A critical investigation of evaluation matrices to inform coastal adaptation and planning decisions at the local scale

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Abstract

Local governments are under pressure to tackle an increasing spectrum of complex contemporary problems, such as climate change, whilst ensuring multiple stakeholder interests are incorporated into decision processes. Multi-criteria decision tools can assist but challenges remain in creating an enabling environment for incorporating and balancing different stakeholder perspectives. Here, we draw on interview data and a sensitivity analysis to investigate the use of an evaluation matrix to guide local coastal adaptation decision making in South Africa. We adopt a Participatory Action Research framework and find that decision making is influenced by individual, departmental and institutional values that are not adequately captured in the matrix approach. Our study reveals the compromise between achieving broad stakeholder representation and utilising technical expertise, and that altering matrix assumptions can imply different decision outcomes. Suggestions are made to improve multi-criteria decision approaches to better facilitate Integrated Coastal Management in responding to local coastal adaptation challenges.

Key words: climate change; decision analysis; stakeholder engagement; complexity; governance

1. Introduction

Making decisions on the implementation of adaptation options in the context of complex dynamic systems and future uncertainties requires careful consideration. Decision-makers and planners use a range of tools and frameworks to give structure to, and guide decision processes. Though many approaches are adopted, few are assessed in detail to examine their strengths and limitations when used in different contexts and for different applications. Many decisions require the balancing of multiple factors (Belton and Stewart 2002) and coastal adaptation decisions are no exception (Nicholls et al. 2008; Burkett and Davidson 2012). Furthermore, in situations where numerous stakeholders stand to gain or lose from an intervention, combining multiple stakeholder perspectives and negotiating conflicts is critical to the sustainability and success of the project (Renn and Schweizer 2009; Thabrew et al. 2009). Achieving consensus at the local scale, where opposing views, agendas and values are common, is a non-trivial task.

Multi-Criteria Decision Analysis (MCDA) techniques are often used to aid decisions that have cross-sector implications, involve multiple stakeholders and are sensitive to a range of uncertain driving factors. Recent studies have assessed and reviewed the application of MCDA techniques in different contexts (Kiker 2005; Mendoza and Martins 2006; Lai et al. 2008; Ananda and Herath 2009; Wang et al. 2009; Chen 2011) and all share the common finding that conducting a MCDA can be a valuable way to bring multiple stakeholders together to collaboratively reach decisions. Using case studies from Australia, Mosadeghi et al (2013) argue that MCDA techniques can be successfully employed in complex situations fraught with epistemic uncertainties – i.e. uncertainties arising from imperfect knowledge and a lack of capacity or ability to adequately model system behaviour. Additionally, Hajkowicz (2008) states that even simple MCDA approaches can aid group decisions where conflicting stakeholder interests are present. However, knowing how and when to include, even very simple, MCDA tools in the decision-making process for different applications remains a challenge. Equally as challenging is the process of deciding who should choose and define the various response options, as well as determining who and how to weight the different decision criteria. Belton and Pictet (1997) provide a framework for reaching group decisions using MCDA approaches, emphasising the role of "sharing, aggregating, and comparing" as elementary procedures for discussing different options and aspects of the decision problem. The framework has particular value when the stakeholders have different levels and areas of expertise, but the authors also acknowledge residual issues, such as the risk of a solution that pleases no one, the need for skilled facilitators and significant time commitments. Critically assessing how MCDA tools, and similar decision approaches, are used in various decision contexts can better equip planners and adaptation practitioners to understand the strengths and limitations of different approaches.

The focus of this study is on local level environmental and coastal adaptation decisions, which are being made in the context of a highly complex environment, both in terms of physical processes as well dynamic socio-political conditions (Chuenpagdee et al 2008). Over the last two decades, and recognising the complex nature of the coastal space as a nexus of socio-economic and dynamic systems interactions, the concept of Integrated Coastal Management (ICM) has been developed and is being applied as the most appropriate management paradigm with which to manage the coastal space (Cicin-Sain 1993). ICM aims to achieve sustainable development through multidisciplinary and iterative management processes within a collaborative and co-operative governance framework. Together with the adoption of ICM best practices (DOE 1996; Cummins et al 2002; Stojanovic 2004), Tobey et al (2010) argue that ICM can be applied successfully to address the additional challenges of climate change. However, they state that there needs to be more emphasis on nature-based strategies, longer planning horizons and a greater cognisance of uncertainties. Moreover, in order to achieve successful ICM, Kiambo (2001) states that coastal managers need to have competency in four areas: project management; ICM practice and processes; professional skills; and technical skills in a relevant natural or social science. Within local government planning authorities, and particularly in developing countries, some or all of these competencies are often lacking (Pasquini et al 2014); responding to coastal pressures is often still considered the domain of coastal engineers, and as such responses to these issues are typically restricted to engineered responses with little engagement with other disciplines (Cooper and McKenna 2008). Furthermore, current literature is largely silent on how local government agencies should structure themselves from an institutional perspective to enable increased degrees of ICM (as a means to draw on a wider spectrum of disciplines in the decision making and planning process) and thus be more effective at responding and adapting to coastal risks. Enabling local adaptation and coastal management activities that conform to best practice ICM therefore requires tools and approaches which are transferable and workable at the local scale.

Here we analyse and critique the use of a multi-criteria evaluation matrix used as a tool to guide coastal adaptation decisions in Cape Town, South Africa. We examine whether or not the matrix is a useful tool to enhance adaptation responses to coastal risks and to promote ICM in the absence of dedicated ICM specialists. We focus on a case study where different institutions have been working together to find a sustainable and mutually agreeable solution to deal with erosion and rising sea levels along a section of Cape Town's coastline. The aim of this paper is to scrutinise the matrix approach and identify the strengths and limitations of using the approach to inform coastal adaptation decisions at the local level. In this regard, the objectives of the study are to:

- Understand the impact of matrix assumptions on the decision outcome and test the robustness of the MCDA approach for local scale decision making.
- Determine and compare the views of stakeholders on how the decision process was structured and implemented, as well as the overall value of the matrix approach.
- Assess the capacity of the evaluation matrix to achieve the principles of ICM at the local scale.
- Make recommendations for how the matrix may be improved for use in future local level decision-making processes.

An author of this paper is a City of Cape Town employee and was the project manager for the case study being investigated. Part of the motivation for this research was to determine ways of improving the City's approach to coastal adaptation planning. As such, a Participatory Action Research (PAR) framework has been applied as a reflexive process amongst the relevant stakeholders involved in the decision making (Whyte 1991; Kindon et al 2008). This article provides the findings of the PAR process and will be used to guide and inform policy stances related to climate change responses at the local municipality level.

Further contextual details for the case study are provided in section 2. In this section we also describe the matrix used in the case study and the outcome of the matrix process. Section 3 briefly describes the methods for gathering empirical data used in this study, and section 4 presents the results of the stakeholder interviews and a sensitivity analysis of the matrix. The findings are discussed further in section 5 and section 6 concludes with recommendations on ways to improve the matrix approach for use in future local level decision making processes.

2. Case study background

2.1 Adaptation along the Cape Town coastline

The City of Cape Town (hereafter the "City") manages approximately 240km of coastline. The coastline is a highly sensitive, complex and dynamic space that provides communities and visitors with numerous social and economic benefits. Paradoxically, the coastline is also a source of risk to the City (Cartwright 2008); a land area of 25km^2 is considered highly vulnerable to sea level rise and storm surges over the next 25 years (Brundrit 2008). With emerging risks from rising sea levels and climate change, and inherited risks from historical spatial planning decisions, there is an urgent need for risk management interventions (City of Cape Town 2005; Mukheibir and Ziervogel 2007). However, it is considered especially important that any intervention should retain, and where possible enhance, the socio-economic and environmental value of the City's coastline (Burns et al. 1993; Colenbrander et al 2012). A particular challenge for City and municipal planning throughout South Africa is the absence of an overarching, integrated and city-wide strategic decision support framework to guide management decisions for existing coastal infrastructure at risk (City of Cape Town 2012).

The dynamic nature of the coastline is reflected by accretion of the beaches on the eastern side of the city in winter (May to September) and regression in the summer (October to April); the opposite occurs on the western Atlantic coastline. The seasonal cycle is primarily driven by periodic westerly mid-latitude cyclones (i.e. storms) during the winter months, and the south Atlantic high pressure system bringing strong and persistent south-easterlies during the summer months (Tadross et al. 2012). Less predictable coastal dynamics affecting the coastline include the migration of estuary mouths and localised erosion events. Damage to infrastructure resulting from these processes is expected to be compounded by the impacts of climate change through sea level rise, more intense storm surges and an increased duration of persistent south-easterly driven wave chop (rapid short, steep motion of breaking waves) (Brundrit 2008; Cartwright et al. 2008). A key challenge for the City's long-term planning and current adaptation projects is dealing with the uncertainty associated with future climate projections (Daron 2014) and understanding how the impacts might manifest locally.

2.2 Vulnerability of the Southern Peninsula Transport Corridor

The southeast quadrant of Cape Town comprises False Bay – a large (>1000km²) shallow bay with a maximum depth of 80 meters (Brundrit, 2008). The South Peninsula Railway Line, built along the western shore of False bay in the 1890s, provides multiple critical services including transport for commuters, the transport of goods to and from Simon's Town harbour, as well as supporting the local tourism industry. Together with a north-south arterial road the transport network forms the South Peninsula Transport Corridor (SPTC) and extends from Muizenberg in the north to Cape Point in the south (Figure 1).

At many locations along the SPTC the railway is vulnerable to pressures from coastal processes. Glencairn Beach, located five kilometres north of Simon's Town, is a pocket beach situated between two rocky headlands measuring approximately 400 meters (photograph, Figure 1). Until about 200 years ago the beach formed part of a sediment by-pass system connecting False Bay coast to the Noordhoek basin on the west coast (CSIR 1987). Sediment was transported along this by-pass system by south-easterlies in summer and north-westerlies in winter. The construction of the railway and road across Glencairn Beach has disrupted this sediment by-pass system and been a potential cause of prolonged beach regression at Glencairn (CSIR 1987). As the drivers of the sediment by-pass system are still in place, the road and railway line are frequently smothered in sand. In addition, the railway line, located between the road and the beach, is subject to episodic coastal erosion events (see Figure S1, Supplementary Material) induced by south-easterly driven wave chop in the summer and mid-latitude driven storms in the winter. This poses a significant health and safety concern as the structural integrity of the rail may be compromised posing a risk to commuters and cargo, as was recently the case for a railway on the mouth of the Amanzimtoti River in KwaZulu-Natal where a train de-railed and overturned as a consequence of erosion following heavy rainfall (BDLive 2012). The impacts of erosion, wave damage and wind-blown sand on the transport infrastructure burden the management authorities with high maintenance and safety precaution costs, as well as exposing authorities to potential liability claims.

2.3 The SPTC study

In response to existing and emerging pressures facing the SPTC, the City and its partners commissioned a study to further investigate the vulnerability of the SPTC and determine suitable short-term (five year time horizon)[1] remedial interventions (Cape Times 2012). Recommended solution(s) needed to be appropriate to meet a range of differing stakeholder values, not only between the various organisations involved in the study (as per their respective mandates) but critically also the interests of the general public and affected local communities.

Table 1. Stakeholders represented in the PMT for the SPTC study.

Stakeholder	**Department**	**Area of Expertise**
1	Environmental Resource Management (ERMD, City) – PMT Project Manager	Integrated coastal management, environmental planning and policy
2	Environmental Resource Management (ERMD, City)	Principal environmental officer, urban environmental planning and policy
3	Transport, Roads and Stormwater (City)	Managing transport infrastructure systems
4	Catchment, Stormwater and River Management (City)	Coastal engineering and hydrology
5	Western Cape Government, Transport and Public Works (Province)	Rail and transport safety, policy and implementation
6	Metrorail Cape Town, PRASA	Regional engineer

A consortium of organisations jointly funded and coordinated the study to be conducted by a contracted service provider. The consortium consisted of the City, the Western Cape Provincial Department of Transport and Public Works, and the Passenger Rail Agency of South Africa

[1] It has been acknowledged by the PMT that a more detailed and extensive resource economics study should be undertaken to determine the long term future (>25 years) of the rail and road infrastructure along the SPTC.

(PRASA). Representatives from each of the organisations were nominated to form the Project Management Team (PMT) responsible for funding, administering and guiding the SPTC study. Details of the PMT are given in Table 1; individual stakeholders are referred to throughout this paper by the number assigned in the left column.

2.4 Details of the SPTC study approach

The PMT jointly determined the terms of reference for the study, which consisted of two phases. Phase One focused on the current and future analysis of physical risks to the coastline, requiring the service provider to model trends in sediment dynamics, and other relevant climatic and non-climatic variables informing the risk profile of the SPTC in the short, medium and long-term (Worley Parsons 2013). Phase Two involved determining the most appropriate short-term management intervention(s) for the rail infrastructure at Glencairn Beach. These recommendations had to include site specific intervention designs, capital and operational costs, and, substantiation of the preferred intervention(s). In achieving this a multi-criteria assessment was undertaken to establish a consensus on the most appropriate way forward and to articulate the interests of the various organisations comprising the PMT.

The SPTC study will be followed by an in-depth Environmental Impact Assessment (EIA) that will incorporate public opinions on the suggested remedial interventions determined in phase 2. Only after this step has been completed, and funding agreed, will any solution(s) be implemented. The local communities continue to be engaged through regular meetings, providing information on the study and the broader decision process.

2.5 The multi-criteria evaluation matrix

The MCDA matrix used in the SPTC study was developed through a consultative process involving the stakeholders represented in the PMT. A preliminary meeting was held to introduce the concept of the matrix, discuss a set of essential decision criteria and suggest weightings that should be assigned to each criterion. The consulting firm provided the PMT with descriptions and photographs of the various response options for clarity, as well as a set of descriptions and considerations related to the decision criteria (see Tables S1 and S2, Supplementary Material). Whilst there was consensus within the PMT on the need to use weightings, there was disagreement on what values those weightings should take. It was resolved that the service provider would provide a first attempt at determining the weightings and then circulate a draft matrix to the PMT for general comment. In a follow-up meeting, comments and concerns from the PMT were discussed and subsequently a final matrix was drafted (in Microsoft Excel) for circulation and completion. The matrix required the stakeholders score each remedial intervention[2] against the set of agreed decision criteria based on an integer scoring scale; from one (worst) to five (best)[3]. The matrix automatically computed the weighted average score for each intervention and ranked them accordingly. In total, fourteen interventions were identified and each was assessed against nine decision criteria.

Six individual matrices were completed by the different stakeholders represented in the PMT (see Supplementary Material). The results of these matrices were averaged (on a score-by-score basis) and presented to the PMT in an aggregate combined matrix. This matrix was then discussed and formally included as part of the decision process. In order to assess both the subjective shortfalls in the matrix design and the robustness of the combined matrix to stakeholder assumptions, a sensitivity analysis was conducted. This analysis was not undertaken as part of original SPTC study but is included as part of our investigation (see section 3.2).

2.6 Evaluation matrix outcomes

The combined matrix results (Figure 2) show the average scores obtained for each option across the nine decision criteria. The final weightings (see top row, Figure 2) were applied and the weighted scores for each option are shown in the 'Total' column; the associated rankings are displayed in the final 'Ranking' column. The matrix incorporates responses from only five of the six stakeholders as one stakeholder did not submit a completed matrix in sufficient time to be included in the SPTC

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[2] Some members of the PMT were not familiar with all remedial interventions in the matrix. The PMT therefore requested the service provider for further information on each intervention to aid in the scoring process (see Figure S2, Supplementary Material).

[3] Note: MCDA approaches typically adopt a range of one to nine but it was the choice of the consultant Worley Parsons to adopt a one to five scoring scale.

study. However, in the interview process this stakeholder provided verbal support for the option ranked highest in the combined matrix; the sensitivity analysis presented in section 4.2 demonstrates the impact of including their scores.

The geotextile container revetment (see Figure S2, Supplementary Material) was the highest ranked option, followed by dune creation and stabilization, and then managed retreat. The detached breakwater (combined with beach nourishment) ranked lowest. No single option outperforms all other options across the different decision criteria. For example, while the geotextile container revetment is the best overall it has a lower score than six other options when assessed against the 'visual' criterion. Similarly, no single option is the worst performing option across all criteria. Despite the detached breakwater being ranked last it performs well when assessed for 'effectiveness', which is the highest weighted criterion. Some options receive similar scores for each criterion; the gabion wall option consistently scores threes and fours. Conversely, other options, such as raising infrastructure, span the range of possible scores across the different criteria. The matrix demonstrates that trade-offs are inevitable in this decision context and the remedial interventions considered most appropriate using this method are those that best achieve a balance across the different criteria.

Despite the general agreement among the PMT that something must be done to reduce the vulnerability of the transport infrastructure, the do nothing option is ranked equal seventh alongside beach re-profiling and the gravel/shingle beach berm. The value of including the do nothing option is discussed in more detail in section 4.1 and section 5, but it is important to highlight that by including this option the evaluation process identifies those options which are assessed to be worse than doing nothing and may therefore be deemed maladaptive; i.e. they risk increasing vulnerability and/or compromising the value of the existing coastline.

3. Methods

3.1 Interviews with stakeholders

The focus of this study is to draw insight from those involved in the SPTC project and to explore the value of the MCDA approach for promoting enhanced ICM, especially where ICM is not yet a dedicated competency within the City of Cape Town, nor any other local government in South Africa. In order to assess different perspectives on the value of the matrix approach and to elucidate the rationale behind the scores given by the different stakeholders, semi-structured interviews were held with five (out of six) PMT stakeholders in July and August 2013; the remaining stakeholder is an author of this paper and was therefore excluded from the interview process. Each stakeholder was asked a common set of questions relating to the details and functionality of the matrix as well as the overall value of the matrix for the SPTC study (see Supplementary Material). The interviews were transcribed and themes emanating from the interviews were identified. Key quotes signalling these themes are listed in the tables presented in section 4. The analysis draws on contrasting and shared views, and identifies key criticisms and suggestions for improving aspects of the matrix approach in future studies. Interview respondents are referred to as stakeholders for consistency with previous sections.

3.2 Matrix Sensitivity Analysis

A sensitivity analysis was undertaken to further examine the influence of the matrix assumptions on the decision outcomes. The analysis presented in section 4.2 consists of three components: individual stakeholder matrix outcomes; combined results when a specific criterion is removed; and combined results when the weighting of a specific criterion is doubled. Each remedial intervention is assigned a letter and the top four ranked options in the combined matrix are colour-coded for emphasis. The analysis also shows the combined ranking of the options when the sixth stakeholder's matrix is included.

4. Results

4.1 Interview data

4.1.1 Selecting and weighting the decision criteria

Table 2. Selected interview quotes relevant to the selection and weighting of decision criteria.

Stakeholder	Quote
2	You need some independent person that's neither an engineer nor an environmentalist

	to set out the criteria. Weighting them is the easy part, it's the setting up. I'd like to see the environmental components getting a better deal.
3	We would be looking to make sure that the maintenance, effectiveness and the resilience are high profile.
4	This thing is quite heavily weighted. The number of columns is slightly in favour of a softer solution.
4	All of them should be effective.
5	There was debate around the weighting of this, around effectiveness and constructability and obviously the issue of maintenance and cost, you cannot run away or shy away from this.
6	I am of the firm belief that you must try and engineer maintenance out as far possible.

The most common concerns raised by the stakeholders in the interviews relate to the selection of decision criteria and the associated weightings. While the consultation process sought consensus on the different criteria and weightings in the formulation and finalisation of the matrix (as debated in the PMT meetings), the interview data shows that the stakeholders had differing opinions about certain aspects of the final matrix.

One of Stakeholder Two's responses (Table 2) suggests environmental considerations should have played a more influential role, while Stakeholder Four held a contrasting opinion and believed that the matrix had been specifically designed and structured to favour "softer" options. Stakeholder Three thought that effectiveness and resilience ought to have central prominence and Stakeholders Three, Five and Six all recognised the importance of maintenance. The controversial nature of the weighting process was highlighted by Stakeholder 5 who stressed that no matter what opinions or institutional biases people had, the issue of maintenance and cost were of critical importance. Each of these responses reflects different values that strongly align with the 'core business' of each institution and department represented by the stakeholders. Balancing these alternative perspectives cannot be adequately addressed by simply averaging individually assigned weights. Rather it requires a more nuanced approach utilising forums that enable discussions about trade-offs.

Stakeholders largely agreed that the matrix must include both 'hard' and 'soft' decision criteria reflecting the broad range of engineering, social and environmental considerations. Yet some stakeholders commented that their personal and professional perspectives altered their views on which factors should be weighted most highly and thus receive the greater chance of selection. Stakeholder Four thought that effectiveness was a redundant measure to assess and that whatever option was selected must be implemented to achieve the desired effectiveness. This opinion presents a problem for an approach that uses relative weightings. If a certain criterion is deemed critically important, where failure to address it yields an unacceptable solution, then such an approach risks the prioritisation of undesirable options. To address this, some stakeholders commented on the need for a mechanism to identify and consider 'non-negotiable' criteria.

4.1.2 Scoring of possible remedial interventions

Table 3. Selected interview quotes relevant to the scoring of remedial interventions.

Stakeholder	Quote
2	We didn't need all those.
3	I'd rather have as many options as possible included so that we can actually make a professional and technical decision as to whether they should be there or not.
4	I would think if it was a non-starter it shouldn't be on the list.
4	On all of the scoring I generally tried to give ones and fives to try and kick things out, or kick one out and highlight another one.
5	In terms of collating all the scores, that's when the combinations come out. If you have to choose a combination, then you know your number one, and number two and you know that if you have a combination of those, you'll be fine.
5	Maybe it could have been better if they had some video clips so that you could also see the movement and, if there are people on the beach, how they are navigating the structures.
6	You need to give a number of options. But it's no use giving an option which you know is just a total non-starter.
6	No matter how cost effective a solution is, how visually pleasing, how it enhances the beach amenity, the effectiveness and all sorts of things, if it falls completely flat on any one of these items, like maintenance – if it is not a maintainable solution – then it doesn't work.

Whilst the options selected could all, in theory, be implemented, there was disagreement about whether or not all fourteen options ought to be included in the evaluation. Stakeholder Two didn't believe all of the options listed were worth considering but Stakeholder Three stressed the importance of keeping options open at this stage in the analysis. Stakeholder Six commented on the notion of a 'non-starter' (Table 3) and proposed an amendment to the matrix using a zero score to allow stakeholders to explicitly identify those options they believe to be completely unacceptable. This notion was supported by some, but not all, of the stakeholders. Stakeholder Four had a different perspective preferring instead to use the current scoring system to identify poor performing options. One of the unintended consequences of not including a zero score was that one stakeholder decided not to score some options on the basis that they were non-starters and two stakeholders scored the do nothing option with a 1 (implying worst) for all criteria (see Figure 3 and Supplementary Material).

Given that the final implemented solution could be a combination of options, the stakeholders were asked whether or not the matrix should have included further combinations, such as a geotextile container revetment combined with dune creation. In this instance the stakeholders were in agreement and expressed that there wouldn't be much benefit to considering combinations; this is despite the fact that the eventual solution proposed by the consultancy was a combination of different options (see section 5).

Stakeholders were asked about the level of detail provided by the service provider regarding each remedial option. Some stakeholders expressed their satisfaction with the descriptions and photographs provided but others felt that additional information would have been beneficial. The stakeholders with greater technical background were more confident in their ability to appropriately score the options as they were familiar with the technologies and designs. However Stakeholder Five, who had less working knowledge of coastal adaptation interventions, suggested that video clips of the options in use elsewhere (where possible) could have helped to illustrate the potential impacts of the options.

An additional concern was raised regarding the difficulty of quantifying the impacts of the various interventions for specific decision criteria (e.g. beach amenity, aesthetics and environment). Stakeholder Two stated that the scoring process was better for assessing engineering factors, that can be easily quantified (e.g. constructability and cost), than environmental factors which are typically more subjective. To address this, Stakeholder Two suggested that the PMT score each option against engineering and environmental considerations in separate matrices, and then integrate both with cost, creating a "level playing field" between engineering and environmental indices. This reflects the problematic nature of using a quantitative matrix approach for assessing options against criteria that can be interpreted in qualitatively different ways. A potential way to address this is to apply contingent valuation methodologies that encourages evaluation of the less 'easy to quantify' impacts after completing an initial matrix assessment. This however requires expertise beyond the engineering domain, an idea that Garmendia et al (2010) considers in the development of a MCDA that places emphasis on the social value and acceptability of solutions to achieve the objectives of ICM.

4.1.3 Outcomes of the matrix

Table 4. Selected interview quotes relevant to the outcomes of the matrix.

Stakeholder	Quote
2	We kind of made sure that the geotextile option came out first because that is what we wanted.
2	I was surprised about what came out second and third. I'm surprised managed retreat has come in so high.
6	The way it was scored must have been wrong.

In general, the stakeholders were not surprised that the geotextile container revetment ranked first. Inevitably there was discussion throughout the project about which options might be more suitable and the scoring process in the matrix simply provided a way to articulate preferences. Stakeholder Two commented that the matrix was scored to ensure the geotextile option ranked highly (Table 4), reflecting the wider preferences of the ERMD department. This was acknowledged as particularly problematic from a process perspective and highlights a risk of using formalised quantitative approaches to help explore a subjective decision space.

There was much more surprise about which options were the next highest ranked, demonstrating one of the more valuable features of the matrix approach in challenging preconceptions. The surprise was not only confined to the combined matrix results but also their own individual matrices. Stakeholder Two was particularly surprised about how well the option of managed retreat scored whilst Stakeholder Six was surprised to find that rock revetment came out as their third highest ranked option; on seeing this information, they assumed they must have made a mistake when scoring the option (Table 4). These examples illustrate the potential value in the matrix as a way to test personal expectations and assumptions in a logical and transparent manner. In addition, Stakeholder Three commented on the radical differences between the four highest ranked options voicing concern that the ordering was likely to be highly sensitive to the assumptions and scoring in the matrix. Indeed all stakeholders expressed an interest in understanding the sensitivities of the outcomes to the matrix structure and choices about the weighting. It was therefore deemed worthwhile to conduct a sensitivity analysis as part of this study (see section 4.2).

4.1.4 Benefits of the matrix approach

Table 5. Selected interview quotes relevant to the Benefits of the matrix approach.

Stakeholder	Quote
2	We have said all along that it isn't going to be the only decision-making element.
3	I thought it was very helpful because it allowed different people with different experience and different backgrounds to use a common approach.
4	It is a good consensus reaching tool.
6	You're not going to base your total recommendation on this but it's a good first order separation, or a first order ranking.

All stakeholders agreed that the matrix was a useful way to structure thought processes and to facilitate a dialogue across disciplines and institutes on the strengths and limitations of the possible remedial interventions. While some stakeholders acknowledged that this step formed only one part of the decision process, the common view was that the matrix helped in reaching a consensus agreement about the most appropriate options to take forward; Stakeholder Four reflected that the matrix was very useful as a "consensus reaching tool" (Table 5). Comments also reflected the notion that the evaluation process was inclusive and that each stakeholder was given an equal platform to articulate and represent their concerns; however this somewhat contradicts the emerging finding that not all views were adequately captured in the PMT group meetings. Stakeholder Three stated that the approach was useful for bringing together people with different backgrounds and technical expertise, a central principle of ICM. Some stakeholders also commented that the matrix was useful to maintain transparency in the decision-making process, enabling officials and the public to examine the steps that have been taken to reach a consensus agreement.

According to the City's decision-making process, as noted in section 2.4, the public will be consulted formally through an EIA after the vulnerability and modelling study has been completed, and various remedial interventions identified. Therefore local residential and business representatives were not asked to complete the matrix. When questioned about the possibility of including public participation in the population of the matrix, the stakeholders largely agreed that it would have been unwise to request local communities to comment on the technical aspects of the initial investigation. One stakeholder noted that while the local community must have a voice, there are only certain aspects that they can be expected to understand and express preferences on. Another stakeholder commented that the public will have other subjectivities but that most wouldn't have the technical knowledge to provide useful input for the initial investigation. Much of the literature on approaches to ICM and climate change adaptation stresses the importance of including local communities in adaptation planning but, as discussed by Few et al (2007), such inclusion can lead to tensions, particularly in cases of anticipatory planning where decision makers must consider the broader long-term context. In addition, as highlighted in the stakeholder responses, including additional stakeholders in the initial phases of local level decision processes places further demands on finances and human resources, and risks delaying the implementation of interventions.

4.2 Sensitivity analysis

No individual stakeholder ranks the options in the same way as the combined matrix ranking (see 'Individual Responses', Figure 3). In fact with the exception of the geotextile container revetment, which comes first in all but one of the stakeholder's matrices, there was widespread disagreement about the appropriateness of the other options; for example, beach drainage is ranked lowest according to Stakeholder One and Two while Stakeholder Five ranks this option second. As described in section 4.1.3, some stakeholders expressed surprise at these outcomes but despite the differences in the individual responses there was little debate in the PMT meetings about the combined matrix results. This may be because of the general consensus surrounding the geotextile container revetment but perhaps also because the stakeholders recognise the need for compromise given different perspectives.

Perhaps the most striking result of the sensitivity analysis is that when a specific criterion is omitted, or given double the weight, the top four ranked options remain the same top four ranked options, albeit in a different order. This set of remedial interventions therefore appears to be relatively stable and insensitive to the matrix assumptions assessed. Yet, as noted by Stakeholder Three, these four options are very different types of solution and, if implemented, would impact Glencairn Beach in highly contrasting ways. The sensitivity analysis therefore shows that if certain decision criteria were omitted or given increased weight then the recommended solution would imply very different impacts at Glencairn. When either cost or constructability is omitted, managed retreat becomes the highest scoring option. Clearly the implementation of this solution would have profoundly different impacts on the beach, infrastructure and local community than the geotextile container revetment. Cost and constructability are however recognised by all of the stakeholders as particularly important considerations and this is reflected in the weightings assigned to them. As such, considerations of cost and constructability played a significant role in shaping the outcomes of the matrix. The sensitivity analysis raises the prospect that if additional funds were available or perhaps if constructability was considered less important, managed retreat might have become the highest ranked option.

5. Discussion

Making coastal adaptation decisions is made difficult by the need to navigate a complex decision space comprising environmental, social, economic, cultural and political interests, in addition to technical considerations. This study also clearly demonstrates that decision making at the local level is subject to individual, departmental and institutional values. The decision process includes representation by stakeholders with different objectives, agendas, areas of technical expertise and decision making philosophies, so finding a solution that addresses the underlying risks while remaining sensitive to different stakeholder perspectives is a non-trivial process.

The matrix approach constitutes one step in this decision process but as highlighted by the stakeholders in section 4.1.4, it was considered useful for achieving a consensus. This view reflects the conclusions of other studies where MCDA approaches have been applied, as discussed in section 1, and demonstrates the value of using a formal analytical approach, even when there are project constraints and the number of stakeholders is relatively small. However this study shows that the approach has significant limitations. In particular, there are issues regarding the scoring process, the assumptions in the criteria selection and the associated weightings. The PMT meetings were used specifically as a platform to generate decisions based on a 'collective wisdom', thus representing the interests of the various stakeholders and accommodating their core business needs. However, as indicated in section 4.1.1, it was revealed that despite the opportunity for individuals to raise concerns at PMT meetings, contrasting views and unresolved queries persisted beyond the design phase of the matrix and which were only raised "behind closed doors". This raises an important issue from a process and transparency perspective. Were the stakeholders less willing to share opinions in a group setting, did stakeholders not appreciate the consequences of choosing different criteria and weightings until after the matrix had been completed, or did the stakeholders decide not to voice their concerns at PMT meetings because of an intimidating environment resulting from the perceived strength of knowledge emanating from other, perhaps more qualified or senior, 'specialists'? The risk of the latter is particularly prevalent across all three spheres of government (including parastatals) in South Africa where highly qualified consultants are appointed to address a shortage of capacity within these organisations. Although the MCDA framework put forward by Belton and Pictet (1997) aims to address these issues, it is particularly challenging to create an enabling environment that ensures knowledge transfer and facilitates open dialogue between stakeholders relating to coastal adaptation challenges, especially where resources and time is limited.

This research has highlighted challenges inherent in navigating decision processes across multiple institutions and stakeholders. The evidence gathered through engagement in this study suggests that a clear articulation of stakeholder views and values is essential prior to populating the matrix. However, the method of articulating such views requires careful consideration. Given the time constrains and scale of this local level project it may have been impractical to engage in a more in-depth and time consuming process to articulate different stakeholder views regarding the construction of the matrix but clearly there are limitations to collating these views in group settings.

The data from the interviews, and the individual matrix responses, reveal the commonalities and differences in the perspectives of different stakeholders. Options such as beach drainage and managed retreat came out either very well or very poorly depending on who was scoring the options. Also, while there was widespread support for the matrix approach, some people expressed clear dissatisfaction with certain elements and made suggestions on how it might be improved. In particular, there was disagreement about the weightings of 'soft' versus 'hard' criteria that was seen, by some, to have a significant influence on the outcome. There is clearly a weakness in applying a common scoring approach for those social and environmental criteria where the potential impacts of implementing interventions are not easily quantified, either in a relative or absolute sense. For example, and even with guidance text, aspects such as beach amenity will inevitably be interpreted in different ways and deciding on a single integer that quantifies impacts on beach amenity, and recognises the multiple uses and values of different users, is extremely challenging.

The interview data revealed that there were some differences of opinion in the structure and content of the matrix. However, the sensitivity analysis reveals that although the ordering of options in the combined matrix was subject to value judgments the top four ranked options were relatively insensitive to the matrix assumptions. In addition, there was consensus about some key aspects. None of the stakeholders thought it was worth considering combinations at this stage of the decision process. This is particularly interesting as the eventual solution proposed by the consultancy following this process was a combination of geotextile sandbags with dune creation and stabilisation at the northern end of the beach and an upgrade of the existing sea-wall on the southern end of the beach. The choice of these options was no doubt informed by the matrix outcomes but was also grounded in the physical realities and constraints imposed by the existing infrastructure and beach profile.

The queries and concerns of the various stakeholders regarding the structure and content of the matrix provides an indication of the interests, values and core business of each of the institutions represented by the stakeholders. As evidenced in section 4.1.3, some stakeholders used the matrix as a way to articulate their preferred option according to their institutional values and agendas. Creating an enabling environment that encourages a reciprocal understanding of different institutional values is therefore an important pre-cursor for developing the MCDA tool. In constructing and negotiating the elements of the matrix, the approach has the potential to help decision makers gain an understanding of institutional landscapes (and institutional idiosyncrasies) relevant to coastal decision making. Through an increased awareness of these landscapes, the approach helps to achieve the principles of ICM and collaborative governance, improving adaptation decision making at the local level.

There are also broader considerations relevant to our critique of the decision approach adopted in the SPTC study. Cooper and McKenna (2008) analysed case studies of coastal erosion management in the UK and applied an alternative approach to the conventional 'cost benefit analysis' when responding to coastal risk. While a cost benefit analysis is guided by economic considerations, a 'social justice' lens leads to an analysis that informs our understanding of the distribution of benefits and burdens within the everyday lives of people at every level of society (Dobson 1999, cited in Cooper and McKenna 2008). Cooper and McKenna (2008) argue that considering social justice arguments improve the decision-making process, concluding, "At the long-term and large spatial scale these social justice arguments (greatest benefit for greatest number of people) lend support to the goal of environmental sustainability, whereas at the short-term and small spatial scale they oppose it." In the SPTC study, where an intervention was sought for reducing vulnerability in the short-term – over the next five years – invoking a social justice lens raises questions about who will benefit and by what means. By using this planning time horizon and only consulting stakeholders who will be directly impacted by the intervention (i.e. the City, PRASA, the Department of Transport and Public Works, and eventually the local residents), the conclusions of Cooper and McKenna (2008) imply that there is a risk of implementing unsustainable solutions that may "lock in" environmental and socio-economic risks for future generations. Is there a need to expand the consultation process to a broader stakeholder base and at what point during the project phase does this become appropriate? How can such decision processes achieve long-term national and regional sustainability objectives whilst addressing short term interests at the local level, especially when damage to property and infrastructure from erosion is iminent?

Questions of sustainability are even more relevant when considering the uncertain nature of many of the driving factors. Physical climate change uncertainties, such as those associated with sea level rise (Church et al 2013), are clearly relevant to assessing the viability of different options and strategies. While the sensitivity analysis here focuses only on the assumptions in the scoring and weighting of options, a complimentary analysis examining the uncertainties in the driving factors could be relevant to inform decision makers; though these aspects are being considered in the SPTC study at other stages in the project. In the context of climate change, and consistent with the findings of Tobey et al (2010), there also needs to be greater understanding of how decisions made using such approaches affect the long-term resilience of the coastline. The results and methodology adopted in the SPTC study are likely to influence further coastal adaptation decisions in Cape Town and indeed across South Africa so it is important to reflect on these broader issues to understand the implications of using specific decision approaches.

The matrix approach investigated, and the data presented to illustrate the commonalities and differences in perspectives regarding the outcomes and value of this approach, is taken from only one real-world application and generalising to other situations is necessarily tentative. While this process resulted in general agreement about the preferred intervention and the value of the approach in building a consensus, under different circumstances the approach may not have been so widely supported. In this case the matrix served as a tool for discussion and the outcomes guided the service provider in their analysis of which remedial interventions were appropriate. Used as a guiding tool it seems likely that the matrix approach will be valuable in other contexts but based on our investigation, there are some possible amendments, detailed in section 6, that are worth considering.

6. Conclusions and Recommendations

For the City of Cape Town, the SPTC study represents a ground-breaking approach to integrated coastal risk management at the local municipality scale. The application of the evaluation matrix, as a relatively simple form of MCDA, was used to systematically assess and organise information and expertise from a range of stakeholders. The matrix helped to support a participatory and multidisciplinary approach, thus advancing from previous coastal risk decision methodologies which have relied almost exclusively on applying engineering expertise and criteria.

While the matrix approach enabled a multidisciplinary consensus for the most appropriate response, interviews with key stakeholders and a sensitivity analysis indicate that some adjustments could add further value to the approach. Using a PAR approach with representation from one of the PMT stakeholders in the analysis and co-authorship of this paper has enabled an introspective interrogation of the merger between science and local level decision making, helping to frame the following recommendations as outcomes of a reflexive process.

Our recommendations regarding the technical aspects of the matrix are:

1. Remove the "Total" and "Ranking" columns in the matrix when stakeholders are scoring the options. This would help to create a more honest scoring process, preventing stakeholders from tracking scores during the population of the matrix and modifying them to ensure specific outcomes.
2. Include a zero-score. This would help stakeholders to identify those interventions that are perceived to be unfeasible in a relative and absolute sense for a specific criterion, without affecting the aggregation process required for a combined matrix.
3. Adopt a consultative approach that highlights trade-offs in assigning weights to criteria rather than simply average individually assigned weights. The impact of the chosen weights should then be re-assessed in a sensitivity analysis following the completion of the matrix.
4. Provide a confidential feedback form during the design phase of the matrix. To avoid under-reporting of opinions regarding the details of the matrix (e.g. weightings), a more formal but discreet method for gathering opinions would be beneficial, rather than solely relying on feedback from PMT meetings that can generate an intimidating environment.

Our recommendations from a decision process perspective are:

1. Acknowledge that there is a range of difficult to quantify socio-environmental dimensions that require contingent evaluation exercises specific to the site. The outcomes of which must be used to identify the decision criteria and inform the weightings assigned to each criteria.
2. Create an enabling environment for iterative, reflexive and open dialogue during the development of the matrix. Principles of inclusivity and participation must be enabled through establishing suitable forums of discussion over sufficient periods of time to synthesise the different perspectives.

In adopting these recommendations the matrix approach could be improved for use in future local level coastal management and adaptation studies, and in promoting ICM in municipalities where the competency does not exist or where it is poorly implemented.

Our analysis provides evidence to help support the use and development of MCDA tools in coastal adaptation decisions at the local scale. However, further engagement with real-world planning decisions at the local level will enable a greater appreciation of the strengths and weaknesses of such approaches when used in practice.

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References

Ananda, J. and G. Herath. 2009. “A critical review of multi-criteria decision-making methods with special reference to forest management and planning.” *Ecological economics* 68 (10): 2535–2548.

BDLive. 2012. Business Day Live article, 11 December 2012: “Train plunges into Amanzimtoti River, while six die in Mpumalanga bridge collapse.”

http://www.bdlive.co.za/national/2012/12/11/train-plunges-into-amanzimtoti-river-while-six-die-in-mpumalanga-bridge-collapse

Belton, V. and J. Pictet. 1997. "A framework for group decision using a MCDA model: sharing, aggregating or comparing individual information?" *Journal of decision systems* 6 (3): 283–303.

Belton, V. and T. Stewart. 2002. *Multiple Criteria Decision Analysis: An integrated approach*. Norwell, Massachusetts, USA: Kluwer Academic Publishers.

Brundrit, G. 2008. *Global Climate Change and Adaptation: A Sea-Level Rise Risk Assessment. Phase five: Sea Level Rise Model.* City of Cape Town Working Paper.

Burkett, V. and M. Davidson. 2012. *Coastal Impacts, Adaptation, and Vulnerabilities: A Technical Input to the 2012 National Climate Assessment*. Cooperative Report to the 2013 National Climate Assessment, pp 150.

Burns, M., Barwell, L. and T. Heinecken. 1993. "Analysis of critical coastal processes affecting recreation and tourism development opportunities along the South-Western cape coastline." In *Tourism vs. Environment: the case of coastal areas*, edited by P. P. Wong (ed), 19–32. Boston, USA: The GeoJournal Library, Kluwer Academic Publishers.

Cape Times. 2012. Municipal Notices: Invitation to tender. Published August 10. Tender No: 47C/2012/13: provision of professional services to model sediment dynamics in False Bay and to provide recommendations for remedial options for the Glencairn railway line.

Cartwright, A. 2008. Global Climate Change and Adaptation. Phase three: Final Report, A Sea-Level Rise Risk Assessment. City of Cape Town Working Paper.

Cartwright, A., Brundrit, G. and L. Fairhurst. 2008. Global Climate Change and Adaptation. Phase four: Final Report, Sea-Level Rise Adaptation and risk mitigation measures for the City of Cape Town. City of Cape Town Working Paper.

Chen, H. 2011. "Uncertainty analysis in a GIS-based multi-criteria analysis tool for river catchment management." *Environmental modelling & software* 26(4): 395–405.

Chuenpagdee, R., Kooiman, J. and Pullin, R. 2008. "Assessing governability in capture fisheries, aquaculture and coastal zones". *Journal of Transdisciplinary Environmental Studies* 7(1): 1-20.

Church, J. A. et al. 2013. "Sea Level Change." In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F. et al (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA

Cicin-Sain, B. 1993. "Sustainable development and integrated coastal management." *Ocean & Coastal Management* 21(1–3): 11–43.

City of Cape Town. 2005. City of Cape Town's coastal zone management strategy, coastal zone management review and state of the coast Year two: Nov 2004 – Oct 2005. City of Cape Town Working Paper.

City of Cape Town. 2012. City of Cape Town coastal set-back delineation: method and process 2012. City of Cape Town Working Paper.

Colenbrander, D., Sutherland, C., Oelofse, G., Gold, H. and S. Tsotsobe. 2012. "Reducing the pathology of risk: developing an integrated municipal coastal protection zone for the City of Cape

Town." In *Climate Change at the City Scale: Impacts, Mitigation and Adaptation in Cape Town*, edited by A. Cartwright, S. Parnell, G. Oelofse, and S. Ward. Abingdon: Routledge.

Cooper, J. and L. McKenna. 2008. "Social justice in coastal erosion management: the temporal and spatial dimensions." *Geoforum*, 39: 294–306.

CSIR. 1987. Glencairn Beach Management Plan. Tech. Rep. OX/C/CSW2/2.

Cummins, V., O'Mahony, C. and N. Connolly. 2002. "Review of integrated coastal zone management and principles of best practice." Prepared for the Heritage Council by the Coastal and Marine Resources Centre, University College Cork, Ireland.

Daron, J. 2014. "Challenges in the use of a Robust Decision Making approach to guide climate change adaptation decisions in South Africa." *In press, Climatic Change.*

DOE. 1996. Coastal Zone Management - Towards Best Practice. Department of Environment, London, UK.

Few, R., Brown, K. and E. L. Tompkins. 2007. "Public participation and climate change adaptation: avoiding the illusion of inclusion." *Climate Policy* 7 (1): 46-59.

Garmendia, E., Gamboa, G., Franco, J., Garmendia, J. M., Liria, P. and M. Olazabal. 2010. "Social multi-criteria evaluation as a decision support tool for integrated coastal zone management." *Ocean & Coastal Management* 53 (7): 385–403.

Hajkowicz, S. 2008. "Supporting multi-stakeholder environmental decisions." *Journal of environmental management* 88 (4): 607–614.

Kiker, G., Bridges, T., Varghese, A., Seager, T. and I. Linkov. 2005. “Application of Multicriteria Decision Analysis in Environmental Decision Making.” *Integrated Environmental Assessment and Management* 1 (2): 95–108.

Kiambo, R., Coley, C., Francis, J., Amaral, M. and L. Hale. 2001. “Coastal management in the western Indian Ocean region: a capacity needs assessment.” Western Indian Ocean Marine Science Association Coastal Resources Center, University of Rhode Island

Kindon, S., Pain, R. and M. Kesby. 2008. “Participatory action research.” In *International encyclopedia of human geography*. Elsevier, Amsterdam, London. 90–95.

Lai, E., Lundie, S. and N. Ashbolt. 2008. “Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems.” *Urban water* 5(4): 315–327.

Mendoza, G. and H. Martins. 2006. “Multi-criteria decision analysis in natural resource management: a critical review of methods and new modeling paradigms.” *For Ecol Manage* 230 (1–3): 1–22.

Mosadeghi, R., Warnken, J., Tomlinson, R. and H. Mirfenderesk. 2013. “Uncertainty analysis in the application of multi-criteria decision-making methods in Australian strategic environmental decisions.” *J. Environ. Plann. Man.* 56 (8): 1097–1124.

Mukheibir, P. and G. Ziervogel. 2007. “Developing a municipal adaptation plan (MAP) for climate change: the City of Cape Town.” *Environment and Urbanisation* 19: 143–158.

Nicholls, R., Wong, P., Burkett, V., Woodroffe, C. and J. Hay. 2008. “Climate change and coastal vulnerability assessment: scenarios for integrated assessment.” *Sustainability Science* 3: 89–102.

Pasquini, L., Ziervogel, G., Cowling, R. and C. Shearing. 2014. "What enables local governments to mainstream climate change adaptation? Lessons learned from two municipal case studies in the Western Cape, South Africa." *Climate and Development* DOI: 10.1080/17565529.2014.886994.

Renn, O. and P. Schweizer. 2009. "Inclusive risk governance: concepts and application to environmental policy making." *Environmental Policy and Governance* 19 (3): 174–185.

Stojanovic, T., Ballinger, R.C. and C. S. Lalwani. 2004. "Successful integrated coastal management: measuring it with research and contributing to wise practice." *Ocean & Coastal Management* 47(5–6): 273–298.

Tadross, M., Taylor, A. and M. Johnston. 2012. Understanding Cape Town's climate. In Cartwright, A., Oelofse, G., Parnell, S. and Ward, S. (eds) Climate Change at the City Scale: Impacts, Mitigation and Adaptation in Cape Town, Routledge-Earthscan.

Thabrew, L., Wiek, A. and R. Ries. 2009. "Environmental decision-making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation." *Journal of Cleaner Production* 17 (1): 67–76.

Tobey, J., Rubinoff, P., Robadue Jr., D., Ricci, G., Volk, R., Furlow, J. and G. Anderson. 2010. "Practicing coastal adaptation to climate change: lessons from integrated coastal management." *Coastal Management* 38: 317–335.

Wang, J., Jing Y., Zhang, C. and J. Zhao. 2009. "Review on multi-criteria decision analysis aid in sustainable energy decision-making." *Renewable and Sustainable Energy Reviews* 13 (9): 2263–2278.

Whyte, W. 1991. *Participatory action research*. Sage Publications, Inc., CA, US. Vol 123, 247 pp.

Worley Parsons. 2013. Provision of professional services to model sediment dynamics in False Bay and to provide recommendations for the remedial options for the Glencairn railway line. Technical. Report 269990-00-CS-REP-0001.

Figures

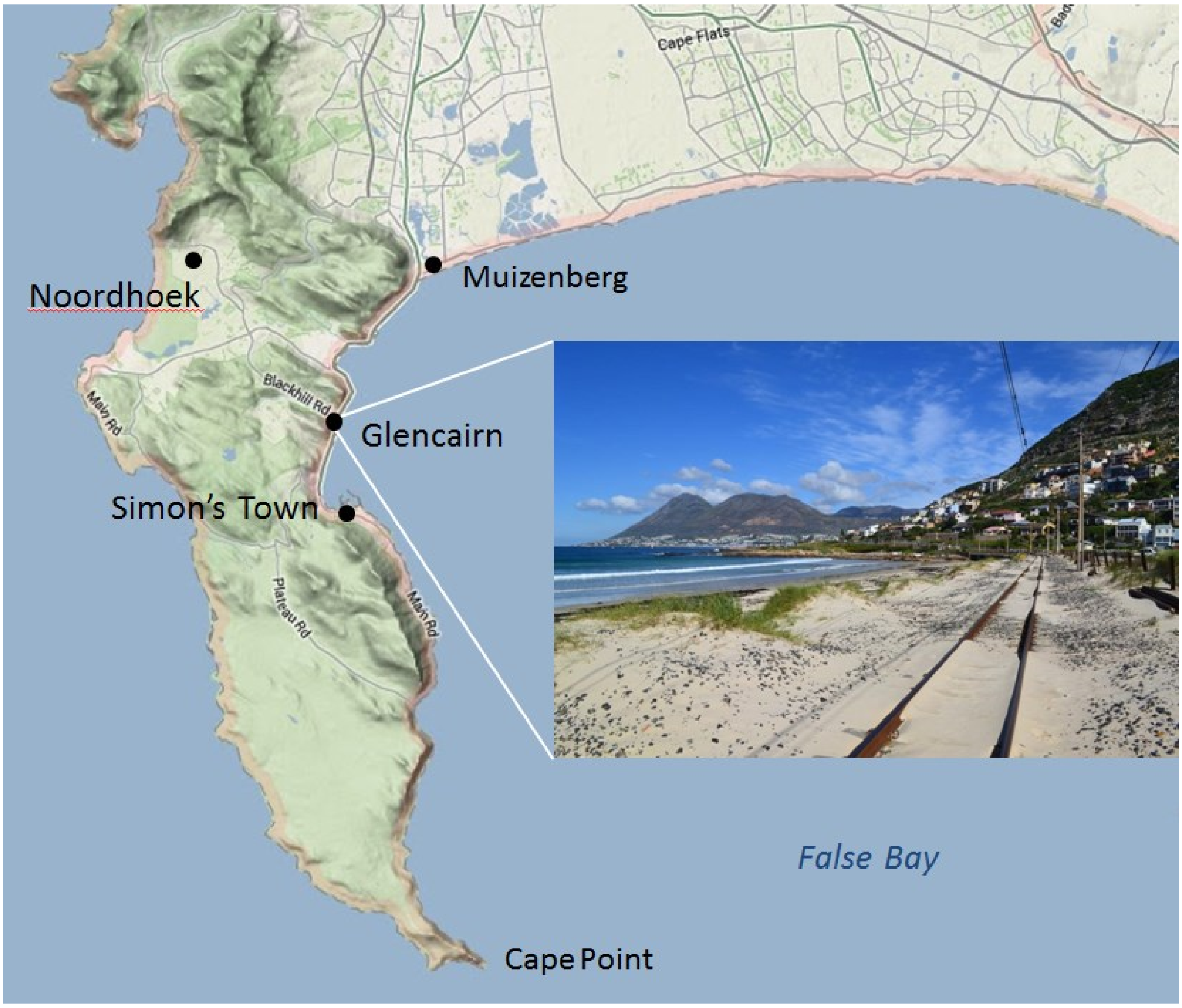

Figure 1. South Peninsula Transport Corridor: the railway and road at Glencairn Beach (Worley Parsons 2013) superimposed onto a map showing the location of the transport route along the east side of the peninsula from Muizenberg in the north to Cape Point in the south (Google Earth; AfriGIS Ltd; GeoEye, 2013).

Decision Criteria

Response	Visual	Cost	Environment	Adaptability/ Reversibility	Beach Amenity	Maintenance	Effectiveness	Constructability	Resilience	Total	Ranking
Weight (%)	5	15	10	10	10	15	20	10	5	100	
Do nothing	3	4	4	4	3	2	1	5	1	**2.9**	**7**
Beach re-profiling	4	3	3	5	4	1	2	4	2	**2.9**	**7**
Beach nourishment	5	2	3	5	4	1	2	2	3	**2.65**	**10**
Gravel/shingle beach berm	2	4	2	3	2	3	3	3	3	**2.9**	**7**
Dune creation and stabilization	5	4	5	4	5	3	3	4	3	**3.85**	**2**
Beach drainage	4	2	2	3	3	3	2	2	2	**2.45**	**13**
Geotextile container revetment	3	3	4	4	3	4	5	4	4	**3.9**	**1**
Groynes/Headlands*	2	2	2	1	2	3	4	1	4	**2.45**	**12**
Gabion wall	3	4	3	3	3	4	4	4	4	**3.65**	**4**
Detached breakwater *	2	1	2	1	3	1	4	1	4	**2.1**	**14**
Rock revetment	2	4	2	1	1	4	5	3	4	**3.2**	**5**
Managed retreat	5	1	5	4	4	4	5	2	5	**3.75**	**3**
Rasing infrastructure	5	1	3	1	2	3	4	1	4	**2.55**	**11**
Vertical seawall	1	3	3	1	2	4	5	3	3	**3.15**	**6**

1	Worst
2	
3	
4	
5	Best

**to be combined with nourishment*

Figure 2. Evaluation matrix used in the SPTC study containing the combined results of five stakeholders; the sixth stakeholder didn't provide a completed matrix in time for inclusion in the SPTC study. For each grid cell, the scores from the individual matrices (see Supplementary Material) were added together and divided by the number of respondents to provide a combined average.

Ranking	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Combined responses														
Combined (without Stakeholder Six)	G	E	L	I	K	N	D	B	A	C	M	H	F	J
Combined (all stakeholders)	G	E	I	L	K	N	D	N	B	C	A	H	J	F
Individual responses														
Stakeholder One	G	L	E	I	K	M	N	B	D	C	H	A	J	F
Stakeholder Two	G	L	I	E	B	K	N	A	D	C	M	H	J	F
Stakeholder Three	G	K	N	H	L	M	I	A	C	E	D	J	F	B
Stakeholder Four	E	L	A	G	I	D	K	N	B	C	M	F	J	H
Stakeholder Five	G	F	N	I	E	M	K	D	H	L	C	B	J	A
Stakeholder Six	G	I	N	E	K	D	H	J	F	A	C	B	L	M
Combined (without Stakeholder Six) responses with omission of one criterion														
No visual	G	E	I	L	K	N	D	A	B	C	H	M	F	J
No cost	L	G	E	I	N	K	B	M	C	D	A	H	F	J
No environment	G	E	I	L	K	N	D	B	A	C	F	H	M	J
No adaptability/reversibility	G	E	I	L	K	N	D	A	M	B	H	F	C	J
No beach amenity	G	E	I	L	K	N	D	A	B	M	H	C	F	J
No maintenance	E	G	L	I	B	A	K	N	C	D	M	H	F	J
No effectiveness	E	G	I	L	A	B	D	C	K	N	F	M	H	J
No constructability	L	G	E	I	K	N	D	B	M	C	A	H	F	J
No resilience	E	G	L	I	N	K	A	B	D	C	F	M	H	J
Combined (without Stakeholder Six) responses with doubled weight for one criterion														
Double visual	E	G	L	I	K	N	B	A	D	C	M	F	H	J
Double cost	E	G	I	L	K	N	D	A	B	C	F	H	M	J
Double environment	E	G	L	I	N	K	A	B	D	C	M	H	F	J
Double adaptability/reversibility	G	E	L	I	B	A	K	N	D	C	F	M	H	J
Double beach amenity	E	G	L	I	B	A	C	N	D	K	F	M	H	J
Double maintenance	G	L	E	I	K	N	D	A	B	M	H	F	C	J
Double effectiveness	G	L	E	I	K	N	D	B	C	A	M	H	F	J
Double constructability	G	E	I	L	A	B	K	N	D	C	F	M	H	J
Double resilience	G	L	E	I	K	B	N	D	A	C	M	F	H	J

Key: coding for the remedial interventions

A	B	C	D	E	F	G
Do nothing	Beach Re-profiling	Beach Nourishment	Gravel/Shingle beach berm	Dune creation and stabilization	Beach Drainage	Geotextile Revetment
H	**I**	**J**	**K**	**L**	**M**	**N**
Groynes/ Headlands*	Gabion Wall	Detached breakwater*	Rock Revetment	Managed retreat	Raising infrastructure	Vertical seawall

**to be combined with nourishment*

Figure 3. Sensitivity analysis of the evaluation matrix output used in the SPTC study. The different groupings correspond to different combinations of responses and weighting assumptions. The coloured options correspond to the top four ranked options in the combined matrix.

Supplementary Material

Figure S1. Ad hoc protection using old railway sleepers to prevent further erosion to the railway following a significant event in 2011.

Figure S2. Geotextile container revetment at Langebaan lagoon at the West Coast National Park, South Africa. Photograph taken 9 August 2013.

Figure S3. Glencairn beach when subject to strong south-easterly winds in summer. Photograph taken from Elsie's Point on 7 December 2013.

Criteria	Description/Considerations
Visual	• Overall acceptability and physical appearance (aesthetics)
Cost	• Capital cost • Cost effectiveness
Environment	• Accommodating environmental requirements • Potential environmental impacts during construction • Risk of vandalism • Potential environmental benefits of the scheme
Adaptability/Reversibility	• Removal of solution in future • Adaptability or change of area of solution over time
Beach Amenity	• Sandy beach area for recreational purposes • Facility of beach access • Health and safety (rip currents, rail crossing, etc.)
Maintenance	• Frequency and extent of intervention • Availability of suitable resources for repair (materials, plant, • expertise), if relevant • Expected maintenance costs and funding requirements • Accessibility for construction plant
Effectiveness	• Achievement of functional requirement (e.g. preventing erosion, retention of sand including beach width buffer, reducing wave overtopping) • Changes in acceptable probability of failure over time • Resistance to climate change
Constructability	• Health and Safety issues • Access of construction plant • Construction materials • Site area for storage of materials and operations • Vulnerability during construction (e.g. storm frequency)
Resilience	• Ability to recover after major storms • Ability to withstand sequence of significant storm events

Table S1. Description and considerations for criteria in evaluation matrix (reproduced from Worley Parsons, 2013)

Type of Intervention	Description
Do nothing	The "do-nothing" option would imply that the coastline at Glencairn would continue to be subject to inundation and erosion events.
Beach re-profiling	Beach re-profiling consists of mechanically moving sand from one area of the beach to another. In the Glencairn situation, sand would probably be taken from the lower beach or from the northern side and dumped along the southern (eroding) embankment providing a short-term buffer against wave attack during storms. This would cause some disruption to the natural coastal dynamics of the beach.
Beach nourishment	Beach nourishment or beach recharging can be defined as the importation of sand to an eroding beach. Sand can be delivered to the beach either by trucks or dredgers. There are several options for the placements of sand which can be within the surf-zone generating (or increasing) a sand bar, directly on the dry beach or a combination of the two. This additional sand will provide additional protection to wave attack as the waves will dissipate their energy before reaching the existing eroding area.
Gravel/shingle beach berm	The concept behind a gravel or shingle beach berm is to place large quantities of coarse material which is not easily mobilized by the action of waves, whilst providing a natural look to the beach. The gravel beach berm would not be statically stable (no movement) but would adjust to prevailing conditions (waves, water level, currents). This solution is relatively inexpensive when compared to hard structures and does not fail in the manner that can occur for hard structures.
Dune creation and stabilization	Dune creation can be viewed as either a stand-alone solution or a complementary measure (for example the creation of a dune over a revetment). In a similar manner to the beach nourishment, the creation of a dune will provide an additional buffer zone for protection of the coastline against wave attack. Any dune built in Glencairn would have to be stabilized by vegetation (sand and salt tolerant species) to avoid sand being blown by the characteristic strong winds. The vegetation on the dunes will need frequent irrigation. These dunes could also be preserved by the provision of fencing to prevent public access and the provision of dedicated walkways to facilitate access to the beach.
Beach drainage	The purpose of installation of beach drains is to lower the water table within the beach. As the swash generated by waves runs up on the beach the water is quickly drained out leaving any suspended sediment to accumulate on the upper beach. The main advantage of this system is that it is completely buried resulting in no visual impacts.
Geotextile container revetment	Geotextile containers of various sizes can be used to form shore-parallel or shore-perpendicular structures. The containers are typically filled on site using available sand from the beach. They provide an effective short-term solution and, when no longer required, can be ruptured, the sand dumped onto the beach returning to the natural system and the geo-container bags removed. At Glencairn a possible solution would be to build a revetment in front of the existing eroded embankment. These could be buried by sand.
Groynes/headlands (to be combined with nourishment)	Equilibrium bay-shaped beaches exist naturally and consist of beaches that are shaped by the wave action and its interaction with adjacent headlands. These beaches are bay shaped and can be in static (no sediment sources/sinks) or dynamic equilibrium. The development of such a solution in Glencairn would involve the construction of one or two artificial headlands/groynes connected to each of the existing natural rocky headlands. Beach nourishment would be required to obtain a stable beach.
Gabion wall	Gabions are composite structures generally comprising double-twist wire mesh baskets filled with hard durable stone. They are mostly used to construct retaining structures for scour protection, channel linings and weirs for hydraulic structures, and for erosion protection on riverbank revetments. Gabions may be combined with bio-engineering applications including vegetation, tree cuttings and grass mats to provide a more natural aspect. Gabions have been used for coastal protection in Cape Town for some time. Kommetjie beach is an example of a beach which is protected by a gabion wall.

Detached breakwater (to be combined with nourishment)	Offshore located breakwater parallel to the shore allows for variable level of protection along frontage. May allow some longshore sand transport.
Rock revetment	Rock revetments consist of shore-parallel rock structures designed to hold the coastline. These can be designed in layers of different rock sizes (acting as filters) or by a single rock size distribution (rip-rap), and can be constructed from a variety of materials including concrete and quarried armour stone. The sizing of these individual components is based on knowledge of the near-shore wave climate.
Managed retreat	Removing infrastructure and assets in a phased manner and retreating inshore, beginning with the most critically vulnerable infrastructure and assets.
Raising infrastructure	Increasing the height of the railway above sea level through infrastructural measures.
Vertical seawall	A seawall is a free-standing structure built parallel to the shoreline with the purpose of separating the land and water so as to protect against erosion and other wave induced damage. Seawalls are typically constructed from concrete or quarried stone, and can take a range of forms including a smooth vertical face, a stepped face or a curved face

Table S2. Description of the remedial interventions assessed in the evaluation matrix (reproduced from Worley Parsons, 2013)

Individual stakeholder matrices

Stakeholder 1

Type	Visual	Cost	Environment	Adaptability/ Reversability	Beach Amenity	Maintenance	Effectiveness	Constructability	Resilience	Total Score	Ranking
Weight (%)	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Do-nothing	3	1	4	4	3	1	1	5	1	2.3	12
Beach Re-profiling	4	2	4	4	3	2	3	4	3	3.05	8
Beach Nourishment	5	1	4	5	3	2	3	1	3	2.75	10
Gravel/Shingle beach berm	2	4	2	4	2	3	3	2	3	2.9	9
Dune creation and stabilization	5	3	5	5	4	3	3	4	4	3.75	3
Beach Drainage	2	1	1	3	3	3	2	2	2	2.1	14
Geotextile Container Revetment	4	4	4	4	3	4	5	4	4	4.1	1
Groynes/Headlands (to be combined with nourishment)	2	3	3	1	2	2	4	1	3	2.5	11
Gabion Wall	3	5	3	3	3	4	4	4	3	3.75	3
Detached breakwater (to be combined with nourishment)	2	1	2	1	2	2	4	1	4	2.15	13
Rock Revetment	2	5	2	1	1	5	5	5	3	3.65	5
Managed retreat	4	1	5	5	4	5	5	1	5	3.85	2
Rasing infrastructure	5	1	4	2	3	4	5	1	4	3.2	6
Vertical seawall	1	3	2	1	2	5	5	3	2	3.15	7

1	Worst
2	
3	
4	
5	Best

Stakeholder 2

Type	Visual	Cost	Environment	Adaptability/ Reversability	Beach Amenity	Maintenance	Effectiveness	Constructability	Resilience	Total Score	Ranking
Weight (%)	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Do-nothing	3	5	3	5	3	1	1	5	1	2.9	8
Beach Re-profiling	4	4	3	5	5	1	1	5	1	3	5
Beach Nourishment	5	2	3	5	5	1	1	3	1	2.55	10
Gravel/Shingle beach berm	1	4	2	3	2	2	2	4	2	2.55	9
Dune creation and stabilization	5	4	5	5	5	2	1	4	2	3.35	4
Beach Drainage										0	14
Geotextile Container Revetment	3	3	4	5	4	4	5	5	5	4.25	1
Groynes/Headlands (to be combined with nourishment)	2	1	2	1	2	3	3	1	3	2.05	12
Gabion Wall	4	3	2	3	3	4	4	4	4	3.45	3
Detached breakwater (to be combined with nourishment)	1	1	3	1	2	1	3	1	3	1.8	13
Rock Revetment	1	2	1	1	1	5	5	3	5	2.95	6
Managed retreat	5	1	5	5	5	3	4	1	5	3.5	2
Rasing infrastructure	5	1	2	1	2	3	3	1	4	2.25	11
Vertical seawall	1	2	1	1	1	5	5	4	3	2.95	7

Stakeholder 3

Type	Visual	Cost	Environment	Adaptability/ Reversability	Beach Amenity	Maintenance	Effectiveness	Constructability	Resilience	Total Score	Ranking
Weight (%)	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Do-nothing	5	5	5	3	1	1	2	5	1	3	8
Beach Re-profiling	5	1	3	5	4	1	1	5	1	2.5	14
Beach Nourishment	5	3	3	5	4	1	2	4	1	2.9	9
Gravel/Shingle beach berm	3	2	3	4	3	2	2	4	2	2.65	11
Dune creation and stabilization	4	2	3	4	4	2	2	3	2	2.7	10
Beach Drainage	5	1	4	4	5	1	2	2	2	2.55	13
Geotextile Container Revetment	4	2	4	3	4	3	4	4	3	3.4	1
Groynes/Headlands (to be combined with nourishment)	3	1	3	2	5	2	5	4	4	3.2	4
Gabion Wall	3	2	3	3	4	2	3	5	3	3	7
Detached breakwater (to be combined with nourishment)	2	1	3	2	5	1	3	4	4	2.6	12
Rock Revetment	3	3	3	4	3	3	3	4	4	3.25	2
Managed retreat	5	1	3	1	5	2	5	4	4	3.2	4
Rasing infrastructure	4	1	4	1	5	2	4	4	4	3.05	6
Vertical seawall	4	2	3	2	5	3	4	3	4	3.25	2

Stakeholder 4

	Weight (%)										
	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Type	**Visual**	**Cost**	**Environment**	**Adaptability/ Reversability**	**Beach Amenity**	**Maintenance**	**Effectiveness**	**Constructability**	**Resilience**	**Total Score**	**Ranking**
Do-nothing	4	5	4	3	3	5	1	5	1	3.45	3
Beach Re-profiling	4	3	3	5	4	1	2	4	2	2.9	9
Beach Nourishment	5	2	2	5	4	1	2	3	4	2.7	10
Gravel/Shingle beach berm	3	4	3	3	2	3	3	4	3	3.15	6
Dune creation and stabilization	4	4	5	3	5	3	4	4	3	3.9	1
Beach Drainage	5	2	2	3	3	2	2	2	2	2.35	12
Geotextile Container Revetment	3	3	3	4	2	4	4	3	4	3.4	4
Groynes/Headlands (to be combined with nourishment)	1	1	1	1	2	1	4	1	5	1.9	14
Gabion Wall	3	4	4	3	2	3	4	3	4	3.4	5
Detached breakwater (to be combined with nourishment)	2	1	1	1	4	1	4	1	4	2.1	13
Rock Revetment	2	4	3	2	1	3	4	2	5	3	7
Managed retreat	5	2	5	1	3	3	5	4	5	3.55	2
Rasing infrastructure	4	1	4	1	2	2	4	1	4	2.45	11
Vertical seawall	1	3	3	2	4	2	4	2	4	2.9	8

Stakeholder 5

	Weight (%)										
	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Type	**Visual**	**Cost**	**Environment**	**Adaptability/ Reversability**	**Beach Amenity**	**Maintenance**	**Effectiveness**	**Constructability**	**Resilience**	**Total Score**	**Ranking**
Do-nothing	1	1	1	1	1	1	1	1	1	1	14
Beach Re-profiling	3	1	4	2	4	2	1	2	2	2.1	12
Beach Nourishment	3	1	4	2	4	1	2	3	2	2.25	11
Gravel/Shingle beach berm	3	3	4	3	2	2	4	4	4	3.2	8
Dune creation and stabilization	4	4	4	4	4	2	3	3	3	3.35	4
Beach Drainage	3	3	3	5	3	4	4	4	4	3.7	2
Geotextile Container Revetment	3	4	4	4	3	4	4	4	4	3.85	1
Groynes/Headlands (to be combined with nourishment)	3	2	2	2	3	4	3	3	3	2.8	9
Gabion Wall	2	4	2	4	2	3	4	4	4	3.35	4
Detached breakwater (to be combined with nourishment)	2	1	1	2	1	2	4	2	3	2.1	13
Rock Revetment	1	3	3	3	1	4	4	4	4	3.2	7
Managed retreat	4	1	3	2	4	3	3	3	3	2.75	10
Rasing infrastructure	3	2	3	3	4	3	4	4	3	3.25	6
Vertical seawall	2	4	2	4	2	5	4	4	3	3.6	3

Stakeholder 6

	Weight (%)										
	5%	15%	10%	10%	10%	15%	20%	10%	5%	100%	
Type	**Visual**	**Cost**	**Environment**	**Adaptability/ Reversability**	**Beach Amenity**	**Maintenance**	**Effectiveness**	**Constructability**	**Resilience**	**Total Score**	**Ranking**
Do-nothing	1	1	1	1	1	1	1	1	1	1	10
Beach Re-profiling						1				0.15	12
Beach Nourishment							1			0.2	11
Gravel/Shingle beach berm	2	2	1	4	1	2	3	5	2	2.5	6
Dune creation and stabilization	3	1	4	3	3	1	4	3	1	2.6	4
Beach Drainage	5	1	1	1		1	1	2	2	1.25	9
Geotextile Container Revetment	3	1	4	4	4	4	5	4	4	3.7	1
Groynes/Headlands (to be combined with nourishment)	2	2	2	2	2	2	2	2	2	2	7
Gabion Wall	2	1	4	4	4	4	5	4	4	3.65	2
Detached breakwater (to be combined with nourishment)	2	1	1	2	3	2	2	3	2	1.95	8
Rock Revetment	1	2	1	3	2	2	4	3	4	2.55	5
Managed retreat										0	13
Rasing infrastructure										0	13
Vertical seawall	1	1	1	3	1	5	4	2	4	2.65	3

Guiding questions for stakeholder interviews

Questions focus on two areas:

A. Details of how the evaluation matrix was used in the Glencairn study
B. Strengths/limitations of evaluation matrices for informing adaptation decisions

Part A

1) What are the primary objectives to be met in the Glencairn study?

2) What would you state as the most important factor(s) to be included in the evaluation matrix and why?

3) Do you consider any of the adaptation options listed as "non-starters"?

   - If so, why?

4) Do you think the preferred option has limitations and if so what are they?

5) Do you think weighting the individual factors is a sensible approach, and what would you assign the highest weighting to?

6) How challenging was it to assign quantitative values in the matrix, and why?

7) Did the matrix support the consideration of combinations of options?

8) Did the outcome of the evaluation matrix surprise you?

9) When considering the cost implications of doing nothing in response to the protection of the rail, what time frame did you apply and why?

Part B

1) Do you think that an evaluation matrix is a useful way to navigate the decision making process and why?

2) What alternative approaches could/should have been used to inform the selection of adaptation options?

3) How do you think the City of Cape Town will use the outcome of the evaluation process?

4) Has this process adequately addressed your needs and interests?

References

Worley Parsons. 2013. Memorandum for project 269660 – Glencairn Coastal Erosion: Coastal Protection Evaluation Matrix. Technical Report 269660-00-CS-DSP-001.