A Guide to the Development of Use Conflict Maps

Compiled as part of the Corepoint Project

Feb 2006

Margaret Carlisle, David R. Green

University of Aberdeen

Executive Summary

This report was developed in response to a request for guidelines from the Corepoint partners on how to produce use-conflict maps.

A multi-disciplinary approach is required for this task, incorporating the disciplines of *decision theory* and *geographical information systems (GIS)*. This report describes three decision theory techniques and incorporates one of them into a GIS for illustrative purposes.

Preferred Reference:

Carlisle M.A. & Green D.R. (2006). A Guide to the Development of Use Conflict Maps. *University of Aberdeen* http://www.abdn.ac.uk/cmczm/about.htm. *& COREPOINT* February 2006, pp30.

This project has received European Regional Development Funding through the INTERREG III B Community Initiative

Contents

1. Introduction

Several authors have commented on use-conflict within coastal zone management:

"Given the diversity of interest groups of interest groups, stakeholders, managerial authorities and administrative structures that converge at the shore, conflicts are almost inevitable between and among coastal users, managers, developers and the wider public, as well as between human society and the natural environment." (Bartlett 2000)

"There is a need for a wider dissemination of knowledge relevant to the importance of coastal and marine areas to the world's well-being, and a re-evaluation of societies' attitudes towards these spaces. Good coastal and marine governance (e.g. information dissemination, management, monitoring etc.) is therefore a key factor in the sustainable use of these environments and will require an integrated, coordinated and equitable approach." (Macharia 2001)

"Amongst the key challenges facing coastal zone managers are the need to widen public consultation and strengthen public participation during the selection of management options, and the requirement to improve the information dissemination process once decisions have been made. Shoreline Management Plans are complicated documents for those without prior technical knowledge of coastal processes, and the method in which they are prepared has been criticised for lacking adequate scope for public participation. It has been argued that this has led to suspicion amongst local communities regarding the beneficiaries of the plans." (Jude *et al* 2001)

The discipline known as *decision theory* is an important theoretical base for environmental management. The emphasis is on maximising *objectivity*. This is not trivial – in most major resource management decisions (i.e. those with stakeholders with conflicting interests) estimates of impact magnitude and significance are often fiercely contested, dependent as they often are on subjective value judgements. This subjectivity 'hides' stakeholders' values and interests (particularly vested interests and unconscious interests), often leading to skewed and/or inconsistent outcomes.

Decision theory encompasses a suite of tools of varying mathematical complexity. Some have no mathematical aspect and instead rely on natural language and non-numerical categorisation of the considerations in a choice. Qualitative methods are easier to use and may well be the best model for people who use numbers infrequently or want to make a claim based on rights – these methods have proved successful in the economic restructuring of the Former Soviet Union. Quantitative methods do well at preserving detail and incorporating uncertainty. Both approaches help to reduce the apparent complexity of decisions (Flanders *et al* 1998).

There has previously been much interest in the literature in the usefulness of information technology in general and GIS in particular as a decision support tool. This subject was reviewed by Scholten & van der Vlugt (1990), and is illustrated in Table 1.

Table 1: GIS, type of user, kind of need (Scholten & van der Vlugt 1990)

TYPE OF USER	INFORMATION DEMAND	USER DEMAND	TYPE OF INFORMATION SYSTEM	DEVELOPMENT
A: Information specialist	Raw data	Analysis Flexibility	Large Flexible	Links to other packages
B: Policy analyst	Raw data and pre-treated data (=information)	Analysis Good accessibility	Compact Manageable	Macro Languages Interfaces to other packages
C: Policy decision-maker	Strategic information	Good accessibility to users Weighting and optimalisation models	Small and concise	User friendly interface Key information
D: Interested citizen Special interest groups	Information	Good accessibility to users	Small and concise	User friendly interface

A GIS is a particularly useful tool for Use-Conflict Analysis because of the inherent capacity for fulfilling the following objectives:

- Integration of information from a variety of sources
- Evaluation of multiple criteria
- Adding value to existing information
- Enabling an appropriate research strategy to be developed
- Enabling a precautionary approach to be adopted.

Three quantitative decision theory approaches are described in more detail in this guide – SWOT Analysis, EIA matrices and Pairwise Comparison. Additionally, a GIS example is worked through which takes the results of one of these techniques (Pairwise Comparison) and implements them in a spatial mapping scenario.

2. SWOT Analysis

Assessing the Strengths, Weaknesses, Opportunities and Threats of a project is a standard technique. It is particularly useful for looking at site options – the following example is taken from a study looking at several sites for locating a visitor centre themed around the nature conservation values of a river.

The first step is the field survey. This is necessary for acquiring landscape information which cannot be discerned from maps particularly about visual impact, landscape context, river activity, local habitat/ecology and river access. The ground level view obtained in a field visit is how the site context is normally perceived. In this example two landscape resource/planning specialists surveyed each location by foot. Survey sheets were completed for each site, taking into account such data as access, physical requirements, visual impact and theming objectives.

Table 2: SWOT Analysis example

Site Name & Number	Score	Multiplier	Total score
Access by all forms of transport	4	3	12
Site access	5	3	15
Planning constraints	3	3	9
Visual impact	3	3	9
Visitor Centre theme objectives	4	3	12
Landscape context	3	3	9
Socio-economic market	5	3	15
Availability of services and infrastructure	3	2	6
Site availability	3	2	6
Community support	4	2	8
Visitor impact	4	2	8
Physical site characteristics	3	1	3
Site layout/development footprint	4	1	4
Development context	4	1	4
TOTAL			**120**

The criteria for the analysis of the strengths, weaknesses, opportunities and threats of the shortlisted sites are listed in Table 2. Each site is scored, on a scale of 1 (very weak) to 5 (very strong) as to how well it satisfies these criteria. Some of the criteria are more significant than others, and this is reflected in the matrix scoring system by the use of a multiplier scale of 1 (least significant) to 3 (most significant).

Example: Socio-economic market: This indicates how well placed the site is in relation to attracting visitors, and in sufficient numbers to facilitate economic viability. Factors such as nearby commercial ventures which may be synergistic or competitive are taken into account.

In favour of this technique are the facts that it is quick, simple and easy to use, and also easy to teach to others. Against it are:

- Subjective score
- Subjective weights
- Sensitive to selection of criteria
- Crude scale
- One use at a time examined.

3. EIA Matrix

Some tools, such as the standard Environmental Impact Assessment (EIA) techniques of matrices, networks, weighted parameter check-lists and project appraisal, are fairly simple mathematically. These techniques take qualitative value judgements and use quantification, expression of impacts in numerical terms and normalisation to a common base to enable comparison of different criteria. They are sensitive to subjectivity in the assignment of 'weights' to the different criteria, however.

An example of a simplified EIA matrix (taken from a study of Siberian hydrocarbon pipelines) is shown in Table 3 on the next page.

The magnitude of an action's impact on a given environmental factor is estimated on a scale of 0 to 3. The significance of such an impact is estimated on a scale of 0 to 3. This is a very much simplified quantitative scale, and if greater subtlety is required larger scales can be used (eg. 0 to 5 or 0 to 7). However, it should be remembered that a greater numerical range can give the erroneous impression of greater scientific precision – in many cases a simpler scale is more transparent and justifiable.

Multiplying the magnitude and significance values gives a range of impact values, which can be used to provide a summarised environmental impact evaluation matrix (Table 4). Impact values of 9 (3x3) are categorised as extreme impact, values of 6 (2x3 or 3x2) are categorised as very severe impact, values of 4 (2x2) are categorised as severe impact and all values of 1 to 3 (1x1, 1x2, 1x3 etc.) are categorised as low impact.

	Crude Oil Pipeline				Natural Gas Pipeline			
Physical	**Norm. Oper.**	**Chron Spill**	**Acute Spill**	**Clean Up**	**Norm. Oper.**	**Chron Leak**	**Acute Leak**	**Clean Up**
Air Quality	- -	- -	2 1	- -	- -	1 1	3 2	- -
Surface Water	- -	2 3	3 3	3 3	1 1	2 2	3 2	- -
Ground Water	- -	1 1	1 1	1 1	- -	- -	- -	- -
Soil	2 2	2 3	3 3	3 3	2 2	2 2	3 3	- -
Thermal Regime	2 2	2 3	3 3	3 3	2 2	2 2	3 3	- -
Visual	2 2	2 3	3 3	3 3	2 2	2 2	3 3	- -
Noise/Vibration	- -	1 1	3 1	- -	- -	1 1	3 1	- -
Biological								
Vegetation	1 1	2 2	3 3	3 3	1 1	2 2	3 3	- -
Habitat	- -	2 2	3 3	3 3	- -	2 2	3 3	- -
Birds	1 1	2 3	3 3	2 2	1 1	2 2	3 3	- -
Insects	- -	2 3	3 3	2 2	- -	2 2	3 2	- -
Mammals	1 1	2 3	3 3	2 2	1 1	2 2	3 3	- -
Fish	- -	2 2	3 2	2 3	- 1	2 1	3 2	- -
Hazard								
Explosion	- -	- -	- -	- -	- -	3 3	3 3	- -
Forest Fire	- -	1 2	1 2	- -	- -	3 3	3 3	- -
Human Activities								
Herding	1 3	2 3	3 3	3 3	- -	3 3	3 3	- -
Fishing	- -	2 3	3 3	3 3	- -	2 2	3 2	- -
Industry	- -	2 2	3 3	- -	- -	2 2	3 3	- -
Financial resources	1 2	- -	- -	3 3	1 2	- -	- -	3 3

Table 3: Magnitude/Significance Environmental Evaluation Matrix

3 Major impact 2 Medium impact 1 Minor impact - No impact

3 2	Magnitude Significance

	Crude Oil Pipeline				Natural Gas Pipeline			
Physical	**Norm. Oper.**	**Chron Spill**	**Acute Spill**	**Clean Up**	**Norm. Oper.**	**Chron Leak**	**Acute Leak**	**Clean Up**
Air Quality							VS	
Surface Water		VS	X	X		S	VS	
Ground Water								
Soil	S	VS	X	X	S	S	X	
Thermal Regime	S	VS	X	X	S	S	X	
Visual								
Noise/Vibration								
Biological								
Vegetation		S	X	X		S	X	
Habitat		S	X	X		S	X	
Birds		VS	X	S		S	X	
Insects		VS	X	S		S	VS	
Mammals		VS	X	S		S	X	
Fish		S	VS	VS			VS	
Hazard								
Explosion						X	X	
Forest Fire						X	X	
Human Activities								
Herding		VS	X	X		X	X	
Fishing		VS	X	X		S	VS	
Industry		S	X			S	X	
Financial resources				X				X

Table 4: Summarised Environmental Impact Evaluation Matrix

X Extreme impact VS Very severe impact S Severe impact

As can be seen from the above example, the last part of both tables (the Human Activities section) is in effect a use-conflict technique, in this case describing the conflict between one use (hydrocarbon pipelines) and other economic uses.

In favour of this technique are several points: it is quick, fairly easy to use and teach, enable comparison of several uses (though one use is the focus), and is standardised for use at local authority level. Against it are: subjective score, subjective weights, crude scale.

4. Pairwise Comparison

Both EIA matrices and SWOT analysis are quick and easy to use, but both suffer from the problem of subjectivity, particularly with regard to the choice of weights.

There are several multi-criteria analysis techniques available to address this – see Malczewski 1999 (*GIS and Multi-Criteria Decision Analysis*) for a detailed description. In this report we will work through an example of one technique, pair-wise comparison.

The example: An area of coast is under pressure for development for beach based tourism, particularly large hotels (Use 1). However, much of the coast is also of nature conservation importance (Use 2).

4.1 Pair-wise comparison – Stage 1

The first operation is obtain an initial list of important decision criteria from discussion with stakeholders from the two conflicting user groups (developers and conservationists). Feick & Hall (2002) developed a list of 17 criteria for a very similar real world example. However each added criterion multiplies the complexity of the subsequent analysis, so for this example we shall use 7 criteria:

A. Distance to airport
B. Distance to road
C. Distance to nearest built-up area
D. Distance to attractive beach
E. Use of a site with physically sensitive topography (eroding coast, marshland prone to flooding or mobilisable sand dunes)
F. Use of a site with conservation interest
G. Use of a brownfield site rather than a greenfield site.

4.2 Pair-wise comparison – Stage 2

The second operation is to get one or more representatives of each stakeholder group to undertake the pairwise comparison exercise. This is the method described in detail in Saaty's seminal 1980 work *The Analytical Hierarchy Process*.

As described by Feick & Hall (2002) "evaluators compare each pair of criteria and indicate the relative importance of criterion to each other on the following nine-point scale with even numbers being considered as intermediate points between adjacent values:

1. Criteria j and k are equally important
3. Criterion j is moderately more important than criterion k
5. Criterion j is strongly more important than criterion k
7. Criterion j is very strongly more important than criterion k
9. Criterion j is extremely more important than criterion k.

For each pair of criteria, ratios of their relative importance into a positive pair-wise reciprocal matrix. A total of n(n-1)/2 comparisons are required to complete the matrix, making this method more demanding when comparing a large number of criteria." For example, for 7 criteria there are 21 comparisons required, but for 17 criteria there are 136 comparisons required.

Let us take a hypothetical developer and a hypothetical conservationist and run some probable numbers into the pairwise comparison matrices. Looking at the developer's judgement first:

DEVELOPER (**Table 5**)

	A	B	C	D	E	F	G
A	1	3	5	1/5	7	9	5
B	1/3	1	5	1/7	5	5	7
C	1/5	1/5	1	1/9	1	3	3
D	5	7	9	1	9	9	9
E	1/7	1/5	1	1/9	1	3	1
F	1/9	1/5	1/3	1/9	1/3	1	1/3
G	1/5	1/7	1/3	1/9	1	3	1

The number in the cell is estimated from comparing the Row ID (j) to the Column ID (k). Our theoretical developer thinks that distance to the beach is strongly more important than distance to the airport, so the value in cell (Row D, Column A) is 5. The reciprocal cell (Row A, Column D) must, of logical necessity, have the reciprocal value (1/5). Looking at the overall matrix it becomes apparent that distance to the beach is the most important developer criterion, because looking along row D it is obvious that it scores very highly in comparison with all the other criteria, with no values in the row less than 1. Distance to the airport and to roads (to minimise building costs) are also important to this developer, but whether a conservation area or a brown field site is used or not are both relatively unimportant.

Next we look at the matrix for the conservationist:

CONSERVATIONIST (**Table 6**)

	A	B	C	D	E	F	G
A	1	1/2	1/3	1/3	1/9	1/9	1/3
B	2	1	1/1.5	1	1/7	1/7	1/2
C	3	1.5	1	1	1/5	1/5	1
D	3	1	1	1	1/5	1/5	1
E	9	7	5	5	1	1	1/5
F	9	7	5	5	1	1	1/5
G	3	2	1	1	5	5	1

Looking at the overall matrix it becomes apparent that distance to physically sensitive or conservation habitats are the most important conservationist criteria.

4.3 Pair-wise comparison – Stage 3

The developer him/herself has to work through the developer matrix (either individually or in a workshop with other developers). The same is true of the conservationist matrix. The next stage, however, needs to be undertaken by a scientist familiar with statistics, specifically Principal Components Analysis (PCA). This operation is the calculation of the Consistency Ratio (CR). If the matrix above is completely consistent (CR=0), then if X has been judged as value 2 in comparison to Y, and Y is judged as value 4 in comparison to Z, then X should be judged as value 8 in comparison to Z. However it is remarkably difficult to get perfect consistency in such a matrix – at least at first go. Two methodologies are described in detail in Appendices 1 and 2.

Both methodologies show that the Conservationist matrix as above is not consistent – the amended (consistent) matrix is as follows:

CONSERVATIONIST (**Table 7**)

	A	B	C	D	E	F	G
A	1	1/2	1/3	1/3	1/15	1/15	1/3
B	2	1	1/1.5	1	1/7	1/7	1/2
C	3	1.5	1	1	1/5	1/5	1
D	3	1	1	1	1/5	1/5	1
E	15	7	5	5	1	1	5
F	15	7	5	5	1	1	5
G	3	2	1	1	1/5	1/5	1

The amended sections are highlighted in green (major amendment) and blue (minor amendment). See Appendices 1 and 2 for details.

4.4 Pair-wise comparison – Stage 4

The next stage is to normalise each matrix element by its corresponding column total. The process for the developer matrix is illustrated in the table below.

Table 8: Normalisation of a pairwise comparison matrix

	a	b	c	d	e	f	g
a	1.00	3.00	5.00	0.20	7.00	9.00	5.00
b	0.33	1.00	5.00	0.14	5.00	5.00	7.00
c	0.20	0.20	1.00	0.11	1.00	3.00	3.00
d	5.00	7.00	9.00	1.00	9.00	9.00	9.00
e	0.14	0.20	1.00	0.11	1.00	3.00	1.00
f	0.11	0.20	0.33	0.11	0.33	1.00	0.33
g	0.20	0.14	0.33	0.11	1.00	3.00	1.00
	6.99	11.74	21.67	1.79	24.33	33.00	26.33

	A1	B1	C1	D1	E1	F1	G1	
A1	0.14	0.26	0.23	0.11	0.29	0.27	0.19	0.21
B1	0.05	0.09	0.23	0.08	0.21	0.15	0.27	0.15
C1	0.03	0.02	0.05	0.06	0.04	0.09	0.11	0.06
D1	0.72	0.60	0.42	0.56	0.37	0.27	0.34	0.47
E1	0.02	0.02	0.05	0.06	0.04	0.09	0.04	0.05
F1	0.02	0.02	0.02	0.06	0.01	0.03	0.01	0.02
G1	0.03	0.01	0.02	0.06	0.04	0.09	0.04	0.04
								1.00

The 6.99 value is the sum of Column A. The 0.14 value is the Row A value (1.00) divided by 6.99. The 0.21 value is the mean of Row A1. The final result is the column on the extreme right, which gives the proportional importance for each criterion. This is referred to as the **estimated solution vector**.

It is apparent that the most important criterion is the distance to beach (D), which takes 47% of the developer's 'votes'. Next most important are distance to airport (A) with 21% and distance to roads (B) with 15%. At this stage it may be useful to further delimit the number of criteria, so the 17% from the remaining four criteria can be proportionally divided between the top three factors to give A 25%, B 18% and D 57%. Doing the same process for the conservationist(amended matrix) gives E 45%, F 45% and G 10%.

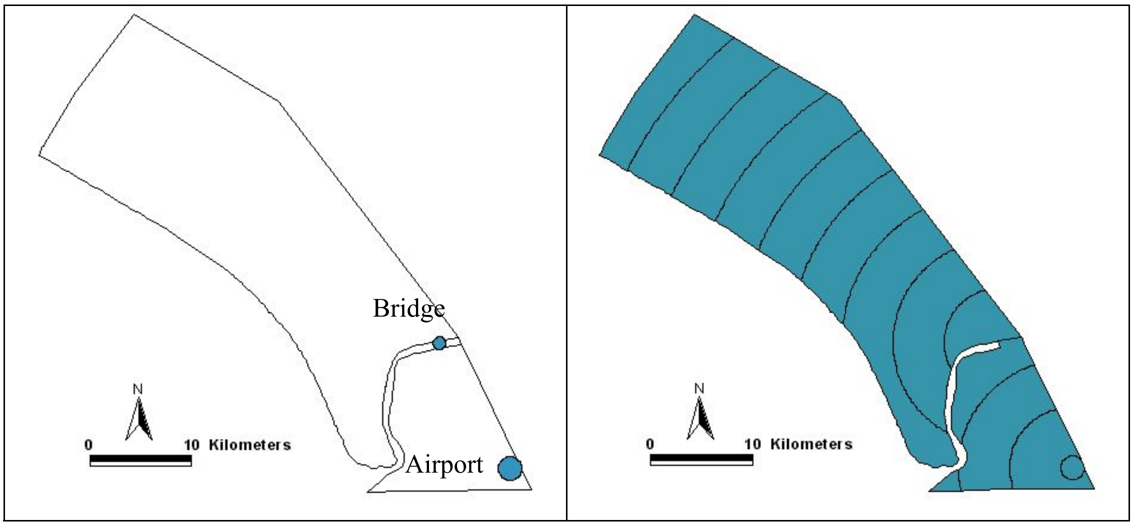
5. Implementation of Pairwise Comparison within a GIS

5.1 GIS implementation – Stage 1

Not only do the pairwise comparison processes above give us the relative importance of each criterion for a given stakeholder, they also tell us which criteria to map in the GIS – in this case A (distance to airport), B (distance to roads), D (distance to beach), E (physical sensitivity), F (conservation) and G (brownfield sites). Thus we do not have to waste time mapping criterion C (distance to built up areas). This would be even more useful in a larger set of criteria, and emphasizes the point that this is a useful exercise to undertake prior to a major mapping exercise, as it will save resources by focusing attention on only those criteria that are actually pertinent to the conflicting uses.

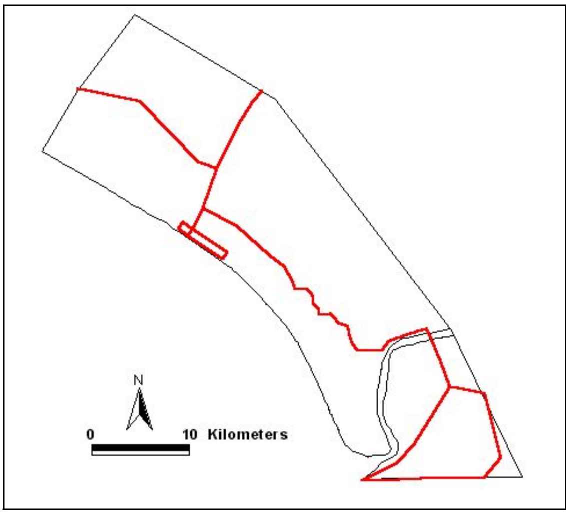
This stage, therefore, is the first GIS stage. The following maps are taken from a real coastal area, but for the purposes of this intellectual exercise certain imaginary data has been added – specifically the airport and one major road. The coast is on the left (eastern) side of the map – the boundaries to the north, south and west delimit the landward extent of the area of interest. A major river bisects the area of interest.

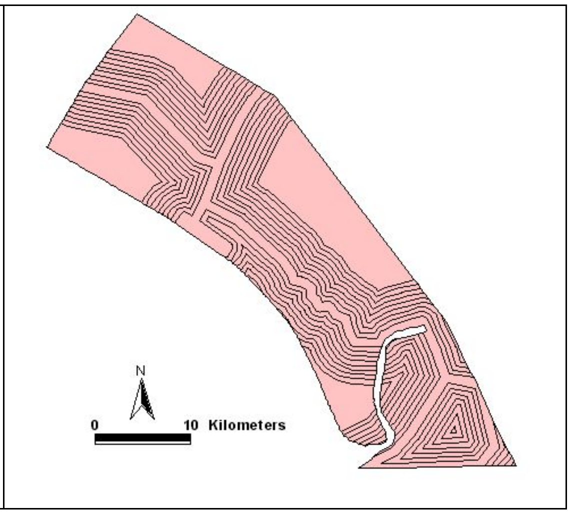
Figures A1 & A2 – Airport & airport buffer



The developer identified distance to airport as a major criterion, therefore the developer should be asked to give an idea of useful distance units to use for the buffer – in this case 5km units are used.

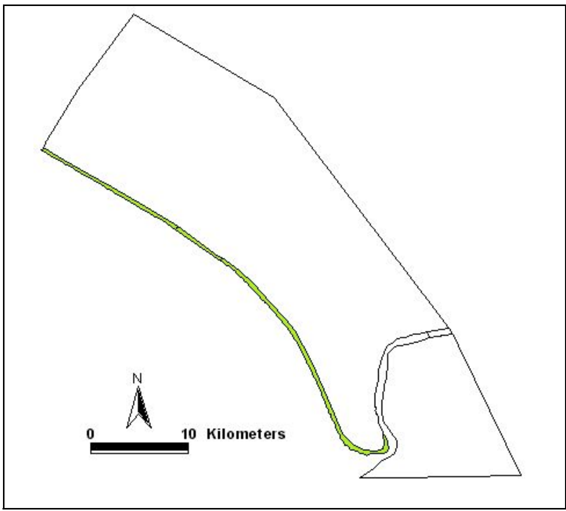
Figures B1 & B2 – Roads & road buffer

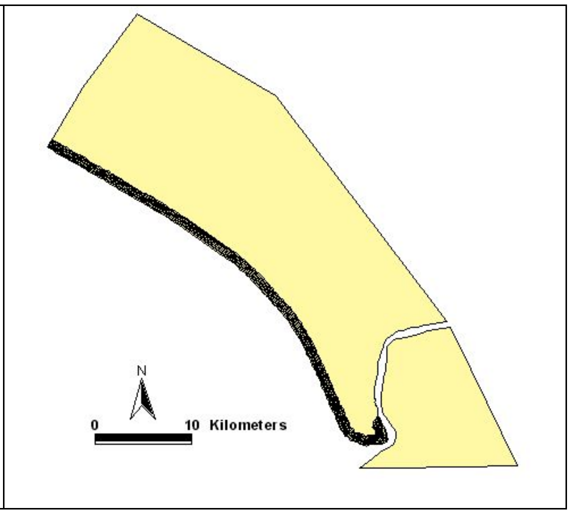




In this case 500m units were used for the buffer. Again, these units should be chosen in discussion with the stakeholder.

Figures D1 & D2 – Beach & beach buffer





Walking distance is important here, so the distance units are smaller still – the buffer is in 100m units.

Figure E1 – Physically sensitive areas (No E2 required)

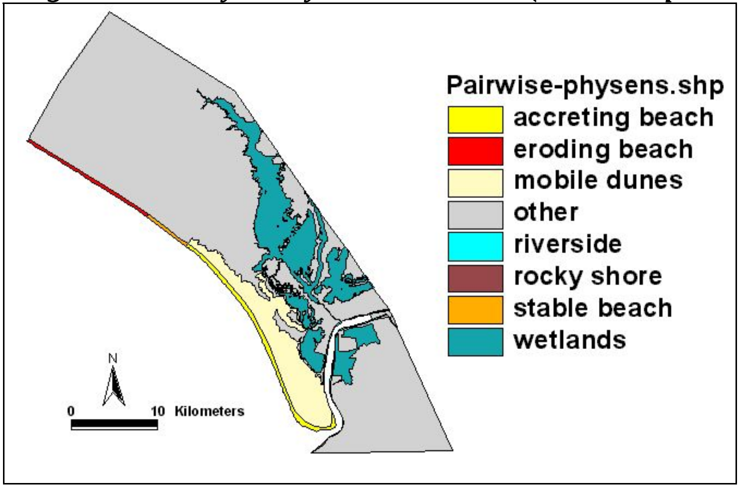


Figure E1 – Conservation areas (no E2 required)

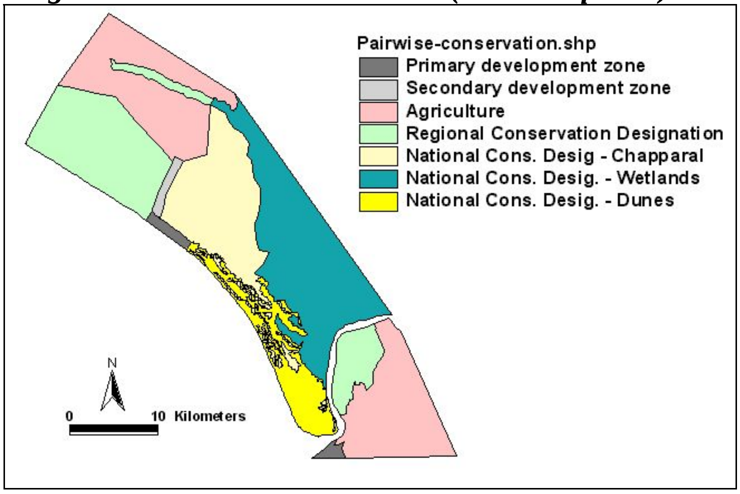
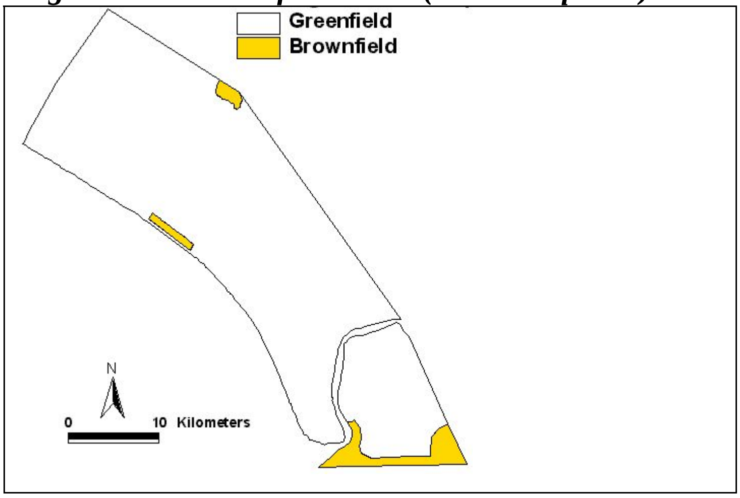


Figure G1 –Brown field areas (No G2 required)

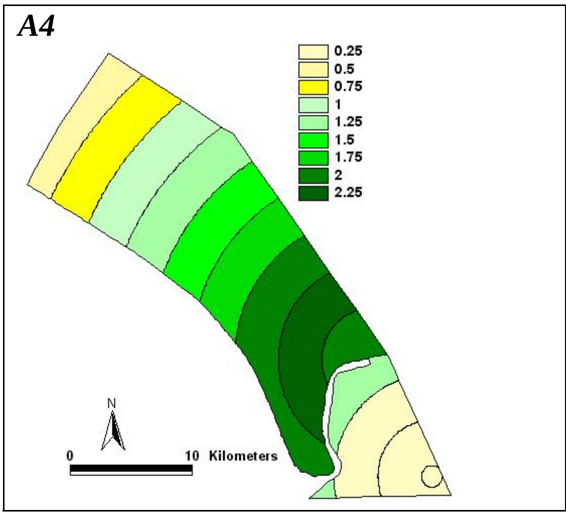


5.2 GIS implementation – Stage 2

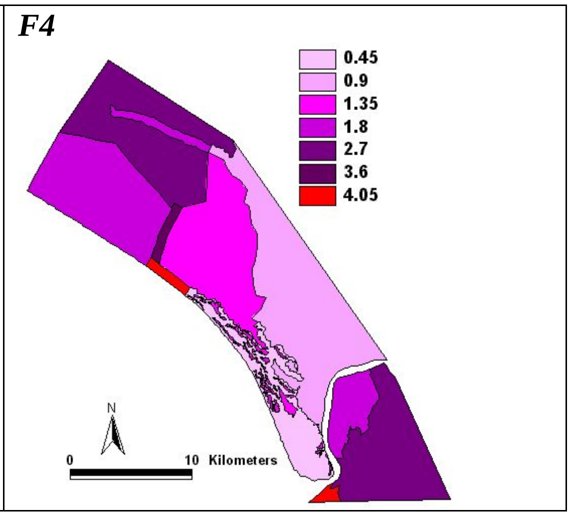
The next step is to put each of these mapped criteria onto a common quantitative scale. This scale is the *suitability scale*, which ranges from 1 to 9 with 9 being most suitable for the proposed use and 1 the least suitable for the proposed use. For example, for criterion A the developer estimated that the first 10km would be too close to the airport (too noisy), 20-25km would be the perfect distance from the airport (little noise and minimal travel time), and that there would be a gradual drop off in suitability out to 60km from the airport. Similar 'thought experiments' were undertaken for each of the other criteria, with the results shown in Maps A3 to G3 (next page).

Each of these maps can then be multiplied by the previously calculated multiplier (0.25 for A, 0.18 for B, 0.57 for D, 0.45 for E & F and 0.10 for G) to produce the next map stage. Maps A4 and F4 are shown for illustration.

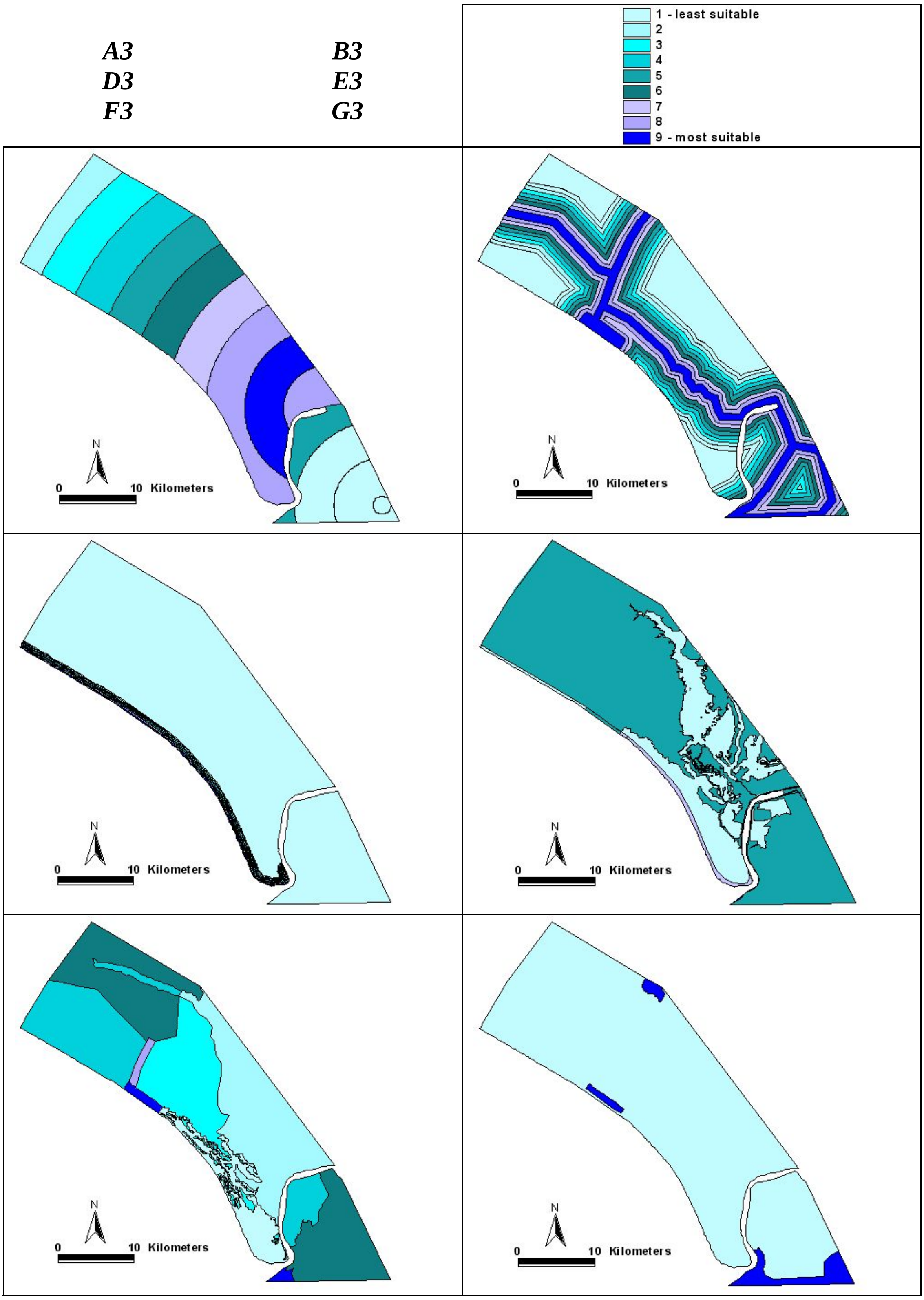
A4



F4



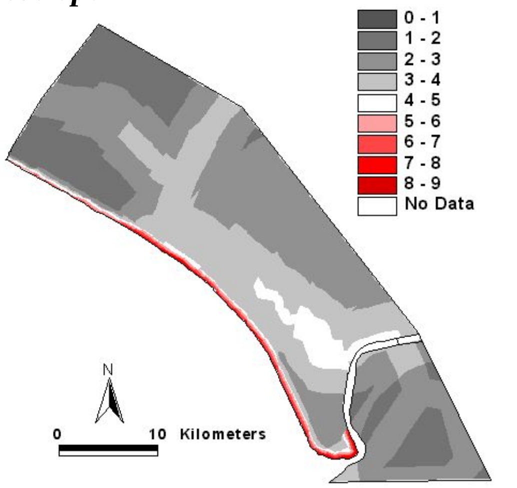
These vector maps were then all converted to grids (100m square) to enable their use in ArcView Modelbuilder.


A3
B3
D3
E3
F3
G3
1 - least suitable
2
3
4
5
6
7
8
9 - most suitable
N
0
10 Kilometers

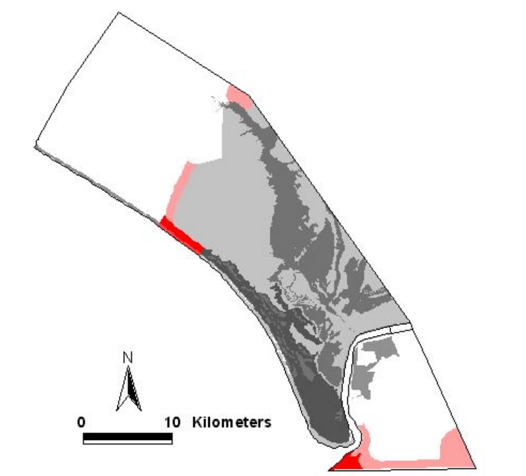
5.3 GIS implementation – Stage 3

The final developer overlay is calculated from adding GridA4, GridB4 and GridD4 (equivalent to adding 0.25xA3, 0.18xB3 and 0.57xD3). The final conservationist overlay is calculated from adding GridE4, GridF4 and GridG4. 1 is the least suitable category and 8-9 the most suitable.

Developer



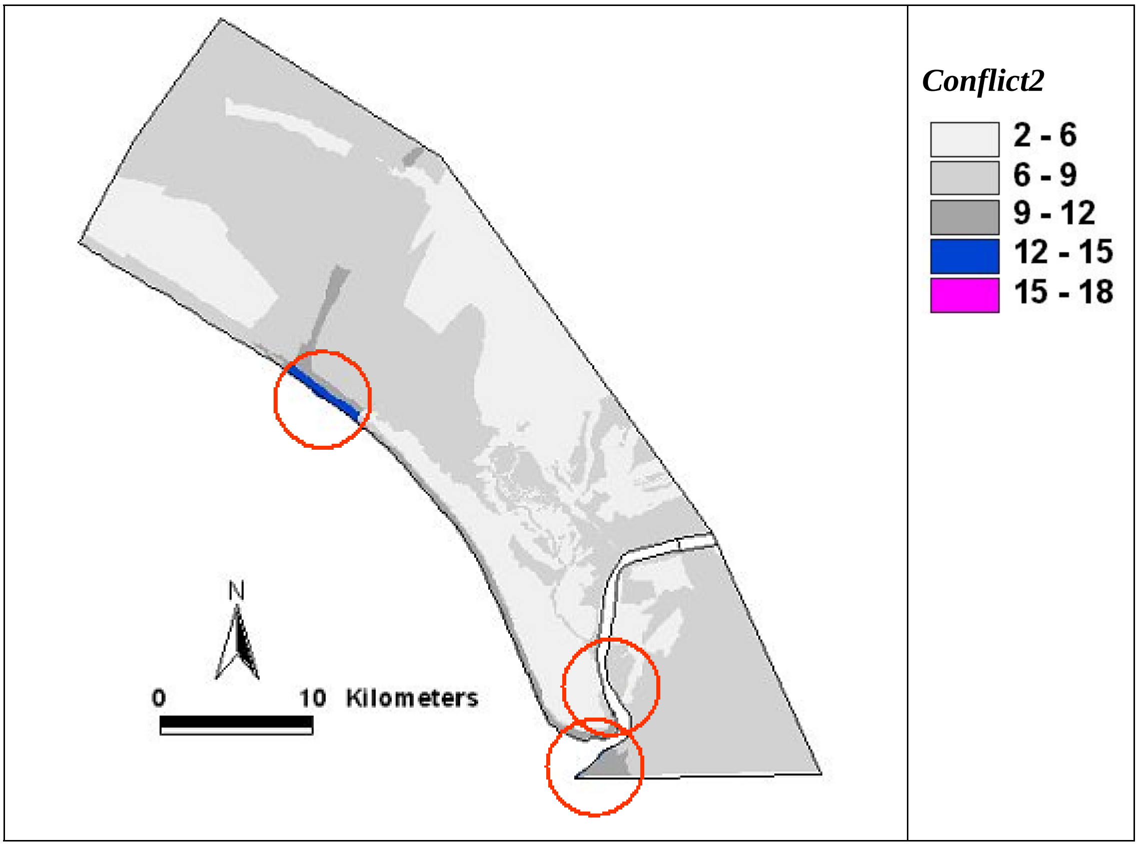
Conservationist



These two grids can be combined in a number of ways to further illuminate the use conflict. For example, subtracting the developer grid from the conservationist grid gives Conflict1.

Those areas in green are favoured by conservationists but not developers, and those areas in purple are favoured by developers but not conservationists. This illustrates that the beach areas in particular are under development pressure

Another approach is to add the two grids. Remembering that each grid is on a scale of 1 to 9, and that corresponds to: 1: very unsuitable, 3: moderately unsuitable, 5: equally suitable/unsuitable, 7: moderately suitable, 9: very suitable.
Grid squares with high values from one stakeholder but very low values from the other will be focus points for conflict – any square with a value of less than 12 may be such a focus. However, squares with values of greater than 12 must have a minimum value of 3 from both stakeholders, and such squares are therefore worthy of development focus. This is illustrated in Conflict2.



This illustrates that there are 3 potential areas that are worthy of further investigation.

6. Conclusion

Malczewski (1999 pp107-108) states that a set of decision theory criteria/attributes should be:

a.) Complete – cover all aspects of the decision problem.

b.) Operational – can be used meaningfully in the analysis.

c.) Non-redundant – avoid problems of double counting.

d.) Minimal – number kept as small as possible.

Of the three decision theory techniques described in this report, pairwise comparison is the most successful at incorporating all of these criteria.

Nonetheless, SWOT analyses and EIA matrices have their place in the field of decision support. SWOT analysis is particularly useful for a quick appraisal of many different sites with regards to a.) one proposed use, and b.) one stakeholder. As such it is widely used in the fields of business and economic development.

EIA matrices are required by law for all large developments in the EU, and their form and function is set at an agreed EU standard. This standardisation of technique makes it possible to compare and contrast same sector developments in different regions and different sector developments in the same region.

Pairwise comparison is a more complex methodology than either of the other two techniques. It requires a great deal of input from stakeholders, and is dependent on all stakeholders being involved. These negative aspects, particularly the demands on stakeholders' time, mean that it is a difficult technique to practise in a real world situation.

However, pairwise comparison has several great advantages over the other two techniques, namely:

- Increases objectivity of selection of criteria
- Increases objectivity of selection of weights
- Increases objectivity of selection of scores
- Incorporates balance of opposing views
- Enables examination of multiples uses within same analytical system
- Incorporates stakeholder information.

Finally, the penultimate section of this report, incorporating the 'thought experiment' pairwise comparison into a GIS with real world data, illustrates yet again the strengths of GIS as a tool for such multi-disciplinary study.

7. References & Bibliography

Abdus S.M., & Ross L.G., (2005). Optimizing sites selection for development of shrimp (Penaeus monodon) and mud crab (Scylla serrata) culture in Southwestern Bangladesh. http://www.aquaculture.stir.ac.uk/GISAP/Pdfs/Shrimp&Crab.pdf

Brtlett, D.J., (2000). Working on the Frontiers of Science: Applying GIS to the Coastal Zone, In *Marine and Coastal Geographical Information Systems* edited by Wright, D. and Bartlett, D. (London: Taylor & Francis).

Carr M. & Zwick P., (2005). Using GIS suitability analysis to identify potential future land use conflicts in North Central Florida. http://www.journalconsplanning.org/2005/volume1/issue1/carr/manuscript.html

Feick R.D. & Hall G.B., (2002). Balancing consensus and conflict with a GIS-based multi-participant, multi-criteria decision support tool. *GeoJournal* 53: 391-406.

Flanders N.E., Brown R.V., Andre'eva Y., Larichev O., (1998). Justifying public decisions in Arctic oil and gas development: American and Russian approaches. *Arctic* 51(3); 262-279.

Jude S.R., Jones A.P., and Andrews J.E., (2001). Visualisation for Coastal Zone Management, In *GIS for Coastal Zone Management* edited by Bartlett, D. and Smith, J. (CRC Press Boca Raton Florida).

Klauer B., Drechsler M., and Messner F., (2002). Multicriteria analysis under uncertainty with IANUS – method and empirical results. http://www.ufz.de/data/Disk_Papiere_2002-021568.pdf

Macharia S.N., (2001). New Directions for Coastal and Marine Monitoring: Web Mapping and Mobile Application Technologies, In *GIS for Coastal Zone Management* edited by Bartlett, D. and Smith, J. (CRC Press Boca Raton Florida).

Malczewski J., (1999). *GIS and Multi-Criteria Decision Analysis*. John Wiley & Sons, New York.

Mwasi B., (2001). Land use conflicts resolution in a fragile ecosystem using multi-criteria evaluation (MCE) and a GIS-based decision support system (DSS). *International Conference on Spatial Information for Sustainable Development*, Nairobi, Kenya 2-5 October 2001.

Saaty T.L., (1980). *The Analytical Hierarchy Process*. McGraw-Hill International, New York. 287pp.

Scholten H., van der Vlugt M., (1990). A review of GIS applications in Europe, In *Geographic Information Systems: Developments & Applications* edited by Worrall L., (Belhaven Press, London).

PCA websites
http://149.170.199.144/multivar/eigen.htm

http://149.170.199.144/multivar/spss_fa5.htm

http://www.ats.ucla.edu/stat/spss/

Appendix 1: Principal Component Analysis using method of Saaty (1980)

The following text is reproduced directly from “The Analytic Hierarchy Process”, Thomas L. Saaty 1980.

“If we may assume that the reader knows how to multiply a matrix by a vector, we can introduce a method for getting a crude estimate of consistency. We multiply the matrix of comparisons on the right by the **estimated solution vector** [see Section 4.4] obtaining a new vector (**Vector 2**). If we divide the first component of this vector by the first component of the estimated solution vector, the second component of the new vector by the second component of the estimated solution vector and so on, we obtain another vector (**Vector 3**). If we take the sum of the components of this vector and divide by the number of components we have an approximation to a number λmax (called the maximum or principal eigenvalue) to use in estimating the consistency as reflected in the proportionality of preferences. The closer λmax is to *n* (the number of activities in the matrix) the more consistent is the result.

Deviation from consistency may be represented by (λmax – n)/(n-1) which we call the *consistency index* (C.I.).

We shall call the consistency index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocals forces, the *random index* (R.I.). Average R.I.’s were generated for matrices of order 1-15 using samples sizes of 500 (100 for *n*=12, 13, 14, 15). The following table gives the order of the matrix (first row) and the average R.I. (second row) determined as described above.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The ratio of C.I. to the average R.I. for the same order matrix is called the *consistency ratio* (C.R.). A consistency ratio of 0.10 or less is considered acceptable.”

The following page shows the Saaty calculations for the matrices in Section 4.2

Appendix 1 continued: 1st matrix – developer, 2nd matrix – conservationist, 3rd matrix – amended conservationist.

	A	B	C	D	E	F	G	Est sol vct	Vector 2	Vector 3		
A	1.00	3.00	5.00	0.20	7.00	9.00	5.00	0.21	1.79	8.38	54.33	Sum of components of vector 3
B	0.33	1.00	5.00	0.14	5.00	5.00	7.00	0.15	1.21	7.93	7.00	No. of components
C	0.20	0.20	1.00	0.11	1.00	3.00	3.00	0.06	0.42	7.39	7.76	Max eigenvalue
D	5.00	7.00	9.00	1.00	9.00	9.00	9.00	0.47	4.10	8.79		
E	0.14	0.20	1.00	0.11	1.00	3.00	1.00	0.05	0.33	7.27		CI=7.76-7/6=0.13
F	0.11	0.20	0.33	0.11	0.33	1.00	0.33	0.02	0.18	7.45		CR=CI/RI=0.13/1.32=0.10
G	0.20	0.14	0.33	0.11	1.00	3.00	1.00	0.04	0.29	7.12		

	A	B	C	D	E	F	G	Est sol vct	Vector 2	Vector 3		
A	1.00	0.50	0.33	0.33	0.11	0.11	0.33	0.02	0.35	14.78	73.76	Sum of components of vector 3
B	2.00	1.00	0.33	1.00	0.14	0.14	0.50	0.05	0.56	11.96	7.00	No. of components
C	3.00	3.00	1.00	1.00	0.20	0.20	1.00	0.08	1.04	12.86	10.54	Max eigenvalue
D	3.00	1.00	1.00	1.00	0.20	0.20	1.00	0.07	0.95	14.00		
E	9.00	7.00	5.00	5.00	1.00	1.00	0.20	0.30	2.00	6.61		CI=10.54-7/6=0.59
F	9.00	7.00	5.00	5.00	1.00	1.00	0.20	0.30	2.00	6.61		CR=CI/RI=0.59/1.32=0.45
G	3.00	2.00	1.00	1.00	5.00	5.00	1.00	0.56	3.91	6.95		

	A	B	C	D	E	F	G	Est sol vct	Vector 2	Vector 3		
A	1.00	0.50	0.33	0.33	0.07	0.07	0.33	0.02	0.17	7.10	49.63	Sum of components of vector 3
B	2.00	1.00	0.33	1.00	0.14	0.14	0.50	0.05	0.33	7.02	7.00	No. of components
C	3.00	3.00	1.00	1.00	0.20	0.20	1.00	0.08	0.58	7.09	7.09	Max eigenvalue
D	3.00	1.00	1.00	1.00	0.20	0.20	1.00	0.07	0.48	7.11		
E	15.00	7.00	5.00	5.00	1.00	1.00	5.00	0.35	2.51	7.10		CI=7.09-7/6=0.02
F	15.00	7.00	5.00	5.00	1.00	1.00	5.00	0.35	2.51	7.10		CR=CI/RI=0.02/1.32=0.01
G	3.00	2.00	1.00	1.00	0.20	0.20	1.00	0.07	0.53	7.10		

The CR value for the developer matrix is acceptable at 0.10.

The CR value for the conservationist matrix is 0.45, which is considerably greater than the acceptable figure of 0.10. So, this matrix needs re-examination. Doing this showed that, in fact, the values for G in relation to E and F were reversed – the conservationist intended to state that G (using brownfield sites) was strongly *less* important than E and F (physical sensitivity and conservation), but in fact the numbers state the opposite. This is a very easy mistake for a stakeholder to make, and illustrates the importance of using PCA as a 'quality control check' at this stage.

Additionally, the re-examination made it apparent that there was inconsistency between the comparison of E & F with D and A.

D (distance to the beach) is 3 times as important as A (dist to airport), and E & F (physical sensitivity & conservation) are judged to be 5 times as important as D (distance to the beach). This means that logically E & F are 15 times as important as A. Normally D/A and E&F/D would be adjusted downwards in order to enable their product to equal 9, but in exceptional circumstances (i.e. the stakeholder strongly desires it) the range can be extended (in this case to 15). As the matrix is normalised later anyway this does not create mathematical inconsistency in the GIS – the reason for adhering to a 1-9 scale is because it is judged by most authors as offering the optimum balance of sensitivity vs. clarity for decision makers.

Correcting Rows & Columns A and G gives a CR value of 0.01, which is highly acceptable.

Appendix 2: Principal Components Analysis using SPSS

As noted above following Saaty's notation (1980) a consistency index CI can be defined as: $CI = \frac{(\lambda max - n)}{(n-1)}$

λmax is the largest eigenvalue (Principal Components Analysis). For a perfectly consistent matrix λmax will equal *n*, and therefore CI will be zero. For Saaty's approach λmax is always greater than or equal to *n*, therefore the CI and resultant CR will be positive in value.

However, the statistics software SPSS uses a slightly different theoretical approach (described in detail at http://149.170.199.144/multivar/eigen.htm, http://149.170.199.144/multivar/spss_fa5.htm, & http://www.ats.ucla.edu/stat/spss/), resulting in λmax always being less than or equal to *n*.

Using the factor analysis option (PCA sub-option) in SPSS software to calculate the eigenvalues for the developer matrix gives the following result:

$CI_D = (6.175 – 7) / 6 = -0.14$

And for the original conservationist matrix:

$CI_C = (4.369 – 7) / 6 = -0.44$

SPSS factor analysis PCA generates n eigenvalues, the sum of which = n. For example, for the developer matrix above the seven eigenvalues are 6.175, 0.596, 0.201, 0.023, 0.004, 0.001, 0.000. A perfectly consistent matrix would have λmax=7, and all other eigenvalues=0, i.e. the matrix can be described with only one dimension (the first eigenvector). A perfectly inconsistent matrix would require all n dimensions for description, on an equal basis, therefore the seven eigenvalues must all=1. Therefore λmax=1 (see http://149.170.199.144/multivar/eigen.htm for a detailed explanation). Therefore, for a perfectly inconsistent matrix $CI_I = (1 – 7) / 6 = -1$

Therefore the developer consistency ratio CR_D = -0.14 / -1 = 0.14

And the (original) conservationist consistency ratio CR_C = -0.44/-1 = 0.44

Again this procedure highlights the fact that the conservationist matrix CR is considerably greater than the acceptable figure of 0.10.

As already described in Appendix 1, the matrix needs re-examination. In SPSS the first step is to take out one factor at a time (eg take out Row A and Column A) and then run the PCA looking to see how close λmax gets to the optimum value (for a 6 factor matrix) of 6. Doing this process showed that factor G is the problem, as taking this out enabled λmax to reach a value of 5.940 (CR=0.01). As already noted in Appendix 1 "Re-examining the matrix showed that, in fact, the values for G in relation to E and F were reversed – the conservationist intended to state that G (using brownfield sites) was strongly *less* important than E and F (physical sensitivity and conservation), but in fact the numbers state the opposite. This is a very easy mistake for a stakeholder to make, and illustrates the importance of using PCA as a 'quality control check' at this stage."

As already described in Appendix 1, Row & Column A is also inconsistent, but only minimally so – removing A enabled λmax to reach 3.765 (CR=0.44), so no significant change in consistency. However, having identified an inconsistency it is usually worthwhile correcting it.

Correcting Rows & Columns A and G gives λmax = 6.948. This gives a CR value of 0.01, which is highly acceptable.

It should be noted that SPSS gave the same or very similar values to Saaty's method for both the original and amended conservationist matrices (0.44 cf. 0,45, 0.01 cf 0.01). However, it gave a slightly larger value that Saaty's method for the developer matrix (0.14 cf. 0.10). This matrix has several small inconsistencies (whereas the original conservationist matrix had one large inconsistency and one very minor one), and it appears that the SPSS method is more sensitive to many small inconsistencies than the Saaty method. Using SPSS in this case would have led to a recommendation to re-examine the developer matrix as again "CR values less than or equal to 0.10 signify that the pair-wise comparisons are reasonably consistent" and 0.10 is taken as the acceptable quality level.