Of Meuse and Man: the geomorphogenetic and archaeological predictive maps of the Dutch Meuse valley

R.F.B. Isarin[1,*], E. Rensink[2], G.R. Ellenkamp[3] & E. Heunks[4]

[1]   Crevasse Advies, Nieuwstraat 14, 3628 AC Kockengen, the Netherlands
[2]   Cultural Heritage Agency of the Netherlands (RCE), Smallepad 5, 3811 MG Amersfoort, the Netherlands
[3]   RAAP Archaeological Consultancy. De Savornin Lohmanstraat 11, 6004 AM Weert, the Netherlands
[4]   Eckhart Heunks Landscape Archaeology. Kievitdwarsstraat 26, 3514 VE Utrecht, the Netherlands
[*]   Corresponding author. Email: isarin@crevasse.nl

Abstract

For the first time, geomorphology and archaeology are combined for a 165 km long stretch of the Meuse river, resulting in a geomorphogenetic map (GKM) and a series of archaeological predictive maps (AVM). The maps cover the central part the Meuse valley, located in the province of Limburg between Mook in the north and Eijsden in the south. The area consists of fluvial and aeolian landforms of the Holocene Meuse floodplain and Younger Dryas aged terraces along it, spanning a period of approximately 15,000 years of landscape genesis and human habitation. The GKM more clearly discriminates between map units of Younger Dryas and early Holocene age than in previous mappings of the Meuse valley. The AVM series provide predictive information on the location of sites for four distinct consecutive archaeological periods and four main cultural themes. The maps contribute to a better understanding of landscape processes (fluvial and aeolian geomorphology and the impact of man on river behaviour), and the possibilities for human habitation and land use in prehistoric and historic times.

Keywords: geomorphology, Holocene, landscape archaeology, Lateglacial, the Netherlands, predictive modelling

Introduction

The Meuse river enters the Netherlands at Eijsden just south of Maastricht and follows a northerly course through the Limburg province and a small, adjacent part of eastern Belgium and the Dutch province of Brabant, towards the Cuijk and Mook area, 165 km downstream (Fig. 1). This part of the river is called the Meuse valley due to its position in a terraced landscape and is the study area of this paper. The Meuse valley landscape developed under the influence of Pleistocene climate changes, tectonics and human activities. Downstream of it, the river bends westward, and runs through a Holocene delta plain landscape to reach the North Sea in its estuary near Rotterdam.

In the study area, the Late Weichselian and Holocene, lowest terrace and floodplain levels are on average 2–5 km wide. This youngest part of the valley geomorphology comprises the Weichselian Lateglacial Interstadial and Younger Dryas river terraces, dissected by Holocene channel belts, and reflects *c.*

15,000 years of fluvial and aeolian landscape formation, human habitation and land use. In the course of time, humans started to influence and shape the landscape. Regional geomorphological–geological studies of the Meuse and larger tributaries include Van den Broek & Maarleveld (1963), Kasse et al. (1995, 2005), Huisink (1997) and Tebbens et al. (1999). These studies focused on the Weichselian Pleniglacial to Younger Dryas landscape development, and mainly covered the northern half of the study area (north of the town of Roermond). Comparable studies for the southern part of the Dutch Meuse valley, such as Paulissen (1973), are relatively rare, and pay more attention to the Holocene geomorphological elements. In part, the difference in research attention is due to the difference in geomorphology of the two sections: a narrow Holocene floodplain in the north and a broader one in the south where the Meuse valley crosses the Roer Valley Graben.

With the start of the 'Maaswerken' project in the mid-1990s and due to the 1992 Valletta (Malta) Convention legislation,

Fig. 1. Research area.

large-scale archaeological research along the Meuse increased significantly. At that time, little was known about human habitation, especially in the Holocene bottom of the Meuse valley (see e.g. Verhart, 2000; Rensink, 2017). Since then an increasing amount of data from excavations and other field studies has revealed a wealth of Meuse valley archaeological sites, ranging in time from Early Mesolithic settlements at Well–Aijen to an 18th-century mass horse grave at Borgharen. Large-scale (>100 ha) water-management, sand- and gravel-extraction and nature-development projects and associated (geo)archaeological research have taken place in, for example, Well–Aijen (Tichelman, 2005; Ellenkamp & Ruijters, 2012; Ter Wal & Tebbens, 2012; Kimenai & Mooren, 2014; Ellenkamp & Ruijters, 2015), Lomm (Gerrets & De Leeuwe, 2011) and Ooijen–Wanssum (Van Kappel et al., 2009; Zuidhoff et al., 2012; Van Putten, 2015; Ruijters et al., 2016). Upstream of Roermond, key sites include Borgharen (Loonen & Van de Graaf, 2013) and Itteren (Meurkens & Tol, 2011). Rensink (2017) provides a detailed description of Meuse valley archaeology.

Unfortunately, the evident richness of archaeological heritage conflicts with the necessity to provide more space and storage capacity for the Meuse river during excessive discharges. To safeguard the downstream regions of the Netherlands from

floods, new river channels are dug and levees are lowered. The looming high costs of archaeological research in large plan areas, totalling several thousands of hectares, until the year 2050 required policy and policy-making tools.

The Cultural Heritage Agency of the Netherlands (RCE), Rijkswaterstaat and the Province of Limburg all reacted to the noted conflict of interest and need for policy. As a consequence of the 1992 Valletta Convention, the process of Archaeological Heritage Management was introduced in the Netherlands. Legislation required archaeology to be firmly incorporated in spatial planning. In areas with a high probability of archaeological sites, initiators of ground-disturbing projects need to start the stepwise research process of desktop, auguring and trenching. Ultimately, this inventory process may reveal sites that need protection, *ex situ* by excavation or, preferably, *in situ*. In the process, local, provincial and state authorities act as inferential government.

The RCE is committed to optimally ensuring cultural heritage (in a wider sense than archaeology) in spatial planning. The national programme of 'Identity and Safety' (Dutch: 'Eigenheid en Veiligheid') focuses on cultural heritage in water-related spatial projects. In 2011 the Province of Limburg started to develop archaeological policy for the Meuse valley. The primary

policy-making aim was to develop proportional research in which the costs of research were proportional to the yield in scientific knowledge. In 2013, RCE, Rijkswaterstaat and the Province of Limburg decided to combine their efforts and collectively pursue a new predictive map for the Meuse valley in Dutch Limburg.

This article describes the conception and main features of two of these policy-making tools: a geomorphogenetic map and an associated archaeological predictive map series of the Meuse valley. Furthermore, a short introduction to landscape evolution of the Meuse valley and human presence during the last 15,000 years is provided. Our contribution does not, however, aim at a comprehensive detailed reconstruction of the Meuse valley landscape genesis with its fluvial terraces and its (pre- and proto-)historic and modern-day inhabitants.

Landscape evolution and habitation

During the Lateglacial Interstadial, the Meuse river lowered its valley floor and formed a meandering channel belt, narrowing relative to the braid plain of the previous stadial stages (Huisink, 1997). During the Younger Dryas, when winter temperatures in northwest Europe dropped to near-glacial values, and vegetation cover and discharge regimes changed accordingly (e.g. Isarin & Renssen, 1999), the Meuse channel belt widened to accommodate increased spring meltwater discharges. Although a (fully) braided style is often assumed to have characterised the river in Younger Dryas times, the morphology of the main channel of that time is not preserved and thus remains unclear. The Meuse main channel may have been a sinuous one, despite the braided style of secondary channels observed in the abandoned river-plain-edge terrace morphology. In that case, a better characterisation of the Younger Dryas situation than 'braided' may be a 'wandering' system, with channels regularly shifting over the valley floor (Cohen, 2003; Cohen et al., 2012). The key to understanding the behaviour is the response of the river to climate and environmental changes, being rapid or more gradual. Under westerly winds extensive dunes were formed on the terraces east of the active river plain (e.g. Isarin et al., 1997).

Traces of human activities during the Younger Dryas stadial may be found on the Interstadial and older terraces close to the active river plain. It may safely be assumed that Late Palaeolithic hunters and gatherers will have exploited food and raw material resources in the plain. However, the dynamic character of the shifting Meuse channels will have erased much, though not all, of the *in situ* evidence during early-spring peak discharges.

The winter and summer temperatures rapidly rose at *c.* 11.7 ka BP, signifying the Pleistocene–Holocene transition and leading to a change from a multichannel wandering to a single-channel meandering river. The Meuse river incised, this lowering of the bed elevation being due to sediment reworking.

Overbank flood deposition of fine-grained, silty sediments took place outside the incising channel belt. The meandering Meuse formed an approximately 1 km wide flood plain, the formation of which gradually slowed down during the relatively stable Middle Holocene. This Mid-Holocene period was preceded by a phase of distinct Early Holocene climate and environmental changes around 6200 BC (8.2 ka event; e.g. Wiersma et al., 2011; Walker et al., 2012). The noted deceleration was caused by the increased forest development of the warm and humid Atlantic period, leading to storage of water in the extensive 'climatic optimum' deciduous forest.

During the Preboreal, Boreal and Atlantic, the pointbars, levees and residual channels must have provided a relatively risk-free, open and naturally rich and varied environment, as testified by Mesolithic to Middle Bronze Age finds in Well–Aijen (e.g. Bouma & Müller, 2014; Kimenai & Mooren, 2014). The relatively stable landscape, with abundant forest cover along and at distance from the river (over time increasingly cleared by humans), led to intensive oxidation and leaching of high-lying sandy soils and to consolidation of the low-lying clayey soils. Most probably, the relatively stable situation changed at the end of the Bronze Age and start of the Iron Age, with an increase of river activity. Although archaeological data are limited (the absence of evidence is not evidence of absence), it is assumed that subsequently habitation moved from the pointbars and levees to the higher and safer Younger Dryas terrace. Clearly, more archaeological data are needed to verify the timing of this shift in habitation. The moment of the shift may very well be asynchronous, depending on local geomorphology.

Project approach

The mapping project consisted of two phases. The first phase focused on mapping the geomorphology of the Meuse valley in Dutch Limburg (Isarin et al., 2014). The second phase was the translation of this geomorphogenetic map (Dutch: Geomorfogenetische Kaart van het Maasdal; GKM) to a series of archaeological predictive maps (Dutch: Archeologische Verwachtingskaart van het Maasdal; AVM). To create a new landscape map in the short time available, the mapping started from expert-judgement and lidar imagery interpretation. No formal written source material synthesis was executed at that stage. During workshops and brainstorm sessions the project team, consisting of earth scientists and geoarchaeologists experienced in Meuse valley landscape development, literally plotted their expertise and field knowledge on the highly detailed height maps of the lidar Digital Elevation Model (DEM) (Dutch: Actueel Hoogtebestand Nederland, AHN; Fig. 3). As a starting point for the GKM, the local-scale geomorphological maps and legend of Zuidhoff & Huizer (2015) and Zuidhoff et al. (2012) were used. These studies produced geomorphological maps for 18 'plan areas' in the northern half of the Meuse valley (north of Roermond),
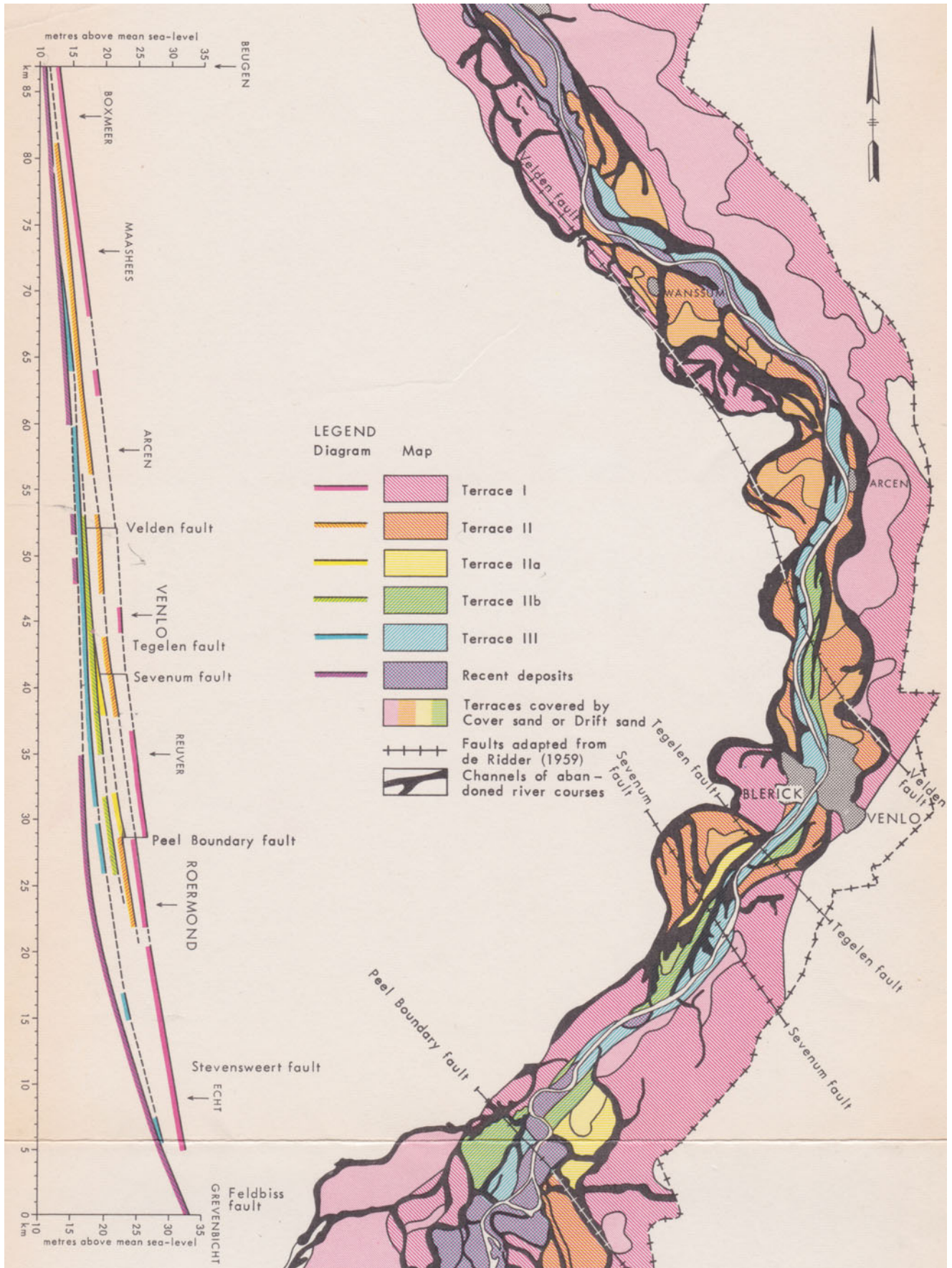
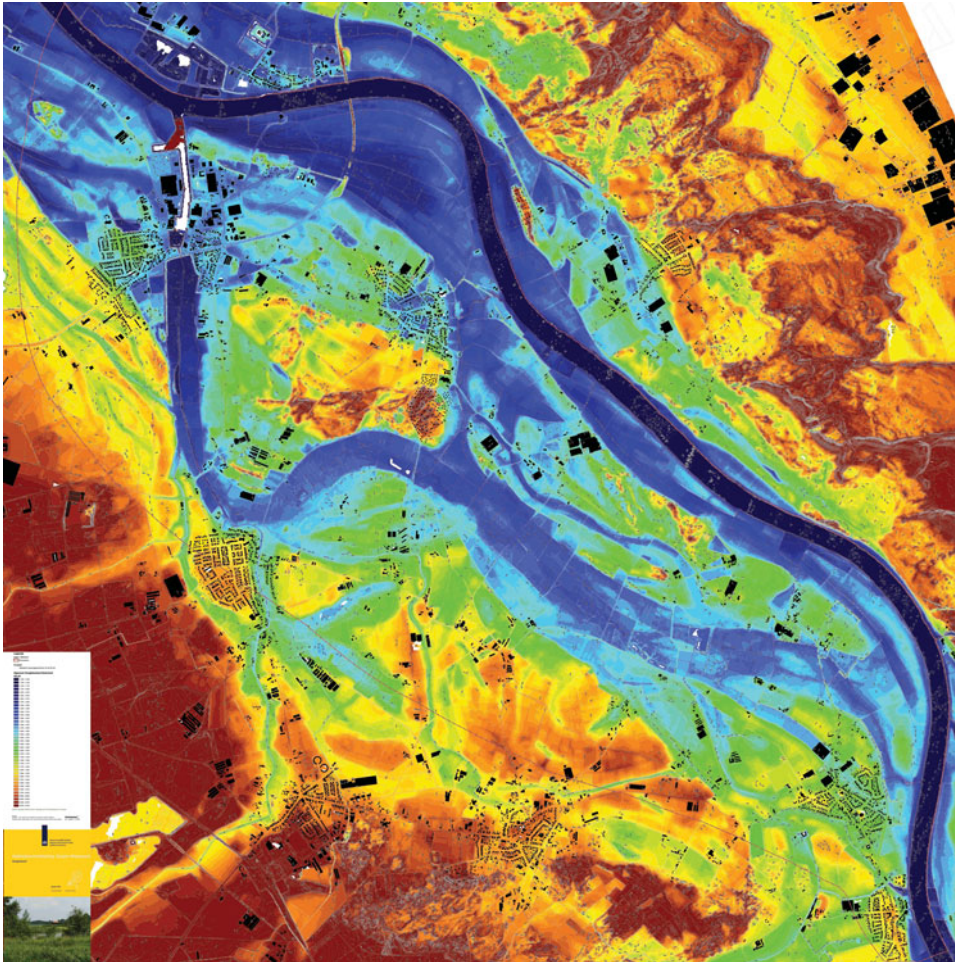Fig. 2. Classical terrace map by Van den Broek & Maarleveld (1963).

Fig. 3. Digital Elevation Model of the Ooijen–Wanssum area, northern Limburg.

supported by 200 lithogenetically interpreted cross-sections. Subsequently, the surrounding areas were mapped by extrapolation from the 'plan areas', primarily using the lidar DEM. The legend was optimised by iteration. Then source material comprising reports, articles, theses and (historical) map series was used as verification for the concept landscape model and concept maps. Finally, the maps were digitised for subsequent GIS-based translation to the archaeological predictive map series.

We conceived the predictive map series of the AVM using a similar strategy to that of its geomorphogenetic predecessor, i.e. by collecting, integrating and synthesising expert judgement gathered from extensive field experience. In practice, the GKM earth-scientific team was expanded with equally experienced archaeologists to form the AVM team. The first challenge was to realise an archaeological predictive model valid for the entire Meuse valley in Dutch Limburg. Predictive models may differ between (geo)archaeologists or research firms. Similar datasets may and do lead to different predictive maps, which in turn may lead to differences in the scope and intensity of research in the case of spatial projects (e.g. Verhagen et al. 2005; Cohen et al. 2014). The GKM provided a solid and uniform basis for this predictive model, whereas the large and representative AVM team provided a wide basis and collective acceptance.

The expert knowledge involved in constructing the predictive map series is primarily based on site-oriented research. At the same time, these sites were used for testing, simply because they constitute the only available archaeological dataset. We realise that, from the perspective of statistical testing of archaeological concepts, both the landscape model and the archaeological predictive model should be separated from the data necessary to test these models. On the other hand, this separation may not be ideal for creating a map that maximally honours all existing earth-scientific landscape data. Logically, data and model are closely related and therefore interacting and interdependent. In other words, the models may not be truly conceptual, based on data that are also present in the personal knowledge and experience of the GKM and AVM teams. Thus, specific data, both raw and interpreted, transformed into information and knowledge, were used for the models and for testing.

Constructing the GKM

The northern section of the GKM is to a large extent based on a relatively large dataset consisting of *c.* 4500 hand-augered borehole descriptions and 200 lithogenetical cross-sections,

oriented to the Meuse valley axis ('Verkenning^PLUS': in English, inventory). In 2012, ADC ArcheoProjecten, a Dutch research firm, started a geoarchaeological coring campaign in 18 research areas located between Mook and Roermond, covering a total of *c.* 2750 ha (Zuidhoff et al., 2012; Zuidhoff & Huizer, 2015). The focus was on lithogenesis instead of the traditional lithology. In addition, 2 × 2 m test pits were used for detailed profile analysis. The primary aim was to map and reconstruct the litho- and morphogenesis of the main potential water-management project areas (see Isarin et al., 2014). In the course of the process, the landscape proved more varied and complex than assumed. Consequently, other litho- and geomorphogenetic units and profile types were incorporated in the landscape model and its legend. In the drawing room, we mapped the lithogenetic units on detailed lidar DEM (Fig. 3) plots using criteria such as channel pattern, relative and absolute heights of the surface and channel deposits (gradient lines), texture and the 'freshness' of the landscape, i.e. the intactness and visibility of the morphology at the present-day surface. Furthermore, we used reference images from comparable present-day rivers, such as the Allier (France) and Wolga (Russian Federation), as well as from recent fluvial sedimentology process research (e.g. Lageweg et al., 2013). Subsequently, hand-drawn boundaries were digitised. The team collectively inspected the digital maps and corrected errors. The conception of the subsequent AVM offered a second round of verification of the GKM, by confrontation with archaeological data, knowledge and expertise.

The GKM shows four dimensions, with x, y (map) as well as z and time (legend). Incorporation of the factor time was essential, in anticipation of the second phase of the project, the translation of the GKM into archaeological predictive maps for four designated archaeological periods. We distinguished five map levels: (1) terraces, (2) fluvial units, (3) age, (4) relatively high (and old) levee and floodplain deposits and (5) relatively low (and young) levee and floodplain deposits (Fig. 6, further below). Added to these five units are specific easily visible elements in the landscape, such as embankments, extraction pits and canals. However, no detailed analysis of surface disturbances was executed.

In general, three Meuse terraces may be distinguished (within the set study area): the Holocene floodplain (H), the Younger Dryas Terrace (D) and the Lateglacial Interstadial Terrace (I). It must be noted that the Lateglacial Interstadial Terrace may include at least two phases of formation (classically placed in the two relatively warm periods of the Bølling and Allerød) and that equally within the Younger Dryas and Holocene floodplain one can see subdivisions, at least locally. Outside the study area, the terrace staircase continues to higher, older levels such as from the Last Glacial (Late Pleniglacial) and older. Small patches of Late Pleniglacial terrace age cannot be fully excluded to have locally preserved within the study area as well (within the Interstadial terrace complex, below Younger Dryas aeolian cover).

In terms of fluvial units, we distinguished floodplains (K after the term 'Kom' in Dutch), levees (O after the Dutch 'Oeverwal'), residual channel (G, referring to 'restGeul'), point-bar (W, 'kronkelWaard'), brook valley (B, 'Beek'), tributary (R, 'zijRivier') and alluvial fan (U, after the Dutch term 'dalUitspoelingswaaier'). Furthermore, a subdivision was made within the terraces based on elevation: a relatively low (L) or relatively high topographical position (H), and unknown (T). At several locations Zuidhoff & Huizer (2015) observed that the Younger Dryas Terrace has at least two development phases, represented by a difference in height (approximately 0.5–1.5 m). The exact genesis and placement in time of this phenomenon are not yet clear. It may be envisaged that the centre of river activity shifted during the course of the Younger Dryas (possibly because of extensive dune formation or choking by coversands, or tectonics) and down-cutting took place, followed by renewed sedimentation by the (semi-)braiding Meuse river (see also Kasse, 1995; Cohen et al., 2012).

Although the existence of an Early Holocene phase of point-bar formation, associated with significant incision during the Pleistocene–Holocene transition, had been recognised before, the true significance of these 'old' pointbars – also in archaeological terms – became clear only during the Well–Aijen project (Kimenai & Mooren, 2014). It turned out that on these point-bars intensive and continuous human activities took place from the Early Mesolithic until the Middle Bronze Age. These data suggest relatively limited river activity during the Early and Middle Holocene. Recent studies at Wanssum suggest that, at least locally, point-bar formation restarted in the course of the Subboreal (Ruijters et al., 2016). A third phase of intensified (most probably partly man-induced) river activity and pointbar formation is attributed to the Roman period (Subatlantic). The recognition of phases of point bar formation (either generic or local) required a chronological subdivision of pointbars (W) and related channels (G) on the GKM:

1. Early Holocene and Middle Holocene (Preboreal–Atlantic, GKM code 1);
2. Mid-Holocene (Subboreal, GKM code 2);
3. Late Holocene (Subatlantic, GKM code 3) not specified;
4. Late Holocene Roman Times–Early Middle Ages (GKM code 4);
5. Late Holocene Late Middle Ages–Modern Times (GKM code 5);
6. Late Holocene nineteenth century (GKM code 6).

It may be clear that due to a lack of areal coverage (and national scale overview; see Hoek et al., 2017) of absolute (^14C, OSL) and relative (pollen, archaeology) dates, and the sheer size of the area under study, it is impossible to attribute accurate absolute ages to the units and features of the GKM. The geomorphogenetic units were mapped, after which an approximate age was attached. Actual direct dates of the units are available from a few geoarcheologically investigated sites and sites of previous research only. As a result, slight diachronicity may be present, for example between geomorphological units on the one hand
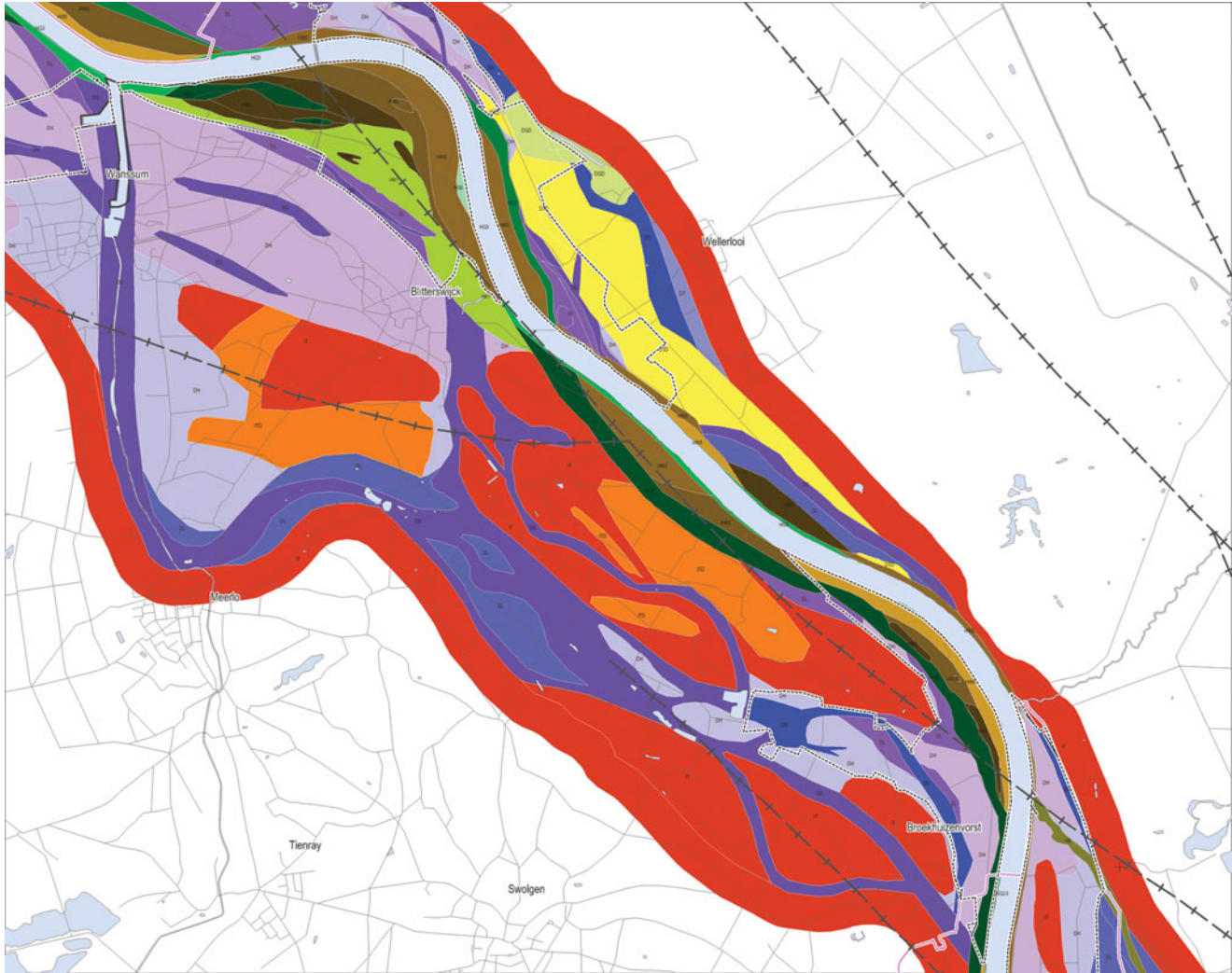
Fig. 4. Cut-out from the GKM: the Ooijen–Wanssum area, northern Limburg.

and periods 1, 2 and 3 on the other. In addition, the phases in the landscape development, being generic or local, synchronous or not, have only recently been recognised. The effects on the behaviour of the Meuse of tributaries and streams, such as the Geleenbeek in Sittard (Ruijters et al., 2015), the Geul (De Moor et al., 2008) and Roer rivers (Van Balen et al., 2017), tectonics (Houtgast & Van Balen, 2000) and the erosion of older fluvial formations, are only partly understood. Therefore, we attempted to provide a relative chronological framework at best, by using available sources, such as historical maps. It must be noted that periods 1–6 become shorter in duration towards the present and thus do not represent equally long periods. Cohen et al. (2014) applied a similar series of decreasing time steps (nine instead of six) in their riverside archaeological predictive mapping (UIKAV). The longer the time period, the more landscape changes may have taken place, making it difficult to capture these in one time slice.

Units four and five in the GKM legend are the relatively old and young levee and floodplain deposits, and aeolian sediments respectively. Sand, silt and clay were deposited and conserved primarily, though not solely, on top of the (pre-)Younger Dryas terrace either as fluvial deposits or as dunes. The relatively old fluvial sediments include the flood deposits of the so-called Wijchen member, dated to the Preboreal and Boreal, as well as the presumed Subboreal levee and floodplain sediments. Dunes formed during the Younger Dryas are present on the eastern bank of the Younger Dryas floodplains (e.g. Kasse, 1995; Isarin et al., 1997). These dunes primarily cover Lateglacial Interstadial or Late Pleniglacial terraces. Their parabolic shape may easily be recognised in the brown colours in the northeast from the present-day Meuse channel (Fig. 3). However, locally, for example in Lomm and Well, the dunes were observed within the Younger Dryas floodplain, albeit restricted in size (Ellenkamp & Ruijters, 2015). The relatively young deposits comprise dunes reworked by wind in the Middle Ages (Dutch: 'Stuifzanden') and late medieval to present-day fluvial flood sediments.

As an example, we include two figures showing a cut-out from the GKM for the Ooijen–Wanssum area (northern Limburg) (Fig. 4) and for the area northwest of Sittard (southern Limburg) (Fig. 5). Figure 4 may be compared with the lidar DEM

Fig. 5. Cut-out from the GKM: northwest of Sittard, southern Limburg.

image (Fig. 3). Note, in red, the Interstadial (or older) terrace between the Younger Dryas terrace remnants and the Holocene channel belt with the present-day Meuse channel to the northeast and a Younger Dryas terrace on the southwest side. Figure 5 shows a relatively wide Holocene channel belt west of the present-day Meuse and a wide Younger Dryas terrace east of the Meuse. See Figure 6 for the legend of the GKM, showing the distinguished geomorphogenetic units.

Constructing the AVM

The AVM is in fact a series of five maps, i.e. a map for four archaeological periods and a cumulative map in which the four distinguished periodic maps are combined. The four archaeological periods distinguished by Groenewoudt & Smit (2014; see also Table 1) are:

- hunter-gatherers and early farmers: Late Paleolithic (12 000 BC) to Middle-Neolithic A (3400 BC). The AVM uses the abbreviation 'JV', after the Dutch 'jagers – Verzamelaars';
- early agricultural societies: Middle-Neolithic B (3400 BC) to Middle-Bronze Age (1500 BC). The AVM uses the abbreviation 'LBV', after the Dutch 'LandBouwers Vroeg';

- late agricultural societies: Middle-Bronze Age (1500 BC) to Early Middle Ages C (AD 900). The AVM uses the abbreviation 'LBL', after the Dutch 'LandBouwers Laat';
- state societies: Early Middle Ages C (AD 900) to present day (AD 1950). The AVM uses the abbreviation 'SSL', after the Dutch 'StaatsSamenLevingen'.

For each of these four periods, four main cultural themes were specified, according to Rensink & Van Doesburg (2015):

- habitation, including defence, signified with the letter 'W' (Dutch: 'Wonen');
- burial signified with the letter 'B' (Dutch: 'Begraving');
- economy and infrastructure, signified with the letter 'E' (Dutch: 'Economie');
- rituals, signified with the letter 'R' (Dutch: 'Rituelen').

For both 'economy and infrastructure' and 'rituals' we distinguished between a wet (w) and dry (no code) setting variety.

It is beyond the scope of this article to describe in detail the conception of the AVM. The concepts are quite similar to those applied in the mapping project for the downstream part of the Meuse and the Dutch Rhine river branches: the 'Archeologische Verwachtingskaart Uiterwaarden Rivierengebied' (UIKAV; Cohen et al. 2014). These authors applied a base prediction
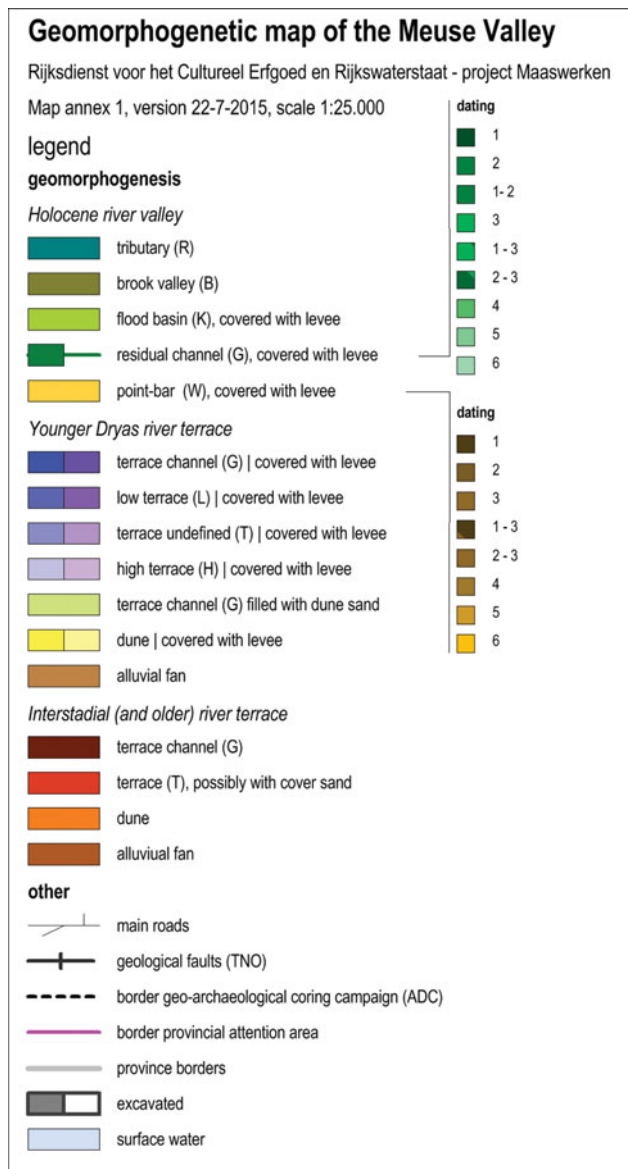
Geomorphogenetic map of the Meuse Valley

Rijksdienst voor het Cultureel Erfgoed en Rijkswaterstaat - project Maaswerken

Map annex 1, version 22-7-2015, scale 1:25.000

legend

geomorphogenesis

Holocene river valley

tributary (R)

brook valley (B)

flood basin (K), covered with levee

residual channel (G), covered with levee

point-bar (W), covered with levee

Younger Dryas river terrace

terrace channel (G) | covered with levee

low terrace (L) | covered with levee

terrace undefined (T) | covered with levee

high terrace (H) | covered with levee

terrace channel (G) filled with dune sand

dune | covered with levee

alluvial fan

Interstadial (and older) river terrace

terrace channel (G)

terrace (T), possibly with cover sand

dune

alluvial fan

other

main roads

geological faults (TNO)

border geo-archaeological coring campaign (ADC)

border provincial attention area

province borders

excavated

surface water

dating
1
2
1 - 2
3
1 - 3
2 - 3
4
5
6

dating
1
2
3
1 - 3
2 - 3
4
5
6

Fig. 6. Legend of the GKM (see Figs 4 and 5).

using landscape zonation polygon-by-polygon, and locally raised the scores on additional criteria (features noted on municipal maps, nationally protected areas). The actual implementation in our maps, however, differs: we also apply a base prediction based on landscape zonation, and for specific locations in the landscape (e.g. confluences of brooks with the Meuse terraces affecting distance to water source) further location-based scores are added (via buffer polygons calculated in GIS). We now stepwise focus on the main stages of the, strongly iterative, production process of the AVM.

The first step was identification of habitation and land-use models (Dutch: 'Bewoningsbeelden'). The limited number of available excavated, well-documented and well-dated sites hampers an inductive way of constructing the AVM. Therefore, instead of focusing on the statistically established and quantitative habitation–landscape relation, we applied more qualita-

tive habitation models, based on the generally accepted, generic relation between landscape (high, dry and safe versus wet and risky terrain) and human activities, such as habitation, hunting, agriculture, burial and rituals, in the past. The identification of the habitation and land-use models, based on and starting from the map units in the GKM (e.g. dune, pointbar from time period '1' or relatively low part of the Younger Dryas terrace) and the four archaeological periods and cultural themes mentioned above, was one of the main tasks of the AVM team.

Secondly, to construct the habitation and land-use model and to calibrate the connection of the model to landscape units, we identified key sites and reference sites. Archaeological key sites are the best-documented and most informative archaeological sites within the research area. Reference sites are comparable sites, located outside the Meuse valley, but relevant for understanding the landscape–human-activity relation. At the same time, we assigned an archaeological base prediction to the GKM's geomorphogenetical units by applying generic and specific knowledge of the Meuse valley landscape and the expert-judgemental habitation models (see step 1). In practice, this step meant a simple 'yes' or 'no' to the question whether specific geomorphogenetic units were available to and used by humans during a specific period. Not surprisingly, GKM units such as 'dunes located on relatively high parts of the Younger Dryas terrace' turned out to be preferred locations for all of the four distinguished cultural themes or activities in all four periods.

The base prediction (step 3) is the first of two building blocks of the AVM. The second block is the systematic refinement of the basic prediction by specification (step 4) and operationalisation (step 5) of so-called supplementary location criteria. Evidently, the basic prediction is rather general, hampering statements about chances to find specific sites. Some of the GKM's units are in fact significantly large areas that require a more refined prediction model. We define supplementary criteria as the generic site-location factors related to the natural environment, such as the distance to open water sources or to a specific gradient zone. These landscape-related factors identify differences in human activities between and within geomorphogenetic units. For the AVM, supplementary criteria were defined for the habitation (W) and burial (B) themes only. Obviously, and in contrast to the two other cultural themes – economy and infrastructure, and rituals – activities related to habitation and burial require the best landscape positions. The supplementary criteria are:

1. distance to the (during that specific period) active Meuse;
2. distance to the mouth (confluence) of the Meuse tributaries;
3. distance to the next terrace level, often marked by a distinct and steep rise in height and vegetation change;
4. 'dry and fertile'. This criterion describes the way specific units are drained, suited for agriculture and located high enough for safe habitation. The GKM legend implicitly includes sand sorting and grain size;
5. distance to the water source, other than 1 and 2.

Table 1. *Geological and archaeological chronology of the Meuse valley geomorphogenetic (GKM) and archaeological (AVM) map series.*

GKM dating		Geological period	Start of period	Archaeological four-period system	Archaeological main period
1		Preboreal	9700 BC		Mesolithic
		Boreal	8700 BC		
		Atlantic	7300 BC	Hunter-gatherers and early farmers	
			5300 BC		Neolithic
2		Subboreal	3700 BC		
			3400 BC	Early agricultural societies	
			2000 BC		Bronze Age
			1500 BC		
			800 BC		Iron Age
3			450 BC	Late agricultural societies	
	4		15 BC		Roman period
			AD 450		Early medieval period
		Subatlantic	AD 900		
	5		AD 1050	State societies	Late medieval period
			AD 1500		Post-medieval and modern period
	6		AD 1800		

For example, a value of 190 m for the distance to the Meuse, confluence and water sources other than the former two was calculated for the period of hunter-gatherers and early farmers, by statistically analysing all the predictive maps of Meuse valley municipalities.

The criteria were subsequently awarded weight, depending on their importance for and contribution to the choice of location in the past. For instance, we considered the distance to the active river in the periods of the hunter-gatherers and early farmers ('JV') and early agricultural societies ('LBV') of greater importance than in later times.

We ultimately generated the AVM maps by simply adding the scores of the basic and supplementary prediction. The higher the predictive scores, the higher the potential of finding sites from that specific period during field research. The maps were then validated in two stages using the national archaeological database, ARCHIS2. In the first stage, all ARCHIS records (i.e. 17,463 records, corresponding to a single find) within the study area were used to calculate the correlation between the appearance of period-specific sites and their corresponding predictive areas. Overall this showed a relatively good correlation, varying from 58% to 100%. In the second stage an edited version of the ARCHIS2 database was used. The raw dataset contains single finds, whereas the dataset of the edited version is narrowed to correctly dated sites gathered by archaeological excavations. This resulted in a dataset of 684 records, each representing a 'pure' archaeological site. In general, the correlation

between an archaeological site and its AVM prediction is high for the base prediction (>72%). For the supplementary prediction, however, a clear distinction is observed for the older periods (JV and LBV) where the correlation is relatively low (35–64%) and the younger periods (LBL and SSL) where the correlation is relatively high (93–100%). There are several explanations for this, but most likely the effect of increasing uncertainty with increasing age (for knowledge about geomorphogenesis as well as archaeology) is the main factor. See Ellenkamp (2015) and Isarin et al. (2015) for a detailed account of the validation process.

As an example, Figure 7 shows a cut-out from the AVM periodic map of hunter-gatherers and early farmers for the Ooijen–Wanssum area. The orange and reddish colours signify the zones with relatively high predictive values, i.e. near the active channel belt (white) and residual channels (light blue). The associated legend is presented in Figure 8.

Discussion

The add-on value of the GKM and AVM map series, in comparison to traditional earth-scientific and predictive maps, results from the combined use of (1) information on landscape evolution (morphology, genesis, lithology, soil) and (2) habitation and land-use models specified for four different archaeological time periods. This integration enables the coupling of landscape
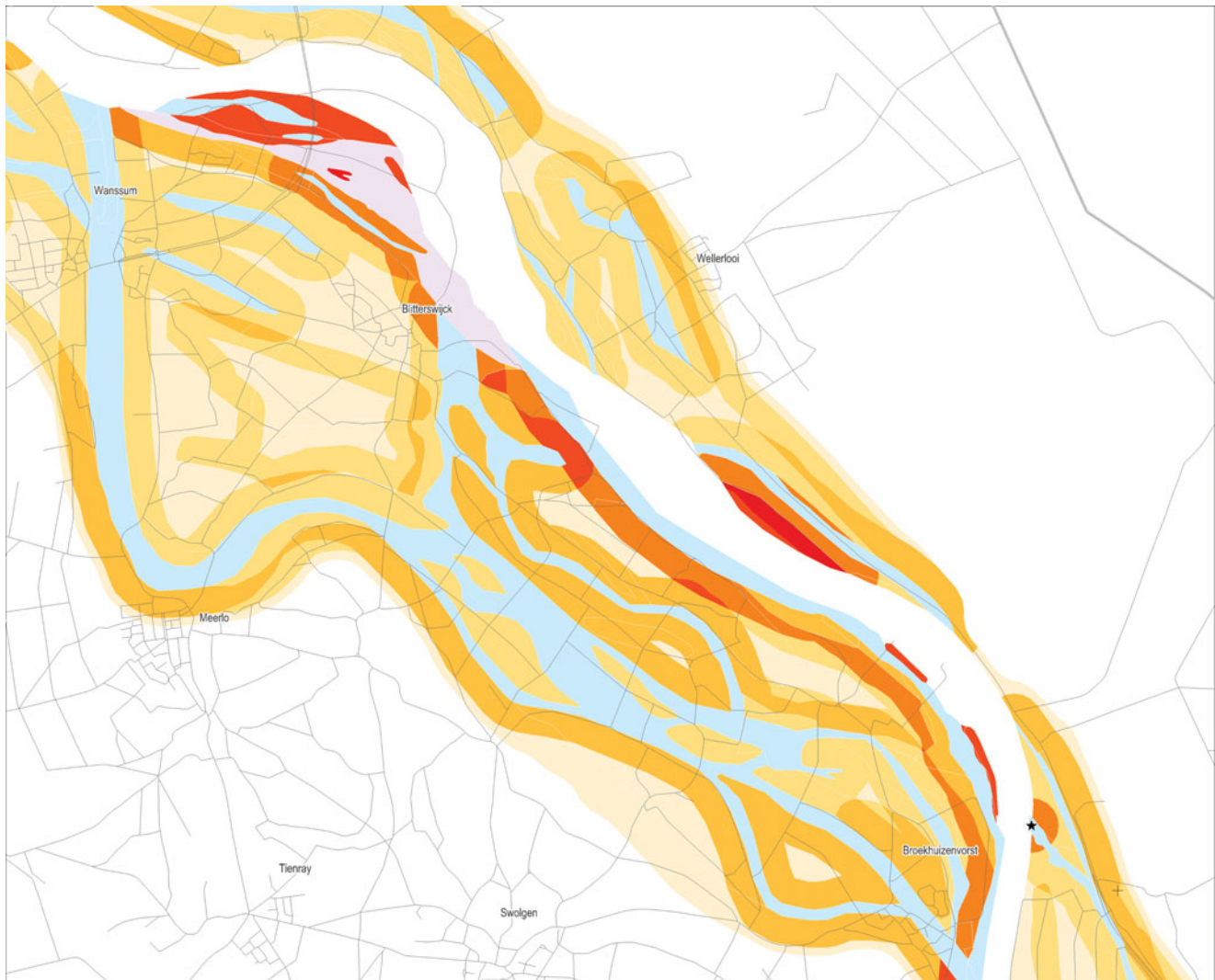
Fig. 7. Periodic map of hunter-gatherers ('JV'). Cut-out from the AVM for the Ooijen–Wanssum area, northern Limburg.

use and human behaviour in the past with specific parts of the fluvial landscape of the Meuse valley through time.

It should be noted that for the AVM series, the scale of the predictive maps is an issue. The reliability of large-scale maps such as the GKM and AVM strongly depends on the availability of field data. Fieldwork intensity varies between areas, and even within one and the same research area. Consequently, the representativity of the collected data should be taken into account. The augering campaign in a plan area in Ooijen–Wanssum using a 17 × 20 m grid (Van Putten, 2015) provided highly detailed lithogenetic information. In comparison, the number of landscape-reconstruction oriented cores in the preceding inventory phase was only 429 (Zuidhoff et al., 2012), as opposed to Van Putten's 3520 cores used to map both landscape details and archaeological site loci. Overall, it should be stressed that information from the northern section of the GKM (*c.* 83 Meuse kilometres, downstream of Roermond) is more accurate than the southern section. This is primarily due to the approximately 200 lithogenetic profiles (on average, every 500 m) referred to above.

Extrapolations from these areas and interpretations are to a significant extent based on lidar DEM data. The more pronounced the height differences are, the more reliable the GKM map and therefore also the AVM are. On the other hand, a large flat area has fewer polygon boundaries than a highly accentuated terrain. As a consequence, this part of the map is more accurate and more reliable. The more categories of relative elevation there are, the more map reliability is hampered. In general, the differences in surface height decrease going downstream. In spite of these difficulties related to extrapolation and interpretation, we consider the landscape to be the principal basis for understanding and predicting human habitation and activities. Therefore, we believe that the underlying concepts of our landscape and predictive model are strong. Since the archaeological periods considered largely pre-date organised states, the high degree of 'landscape determinism' of the approach is defensible.

Ideally, the GKM and AVM are used by the Limburg and Noord-Brabant provinces and 'Meuse municipalities' and incorporated into their predictive maps (or at least used as a
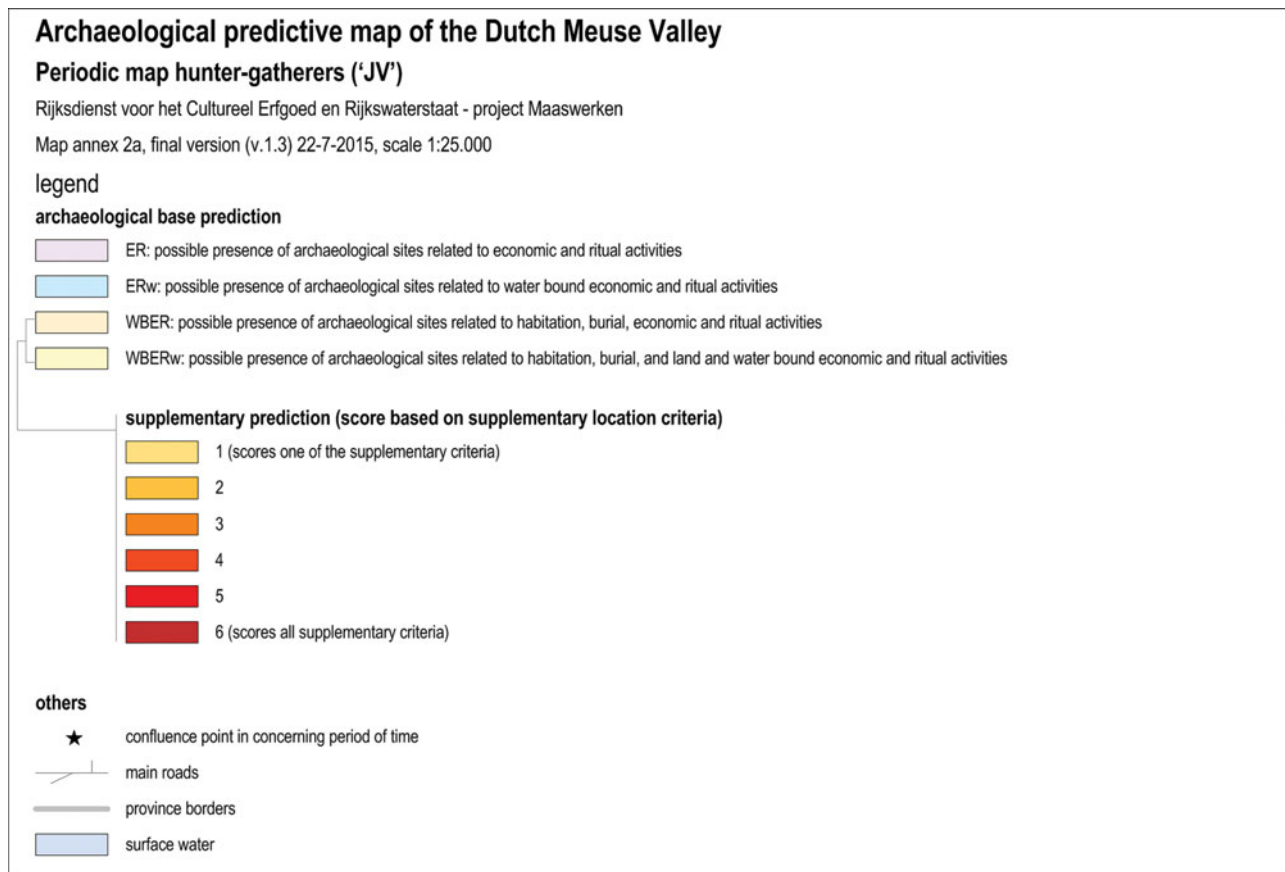
Archaeological predictive map of the Dutch Meuse Valley

Periodic map hunter-gatherers ('JV')

Rijksdienst voor het Cultureel Erfgoed en Rijkswaterstaat - project Maaswerken

Map annex 2a, final version (v.1.3) 22-7-2015, scale 1:25.000

legend

archaeological base prediction

ER: possible presence of archaeological sites related to economic and ritual activities

ERw: possible presence of archaeological sites related to water bound economic and ritual activities

WBER: possible presence of archaeological sites related to habitation, burial, economic and ritual activities

WBERw: possible presence of archaeological sites related to habitation, burial, and land and water bound economic and ritual activities

supplementary prediction (score based on supplementary location criteria)

1 (scores one of the supplementary criteria)

2

3

4

5

6 (scores all supplementary criteria)

others

★ confluence point in concerning period of time

main roads

province borders

surface water

Fig. 8. Legend of the AVM (see Fig. 7).

secondary reference) and archaeological policy. Initiators and spatial planners may also use the AVM, for it is relatively easy and straightforward to translate the periodic predictive maps into risk maps. The maps allow for avoiding the risk of delays and high budgets for investigations, and thus for a priori *in situ* conservation of archaeological sites. Although the maps may in the first place serve as a pragmatic tool for policy-making and optimising research strategy tools in heritage management, and as a basis for optimising spatial plans (water management, sand and gravel extraction and nature development), the scientific value of the GKM and AVM series is evident. The GKM makes a clearer discrimination within the Holocene floodplain, and between the Younger Dryas and Early Holocene geomorphological units, than hitherto available. Furthermore, during the conception of the maps the Early Holocene phase itself was better understood, whereas the Middle and Late Holocene were contrasted as being very different to the earlier phases.

Future research

The wide basis and collective acceptance for the predictive model underlying the AVM is certainly positive, but does not guarantee scientific quality in the long term. It is absolutely necessary

that geological and archaeological data from future research be used as input for improvement of the models and ultimate maps. Available and future palaeoecological and chronological data should be incorporated to provide a better time control of both landscape changes and human activities (Hoek et al., 2017; Zuidhoff & Bos, 2017). Moreover, the GKM and AVM map series cover the Holocene bottom of the Meuse valley and adjacent (sections of) Lateglacial terraces only, leaving the Interstadial and Pleniglacial landscape and its inhabitance out of consideration.

It may be noted that the ultimate archaeological predictive model was somewhat biased to the latest data (especially from Well–Aijen and Ooijen–Wanssum) and thus quite fresh at the time of adopting and applying it. Future archaeological research results must be used to test the validity of the models and underlying assumptions. New data may show differences in habitation patterns and site distribution between the various landscapes of the 165 km long Meuse valley.

Due to the increased effort to understand the landscape, the different phases of pointbar and levee formation have only recently been recognised. The lack of time control is reflected in the GKM and AVM by the modelled and fairly rigid distinction of six phases. Testing of both maps is a crucial part of Malta-based archaeology in the Limburg Province and its Meuse

municipalities and, ideally, those of the province of Noord-Brabant and the neighbouring parts of Belgium. This testing requires adequate dating of archaeological sites and sediments, for example by ceramic or flint typology, accelerator mass spectrometry (AMS) and optically stimulated luminescence (OSL) dating. Moreover, it is required that lidar DEM data from the Belgian part of the Meuse valley are incorporated in a new version of the GKM.

The increased accuracy of geomorphology mapping, thanks to the lidar data, reveals a stronger sense of the lack of local dating. However, Malta-based archaeology research programmes may not provide all the chronological answers we require in the near future. We therefore still need upgraded geomorphogenetic understanding, for which the GKM is a starting point. At the same time, archaeological landscape occupancy models for different time periods need constant improvement, for which the AVM series and methodology provide a starting point.

Finally, it is crucial that researchers can notify their observations at a central point, to enable modifications and improvements to both maps and the underlying landscape and archaeological model. If not, the maps lose their dynamics and validity, turning the predictive archaeological map series into a more traditional static one.

Acknowledgements

References

Bouma, *N.* & *Müller*, *A.* (eds.), 2014. Tienduizend jaar landschaps- en bewoningsgeschiedenis tussen Well en Aijen. Een verkennend en waarderend onderzoek in de deelgebieden 1 en 4 en een archeologische opgraving in deelgebied 2 te Well-Aijen Hoogwatergeul werkvak 4. ADC Rapport 3472 (Amersfoort).

Cohen, *K.M.*, 2003. Differential subsidence within a coastal prism. Late-Glacial – Holocene tectonics in the Rhine–Meuse delta. Netherlands Geographical Studies 316: 172 pp.

Cohen, *K.M.*, *Stouthamer*, *E.*, *Pierik*, *H.J.* & *Geurts*, *A.H.*, 2012. Rhine–Meuse Delta Studies' Digital Basemap for Delta Evolution and Palaeogeography. Department of Physical Geography, Utrecht University (Utrecht). Digital Dataset. DANS. https://doi.org/10.17026/dans-x7g-sjtw.

Cohen, *K.M.*, *Arnoldussen*, *S.*, *Erkens*, *G.*, *Van Popta*, *Y.T* & *Taal*, *L.J.*, 2014. Archeologische Verwachtingskaart Uiterwaarden Rivierengebied. DELTARES – Rijksuniversiteit Groningen – Universiteit Utrecht. Digital Dataset & Report. DANS. https://doi.org/10.17026/dans-zbt-xcck.

De Moor, *J.J.W.*, *Kasse*, *C.*, *Van Balen*, *R.T.*, *Vandenberghe*, *J.* & *Wallinga*, *J.*, 2008. Human and climate impact on catchment development during the Holocene: Geul river, the Netherlands. Geomorphology 98: 316–339.

Ellenkamp, *G.R.*, 2015. Archeologische verwachtingskaart Maasvallei – technisch document. RAAP Adviesdocument 771 (Weesp).

Ellenkamp, *G.R.* & *Ruijters*, *M.H.P.M.*, 2012. Depotlocatie Maaspark te Well Gemeente Bergen. Archeologisch vooronderzoek: een inventariserend veldonderzoek (Kartering plus). RAAP Rapport 2601 (Weesp).

Ellenkamp, *G.R.* & *Ruijters*, *M.H.P.M.*, 2015. Gewikt en voor de ruggen gekozen. Vergrote Voorhaven Noord Maaspark Well, gemeente Bergen; archeologisch vooronderzoek: een bureau- en inventariserend veldonderzoek tot en met waarderende fase. RAAP Rapport 3060 (Weesp).

Gerrets, *D.A.* & *De Leeuwe*, *R.* (red.), 2011. Rituelen aan de Maas. Lomm Hoogwatergeul fase II, een archeologische opgraving. ADC Rapport 2333 (Amersfoort).

Groenewoudt, *B.* & *Smit*, *B.*, 2014. Archeologisch vierperioden systeem. Project Best practices prospectie, Project Verwachtingen in Lagen, Rijksdienst voor het Cultureel Erfgoed (Amersfoort).

Hoek, *W.Z.*, *Lammertsma*, *E.*, *Bohncke*, *S.*, *Bunnik*, *F.*, *Kasse*, *C.*, *Schokker*, *J.* & *Westerhoff*, *W.*, 2017. Lateglacial and early Holocene vegetation development and fluvial system changes in the northern Meuse valley, the Netherlands: a review of palynological data. Netherlands Journal of Geosciences / Geologie en Mijnbouw, this issue.

Houtgast, *R.F.* & *Van Balen*, *R.T.*, 2000. Neotectonics of the Roer Valley Rift System, the Netherlands. Global and Planetary Change 27(1): 39–52.

Huisink, *M.*, 1997. Late-glacial sedimentological and morphological changes in a lowland river in response to climatic change: the Maas, southern Netherlands. Journal of Quaternary Science 12(3): 209–223.

Isarin, *R.F.B.* & *Renssen*, *H.*, 1999. Reconstructing and modelling Late Weichselian climates: the Younger Dryas in Europe as a case study. Earth-Science Reviews 48: 1–38.

Isarin, *R.F.B.*, *Renssen*, *H.* & *Koster*, *E.A.*, 1997. Surface wind climate during the Younger Dryas in Europe as inferred from aeolian records and model simulations. Palaeogeography, Palaeoclimatology, Palaeoecology 134: 127–148.

Isarin, *R.*, *Ellenkamp*, *R.*, *Heunks*, *E.*, *De Kramer*, *J.*, *Paulussen*, *R.*, *Tebbens*, *L.* & *Zuidhoff*, *F.*, 2014. Verantwoording methodiek en kaartbeeld van de Geomorfogenetische Kaart van het Maasdal tussen Mook en Eijsden, Rijksdienst voor het Cultureel Erfgoed (Amersfoort).

Isarin, *R.*, *Rensink*, *E.*, *Ellenkamp*, *R.* & *Heunks*, *E.*, 2015. Verantwoording methodiek en kaartbeeld van de Archeologische Verwachtingskaart Maasdal (AVM) tussen Mook en Eijsden. Rijksdienst voor het Cultureel Erfgoed (Amersfoort).

Kasse, *C.* 1995. Younger Dryas cooling and fluvial response (Maas River, The Netherlands). Geologie en Mijnbouw 74: 251–256.

Kasse, *C.*, *Vandenberghe*, *J.* & *Bohncke*, *S.*, 1995. Climatic change and fluvial dynamics of the Maas during the late Weichselian and early Holocene. European

river activity and climate change during the Late Glacial and early Holocene. Palaoklimaforschung / Paleoclimate Research 14: 123–150.

Kasse, *C.*, *Hoek*, *W. Z.*, *Bohncke*, *S. J. P.*, *Konert*, *M.*, *Weijers*, *J. W. H.*, *Cassee*, *M. L.* & *Van der Zee*, *R. M.*, 2005. Late Glacial fluvial response of the Niers-Rhine (western Germany) to climate and vegetation change. Journal of Quaternary Science 20: 377–394.

Kimenai, *P.* & *Mooren*, *J.R.*, 2014. Steentijdsites langs de Maas. Hoogwatergeul Well–Aijen, Werkvak 2, Inventariserend Veldonderzoek. BAAC Rapport A-10.0340 ('s-Hertogenbosch).

Lageweg, *W. I.*, *Van Dijk*, *W. M.* & *Kleinhans*, *M. G.*, 2013. Channel belt architecture formed by a meandering river. Sedimentology 60(3): 840–859.

Loonen, *A.* & *Van de Graaf*, *W.S.*, 2013. Het massapaardengraf van Borgharen. Archeodienst Rapport 558 (Zevenaar).

Meurkens, *L.* & *Tol*, *A.J.*, 2011. Grafvelden en greppelstructuren uit de ijzertijd en Romeinse tijd bij Itteren (gemeente Maastricht). Opgraving Itteren-Emmaus vindplaatsen 1 & 2. Archol Rapport 144 (Leiden).

Paulissen, *E.*, 1973. Geomorfologie en Kwartair-stratigrafie van de Maasvallei in Belgisch Limburg, Verhandelingen van de Koninklijke Academie voor Wetenschappen, Letteren en Schone Kunsten. Klasse der Wetenschappen, Brussel (Brussels).

Rensink, *E.*, 2017. Archaeological heritage management in the Meuse valley from a national perspective: aims, methods and results. Netherlands Journal of Geosciences / Geologie en Mijnbouw, this issue.

Rensink, *E.* & *Van Doesburg*, *J.*, 2015. Clustering van groepen complextypen naar hoofdthema's. Project Best Practices prospectie, Project Verwachtingen in Lagen, Rijksdienst voor het Cultureel Erfgoed (Amersfoort).

Ruijters, *M.H.P.M.*, *Ellenkamp*, *G.R.* & *Tichelman*, *G.*, 2015. De beek die geeft en de beek die neemt. Plangebied Ligne, gemeente Sittard-Geleen. Archeologisch onderzoek: een archeologische begeleiding protocol opgraving. RAAP Rapport 2989 (Weesp).

Ruijters, *M.*, *Van Dijk*, *X.C.C.*, *Ellenkamp*, *G.R.* & *Tichelmann*, *G.*, 2016. Archeologische proefsleuven in onderzoeksgebied Ooijen-Wanssum Gemeenten Venray en Horst aan de Maas Archeologisch vooronderzoek: een inventariserend veldonderzoek (proefsleuven). RAAP Rapport 3153 (Weesp).

Tebbens, *L. A.*, *Veldkamp*, *A.*, *Westerhoff*, *W.* & *Kroonenberg*, *S. B.*, 1999. Fluvial incision and channel downcutting as a response to Late-glacial and Early Holocene climate change: the lower reach of the River Meuse (Maas), The Netherlands. Journal of Quaternary Science 14(1): 59–75.

Ter Wal, *A.* & *Tebbens*, *L. A.*, 2012. Well-Aijen Werkvak 1. Archeologische opgraving. BAAC Rapport A-09.0395 ('s-Hertogenbosch).

Tichelmann, *G.* (red.), 2005. Archeologisch Onderzoek in het kader van De Maaswerken. Inventariserend Veldonderzoek (IVO), waarderende fase Well-Aijen. ADC Rapport 404 (Amersfoort).

Van Balen, *R.*, *Kasse*, *C.* & *Bohncke*, *S.J.P.*, 2017. Fluvial system change and rapid incision during the last glacial–interglacial transition, Roer river, the Netherlands. Netherlands Journal of Geosciences / Geologie en Mijnbouw, this issue.

Van den Broek, *J.M.M.* & *Maarleveld*, *G.C.*, 1963. The Late-Pleistocene terrace deposits of the Meuse. Mededelingen van de Geologische Stichting 16: 13–24.

Van Kappel, *K.*, *Hanemaaijer*, *M.*, *Zuidhoff*, *F.S* & *Bos*, *J.A.A.*, 2009. Hoogwatergeul, Wanssum, Gemeente Meerlo-Wanssum. Een Inventariserend Veldonderzoek in de vorm van een verkennend booronderzoek en een oppervlaktekartering. ADC Rapport 1865 (Amersfoort).

Van Putten, *M.J.*, 2015. Gemeenten Horst aan de Maas en Venray. Gebiedsontwikkeling Ooijen - Wanssum te Ooijen en Wanssum. Inventariserend veldonderzoek (karterende fase plus). BAAC Rapport V-13.0227 ('s Hertogenbosch).

Verhagen, *Ph.*, *Deeben*, *J.*, *Hallewas*, *D.*, *Zoetbrood*, *P.*, *Kamermans*, *H.* & *Van Leusen*, *M.*, 2005. A review of predictive modeling for archaeological heritage management in the Netherlands. *In*: Berger, J.-F., Bertoncello, F., Braemer, F., Davtian, G. & Gazenbeek, M. (eds): Temps et espaces de l'homme en sociéte; analyses et modèles spatiaux en archéologie. XXVe rencontres internationales d'archéologie et d'histoire d'Antibes. Éditions APDCA (Antibe): 83–92.

Verhart, *L.B.M.*, 2000. Times fade away. The neolithisation of the southern Netherlands in an anthropological and geographical perspective. Archaeological Studies Leiden University 6 (Leiden).

Walker, *M.J.C.*, *Berkelhammer*, *M.*, *Bjorck*, *S.*, *Cwynar*, *L.C.*, *Fisher*, *D.A.*, *Long*, *A.J.*, *Lowe*, *J.J.*, *Newnham*, *R.M.*, *Rasmussen*, *S.O.* & *Weiss*, *H.*, 2012. Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy). Journal of Quaternary Science 27(7): 649–659.

Wiersma, *A.P.*, *Roche*, *D.M.* & *Renssen*, *H.*, 2011. Fingerprinting the 8.2 ka event climate response in a coupled climate model. Journal of Quaternary Science 26(1): 118–127.

Zuidhoff, *F.S.* & *Bos*, *J.A.A.*, 2017. Sedimentation and vegetation history of a buried Meuse terrace during the Holocene in relation to the occupation history (Limburg, the Netherlands). Netherlands Journal of Geosciences / Geologie en Mijnbouw, this issue.

Zuidhoff, *F.S.* & *Huizer*, *J.*, 2015. Vijftienduizend jaar landschapsdynamiek tussen Roermond en Mook. Inventariserend archeologisch onderzoek 'Verkenning Plus Project Maasvallei' voor vijftien plangebieden, Amersfoort. ADC Monografie 19 / ADC Rapport 3750 (Amersfoort).

Zuidhoff, *F.S.*, *Huizer*, *J.* & *De Jonge*, *N.*, 2012. Gebiedsplan Ooijen – Wanssum, gemeente Horst a/d Maas en Venray. Inventariserend archeologisch onderzoek 'Verkenning Plus' Project Maasvallei Deelgebieden Hoogwatergeul Ooijen, Kop van Ooijen, Hoogwatergeul Wanssum en Wanssum haven. ADC Rapport 3183 (Amersfoort).