



IRRIGATION in EARLY STATES NEW DIRECTIONS

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THE ORIENTAL INSTITUTE OF THE UNIVERSITY OF CHICAGO
ORIENTAL INSTITUTE SEMINARS • NUMBER 13

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Remote Sensing of Ancient Canal and Irrigation Systems

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ONE OF THE ATTRACTIONS of historical archaeology is the possibility to combine textual data with the archaeological record. In the world of Near Eastern archaeology, however, often the evidence of texts is taken to be the more reliable source, and elaborate historical reconstructions are occasionally made with little or no archaeological input. Such an imbalanced scenario is particularly dangerous with regard to ancient water systems, but the most successful attempts for Mesopotamia have been multidisciplinary collaborations,¹ often incorporating ethnographic or ethnohistoric data.²

Despite the perceived limitations of archaeological data, the most successful irrigation studies have involved them, for several reasons. The written sources on irrigation derive mostly from royal inscriptions.³ These texts reflect the priorities of the royal households that commissioned them, priorities that emphasize the legitimization of existing power structures. They describe not an objective reality (if such a thing is ever possible), but rather an idealized situation that supports the political agendas of the text-producing elite. Rarely do the political interests of the text producers correspond to the academic interests of modern scholars. For instance, royal inscriptions will emphasize the agency of the king in creating water systems (often acting with the blessing of the gods) but fail to mention the preexisting systems that the king expanded, or the local systems of water sharing that brought water to individual fields.

Very often, the empirical elements of water systems were not considered significant enough to be mentioned. Yet, for archaeologists, the physical dimensions of those systems are important for conclusions about economy and society. Elements of system scale (e.g., width and depth of canals, length of system, volume of water, irrigated area) are rarely described, but such elements are critical for assessing the extent of political authority, whether through the control of land or through the ability to mobilize the labor necessary for system construction. The absolute scale of an irrigation system can help archaeologists determine whether it was a critical element of the subsistence economy or a vanity project. When analyzed on a regional scale, archaeological evidence can overturn major theories of

1 E.g., Gasche and Tanret 1998; Wilkinson, Gibson, and Widell 2013.

2 E.g., Rost and Hamdani 2011.

3 Bagg 2000.

social evolution; for example, the once-influential hydraulic hypothesis of Karl Wittfogel⁴ has fallen largely out of favor, since Robert McCormick Adams demonstrated that urban settlement patterns preceded major irrigation systems by a millennium.⁵

THE IMPORTANCE OF A REMOTE PERSPECTIVE

Elements of water systems can be found via ground-based observations. In the north of Iraq, many monumental elements of the Neo-Assyrian systems of the ninth to seventh centuries BCE were already known by the early twentieth century; indeed, some were already known to Layard. These features were built elements such as dams, aqueducts, tunnels, and associated rock reliefs.⁶

The canals themselves, however, tend to be far more ephemeral, especially if they are small or used for a short term, and therefore lack the upcast mounds that are the product of long-term maintenance. Such canals are easily removed by subsequent activity, whether natural (wind deflation, water erosion) or cultural (agriculture, newer irrigation systems). Faced with such challenges, earlier landscape archaeologists reconstructed river and irrigation systems by “connecting the dots” between archaeological sites of the same time period.⁷ This method can propose the locations of primary canals, but secondary or tertiary canals are impossible to reconstruct in this manner.

If they survive at all, ancient canals require a remote perspective for detection. The canals themselves are most often buried and can be detected only by proxy. For example, an infilled and plowed-out canal may still have some microtopography that collects moisture, and therefore a dark, linear soil mark may be visible under certain rainfall conditions. The buried canal bed may still arrest water infiltration, and therefore deep-rooted plants such as *Prosopis* often grow in disproportionate abundance compared to surrounding areas. These soil and vegetation marks can be recognized on the ground only with difficulty, but they are often strikingly clear from the vertical perspective of an airplane or space. With distance, features that seem to be isolated when detected on the ground are often revealed to be part of larger and coherent systems of features.

REMOTE-SENSING DATA SOURCES FOR IRRIGATION SYSTEMS

If one agrees that archaeological data for irrigation systems are important, and that a vertical/remote perspective is the best way to acquire such data, the question is then how to find remote-sensing data. Fortunately, remotely sensed imagery of the earth has never been more inexpensive and widely available. Although aerial archaeology is more than a century old, early coverage was focused on individual sites rather than full landscapes and was not very systematic. As Middle Eastern countries attained independence from European powers, their governments became less likely to share aerial imagery with

4 Wittfogel 1957.

5 Adams 1981.

6 Bachmann 1927; Jacobsen and Lloyd 1935; Reade 1978.

7 E.g., Adams 1981.

foreigners, including archaeologists, who had acquired a reputation for working with intelligence agencies.

Beginning in the 1970s and into the 1980s, government-operated scientific satellite sensors, such as the US Landsat and the early French SPOT, became available. The spatial resolution of their imagery was, however, too coarse to detect most archaeological phenomena. With the launch of commercial high-resolution satellites in the late 1990s, imagery with resolution of 1 m or less became available, though at high costs that were prohibitive for most archaeologists. Some of these satellites (e.g., Ikonos, QuickBird, GeoEye, WorldView) also could image the visible and even near-infrared parts of the spectrum. Their major drawback, apart from cost, was the fact that they showed the contemporary landscape, which was heavily transformed by settlement expansion and land-use intensification in the 1960s and 1970s.

When photographs from CORONA, the first US intelligence satellite, were made available via the US Geological Survey in 1998, they precipitated a great expansion of regional-scale landscape research in the Near East. CORONA, which operated from 1959 to 1972, has been discussed extensively.⁸ More recently, photographs from the high-resolution GAMBIT satellite became available in 2000. In 2013, imagery from HEXAGON, the CORONA successor that ran from 1971 to 1986, was released to the US National Archives and Records Administration (NARA). In the past decade, and with little fanfare, film from various U2 aerial missions (1958–60 for Middle Eastern missions⁹) has also been released to NARA. The imagery from these latter programs are all high-resolution grayscale film negatives, with GAMBIT, HEXAGON, and U2 imagery as good as 0.5 m (fig. 1). They can be challenging to use in a geographic information system environment because of the geometric distortion involved, especially in CORONA and HEXAGON satellite photographs. U2 photographs are difficult to acquire; since NARA does not distribute digital versions, researchers must view them in the Cartographic Reading Room in the NARA II facility in College Park, Maryland.

CASE STUDIES IN REMOTE SENSING OF PREMODERN IRRIGATION

The three following case studies give a sense of how remote-sensing analysis, especially using declassified intelligence imagery, has enabled reconstruction of premodern irrigation systems and allowed insight into the social and economic systems within which they were created.

THE KISIRI CANAL ABOVE NINEVEH (CA. 700 BCE)

Of all of the Neo-Assyrian kings, Sennacherib (704–681 BCE) was the most prolific commissioner of canal systems,¹⁰ many of which have now been documented via satellite photographs and ground observations. One of the earliest of these systems is mentioned in many of his royal inscriptions. For example:

⁸ Casana, Cothren, and Kalayci 2012; Fowler 2013; Ur 2013a, 2013b.

⁹ See Hammer and Ur 2019.

¹⁰ Bagg 2000; Reade 1978.

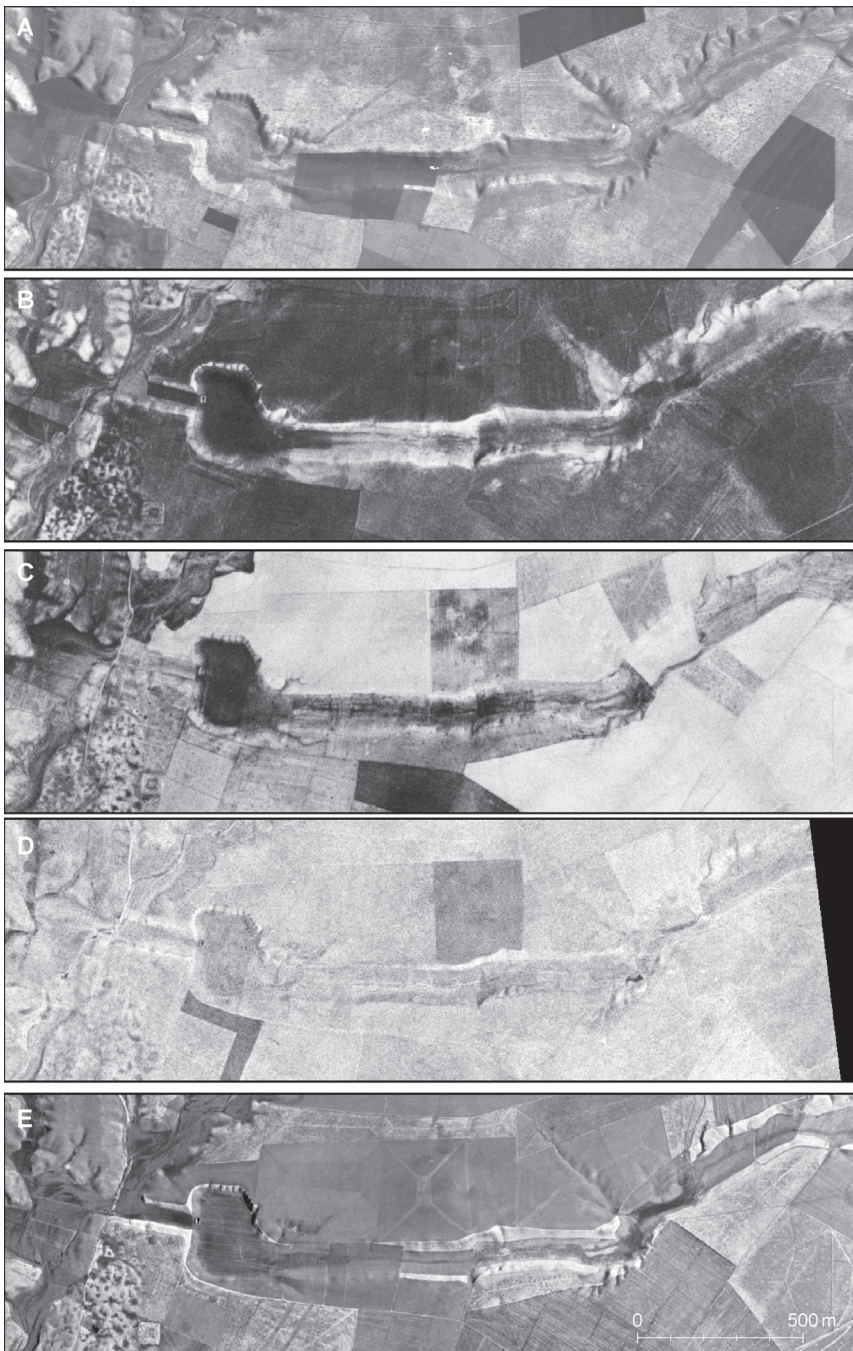


Figure 1. Comparison of declassified intelligence images at the likely cross-watershed earthwork on the Erbil Plain in Assyria (Ur and Osborne 2016). A. U2 aerial photograph (mission 1554, January 29, 1960). B. KH4A CORONA satellite photograph (mission 1039, February 28, 1967). C. KH4A CORONA satellite photograph (mission 1046, March 19, 1968). D. KH4B CORONA satellite photograph (mission 1104, August 16, 1968). E. KH9 HEXAGON satellite photograph (mission 1202, February 1, 1972). All to the same scale.

To plant gardens, I subdivided the meadowland upstream of the city into plots of 2 *pānu* each for the citizens of Nineveh and I handed (them) over to them. To make (those) planted areas luxuriant, I cut with iron picks a canal straight through mountain and valley, from the border of the city of Kisiri to the plain of Nineveh. I caused an inexhaustible supply of water to flow there for a distance of one and a half leagues (*beru*) from the Ḫusur River (and) made (it) gush through feeder canals into those gardens.¹¹

Archaeologists have attempted to use the distance measure in the inscription (roughly 16 km) to estimate the location of the Assyrian town of Kisiri. Thorkild Jacobsen equated Kisiri with a mound called Tell Inthah,¹² whereas Julian Reade¹³ proposed to seek it near a restored but probably ancient dam with the Arabic name al-Shallalat near the village of Beybokht.

With these potential starting points in mind, it was possible to locate nearly the entirety of the Kisiri canal on a series of CORONA satellite photographs,¹⁴ and now to extend and improve that reconstruction with HEXAGON, GAMBIT, and U2 imagery. On photographs from these sources, the canal itself is visible as a dark line that disregards modern roads and field boundaries, an important clue that the feature is premodern. On the earliest imagery, the downslope side of the canal is visible as a light line, probably because it was originally slightly raised. The dark line of the canal appears to be roughly 10 m wide, in the places where it can be measured.

Recently available imagery suggests that the canal began farther upstream than earlier reconstructions afforded.¹⁵ The canal appears to have originated from a weir at a bend in the Khosr river 800 m southeast of Tell Najmok (fig. 2). For its first two kilometers, it ran closely along the right (west) bank of the Khosr, after which it turned to the southwest, following closely the natural contours of the landscape, until it passed over a wadi at the village of Sayid Lar (fig. 3). From there, it ran southward, more than a kilometer distant from the Khosr, and more than 30 m above the level of the river today (which has certainly cut down into its bed in the past millennia), still weaving in and out of the natural right-bank drainages. Around 1.5 km from the northern corner of Nineveh's city wall, the canal appears to flow into a natural drainage, which had been captured and redirected to Nineveh's northern corner. At this point, its waters could have flowed around the city via a moat (visible into the 1960s along its northeastern and northwestern walls) into an artificial marsh, or even into the city itself). A poorly preserved western branch may have flowed into a Tigris drainage above the city, making water available for fields to the northwest.

The empirical description of the Kisiri canal is more than an illustration of a feature known from texts. It enables a critical assessment of how royal inscriptions depict reality. The inscription describes the landscape in two ways that appear to exaggerate the difficulty of the engineering undertaking. First, the canal cut through a "mountain" (written with the logogram KUR). To the contrary, the course of the canal was almost wholly dictated

11 Sennacherib 1 lines 88–90; Grayson and Novotny 2012, 39.

12 Jacobsen and Lloyd 1935, 33.

13 Reade 1978, 64.

14 Ur 2005, 322–24.

15 E.g., Ur 2005, 322; Reade 1978, 64.

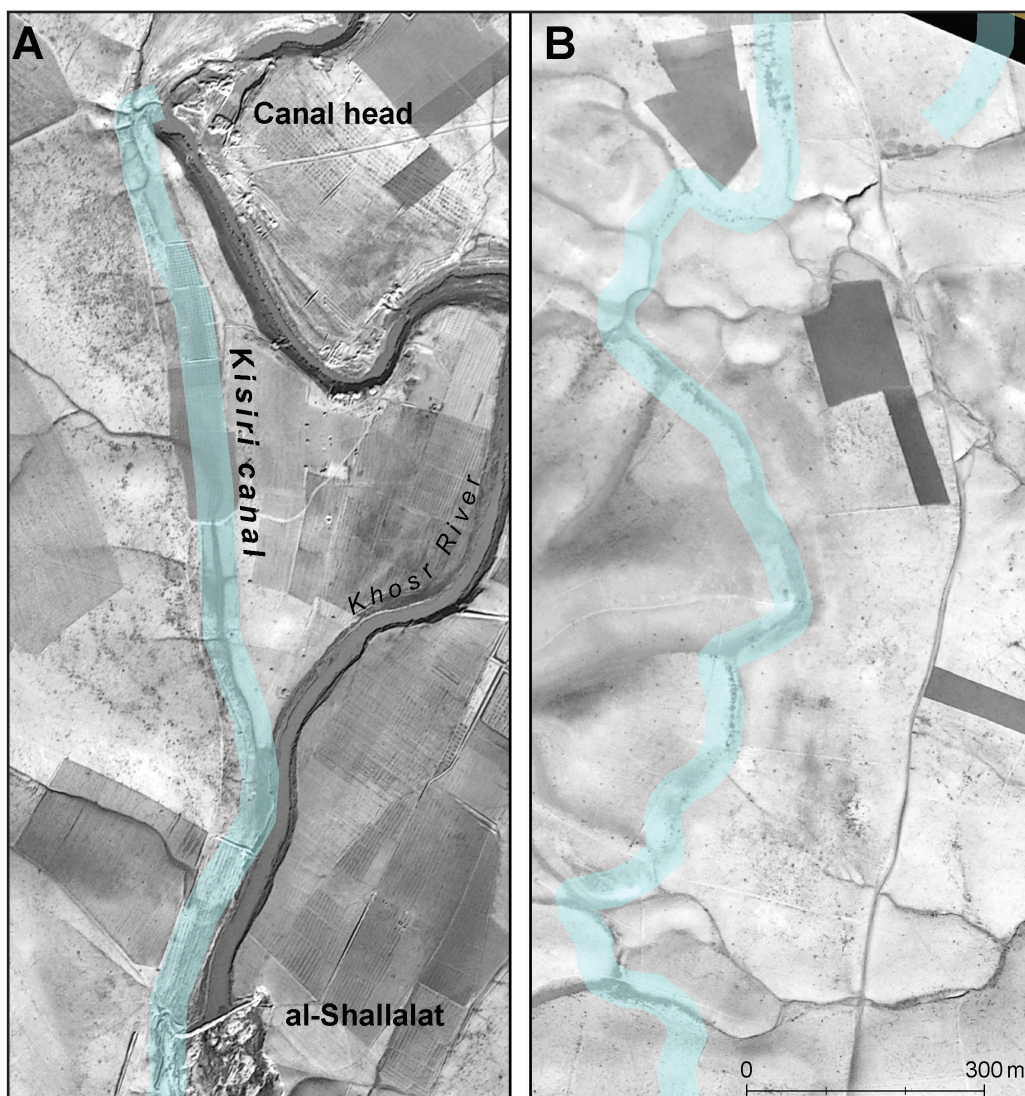


Figure 2. The Kisiri canal on U2 aerial photography (mission 1554, January 29, 1960). A. The canal head. B. The canal near Nineveh. Both photographs to the same scale. See figure 3 for locations.

by the terrain. It may be the case that, in places, its engineers cut into the sides of the hills surrounding the Khosr River valley, but it is doubtful that any person living in the shadows of the Zagros foothills would consider the gently rolling land above Nineveh to be mountainous. The canal is said to go “straight through mountain and valley.” As just described, the canal was anything but straight. For example, the straight-line distance between Sayid Lar village and the point at which the canal descends toward Nineveh is 3,500 m, but the length of the canal between those points is 4,400 m.

Most striking, however, is the overall modest size of the Kisiri canal (see fig. 3). At 15.8 km long, it was much shorter than, for example, Ashurnasirpal’s canal for Nimrud,

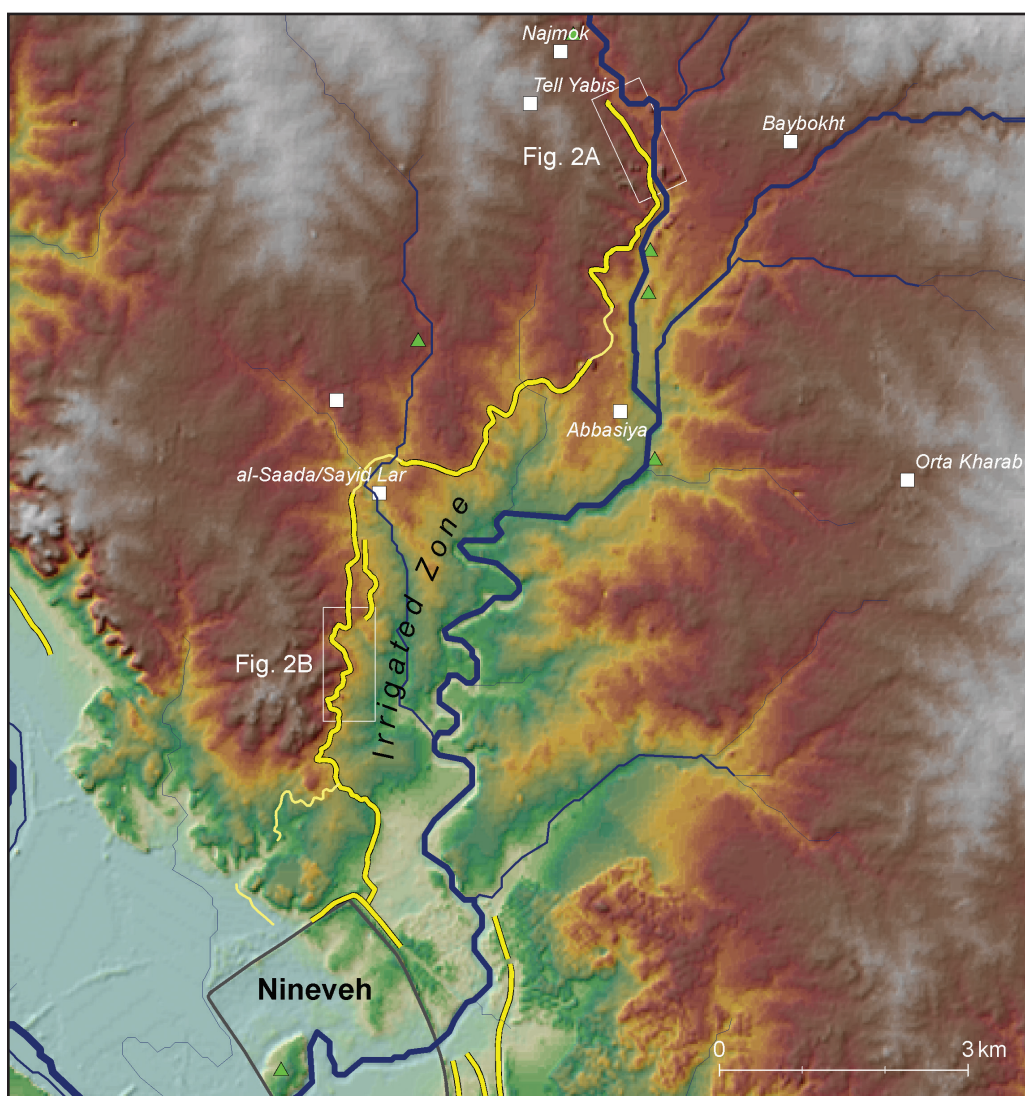


Figure 3. Plan of the Kisiri canal, north of Nineveh.

which was at least 21.6 km and may have been as long as 40 km.¹⁶ It was also dwarfed by the enormous systems commissioned later in Sennacherib's reign, especially the 90 km Khinis-Jerwan canal.¹⁷ The maximum irrigated area of the Kisiri canal (not counting Tigris floodplain fields, which cannot be estimated) was not quite 12 sq km. This area was about half the size of the terrace-irrigated area of the Nimrud canal, and only a fraction of the more than 100 sq km potentially irrigated by the Khinis-Jerwan canal on the Navkur Plain.

¹⁶ Ur and Reade 2015.

¹⁷ Ur 2005, 335–39; Jacobsen and Lloyd 1935, 31–43.

THE EARLY ISLAMIC ESTATE AT TELL BRAK (CA. 800 CE)

Tell Brak was a long-inhabited settlement that took a variety of urban forms over five millennia.¹⁸ Most research has concentrated on its earliest phases,¹⁹ but ironically it is only in its final settlement that irrigation seems to have arrived. At the northeastern corner of the Brak settlement complex is the “Castellum,” so named by the Jesuit priest and archaeologist Antoine Poidebard, who photographed a square fortified feature from the air and made small soundings.²⁰ Most subsequent scholars have followed Poidebard’s dating of the site to the late Roman period, based on his interpretation of its architecture.²¹

With more recent field investigations, the Castellum has proven to be one of the most complex elements of Brak’s already-complex settlement landscape. Surface collection²² recovered no Roman material whatsoever; the Castellum is in fact an Early Islamic fortified estate, with a town outside its walls, covering 14 ha. The settlement complex is only one element of its landscape, however. An enclosure north of the fortified structure walled off a 10 ha area, perhaps for a garden or paddock. Linear trackways extended outward from the complex in nearly every direction. Finally, a series of small canals extended from the nearby Jaghjagh River.

Brak’s offsite landscape is a complex palimpsest of modern and recent tracks, field boundaries, and plow envelopes²³ overlaying at least 4,000 years of earlier features, most of which are wide hollow ways dating to the Early Bronze Age (ca. 2600–2000 BCE) and narrower ones contemporary with the Early Islamic settlement.²⁴ These premodern features all appear as dark lines that disregard the modern landscape elements. Further complicating the palimpsest is a number of features that appear superficially similar to hollow ways but avoid elevated terrain. These features are canals, and at Brak they are closely associated with the Castellum.²⁵

The Early Islamic system began at a weir across the Jaghjagh, approximately 6.3 km to the northeast of Brak (fig. 4). The canal, which appears approximately 15 m wide, flowed first through a large early Islamic town (BKS-39²⁶) before turning to the south. It ran for about 6 km between the Jaghjagh to its left (east) and an elevated area of gravel hills to its right (west). Once the terrain allowed it, the canal turned to the southwest and ran in the direction of the town, making a slight bend to the south to accommodate the southern end of the gravel hills. The canal reached the northeast corner of the town and flowed through it, much like it had at BKS-39; a narrower canal may have flowed around its southern edge as a sort of moat, rejoining the main canal where it emerged from the town to the

18 Ur 2014.

19 Oates et al. 2007.

20 Poidebard 1934.

21 E.g., Oates and Oates 1990.

22 Ur, Karsgaard, and Oates 2011, 15–16.

23 For the latter, see Ur 2010, 131.

24 Wilkinson et al. 2010.

25 Ur, Karsgaard, and Oates 2011, 16.

26 See Wright et al. 2006–7; Poidebard 1934, pls. II–III.

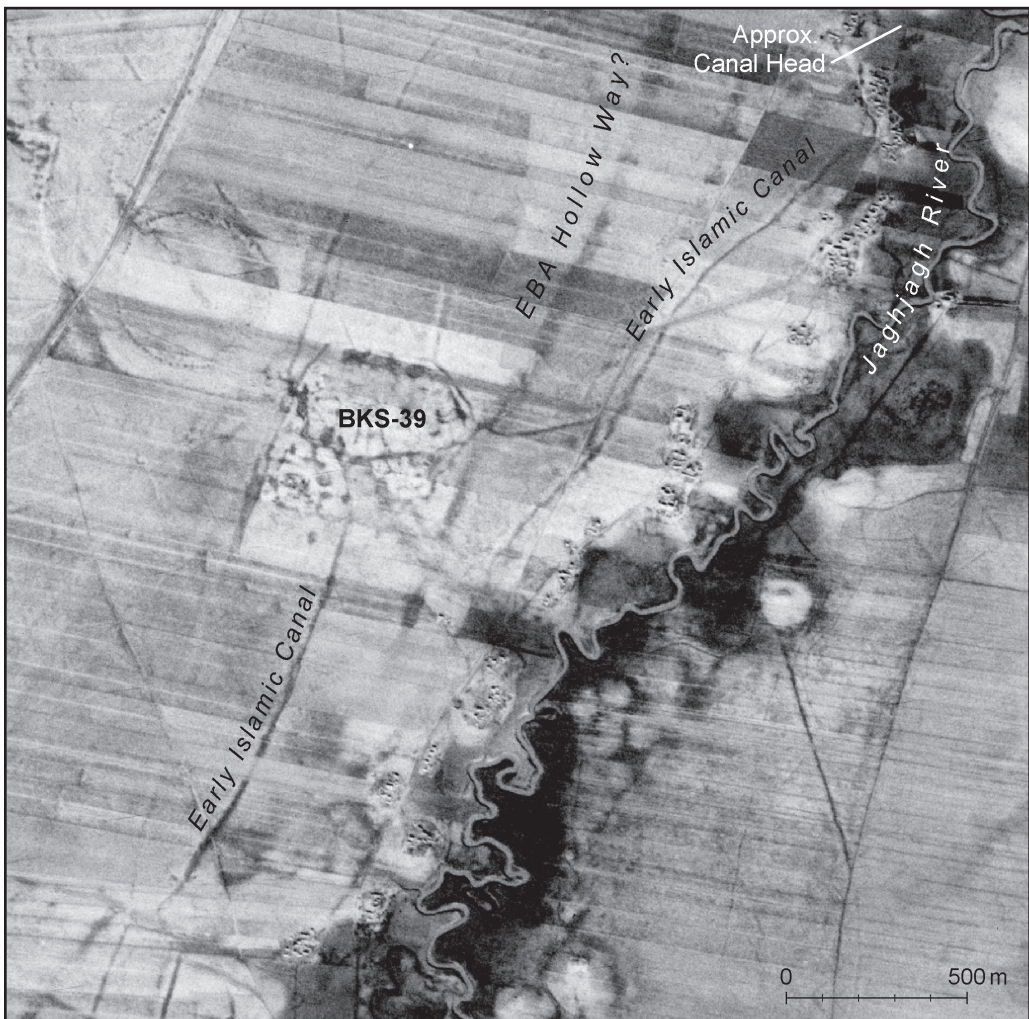


Figure 4. KH4A CORONA photograph of the Early Islamic canal head at BKS-39 (mission 1045, February 6, 1968).

northwest. At that point, the canal continued into the long-since-abandoned ruins of the main Tell Brak site, navigating the low relief of Bronze Age brick pits and hollow ways. Segments of the canal are probably to be seen running west and southwest from Brak's fourth- to second-millennium lower towns, but they are difficult to distinguish on imagery from trackways of the Early Bronze Age and Islamic periods (and indeed were probably actively using the former).

Along the canal segment between the Jaghjagh terrace and the Early Islamic town, three offtakes flowed to the south (fig. 5). One of these distributaries can be traced for over 2 km. Although water flowed all about the Brak settlement complex, the area southeast of the Early Islamic town was intensely irrigated. It therefore is much less puzzling that the Early Bronze Age landscape features that survive in abundance on all other sides of Tell

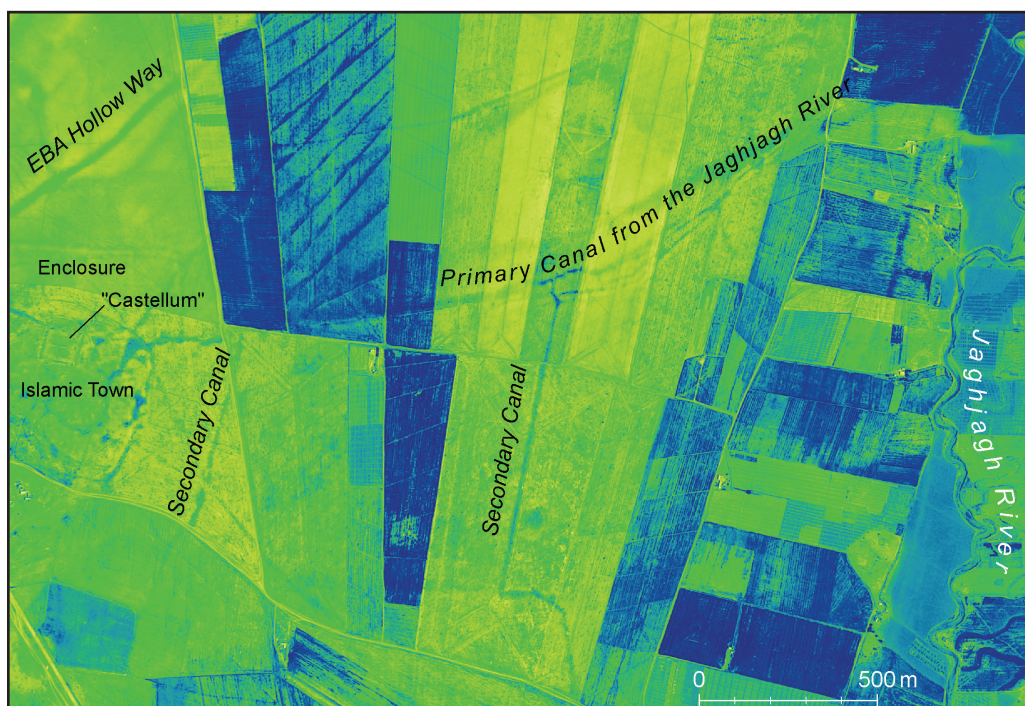


Figure 5. False-color KH9 HEXAGON photograph of primary and secondary canals east of the Early Islamic Brak town (mission 1215, May 5, 1979).

Brak are not present in this area: few of the abundant hollow ways are present, and the density of field scatters (a by-product of manuring in the Early Bronze Age) is much lower.²⁷

Tell Brak gives a glimpse into a surprisingly vibrant Early Islamic rural landscape, with towns and fortified estates connected by small (in comparison with Assyrian) local canal systems (fig. 6). The Brak system is of interest in its own right, but it is also of interest for its taphonomic impact on earlier landscapes. The zone of Early Islamic intensive irrigation agriculture corresponds precisely with a lacuna in Brak's otherwise vivid Early Bronze Age system of fields and trackways. This void would be otherwise inexplicable. Indeed, irrigation continues to be a destructive force on landscape features around Brak. Since the 1980s, diesel pumps drawing on the water table have rendered nearly all surfaces potentially irrigable, and local cultivators have taken advantage. The monumental elements of the Early Bronze Age landscape have persevered, but the more fragile Early Islamic canals have been completely effaced. Today they survive only as marks on historic satellite and aerial photography.

THE IRRIGATED HINTERLAND OF NISIBIN

The final irrigation case study is the most monumental but also the most enigmatic. The context of this system is the southern hinterland of the city of Nisibin, first known to

²⁷ Ur, Karsgaard, and Oates 2011, fig. 6.

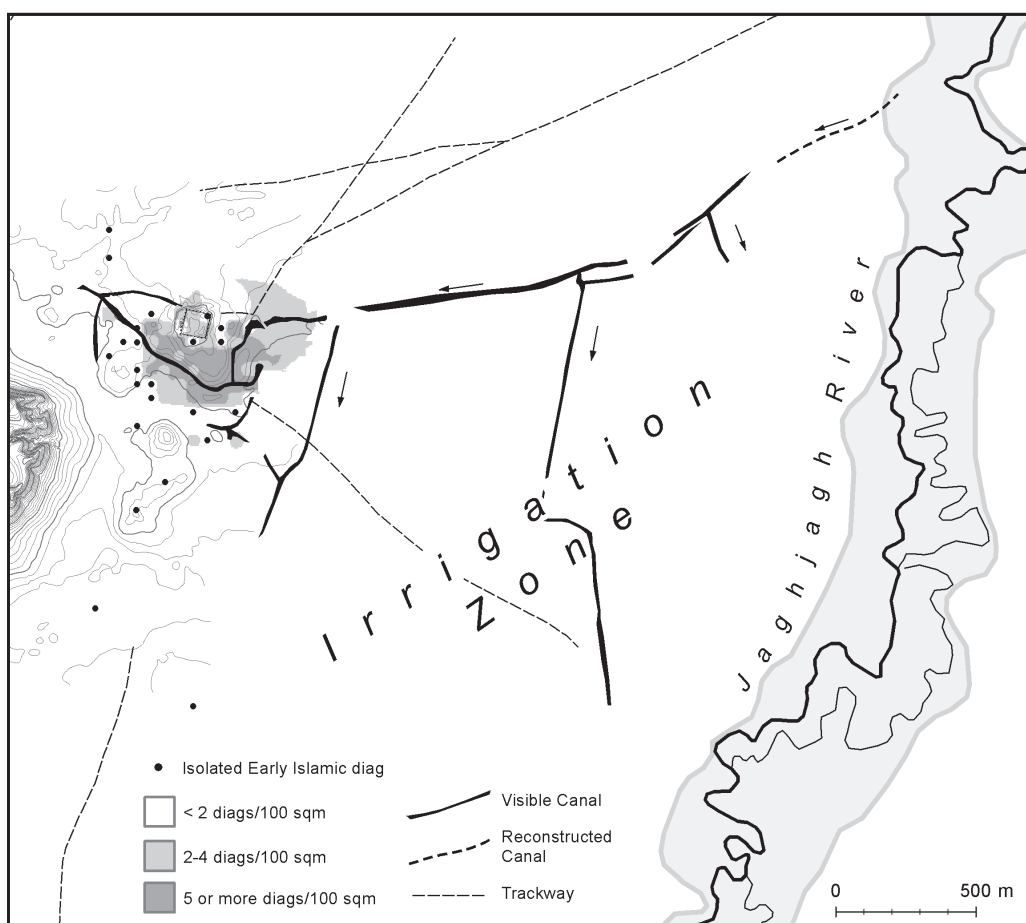


Figure 6. The Early Islamic landscape of Tell Brak.

history as the Neo-Assyrian provincial capital Nasibina in the early first millennium BCE.²⁸ It was occupied continuously since that time, and was an important frontier town in Roman-Parthian times and through late antiquity.²⁹ It was the capital of the Ottoman *livā* of Nişibîn in the sixteenth century.³⁰ Today, the border between Turkey and Syria runs across the archaeological site, and modern settlement is divided between the town of Nusaybin in Turkey and Qamishli in Syria. The Syrian part of Nisibin has been surveyed,³¹ as has its southern hinterland,³² but the latter project largely disregarded post-Bronze Age settlement.

28 Streck 1999.

29 Dillemann 1962.

30 Göyünç and Hütteroth 1997, 61–64.

31 Lyonnet 2000.

32 Meijer 1986.

Despite the importance of Nisibin over the past three centuries, no archaeologist or historian, with one exception,³³ has remarked on the traces of a massive canal system extending nearly 30 km to its south, irrigating the watershed between the Jaghjagh River and the wadis to its east. Elements of this system appear in a 1:200,000-scale French Mandate era map, but its details and extent are fully reconstructable from CORONA, GAMBIT, and U2 photographs (which are abundant because of the airfield south of Qamishli, which was of great interest to the US military).

The signature of most of the canals in the Nisibin system is very different from that of the Kisiri and Brak canals. While some have the dark linear appearance of those systems, most of the Nisibin canals appear as meandering lines, similar to the behavior of natural rivers and wadis in the region. They meander, however, within very narrow and linear belts, and often in parallel and redundant channels (fig. 7). This signature arises when artificial canals cease to be maintained and silt up, but still carry water for at least some time. At the time the photographs were taken (between 1959 and 1972, for those used in this study), the canals had not fully silted up, nor had they been removed by expanding rain-fed fields.

The primary canal can be traced for about 25 km. It flowed along the top of the watershed, so its waters were available to irrigate the lands on either side. The system has not been mapped completely, but it could have irrigated at least 700 sq km below Nisibin (fig. 8).

We owe the survival of the Nisibin irrigation system to two factors. First, the system must have gone out of use relatively recently, as most channels have not had time to silt up. Second, when the area southeast of Nisibin was recolonized by sedentary agriculturalists, they used the former channels to demarcate their fields. Hence the former channels, though no longer flowing, were fossilized by the modern patterns of land tenure.

It is difficult to date the use of this system without targeted survey. Nisibin was important already in the Neo-Assyrian period, and other western provincial capitals are known to have had extensive irrigation systems,³⁴ but an Assyrian origin is purely hypothetical. More solid is a date in the Ottoman period. The tax records of the region in the sixteenth century record abundant rice production in the *livā* of Nisibin.³⁵ Rice farming is very water intensive and would require abundant and reliable water that only artificial irrigation could supply.

The Nisibin system is another example of the impacts of irrigation on the landscape palimpsest. The Upper Khabur basin has perhaps the most extensive premodern system of trackways, mostly from the Early Bronze Age but also the Early Islamic period, which extend in aggregate over 6,000 km.³⁶ The area below Nisibin has a pronounced void in the trackway network. One might assume that movement had been minimal, or that the agricultural intensity that drove trackway formation was not at play in the Early Bronze Age. To the contrary, it seems that once again the taphonomic effects of later irrigation have fragmented the earlier landscape record. The Bronze Age survives mostly as a series of prominent tells that stood above the Ottoman fields and channels; all else was wiped clear.

33 Dillemann 1962, 51–55.

34 E.g., Ergenzinger and Kühne 1991.

35 Göyünç and Hütteroth 1997, 113–15.

36 Ur 2010, 129–46, maps 2–3.

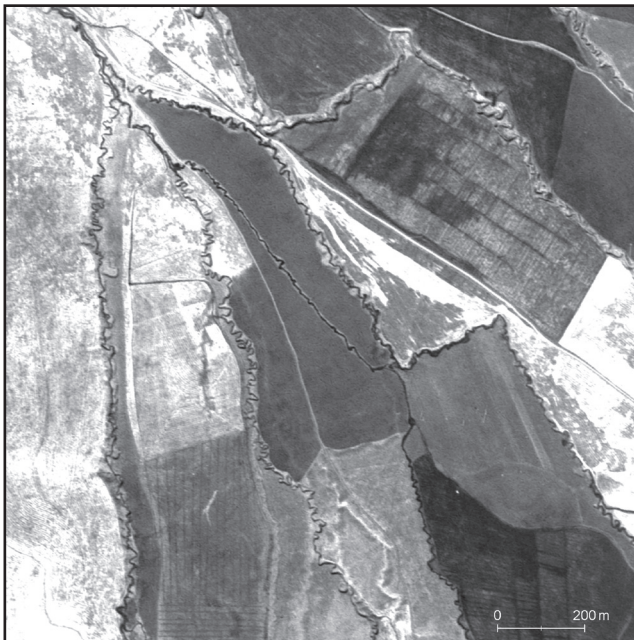


Figure 7. KH7 GAMBIT photograph of meandering relict canals southeast of Nisibin (Qamishli, Syria)(mission 4022, October 1, 1966).

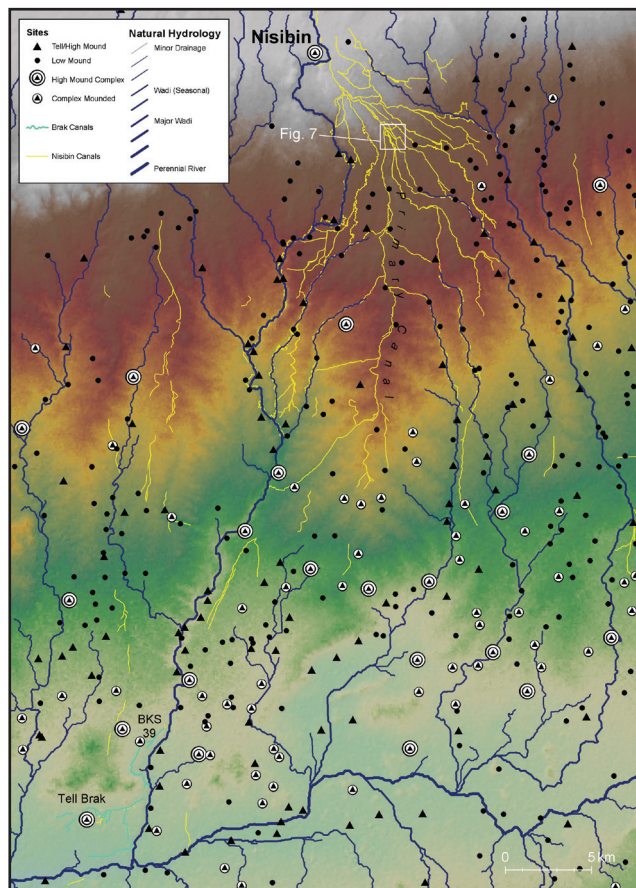


Figure 8. The canal system below Nisibin (yellow). Canal traces derived from KH7 GAMBIT and U2 imagery. For scale comparison, note the Early Islamic canal system around Tell Brak (blue) at lower left.

CONCLUDING THOUGHTS ON REMOTE SENSING OF IRRIGATION

In a case study-based review such as this one, it is probably not prudent to make wide-ranging conclusions. Nonetheless, several generalizations seem reasonable. It should not be surprising to conclude that remote sensing is, generally, a critical component of any study of irrigation or water management. An empirical data set grounded in archaeological observation is both a critical check on the pronouncements of royal inscriptions and a necessity for investigating the questions that historians and archaeologists ask, which rarely coincide with the information that inscriptions provide.

Fortunately, remote-sensing sources are more available than ever, and new digital technologies have enabled sophisticated analytical methods. Not all images are equally useful, however. The case studies presented here have relied heavily on the earliest photographs available. Commercial imagery of very high resolution and in true color has been available for the past twenty years, but it is of limited use in these case studies. Most of the Kisiri canal, for example, is beneath the al-Sukar and al-Baladiyat neighborhoods of Mosul, and development continues to creep northward (fig. 9). Brak's Early Islamic canal system has fallen victim to aggressive deep plowing, though many of its Early Bronze Age hollow ways have persevered. Even with early imagery, much depends on good ground conditions at the time the photograph was taken; most of the canals discussed in these case studies fade to invisibility under the hot and dry conditions of summer.

Early imagery is powerful, but it still has its limitations. The reader will note that the earliest case study presented here comes from the last century of the Neo-Assyrian Empire; the other two cases fall within the past 1,500 years, assuming that the Nisibin system is largely early Ottoman. Excepting massive primary canals, irrigation systems tend to be ephemeral. They are subject to environmental and cultural destruction, and all things being equal, the less time has passed since they went out of regular use, the more likely they will survive for archaeologists to document them. The archaeologist who aims to identify the canals involved in the third-millennium BCE Lagash-Umma boundary dispute is going to be disappointed, but with good imagery and proper field survey, that same archaeologist could probably make great strides toward reconstructing the irrigation economy of the Sassanian state.

ACKNOWLEDGMENTS

I am indebted to various individuals, foundations, and government agencies for access to the historical and recent imagery that enabled this research, including the US Geological Survey (for CORONA satellite photography) and the staff of the US National Archives in College Park, Maryland, especially Gerald Luchansky (for KH-9 HEXAGON satellite photography and U2 aerial photography). I thank Lin Xu and Emily Hammer for their advice and expertise on declassified intelligence imagery, and Harvard's Center for Geographic Analysis for research assistance with Sentinel-2 data. John MacGinnis provided feedback on Akkadian terminology. The American Schools of Prehistoric Research at Harvard University funded imagery acquisition. Field observations of the Early Islamic landscape of Tell Brak were made possible by Joan and David Oates, Geoff Emberling, and Henry Wright.

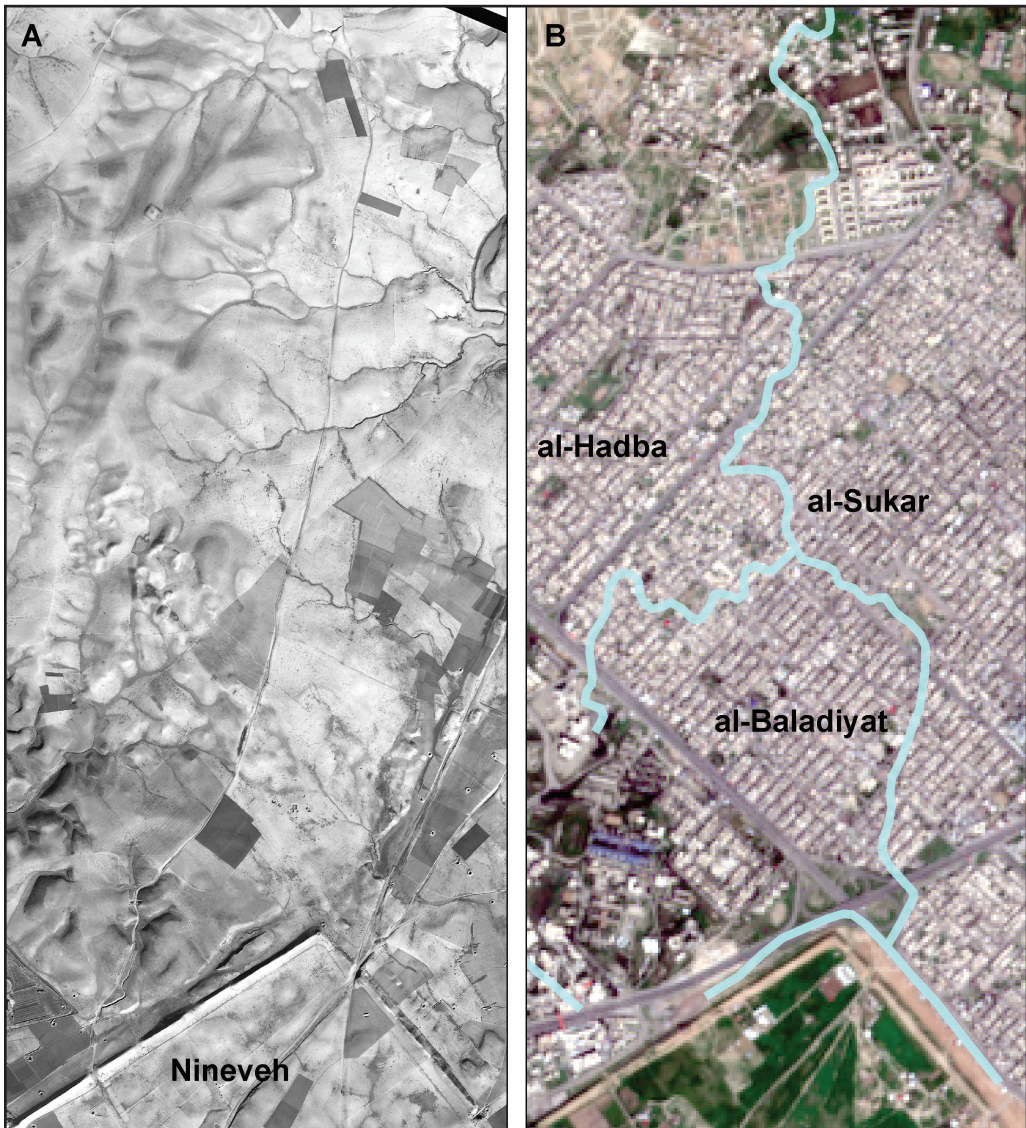


Figure 9. The destruction of the Kisiri canal by the expansion of Mosul, 1960 to present. *A.* U2 aerial photograph (mission 1554, January 29, 1960). *B.* Sentinel-2 image (March 8, 2016).

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