GENERATING ALTERNATIVE ALIGNMENTS IN TERRAIN SUITABILITY STUDIES FOR ENVIRONMENTAL IMPACT ASSESSMENTS OF LINEAR DEVELOPMENTS

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ABSTRACT

The construction of linear developments, such as roads, railways, pipelines and power lines, in South Africa requires a number of alternatives to be considered prior to the submission of a proposed development for an Environmental Impact Assessment (EIA). Though legislation requires a screening or scoping of alternative options prior to the EIA, the use of Geographical Information Systems (GIS) is seldom used in generating alternatives through a Terrain Suitability Study (TSS).

The inclusion of a wide variety of specialist in a TSS could ensure a well informed choice of alternatives for the EIA and a choice of optimum corridors, could result in cost savings. This may in turn avoid delays during the EIA process if routes were rejected completely by the public and have to be rerouted and new specialist studies done.

This study investigates the benefits of generating alternative corridors in a TSS as part of the preplanning phase of an EIA. The inclusion of a number of specialists and environmental aspects are discussed to ensure a democratic and participative process. Methods for generating alternatives using GIS, are also described. The results are shown to demonstrate how the alternatives were voted for by the specialists and recommendations made on improvement and proceeding into the EIA.

Overall the project was found to be beneficial to the client as part of the preplanning phase of an EIA. Benefits included the increased awareness and understanding of all environmental aspects involved in an interdisciplinary approach to corridor selection. The open and explicit process that was followed ensured an audit trail was documented for the selection of alternative corridor options. Increasing the number of options through a GIS TSS enabled the comparison and voting for feasible preferences. The TSS is furthermore changeable and repeatable, though the availability, scale and accuracy of geospatial data may impact on the success of using GIS to create alternative options.

This study demonstrated the value of a TSS prior to an EIA in South Africa, and hopefully internationally, to motivate the benefits of doing a TSS as a general practice prior to an EIA.

* Owing to the sensitivity of the project, no reference is made to the company or location of the linear development.

Keywords: TSS, linear developments, generating alternatives for EIA, multi-criteria analysis

INTRODUCTION

The Department of Environmental Affairs & Tourism (DEAT) recently published regulations for Environmental Impact Assessments (EIAs) in South Africa require the inclusion of alternatives for linear activities in basic assessments and scoping reports (DEAT, 2010: Chapters 3, Part 2:22(h) and Part 3:28(j)) and a comparison of alternatives during the EIA process (DEAT, 2010: Chapters 3, Part 3:31(i)). The regulations focus primarily on the impact the linear activity would have on the environment, and not on identifying the alternatives that are the least intrusive on the environment. It is further argued that these regulations do not provide practitioners and developers with enough guidance with regards to generating alternative location choices. Inclusion of Terrain Suitability Studies (TSS) and the use of geospatial data could fulfil this role and could avoid unforeseen cost of redesign during the EIA process.

Ideally, corridors selected for development of linear features (e.g. power lines, pipelines or roads) should be geotechnically suitable, be least intrusive from the broadest environmental perspective, result in minimum mitigation measures, be economically viable (*i.a.* through minimizing line length and development costs), socially responsible and minimise risk. Providing alternative corridors during the preplanning phase of a development would ensure that feasible alternatives are generated, motivated and prioritised, prior to a full Environmental Impact Assessment (EIA).

A TSS combines a set of geospatial data into a single layer, indicating various classes of combined terrain suitability for a specific purpose. Each layer is first ranked according to a consistent scale based on its suitability for the intended purpose. In some instances, data layers are combined with equal importance into a final layer reflecting the impedances the terrain presents to the proposed development, while in other instances each layer is weighted according to the significance of its impedance to the development. Geographical Information Systems (GIS) now easily provide the means for automating geospatial data analysis through the ranking and combining of terrain layers into impedance data sets and to generate alternatives for consideration (Moreno and Siegel, 1988; Jankowski and Richard, 1994; Joerin *et al.*, 2001; Malczewski, 2006). It should therefore be easy to perform a TSS as part of the preplanning phase of an EIA.

Benefits of Terrain Suitability Studies in preplanning for an EIA.

Simply stated, TSSs are geospatial multi-criteria analyses (MCAs) that identify an optimum route or routes suitable for a linear development (Moreno and Siegel, 1988; Jankowski and Richard, 1994; Joerin *et al.*, 2001; Piantanakulchai, 2005; Malczewski, 2006). Anavberokhai (2008:12) presented the advantages of MCA as an ‘open and explicit’ process with an ‘audit trail’ that can be reviewed, changed and repeated. Further they provide a means of communication between the community, decision makers and interested and affected parties (I&APs); which can be done prior to fieldwork as a desktop study using software, thereby minimising costs and initial time spent in the field. Field visits may therefore become more focussed, with only certain areas targeted which results in a reduction in costs. Aside from the cost savings on fieldwork, Feldman *et al.* (1995) found that a least cost pathway (LCP) can be cheaper than a straight line pathway: in this study the straight line pathway was 9 km shorter than the LCP, but 14 % more expensive in terms of construction cost.

An interdisciplinary approach in TSS is preferred in participatory processes and decision making (Malchewski, 2006). Concerns against the inclusion of a number of experts from disparate disciplines may lead to the normative effect in the decision-making process

(Banuelas and Antony, 2004). Bryson (1996) however concluded that electronic information communication reduces the normative effect. Banuelas and Antony (2004) agree though, that the selection of a group of subject-matter experts is vital for the success of the technique. The consideration of a selection of experts from different disciplines and the use of a wider set of geospatial data in the generation of corridors would ensure that all bases are covered and that the decision maker or client is well informed and prepared for the EIA. The inclusion of interdisciplinary experts was found to be successful in a number of linear developments (BP, 2002; Georgia Transmission, 2009). Other studies mention the generation of alternative corridors; though they do not always mention methods used for generating corridors or rules of combination in impedance layers (Van der Merwe, 1997; Moreno and Siegel, 1988).

Using GIS and geospatial data in a Terrain Suitability Study

The generation of alternative corridors as part of the preplanning process is valued by some and is seen as a major weakness or gap in current decision-making processes (Moreno and Siegel, 1988; Jankowski and Richard, 1994; Zhang and Armstrong, 2008). The importance of a proper preplanning, before an Impact Assessment (IA) is strongly motivated by Dey (2002). Without the study of alternatives prior to the IA phase and construction phase, a few problems may occur including rerouting that may add to financial costs incurred in the project and the possible revision of routes during the these phases. In the worst cases statutory approval is granted before the public participation process which may result in the resubmission of alternatives required during the EIA, and having to revise specialist studies, with unnecessary cost implications. Further implications as a result of improper preplanning, may result in difficulties in maintenance and additional costs owing to improper planning (*e.g.*, corrosion, leaks, lower capacity of throughput; rerouting owing to increased risk associated with nearby mining activities). A TSS could provide possible options in a larger region to be considered, with evidence and motivation of choice and therefore potentially minimising deviations, risk and unforeseen costs during the EIA.

A great variety of TSS and MCA methodologies have been developed since the initiation of terrain suitability studies by McHarg (1971). The generation of alternative corridors for linear activities is also a challenge in TSS. Typically this is undertaken by experts and only a limited number of alternatives are identified. Usually these alternatives are routes or alignments and not corridors. Furthermore, while GIS is rarely used in the generation of alternative corridors, linear activities planned in unknown areas, areas that people have an emotional association with and/or which cross international borders, may benefit from using GIS in a TSS to indentify least intrusive corridors at a regional scale (Madison, 1991; Jankowski and Richard, 1994; Van der Merwe, 1997; Bailey, 2003). Particularly in linear developments, alternative corridors or routes are selected based on a number of criteria, including the option to follow existing infrastructure or fences; avoiding cultivated and built up areas; favouring the shortest geotechnically sound or least cost routes; or a selection based on intermediate and destination points; the one which has the least financial cost or politically acceptable routes (Madison, 1991; Feldman *et al.,* 1995; Dey, 2002; Luettinger and Clark, 2005; Colt Engineering; 2009).

Where GIS has been used to integrate ranked layers from a variety of disciplines, a least cost path (LCP) analysis is used to identify the shortest route based on the impedances set. This method does not generate corridors, and only calculates one part for an impedance layer as not all options are considered. Typically two approaches are used for the generation of LCP based alternatives: the first approach attempts at creating a number of impedance layers and then runs a LCP for each: the second is to iteratively run modified shortest path algorithms on the same impedance surface (Martin, 1987; Zhang and Armstrong, 2008). Zhang and Armstrong (2008) recognised that the generation of corridors may have properties similar to genetic operators such as ‘reproduction, crossover, and mutation’ (Zhang and Armstrong, 2008:153) and therefore developed a new approach named Multiobjective Genetic Algorithms (MOGA) which recognise the possibilities of generating alternatives that may overlap with alternatives.

The use of GIS in the generation of impedance layers and alternative corridors can only be successful if sufficient geospatial data is available for the use of the technology in a TSS. In developing countries such as South Africa the availability, scale and accuracy of geospatial data is one of the greatest limitations in conducting TSSs. Often data is only collected during the EIA process and only available at regional scales, whereas fine-scale data is essential for each stage of the process. Examples include a lack of complete and accurate regional scale wetland delineation, salinity information for cathodic protection planning, channel width to determine costs of crossing, regional to fine-scale soil data, erosion potential or location of dongas / erosion gullies, ecological sensitive areas and complete heritage data sets.

In a linear development study in South Africa, which previously experienced the risks of minimum alternatives in an EIA, a TSS was done during the preplanning to improve on the motivation for and selection of corridors.

The project aimed to generate a number of alternative corridors which would be evaluated by an interdisciplinary team of experts. The experts could then prioritise corridors for the next phase in preplanning which would entail obtaining more fine-scale geospatial data and route planning. The advantages of a TSS and the options and limitations as discussed above were carefully considered during the TSS, and some new initiatives taken to improve on the limitations where possible.

The aim of the project was therefore to use a TSS in the preplanning of a new EIA to ensure the generation of a number of feasible alternatives and the prioritisation of these as motivated by the specialists.
The objectives included:

- Ensure defensible well researched alternative corridors are generated in the preplanning process that would comply with relevant RSA legislation,
- That the process of corridor generation is a democratic participative process with a wide variety of representative discipline experts;
- Exploit the use of GIS and geospatial data as part of a TSS in the preplanning process.
- The specialists advise and vote for the preferred alternative corridors to be used for route design prior to the EIA.

MATERIALS & METHODS

Aspects which are considered essential in certain EIAs in South Africa (DME, 2006), were presented for consideration. Seven of these could be geospatially represented and therefore acceptable for use in the preplanning phase. Additional aspects which have legal implications were also included as aspects. The final list is shown below.

- Geotechnical suitability
- Dongas and gullies (erosion potential)
- Freshwater areas to avoid (including wetlands which may be obstructive for routing or have design implications)
- Ground water dependencies
- Depth to ground water

- Ecologically unsuitable areas (including wetlands from an ecological perspective)
- Cultural and palaeontological heritage sites
- Transport and other infrastructural constraints
- Social land use
- Land ownership
- Social perception (reputation risk)

One of the first steps considered essential in this TSS was the selection of experts, who would represent the above-listed aspects, to participate in specialist workshops. The experts included geotechnical engineers, a freshwater specialist, geohydrologists, an ecologist, heritage specialists (an archaeologist and palaeontologist), transport engineers, social experts and geo-information specialists. In the first workshop the specialists were provided with background information to the development, where they had the opportunity to query the client on any issue and were given an overview of TSS concepts. During this meeting the selection of aspects was also discussed. In this paper, the term "aspect" is used to refer to an environmental aspect, which is considered a characteristic or feature of the environment through which the development could potentially pass through. Environmental aspects that could be represented geospatially, were called 'criteria'. Non-spatial issues were addressed in later phases of the preplanning.

After discussion, a number of environmental aspects were listed as 'opportunities' in the landscape, where the linear feature development would have the opportunity to cross obstructive areas; these include:

- Freshwater crossings such as bridges or existing infrastructure crossing rivers
- Transport alignment (*i.e.* servitudes) and existing crossings (e.g. a bridge over a railway line)
- Areas parallel to a historic railway line (which yielded the required slope for the development already).

In preparation for the second workshop, each specialist was asked to collect relevant literature and geospatial data based on the criteria to be included in the TSS. Criteria had to be ranked according to the 9-point continuous scale used (see Table 1) often used in the Analytical Hierarchy Process (AHP) (Saaty, 1990). They also had to consider whether or not each criterion was negotiable (remediation or pay-offs are possible), or non-negotiable (serious or significant implications). The geotechnical considerations and slope was in this linear development considered as a non-negotiable category, as the costs increase immensely should the alignment cross unsuitable areas. For the negotiable category, two possibilities existed: some of the negotiable criteria posed site constraints to the development passing through the landscape (*e.g.*, road surfaces), whereas others provided opportunities for alignment (opportunities), such as bridges crossing a river or in some instances, transport servitudes.

Table 1: The 9-point continuous ranking scale used in the terrain suitability study.
(This was used to rank classes of criteria according to their suitability for the construction and operation of the linear development.)

9	7	5	3	1	1/3 or -3	1/5 or -5	1/7 or -7	1/9 or -9
Extremely suitable	Very suitable	Strongly suitable	Moderately suitable	Equally suitable	Moderately unsuitable	Strongly unsuitable	Very unsuitable	Extremely unsuitable

The second specialist workshop was an in depth discussion of all the criteria with the client, the geotechnical engineers who were designing the final routes, specialists appointed for each environmental aspect, environmental practitioners and some I&APs,

totalling between 30 – 40 people. Following presentations by the specialists with their motivation of the proposed criteria and ranks, consensus had to be reached by the group on whether the criteria were appropriate, whether they were negotiable or not, whether there were other opportunities, information or legislation not addressed in the presentation, and whether the final classes of suitability and the ranks of each environmental aspect were acceptable (see for example Table 2). Incompatibility of environmental aspects was addressed ensuring no duplication of criteria or the creation of unrealistic interdependences.

Table 2: Ranks assigned to slope steepness classes in terms of suitability for the construction and operation of the linear development.

Slope degree classes	Rank	Ranks explained
0 - 6.8°	9	Extremely suitable
6.8 - 8.5°	7	Very suitable
>8.5°	1	Equally suitable
Large dam	-9	Extremely unsuitable

On the second day of the workshop when agreement was reached on the selection of criteria, classes and ranks, the rules for combining the spatial data layers were presented to the specialists. The specialists agreed unanimously to make use of the prevailing ranks combination rule. In the prevailing ranks combination rule, the highest suitable rank (e.g. 9) is retained for opportunities and the lowest unsuitable rank (e.g. -9) for constraints.

In an attempt to avoid the combination of unrelated disciplines, the grouping of criteria were discussed, keeping in mind that a number of impedance layers should be created in order to increase the creation of a number of corridors. The participants agreed to the following grouping of criteria: The geotechnical aspect was considered a non-negotiable site constraint and a separate impedance layer and corridor was created for this aspect. Physical site constraints were then chosen as a second option in the creation of an impedance layer and corridor, combining the water, ecology, agriculture, infrastructure and heritage (cultural and palaeontological) layers. A third option was the combination of physical opportunities. The last two options were social site constraints and social opportunities, as these are less absolute and based more on perceptions.

The workshop was followed by the spatial data manipulation tasks and the identification of alternative corridors using impedance rasters and the use of LCP tool to create a set of alternative corridors. This resulted in only five corridors, and to increase the number of options, a second set of layers were created from the same initial five layers, where impedances of protected areas were significantly increased. A straight-line distance was also added for comparison and all potential alignments were buffered by 40 m to create corridors. In total, eleven corridors were generated and considered.

The percentage area for each rank of an environmental aspect was calculated as a total of the corridor surface area and listed in a table for each specialist to consider (see Table 1). Based on these percentages, specialists were required to evaluate the alternative corridors for their particular aspect in a report and identify those with the least impact. The integration of the specialist reports and selections was based on a voting strategy, similar to the mentioned employed by Jankowski *et al.* (1997). Each specialist recommended a number of preferred corridors in their report. The preferences were combined, summarised in a table and sent back to the specialists to comment on in their final report, indicating the implications of these corridors for their particular environmental aspect. The preferred corridor selections therefore had traceable rationale for preferences, with initial perceived risks and pay-offs documented. The total number of votes, one per aspect and per specialist, were added together and listed as the preferred corridors for further investigations.

RESULTS

The percentage surface area of aspect that is suitable (ranks 1 – 9) or unsuitable (ranks -1 to -9) is listed per corridor option in Table 3. Most of the alignments had suitability rankings of 1 or 3 for the Geotechnical aspect (as an example, refer to Appendix A for the full table), and for other environment aspects, mostly had areas that were extremely suitable (rank 9) including freshwater, heritage and palaeontology. The statistical information of Table 3 has been summarised in Table 4 and was used during the voting process.

Table 3: Percentage area for each rank of suitability for the Geotechnical environmental aspect as a total of the surface area of each corridor option.

		% of total surface area of the corridor													
Suitability rank	**Environmental aspect**	**Option 1a**	**Option 1b**	**Option 2a**	**Option 2 b**	**Option 3a**	**Option 3b**	**Option 4a**	**Option 4b**	**Option 5a**	**Option 5b**	**Straight line**	**Previous alignment (a)**	**Previous alignment (b)**	**Previous alignment (c)**
9	Geotechnical	9	6	0	0	0	0	0	0	0	0	0	0	0	0
7	Geotechnical	14	9	6	4	12	11	14	5	6	3	11	5	14	0
5	Geotechnical	7	7	5	6	2	2	9	5	6	4	8	4	3	0
3	Geotechnical	23	13	4	10	16	6	5	9	4	15	6	14	0	15
1	Geotechnical	42	51	70	46	56	47	65	49	70	52	69	57	58	60
-3	Geotechnical	5	11	6	15	10	26	5	17	9	11	4	11	19	17
-5	Geotechnical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7	Geotechnical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9	Geotechnical	1	2	9	18	4	7	3	13	4	15	2	9	6	8

** The above table shows only a shortened version of the actual table used. See Appendix A for the full table.*

Specialists “voted” for the corridors and the number of votes was tallied. The total surface area found suitable is indicated in green under the “Final summary table” in Table 4. Positive values indicate percentage areas within the suitability ranges of the scale and for these higher percentages are ideal. The negative values reflect unsuitable areas and in these cases lower surface area percentages are the ideal.

Table 4: Final summary of suitable and unsuitable areas per corridor option.

Environmental Aspect	Option 1a	Option 1b	Option 2a	Option 2 b	Option 3a	Option 3b	Option 4a	Option 4b	Option 5a	Option 5b	Straight line	Previous alignment (a)	Previous alignment (b)	Previous alignment (c)
Geotechnical	94	87	85	66	86	67	92	69	87	74	94	80	75	75
Freshwater	91	84	93	85	81	73	89	87	93	84	89	83	89	92
Groundwater	-95	-97	-79	-97	-98	-97	-97	-96	-94	-95	-97	-98	-61	-97
Ecological suitability	-92	-73	-90	-71	-77	-66	-84	-68	-93	-76	-95	-71	-91	-73
Heritage sites suitability	100	100	100	100	100	100	100	99	100	100	100	100	100	100
Palaeontological suitability	84	98	96	97	99	98	92	95	96	96	96	99	100	98
Transport suitability	98	91	98	96	29	26	97	94	97	94	99	76	74	9
Transport opportunities	1	4	1	2	37	36	1	3	1	2	0	4	13	45
Social site constraints	-95	-96	-95	-98	-95	-95	-64	-96	-96	-98	-94	-100	-94	-83
Social Opportunities	100	92	100	89	96	92	100	86	100	98	100	90	100	83

Votes:	5	3	6	4	3	4	6	4	5	3	5	2	4	4
Excluding the votes of the social aspect:	4	3	5	4	3	4	4	4	4	3	4	2	3	4

The specialists voted the physical and social site constraint corridors (Option 2a and Option 4a) the most preferred as these had the highest percentages in suitable ranks for most of the criteria. The geotechnical, social opportunities and straight-line corridors came second to the first two preferred corridors.

In commenting on the identification of the preferred corridors, the specialists were given additional information to consider in their recommendations. These include:

- The corridors were graphically presented with the total surface area per corridor and percentage of overlap of the corridors;
- The central line length of each corridor was calculated in comparison to the shortest centreline;
- The number of crossings over 1:500 000 and 1:50 000 rivers were calculated as a surrogate for channel width as channel width information was not available.

The physical site constraints corridor option had a centre line 16.5 km longer than the straight-line corridor, followed by the social site constraints and the geotechnical corridors. In comparison to all the corridors generated, previous alignment a and b, designed for a previously planned EIA, received very low votes from the specialists owing to large part of the alignments falling into areas which were ranked unsuitably for many environmental aspects. Previous alignment c did match in votes to the third category of preference as voted by the specialists. This particular one was originally designed to align to existing infrastructure and therefore falls mostly in the infrastructure opportunities aspect's areas ranked highly suitable.

DISCUSSION

Following the relatively 'poor' performance of the previous alignments as shown in Table 4 in the suitability statistics and preference voting assessment, it is clear that a TSS could benefit a company in the design of corridors in the preplanning phase prior to an EIA. In this project it was found valuable to have a set of corridors considering the regional scale over which this linear development was planned. The benefits of this project were compared to those mentioned in the literature in Table 5. Further preplanning will include the ground truthing of each corridor to collect fine-scale and more accurate geospatial data before the final alignments are drawn by the geotechnical engineers.

Table 5: Evaluation of the benefits of the TSS.

Benefits mentioned in the literature:	Comment
Open & explicit process	The process was experienced as open and explicit. It was agreed that it was most advantages to have open discussions between the disciplines; something the experts have never experience in the EIAs they have been involved with in South Africa.
Audit trail that can be reviewed	An audit trail of reports and minutes is available and documents the processes and decision made.
Changeable & repeatable	The environmental aspects, the assigned suitability classes, ranks and corridor options can be changed and repeated within the same project or for new project locations.
Communication between the community, decision makers and I&APs	Not tested.
Desktop prior fieldwork, more focussed fieldwork	Not tested.
Minimising costs	Not tested.
Interdisciplinary approach	The open discussion of interdisciplinary experts in the workshop increased the awareness and understanding of experts for another environmental aspect in terms of linear developments, as well as further ideas, classes and approaches for each aspect.
Generating a number of alternatives using GIS is beneficial for a study	The full benefits of the study can most probably only be assessed during the EIA or construction phases of the development.

Some limitations remain to such as study:

- Calculation of corridors is still a problem in that the creation of corridors in a GIS is not easily done and still reliant on the use of LCP and buffering of these, and therefore the LCP is used. Adjacent areas that are buffered aside to the LCP are not always as suitable as the centre-line cells. Sharp turns in the path are also not easy to deal with (Feldman *et al.,* 1995) and may result in rerouting in some places or high costs of design changes.
- Comparing environmental aspects from a wide variety of disparate disciplines against one another, still presents the decision maker with illogical comparisons. For example: would it be more suitable for a linear development to pass through cultural heritage sites or sugar plantations? In this case both legal and physical restrictions will have a cost and time delay impact on the project, not to mention the negative feedback that could result from I&APs. This oversimplification of the terrain and social aspects, could provide simple mathematical solutions, but at the same time impair the success of the project approval by the public. The specialists

in this project all agreed that it is not logical to compare criteria from different disciplines to one another, and that all should be considered on their own.

Recommendations for improvement included:

- More complete and accurate geospatial data, even for regional planning, data at a scale of 1:50 000 would be more preferred for the TSS.

The social specialists found that geospatial data was too limiting to represent the complexities of the social aspect and that it was not suitable to be used in a TSS. It was recommended that the social aspect be addressed once the alignments or routes have been finalised.

CONCLUSION

This study attempted to illustrate the importance and value of TSSs prior to EIAs by reflecting on the steps taken in a TSS for a linear development study.
The division of constraints and opportunities and the creation of corridors for groups of environmental aspects, also present a new way of creating a set of corridors for evaluation. The selection of an interdisciplinary team of experts and the two workshops were found to be of immense value as part of the decision making in the preplanning phase. Ideally the prevailing ranks combination rule and the selection of constraints versus opportunities should be adopted in other TSS prior to EIAs based on the value demonstrated in this project.

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Appendix A: Percentage area for each rank of suitability for each environmental aspect as a total of the surface area of each corridor option.

		% of total surface area of the corridor													
Suitability rank	**Environmental aspect**	**Option 1a**	**Option 1b**	**Option 2a**	**Option 2 b**	**Option 3a**	**Option 3b**	**Option 4a**	**Option 4b**	**Option 5a**	**Option 5b**	**Straight line**	**Previous alignment (a)**	**Previous alignment (b)**	**Previous alignment (c)**
9	Geotechnical	9	6	0	0	0	0	0	0	0	0	0	0	0	0
9	Freshwater	91	84	93	85	81	73	89	87	93	84	89	83	89	92
9	Groundwater	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Ecological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Heritage sites suitability	100	100	100	100	100	100	100	99	100	100	100	100	100	100
9	Palaeontological suitability	84	98	96	97	99	98	92	95	96	96	96	99	100	98
9	Transport suitability	1	4	1	2	37	36	1	3	1	2	0	4	13	45
9	Social site constraints	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Social Opportunities	37	33	30	32	28	32	53	31	27	30	35	34	40	8
7	Geotechnical	14	9	6	4	12	11	14	5	6	3	11	5	14	0
7	Freshwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Groundwater	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Ecological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Palaeontological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Transport suitability	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Social site constraints	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Social Opportunities	2	32	2	33	14	37	2	32	4	33	2	24	7	36
5	Geotechnical	7	7	5	6	2	2	9	5	6	4	8	4	3	0
5	Freshwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Groundwater	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Ecological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Palaeontological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	suitability														
5	Social site constraints	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Social Opportunities	0	3	0	2	5	1	0	4	0	7	0	5	20	7
3	Geotechnical	23	13	4	10	16	6	5	9	4	15	6	14	0	15
3	Freshwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Groundwater	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Ecological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Palaeontological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Transport suitability	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Social site constraints	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Social Opportunities	14	25	16	21	25	22	13	20	2	28	23	27	-	27
1	Geotechnical	42	51	70	46	56	47	65	49	70	52	69	57	58	60
1	Freshwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Groundwater	5	3	21	2	2	3	3	3	6	3	3	2	39	3
1	Ecological suitability	8	27	10	28	23	34	16	31	7	24	5	29	9	27
1	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	Palaeontological suitability	0	0	0	1	0	0	0	2	0	1	0	0	0	0
1	Transport suitability	98	91	98	96	29	26	97	94	97	94	99	76	74	9
1	Social site constraints	5	4	6	2	6	6	36	5	5	2	6	0	7	18
1	Social Opportunities	47	0	53	0	24	0	32	-	68	0	41	-	34	5
-3	Geotechnical	5	11	6	15	10	26	5	17	9	11	4	11	19	17
-3	Freshwater	1	1	0	1	1	1	3	0	0	1	2	0	0	0
-3	Groundwater	26	26	34	40	36	27	24	39	32	36	39	33	14	45
-3	Ecological suitability	31	32	50	31	12	27	35	28	35	32	29	34	62	43
-3	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-3	Palaeontological suitability	2	2	2	2	1	2	4	2	4	2	3	1	0	2
-3	Transport suitability	1	0	0	0	1	1	1	0	1	0	0	0	3	2
-3	Social site constraints	9	19	8	16	6	13	5	28	5	6	5	13	2	42
-3	Social Opportunities	-	0	-	-	-	0	-	-	-	0	-	3	-	2
-5	Geotechnical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5	Freshwater	0	0	0	0	0	0	2	1	0	0	0	0	0	0
-5	Groundwater	69	54	45	45	60	52	73	39	62	40	57	52	47	41
-5	Ecological suitability	45	28	31	28	53	25	21	22	41	22	47	22	8	25

-5	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-5	Palaeontological suitability	14	0	2	0	0	0	4	0	1	0	1	0	0	0
-5	Transport suitability	1	3	0	1	8	16	1	2	1	2	0	12	5	5
-5	Social site constraints	5	31	7	34	18	27	3	36	4	41	6	30	18	32
-5	Social Opportunities	-	0	-	-	-	-	-	-	-	1	-	-	-	6
-7	Geotechnical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7	Freshwater	0	1	0	1	0	1	0	1	0	1	0	2	0	0
-7	Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7	Ecological suitability	15	8	8	8	12	10	26	10	17	13	18	12	19	4
-7	Heritage sites suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-7	Palaeontological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-7	Transport suitability	0	0	0	0	0	0	0	0	0	0	0	0	0	1
-7	Social site constraints	73	27	73	31	51	25	49	20	79	33	74	36	61	8
-7	Social Opportunities	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-9	Geotechnical	1	2	9	18	4	7	3	13	4	15	2	9	6	8
-9	Freshwater	8	14	7	13	18	25	7	10	7	14	9	15	11	7
-9	Groundwater	0	17	0	13	2	18	0	18	0	19	2	12	0	11
-9	Ecological suitability	1	5	0	4	1	4	3	8	0	9	2	3	1	0
-9	Heritage sites suitability	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9	Palaeontological suitability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-9	Transport suitability	0	2	0	1	25	21	0	1	0	1	0	8	5	38
-9	Social site constraints	8	18	7	17	20	30	7	12	9	17	9	22	13	0
-9	Social Opportunities	-	8	-	12	5	9	0	15	-	1	-	7	-	10