Push and pull assemblages for modelling visitor's flows in complex landscapes

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Abstract: Visitor flows can be represented as a landscape-recreation-model with eight components: entrances, goals, exits, field units, attractors or detractors, road segments, road junctions and barriers. The model can develop towards a real-time application by increasing its complexity. Starting from a basic situation (a landscape with one road and one entrance), the influence of landscape attractiveness is included; secondly diversity of the terrain and visitor is taken into account, thirdly time variation is added and finally, the interaction between the eight above-mentioned components is incorporated. The basic framework is a cost-distance function, to estimate the probability of on- and off-track visit of any location in a nature reserve on deliberate times and in specific terrain conditions. This can be represented by mean of a push-pull concept: some of the components (like entrances) have a push effect, while others, like goals, exits (when determined in advance) and attractors, have a pull-effect. To support the conversion towards a real-time application, GPS surveys, interviews, camera observation, photographic monitoring of seasonal changes, photo comparisons, step-bridges, walking experiments, experiments about field unit division and landscape preference studies were executed. This model is being developed in marshland nature reserves in central Belgium. Ultimately this system should lead to an impact assessment and decision support tool.

Introduction

Because of increasing social and political interest in nature conservation, an equilibrium has to be found between maximizing social profit and minimizing ecological disturbance in open (accessible) nature reserves (Lindberg & Hawkins 1993, Cessford 2002, Ehrlich 2002, Reinhard et al. 2002). In strongly urbanized areas, like in Flanders, the northern part of Belgium, nature reserves are scattered and dispersed between several land use types. Most of the protected nature reserves are accessible, externally because of a dense public road network and internally because of the absence of fencing and a relatively dense network of trails. Because the probability of disturbance grows with increasing visit density and frequency, some nature reserves risk losing their special quality. Excessive recreation not only causes the degradation of the environment, but may also spoil the recreation experience of the visitor (Manning 2002).

Hard measures, such as fencing off the fragile zones of the reserve, detract from overall site value (Bayfield 1982). One of the possible management principles is to guide visitors towards the robust part of the landscape by track layout adjustments and management practices such as boarding and trail management (Bell 1997).

The interaction between the values of nature and trampling should be studied in two ways: the impact approach (where, when and how?) and the response approach (how does the biotope change?) (Cole 1993, Cole & Bayfield 1993, Roovers et al. 2003). This study concentrates on the first issue.

The aim of this paper is, starting from an overall landscape-recreation-model, based on eight components (entrances, goals, exits, field units, attractors, road segments, road junctions and barriers) to create a specific real-time image of marshland nature reserves and to estimate there the probability of off-track visits in any location at deliberate times and in different terrain conditions. The model is developing towards a real-time application by increasing its complexity. Starting from a basic level (a landscape with one road and one entrance: push-effect), the influence of landscape attractiveness is included (push or pull-effect); secondly diversity of terrain and visitor is taken into account, thirdly time variation is added and finally, the interaction between the eight above-mentioned components is incorporated. To support the conversion towards a real-time application, GPS surveys, interviews (Baarda et al., 2000), camera observation (Muhar et al. 2002), photographic monitoring of seasonal changes, photo comparisons, step-bridges (Cessford et al. 2002), walking experiments, experiments about field unit division and landscape preference studies (Daniel 2001, Kaplan et al. 1998, Wherrett 1998) were executed.

Previous studies about modelling visitors are for example agent based models (Itami & Gimblett 2000, Itami et al. 2002), cellular automata models (Kessel et al. 2002) artificial models (Gimblett et al. 2001), decision-making models (Daniel 2001, Lawson et al. 2002) or other spatial models (Lynch 2002, Gulinck & Dumont 2002).

The originality of this paper is the combination of a friction based model (cost-distance function) and a basic push-pull principle. Some of the eight components (like entrances) have a push effect, while others, like goals, exits (when determined in advance) and attractors, have a pull-effect.

Elementary landscape-recreation model

Visitor flows in a nature reserve can be schematically represented as a landscape-recreation-model (Figure 1) with eight components: entrances, goals, exits, field units, attractors and detractors, road segments, road junctions and barriers. This model was submitted to a friction model. A cost-distance function in GIS estimates the probability of on- and off-track visit of any location in the nature reserve on deliberate times and in specific terrain conditions.

The whole system is conceptualised as a push-pull concept: some of the components (like entrances) have a push effect, while others, like goals, exits (when determined in advance) and attractors, have a pull-effect.

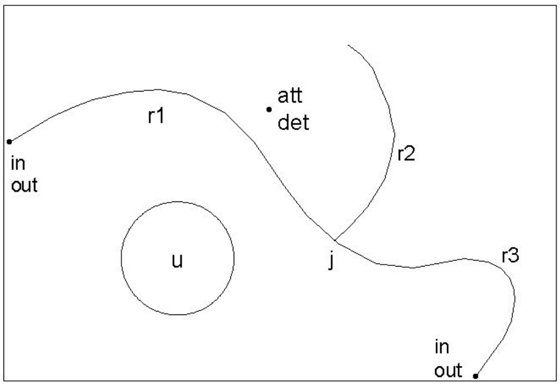

Figure 1. Landscape recreation model.

Legend:
in: Entrance
out: Exit
u: Unit
att: Attractor
det: Detractor
r: Road segment
j: Junction
a: Agents

The construction of the landscape-recreation model can be described in a sequence of complexity (Figure 2).

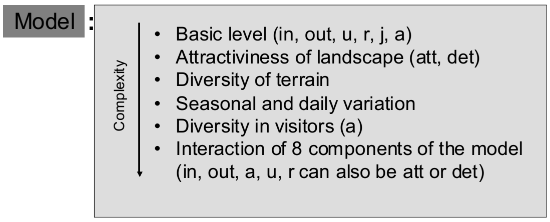

Figure 2. Levels of complexity of the landscape recreation model.

Starting from a basic situation (a landscape with one road, one entrance (push) and one exit (pull), the influence of attractors is added (pull-effect); secondly diversity of terrain and visitor is taken into account and finally, the interaction between the eight above-mentioned components is incorporated.

First, the 'Cost-model' as a **basic level**: Agents (mostly people) enter the landscape (or nature reserve) via entrances with a certain amount of initial energy and they leave via exits. Each entrance is at the same time also an exit with specific features, like for example accessibility and attainability. An agent can move along the road-network (a complex of road segments) or he can choose to walk off-road, while each step he makes decreases his residual energy. The landscape surrounding the road network is divided in units, each unit having its own characteristics (like vegetation type and –height, penetrability, visibility,…). The road network consists of road segments, which are in fact a special kind of unit (a small one).

As cost-model, an isotropic positive growth model (cost-distance function) was applied, based on the following formula:

$N_{i+1} = N_i + \sqrt{2}*R_{i/i+1}$
when both cells are in a diagonal

$N_{i+1} = N_i + R_{i/i+1}$
when both cells are in a straight line

Whereby N_i is the accumulated cost in cell i (a maximum value), $R_{i/i+1}$ is a resistance or friction factor that is taken into account in the transition from position i to i+1 and i and i+1 are respectively source and target-pixel.

The input for this model is a grid with sources and a friction-surface. The costs needed to reach the grid cells are accumulated. Starting from value 0, costs are summarized and the calculation ends when a maximum value is reached, which need to be given in the input of the Cost-Distance function. Each pixel of the landscape was mapped according to the value of the least Cost-Distance pathway (Adriansen et al. 2000).

This basic situation results in a cost-distance map, shown in Figure 3.

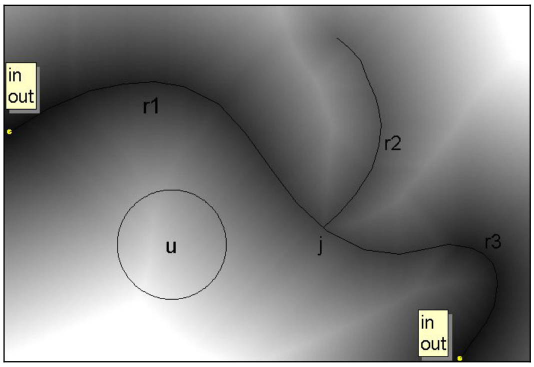

Figure 3a. Cost-Distance function applied on Figure 1, with two entrances used as sources.

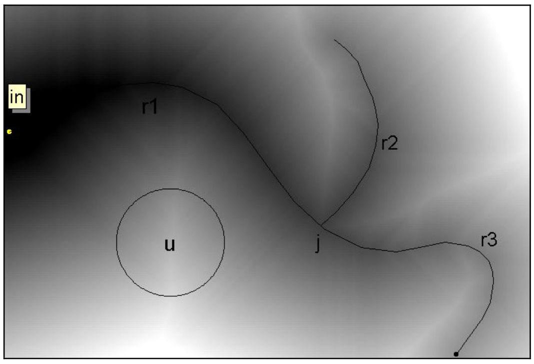

Figure 3b. Cost-Distance function with one entrance used as source.

Legend: dark = easy accessible, high pull value
light = difficult accessible, high push value

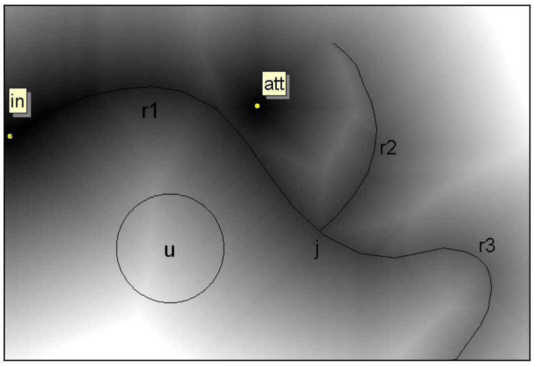

Figure 3c. Cost-Distance function with one entrance used as source and the effect of an attractor.

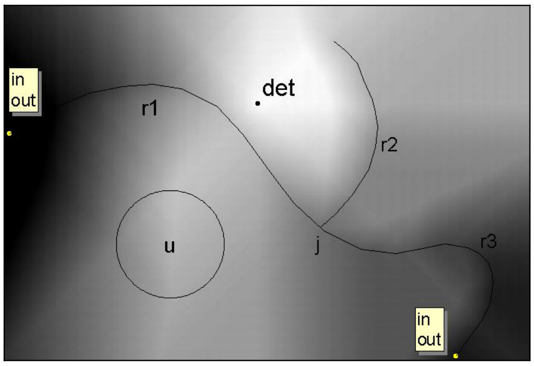

Figure 3d. Cost-Distance function with one entrance used as source and the effect of a detractor.

In cost-distance maps (like Figure 3) the value of each pixel represents accessibility from one or more sources. Dark zones indicate easy accessible locations. In Figure 3a, both entrances are used as a source, while in Figure 3b only the left entrance is used as source. This is why the area around the right entrance in Figure 3a is more accessible than in Figure 3b.

This cost-model can be enriched with the **'principle of attraction'**: Agents can respond on eye-catchers (attractors or detractors) in a positive or negative way, which can influence their choices and preferences. Additional aspects of certain attractors are their energy loading capacity, like for example benches where an agent can reload its energy.

In Figure 3c, the effect of an attractor is incorporated in the cost-distance map, showing the area around the attractor easier to reach. In Figure 3d, the inverse effect of Figure 3c is incorporated (the effect of a detractor), showing a less accessible area around the detractor.

Finally, the previous concept can be integrated in a **'dynamic process'**. Influence of the terrain, visitors and seasonal and daily variation can be simulated. Agents entering the landscape via entrances (push effect), mostly already know which exit they will choose (a goal), which makes this exit (or entrance) an attractor (pull effect). When entering a certain area, an agent has a certain view, with or without an attractor. Possible present agents can, depending on the visitor act as an attractor or detractor. Further on his way, on a junction, an agent makes a choice, determined by physical resistance (vegetation type, height, barriers …) and psychological resistance (presence or absence of attractors, knowledge of the area …). Based on those choices he continues his road and finally leaves the area via an exit.

Additional to this sequence of complexity the double principle of a viewshed can be integrated. When an agent enters a landscape, he has a momentaneous visual reach at specific locations (viewshed of the agent) but, at the other site, specific landscape features (like attractors and detractors) also have their visibility area (viewshed of the object). Figure 3 can partly illustrate this idea: when an agent enters the landscape, he acts according Figure 3b (or Figure 3a, when he knows he is going to leave the landscape via the right cornered exit). From the moment he sees the attractor or detractor, Figure 3c (respectively Figure 3d) becomes the leading scenario.

Towards application in reality

To support the conversion towards a real-time application, nine data gathering tools are used: GPS surveys, interviews, camera observation, photographic monitoring of seasonal changes, photo comparisons, step-bridges, walking experiments, experiments about field unit division and landscape preference studies were executed.

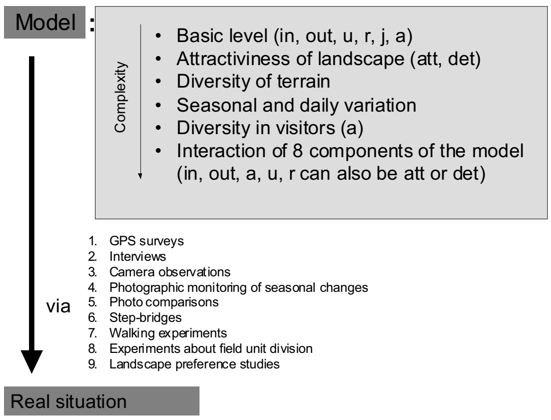

Figure 4. Summary of conversion from the model towards real-time situations.

Study areas

Two study areas were chosen, because of their appropriate characteristics: they are situated in strongly urbanised areas (Flanders) and management must increasingly take care of carrying capacity. All of the components of the models are explicitly present and clearly identifiable.

Demerbroeken

The nature reserve 'Demerbroeken' (marshes of the river Demer) is situated about 45 km east of Brussels and covers an area of 110 ha. It is a typical example of a semi-natural area surrounded by habitation, with high public accessibility. It retains a multifunctional character, since it is not only a nature reserve with fragile habitats and rare bird breeding sites, but the nature reserve is also a popular site for walking. Furthermore it is part of a floodplain, helping to reduce peak flows of the river Demer. The managers of the reserve are greatly concerned about the dilemma between opening up the site for the general public and the protection of fragile sites such as quaking fen (floating organic mats) and rare bird breeding sites.

Torfbroek

The nature reserve 'Torfbroek', 10 km north east of Brussels, covers an area of 31 ha. The specific conditions of this nature reserve originate from lime- and iron-rich seepage water. Those two substances have a positive influence on the value of this unique nature. Apart from flat and arid hayfields, there are spacious pools and ditches which are important for dragonflies and mainly swamp birds.

Nine data gathering tools and relevant results

1. GPS surveys

In Demerbroeken (2001) as well as in Torfbroek (2003) entrances (in), exits (out), at- (att) and detractors (det), road segments (r) and junctions (j) were localized and digitalized.

2. Interviews

Two kinds of interviews (only in 'Demerbroeken' were set up to describe the number of visitors, their trip origin, the length of their stay, the purpose of their visit and their entrance point. The interviews were based on accurate definitions of terms and short, clear, simple and neutral questions.

The first interview schedule was examined on three different days for a total of 98 daily visitors to the 'Demerbroeken'. The second interview was set up for the managers of the nature reserve, to obtain a more detailed picture of the visitor flows throughout the whole year. Also during 2003 forms were repeatedly filled in by terrain managers, on which information about other visitors was recorded. The interviews gather information about the agents (a) of the nature reserve.

The results of the interviews for the daily visitor of the 'Demerbroeken' indicated the walk-in intensity of the different entrances and exits (in, out) was depending on several factors, such as attractive infrastructure nearby (for example a bird observation post), the accessibility, walking tracks, closest entry etc. A one-hour visit was the most common (30%) in the 'Demerbroeken' (a two-hour visit for the managers) and the main activity during visits was walking (34%), twice as high as cycling, relaxing and bird observation (Figure 5). Diversity in visitors (a) can be deduced from those data. People were generally pleased with the accessibility of the terrain, but complained about muddy tracks and impenetrable trails. Some people (12%) pointed out that the amount of benches and parking places were insufficient.

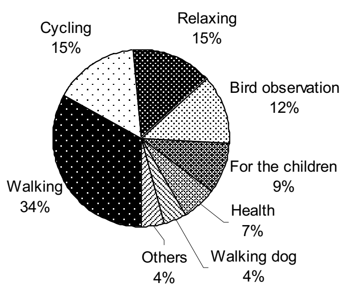

Figure 5. Reason of visit in 'Demerbroeken': information about visitor diversity.

3. Camera observation

On an important junction (j) in 'Torfbroek' a surveillance camera was installed, which registers each four seconds an image, saved at the hard disc of a PC. The camera observations gather information about the amount and walking direction of agents (a) and the percentage that does not follow the indicated trails. Also the variation of road segments (r), junctions (j) and vegetation units (u) can be followed. The observations started in August 2003 and are still running.

Four walking routes and four entrances (or exits) can be observed by the camera and the intensity of use of each route as well as percentage of use of each entrance and exit can be recorded. Results show that August is a much busier month than the following fall and winter months. One route segment is clearly used more than the other routes; however this is less clear in the following months.

The camera data also reveals information about distribution of visitors in time. Firstly, the day in the week which is the most crowded (Figure 6). Saturdays and Sundays are in general the most visited days, but also on Wednesday a lot of visitors came to 'Tofbroek'. This is probably because of the free Wednesday-afternoon at school.

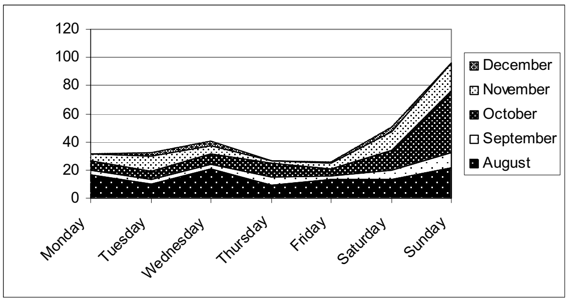

Figure 6. Cumulative visitor intensity of five months represented per day.

Secondly, the hour of the day can be represented per month (Figure 7). In general the afternoon (between 2pm and 4pm) was the busiest.

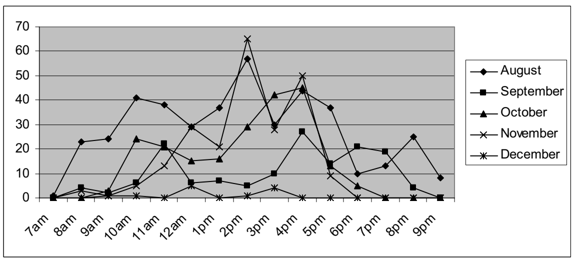

Figure 7. Monthly amount of visitor on each hour of the day.

4. Photographic monitoring of seasonal changes

In both nature reserves, a picture has been taken on previous determined locations, each season. Involved components are entrances (in), exits (out), units (u), road segments (r) and junctions (j), which each can vary in time and space. Also alterations in barriers can be notified.

5. Photo comparisons

Above-mentioned photographs were shown off-site to nine people. They had to organise the photographs in three different classes (less than average, average and more than average) once by aesthetic preference and once based on the clarity of the walking direction on the picture. At- (att) and detractors (det) are the main components involved.

When sorted, based on aesthetics, only 20 photographs were judged to be more beautiful than average. The most beautiful pictures were those of a tree lying in the water, in every season. This tree can be classified as an attractor. 56 % of the most beautiful pictures were taken in spring, which indicates that spring is a very attractive walking season. The less attractive pictures were mostly (61%) taken in fall, but on a rainy day.

Based on sense of direction, much more consistent data were gathered: 37% of the pictures were judged to be very clear about the indicated walking direction. Only 9% was not clear.

6. Step-bridges

A self developed counting system was installed at an important junction in Torfbroek. An electronic counting device registers a pulse each time a visitor (a) crosses the bridge. These data can be combined with the camera observations.

7. Walking experiments

In both nature reserves, two walking experiments were executed, where three kind of questions were asked: thirty people subsequently indicated firstly their preference judgment concerning preselected sites, their preference concerning moving in certain directions and finally their estimation on a continuous scale of the effort needed to move along certain directions throughout certain types of terrain

In 'Demerbroeken' and 'Torfbroek' a total of approximately 100 people were asked about their preferred walking direction. Generally, visitors prefer to follow the path they are walking on, except for two posts in 'Demerbroeken', where visitors wanted to follow an alternative small path or a small wooden bridge. There was no specific preference for any direction at some important junctions in 'Demerbroeken'. Also in 'Torfbroek' on an important junction no significant preferences were observed, which means that visitors are likely to take every road segment with equal frequency.

The quaking fen site (in 'Demerbroeken') is generally judged to be the most attractive site (a value of 89 on a scale from 0 = not attractive to 100 = most attractive) in the landscape, because of the rare phenomenon of floating organic mats and varying vegetation. The least attractive site (a value of 53) is where spruce-firs, nettles, rusty coloured brooks and iron fences disturb the character of the nature reserve.

In 'Torfbroek' the most beautiful site (a value of 83), is mainly because of the open character and the view on the lake. A location, in fact outside the reserve is judged to be the least attractive (value of 40), because the presence of a house and an asphalted road.

For all statistical analyses SPSS was used (SPSS. 10.0, 1999).

8. Experiments about field unit division and landscape preferences

The aim of this experiment is to divide the landscape in different units and to examine if this division is similar with the division of other people. On-site was asked to indicate polygons (spatial units (u)), lines (edges) and points (barriers, eye-catchers (att, det), junctions (j)).

Figure 8 shows how different persons split up the landscape in spatial units. Visually interpreted, most of the units are divided commonly (thick lines in Figure 8).Only a few units were divided intern.

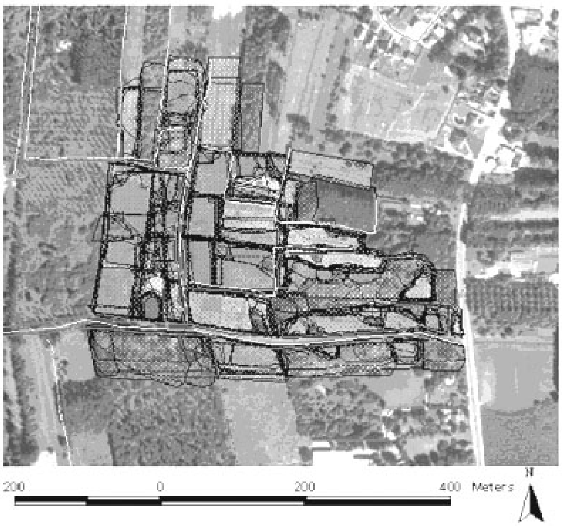

Figure 8. Division of a part of 'Demerbroeken' in spatial units.

Real-time situation in a part of 'Demerbroeken' and 'Torfbroek'

Based on the real situation (real vegetation type, road width and length, ditches, benches, fences, etc.) in 'Torfbroek' and 'Demerbroeken', Figure 9 was realised. One must be taken into account that those maps are not completely correct representations of the full complexity of the model. Variation in visitors and terrain for example are not yet incorporated. Therefore more data should be gathered during the following years, like more seasonal monitoring and interviews. Also the influence of attractors or detractors is not included, same as the interaction of the 8 components of the model. More experiments should be set up to investigate the preferences of visitors.

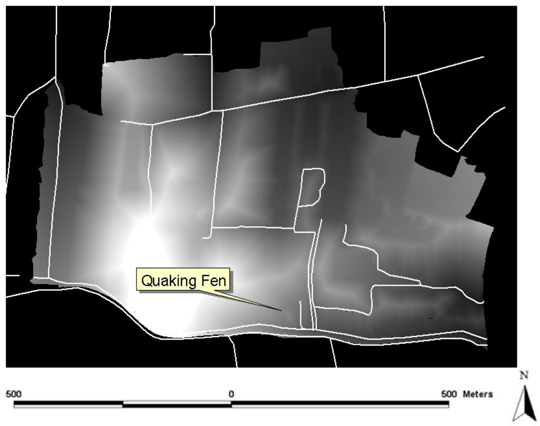

Figure 9a: Cost-Distance function of 'Demerbroeken'

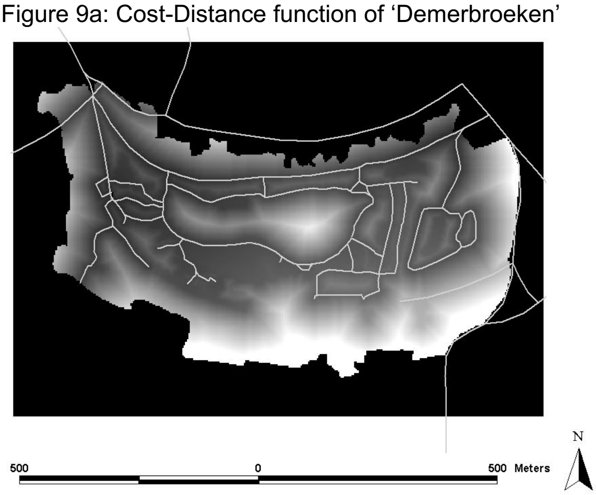

Figure 9b. Cost-Distance function on 'Torfbroek'.

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