

## Appendix A: Network friction

In this paper we have applied a network-friction model similar to the model that was presented by Van Lanen et al. (2015a). One of the main aims of the current paper is to determine the applicability of this method on more detailed micro-regional scale and later time period (which we have designated as the Veluwe NFM). In this section we provide some more background data on the original network-friction method.

### Network-friction method

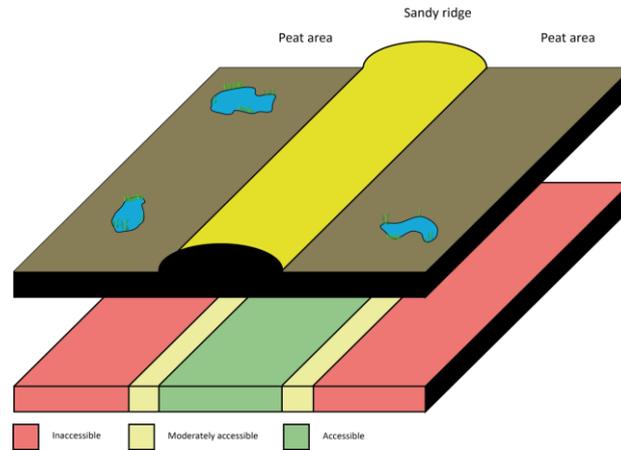
Network friction was developed by Van Lanen et al. (2015a) in order to calculate regional accessibility in dynamic Lowlands. Their main assumption was that in these relatively low and wet regions, a complex mix of environmental variables determines the suitability for potential routes on a specific location. Van Lanen et al. (2015a, 200-201) defined network friction as “... *the variable that determines potential regional accessibility based on the comparison of local and surrounding landscape factors*”. In their paper a grid model was developed with a resolution of 500x500m grid cells covering almost the complete modern Netherlands. This grid-cell resolution was chosen because: 1) this resolution coincides with the scale of most environmental datasets (1:50,000), and 2) due to computational limitations caused by the large size of the study area.

Network friction was specifically designed to calculate accessibility for the Roman and early-medieval periods represented by two time slices: AD 100 and 800. Geoscientific data was imported into the grid model by computing the geometric intersections (.obj) of each dataset with the grid cells within the network-friction model (NFM). The following geoscientific data were used in the model by Van Lanen et al. (2015a):

- Palaeogeography ca. AD 100
- Palaeogeography ca. AD 800
- Geomorphological map of the Netherlands
- Soil map of the Netherlands
- Dutch-elevation model (*Actueel Hoogte Bestand – AHN 1*)

Using these geoscientific datasets they differentiated between 5 different levels of accessibility, i.e. network friction (Table 1). Based on archaeological data they classified certain specific landscape types as being inaccessible and others being accessible, e.g. peat marshes: inaccessible; levees: accessible (Figure 1; for a detailed overview: Van Lanen et al., 2015a, Figure 4; Appendix).

*Figure 1: Accessible and inaccessible landscape units in the network-friction model based in archaeological data. Peat areas are inaccessible with the exception of the section close to sandy ridges that are accessible. The proximity of these parts to accessible areas increases the relative accessibility of these regions (Source: Van Lanen et al. 2015a: Figure 4)*



All other, intermediate landscape units were given a “moderately accessible” accessibility level. As a next step “poorly accessible” and “reasonably accessible” levels were added to the NFM, by calculating their proximity to either “inaccessible” or “accessible” grid cells (Figure 2; Van Lanen et al., 2015a: Figure 5.).

Figure 2: Determination of accessibility values based on the grid. Proximity to accessible grid cells will positively influence lesser accessible grid cells and inaccessible grid cells will have a negative influence (Source: Van Lanen et al. 2015a: Figure 5)

Neighbouring Grid Cell Influence	Level of Accessibility	Grid Cell Accessibility	Network Friction Value
	Inaccessible		1
	Poorly accessible		2
	Moderately accessible		3
	Reasonably accessible		4
	Accessible		5

Based on expert judgement accessibility values were determined per geoscientific dataset for each individual landscape unit (for more specifics and reasoning: Van Lanen et al. 2015a: Appendix). Based on these accessibility values combined network-friction values ( $Nf_v$ ) were calculated for the time slices: AD 100 and 800 using the following equation:

$$(\text{Network friction value}) Nf_{(v)} = \sum_{i=1}^n (\text{dataset}_i)$$

In order to show inaccessible to accessible areas in the study area these network-friction values were then converted into a network-friction averages:

$$\text{Network friction average } Nf_{(avg)} = \frac{\sum(Nf_{(v)})}{n_{dataset}}$$

The NFM differentiates between 5 different levels of accessibility (Table 1). These network-friction levels show the relative accessibility of each individual grid cell. As such these cells represent a surface layer on which multiple further network analyses (e.g. least-cost paths, energy consumption, agent-based modelling) would be possible in the future.

Table 1: Network-friction levels as defined by Van Lanen et al. (2015a).

Description	Network-friction value
Inaccessible	1
Poorly accessible	2
Moderately accessible	3
Reasonably accessible	4
Accessible	5

Since the aim of our study is to determine the applicability of the network-friction method for our study area and time period using the Veluwe NFM, we have applied largely the same method (with the main exception of the grid-cell resolution), accessibility values and datasets as Van Lanen et al. (2015a).

### Network-friction route zones

Van Lanen et al. (2015b) modelled Roman and early-medieval route networks based on an integrated approach combining network friction with archaeological data on amongst other settlements, burial sites and shipwrecks. Their main assumption was that if there was a strong link between the natural landscape and route-network orientation, dominant route zones could be calculated based on the most efficient path between settlements. They defined the most efficient path as the average shortest distance between settlements following the possible best network-friction values, i.e. the least friction. Van Lanen et al. (2015b, p. 145) propagated the evidence-based approach in route-network modelling and validated the modelled ROM and EMA networks with the location of archaeologically excavated infrastructural and isolated finds. The assumption being that if the modelled-route networks represent the areas in which peoples moved in the past, despite these areas only covering a small fraction of the surface area of the study area, the number of infrastructural and isolated finds located in these corridors should be relatively high. The models' outcome were underlined by the fact that 89.2% of the Roman infrastructural, and 81.7% of the isolated finds were located in 13.7%, i.e. 1000m route zone, of the surface area of the research area (Tables 2 and 3). For the Early Middle Ages, these results were slightly lower, with 85.4% of the infrastructural and 72.2% of the isolated finds were located in route zones covering 11.9% of the surface area.

Van Lanen et al. (2015b) validated results using three different route-zone buffers: 500m, 1000m and 2000m. The models' outcome were presented using mainly the 1000m route-zone buffer since this buffer reflects the most accurate route zone possible in a 500x500m grid-cell model: 500m, plus a 250m deviating within the model based on the uncertainty of settlement locations within grid cells.

*Table 2: Overview of test results for Roman and early-medieval infrastructure. For each route zone the percentage of correctly modelled infrastructural finds within the route network is given (adapted from Van Lanen et al. 2015b).*

Route buffer	Roman Period		Early Middle Ages	
	Number of infrastructural finds	% finds within buffer	Number of infrastructural finds	% finds within buffer
500m	544	73.6%	81	77.7%
1000m	658	89.2%	89	85.4%
2000m	698	94.1%	92	88.3%
Outside 2000m	44	5.9%	11	11.7%
<b>Total</b>	<b>742</b>	<b>100.0%</b>	<b>103</b>	<b>100.0%</b>

*Table 3: Overview of the test results regarding Roman and early-medieval isolated finds. For each route zone the percentage of correctly modelled isolated finds and total surface area of the route network is given (adapted from Van Lanen et al. 2015b).*

Route buffer	Roman Period			Early Middle Ages		
	Number of isolated finds	% finds within buffer	% Surface area Netherlands	Number of isolated finds	% finds within buffer	% Surface area Netherlands
500m	8609	64.1%	7.2%	2469	52.4%	6.11%
1000m	11153	81.7%	13.7%	3361	72.2%	11.9%
2000m	12402	90.6%	24.4%	4085	87.8%	22.1%
Outside 2000m	1329	9.4%	75.6%	522	12.2%	77.9%
<b>Total</b>	<b>13731</b>	<b>100.0%</b>	<b>100.0%</b>	<b>4607</b>	<b>100.0%</b>	<b>100.0%</b>

In this paper we applied largely the same methods and calculations in order to model route zones in our study area around AD 1500. The main difference is the exclusion of burial sites and shipwrecks in the Veluwe NFM since the relationship between such sites and the landscape fundamentally differ on the Veluwe during the investigated time period.