score at yearly intervals and also after a major injection of funds. 'RGB' colours can also be interpolated and interrogated using GIS systems to quantify change in condition.

8 LIMITATIONS OF THE TOOL

The Strategic Waterways Tool has the power to filter through large GIS data sets to identify priority sites and create a shortlist of potential waterway improvement sites. While this approach would be an improvement on current pollution control objectives in Queensland, for it to be truly effective it needs to be coupled with input from experts as described below:

- This approach is very useful for councils with large spatial data sets. Where a local government has limited or patchy data then a significant step of data acquisition must first be undertaken.
- Input from local experts is needed to decide which data layers get used, how they are weighted and the packing methodology of each data layer (it may need to be adjusted depending on data availability for each council area).
- For a number of test sites, there would need to be a validation process to determine the level of trust in the mapping product.
- Once a shortlist has been produced there will need to be substantial effort to validate or 'ground truth' the projects to ensure project feasibility.



year	0	1		2		3	4
R	225	200	190	175	125	125	150
G	75	110	150	150	200	200	175
B	175	175	80	100	50	50	50

Figure 10: Example: monitoring the health of our waterways.

9 CONCLUSION

The current stormwater pollution regulations in Queensland are not leading the most effective waterway management strategy. The research behind this paper points to the need to explore different ways of managing our waterways. To this end, HLW has created the Strategic Waterways tool to assess the diverse values, hazards and needs of each waterway. From there, a unique intervention can be determined.

The main body of the paper details how catchments can be quickly assessed using GIS and after taking into account cost-benefit and strategy precedence, funding strategies can be implemented to maximize beneficial waterway impact. The unique colour coding system means it is easy to create a visual monitoring system to track waterway condition over time.

With increasing stressors on our waterways from climate change and urban densification, there is an imperative to act to reduce the waterway impact. The cost of mitigating these risks can be reduced from present approaches in Queensland by investing across our catchment strategically. The methodology outlined in this paper allows waterway managers to construct a balanced portfolio of waterway management projects that will help to maintain, protect and enhance waterway value into the future.

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