A decision framework for selecting stormwater management interventions to reduce fine sediments and improve coastal water quality

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Executive summary

There has been 6,200 ha of seagrass lost from Adelaide's coastal waters since 1949. This loss has been attributed to both nutrient pollution and high turbidity associated with sediments. In general, the water quality of flow into St Vincent Gulf from coastal Adelaide has improved in recent years due to mitigation efforts. However, fine sediment inputs from urban runoff continues to be a concern.

In response to concerns over fine sediment, the primary objective of this project was to support state and local government decisions on where and how best to invest in urban water management solutions across Metropolitan Adelaide to remove fine sediment from stormwater runoff in the short-term. This objective was to be achieved by completing several tasks, including the development of a decision-making framework that used existing information on sources of fine sediment to St Vincent Gulf and the performance of appropriate interventions. The framework was applied to local catchments to support the prioritisation of investment into urban stormwater quality management interventions to reduce the load of fine sediment reaching the gulf.

The project methodology included developing a decision-making framework, inputting known data based on a review of literature, applying the framework and documenting findings. The decision framework was developed using Microsoft Excel, to maximise the potential for ongoing distribution, use and development. It considered key sources of fine sediment, and appropriate interventions for fine sediment. A risk score of sources and an effectiveness score for interventions was then provided based on a literature review. The resulting framework can be used to determine the relative risk of a catchment for the generation of fine sediment. The framework may be used to assess one catchment but is more ideally suited to comparing risk of several, where those with the highest weighted score are those with the highest risk for sediment export.

The review activity was undertaken to provide a means to produce 'scores' of risk ranging from low to high (zero to three). This scoring was applied for both sources of sediment (including point sources, diffuse sources and stream derived sources) as well as interventions of sediment (including those that apply at a point, those which treat a diffuse area and those that are stream specific). Scores were provided based on the information available, but it should be noted that the review activity underpinning the operation of the framework revealed significant limitations in local and international data on both sources and treatment types, especially for fine sediment. Key data gaps identified included:

- There is a limited understanding of fine sediment sources on a fine spatial and temporal scales, with very little data available on size fractioned sediment inputs.
- A process of fine sediment source tracking has not been undertaken in Metropolitan Adelaide.
- There was limited local data on the performance of intervention measures, be they structural water sensitive urban design (WSUD) measures, other structural measures such as stream bank armouring, or non-structural measures like policy interventions.
- There was limited data at the international scale, which was specific to fine sediment intervention performance, and as such the framework tended to consider sediment performance in general.

Application of the developed framework was undertaken following consultation with a variety of local government representatives from across Metropolitan Adelaide, including written surveys and interviews. The survey process involved attempting to identify data that may not be widely disseminated to support the framework sediment source and intervention performance ratings with local data. Key data gaps identified form the survey were:

- Apart from that acquired in the literature review, no additional measurements of particle size distribution of runoff were available, and no further land use specific data was available for sediment more generally.
- The condition of stream banks has been assessed – for example, after a significant storm producing high flows in 2016 – but the effectiveness of any interventions such as rock armouring and gabions for preventing sediment transport have not been explored.

- Most respondents indicated there was no fixed catchment surveillance plan.
- All respondents indicated they run regular street sweeping under a planned program to remove litter and sediment from the street surface. There were no investigations into effectiveness of this, such as what material was being collected by machinery or whether sweeping was effective at collecting fine sediment.
- All respondents indicated they were adopting WSUD techniques to reduce the pollutant load, runoff volume and provide passive irrigation for vegetation including street trees. One respondent indicated they had monitored the effectiveness of WSUD assets, and their data was reviewed as part of this study, but there were no other investigations into effectiveness.

As a result of difficulties in acquiring catchment data, the catchment case studies selected to demonstrate the framework were typically dominated by residential developments, with small areas of commercial development included. Based on the framework assessment of six case study catchments, Port Noarlunga catchment (City of Onkaparinga) and the Frederick Street catchment (City of Marion) scored the highest weighted risk scores. This is largely because of the presence of existing WSUD measures at other sites which may collect sediment, including kerb side inlets and infiltration systems. However, it should be noted that the case study catchments provided in this report were for examples and may not represent actual catchments of highest risk more broadly, determination of which will require more effort consulting with state and local authorities.

Based on the review and survey activity which supported the development of the framework described in this report, a number of recommendations are made which would improve local understanding of fine sediment sources and measures to reduce sediment transport to Adelaide’s coastal waters:

- A greater understanding of fine sediment sources on a finer spatial and temporal scale would enable greater precision in elucidating which landuses within a catchment contribute to the fine sediment load and when these contributions take place. Measurements of size fractioned sediment inputs at a sub catchment level would be of the highest value.
- A process of fine sediment source tracking could be key to precisely determining fine sediment sources and, by extension, enable well targeted and effective management interventions.
- Based on the limited available data on the performance of intervention measures, ongoing monitoring is recommended to improve local understanding of intervention performance. For example, monitoring could be included as an eligibility requirement for applying for state government funding for intervention measures in future infrastructure grant initiatives. Key areas of interest include the following:
    - Given that bioretention is a common structural measure for water quality improvement in Adelaide based on previous reporting, it is notable that there is no local data on the performance of these measures in the field. It is highly recommended that further research is undertaken to assess the effectiveness of bioretention measures for water quality improvement – especially fine sediment - in the Greater Adelaide area. There was no local data on the performance of these common structural intervention measures, and little on fine sediment reported at the international scale.
    - Street sweeping is widespread in the Metropolitan Adelaide. It is recommended that a comprehensive audit is undertaken into what is collected by street sweepers in South Australian catchments. This would be highly beneficial to determine the effectiveness of common street sweeping vehicles and sweeping regimes by identifying how much material they collect (mass) and what they collect (e.g. the particle size distribution of sediments captured).

Acknowledgments

The project team would like to acknowledge the contribution of Professor Peter Teasdale to this report prior to his sad passing on 7 August 2020. Peter made an outstanding contribution to environmental science and analytical chemistry in his 25-year career in research and teaching. We are grateful for having the opportunity to work with such a kind, generous, honest, and committed individual during his time working with the University of South Australia and the Goyder Institute for Water Research. Peter was passionate in supporting students and early career researchers and there is no doubt the success of those over whom Peter had some influence will form a significant part of his legacy.

The project team would also like to acknowledge the contribution of the project advisory committee and contributing local governments to this report.

Abbreviations

ACRONYM	DEFINITION
CBD	Central business district
EMC	Event mean concentration
GBR	Great Barrier Reef
GPT	Gross pollutant trap
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
WSUD	Water sensitive urban design
WWTP	Wastewater treatment plant

Glossary of key terms

Please note that a detailed glossary of key terms related to specific sources and treatment measures is provided in the framework spreadsheet and due to length has not been reproduced in this report.

TERM	DEFINITION
Fine sediment	Within the confines of this project, fine sediment was defined to be the fraction of sediment particles less than 63 µm size. This assumption based on the findings of Fernandes et al. (2018).
Suspended solids / suspended sediment	Suspended solids refers to the material that can be removed from a sample of water by filtration. From a stormwater perspective, the greatest mass of solids (or sediment) tends to occur in the 1 to 50 µm size range (Duncan, 2005). As per Rouse et al. (2016), the terms suspended solids (or total suspended solids) and suspended sediment (or total suspended sediment) are often used interchangeably. No differentiation was made in this report between these terms.

1 Introduction

1.1 Background

There has been a total of 6,200 ha of seagrass lost from Adelaide's coastal waters since 1949 (Tanner and Thiel, 2016). This is from shallow and deeper waters and has been attributed to both nutrient pollution and turbidity (McDowell and Pfennig, 2013). The main taxa lost have been two species of sea grass: *Posidonia* and *Amphibolis* (Fox et al., 2007). Key causes of sea grass decline were identified in the Adelaide Coastal Waters Study (Fox et al., 2007) and there have been several policy measures developed to respond, which are described by (McDowell and Pfennig, 2013). In general, the water quality of flow into St Vincent Gulf from Adelaide has improved in recent years due to reduced nutrient loads. These improvements have been largely achieved by investment to improve the water treatment performance of the three main municipal wastewater treatment plants in Adelaide, at Bolivar, Glenelg and Christies Beach(Cheshire, 2018). There have also been some improvements in the management of urban stormwater through uptake of harvesting opportunities, implementation of constructed water sensitive urban design (WSUD) measures and gradual improvements to urban stream systems (Myers et al., 2013)[1]. However, fine sediment inputs from urban runoff to St Vincent Gulf continues to be a concern, with the fine sediments already deposited to the coast also known to resuspend during large storm events (Fernandes et al., 2018; Zijl et al., 2014).

There are two main management strategies for supporting restoration of seagrass communities. The first is active reestablishment of juvenile plants. This has progressed through trials in coastal waters over the past decade with improving success and knowledge of appropriate techniques (Tanner et al., 2021; Tanner and Theil, 2019). The second is the use of water management interventions to prevent or intercept fine sediment prior to entering the Gulf.

The sources of fine sediment became clearer following the development of a catchment model by Rouse et al. (2016), which identified several catchments as the most likely sources of runoff pollution – namely the Barker Inlet, Torrens and Patawalonga, Field River, Christies Creek and Pedler Creek catchments. Furthermore, monitoring at key locations suggests that large inputs can occur during large winter storm events and during a falling hydrograph.

1.2 Objectives and deliverables

The primary objective of this project was to support state and local government decisions on where and how best to invest in urban water management solutions across Metropolitan Adelaide to remove fine sediment from stormwater runoff in the short-term.

This objective was to be achieved by completing several tasks, including the development of a decision-making framework that used existing information on sources of fine sediment to St Vincent Gulf and the performance of appropriate interventions. The framework was applied to local catchments to support the prioritisation of investment into urban stormwater quality management interventions to reduce the load of fine sediment reaching the gulf.

1.3 Assumptions and limitations

Recently, Fernandes et al. (2018) investigated the light climate in Adelaide's coastal waters and how this climate is affected by different factors, including sediments of differing sizes, and chlorophyll-*a*. Of the factors identified, coloured dissolved organic matter and fine sediments in the <63 µm fraction were identified as the two most significant light attenuators. A conclusion from the report by Fernandes et al. (2018) was that control of fine sediment has the greatest potential as a management strategy to enable seagrass

[1] An updated, interactive map of WSUD systems existing in South Australia as developed in this report is maintained online by Water Sensitive SA: https://www.watersensitivesa.com/wsud-projects/

recolonisation in Adelaide's coastal waters. Thus, this study was undertaken with a focus on fine sediment, defined as the fraction less than 63 µm, not all sediment in general.

2 Project methodology

The project methodology was based on developing a decision-making framework, inputting known data from literature, applying the framework an documenting findings. Project deliverables and their inter-dependencies are shown in Figure 1, and the methodology to deliver on each project task is described in the following sections.

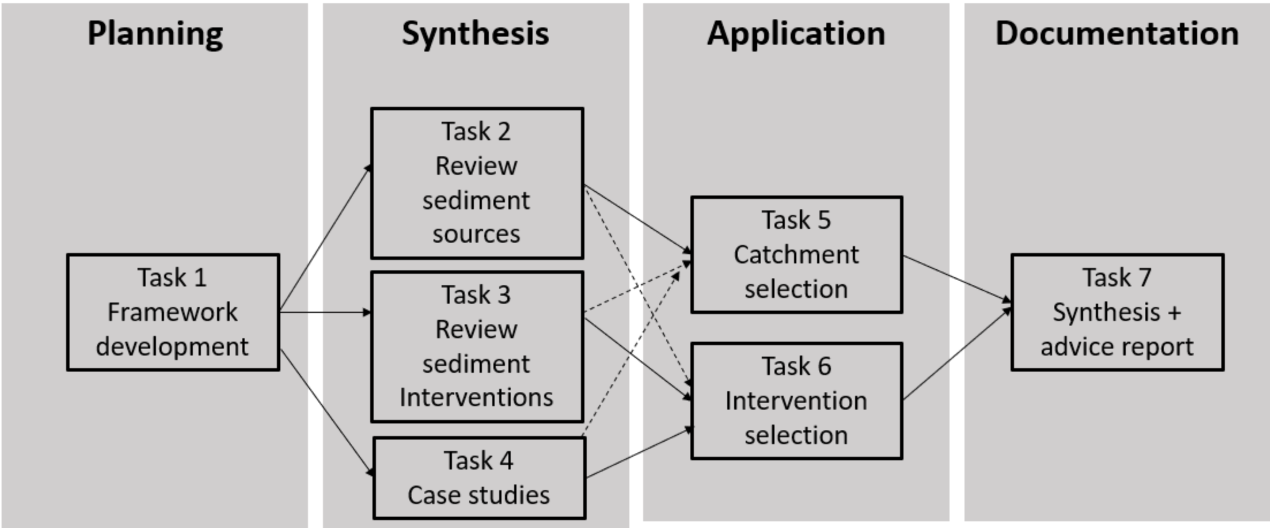

Figure 1: Diagram showing project deliverables and the relationship between them

2.1 Framework development

The decision framework structure that was applied was identified by investigating known or published tools that have been developed to select water quality intervention measures by other researchers in Australia. The approach taken by several tools was studied, including:

- The Model for Urban Stormwater Improvement Conceptualisation (eWater, 2014).
- The Melbourne Water STORM Calculator online tool[2].
- The Cooperative Research Centre for Water Sensitive Cities 'Investment Framework for Economics of Water Sensitive Cities (INFFEWS) Benefit Cost Analysis Tool' (Cooperative Research Centre for Water Sensitive Cities, 2019).
- The River Murray and Lower Lakes Catchment Risk Assessment for Water Quality (Mosley and Billington, 2007).
- The Cooperative Research Centre for Water Quality and Treatment 'Discoloured Water Management Support Tool' (Teasdale et al., 2007).

Based on the items above, a framework approach was developed which was broadly similar to the 'Discoloured Water Management Support Tool' (Teasdale et al., 2007) as a framework structure, which adopted a risk assessment style approach to assign scores to 'causes' of discolouration, and scores to measures which reduce colour in water. However, a key deficiency in that tool was that it was limited to an online interface for which formal support was not available in the long term, and the tool is no longer

[2] https://storm.melbournewater.com.au/

available for use. Based on this, we developed a spreadsheet-based tool for this phase of framework development because it can be easily developed, distributed, hosted online, and applied by an end user.

The decision-making framework was then developed such that it was able to consider the key sources of fine sediment, and appropriate interventions for fine sediment, based on a literature review of water quality guidelines (e.g. Duncan, 2005; South Australian Department of Planning and Local Government, 2010). After identifying potential sources and intervention measures, it was evident that each category could be split into three classes – namely diffuse, point and stream-based sources, and interventions which apply to them. The list of adopted sources and interventions in their respective categories are shown in in Table 1.

Table 1: List of sources and interventions considered in the developed framework and their category

CATEGORY	SOURCES	INTERVENTIONS
Diffuse	Agriculture, bare ground, commercial, forestry, grass, horticulture, industry, livestock, open space, road, roof, rural living, urban and water.	Development regulations, erosion control, filter strips, footpath/verge rehabilitation, gross pollutant traps, runoff interception and infiltration, sediment control measures, revegetation, rainwater tanks, street sweeping, grass swales, water diversion, raingardens and wetlands.
Point	Carpark, construction, mining, wastewater treatment plant, cliff erosion, waste disposal, wind erosion.	Sediment control mat, detention basin, filter strips, flocculation, geotextile sediment fences, infiltration, mulching/composting, pervious pavement, raingardens, remediation, straw bale filters, kerb side inlets and infiltration systems.
Stream / In waterway	Urban - concrete channel, urban - natural channel, rural - stock access, urban concrete – degraded, gully erosion, reservoir overflow, resuspension, sediment deposition, streambank erosion, upstream inputs.	Stock access restriction (fencing), contour banks, in-stream dredging/cleaning, bank armouring, daylighting, gully remediation, detention ponds, reservoir management, riparian/stream revegetation, sedimentation basins, stormwater harvesting, wetlands, earth banks.

After identifying potential sources and interventions and categorising them, a literature review was undertaken to determine source risk scores, and intervention performance scores. The literature review process is described in Section 2.2. All sources were rated on a scale of 0 to 3, and all interventions were rated on the same scale, but with negative numbers (0 to -3). Score descriptions for sources and interventions are shown in Table 2.

Table 2: Source risk and intervention performance ratings

RATING	SOURCE	INTERVENTION
0	The source has no risk of generating fine sediment	The intervention is ineffective at intercepting fine sediment.
1	The source has a low risk of generating fine sediment and generates small quantities.	The intervention has a low performance for intercepting fine sediment.
2	The source has a medium risk of generating fine sediment and generates moderate quantities.	The intervention has a medium performance for intercepting fine sediment.
3	The source has a high risk of generating fine sediment and generates high quantities.	The intervention has a high performance for intercepting fine sediment.
User defined	In the absence of any information or where data on the source of fine sediment is considered to be strongly site specific, the user must manually assign a value between 0 to 3.	In the absence of any information or where data on the performance of an intervention for fine sediment is considered to be strongly site specific, the user must manually assign a value between 0 to 3.

A detailed guide on how to use the framework is provided in Appendix C. In summary, however, application of the framework to a catchment includes the following broad steps:

1. Identify a catchment area to apply the framework.
2. Select all diffuse fine sediment landuse sources present in the catchment area and the percentage cover of these diffuse sources.
3. Select all diffuse interventions that are applied in the catchment area to prevent generating or intercept fine sediment, and the percentage of catchment area to which these interventions are applied.
4. Select all point sources of fine sediment that are present in the catchment, and the area of the catchment affected by that point source.
5. Select all point interventions that are applied in the catchment area to prevent generating or intercept fine sediment, and the percentage of point sources to which these interventions are applied (must not be greater than the point source percentage).
6. Select all in-waterway processes that generate fine sediment that are present in a catchment, and the percentage distance of waterway in the catchment which is affected by this (if there are no natural or near-natural channels in the catchment, none should be selected).
7. Select all in-waterway interventions that prevent or intercept fine sediment, and the percentage distance over which they are applied.
8. Review the risk score, and compare with other reviewed catchments, or apply interventions to see how they may impact on the derived score.

Following all the steps above will generate a risk and intervention score for each category of sources and interventions, and a final score which may be used for comparing the overall risk score with that for other catchments. Catchments with higher scores are those which are considered to have higher potential to generate and export fine sediment at the catchment outlet, while catchments with a lower score are considered to have a lower potential to generate and export fine sediment.

In the decision-making framework, the ratings for source and intervention categories were used to calculate a "raw score" and a "weighted score". The raw score is based on a simple sum of ratings and does not consider how widespread they are in a catchment, while the weighted score does consider the proportion of the catchment to which a risk is applied. As such, the weighted score is the most appropriate value to use any comparison study.

For communicating uncertainty in this review a low, medium and high coding approach has been used in the rating/risk column. Rather than presenting or interpreting findings in terms of uncertainty, it is important in decision-making to describe the level of confidence in the risk/rating of sources/interventions. In most cases, there was some degree of uncertainty due to a lack of local data to support other literature. These uncertainty ratings can be adjusted or modified by the end user.

2.2 Synthesis of data (literature review)

The data synthesis for the framework was based on a literature review activity. The literature review focussed on the following items:

- Sources and dynamics of fine sediment in Adelaide catchments to inform a risk framework, based on local, national and international data.
- The availability and performance of measures (or interventions) to intercept fine sediment, using literature specific to Adelaide and international data.
- Case study literature on approaches to intercept fine sediment.

Detailed review material for sources and interventions has been presented as part of the framework spreadsheet accompanying this report. A brief summary of the literature review with explicit commentary regarding the availability of local data is presented in Section 3.1. Various databases and search engines were reviewed including published articles from peer reviewed journals, government reports and websites, and WSUD guidelines. Commonly used terms included “measures to control fine sediment”, “sources of sediment”, “effectiveness of water sensitive urban design tools”, or “effectiveness of best management practices to control sediments”.

To support this literature review, effort was made to identify any local information that was available but not widely disseminated by asking local government practitioners in Adelaide for information during a survey and interview process. The survey and interview process are described in more detail in Section 2.3.1.

2.3 Application of the framework

Application of the developed framework was undertaken following consultation with a variety of local government representatives from across Metropolitan Adelaide. This process involved attempting to identify data that was not widely disseminated to support the framework source and intervention performance ratings and to identify catchments with known or suspected risk for fine sediment generation. This process is detailed in Section 2.3.1. Finally, the framework was applied to case study catchments to derive a comparative risk score. This process is described in Section 2.3.2.

2.3.1 IDENTIFICATION OF LITERATURE AND POTENTIAL CASE STUDY SITES - LOCAL GOVERNMENT SURVEYS AND INTERVIEWS

A survey questionnaire was developed to collect information on the existing knowledge regarding the sources of fine sediment, as well as the performance of catchment management measures and interventions (or treatment measures) being adopted by local government. The survey was developed by the project team and distributed by email to 17 metropolitan councils in Adelaide. These included City of Adelaide, City of Burnside, City of Campbelltown, City of Norwood Payneham and St Peters, City of Prospect, City of Tea Tree Gully, City of Unley, Town of Walkerville, City of Playford, City of Salisbury, City of Holdfast Bay, City of Marion, City of Mitcham, City of Onkaparinga, City of Port Adelaide Enfield, City of Charles Sturt and City of West Torrens.

Information collected in the surveys was synthesised. Part of the survey asked explicitly if the respondent was willing to participate in a follow up interview. Those who responded positively were invited to participate in a follow up interview to discuss the survey response and any thoughts they had on key priorities to reduce stormwater fine sediment exported from their local government area.

2.3.2 APPLICATION OF THE INTERVENTION SELECTION FRAMEWORK

After synthesising survey responses and undertaking interviews with local government practitioners, the project team developed a list of potential catchments for which the framework was applied by the project team. Key information regarding case study catchments was derived from literature, the local government authority and/or the project team.

3 Study results

3.1 Literature review – summary of findings

3.1.1 SOURCES OF FINE SEDIMENT

Sources and dynamics of fine sediments from Adelaide catchments

Rouse et al. (2016) conducted a thorough review of total suspended solids (TSS) discharged to the Adelaide coast. It was identified that stormwater and wastewater contribute roughly proportionate TSS discharges to Adelaide's coastal waters (Rouse et al., 2016; Wilkinson, 2003). However, of the <63 µm fraction, stormwater discharge contributes a higher proportion, at 54-71% of the total load, as measured from the Gawler, Torrens and Onkaparinga rivers, (Rouse et al., 2016), compared to 30-70% from wastewater discharge from treatment plants in Adelaide (Rouse et al., 2016; Wilkinson, 2003).

Rouse et al. (2016) identified four 'hotspots of coastal impacts from land-based discharges', where water quality failed to meet the requirements for healthy seagrass because of land-based discharges. These hotspots were Christies/Onkaparinga, Torrens/Glenelg/Patawalonga, Barker Inlet and Bolivar/Gawler. Through an approach using 'Overall Impact Indicators', it was identified that the Christies/Onkaparinga and Bolivar/Gawler hotspots were primarily driven by nitrogen loads, while the Barker Inlet hotspot was driven by suspended sediment loads. The Torrens/Glenelg/Patawalonga hotspot was driven by a combination of both nitrogen and sediment. It was further identified by Rouse et al. (2016) that the Torrens and Gawler catchments delivered the greatest percentage of <63 µm sediment, at 71% during winter flows. When this information was coupled with data on the drivers of coastal hotspots above, the Torrens was identified as a catchment which could be prioritised for interventions to reduce the discharge of fine suspended sediment.

An important consideration when determining the sources of sediment are the conditions under which sediment is more likely to be transported. Rouse et al. (2016) identified that the greatest impact on coastal water quality from stormwater discharges occurs in winter. Further, peak flow events deliver the bulk of TSS discharges to the coast, rather than during smaller rainfall events with less than 7 mm of rainfall. For instance, in 2012 the five largest flow events in the Torrens catchment contributed 81% of the sediment load (Rouse et al., 2016).

Identification of sediment sources and development of a risk framework

This section provides a brief synthesis of key previous works which have investigated (fine) sediment runoff from catchments in the greater Adelaide region, broadly from Gawler River in the north to Aldinga in the south, to inform the System Tool.

While sources are separated into diffuse, point source and in-waterway categories in the System Tool, the risk ranking was conducted with all sources combined together, as outlined in Table 3. Rouse et al. (2016) was used as a basis for the functional unit landuse system outlined in Table 3. One aim of Rouse et al. (2016) was to develop tools and knowledge to inform water management decisions to ensure Adelaide's coastal water quality is of sufficient quality to support desired environmental values, such as the presence of seagrass meadows close to the shoreline. To achieve this, available water quality data was synthesised to develop an updated Integrated Urban Water Management (IUWM) and catchment models. This updated modelling was used, as a proof of concept, to simulate catchment impacts on urban water quality under different stormwater management scenarios, and to identify individual stormwater discharge hotspots that contribute to coastal impact hotspots. Of relevance here, TSS event mean concentraitons (EMCs) were synthesised from Fletcher et al. (2004) and Fleming (2010) linked to a standardised system of landuse and functional units to improve comparability. This system of landuse and functional units was largely used in the framework spreadsheet.

Several additional classes were added to the risk ranking process, where there was either data of sufficient quality to warrant inclusion, as in the case of the sources derived from Brodie (2007), or in the case of construction sites, where literature indicated this was an influential source, worthy of consideration.

It is important to note that, while the focus of this report is on fine sediment, few studies fractionate TSS measurements to enable comparison of the relative contributions of each source of a particular particle size fraction. This limitation is discussed later in this section. Thus, to enable the direct comparison of sediment contributions, the aggregate measurement of TSS was used. This represents a shortcoming to the framework that cannot be overcome without more available data.

The suggested risk groupings outlined in Table 3 were derived by separating the data into four quartiles: 0, 1, 2 and 3. These are the suggested risk values. It is anticipated that, where knowledge of specific processes within a catchment is of a high level, these risks can be altered to reflect local conditions.

A detailed discussion of the sources outlined in Table 3 is contained in Table 4.

A more detailed overview of available literature values for the sediment source classes outlined in Table 3 is outlined in Appendix B.

Table 3: Overview of sources included in the risk ranking process

SEDIMENT SOURCE	DEFINITION	EVENT MEAN CONCENTRATION (MG TSS/L)*	SUGGESTED RISK GROUP (QUARTILE 0-3) **	SOURCE
Agriculture	Any broadscale agriculture	131	2	Fleming (2010)
Bare ground	Soil that is exposed, without cover	736	3	Brodie (2007)
Carpark	Sealed carparks, typically in urban settings	64	2	Brodie (2007)
Commercial	Land zoned for commercial use, including education, public institution, retail commercial and services	61	1	Fleming (2010)
Construction site	Any construction site including road, residential (greenfield/brownfield), commercial and industrial	1200	3	Schueler (2003)
Forestry	Land managed for commercial timber production and forestry reserves	66	2	Fleming (2010)
Grass	Turf in an urban area	40	1	Brodie 2007
Horticulture	Broadscale annual or perennial horticulture	308	3	Fleming (2010)
Industry	Land zoned for industrial use, including general industry, food industry and utility industry	40	1	Fleming (2010)
Livestock	Land grazed by livestock	184	3	Fleming (2010)
Mining	Any land used currently or historically for mining or quarrying	40	1	Fleming (2010)
Open space	Recreational areas, golf courses, vacant land and residential areas with native vegetation cover	43	1	Fleming (2010)
Road	Sealed roads with stormwater infrastructure, typically in urban areas	229	3	Brodie (2007)
Roof	Roofs of buildings	16.3	0	Brodie (2007)
Rural living	Land zoned for rural living/residential	131	2	Fleming (2010)
Urban	Residential land, including private, non-private and vacant	61	1	Fleming (2010)
Water	Land covered by water, such as streams, rivers and lakes	0	0	Fletcher et al. (2007)
Wastewater treatment plant	Land used to treat wastewater	40	1	Fletcher et al. (2007)

** TSS = total suspended solids*

*** The data were divided into quartiles from 0 to 3, where 0 is 0-39 mg/L, 1 is 40-62.4 mg/L, 2 is 62.5-170.74 mg/L, and 3 is 170.75-1200 mg/L.*

Table 4: Summary of reports used to inform sediment source risk rankings outlined in Table 3

SOURCE	DESCRIPTION
Brodie (2007)	*Toowoomba, Queensland, Australia* This thesis, entitled 'Investigation of stormwater particles generated from common urban surfaces' contains useful, detailed characterisations of runoff from common urban surfaces, including roads, carparks, roofs, grass and bare ground. Additionally, the relationship between rainfall and non-coarse particle loads was investigated, and the development and application of urban planning tools based on these surfaces were described.
Duncan (1999)	*Review of global literature* The objective of this report was to assess the broadscale behaviour of urban runoff quality in relation to landuse and other catchment characteristics, through an extensive review and statistical analysis of literature reported water quality values. It was found that roads were a major contributor of TSS in urban areas. It was identified that average concentrations of TSS were highest in agricultural catchments, intermediate in urban catchments and lowest in forested catchments. For every increase of 500 mm in mean annual rainfall, the most likely TSS concentration was approximately halved in runoff. It was found that correlations between water quality parameters was often low, leading to the conclusion that there may be other important factors to consider, such as geological age of catchment rock and soils and short-term rainfall intensity.
Fleming (2010)	*Mount Lofty Ranges, South Australia, Australia* This report conducted a significant study into water quality data in the Mt Lofty Ranges in South Australia. Flow weighted, composite water quality data from 16 gauging stations was used in the analysis to generate locally relevance Event Mean Concentrations (EMCs) for total nitrogen (TN), total phosphorus (TP) and TSS. The primary motivation for obtaining better EMC estimations was to parameterise a source catchments model for the Mt Lofty Ranges. While values for suburban areas were calculated, more specific landuses, such as roads, were not. Interestingly, it was concluded that while runoff values for TN and TP were like those reported elsewhere, there was a significant deviation in TSS values for some landuses in the study area, when compared to values elsewhere. Specifically, conservation area, managed forestry and plantations recorded higher TSS EMC values, while suburban and dense urban landuses recorded lower TSS EMC values.
Fletcher et al. (2004)	*New South Wales, Australia* This extensive report was developed in recognition of the need for improved guidance for the selection of stormwater management measures. The report findings, while centred on conditions in NSW, are generally applicable to Australian conditions. One aim of this report was to derive 'best estimates' for water quality (EMCs, including TSS) in relation to landuse. The estimates derived were based on literature review and built on the findings of Duncan (1999). The report also contained some statistical measures of data spread, meaning estimations on certainty could also be generated if required.
Schueler et al. (2003)	*Maryland, United States of America* This report is cited because, at the time of writing, no local or national data for TSS runoff estimations for construction areas could be identified. The ‘Watershed Protection Report’ synthesised a significant number of scientific reports which investigated the impact of impervious cover, and other indicators of urbanisation, on aquatic systems. The hydrologic, water quality, physical and biological impacts of urbanisation were considered. This study reported TSS levels in runoff from construction sites to range between 200-1200 mg/L. This range of values also aligns with more recent measurements outlined by Müller et al. (2020).

Sources not included in the ranking process

Several sources were identified, in addition to those included in Table 4, for inclusion in the decision-making framework. For point sources, these were:

- Cliff erosion,
- Waste disposal and
- Wind erosion.

For in-waterway processes, these were:

- Urban concrete – degraded
- Gully erosion,
- Reservoir overflow,
- Resuspension,
- Sediment deposition,
- Streambank erosion and
- Upstream inputs.

Most of these additional sources were suggested for inclusion by members of the Project Advisory Committee. These sources were not included in the ranking process outlined in Table 3 because they are highly dependent on local conditions and/or available data were insufficient and/or incompatible to enable meaningful inclusion in the ranking process. These have a default risk rating of 'user defined' in the developed framework.

Dry deposition is another recognised sediment source. The Adelaide Coastal Waters Study estimated dry deposition contributed 18% or nearly 2000 t of the solids input to Adelaide's coastal waters (Fox et al., 2007). This variable was not included in the risk ranking process of the framework as it would apply relatively uniformly across all sources.

Discussion

When considering urban sediment sources, it is occasionally reported that established urban catchments have lower levels of TSS discharge than reported mean values because of the increased imperviousness of surfaces. Russell et al. (2017) suggest that this finding is not correct - while urban cover does in effect 'lock up' a number of sediment sources, high intensity urban runoff easily erodes commonly encountered urban surfaces such as construction sites, gravel landscaped surfaces such as road verges, and washes off deposited road sediments.

Construction sites are an urban landuse which can contribute a disproportionate amount of urban sediment (Guan et al., 2017). Russell et al. (2019) investigated an urban catchment in Melbourne and identified that, while construction sites occupied 0.5% of the investigated catchment, they were responsible for contributing 32% of the sediment load. Sediment yields of TSS were reported on a per ha per year basis and construction sites were identified to contribute 2800 kg/ha/yr, gravel surfaces 740 kg/ha/yr, grass/mulch surfaces 84 kg/ha/yr and impervious surfaces 21 kg/ha/yr. All these common urban surfaces produce sediment yields well above background conditions and can have a strong impact on sediment loads in urban catchments. However, the relative lack of data, especially for local conditions in Adelaide, on expected sediment runoff from these surfaces is an impediment to accurate quantification of contributions from these sources.

Another key contributor to sediment load in urban areas is the time it takes for streams to adjust to the altered hydrological cycle which urbanisation brings; it can take 50 years for streams in urban areas to adjust to changes in the hydrologic regime which occur during urbanisation with elevated channel erosion likely to occur during this adjustment period (Russell et al., 2017).

The accurate identification of sediment sources, and their delivery pathways, is of vital importance to sustainable catchment management (Guan et al., 2017). Thus, two key, linked recommendations were arrived at:

1. Per recommendation 5.2.4 in Rouse et al. (2016), a greater understanding of fine sediment sources on a finer spatial and temporal scale would enable greater precision in elucidating which landuses within a catchment contribute to the fine sediment load and when these contributions take place. Measurements of size fractioned sediment inputs at a sub catchment level would be of the highest value. For example, construction site TSS runoff values could be a valuable contribution to the required knowledge base.
2. In concert with targeted sub-catchment scale TSS measurements, a process of fine sediment source tracking could be key to precisely determining fine sediment sources and, by extension, enable well targeted and effective management interventions. Guan et al. (2017) provides a review of techniques that can be used for tracking fine sediment sources within catchments. Key elements of a successful approach to identify fine sediment sources, and their spatial and temporal changes, include the combined use of a multi tracer approach, seasonal and rain-event based monitoring, and the monitoring of channel geomorphological properties within the catchment.

3.1.2 INTERVENTIONS OF FINE SEDIMENT

Interventions of fine sediments in Adelaide catchments

There are a variety of intervention measures present in catchments across Adelaide which may be effective in intercepting sediment. Many of these measures are WSUD structural measures, and their prevalence have been previously documented for the Greater Adelaide Region (Tjandraatmadja et al., 2014). A current database of WSUD measures in South Australia is also maintained by Water SensitiveSA[3]. However, field monitoring works undertaken to identify the performance of these intervention measures for fine sediment are not undertaken or reported.

Generic summary data illustrating the performance of common structural and stormwater specific WSUD interventions are available, however, like that shown in Figure 2. Such information in conjunction with a range of national and international performance literature has been used to assign performance ratings in the developed framework.

[3] https://www.watersensitivesa.com/wsud-projects/

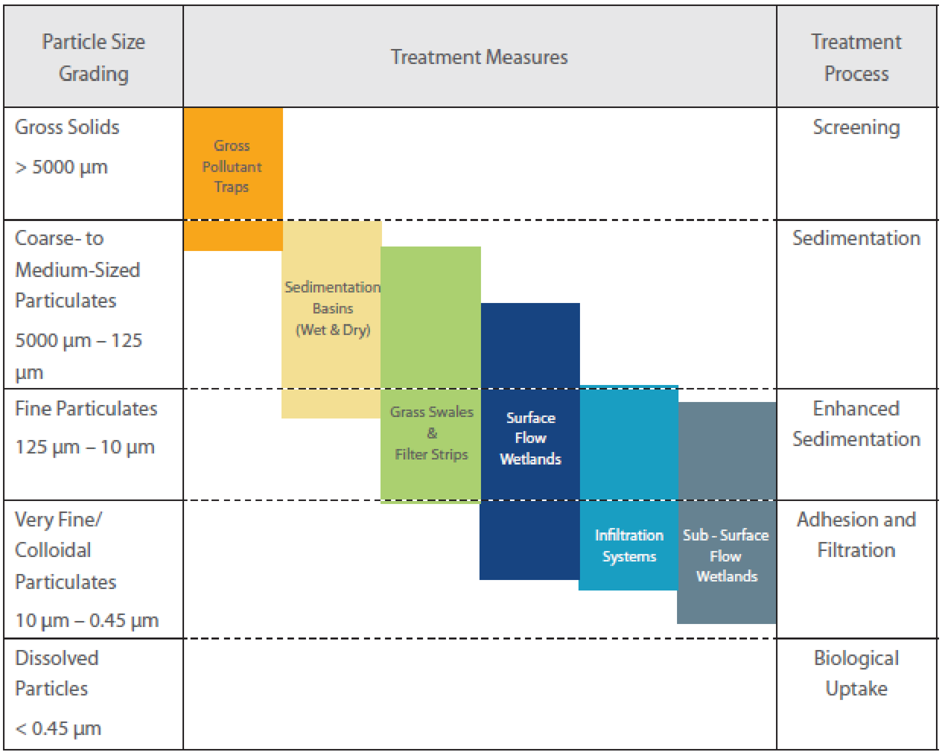

Figure 2: Generic guidance on the performance of some structural water sensitive urban design measures (Engineers Australia, 2006)

Identification of sediment interventions and development of a rating framework

This section provides a brief synthesis of key previous works which have investigated effectiveness of the interventions in removing TSS, particularly fine sediment or suspended solids. The review was divided into local, national, and international data which was used to support treatment performance ratings in the decision framework.

The performance of interventions has been categorised as having negligible, low, medium or high effectiveness to intercept fine sediment as defined in Table 5. The ratings suggested for each measure in this section are also noted to be based on optimal design conditions for each measure and performance may be lower if design is below the optimum standard.

Table 5: Sediment removal percentage and adopted ratings (NSW Environment Protection Authority, 1997)

EFFICIENCY	REMOVAL %	RATING
Negligible	0 to 10	1
Low	10 to 50	2
Moderate	50 to 75	3
High	75 to 100	4

It is important to note that while the focus of this report is on interventions/treatments specific to the fine sediment, very few studies fractionate suspended solids measurements for pre- and post-treatment water quality performance evaluation to enable comparison of the relative removal of a particular particle size fraction. This limitation is discussed later in this section. Therefore, in this report, the mean removal percentage of suspended solids were used from various national and international studies. This represents a limitation to the framework that cannot be overcome without more detailed data on the performance of interventions/treatment measures for individual suspended solid size fractions. It is anticipated that the ratings of the specific intervention measures can be altered by practitioners based on local experience, or the availability of new knowledge.

Interventions not included in ranking process

A number of treatment measures were identified which may have some notable impact on the export of fine sediment from a catchment but for which a performance rating is either very highly uncertain, or where a rating will be highly variable depending on catchment or implementation conditions. These are listed below with respect to scale.

For diffuse interventions:

- Development regulations

For point interventions:

- Remediation
- Sediment control mats

And for waterway interventions:

- Contoured banks
- Instream dredging/cleaning
- Bank armouring
- Daylighting
- Gully remediation
- Detention ponds
- Reservoir management
- Riparian/stream revegetation
- Sedimentation basins
- Stormwater harvesting
- Wetlands
- Earth Banks.

The justification and rating of treatment measures which may be applied in a diffuse manner across a catchment are presented in Table 6. The justification and rating of point treatment measures is shown in Table 7. A list of waterway/stream treatment measures is also shown in Table 8, but note that due to limited review data no effectiveness has been applied for the waterway interventions.

Table 6: Summary outcome for identifying the performance ratings of diffuse treatment measures/interventions for fine sediment (H = high, M = medium, L = Low)

DIFFUSE INTERVENTION	LOCAL DATA	NATIONAL / INTERNATIONAL DATA	POTENTIAL % REDUCTION	ADOPTED RATING (UNCERTAINTY)
Rain gardens	There was no published data on the performance of rain gardens in Adelaide. Data is understood to be limited to unpublished grab sampling from rain gardens in the City of West Torrens, including TSS analysis, but no particle size distribution results.	There were 9 studies related to rain garden performance that were reviewed as part of the study. Very few reports were available on the performance of rain gardens which included particle size or fine sediment. However, the effectiveness of rain gardens for intercepting sediment in general was high, with interception rates cited between 83% to 100%.	83 to 100	-3 (M)
Wetlands	There was no published data on the performance of wetlands that was specific to fine sediment in Adelaide.	The technical guideline for managing urban stormwater reported the effectiveness of wetlands in removing suspended solids was high, with interception rated ranged between 75% to 100% (NSW Environment Protection Authority, 1997).	75 to 100	-3 (M)
Filter strips	A report on the performance of filter strips in Adelaide is available suggesting high removal of sediment in low intensity storms (Slay, 2003).	Five studies were reviewed to determine the rating for filter strip performance. The guideline for managing urban stormwater reported the indicative sediment trapping efficiency of filter strip was high (75% to 100%) however the removal of fine sediment was limited (NSW Environment Protection Authority, 1997).	75 to 100	-3 (M)
Water diversions	There was no evidence-based report identified on the stormwater diversion measures in Adelaide.	The water diversion measures for sediment control required maintenance and vegetative lining and effective at controlling runoff and erosion. Diversions were rated to have up to 50% effectiveness, however there was no specific information available on fine sediment effectiveness (Broz et al., 2017)	50	-2 (H)
Gross pollutant trap (GPT)	There was no published data on the performance of a gross pollutant trap for intercepting fine sediment in Adelaide.	GPTs provide effective treatment for sediment larger than 125 µm, but there was no information identified that was specific to fine sediments (Engineers Australia, 2006).	-	-1 (H)
Kerb side inlet and infiltration system	There is no data available on the effectiveness of runoff interception by kerb side inlets and infiltration systems for Adelaide. Sapdhare et al. (2019), reported the quantity of sediment settled in the infiltration systems but there was no specific data on fine sediment fraction.	There was no study found on the effectiveness of kerb side inlets and infiltration systems in removing the fine sediments.	-	-
Street sweeping	There was no study on the performance of street sweeping machines in	The Coorpoerative Resear4ch Centre for Catchment Hydrology developed a report on the effectiveness of street sweeping for stormwater pollution control (Walker and Wong 1999). The authors reported that	50 and 75	-3 (M)

DIFFUSE INTERVENTION	LOCAL DATA	NATIONAL / INTERNATIONAL DATA	POTENTIAL % REDUCTION	ADOPTED RATING (UNCERTAINTY)
	removing fine sediment from Adelaide streets.	there was no effective sediment removal evident for particle sizes smaller than 125 µm. Based on other international studies the effectiveness of street sweeping for intercepting sediment in general was high, with interception rates cited between 50 and 75% (Selbig and Bannerman, 2007; Stenstrom, 2008).		
Grass swales	There were no studies available on the performance of grass swales in removing fine sediment in Adelaide.	Three Australian studies related to grass swales were reviewed. Grass swales were effective in reducing TSS concentrations overall, with performance ranging from 50 to 80% (Engineers Australia, 2006; Lucke et al., 2014; NSW Environment Protection Authority, 1997).	50 to 80	-3 (H)
Erosion control	There was no study identified on the performance of erosion control measures in Adelaide.	There were two studies related to erosion control effectiveness that were reviewed. We found few reports of the performance of erosion control which reported on performance with respect to particle size or fine sediment. However, the effectiveness of for intercepting sediment in general was high, with interception rates cited to be between 75 and 100% (Broz et al., 2017; Wear et al., 2013).	75 and 100	-3(H)
Rainwater tanks	There was no study identified which reported on the performance of rainwater tanks for fine sediment interception. It is noted however that their performance is generally limited to roof runoff interception (Department of Planning and Local Government, 2010).	Rainwater tanks are effective to intercept roof stormwater however there is no data on fine sediment interception for Australian or International context.	-	-1 (H)
Revegetation	There was no study identified which reported on the effectiveness of revegetation for sediment interception in Adelaide.	Broz et al., 2017 reported that revegetation is the most effective and practical control of sediment loading, rated effectiveness up to 90%. However, there is no specific data available on the removal of fine sediment.	90	-1 (H)
Sediment control measures	There was no report on the sediment control measures removing fine sediment in Adelaide.	Four sediment control measures studies including modelling and field assessment were reviewed. Sediment control measures were stated to intercept between 40 and 90% (Broz et al., 2017; NSW Environment Protection Authority, 1997; Wear et al., 2013; Wossink et al., 2020) However, there was no explicit data on the effectiveness for fine sediment removal.	40 and 90	-3 (M)

Table 7: Summary outcome for identifying the performance ratings of point treatment measures/interventions for fine sediment

POINT INTERVENTION	LOCAL DATA	NATIONAL / INTERNATIONAL DATA	POTENTIAL % REDUCTION	ADOPTED RATING (UNCERTAINTY)
Detention basins	There were no studies available on the performance of detention basins in removing fine sediment in Adelaide. Department of Planning and Local Government (2010) reported that, the relationship between area of detention basins and design discharge for 125µm sediment capture efficiency ranged 70% to 90%. There was no specific data on fine sediments.	There were two studies related to detention basin removal efficiency that were reviewed. The effectiveness of detention basins for intercepting suspended solids in general was rated moderate, with interception rates cited to be between 50% to 70% (NSW Environment Protection Authority, 1997; Wilkinson, 2005)	50 to 70	-3 (H)
Flocculation	There was no study identified which reported on the effectiveness of flocculation for sediment interception in Adelaide.	Four studies were reviewed for flocculation treatment measures. Studies reported that the flocculation is effective method for mean particle size 8µm. Studies reported that the suspended solids in stormwater or river water when entered in sea water with high cation concentrations (salty water) greatly increases their sinking rate and can trapping these sediments near the estuary of water (Eric and Ronald, 1995; NSW Environment Protection Authority, 1997; Webster and Ford, 2010). Stormwater Best Management Practice technical report concluded that the flocculation using chemical agent (cationic polymer) are effective and do reduce turbidity but toxic to aquatic organisms (US EPA, 2013).	-	-3 (H)
Geotextile sediment fences	There was no study on the performance of geotextile sediment fences in removing fine sediment from Adelaide.	Two studies were reviewed for geotextile sediment fences performance to reduce sediments. The studies rated high filter rating between 70% to 97% (Barrett et al., 1998; Sherwood and Wyant, 1979)	70 to 97	-3 (H)
Infiltration systems	There were no studies available on the performance of infiltration systems in removing fine sediment in Adelaide. Water sensitive urban design technical manual reported that, the infiltration trenches are best suited to small catchments (<2 hectare). (Department of Planning and Local Government, 2010). There was no specific data on fine sediments.	Two studies were reviewed for infiltration systems performance in removing sediments. The pollutant retention capacity of infiltration systems was rated high, listed between 71% to 99% (Engineers Australia, 2006; NSW Environment Protection Authority, 1997)	71 to 99	-3 (H)

POINT INTERVENTION	LOCAL DATA	NATIONAL / INTERNATIONAL DATA	POTENTIAL % REDUCTION	ADOPTED RATING (UNCERTAINTY)
Mulching /composting	There were no reports or data on mulching or composting treatment measures for intercepting fine sediment in Adelaide.	Three studies were reviewed for the mulching/composting treatment measures for intercepting sediments. The studies reported that natural mulch or compost such as straw or wood chips can absorb rainfall but can also wash away in a high flow event. The sediment removal performance was noted to be between 50% to 97% (Broz et al., 2017; Wear et al., 2013)	50 to 97	-3 (H)
Straw bale filters	There were no reports or data on straw bale filters treatment measure for intercepting fine sediment in Adelaide.	Three studies were reviewed and studies reported that straw barriers are effective only for low and moderate flows interceptions and rated sediment removal efficiency between 50% and 67% (Broz et al., 2017; Sherwood and Wyant, 1979; Wear et al., 2013).	50 and 67	-3 (H)
Kerb-side inlet and infiltration system	There is no data available on the effectiveness of runoff interception by kerb side inlets and infiltration systems for Adelaide. Sapdhare et al. (2020), reported the quantity of sediment settled in the infiltration systems but there was no specific data on fine sediment fraction.	There was no study found on the effectiveness of kerb side inlets and infiltration systems in removing the fine sediments.	-	-

Table 8: Summary outcome for identifying the performance ratings of waterways treatment measures/interventions for fine sediment

WATERWAY INTERVENTION	LOCAL	NATIONAL / INTERNATIONAL	RATING
Stock access restriction (fencing)	There were no data on stock access restriction measures to remove the fine sediments in Adelaide identified.	-	-
Contour banks, in-stream dredging/cleaning, bank armoring, daylighting, gully remediation, detention ponds, reservoir management, riparian/stream revegetation, sedimentation basins, stormwater harvesting, wetlands, earth banks.	There was no published data identified on the performance of waterway interventions in Adelaide.	-	User defined

3.1.3 CASE STUDIES OF FINE SEDIMENT INTERCEPTION AT THE CATCHMENT SCALE

Great Barrier Reef, Queensland, Australia

The Great Barrier Reef (GBR) is the world's largest coral reef and is situated along the coast of Queensland, Australia. While it is an iconic site of national and international significance, the GBR experiences very similar challenges to overall ecosystem function as the seagrass on the Adelaide coast, and for similar reasons. According to the *Reef 2050 Water Quality Improvement Plan* (State of Queensland, 2018) the key risks to the GBR are as follows:

- Nutrient loads, notably nitrogen and phosphorus, mostly derived from fertiliser use on contributing catchments. The reef water quality improvement plan is currently targeting a 60% reduction in anthropogenic dissolved inorganic nitrogen loads, and a 20% reduction in particulate nutrient loads.
- Sediment loads, particularly very fine sediments (in the case of the GBR, the definition varies but is typically sediment particles less than 16 µm, or in some case less than 10 µm) which remain suspended and reduce water clarity or, when settled, can resuspend or settle on developing coral and sea grasses. Very fine sediment is understood to be sourced from the contributing catchment area, most notably from grazing activity and stream bank erosion. Reduction targets of up between 5 and 25% have been established on a regional basis.
- Pesticides, including herbicides, insecticides and fungicides. While present in very diluted concentrations, levels high enough to have an impact on marine organisms have been found to occur and the impact of long-term exposure to lower concentrations are unknown and considered likely to impact on overall coral fertility and reproduction.

The Queensland Government produced a *Scientific Consensus Statement 2017* for the Great Barrier Reef which included key scientific data which was intended to underpin future management (Waterhouse et al., 2017). While the definition of fine sediment is even finer than this study (less than 16 µm or in some cases less than 10 µm) the documented impacts on coral and sea grasses in the GBR are very similar to those identified for the Adelaide coast. The consensus statement goes into more detail regarding fine sediment sources. For example, based on sediment source tracking studies in several contributing subcatchments (Bartley et al., 2017):

> 'approximately 90% of fine sediment delivered to the Great Barrier Reef is from subsoil erosion (which could be derived from gully, bank, scald or deep rill erosion). Of the sediment coming from subsoil sources, ~50% is estimated to be from vertical surfaces (gullies and riverbanks) and 40% from horizontal surfaces of subsoil (hillslope scalds, rills and gully floors).'

Urban sources in the GBR, particularly greenfield development sites, are important 'at local scales' but do not receive a strong emphasis compared to agricultural sources.

The prevention of fine sediment transport into the GBR ecosystem is based on 'Active engagement with communities and land managers in programs to improve water quality'. More specific, measurable targets include (State of Queensland, 2018):

- 90% of land in priority areas under grazing, horticulture, bananas, sugarcane, and other broad-acre cropping are managed using best management practice systems for water quality outcomes (soil, nutrient and pesticides)
- The management of urban, industrial and public land uses for water quality shows an improving trend
- An increase in riparian vegetation
- No loss of natural wetlands
- 90% of grazing lands will have greater than 70% ground cover in the late dry season

Reduction targets for fine sediment (from a 2013 baseline) are established for regions and for specific rivers in present in the GBR catchment area, and actions underneath these five umbrella targets are further elucidated in the *Reef 2050 Water Quality Improvement Plan* (State of Queensland, 2018)

There are clearly key differences in the GBR catchment area and that of the Adelaide coastal ecosystem. For example, the size of the GBR catchment is much larger at 424 000 km^2 (State of Queensland, 2018) compared to the Adelaide coastal water catchment which has an area of approximately 100 km^2. It is also notable that the catchment area of the Adelaide coastal waters has a higher proportion of urban development, different agricultural land use characteristics and a different climate. However, there is not enough evidence to claim that the GBR catchment management is a suitable case study on which to improve Adelaide coastal waters. Review activity for this project has indicated uncertainty on whether fine sediments delivered to the Adelaide coast are predominately derived from urban or upstream rural catchment areas, and it is recommended that source tracking and fine sediment specific monitoring works are initiated to determine whether the urban or rural land uses dominate or contribute an equal share of fine sediment to the Adelaide coastline.

3.2 Identifying catchments to apply the framework – a local government survey and interview process

3.2.1 SURVEY RESPONSES

To ensure that unpublished local data could be included in this study, and to identify potential catchment case studies on which to apply the decision-making framework, a survey was carried out as described in Section 2.3.1. The survey questions are shown in Appendix D. The survey was delivered to 17 local council representatives in Metropolitan Adelaide. Nine responses were received. All respondents were those responsible for stormwater management in their respective local government area.

The survey posed questions related to water quality management and the management of water quality improvement measures installed in council. A generalised summary of relevant responses is provided below.

Water quality

- Two respondents indicated that they maintained data which included water quality data for water features such as streams, stormwater drains and wetlands. There was no measurement of particle size distribution to support total suspended solids data.
- Two respondents had data available on sediment in runoff at a broad catchment scale. No data was available that was land use specific.
- Two respondents had data on the levels of TSS, turbidity and salinity monitored for stormwater harvesting schemes.

Stream banks

- Two respondents indicated that they collected data on the state of the banks of the Torrens River following an high intensity storm in December 2016 – but there was no previous data on which to assess change in the bank conditions over time.
- Two respondents mentioned that they use rock armouring and gabions on critical points in streams within their local government area. However, there was no documentation available on the effectiveness of these stream management measures.

Catchment management

- For catchment surveillance, five respondents indicated there was no fixed surveillance plan. Two noted that council representatives inspect construction sites for environmental compliance.
- All nine respondents mentioned that their council have regular street sweeping in place under a planned program to remove litter and sediment from the street surface. There were no reported investigations into effectiveness, or what was collected by machinery.

Water sensitive urban design and other interventions

- All respondents indicated they were adopting WSUD techniques to reduce the pollutant load, runoff volume and provide passive irrigation for vegetation including street trees. Measures included gross pollutant traps, swales, raingardens, constructed wetlands, ponds infiltration systems, pervious paving and kerbside inlets and infiltration systems.
- One respondent indicated they had monitored the effectiveness of WSUD assets, and their data was reviewed as part of this study.
- No respondents indicated that they employed chemical treatment measures to control sediment in water bodies.
- No respondents indicated they had reports or other documented information regarding sediment sources or intervention effectiveness in their local government area.

3.2.2 INTERVIEW RESPONSES

Based on the survey, interview sessions were held with four respondents which intended to apply the developed framework to a catchment in the local government area. However, in each case it became apparent that data to apply the framework on a desired case study area was not readily at hand, and as such the implementation of the framework was not undertaken in a single session in collaboration with local government representatives.

We focussed sessions on identifying catchment areas where the framework may be usefully applied. Following the interview process, the following sites were selected to apply the framework. One respondent supplied a catchment boundary and therefore the framework was applied on that suggested catchment. The other five catchments were chosen from previous and current research projects due to site characteristics being readily available. The six sites were:

- Port Noarlunga catchment, City of Onkaparinga
- Eynesbury Avenue catchment, City of Mitcham
- Frederick Street catchment, City of Marion
- Paddocks catchment, City of Salisbury
- Angus Road catchment, City of Mitcham
- Aldridge Terrace catchment, City of West Torrens

The locations of these six sites are presented in Figure 3.

Figure 3: Image showing the location of the selected case study catchments in Metropolitan Adelaide, South Australia (Source: Google Maps. 2020)

3.3 Application of the framework to case study catchments

The i-Tree canopy online tool[4] was employed to calculate the land cover for Port Noarlunga, Paddocks catchment and Aldridge Terrace catchment. The land cover assessment data for Eynesbury Avenue, Angus road and Fedrick catchment were used from previous research. Detailed assessment data for each catchment is presented in Appendix A. The overall raw and weighted score of case study catchments have been summarised in Table 9.

[4] i-Tree Canopy is a free online tool available at https://canopy.itreetools.org/
i-Tree Canopy is part of a suite of software from the Unites States Department of Agriculture. While it is intended to measure tree canopy cover in a catchment area, it can in fact be used to estimate the land use characteristics (or cover classes) in any defined catchment area. It is based on repeated random point selection and manual identification of the land use of that point by the user.

Table 9: Summary of outputs from the decision-making framework assessment of each case study catchment. Results show scores for pollutant sources (positive, contributing to TSS discharge) and interventions (negative, reducing TSS discharge) which sum to provide an overall score of catchment risk (higher total values are higher risk for TSS discharge)

Catchment	Score type	Diffuse source	Inter-ventions	Point source	Inter-ventions	Water-ways	Inter-ventions	Total
Port Noarlunga	Raw	15	-4	7	-3	0	0	**15**
	Weighted	2.84	-0.75	0.10	-0.03	0.00	0.00	**2.16**
Eynesbury Avenue	Raw	13	-6	4	-3	0	0	**8**
	Weighted	2.30	-2.30	0.12	-0.09	0.00	0.00	**0.03**
Frederick street	Raw	13	-4	7	-3	0	0	**13**
	Weighted	2.45	-0.68	0.14	-0.06	0.00	0.00	**1.85**
Paddocks	Raw	15	-7	7	-3	3	0	**15**
	Weighted	2.49	-2.49	0.14	-0.03	0.45	0.00	**2.0**
Angus Road	Raw	13	-6	4	-3	0	0	**8**
	Weighted	2.01	-2.01	-0.09	-0.09	0.00	0.00	**0.03**
Aldridge Terrace	Raw	13	-6	4	-3	0	0	**8**
	Weighted	1.97	-1.58	0.00	-0.09	0.00	0.00	**0.03**

Discussion

The catchment case studies selected were dominated by residential development, with small areas of commercial development also included. Based on the survey analysis, street sweeping is common treatment measure for case study catchments and may reduce sediment loads to some extent from road surfaces. However, the effectiveness of the current sweeping equipment being employed in the case study catchments is unknown. Therefore, to reduce the risk of sediment, various interventions should be considered.

Based on the framework assessment of case study catchments, Port Noarlunga catchment and the Frederick Street catchment scored highest weighted risk scores when compared with the other catchments. This is largely because of the presence of other WSUD in the form of kerb side inlets and infiltration systems being present in the other examples. However, it should be noted that the case study catchments provided in this report were for examples and may not represent actual catchments of highest risk across the metropolitan area. Determination of the highest risk catchment will require more consultation with state and local authorities.

4 Study recommendations

4.1 Recommended case study catchment

The priority catchment for investment based on the case study scores from the framework applied in this study was Frederick Street, or Port Noarlunga. However, it should be noted that the case study catchments provided in this report were for examples and may not represent actual catchments of highest risk across Metropolitan Adelaide, determination of which will require greater effort in consultation with state and local authorities. As such, the following general recommendations are considered primary findings of this study.

4.2 General recommendations to support future decision making

4.2.1 FINE SEDIMENT SOURCE TRACKING

Based on the work undertaken for this study and in accordance with Recommendation 5.2.4 in previous research by Rouse et al. (2016), a greater understanding of fine sediment sources on a finer spatial and temporal scale would enable greater precision in elucidating which land uses within a catchment contribute to the fine sediment load and when these contributions take place. Measurements of size fractioned sediment inputs at a sub catchment level would be of the highest value. For example, the levels of TSS and the particle size distribution in runoff from construction sites could be a valuable contribution to the required knowledge base.

In concert with targeted sub-catchment scale TSS measurements, a process of fine sediment source tracking could be key to precisely determining fine sediment sources and, by extension, enable well targeted and effective management interventions. Guan et al. (2017) provides an excellent review of techniques that can be used for tracking fine sediment sources within catchments. Key elements of a successful approach to identify fine sediment sources, and their spatial and temporal changes, include the combined use of a multi tracer approach, seasonal and rain-event based monitoring, and the monitoring of channel geomorphological properties within the catchment. Under the Coastal Environment Policy, an objective is to restore seagrass communities in nearshore environments along the Gulf St Vincent coastline. An important step to achieve this will be to identify the source risk at diffuse and point sources as well as waterway processes as mentioned in the framework master list.

To illustrate the need, based on the experience of the GBR catchment research, channel bank and bed erosion represented primary sources of fine sediment. For the Greater Adelaide region, there was very limited data available on the extent to which overland, stream bank or stream bed erosion contribute to fine sediment discharge to the Adelaide coast, nor what other high risk sources such as construction activity represent at a catchment scale. Channel bank and bed erosion is known to be a contributor to sediment loads in total, however, as qualitative reports on stream bank conditions were made available (reports which note the issue of erosion, identified by local government or consultants to them). Confirmation of the *extent* to which this erosion contributed to total loads of sediment, particularly fine sediment, at the Adelaide coastline is significant research need.

4.2.2 MONITORING OF SEDIMENT INTERVENTION APPROACHES

Despite the popularity of structural WSUD devices, there has been little to no formal monitoring of the performance of these systems. Among the most popular devices applied in the Greater Adelaide region are biofilters (or rain gardens), and while performance data is available from interstate and overseas, there is no local performance data that has been made public. This is a concern because the performance of these and other WSUD systems may be expected to differ in Adelaide compared to other cities due to the more pronounced wetting and drying cycles which systems are subjected to in the Mediterranean climate of Adelaide. There is also little data nationally or internationally which specifically addresses the ability of bioretention, or other popular WSUD systems to treat ‘fine’ sediment as most studies which report on sediment focus on the overall sediment load and do not identify the particle size distribution, nor report on the intervention of smaller/larger particles. There is therefore an opportunity to undertake research which involves comprehensive monitoring of popular structural WSUD systems, such as rain gardens. Such a study should consider including inflow and outflow water quantity and water quality. For most benefit to the Adelaide coast and to support policy development, water quality monitoring should as a minimum consider TSS, particle size distribution and nutrients (TP and TN). Monitoring of TSS and particle size distribution will provide critical evidence on the benefits that treatment measures can provide specific to impacts on seagrasses. It would also provide practitioners more generally, and the framework developed in this project, with higher confidence in ratings for sediment intervention measures. Performance data for TSS and nutrients are important because this would allow for local calibration of the popular MUSIC software tool, a popular means of assessing the compliance of development proposals with state and local government water quality targets.

In addition to fixed structural measures like WSUD devices, there has also been little research effort into the performance of non-structural measures aimed at interception of fine sediment in urban catchments. For example, despite the prevalence of street sweeping across the Adelaide urban area, there has not been a comprehensive audit of what is collected by street sweepers in SA catchments. A study should commence by reviewing what equipment is in use and how often across greater Adelaide councils. Following this, research investigating the load collected by street sweepers should focus on identifying how much material a sweeping run collects (in terms of mass) and what they collect (in terms of leaves, litter and sediment). The research could focus on assessing multiple types of sweepers currently in use after different 'build-up' duration. The particle size distribution of collected sediment should also be assessed to provide information on the costs and benefits of using street sweeping to improve coastal water quality improvement. Such a study would be highly beneficial to determine the effectiveness of, and perhaps improve, the selection of vehicles and sweeping regimes currently applied by catchment managers.

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Appendix A Case study applications of the decision-making framework

A.1 Port Noarlunga catchment, City of Onkaparinga

A.1.1 CATCHMENT DESCRIPTION

The Port Noarlunga case study catchment is in the City of Onkaparinga, approximately 30 km south of the Adelaide central business district (CBD), South Australia. It consists of residential development with some commercial land use and is bounded to the north by the Onkaparinga River and to the west by the Gulf St Vincent coastline. The catchment is illustrated in Figure A 1.

Figure A 1: Aerial photograph of the Port Noarlunga case study catchment.

A.1.2 LAND COVER ASSESSMENT

An assessment of land use across the case study catchment was undertaken with the i-Tree canopy online tool[5] and a shapefile of the catchment boundary. The derived catchment characteristics are presented in Table A 1.

Table A 1: Characteristics of the Port Noarlunga case study catchment

LAND COVER	% COVER
Bare ground	29.8
Grass	11.7
Impervious road	20.5
Roof	25.3
Tree	10.5
Water	2.2
Total	**100**

A.1.3 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Port Noarlunga case study catchment are shown in Table A 2. The results indicate that this catchment produced a weighted risk score of 2.16.

Table A 2: Framework assessment results for the Port Noarlunga case study catchment

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	15	-4	7	-3	0	0
Weight	2.84	-0.75	0.10	-0.03	0.00	0.00
Overall system risk – Raw score: 15						
Overall system risk – Weighted score: 2.16						

[5] https://canopy.itreetools.org/

A.2 Eynesbury Avenue catchment, City of Mitcham

A.2.1 CATCHMENT DESCRIPTION

The Eynesbury Avenue case study catchment is in the City of Mitcham, approximately 5.6 km south of the Adelaide CBD, South Australia. It consists of residential development with some infill development. The City of Mitcham have installed 28 kerb side inlets and infiltration systems as a means of improving stormwater management. The catchment is illustrated in Figure A 2.

Figure A 2: Aerial photograph of the Eynesbury Ave case study catchment

A.2.2 LAND COVER ASSESSMENT

An assessment of land use area of the catchment was determined using a geospatial analysis tool (QGIS, version 2.10.1) and a shapefile of the catchment boundary. The derived catchment characteristics are presented in Table A 3.

Table A 3: Characteristics of the Eynesbury Ave, Kingwood case study catchment

LAND COVER	% COVER
Bare ground	10
Grass	30
Impervious road	20
Roof	30
Urban	10
Total	**100**

A.2.3 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Eynesbury Avenue, Kingswood case study catchment are shown in Table A 4. The results indicate that this catchment produced a weighted risk score of 0.03.

Table A 4: Framework assessment results for the Eynesbury Avenue, Kingswood case study catchment

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	13	-6	4	-3	0	0
Weight	2.30	-2.30	0.12	-0.09	0	0
Overall system risk – Raw score: 8						
Overall system risk – Weighted score: 0.03						

A.3 Angus Road catchment, City of Mitcham

A.3.1 CATCHMENT DESCRIPTION

The Angus Road case study catchment is in Hawthorn, part of the City of Mitcham, approximately 6 km south of the Adelaide CBD, South Australia. It consists of residential development with some commercial land use. The City of Mitcham has installed 180 kerb side inlets and infiltration systems as a means of improving stormwater management throughout this catchment area. The catchment is illustrated in Figure A 3.

Figure A 3: Aerial photograph of the Angus Road case study catchment

A.3.2 LAND COVER ASSESSMENT

An assessment of land use area of the total catchment was determined using a geospatial analysis tool (ArcMap, v10.1) and a shapefile of the catchment boundary. The derived catchment characteristics are presented in Table A 5.

Table A 5: Characteristics of the Angus Road, Hawthorn case study catchment

LAND COVER	% COVER
Bare ground and grass	58.0
Impervious road	9.4
Other impervious area	15.1
Roof	17.8
Total	**100**

A.3.3 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Angus Road case study catchment are shown in Table A 6. The results indicate that this catchment produced a weighted risk score of 0.03.

Table A 6: Framework assessment results for the Angus Road, Hawthorn case study catchment

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	13	-6	4	-3	0	0
Weight	2.01	-2.01	0.12	-0.09	0.00	0.00
Overall system risk – Raw score: 8						
Overall system risk – Weighted score: 0.03						

A.4 Aldridge Terrace catchment, City of West Torrens

A.4.1 CATCHMENT DESCRIPTION

The Aldridge Terrace case study catchment is in Marleston, in the City of West Torrens, approximately 12 km west of the Adelaide CBD, South Australia. It consists of residential development with some commercial land use. The City of West Torrens have installed 26 kerb side inlets and infiltration systems as a means of improving stormwater management. The catchment is illustrated in Figure A 4.

Figure A 4: Aerial photograph of the Aldridge Terrace case study catchment

A.4.2 LAND COVER ASSESSMENT

An assessment of land use across the case study catchment was undertaken with the i-Tree canopy online tool[6] and a shapefile of the catchment boundary. The derived catchment characteristics are presented in Table A 7.

Table A 7: Characteristics of the Aldridge Terrace, Marleston case study catchment

LAND COVER	% COVER
Grass	15.5
Impervious road	16.0
Roof	42.8
Bare Ground	13.0
Tree	9.0
Commercial	3.7
Total	**100**

A.4.3 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Aldridge Terrace case study catchment are shown in Table A 8. The results indicate that this catchment produced a weighted risk score of 0.

[6] https://canopy.itreetools.org/

Table A 8: Framework assessment results for the Aldridge Terrace, Marlstone case study catchment.

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	13	-6	4	-3	0	0
Weight	1.97	-1.58	0.00	-0.09	0.00	0.00
Overall system risk – Raw score (8)						
Overall system risk – Weighted score (0)						

A.5 Paddocks catchment, City of Salisbury

The Paddocks case study catchment is in Para Hills, City of Salisbury, approximately 15 km north-east of the Adelaide CBD, South Australia. It consists of residential development with some commercial land use. The catchment boundary is shown in Figure A 5.

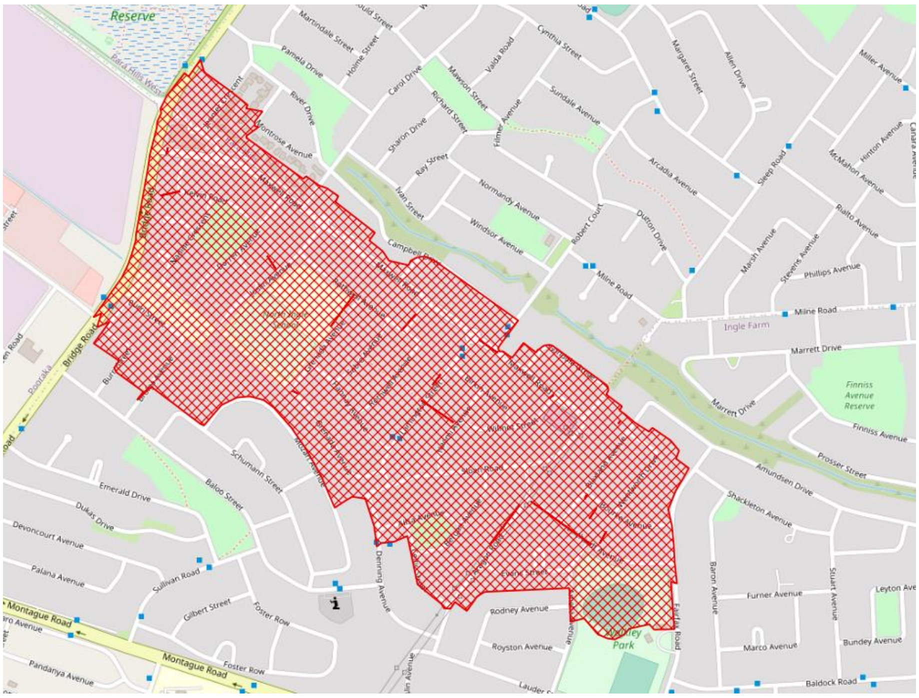

Figure A 5: Aerial photograph of the Paddocks case study catchment

A.5.1 LAND COVER ASSESSMENT

An assessment of land use across the case study catchment was undertaken with the i-Tree canopy online tool[7] and a shapefile of the catchment boundary. The derived catchment characteristics are presented in Table A 9.

Table A 9: Characteristics of the Paddocks case study catchment

LAND COVER	% COVER
Grass	8.0
Impervious road	22.0
Roof	24.0
Bare Ground	14.8
Tree	27.0
Commercial	4.0
Total	**100**

[7] https://canopy.itreetools.org/

A.5.2 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Paddocks case study catchment are shown in Table A 10. The results indicate that this catchment produced a weighted risk score of 0.56.

Table A 10: Framework assessment results for the Paddocks, Para Hills, case study catchment

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	15	-7	7	-3	3	0
Weight	2.49	-2.49	0.14	-0.03	0.45	0
Overall system risk – Raw score (15)						
Overall system risk – Weighted score (0.56)						

A.6 Frederick Street catchment, City of Marion

The Frederick street case study catchment is in Glengowrie, in the City of Marion, approximately 10 km south-west of the Adelaide CBD, South Australia. It consists of residential development with some commercial land use. The catchment boundary is shown in Figure A 6.

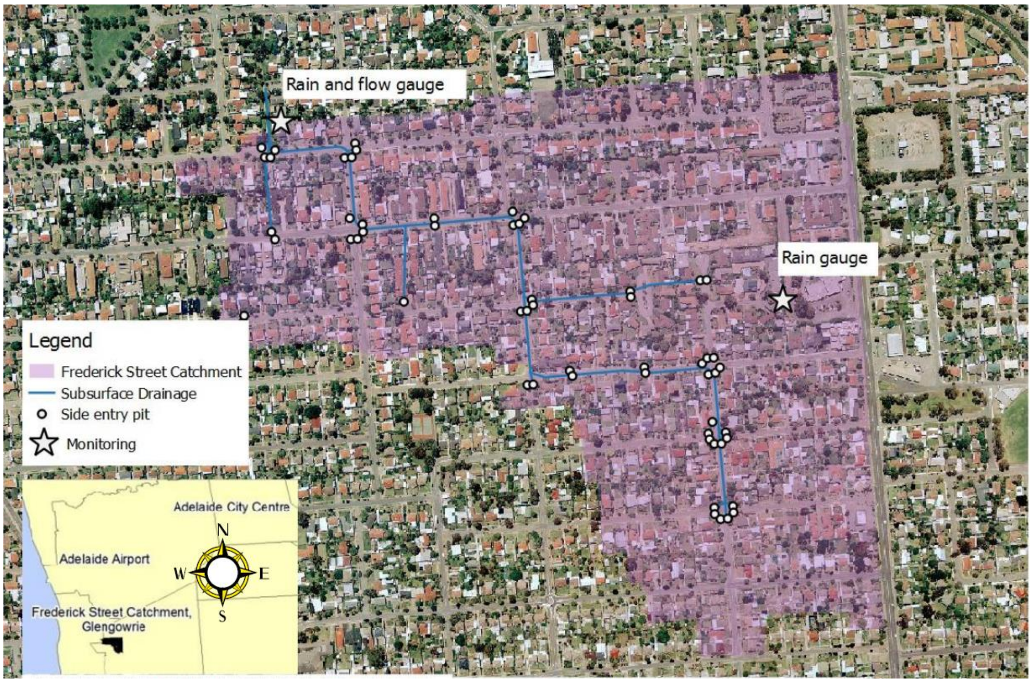

Figure A 6: Aerial photograph of the Fredrick Street case study catchment

A.6.1 LAND COVER ASSESSMENT

An assessment of land use across the case study catchment was undertaken with geographical information system (GIS) to investigate the impervious cover in 2013. The derived catchment characteristics are presented in Table A 11.

Table A 11: Characteristics of the Fredrick Street case study catchment

LAND COVER	% COVER
Other impervious area	13
Impervious area	9
Roof	25
Road	15
Bare ground	39
Total	**100**

A.6.2 FRAMEWORK ASSESSMENT SUMMARY

The framework assessment results for the Fredrick street case study catchment are shown in Table A 12. The results indicate that this catchment produced a weighted risk score of 1.85.

Table A 12: Framework assessment results for the Frederick Street, Glengowrie case study catchment

SCORE	DIFFUSE		POINT		WATERWAYS	
	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS	SOURCE	INTERVENTIONS
Raw	13	-4	7	-3	0	0
Weight	2.45	-0.68	0.14	-0.06	0.00	0
Overall system risk – Raw score (13)						
Overall system risk – Weighted score (1.85)						

Appendix B Detailed overview of sediment source classifications and estimations

Appendix B presents a more detailed overview of available literature values for the sediment source classes outlined in Table 3 of the main body of this report.

Table B 1: A more detailed overview of available literature values for the sediment source classes outlined in Table 3 (EMC = event mean concentration; DMC = dynamic mean concentration)

Landuse class*	Functional Unit from Rouse et al. (2016)	Landuse Classification from Fletcher et al. (2004)	Recommended typical wet weather Total Suspended Solids (TSS) (mg/L)							
			Fletcher et al. (2004)*			Fleming (2010)		Duncan (1999)	Brodie (2007)	Other
			Lower limit	Typical value (EMC)	Upper limit	EMC	DWC	Median value	<500 µm**	
Commercial	**Commercial**	Commercial	40	140	500	61	14			
Education										
Public institution										
Retail commercial										
Services										
Forestry	**Forestry**	Forest/Natural	10	40	150	66	23		40	
Reserve										
Agriculture	**Horticulture/ Agriculture**	Agriculture	40	140	500	131	10	133		
Horticulture						308	21			
Food industry	**Industry**	Industrial	40	140	500	40	12			
Industrial										
Utility industry										
Livestock	**Livestock**	Agriculture	40	140	500	184	12			
Mine/quarry	**Mining**	NA		140		40	12			
Golf	**Open Space**	Forest/Natural	10	40	150	43	10	71		
Recreation										
Vacant										
Residential native cover										
Road	**Road**	Roads	90	270	800	61	14	232	229	
Rural residential	**Rural Living**	Rural	20	90	400	131	10			
Non-private residential	**Urban**	Residential	40	140	500	61	14			
Residential										

Landuse class*	Functional Unit from Rouse et al. (2016)	Landuse Classification from Fletcher et al. (2004)	Recommended typical wet weather Total Suspended Solids (TSS) (mg/L)							
			Fletcher et al. (2004)*			Fleming (2010)		Duncan (1999)	Brodie (2007)	Other
			Lower limit	Typical value (EMC)	Upper limit	EMC	DWC	Median value	<500 µm**	
Vacant residential										
WWTP	**WWTP**	NA								
Beach	**Water**	NA								
Reservoir										
Water										
Roof								41	16.3	
High urban								152		
Construction activity										1200
Bare ground									736	
Carpark									64	

* Fletcher et al (2004) provides these upper and lower concentration limits as a ‘recommended range’ estimate based on limited data.

** Refers to the concentration of sediment that was less than 500 µm.

Appendix C Stormwater suspended sediment management support framework – user Guide

Appendix C provides guidance on the current version of the 'Stormwater suspended sediment management support framework'.

1. **Enter catchment details (see Figure C 1).**

    a. Enter the catchment name, total area and other details at the top of the spreadsheet. These are for record keeping only and do not influence the outcome of the assessment in this version of the framework

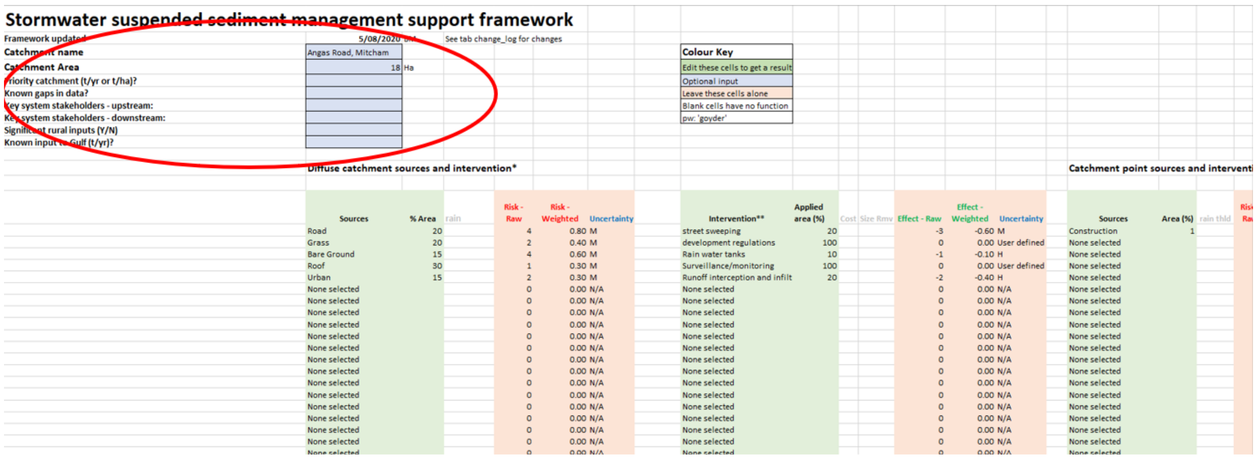

Figure C 1: Catchment name, total area and other optional details

2. **Collect catchment data**

    a. **Determine all diffuse sediment sources present in the catchment and their total area as a percentage of the total catchment area (see Figure C 2).** The diffuse sources currently rated in this version of the framework are listed in Table C 1, but a given catchment may only have a few of these sources present. Note that how you break down the catchment into diffuse sources can vary. For example:

        i. Ideally, you would be able to use existing data from a previous study for land use cover as a percentage of the total.

        ii. In the absence of this, if time is restricted, you may elect to do an estimate based on your knowledge or by working with someone who knows the catchment such as a local government staff member

        iii. Where time permits, you may enter the known source land uses into a mapping tool to determine percentage cover. In this Goyder Institute for Water Research study, the tool adopted for identifying percentage cover was i-Tree Canopy (Version 7.0)[8].

[8] i-Tree Canopy is a free online tool available at https://canopy.itreetools.org/
i-Tree Canopy is part of a suite of software from the Unites States Department of Agriculture. While it is intended to measure tree canopy cover in a catchment area, it can in fact be used to estimate the land use characteristics (or cover classes) in any defined catchment area. It is based on repeated random point selection and manual identification of the land use of that point by the user.

Note that if adopting one of these tools, you will need a shapefile of the catchment boundary. The time required for an assessment in i-Tree Canopy increases with the number of land cover classes identified – as such, it is advised that the user does not enter cover classes (or land uses) from Table C 1 into the i-Tree Canopy assessment process where it is known that they do not exist in the catchment being considered.

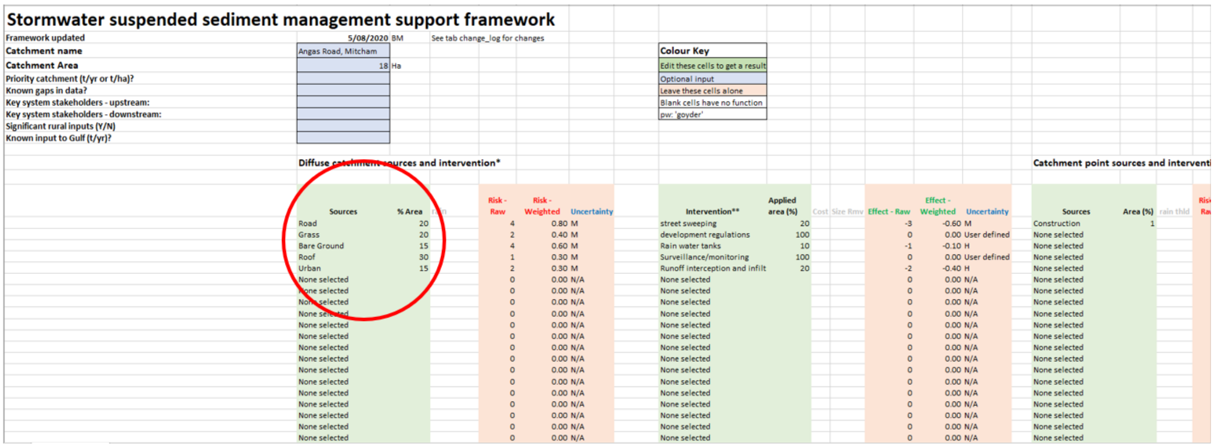

Figure C 2: Entering diffuse sources of sediment and the percentage area from which they are derived in the catchment

Table C 1: List of diffuse land uses and diffuse sediment interventions (treatments) currently rated in the stormwater suspended sediment management support framework

Diffuse sources	Risk	Diffuse interventions	Effectiveness
None selected	0	None selected	0
Agriculture	3	Development regulations	0
Bare ground	4	Erosion control	-3
Commercial	2	Filter strips	-3
Forestry	3	Footpath/verge rehabilitation	0
Grass	2	Gross pollutant traps	-2
Horticulture	4	Runoff interception and infiltration	-2
Industry	2	Sediment control measures	-3
Livestock	4	Revegetation	-1
Open space	2	Rainwater tanks	-1
Road	4	Street sweeping	-3
Roof	1	Grass swales	-3
Rural living	3	Water diversion	-2
Urban	2	Raingarden	-3
Water	1	Wetlands	-3

b. **Determine all diffuse sediment intervention (or treatment) measures present in the catchment area and the total upstream treated catchment area as a percentage of the total catchment area (see Figure C 3).** The diffuse sediment interventions currently rated in this version of the framework are listed in Table C 1, but a given catchment may have few if any of the these present. Where measures are situated within a catchment, each measure should be identified, and the upstream treated area estimated. Some examples are below for guidance on this step:

   i. If the catchment culminates in a wetland or gross pollutant trap, the percentage cover may be assumed to be 100%.

   ii. If a single measure is situated at the midpoint of a catchment and treats road runoff (including all contributing areas to road drainage) the user may elect to enter the treatment system with a treated area of half the total catchment area.

   iii. If the catchment has several measures throughout an entire catchment, the user may consider lumping all measures into a single system – entering such systems individually with individually determined contributing areas, or as a single lumped system with the total area treated, will yield the same outcome

   iv. If street sweeping occurs, the user may assume that all road surface is treated, and therefore the percentage treated is equal to road surface cover.

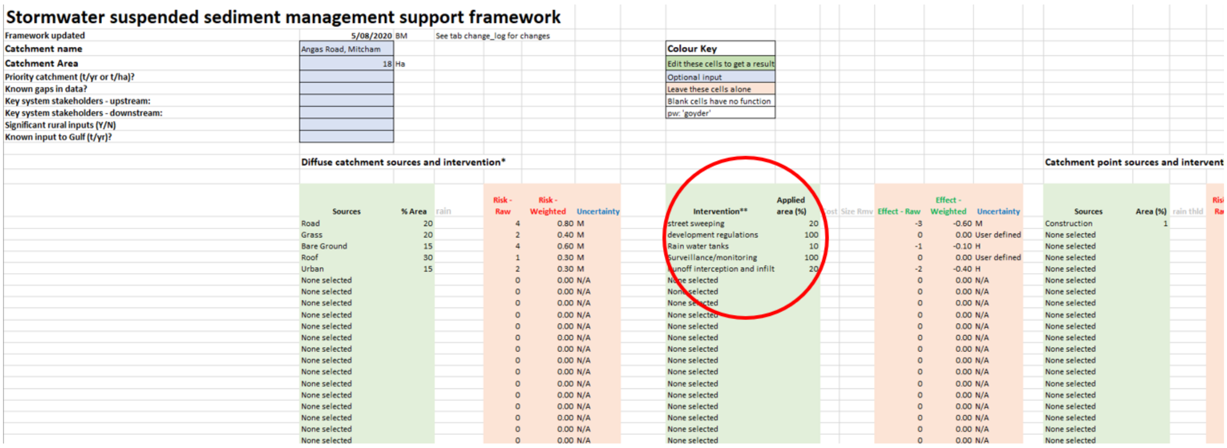

Figure C 3: Entering diffuse sediment interventions and the percentage catchment area to which they are treating

c. **Determine all point sediment sources present and their relative area as a percentage of the catchment surface area (see Figure C 4).** Note that these point sources are intended to provide point scores to smaller areas within pockets of land use that have already been rated in the diffuse sources in Step 2a above. The point sediment sources currently rated in this version of the framework are listed in Table C 2, but a given catchment may only have few if any of these point sources present. Examples are presented below to illustrate.

   i. If analysing a developed catchment with a residential component, and it is known that there will typically be redevelopment occurring in the catchment area, these should be considered as point sources of sediment. The user may elect to conduct a site visit or estimate the typical number of sites that are being redeveloped in a catchment at any given time and determine the total area of residential cover land use that is under construction.

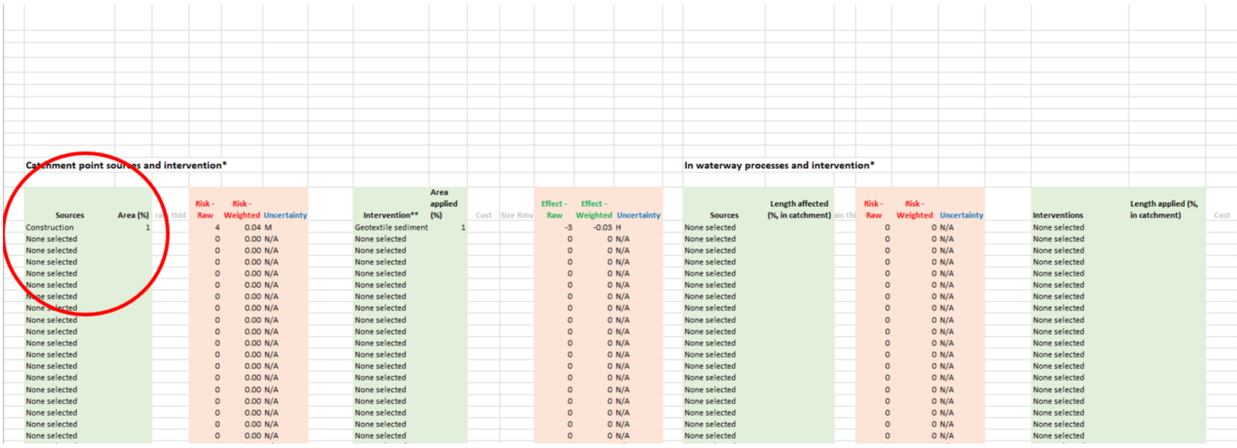

Figure C 4: Entering point sources of sediment and the percentage area from which they are derived in the catchment

Table C 2: List of point sediment sources and point sediment interventions (treatments) currently rated in the stormwater suspended sediment management support framework

Point sources	Risk	Point interventions	Effectiveness
None selected	0	None selected	0
Carpark	3	Sediment control mats	0
Construction	4	Detention basin	-3
Mining	2	Filter strips	-3
Wastewater treatment plant (WWTP)	2	Flocculation	-3
Cliff erosion	0	Geotextile sediment fences	-3
Waste disposal	0	Infiltration	-3
Wind erosion	0	Mulching/composting	-3
		Pervious pavement	-3
		Raingarden	-3
		Remediation	0
		Straw bale filters	-3
		Kerb side inlets and infiltration systems	-3

d. **Determine all point sediment interventions (or treatment) measures present in the catchment area and the total upstream treated area as a percentage of the total catchment area (see Figure C 5).** The point sediment sources currently rated in this version of the framework are listed in Table C 2. Point interventions are only expected to apply to point sources. As such, the sum of point intervention area should NOT exceed the sum of the point sources. The framework will not allow the user to determine point treatments scores more than point source scores in the current version of the framework.

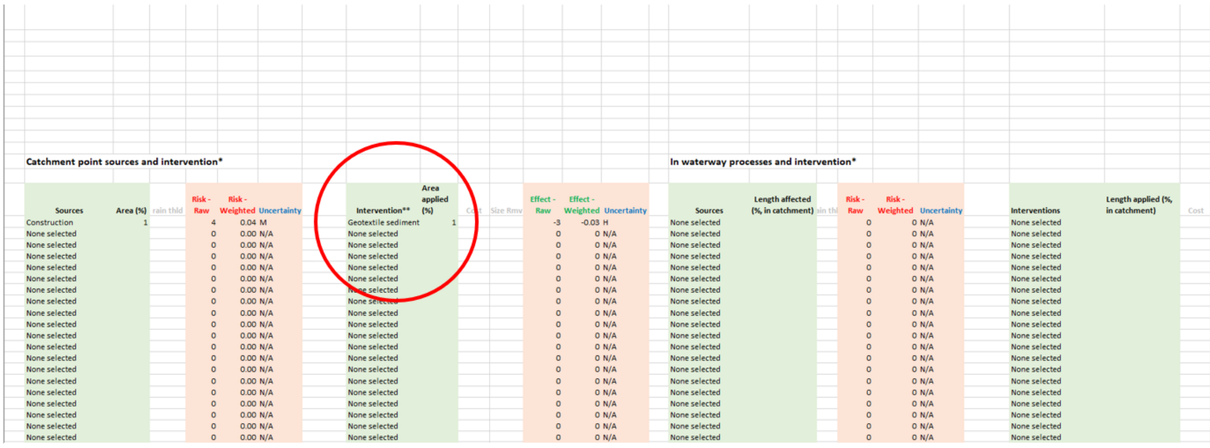

Figure C 5: Entering point sediment interventions and the percentage of catchment area they are treating (must be same or less than the total source percentage)

e. **Determine all waterway related sediment sources present and the length of the channel which provides this source as a function of the total channel length (see Figure C 6) .** Due to very limited data, there is very limited default information available for this step but it is intended that this aspect of the framework be included for future research and development because stream banks may represent a significant source of fine sediment, especially during large storms when erosive forces are high in natural stormwater conveyance channels. The stream derived sources of sediment sources currently listed in this version of the framework are listed in Table C 3, but a given catchment may only have few if any of these sources present.

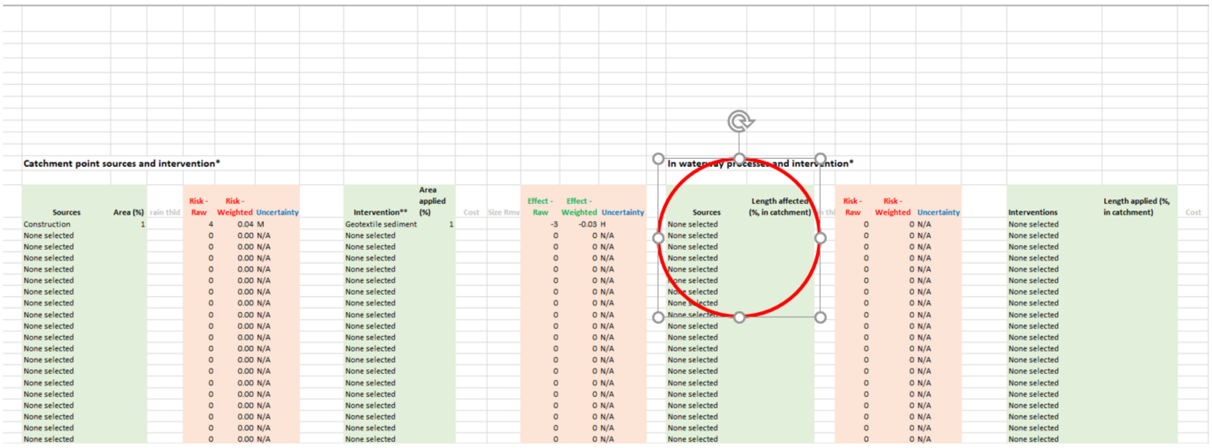

Figure C 6: Entering waterway derived sources of sediment and the percentage length of total waterway from which they are derived in the catchment

f. **Determine all waterway related sediment interventions present and the length of the channel which is subject to the intervention as a function of the total channel length (see Figure C 7).** Due to very limited available data, there is little default information available for this step, but it is intended that this aspect of the framework be included for future research and development into the effect of measures, such as bank armouring. Waterway sediment interventions are only expected to apply to waterway sediment sources. The interventions for stream derived sources of sediment sources currently listed in this version of the framework are listed in Table C 3. The sum of waterway intervention scores should NOT exceed the sum of the waterway sediment sources. The framework will not allow the user to determine waterway sediment intervention scores more than waterway sediment source scores in the current version of the framework.

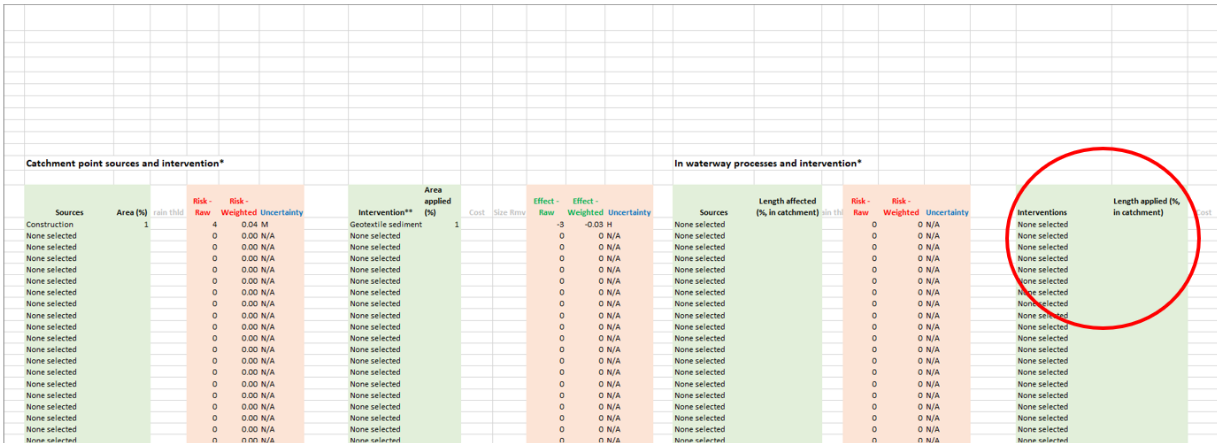

Figure C 7: Entering waterway derived sediment interventions and the percentage of total waterway length they are treating (must be same or less than the total source percentage)

3. **Examine the risk score (see Figure C 8).**

   a. The overall ratings for the catchment categories, and an overall risk score, are shown in a summary table at the base of the spreadsheet. The user is advised that the ‘Weighted score’ is the most appropriate value to use in any comparison study. The raw score is provided as an indictive estimate, which does NOT consider contributing area of the sediment source, nor treated areas of sediment sources. The weighted score can be compared with the scores for other catchments to compare the overall level of risk present and to prioritise the need for interventions.

   b. The final weighted score may now be used for comparing the overall risk score for multiple catchments. Catchments with higher scores are those which are considered to have higher potential to generate and export fine sediment at the catchment outlet, while catchments with a lower score are considered to have a lower potential to generate and export fine sediment.

   c. You may also undertake a scoping level forecast of the impact of interventions by implementing any planned interventions into the finalised risk framework to estimate the potential impact this will have on the catchment risk rating. Note that this is intended to act as a scoping framework tool and results may not be as accurate as other tools which have had much longer periods for ongoing development, such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC).

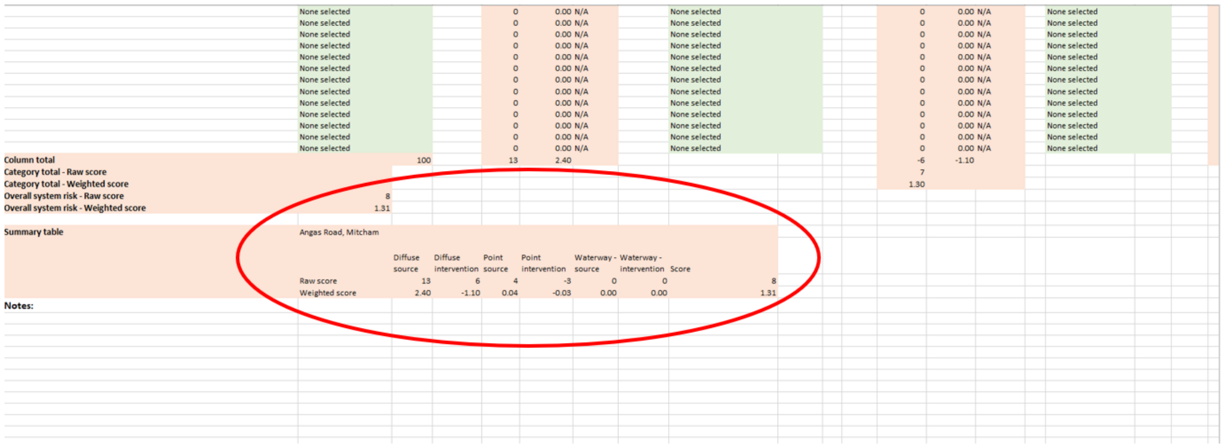

Figure C 8: Catchment risk score summary – note that the weighted score is the key statistic and a higher score indicates a higher risk based on the assumptions of this framework

Table C 3: List of waterway sediment sources and waterway sediment interventions (treatments) currently rated in the stormwater suspended sediment management support framework

In waterway processes	Risk	Waterway interventions	Effectiveness
None selected	0	None selected	0
Urban - concrete channel	0	Stock access restriction (fencing)	2
Urban - natural channel	3	Contour banks	User defined
Rural - stock access	3	In-stream dredging/cleaning	User defined
Urban concrete - degraded	0	Bank armouring	User defined
Gully erosion	0	Daylighting	User defined
Reservoir overflow	0	Gully remediation	User defined
Resuspension	0	Detention ponds	User defined
Sediment deposition	0	Reservoir management	User defined
Streambank erosion	0	Riparian/stream revegetation	User defined
Upstream inputs	0	Sedimentation basins	User defined
		Stormwater harvesting	User defined
		Wetlands	User defined
		Earth banks	User defined

Appendix D Survey questionnaire

The following is a reproduction of the survey questionnaire that was sent to local government representatives

A decision framework for selecting stormwater management interventions to reduce fine sediments and improve coastal water quality

Respondent information

Council:
Contact person name:
Position:
Email:
Phone number:

Introduction

Under the New Life for our Coastal Environment Policy, the South Australian Government has made a commitment to invest in urban stormwater water management projects that support improved coastal ecosystem health. The specific focus is on restoring seagrass communities in nearshore environments along the Gulf St Vincent coastline. There is a growing knowledge of sediment sources but limited information on the specific locations and type of management that will effectively mitigate the discharge of fine sediment to coastal waters.

The purpose of this questionnaire is to investigate the sources of sediments and catchment management (for example street sweeping, council policies) and interventions (for example Water sensitive Urban Design (WSUD) treatments.

The primary outcome of this project will be a decision framework and advice to state and local government on what intervention should be used, and where, to best invest in urban water management solutions across Metropolitan Adelaide to remove fine sediment in the short-term.

Water quality information

1. Water quality management

(a) Does your council have a stormwater quality and/or stream erosion management plan? Y/N
(b) If yes, does this plan consider the management of sediment loads that may runoff into stormwater systems and/or waterways? Y/N
(c) If yes, please provide a summary of available information
(d) Do you agree to a member of the project team contacting you for further information? Y/N

2. Water quality data

(a) Does your council maintain a database or, for example, have past consultant reports, which contain water quality data for any water features such as streams, stormwater drains, wetlands etc. that could be shared with this project? Total suspended solids/sediment (TSS), turbidity and sediment particle size distributions are of particular interest. Y/N
(b) Are any data available that relate to sediment runoff at a broad catchment scale, such as from a residential/industrial/rural area with a defined catchment? Y/N
(c) Are any data available that relate to streambank or channel erosion?

(d) Are any data available that relate to sediment runoff from specific point sources, such as, for example, bare soil, construction sites, used or disused quarries or industrial sites? Y/N
(e) If yes, please provide a summary of available information
(f) Do you agree to a member of the project team contacting you for further information? Y/N

Sediment treatment/ interventions facilities installed in council

1. Catchment management
(a) Do council have any surveillance plan in place (e.g. monitoring pre-/post-development sites for poor sediment management) Y/N
(b) Do council have street sweeping plan in place and check the effectiveness? Y/N
(c) if yes then, do you check type of waste intercepted or any studies on characterisation of collected sediment/waste load? (Y/N)

2. Stream management
(a) Please provide details of councils armouring streams or rehabilitation? please provide effectiveness or any documentation.
(b) Does council have a detention basin policy in any contributing catchment?

3. Water Sensitive Urban Design (WSUD) type treatment
(a) Does your council area monitor performance of WSUD assets? (Y/N)
(b) If yes then, please provide performance/effectiveness characteristics?

4. Does your council use any chemical treatment to control sediment such as flocculation/sedimentation? (Y/N)

5. Do you have any reports or documented information on sediment source and treatments? (please provide).

6. Future strategies for sediments/stormwater control.
(a) would you be in a position to co-fund the design, implementation and operation of a fine sediment intervention measure recommended by this project in the 2020/2021 financial year?

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide, the University of South Australia, and the International Centre of Excellence in Water Resource Management.