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Tracing Settlement Patterns and Channel Systems in Southern Mesopotamia Using Remote Sensing

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The integration of spatial datasets from historical satellite imagery, digital elevation models (DEMs), and past archaeological surveys provides new insights into the nature and remains of past landscape transformations. Using southern Mesopotamia as a case study, this article addresses, both quantitatively and qualitatively, long-held assumptions concerning the nature and relationship of settlement patterns and river channel systems in antiquity. GIS and image analysis are used to fill in gaps in the settlement record and propose a revised location for the Tigris River during most of antiquity. Given that only one-third of the central alluvial plain had been ground surveyed in southern Mesopotamia, how complete was our picture of landscape and settlement? How could gaps in settlement be interpreted? The present work in the area east of Baghdad suggests that archaeologists and historians have underestimated the nature and movements of the Tigris River. Satellite imagery can help reveal the location of the Tigris River prior to its settling into its modern course, shedding light on its potential role in the rise of early Mesopotamian agricultural societies. The work presented here proposes a methodology for unweaving and mapping preserved pieces of ancient landscapes, addressing larger issues of human modification of the landscape.

Keywords: GIS, Landscape, Remote sensing, River channels, Settlement patterns, Southern Mesopotamia

Introduction

Ancient Mesopotamia (southern Iraq) witnessed the rise and collapse of the earliest urban societies in the ancient world. Archaeologists and ancient historians recognize that physical and environmental conditions and the cultural landscape (human-made or -induced actions) have played an important role in shaping and constraining the development of these societies (Adams 1981; Algaze 2008; Wilkinson 2003; Rothman 2004). At the intersection of the ancient natural and cultural landscapes in southern Mesopotamia, was a network of fanning and branching river channels lined with settlements. Originating from the Tigris and Euphrates rivers, these channels provided inhabitants of the plain with reliable access to water for the irrigation of crops, as well as a way to move people and goods from city to city. The networks of channels along with mounded archaeological sites are clearly visible on the flat alluvial plains of southern Iraq today.

Despite centuries of on-the-ground archaeological investigation, the impact of long-term human modification of this ancient landscape remains an obstacle to reconstructing ancient Mesopotamian society (Adams 1981; Wilkinson 2003). Past models have tried to capture the complexity of the ancient landscape using a combination of archaeological, textual, and environmental data. The models were incomplete given acknowledged gaps in the archaeological settlement record (Adams 1981; Pournelle 2003; Hritz 2004) and questions about the impact of the movements of the Euphrates and Tigris rivers and their branches over time. This article demonstrates that the integration of data from satellite imagery, historical maps, digital elevation models (DEMs), and previous archaeological surveys provides new insights into the complexity of past landscape transformation. Using GIS tools, it is possible to address questions about past human-environment interactions and to begin to map these interactions on the modern landscape. GIS methods of georeferencing, or transforming disparate datasets into the same spatial coordinate system and layering data from different chronological periods that emphasize a variety of landscape features, are employed to fill in gaps in the archaeological settlement pattern on the plain and to propose a revised location for the course of the Tigris River in antiquity. This proposed course is visible as a relict levee in the satellite imagery and as topography in the DEM; its location and morphology would have opened up the eastern portion of the plain to early cultivation without the aid of water lifting devices, suggesting that the Tigris

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Figure 1 Map of Iraq showing the Euphrates and Tigris rivers and the area of interest.

played a more important role in early irrigation agriculture than accounted for by past models.

Geography and the Ancient Landscape

Mesopotamia is located in a flat alluvial plain between the modern Tigris and Euphrates rivers (FIG. 1). It is topographically bounded on the north and east by the Zagros Mountains and on the west by the western desert. The plain is a large basin or geosyncline (Buringh 1960: 35) composed of the accumulated soils and sediments eroded from the uplands of Iran, Syria, and Turkey, and brought down to the plain by the rivers and their tributaries (Wilkinson 2003: 76). It lies well outside of the rain-fed agricultural zone, and irrigation is required for the cultivation of crops. The landscape is dominated and shaped by river dynamics; thus, the hydrology of the rivers structured the roles they played in ancient Mesopotamian society. Key differences in the morphology of the rivers are apparent in their courses. The Euphrates, which begins in Anatolia, meanders across Syria, alternating between losing flow to evapotranspiration in the desert and gaining volume from its two major left bank tributaries, the Khabur and Balikh rivers (Kolars and Mitchell 1991: 6). Once it enters Iraq, the main course of the Euphrates, and its major branches become leveed. Levees are topographic ridges created by the deposition of sand or clay alongside the river channels (or irrigation canals) as a result of annual river flooding. This continual action gradually raises the rivers until they flow several meters above the plain on low ridges (Hritz and Wilkinson 2006: 415; Buringh 1957). In southern Mesopotamia, these levees average a few meters in height and range from 4 to 14 km in width. In terms of ancient irrigation, this means that agriculturalists needed only to breach the levee wall and gravity would have brought water to fields. The ancient levees leave clear topographic traces on the modern, flat alluvial plain.

The Tigris River comes directly out of the Anatolian highlands into northern Iraq and begins incising itself into the plain as a single stream. Unlike the Euphrates, it does not lose flow or speed crossing the desert, and its four powerful tributaries (Greater and Lesser Zab, the Adhaim, and the Diyala rivers) increase its volume as it courses through northern Iraq. Thus, the Tigris carries more water and is a more difficult river to utilize. As it flows down the modern plain, the Tigris River does not form a large natural levee. Owing to its tendency to incise rather than form a levee, scholars have assumed it was unsuitable for agriculture prior to the development of water lifting devices sometime during the 1st millennium A.D. in Mesopotamia (Moorey 1994: 4).

The action of the rivers combined with the continuous occupation of the alluvial plain for at least 8000 years have produced a modern landscape composed of discontinuous, often superimposed,

Figure 2 A) Traces of deflated archaeological sites; B) Relict channels amongst dunes in southern Iraq. Photographs courtesy of McGuire Gibson.

horizontal segments of past landscapes. This landscape can be read in the same manner that an archaeologist reads a section, by untangling the superimposed stratigraphy of ancient features. The modern alluvial plain is, in a sense, a palimpsest of modern and ancient features that represent the interactions of humans and their environment (Crawford 1955: 51; Wilkinson 2003: 7) (FIG. 2). The palimpsest is composed of natural channels of the Tigris and Euphrates rivers, hybrid artificial and natural channels, and artificial canals feeding groups of settlements and their agricultural fields. Traditionally, the preserved features of the ancient landscape have formed one piece of evidence in larger studies of Mesopotamian civilization, economy, and political organization; the landscape itself has not, until now, been studied in any detail.

Historical Data

Ancient texts often describe idealized field systems and give generalized details about the organization and character of land use in antiquity (Liverani 1996). These texts are restricted to specific political periods such as those describing the countryside of the city of Umma during the latter part of the 3rd millennium B.C. (Steinkeller 2007). From these texts, it is possible to sketch what the agricultural, riverine, and settlement landscapes might have looked like around a specific city during a particular time period. By their nature, these data lack the broad spatial information needed to trace long-term or cross-alluvium changes in settlement or river systems. Given the limitations in scale and chronology of the historical sources, archaeological survey data must be added to get a broad view of the plain and reveal long-term developments and changes to the natural and cultural landscapes.

The work of Robert McC. Adams (Adams 1965, 1966, 1972, 1981; Adams and Nissen 1972), a pioneer in archaeological survey and landscape analysis in Mesopotamia, forms the basis for archaeological studies in the area. Adams surveyed roughly one-third of the alluvial plain at varying levels of intensity over a period of 30 years, from the 1950s to the 1980s (FIG. 3). He used maps, aerial photographs, and ground walking to map and date archaeological sites as well as their associated relict river channel levees. He produced periodization maps that illustrated settlements and river channels by period throughout ancient Mesopotamian history, and established the standard for archaeological survey in Mesopotamia. His surveys, however, were constrained by time and feasibility and, as he himself recognizes, his maps show broad gaps in coverage and omit sites and ancient landscape features.

Reconstructions of the Ancient Euphrates and Tigris River Systems

The channel-settlement interaction model developed from the survey work of Adams and others (Adams 1981; Cole et al. 1998; Wilkinson 2000) has guided historical reconstructions of ancient Mesopotamian civilization. The model relies on a few basic principles of channel-settlement dynamics. The first and most basic principle is that sites that are in linear alignment represent ancient settlements located along a river channel or canal. Second, throughout most of early Mesopotamian history, river channels that fed irrigation canals and supported settlements were largely natural primary branches of the Euphrates and Tigris rivers with minor human modification of their courses. Therefore, if a channel moved, then settlements should follow. Third, after the 2nd millennium B.C., both large-scale artificial channels and irrigation canals were developed and channel-settlement interaction dynamics changed. In later periods of Mesopotamian history, if a river channel moved, inhabitants of the plain had the ability and technology to move it back to its original position. This dynamic model, which provides a basis for understanding river channel and settlement pattern changes, as well as the complexity of ancient features preserved in the modern landscape of southern Mesopotamia, relied heavily on plotting movements of the Tigris and Euphrates rivers throughout antiquity.

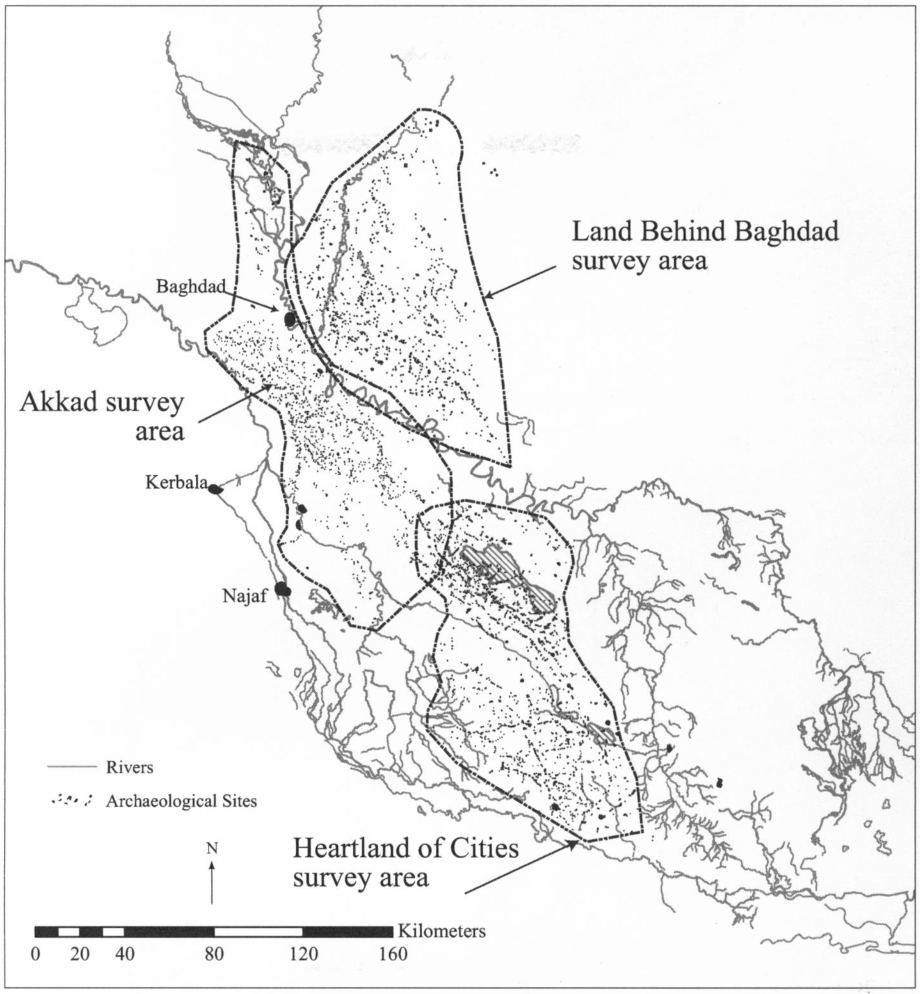

Figure 3 Areas surveyed by Robert McC. Adams from the 1950s to the 1980s.

From his survey data, Adams traced two key changes in the river systems that provide the basis for our understanding of long-term ancient settlement pattern and river channel and canal system changes. The first change was the split of a large joint Tigro-Euphrates course that ran down the center of the alluvial plain until the end of the 4th millennium B.C. The presence of this joint course was first mapped during geomorphological investigations in the Sippar area (Paepe 1971). Adams suggested that the presence of the northern joint course might account for the relatively dense Uruk (4th millennium B.C.) settlement in the vicinity of Sippar (FIG. 4). Using aerial photography and maps in addition to limited ground walking, Adams attempted to trace this course further south by mapping either relict levees or river meander scars preserved in the modern landscape, but the relict landscape features became lost south of the site of Sippar. There was no evidence for the continuation of the joint course over large swaths of the southern central plain. Adams suggested that large meander scars in the dunes NE of Nippur, which are now submerged by Lake Dalmaj (FIG. 4), were the southerly reaches of this course. He concluded that these meanders are evidence of the river channel that became the Tigris River after the split. His analysis of the survey and geomorphological data allowed him to provide a date for the splitting of this joint course at sometime around the end of the 4th millennium B.C.

When the rivers split, the Euphrates River began a series of movements to the west, whereas the Tigris River migrated to the east. Adams traced the movements of the rivers and their large primary branches using the settlement pattern data. Coinciding with the split, settlements began to fan out across the plain. After this period, the location of the Euphrates became relatively common in the texts and from archaeological investigations. The texts described the main body of the Euphrates and its major branches as being in the western portion of the plain. In contrast, there were few clear textual references to the Tigris in antiquity (Steinkeller 2001).

Based largely on interpretation of his survey data, Adams tackled the question of the location of the Tigris River. He described the ancient Tigris River course as being located 30 km SW of its modern location by the 2nd millennium B.C. and running NE–SW (FIG. 4). He pointed to the meanders in Lake Dalmaj as evidence for its presence in the southeastern portion of the plain beginning at the end of the 4th millennium B.C., and to the presence of a large, visible, relict meander south of Baghdad as evidence for its presence in the northeastern part of the plain (Adams 1981: 16–18) (FIG. 4). Integrating

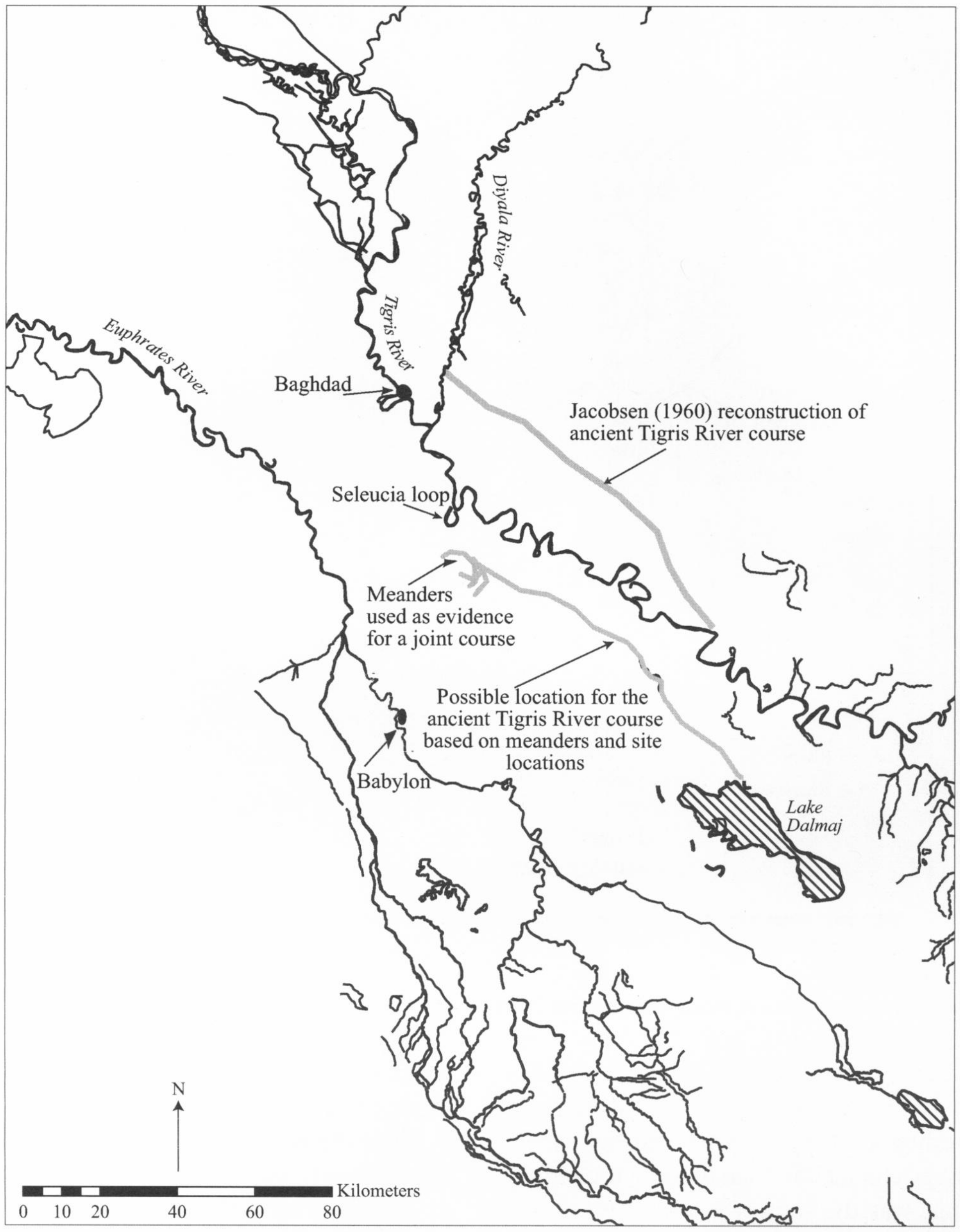

Figure 4 Evidence for the joint courses of the Tigris and Euphrates rivers and possible locations of the Tigris River during antiquity (from Adams 1981: 16–18; Jacobsen 1960).

his survey results with the textual data available at the time, Adams reconstructed the Tigris and Euphrates rivers as running parallel courses along the central portion of the plain during most of antiquity. He noted that each river was likely to move and shift as it does today. The Euphrates tends to avulse and create new branches visible on the southwestern portion of the plain, while the Tigris tends to shift course and create new meander loops.

Despite the compelling picture painted by his survey and geomorphological data, Adams was not able to rule out a northeastern location for the Tigris River, in the Diyala River Basin, during historical periods. It seems that he decided to leave this option open because of the small and disjunctive area in which large meanders of the presumed Tigris River were visible and could be traced and also because of the unclear evidence from the textual records. In the late 1960s, Thorkild Jacobsen (1960) investigated the question of the location of the Tigris River during antiquity in textual sources. He correlated toponyms from historical records with survey data collected during Adams' (1957) Akkad survey. Based on his analysis, Jacobsen formulated a convincing argument that the Euphrates River was the primary source of water on the plain. Further, he concluded that texts from sites in the Diyala Basin referred to the Tigris River as locally based.

Adams also described a second significant change in the Euphrates-Tigris system that transformed ancient settlement patterns and agricultural structures, and contributed to the fractured ancient landscape visible today. This shift occurred in the 2nd millennium B.C. At the time, the main body of the Euphrates, which had been flowing NW–SE since the split in the later 4th millennium B.C., turned almost directly south. The dramatic shift in the Euphrates course would have resulted in a loss of water in the center of the alluvial plain. The inhabitants of the plain would have been faced with two main options: shifting settlements to follow the new location of the Euphrates and its major branches, or developing artificial canals that cut across the topography of the plain and brought water to established settlements.

Interpreting his settlement and channel data, Adams suggested that inhabitants coped with this major river channel shift, first, by shifting settlement locations to the west, and second, by creating large networks of artificial channels (canals) which brought water back to the central portion of the plain (Adams 1981: 165; Brinkman 1984). The development of these new, artificial canal networks represents a fundamental shift from the earlier model of "settlements following river channels" to the third principle of Adams' model: river channels and canals following settlements. It also reveals that by this period, inhabitants of the plain had a flexible set of coping mechanisms that could be harnessed in the face of natural or physical environmental shifts, including the ability to marshal labor resources and create entirely new canal networks. These new networks of river channels and canals formed the basis for the later 1st millennium A.D. irrigation systems whose traces dominate the modern archaeological landscape of southern Iraq.

The model of shifting Mesopotamian landscape and settlement pattern interactions has been the basis for understanding the development of ancient southern Mesopotamian society for the past 30 years. In the late 1990s, a team from the University of Ghent acquired a series of 1 : 25,000 topographic maps for a small area west of Baghdad (Cole et al. 1998). Their analysis of these maps and the incorporation of textual data referring to named branches of the rivers revealed a more complex picture of the ancient Mesopotamian landscape, including the shifting of the rivers. Using the 2 m contours of these maps, the Ghent team mapped the drainage and relict topographic levees of the plain SW of Baghdad (Cole et al. 1998: 52). They found that some of Adams' channels followed courses that were topographically impossible, running up and over pre-existing levees. In short, they were able to demonstrate the topographic complexity of this seemingly flat landscape and point out that just because features appear to be contemporary in the modern landscape does not mean that they are of the same date. This work demonstrated that previous models of the ancient Mesopotamian landscape failed to capture the complexity of the layers of ancient landscapes preserved on the modern landscape.

Methods and Remote Sensing Data

Merging satellite imagery and photography with past survey data begins to reveal the complexity of the layers of the ancient landscape and to address lingering questions about the settlement pattern record and the locations of the rivers in antiquity. The use of GIS software to bring disparate spatial datasets into a single format for analysis has not been uniformly adopted by archaeologists. Although GIS tools are part of the methodological cannon among European and North American archaeologists, in addition to a relatively small community of geomorphologists, they are still fairly novel in a Middle Eastern context. Notable exceptions include work by Herman Gasche and Kris Verhoeven at the University of Ghent on river channel changes in southern Mesopotamia, Tony Wilkinson and the development of the Center for the Archaeology of Middle Eastern Landscapes at the University of Chicago, Steven Savage and the Jordan Archaeological Database and Information System based at Arizona State University, and various others who are incorporating GIS in their research designs (Pournelle 2003, 2007; Stone 2008; Parcak 2009; Ur 2003). While remote sensing data in the form of historical aerial photographs and satellite imagery have been used in studies of Mesopotamian settlement patterns and river channel systems (Adams 1981; Stone and Zimansky 2004; Pournelle 2003), the transformation of past survey data into digital form and the comparison of multiple spatial datasets layered in a GIS format are still in the early stages.

The primary data employed in the present study are from declassified Corona Spy Satellite photographs (Beck et al. 2007; Casana and Cothren 2008; Pournelle 2007; Ur 2003; Kouchoukos 2001). Obtained as filmstrips and scanned at 1600 dpi, they provide a spatial resolution of between 2 and 5 m. Even when scanned at the highest possible resolution of 7 microns, the spatial resolution is not much more than 2–5 m; this is a result of the limitations of the original film strip for the scanner, which cannot give a greater ground resolution than the negative filmstrip has captured. The Corona imagery is particularly useful for southern Mesopotamia for several reasons. First, the images were taken at the same time as Adams and others were conducting their ground surveys and therefore the images record the same landscape that was visible to the surveyors. Second, the images capture the landscape prior to the major agricultural transformation activities of the 1970s and later. These activities have significantly altered or obscured the ancient landscape. Finally, the Corona satellites flew thousands of missions between 1958 and 1970, and thus provide a corpus of seasonal coverage that can be used for comparison.

A second, crucial group of data used in the present study are the 1919 British military maps. These maps cover most of the country and can be used to provide "ground truth" for features detected in satellite imagery. The most useful aspect of this map series is that the British surveyors covered areas that were not visited by later archaeologists, and they usually documented the locations of relict levees and ruins.

With the release of DEMs provided by the Shuttle Radar Topography Mission (SRTM), it is now possible to view the microtopography of the entire Mesopotamian plain revealing the pattern of levee systems that resulted from long-term river channel development (FIG. 5) (Hritz and Wilkinson 2006: 415). SRTM was launched in 2000 with the objective of acquiring elevation data for the entire globe. It is available for Iraq at 90 m resolution, which means that while small narrow features, such as small sites or local irrigation canals, are not visible, the long-lived levees of the plain that are kilometers wide appear as distinct topography.

One advantage of the DEM is that it acts to filter out modern features. Because the plain appears essentially flat, the "noise" in the topographic data is minimal. Modern field systems, roads, canals, etc. contribute to an information overload that can obscure the visibility of past river channels, canals, and archaeological sites on satellite images; however, the SRTM filters out these recent additions and emphasizes features which exhibit a topographic signature alone. Moreover, the 90 m resolution (as opposed to the 30 m resolution of the SRTM available for other parts of the world) reveals features with topographic significance rather than modern, short-lived features such as small irrigation canals. Most importantly, all of these data reveal the archaeological landscape of southern Mesopotamia without the imposition of survey boundaries and can be used to view areas outside the survey boundaries established by Adams and others.

Using the basic tools of GIS, the satellite imagery, topographic data, and past survey data were georeferenced in ERDAS IMAGINE and adjustments for map error were attempted (Hritz 2005; Ur 2003; Pournelle 2003). The data were transferred into ArcGIS for layering and analysis. Relevant features, such as archaeological sites, active roads, canals, and relict levees, were digitized from the maps and coded with descriptive and chronological data in a geodatabase format (Hritz 2004).

Filling in Gaps in the Settlement Patterns

With the incorporation of these data into a single format, particularly Adams' survey data and the Corona satellite photography, it was possible to begin to fill in gaps in the existing settlement pattern maps (FIG. 6). Adams mapped 3146 archaeological sites in southern Iraq. Using imagery and looking beyond his survey boundaries, I was able to add an additional 2129 possible archaeological sites. Potential sites were identified by comparing the signatures of possible tells in the imagery with the signatures of known tells on Adams' maps (Hritz 2005). The appearance of sites in the imagery was not uniform across the plain, and local environmental and man-made differences were apparent. For example, sites in the Euphrates Basin showed the effects of cultivation encroachment and salinization, while sites in the Tigris Basin were less affected by modern agriculture with few traces of salinization. The appearance of the sites on the imagery allowed for the description of zones of preservation and destruction of archaeological features, acting as templates for future archaeological survey. The accurate dating of these sites was only possible if the site was located on a river channel or a continuation of a channel mapped and dated by Adams. Nonetheless, the addition of new sites revealed the distribution of settlements outside of the traditional, narrow corridor in the central portion of the plain.

Microscale Reconstruction of Channels: The Zubi

The next step in the analysis was to incorporate the Ghent maps into the GIS and compare the topographic levees mapped by the Ghent team with those visible on the SRTM DEM (Hritz and Wilkinson 2006). In general, the two datasets matched, showing corresponding topographic traces of identical river channel levees. The SRTM DEM showed the same system of levees and channels as those on the maps, which ranged in size from the main river channel running past both Sippar and Tell ed-Der down to secondary river channel branches and canals (FIG. 7). This correspondence validated the accuracy of the SRTM DEM for detecting relict river channel levees. SRTM DEM is an elevation model that also captures the height of the levees as well as the pattern of channel branches. The areas that did not correlate, however, were most useful for elaborating the ancient Mesopotamian river channel system.

One example illustrates the layering of relict river channel levees and the difficulty of unweaving these layers of the landscape. In their early reconstructions, the Ghent team mapped the Zubi River channel (the Sippar Leveen in Figure 7) cutting across the plain from the Euphrates and passing the sites of Sippar and Tell ed-Der towards the modern Tigris River (Cole et al. 1998). As the channel reached the Tigris, they suggested that it turned south and followed along the eastern edge of the plain in the Akkad area. This reconstruction corresponds with a relict river channel mapped by British surveyors (Selby et al. 1885), during their survey of Babylonia for the British government. In their most recent reconstructions, the Ghent team revised this mapping and split the line into two distinct river channels. The first channel is the Sippar levee which originates at the Euphrates, crosses the plain and terminates at the modern Tigris River near Baghdad. The second Zubi channel line begins in the area of the modern Tigris River and

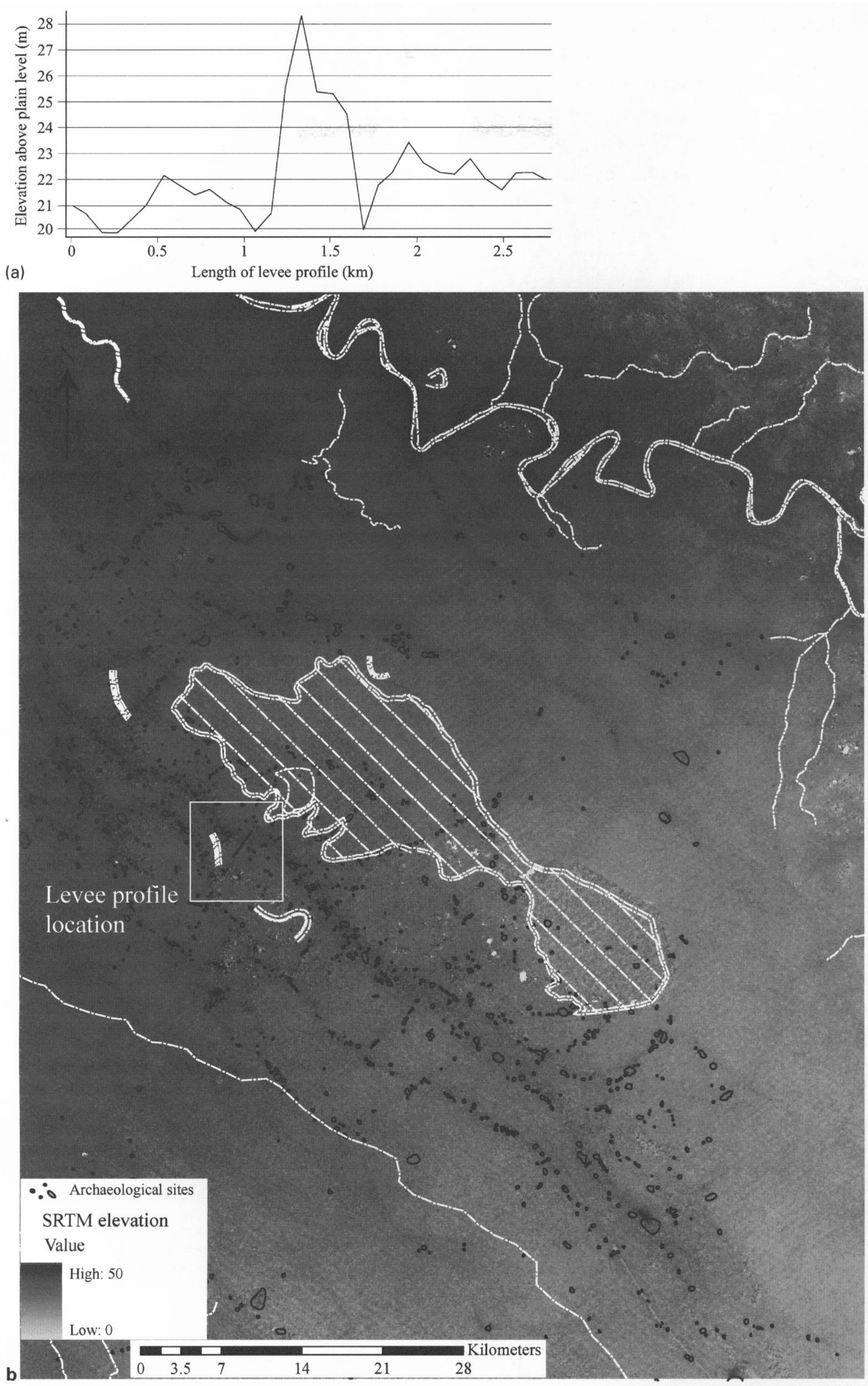

Figure 5 A) Graph of levee profile showing the height and width of the levee captured by the DEM; B) Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) for southern Mesopotamia (with Lake Dalmaj in the center) showing levees and one levee in profile. Darker pixels are higher elevations and lighter pixels are lower elevations. Stripes and stray pixels in lighter areas are sinks or sensor errors in the elevation dataset.

continues south with at least two secondary branches. They interpret the Zubi line as reflecting an ancient Tigris River channel (Cole et al. 1998).

The SRTM DEM can clarify these two conflicting reconstructions. The Sippar levee is distinct on the SRTM DEM and can be traced from the area of Sippar across the plain towards the Tigris and Baghdad. While the maps and satellite imagery become muddled with the modern sprawl of Baghdad and agricultural features, the SRTM DEM filters out these features and allows for a clear tracing of the continuation of the channel levee. It seems that rather than terminating at

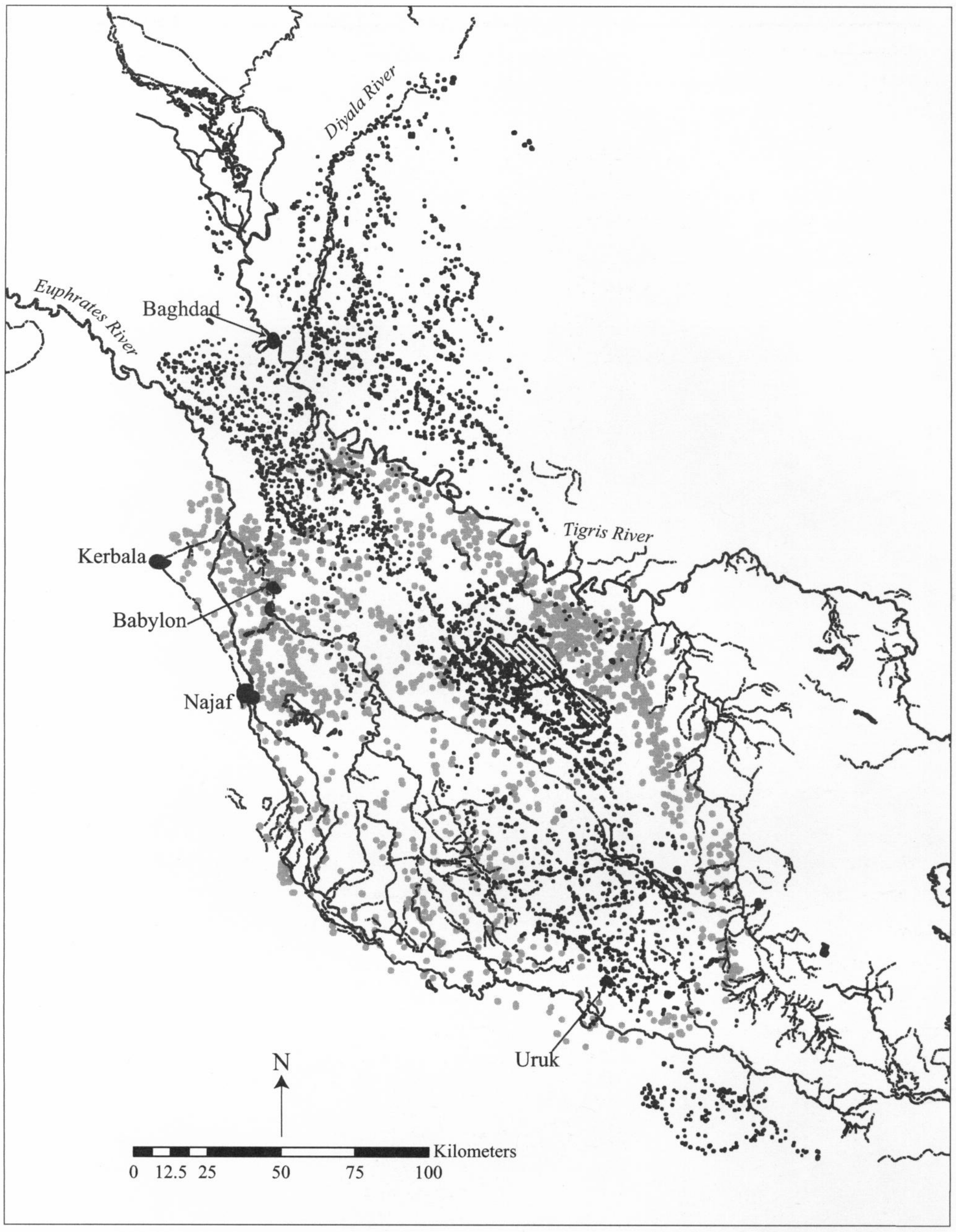

Figure 6 Surveyed archaeological sites (3146) are in black. An additional 2129 possible archaeological sites are in gray. The total number of sites is 5275. The addition of remotely detected sites (in gray) illustrates the density of settlement outside the narrow band between the river channels in the center of the plain.

the modern Tigris, the same levee turns south and runs a parallel path with the modern Tigris, roughly a few kilometers to the SW. In this case, the SRTM DEM data correspond with the original reconstructions made by the Ghent team and reveal that the Zubi River channel is a continuation of the Sippar channel and not a distinct second channel.

Additional secondary branches of the levee appear as distinct topography on the SRTM DEM. These channels can be traced outside the boundaries of the Ghent reconstruction (Cole et al. 1998) to further explore the structure of the ancient river channel system (FIG. 7). Four branches of the channel system may be traced on the SRTM DEM through the Akkad area and into the heartland of southern Mesopotamia, skirting the northeastern edge of Lake Dalmaj. As one moves farther south, however, the reconstruction of the channel line becomes more tentative because large E–W canal systems cut across and reuse portions of the relict river channel levee. The reuse of portions of the Zubi channel result in a layered archaeological landscape of superimposed relict river channel levees. While it is possible to separate or unweave some of the recent use of the channel levee based on shifts in the orientation of the channel course, this channel serves as an example of the complexity of landscape modification and the caution that is required in mapping preserved pieces of the ancient landscape.

Thus, by incorporating the SRTM DEM with the interpolated Ghent map data, it was possible to interpret the structure and significance of the river

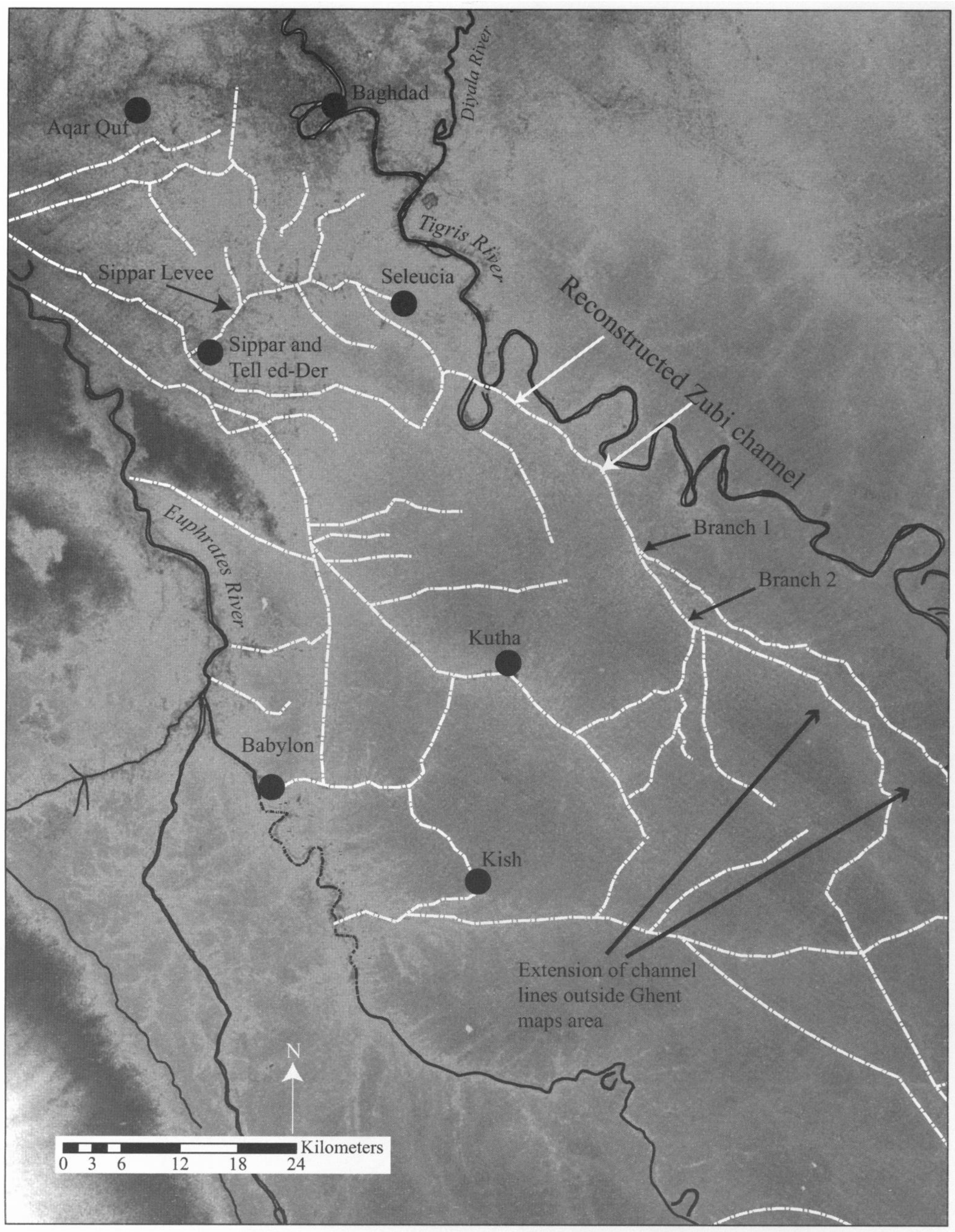

Figure 7 SRTM DEM levees corresponding with 1: 25,000 topographic maps (Cole et al. 1998). Elevation gradient scale shows higher areas reflected as lighter colors and lower areas as darker.

channel system. First, the broad view afforded by the GIS permitted the elaboration of channel systems over a broad area of the plain. Second, it seems that the Zubi channel system was a continuation of the Sippar levee and conducted Euphrates water into the eastern portion of the plain. Third, the Zubi channel system continued much further south into the heartland of southern Mesopotamia, but it was lost in later reuse and modification of the relict channel levee. Fourth, the SRTM DEM revealed a plain dominated by levee branches of the Euphrates with little evidence for Tigris branches. In this case, the elevation data corresponded rather closely with the channel layouts reconstructed by Jacobsen (1960) (above). These smaller-scale reconstructions paved the way for addressing broader regional questions of settlement pattern and channel system changes, particularly the location of the Tigris River.

Macroscale Reconstructions of River Channels: Where was the Tigris River?

The role of the Tigris River in Mesopotamian history has long been debated. Neither archaeological nor textual information provide a clear record of the location of the main body of the Tigris throughout antiquity. During specific periods, the texts suggest that water from the Tigris River was important for transportation and irrigation around several cities (Steinkeller 2001). It is unclear whether the texts are referring to branches of the Tigris River or to the main body of the river itself. The archaeological evidence is also unclear, with several partially visible relict river channel levees standing as possible ancient Tigris River courses (Stone and Zimansky 2004; Steinkeller 2001).

With the lack of clarity in the archaeological survey data and cuneiform records, remote sensing data

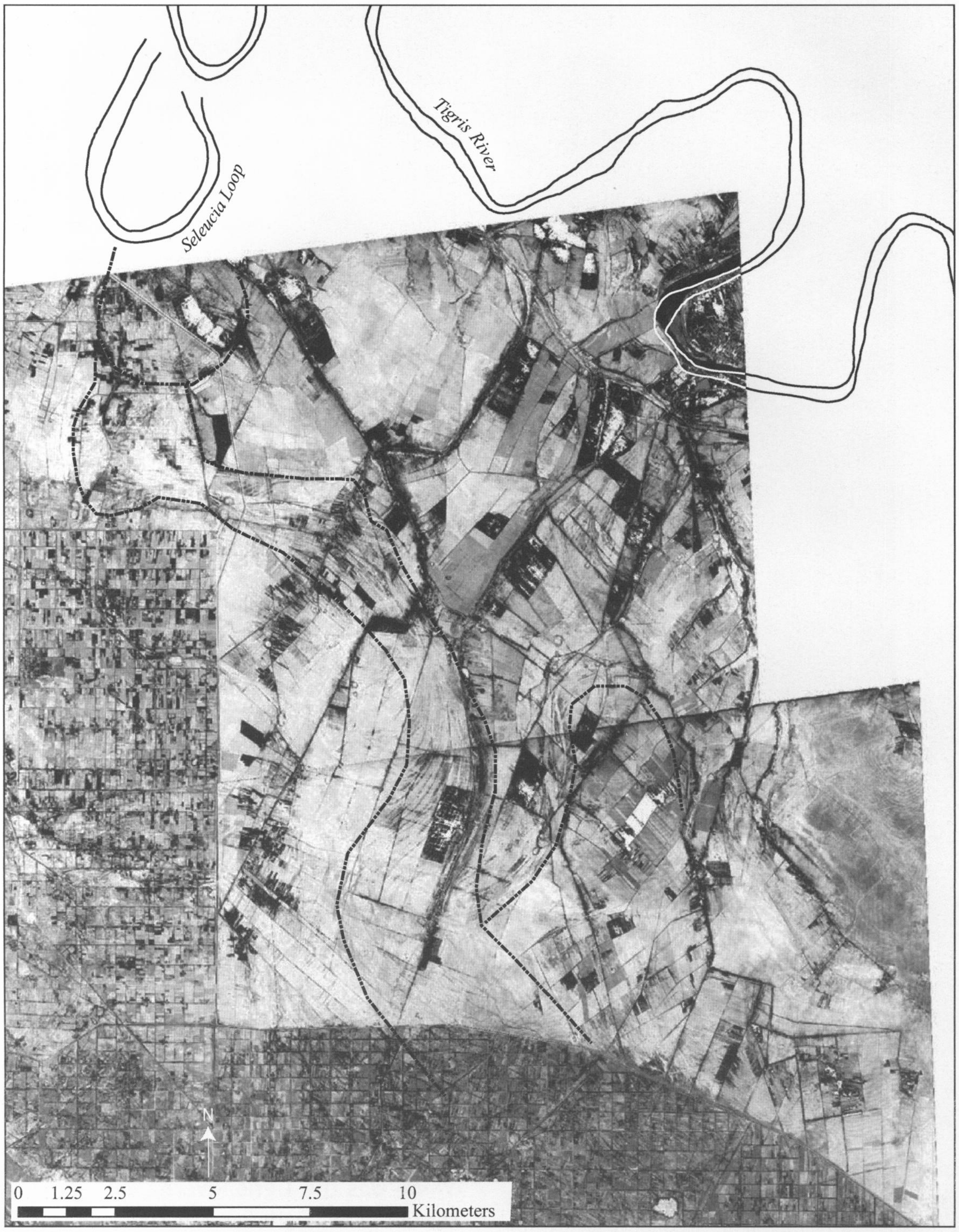

Figure 8 The visible meander scar southwest of Baghdad traced by Adams (1981) and Buringh (1960) on a Corona satellite image. Dotted black lines outline the remnants of the meander (also in Figure 9) are preserved as vegetation differences in modern agricultural fields. Corona Mission 1104-2138DA038, 08/16/1968 courtesy of USGS.

provide an additional source that may be used to clarify the locations of the rivers in the ancient past. As stated above, a primary line of evidence for the location of a joint course of the Tigris and Euphrates rivers in the central corridor of the plain is based on the presence of large meander scars and levees mapped by Adams (FIGS. 4, 8). The stratigraphy and relationship of these meander scars and levees were elaborated by Pournelle (2003). Using Corona imagery, ASTER imagery and its derived DEM, and Adams' survey data, Pournelle suggested that the meander scars traced NE of Nippur and the levee remains conflate two different channel systems from two different periods. This new analysis directly challenged previous evidence for the joint river course. The implication is that the river channel, which was previously thought to be the Tigris River because of its size, was actually two channels that could have been primary branches from either the Tigris or Euphrates rivers. Pournelle (2003: 147–153) also questioned the dating of these features and, using satellite imagery, determined that the sites used to date the meanders were in fact related to a second, later channel.

Maps of levee and meander traces used to argue the location of the Tigris River after the Tigris and Euphrates rivers split present the same difficulty in interpretation. The key line of physical evidence cited for the location of the Tigris River on the plain during most of antiquity was the presence of a levee and a meander first mapped by Buringh, and the interpretation of stratigraphic cores in the area of Sippar and Tell ed-Der, sw of modern Baghdad (Buringh 1960: Exploratory Soil Map of Iraq; Adams 1981: 62; Paepe 1971: 9–27). Reanalysis of the landscape in the present study raises a number of questions about past interpretations of the date of the meander scar. Traced in Corona imagery, the meander has a wavelength similar to those of the modern Tigris, and likely represents a Tigris course at some point (FIG. 8); however, no sites are directly associated with the meander. Rather, a number of neo-Babylonian (600–400 B.C.) sites lie over the meander and follow channels that cut across it. The meander is visible on satellite imagery through differential retention of moisture in this relict feature, resulting today in a markedly different vegetative cover in the meander by comparison to the land cover in the surrounding agricultural fields. The differential soil moisture content has fostered the growth of visually distinctive tamarisks in the former bed.

The relationship between the sites and the meander in the satellite imagery illuminates two characteristics of the archaeological landscape. First, it reveals the complexity of layering of archaeological features in the landscape. Although the sites and the meander appear to be contemporary, detailed mapping of their signatures in satellite imagery, combined with ground survey data, reveals that these features represent pieces of different ancient landscapes, each only partially preserved. Second, mapping these features demonstrates the difficulty of unweaving the stratigraphy of features and dating them. For example, the meander cannot be dated with the archaeological evidence available and could be related to a landscape far older or younger than previously suggested. Furthermore, the use of the meander and its proposed connection levees farther south that form the continuation of the relict course of Tigris River on the plain poses similar problems.

Most recently, Stone (2003) has discussed evidence for the location of the ancient Tigris River on the eastern portion of the southern plain. Stone mapped a levee that runs east of Mashkan-Shapir and interpreted it as the relict Tigris River dating to the 2nd millennium B.C. The levee was mapped as a continuation of the river channel represented by the meander in the north, documented by Buringh near Sippar (FIG. 9). Her reconstruction faced the same difficulties as tracing the Zubi line out of the northern portion and into the southern central portion of the plain. When the high resolution Corona imagery was combined with the lower-resolution 10 m SPOT imagery, the levee appeared in small disjunctive sections. Adding the SRTM DEM data did not reveal a coherent course for this levee. Despite unweaving the successive river channels in this area, it was not possible to connect any particular relict levee to the meander scar in the north.

A second concern regarding the use of a levee in this portion of the plain as evidence for the relict course of the Tigris River is the morphology of the Tigris itself. Assuming that its fundamental morphology on the plain has not changed (and we have no evidence that it has), the Tigris is an incised, not a leveed, river in this area, and a change in gradient or flow would have been required for the Tigris to build a levee. The impact of such a change in gradient on the course of the Tigris is evident farther south in the area of the Shatt al-Gharraf, where the Tigris does build levees (FIGS. 9, 10). It seems unlikely, therefore, that the relict river levee running along the eastern edge of Lake Dalmaj and around Mashkan-Shapir (FIG. 9) represents an ancient channel conducting the main flow of the Tigris. It is possible and even probable that a major branch of the Tigris ran east of Mashkan-Shapir. Thus, the channel detected during investigation at Mashkan-Shapir (Stone and Zimansky 2004: 9–10) (FIG. 9), and the textual references to the Tigris River in the area could be explained by the presence of one of perhaps many branches of the main body of the Tigris River. Jacobsen (1960) and Adams (1981) initially explained cuneiform references to the Tigris in this part of the plain as confusing references to secondary branches of the main body of the Tigris but not the main course of the ancient river. In light of the questions raised by the topographic data, an alternative location for the Tigris had to be explored.

When the remotely detected sites are added, a dense alignment of potential archaeological sites is evident in the area of the modern Shatt al-Gharraf (FIG. 10). The alignment on the plain stretches from the vicinity of the modern Tigris River south towards the area of the modern Euphrates River. The density of settlement along this line is suggestive of a large river channel, similar to the alignment seen along the main branches of the Euphrates. In order to view this site distribution within a landscape context, it was necessary to take an even broader view of Mesopotamia.

The dense settlement pattern may be related to an alignment of sites along a levee in the area of the modern Diyala River (FIG. 10). In this area, a number of sites line the large levee, which represents the Sasanian period (A.D. 224–651) Nahrwan canal. Using the SRTM DEM, it was possible to trace the

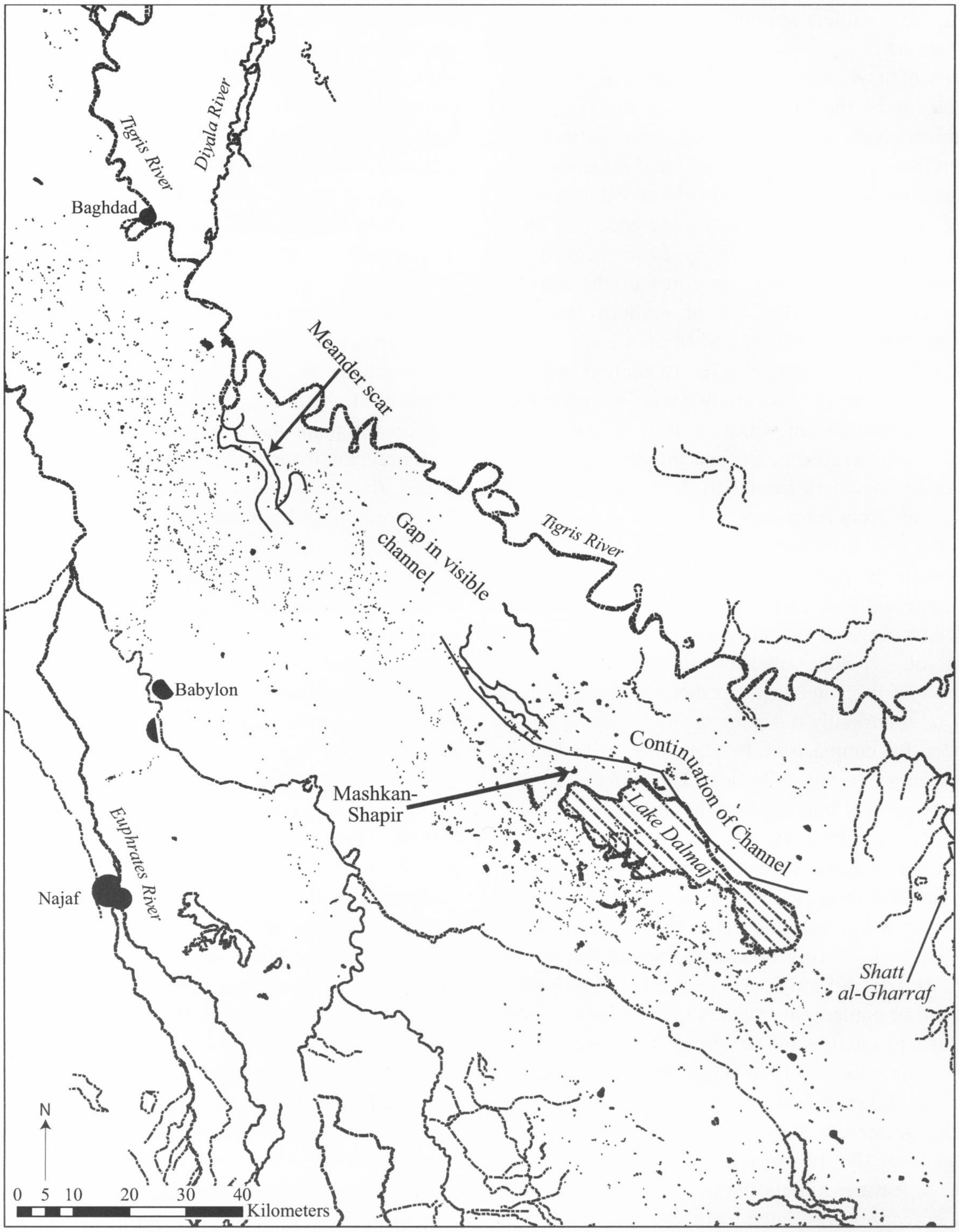

Figure 9 The levee mapped by Robert McC. Adams and Elizabeth Stone with large gaps in visibility. Compiled from maps by Adams (1981: 56) and Stone (2003: 157).

relief of the levee (FIG. 11). The latest Nahrwan Canal levee is clear, straight, and somewhat thin (roughly 1 km wide × 3 m high). Sites along the canal levee date primarily to the Sasanian and later periods.

In addition, an earlier channel levee distinct from the Nahrwan Canal levee could be traced on the relief. The relict channel levee (2 km wide × 4 m high) is wide, sinuous, and has a longer traceable course than the Nahrwan levee. The wide levee runs NE from the modern Diyala River to the SW where it is lost in the modern Tigris bed (FIG. 12). Its southernmost reaches are the relict levee detected under the later Nahrwan Canal. A longitudinal profile and two smaller vertical profiles created in the GIS program allowed for the tracing of both the levee morphology and its hydrological gradient along its course through the Diyala River area and onto the alluvial plain (FIGS. 12, 13). Adding Adams' survey data as a layer over the SRTM DEM, it was possible to provide a date range for the earlier levee. Sites along the northeastern portion of the levee, where it had not been covered by the later Nahrwan Canal levee, date from the 5th to 3rd millennia B.C. More detailed dating will require future work on the ground.

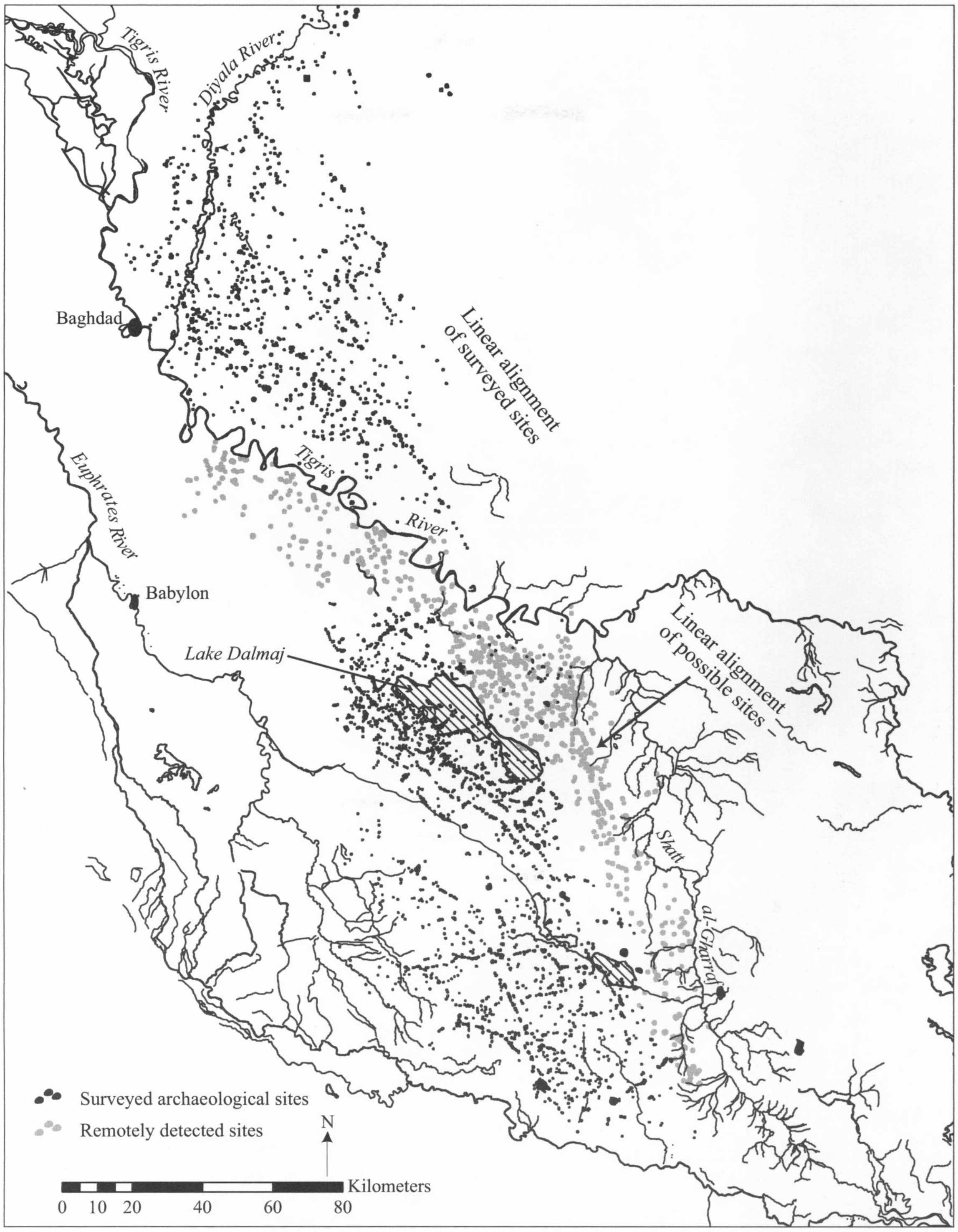

Figure 10 The alignment of surveyed sites in the Diyala Basin and the linear alignment of possible sites on the plain detected by remote sensing.

The microtopographic and settlement data suggest that the Nahrwan Canal system may have reused a part of an earlier relict river channel levee dating from the 5th to 3rd millennia B.C. The earlier river channel levee is distinct in its wide, sprawling levee morphology, which suggests that it was much larger and conducted more flow than the later, artificial Nahrwan Canal. The remains of the earlier channel are increasingly obscured by later human modification of the landscape as one follows its course from NE to SW. Nonetheless, the earlier levee system can be traced underneath the Nahrwan Canal and seems to have continued farther to the south and west than the Nahrwan system. Considering the alignment of possible archaeological sites and the traces of relict levee visible on the SRTM DEM, it was possible to reconstruct the layering of the earlier river channel and later canal levees, as well as trace the earlier channel entering the alluvial plain proper.

Based on the synthesis of the remote sensing and archaeological survey data, I suggest that the Tigris River was primarily located in the area of the Diyala River and NE of its modern course during the earliest

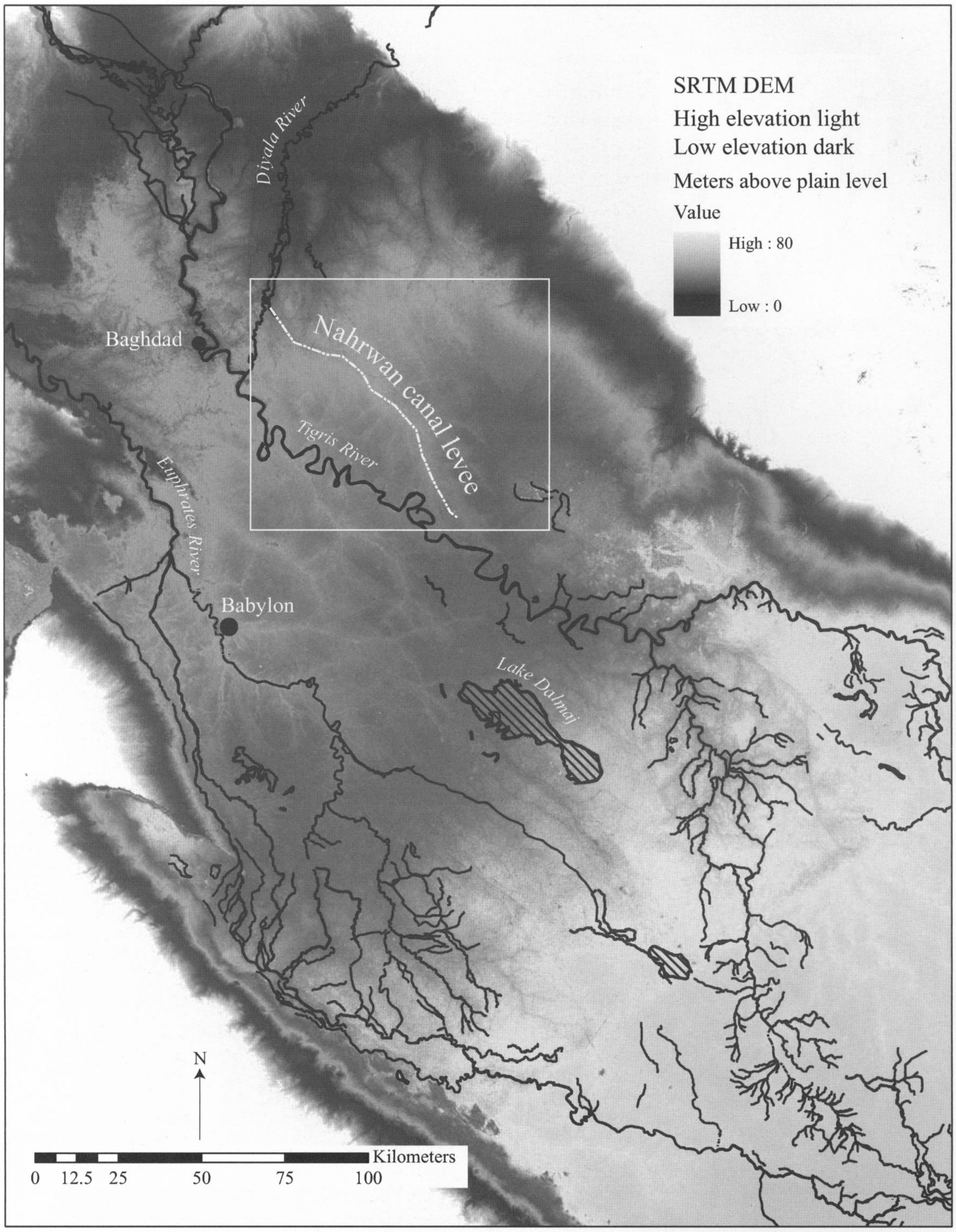

Figure 11 SRTM DEM showing the location of the Sasanian period Nahrwan Canal. The inset box shows the location of levee profiles in Figure 12.

periods of settlement on the alluvial plain (FIG. 14). A leveed Tigris is possible in the Diyala area because of a much higher variation in gradient in the Diyala fan. This means that gravity flow irrigation agriculture was possible here. More detailed analysis is needed to clarify the relationship of the site alignments and the Nahrwan levee, including stratigraphic coring of the levee itself and archaeological ground survey of the sites in the Tigris River basin. The presence of a leveed Tigris River, however, would have presented the inhabitants of the plain with additional irrigation and transportation options.

The archaeological and geomorphological evidence used to argue for the location of the Tigris River on the alluvial plain may be a result of misinterpretation of the stratigraphic layering of ancient features. For example, the meander scar traced south of the Seleucia loop (FIGS. 4, 7–9) may be interpreted as evidence for one of perhaps numerous lateral shifts in the river, as sediment from the Diyala River forced it SW onto the plain. These lateral movements would have buried archaeological sites and the ancient river channels associated with them, thereby leaving the meander scar as the remaining window onto this ancient landscape.

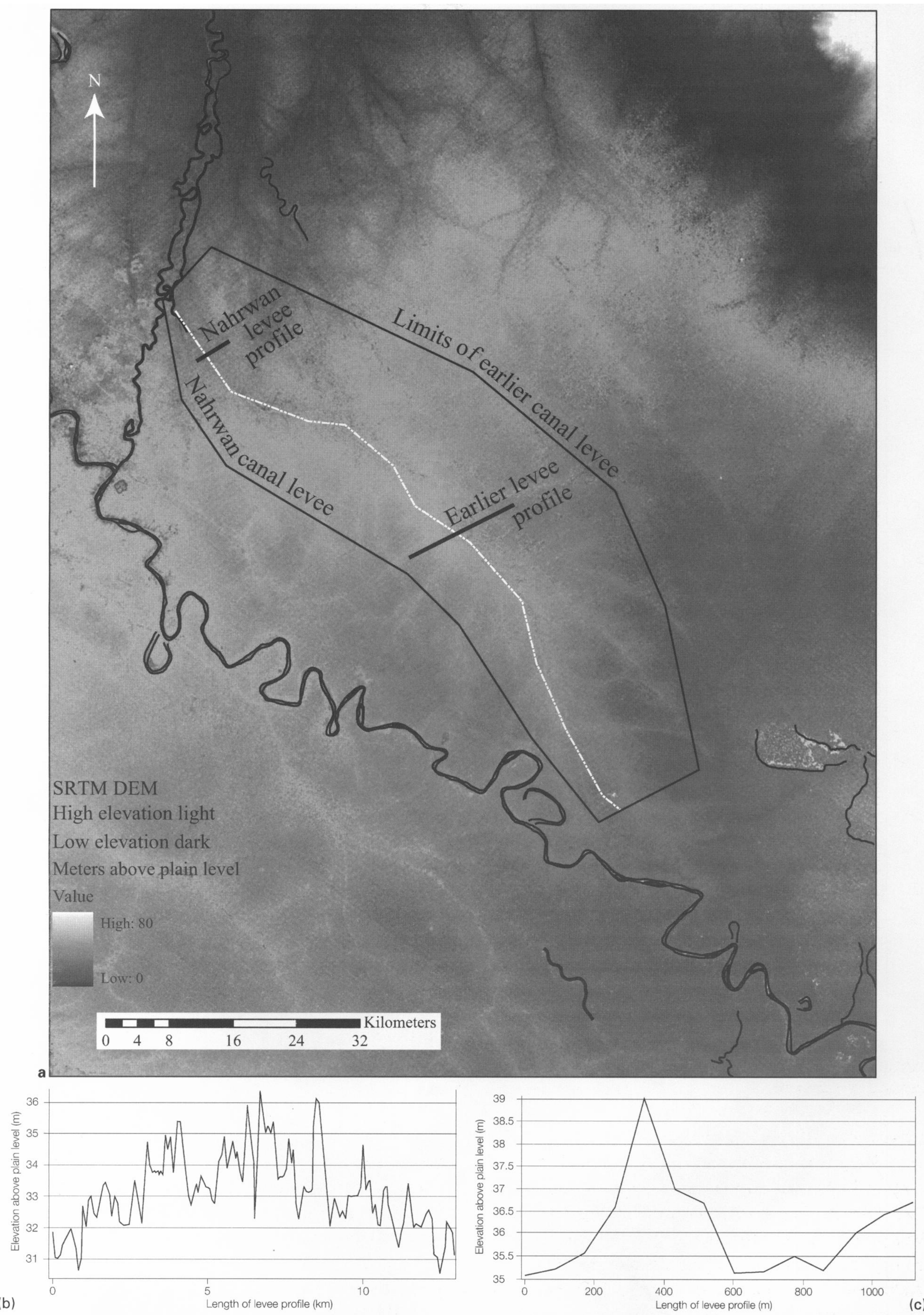

Figure 12 A) The Nahrwan Canal and earlier levee appearing stratigraphically in the SRTM DEM. Generated profiles reveal the topographic and morphological differences between the two features. The graphs show the difference in height and width; B) The earlier channel levee; C) The levee of the artificial Nahrwan Canal.

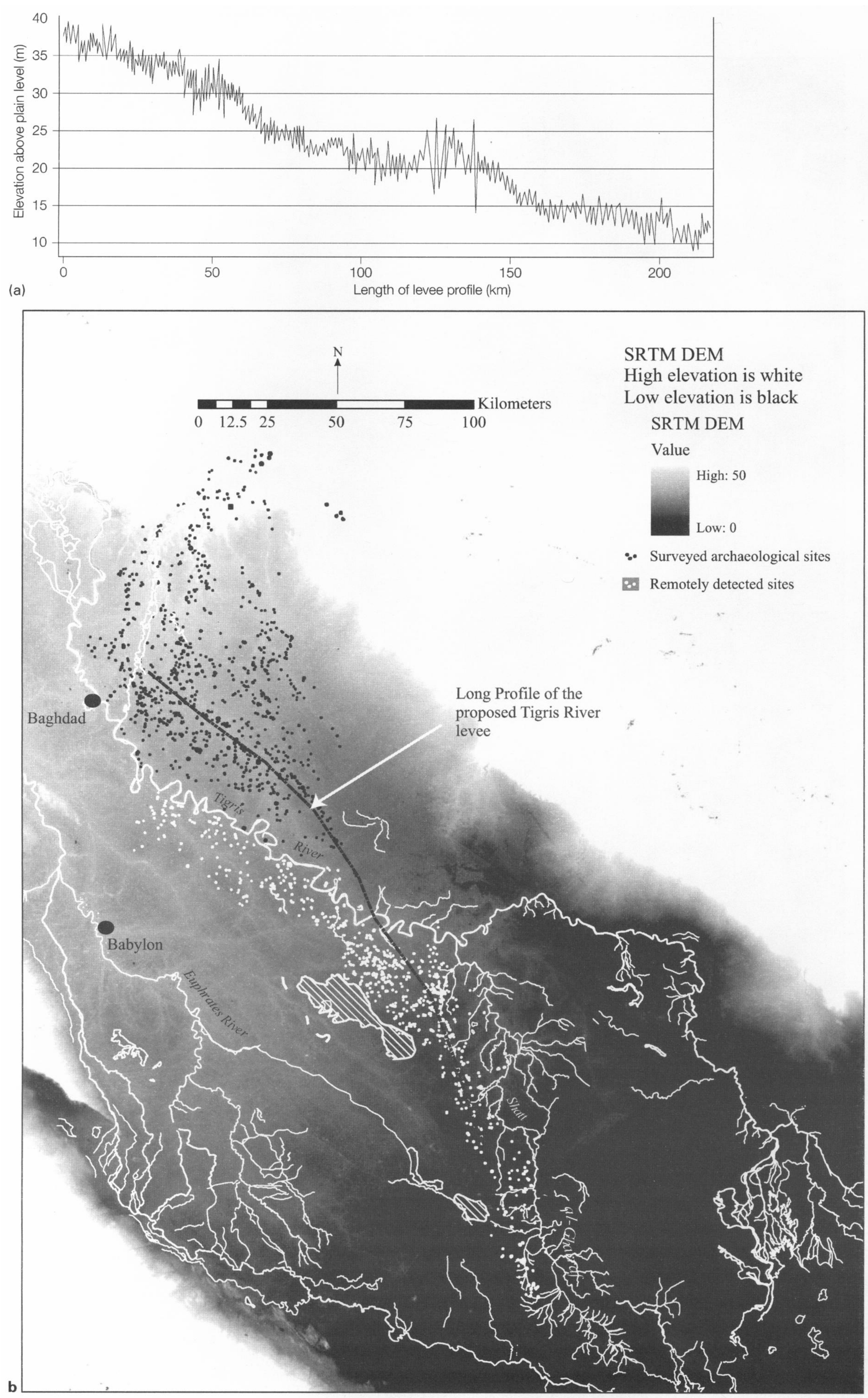

Figure 13 A) Long profile of the proposed Tigris River levee; B) Location of the levee profile on the SRTM.

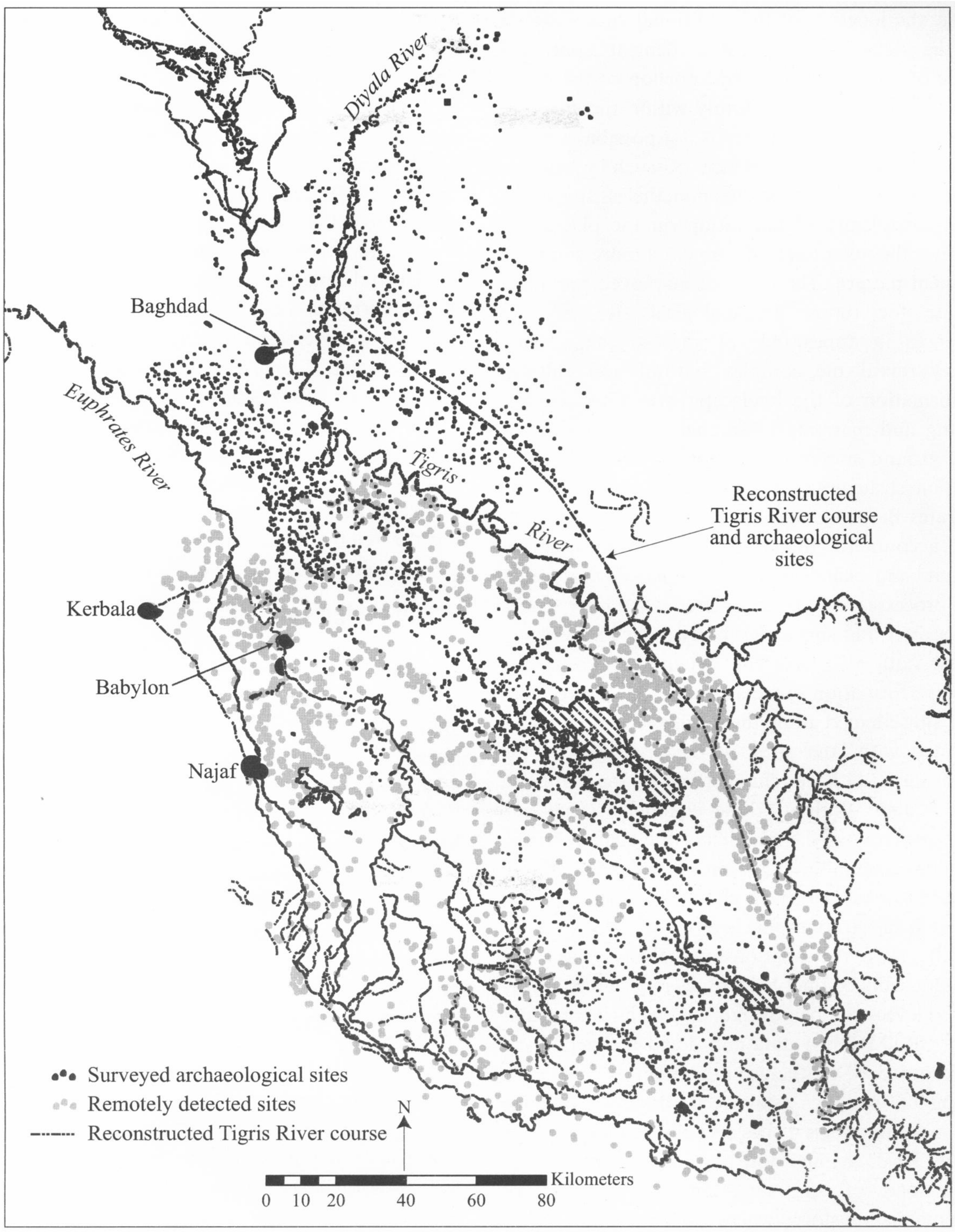

Figure 14 Proposed Tigris River course with surveyed and remotely detected sites.

Conclusions

The modern landscape of southern Iraq contains the remains of thousands of years of continual human activity, patterned and interwoven with modern landscape features. The most enduring elements of the ancient Mesopotamian landscape are archaeological sites and relict river channel and canal networks. By incorporating remote sensing and past archaeological survey data into a GIS format, it was possible to begin to map the complexity of ancient features and place them in the larger context of Mesopotamian history. This article addresses several key questions in Mesopotamian archaeology and history, and points toward new analytical solutions for merging historical data with recent technological tools.

With the integration of comparative satellite and photographic imagery, it is possible to fill in gaps in the settlement record of southern Mesopotamia. Past descriptions of archaeological sites based on ground survey have aided the detection of at least 2129 unsurveyed, probable archaeological sites using remote sensing data. The addition of these new sites has dramatically changed our quantitative view of Mesopotamian settlement patterns. The core of Mesopotamian settlement can no longer be seen as confined to a narrow ribbon in the center of the plain.

Rather, the location of the additional sites suggests that the density of ancient settlement continued outside of the southern central portion of the plain. While locating these sites firmly within the chronology of Mesopotamian history is not possible without ground truthing, the presence of such a massive number of possible settlements nonetheless suggests a greater complexity of habitation on the plain, and illustrates the potential to document a more complete settlement pattern. The methods employed provide a template for future archaeological surveys. The differences in appearance of sites in the satellite imagery reveal the complex natural and cultural transformation of the landscape over time. Understanding and mapping these characteristics can aid future ground survey by guiding survey design and collection strategies. For example, surveying in the Euphrates Basin would require research designs that would account for the effects of agricultural encroachment and salinization of archaeological sites. These processes must be considered when interpreting sherd scatter and surface visibility during survey.

These data also have the potential for revealing landscape formation processes in which features with earlier sites aligned along them are overlaid by levees associated with later sites, as demonstrated by the levee of the Zubi River channel and by the Nahrwan Canal system. Both of these channel systems are visible primarily as the remains of the ancient levees. Long-term human modification of the landscape and natural processes of river channel branching have resulted in the stratigraphic layering of levee systems. In both cases, the relationship between pieces of chronologically distinct landscapes reflected in superimposed levees can be distinguished using a combination of SRTM DEM data and dated archaeological sites recorded by on-the-ground survey.

Using the methods established for unweaving the layers of archaeological sites and channel levees along the Zubi River channel system, it has been possible to address one of the long-standing questions of Mesopotamian history: where was the Tigris River located during antiquity? The location of remotely detected, possible archaeological sites and the topography of the Diyala River Basin reveal a layered levee system represented in its latest form by the Sasanian period Nahrwan Canal. The SRTM DEM data demonstrate that the Nahrwan recaptured an earlier relict river channel levee. The earlier levee, which can be traced further NE and SW than the Nahrwan Canal, is associated with settlements that predate the development of Nahrwan (5th millennium B.C.) and were abandoned before the Nahrwan Canal was in use (by the late 3rd millennium B.C.). The presence of a leveed Tigris River in the Diyala Basin during early periods of antiquity would have offered the inhabitants of the plain new irrigation opportunities. For example, lifting devices would not have been needed to irrigate from a leveed river, making irrigation directly from the Tigris a possibility before the end of the 1st millennium B.C. Use of the Tigris River for irrigation would have opened up areas in the eastern portion of the plain for cultivation, perhaps providing some insight into the capabilities of the large, later 3rd millennium B.C. irrigation systems referred to in the textual records (Steinkeller 2001). As a leveed river, the Tigris would have created branches similar to the major branches of the Euphrates, further enabling irrigation development.

Finally, understanding the relationship between the Nahrwan Canal and the ancient Tigris River provides a new foundation for understanding the role of the Tigris River in ancient Mesopotamian history. Such relationships, if confirmed by more detailed studies, will help disentangle some of the knottier problems of the history of irrigation systems including the relative contributions of the Euphrates and Tigris rivers to their development.

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