CHAPTER 2

PHYSICAL GEOGRAPHY, ENVIRONMENTAL CHANGE AND THE ROLE OF WATER

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THE ROLE OF THE ENVIRONMENT IN GREATER MESOPOTAMIA

Between 2007 and 2009 the northern Fertile Crescent suffered a major drought, its worst for some 40 years: as a result, natural vegetation showed signs of extreme stress and grain production in northern Syria and Iraq decreased significantly (Trigo et al. 2010). Moreover, hydrological models demonstrate that Tigris-Euphrates stream flow, which partly depends upon snowmelt from the Zagros and Taurus Mountains, will decrease in the twenty-first century AD under the influence of global warming, significantly diminishing riverine discharges as a result (Özdoğan 2011). These two examples eloquently demonstrate how the civilizations of the Fertile Crescent depend upon an environment which is not only variable and dynamic but can also withdraw some of its blessings. However, although the environment has probably played a fundamental role in the region's economy as well as other aspects of daily life, it is overly simplistic to suggest that it determines patterns of behaviour. The aim of this chapter is to summarize the physical geography and the role of water in the Fertile Crescent and to provide the framework for the models elaborated upon in later chapters.

Opinions vary as to the precise ways in which past human societies were influenced by the environment, and the literature generated on this subject is so large that new lines of research often revive earlier arguments, such as 'environmental determinism', without any awareness of the original works which pioneered these ideas (Judkins et al. 2008). Most scholars acknowledge that humans have a complex and intertwined relationship with the environment, but the degree to which human behaviour has actually been influenced by the environment continues to ignite fervent debates. Around the turn of the twentieth century environmental determinism was a major intellectual movement. Supporters of this school of thought argued that the environment had a disproportionally strong influence on human settlement and behavior. In recent times, a more nuanced approach has been outlined by intellectual movements that recognize the complexities of the situation. For example, behavioralism recognises the active role played by humans in shaping their environment, whereas proponents of structuralism argue that the environment played a less important role in the human story (Judkins et al. 2008: 20-21). What is significant, however, is that all perspectives recognize, to some degree, the impact of the environment in every day life. Whereas some see the environment as a pervasive factor often responsible for 'forcing' human settlement and even state development (De Menecol 2001; Kennett & Kennett 2007) others, including the MASS group, see the environment as being an important factor in human decision-making, but only one of a set of many social, economic and political factors that influence the daily lives of human groups.

The environmental framework of greater Mesopotamia

This chapter summarizes key environmental features germane to the modeling of human societies in northern and southern Mesopotamia. In this context 'environment' refers to the geomorphology, soils, hydrology, plants and climate which form the physical and biological surroundings for everyday life in Mesopotamia. It is impossible to provide a comprehensive treatment here, more detailed studies being available in Buringh (1960) on soils, Adams (1981), Verhoeven (1998) on geomorphology and hydrology, and more generally Butzer (1995), Potts (1997), Sanlaville (2000), Robinson et al. (2011), and Wilkinson (2012).
The basin of the Tigris and Euphrates rivers gathers waters from a broad catchment comprising the Zagros and Taurus mountains and their forested hill-slopes, the semi-arid steppe lands of northern Syria and Iraq and southern Turkey, the deserts to the west of the Euphrates which also includes a strip of land between the Zagros

mountains south and east of Baghdad, and the alluvial plains and marshlands of southern Mesopotamia (Knappen et al. n.d. II-9).

Spring snowmelt is the dominant source for stream flow in the Tigris-Euphrates basin (Jones et al. 2008), and due to the snow melt discharged from the surrounding Zagros and Taurus mountains combined with spring rainfall the maximum discharge of the Tigris occurs in April (see below). Because the Tigris-Euphrates basin has changed considerably over recent glacial-interglacial cycles it is appropriate to consider a much larger area than that of the present-day hydrological catchment. This greater region can be broken up into the following sub-divisions:

- An upstream hydrological catchment within the Anatolian plateau incorporating the Zagros and Taurus mountains, which include the upper reaches of the Tigris-Euphrates rivers and their tributaries.

- A zone where these rivers cut through the rolling steppe of the Jazira, namely the land of northern Iraq and Syria between the Tigris and the Euphrates (often known as 'Upper Mesopotamia'). This landscape, sprinkled by a dense scatter of archaeological tells up to 100ha in size, forms the northern settlement zone of the modeling project.

- The alluvial plains of southern Mesopotamia, the home of Sumerian and Akkadian civilizations, and the location of the southern area under consideration here. This area, which is crossed by the anastomosing channels of the Tigris Euphrates, extends to the virtually flat marshy margins that flank the head of the Persian Gulf.

- Extending from southeastern Iraq to the Musandam Peninsula between Oman and Pakistan is the Persian Gulf. This formed a broad, probably arid, lowland during the glacial maximum, approximately 18,000 years ago, but is now submerged below the waters of the Gulf. During the Late Pleistocene this was a waterless depression with a few swampy tracts (Vita Finzi 1978: 258) drained by a locally incised river dubbed (by some) the 'Ur-Schatt River' (Kennett & Kennett 2007: 233-35). This channel received occasional water discharged from tributaries draining the Zagros to the north and the Arabian interior to the south (Wilkinson 2003: fig. 2.3) to form a vast extended Tigris-Euphrates basin that was probably double the area of the present basin. This 'Gulf zone' is important to the long-term settlement history of the region because not only would it have been the locus of long-term human activity during the Late Pleistocene, but also any inhabitants would have been rudely evicted by the rapid transgression that swept up the Gulf in the early Holocene into the neighboring regions of Iran, Arabia and Mesopotamia – perhaps to contribute to the founder populations of later civilizations.

The drainage basin of the Tigris-Euphrates included the home of the origins of agriculture and was the locus of the urban revolution that followed. The Tigris and Euphrates rivers formed 'an enormous dendritic transportation system' (Algaze 2001: 204) that both fed the erosional products of the upper catchment down to the lower Mesopotamian plains and allowed humans to float the products of the mountains and the Jazira region downstream to the Mesopotamian lowlands. By providing a framework for trade and human connections, the river basin played a major integrative role in the development of Mesopotamian civilizations.

There were two distinct trajectories of development for Greater Mesopotamia civilization: one in the rain-fed north and another in the irrigated south (Fig. 2.1). Whereas in the north (northwestern Iraq, northern Syria and southern Turkey) agriculture is reliant upon rainfall for successful crops, in the arid south, where rainfall is less than 200mm per annum, irrigation is crucial for successful agriculture.

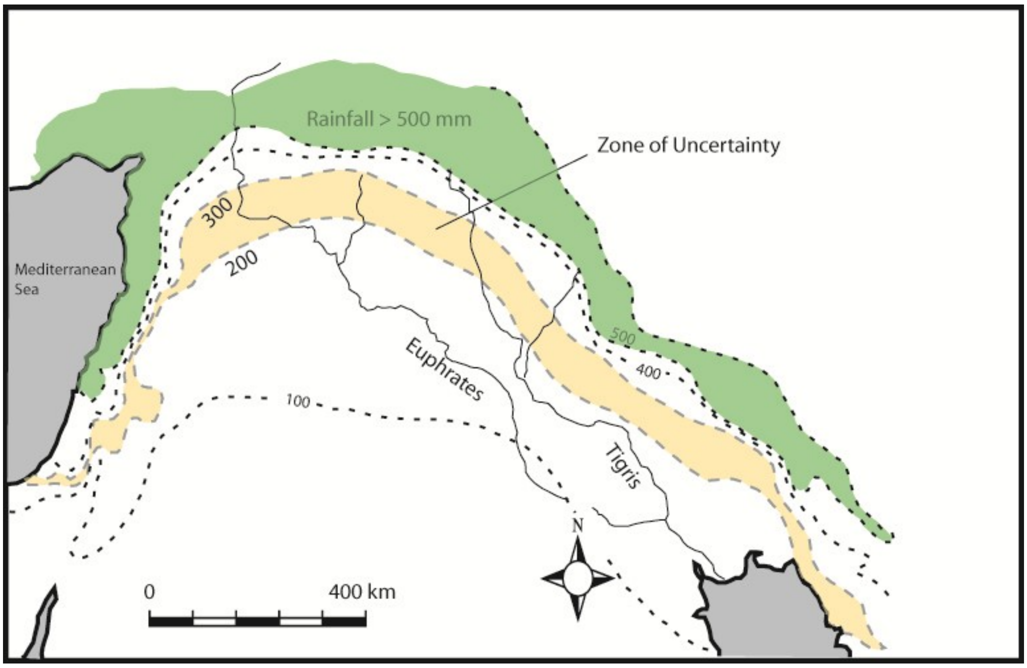

Fig. 2.1 Rainfall in Greater Mesopotamia showing both the rain-fed north and the irrigated south (in boxes) as well as the region of higher rainfall (> 500 mm p.a.) and the 'zone of uncertainty' (180/200-300 mm p.a.) (simplified from Sanlaville 2000, fig. 21).

Geologically, the northern steppe of Syria and Iraq developed upon rolling terrain of Cretaceous and Tertiary limestone, sandstone and some basalt, broken up by the broad alluvial basins of the Khabur, Balikh and Saruj and cut by the troughs of the Tigris and Euphrates rivers. These riverine troughs are flanked by staircases of Pleistocene terraces capped by occasional basalt flows, the radiometric dates of which suggest that over roughly 9 million years the Euphrates River incised through some 270m of bedrock (Demir et al. 2007). Palaeolithic artifacts collected from alluvial terraces high above the river level suggest that approximately 80m of incision has occurred over the last 1.8 million years, a period that spans much of the Pleistocene period (Demir et al. 2007).

The plains of southern Mesopotamia form a broad alluvial lowland sandwiched between the arid limestone steppe of the Arabian platform to the west and the active fold belt of the Iranian Zagros Mountains to the east (Pournelle 2003: 68-73; Fouad & Sissakian 2011). The geologically unstable Mesopotamian geosyncline in between has been accumulating sediments throughout the past 2 million years of the Quaternary period, so that the plain which formed the foundation for the later civilizations can be seen to have a long and complex history, only a small part of which can be inferred from the sediments exposed on the surface (Yacoub 2011).

Palaeoenvironmental history

Since the pioneering studies of Lamb (1977) and Butzer (1958), scholars have been aware that through the last 10,000 years of the Holocene period, the climate has varied through cycles of increased moisture, heat and storminess. Nevertheless, during the 1970s and 1980s a new orthodoxy argued that over at least the past 6000 years, and indeed virtually the entire Holocene, the climate had been essentially stable (Raikes 1967). This stable Holocene scenario was reinforced by initial interpretations of the Greenland ice cores, which implied a much less tempestuous Holocene than the preceding glacial phases (Anderson et al. 2007: 148-49). However, the earlier research has now been vindicated, as numerous studies have demonstrated that the climates of the non-polar regions have indeed varied significantly. For example, six periods of 'rapid climate change' have been identified over the last 8200 years (Anderson et al. 2007: fig. 1.2). Nevertheless, the definition of what constitutes a climatic 'spike' is subjective, and the ways in which these have influenced past human activity remains as hotly contested as ever (Weiss et al. 1993; Butzer 1997; Zettler 2003; Kuzucuoğlu and Marro 2007).

The nearest high resolution climate proxy curve to Upper Mesopotamia was developed from cores taken through the sediments of Lake Van, located in the east Anatolian highlands some 200-300km north of the Syrian/Iraqi Jazira (Lemcke & Sturm 1997). This record of oxygen and hydrogen isotopes and geochemical indicators has been dated by counting annual laminations in sediment (varves) to provide a record of atmospheric moisture, temperature and water quality back to ca. 13,700 years before present (i.e. 1950= BP). As with most proxy records, these curves include errors and problem areas. These include the earlier part of the sequence (before 8200 BP) which may be in error by 1000-1600 years. Fortunately, for the purpose of modeling the development of ancient towns and cities, this error occurs before significant urbanization.

The Lake Van record can be summarized as follows (Fig. 2.2; Lemcke & Sturm 1997; Kuzucuoğlu 2007: 468):

- from ca. 5500 BP (during the later Neolithic) until ca. 3050 BC (the beginning of the EBA) the climate was moister than in the present day
- there followed a transition phase from 3050 to 2050 BC, which showed increasing aridity interrupted by drier phases at 2400 and 2150 BC and was characterized by drier conditions in the final quarter of the millennium
- from ca. 2050 BC – that is, during the Middle and Late Bronze Ages and the Iron Age – conditions remained drier than the present day, becoming similar to the present day at around 1 BC
- by the Parthian and Sasanian periods (in the last centuries BC and first centuries AD) conditions stabilized around those experienced today, but with occasional fluctuations. When applied globally, terms used to describe events that followed such as the 'medieval warm period' and the 'Little Ice Age' are often disputed (Anderson et al. 2007: 186-7) and are virtually lost within the noise of the Van data. However, even during the late Holocene phase of 'present day conditions' the realities of climate fluctuations and associated catastrophes, such as swarms of locusts and bubonic plague, were a constant threat and are well recorded in the chronicles of historians such as Michael the Syrian (Widell 2007).

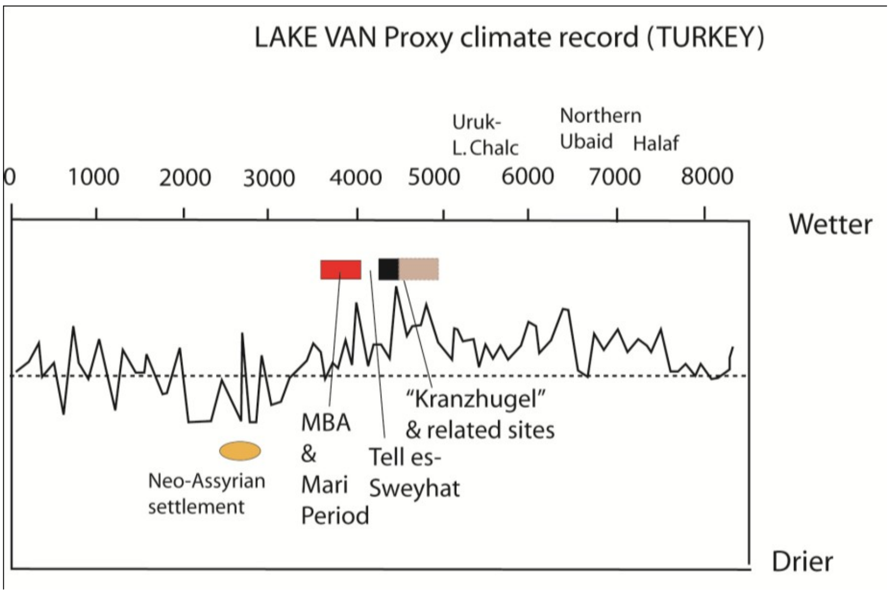

Fig. 2.2 Moisture proxy record from Lake Van (from Lemcke & Sturm 1997). Superimposed are the approximate durations of Early Bronze and Middle Bronze Age urbanization and in northern Mesopotamia.

Palaeoclimatic records from Lake Zeribar in western Iran, close to the catchment of the headwaters of the Tigris River, provide a cross-check to the record from Lake Van (Snyder et al. 2001; Stevens et al. 2001). According to the Zeribar records, atmospheric conditions were again moist in the earlier Holocene (around 6000 BP), after which lake salinity increased and the atmosphere became drier. This drying was especially evident between 4000 and 3000 BP (that is, during the Middle-Late Bronze Age).

In addition to these broad trends in climate, a number of shorter episodes of rapid climate change have been identified ca. 5200 and 4200 BP. Of these, a much-debated episode of climate drying dated to ca. 2300-2200 BC (ca. 4200 BP) appears to have continued into and even intensified in the second millennium BC, during which time conditions became even drier. Whether a slightly moister episode that preceded the late third millennium dry episode between 5000 and 4400 BP actually helped fuel the secondary urbanization of the Early Bronze Age is possible but uncertain (Fig. 2.2). It is indicative of the ambiguity of the relationship between climate and settlement that some sites – Tell es-Sweyhat, for example – grew to their maximum size during a period when the climate was drying. Although this relationship is apparent from Figure 2.2, it is demonstrated even more clearly by plotting the rise and fall of this 40ha 'citadel city' against the refined climate proxy record from Soreq Cave in Israel (Fig. 2.3). Here, however, we must exercise caution, given that Soreq Cave is more than 200km from Sweyhat and may not reflect climatic trends in the Middle Euphrates.

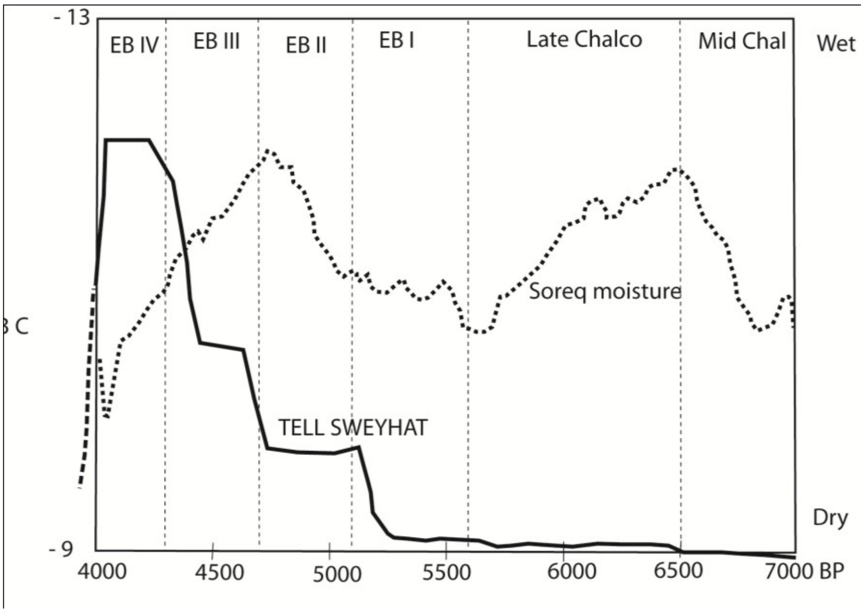

Fig. 2.3 The approximate trajectory of growth and decline of the site of Tell es-Sweyhat (northern Syria) against the climate proxy curve for Soreq Cave (broken line). (Based upon data in Zettler 1997; Wilkinson et al. 2012 and Bar-Matthews & Ayalon 2011).

During the Middle Bronze Age, when the Van record indicates significant climatic drying (Fig. 2.2), sedentary settlement became patchy throughout the Khabur basin; pastoral nomadism reasserted itself within the western Khabur, but there was a concentration of settlement in the northeastern Khabur and northwestern Iraq (Lyonnet 1998; Wilkinson 2002; Ristvet 2008). It is therefore quite possible that this distinctive phase of devolution of sedentary settlement was partly a result of increasingly dry conditions in the region. However, because there is a tendency for climatic cycles to be viewed simply as 'wetter' or 'drier', much of the discussion of early urbanization is couched in subjective or deterministic terms. Consequently, there is a need to analyze interactions between humans and the environment in terms of actual human behavior and its results: the response, for example, of crops to more finely graded climatic events than decadal or century scale averages. Agent-based models provide a first step in such analyses.

Although it has been claimed that settlement decline in the late third millennium BC corresponded with a phase of drier atmospheric conditions (Weiss et al. 1993), Kuzucuoğlu and Marro (2007, and papers therein) argue that this relationship is by no means a straightforward one. Settlement and state development does not simply increase during wet conditions and collapse during dry episodes. Nevertheless, settlement at the arid margins of settled areas appears to have increased during the early or mid-third millennium BC and retreated towards the end of the millennium, especially in the so-called kranzhügel[1] zone to the west of the Khabur basin. As noted above, in the later third and early second millennium BC, settlement in the western Khabur appears to have been replaced by nomadic adaptations. These changes are well documented in cuneiform records from Mari that refer to the Hanaeans and other groups in the steppe-lands fringing the Euphrates (Fleming 2004). On the other hand, the apparent decrease in urbanization that took place in the Jazira during the early third millennium BC (Ninevite V period) occurred when conditions were apparently moister. Such early third-millennium urban and perhaps state decline must also be seen in the context of the massive growth in settlement that occurred in southern Mesopotamia during Early Dynastic times (Chapter 3). In fact, urbanization and state development in Sumer may have been so pronounced that the irrigated south became a magnet, attracting some population from the north. In other words, economic, social and political factors may have overridden the attractions of better or more reliable harvests. This raises an important point that complicates our interpretations of human-climate relationships: not only is climate spatially and temporally variable, but some areas of settlement will also increase at the expense of others that experience a population decrease. Because of the propensity for human populations to be mobile and sometimes to migrate to places that are attracting inhabitants for purely political, social or religious reasons, it is difficult to distinguish between populations which have changed as a result of crop failure resulting from drought and those which have undergone cultural changes.

One explanation for the settlement collapse (or devolution) that took place around 2300, 2200 or 2000 BC (Kuzucuoğlu & Marro 2007 for details) was that it was not simply the result of climatic aridity and associated crop failure alone. Rather, the increased urbanization and population density that prevailed in the Jazira during the late Ninevite V period and Akkadian times took place in the face of increasing aridity and in some cases in climatically marginal areas (Figs. 2.2 and 2.3). One model holds that, as a result of the increased frequency of cropping and decreased use of fallow, there was a tendency for these communities and their agricultural systems to become less resilient to external shocks (Wilkinson 1997; Marro & Kuzucuoğlu 2007: 588; see below). The combination of high population levels and lower soil moisture, perhaps compounded by the increased taxation or tribute associated with increased social complexity, would have stressed existing agricultural systems to the limit, so that the climate drying episodes of the late third and second millennium resulted in the fragile cropping systems failing, at least around selected settlements; this would have resulted in localized famine, desertion or perhaps a shift to more well adapted nomadic pastoralism (Wilkinson 1994; Deckers & Riehl 2008). Unfortunately, conventional methods of relating archaeological evidence to environmental data do not allow us to test these models.[2] One of the strengths of agent-based models is that they allow us to run 'experiments' in which ancient households and communities can live within a simulation 'environment' and produce crops and herds that develop according to a proscribed set of conditions.

The above-mentioned complexities should not, however, be used to diminish the significance of climatic fluctuations and other natural disasters on human populations. The occurrence and significance of dry episodes and dust storms is recorded in cuneiform texts from eleventh and tenth century Assyria (Neumann & Parpola 1987) and, from a later period, a wide range of types of natural disaster have been recognized in the chronicles of Michael the Syrian. Of these, drought was cited third most frequently after very cold winters and locusts (Widell 2007: table 2). Such episodes probably occurred throughout the Holocene, including the third millennium BC, but at present the archaeological records are not sensitive enough to recognize their impact.

[1] Kranzhügel, sometimes referred to as “wreath-shaped” mounds, are circular settlements of the third millennium BC, found primarily in the north central steppe of Syria between the Balikh River (in the west) and the western Khabur basin.

[2] Despite this, statistical analysis that combines regional climatic data and palaeoclimatic proxy records is now providing important new insights into the relationship between climate, settlement and agricultural productivity in Upper Mesopotamia (Kalaycı 2013).

Because of their location within the headwaters of the Tigris and Euphrates rivers, the Lake Van cores do not merely give us a picture of rainfall within the northern Fertile Crescent; they can also be harnessed to indicate the discharge of the main rivers. A much-cited study that linked palaeoclimate and river discharge records was based upon cores taken from Lake Van during the 1970s (Kay & Johnson 1981). Unfortunately, this pioneering study is weakened by dating errors since parts of the sediment core proved to be missing. The fact that climate in the northern basin was correlated with river discharge in the south is important for understanding the human ecology of the region, and more recent studies using coupled global climate and hydrological models demonstrate that under conditions of global warming, the discharge of the Euphrates would decrease significantly by the end of the twenty-first century AD (Kitoh *et al.* 2008; Özdoğan 2011).

It is difficult to interpret the more recent Lake Van data directly in terms of river flow, since rainfall, evaporation and catchment conditions must all be taken into account. Bearing that caveat in mind, the Euphrates would probably have carried a higher discharge than today during the period ca. 8000-4000 BP (Riehl & Bryson 2007: fig. 1). Flow likely declined during the late Early Bronze Age, the Middle Bronze Age, Late Bronze Age and Iron Age (i.e. from the Ur III period through to the Parthian empire). During these two millennia, flow was slightly lower but was also subject to significant fluctuations. Cuneiform sources provide seemingly contradictory evidence for the Euphrates and some of its branches: in places their channels were choked with silt and reeds, presumably because of low flow, but there were also unusually high flows, especially in the Euphrates near Mari and in its tributary the Khabur (Cole & Gasche 1998: 9-11). Such conclusions can be connected with the palaeoclimate record from Lake Van by assuming that dry conditions and associated siltation of channels would clog channels so that the subsequent spring flood would not be able to flow freely downstream (Cole & Gasche 1998: 11). Alternatively, they may reflect the slightly drier, but more variable flows shown in the models of Bryson (Riehl & Bryson 2007: fig.1).

THE NORTHERN STEPPE AND RAIN-FED AGRICULTURAL ECONOMIES

The ecological conditions under which the earliest cities developed in northwest Iraq and northern Syria were very different from those that prevailed in the irrigated south. In northern Syria and Iraq rainfall is sufficient for arable crops, but the frequency of crop failure increases towards the south within what can be described as the 'zone of uncertainty' (Jas 2000; Wilkinson *et al.* 2012). The considerable degree of year-to-year variation is evident from the rainfall statistics compiled for three cities within northern Mesopotamia (Fig. 2.4; see also Kalaycı 2013: 80-99). Since at least the Chalcolithic this region formed a major 'bread basket' dominated by the cultivation of wheat and barley, with lentils, vines and olives in the wetter north and west.

Most tells, especially those dated to the Bronze Age, are found on the broad plains which extend along the major rivers of the Khabur, the Balikh, the Euphrates, and their tributaries (Menze & Ur 2012). Although tells are more frequent along wadis (Deckers & Riehl 2008), it appears that physical attractors such as proximity to water were not necessarily the only factors that contributed to the location of tell sites. In fact, some of the largest and most prominent tells – Brak and al-Hawa, for example – are situated neither on wadis nor on channels with permanent flow in the mid-Holocene. Rather, they were mainly supplied with water by wells, minor springs or seepages. This suggests that factors other than environmental ones may explain the location of some of the more successful settlements.

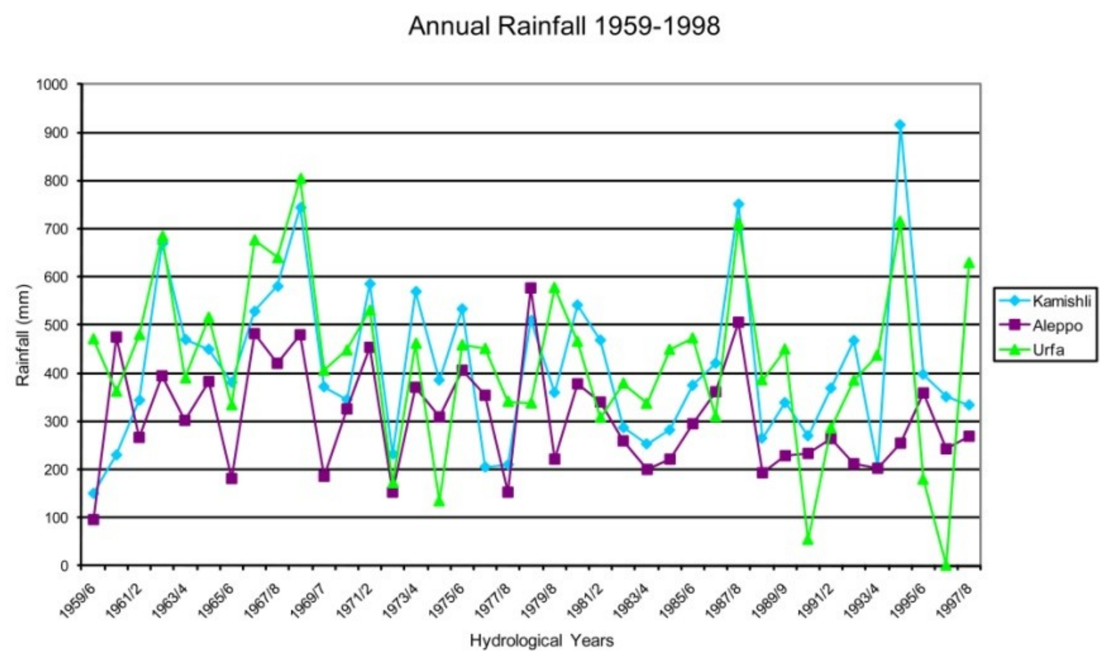

Fig. 2.4 Mean annual rainfall at Kamishli (Qamishli) and Aleppo (Syria), and Urfa (Turkey) between 1959 and 1998. Based upon World Weather Records: note that 0 mm ca. 1996 / 1997 may be an error in the records. The data has been classed according to hydrological years (September to end of August in each year). (Compiled by C. Coyle for the MASS Project). Note that all three records show a gradual decline through the period in question, with the decline at Urfa being the greatest (gradient m= -4.16), Aleppo less (gradient = -2.22) and Kamishli least (gradient = -0.49).

The availability of deep cultivable soils was also a key factor for the development of tell settlements, and these soils are particularly prevalent within the broad agricultural basins of the northern Fertile Crescent (Fig. 2.5 a & b). The Jazira falls into the calcic xerosol group of soils which, over millennia, have accumulated calcium carbonate concretions within the subsoil B horizon (UNESCO; Van Liere n.d.). When the first European travelers crossed the Jazira, regions with these soils were sparsely populated, but they were recognized as being potentially very fertile. Since then, archaeological surveys have demonstrated that tells predominate on such soils and that, where these soils thin out on the surrounding limestone or basalt plateaus, tells virtually disappear and archaeological sites become sparse or of a very different character. Soils in the Jazira are determined by the combined effects of geology, climate and plant cover, although as Van Liere (n.d.) maintains, good practices of management also contribute to their fertility and to the production of good crops. Hints of such good management practice can be inferred from the scatters of pottery and kiln waste that surround Bronze Age archaeological sites and testify to the spreading of organic rich settlement waste on the fields to maintain fertility (Chapter 4). Nevertheless, since many soils in the Khabur and Balikh basins have been cultivated almost continuously for some 8000 years or more, Jazira soils must have been punished by millennia of nutrient depletion. This is supported by computer simulations which suggest that soil nutrient status continues to provide one of the major limitations to agriculture (Altaweel 2008; see also Chapter 11). Within the upper Khabur basin and neighboring areas of northwestern Iraq, the main cultivated areas are found on soils developed upon ancient alluvial sediments, except in northeastern Syria where soils on plateau basalts predominate. Where basalt-derived soils are sufficiently deep and occur in well-watered areas, such as the northeast of Syria, they can support sustained cultivation. Elsewhere, however, such as the areas to the west of Tell Beydar, the thin soil cover remained uncultivated until recently, and even in the twentieth century AD some basalt land was given over to pasture. Other pasture areas probably also existed along the Wadi Radd, where groundwater soils indicate the former presence of marshlands. Towards the southern edge of the upper Khabur basin, south of Tell Brak, where rainfall is less than 200mm per annum, the calcium carbonate-enriched subsoil horizon is replaced by gypsum. Soil cover is also much shallower than in the north and the area was and is dominated by pastoralism.

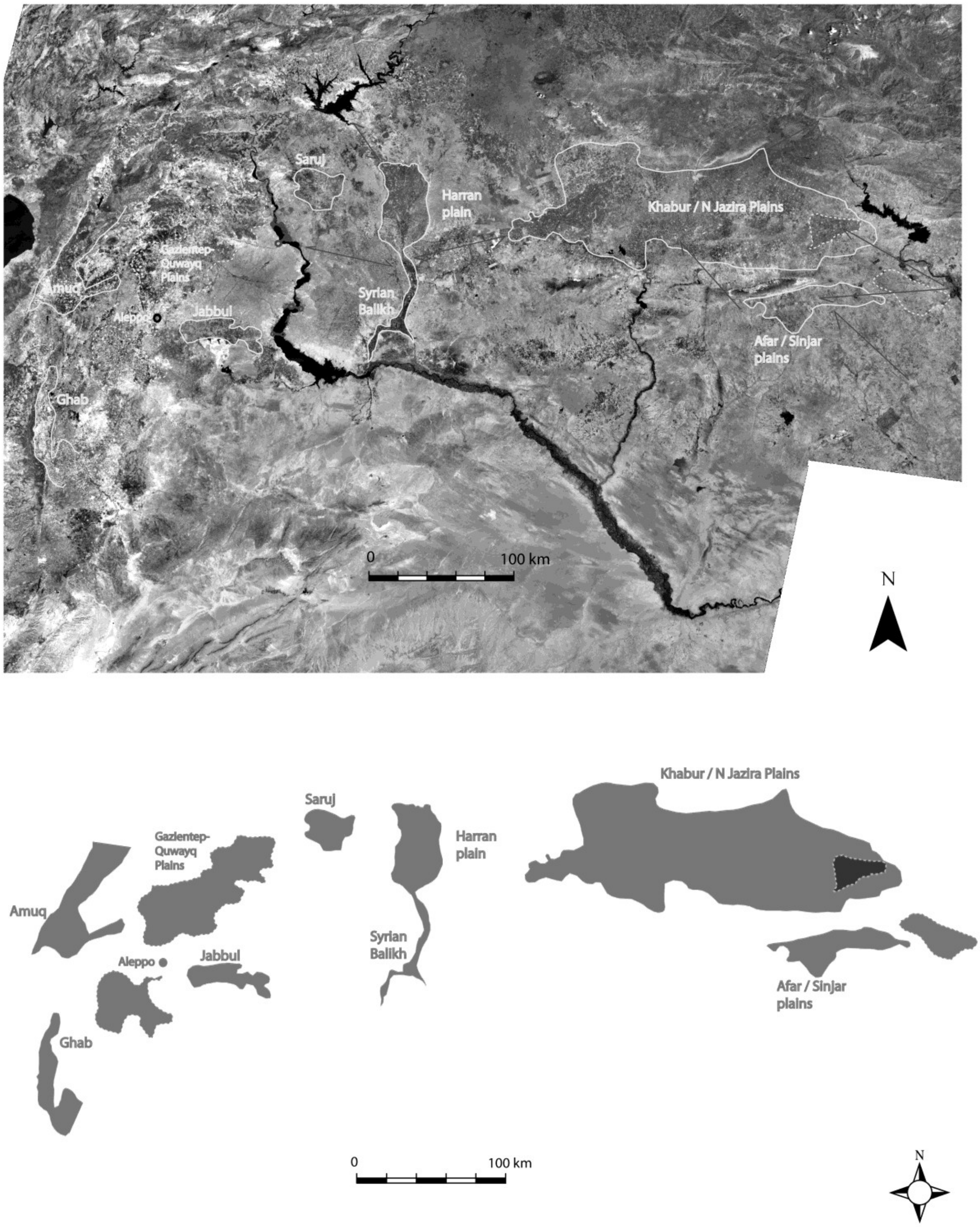

Fig. 2.5 Top: Agricultural basins and plateaus of the northern Fertile Crescent superimposed on a LANDSAT image. Boundaries of the agricultural plains have been checked against changes of slope as derived from SRTM images (based upon data compiled by N. Galiatsatos for the Fragile Crescent Project. Below: outlines of the agricultural plains derived from the top image.

Despite being virtually devoid of woodland today, during the early Holocene much of the Jazira would have been covered by deciduous oak woodland in those areas where rainfall was greater than approximately 350mm per annum. Further south, terebinth-almond (i.e. pistachio-almond) steppe occurred within what is today an area marginal for rain-fed agriculture – that is, where rainfall is between 200-350mm per annum (Fig. 2.6; Hillman, in Moore et al. 2000; Deckers & Pessin 2011). The high density of settlement and population that prevailed during the fourth and third millennia BC probably accounts for the loss of this vegetation, although this is difficult to demonstrate directly. Long-duration pollen sequences mainly fall outside the region, but carbonized plant remains, although influenced by both human and natural processes, chart the diminution of woodland cover during the fourth and third millennia BC (Miller 1998). Whereas during the late fourth and third millennia BC the upper Khabur basin and parts of the Euphrates valley retained their cover of oak park-woodland, in the middle Khabur the terebinth-almond woodland and neighboring steppe were showing signs of significant degradation or were gone completely by the Early Bronze Age (Deckers & Riehl 2007; Kuzucuoğlu & Marro 2007: 577). The most densely settled areas of northeastern Syria and northwestern Iraq must have lost much of their tree cover by the mid-third millennium BC, as archaeological surveys demonstrate that cultivation systems must have covered virtually the entire terrain between tells, particularly in the regions of Tells Hamoukar and Hawa (Wilkinson & Tucker 1995; Ur 2002; 2010). Nevertheless, during the Late Chalcolithic and Early Bronze Ages, the loss of woodland cannot have been total, and significant stands of oak seem to have remained in the Khabur in the third millennium BC and even into the Byzantine period in places (Rosen 1997; Deckers & Riehl 2007).

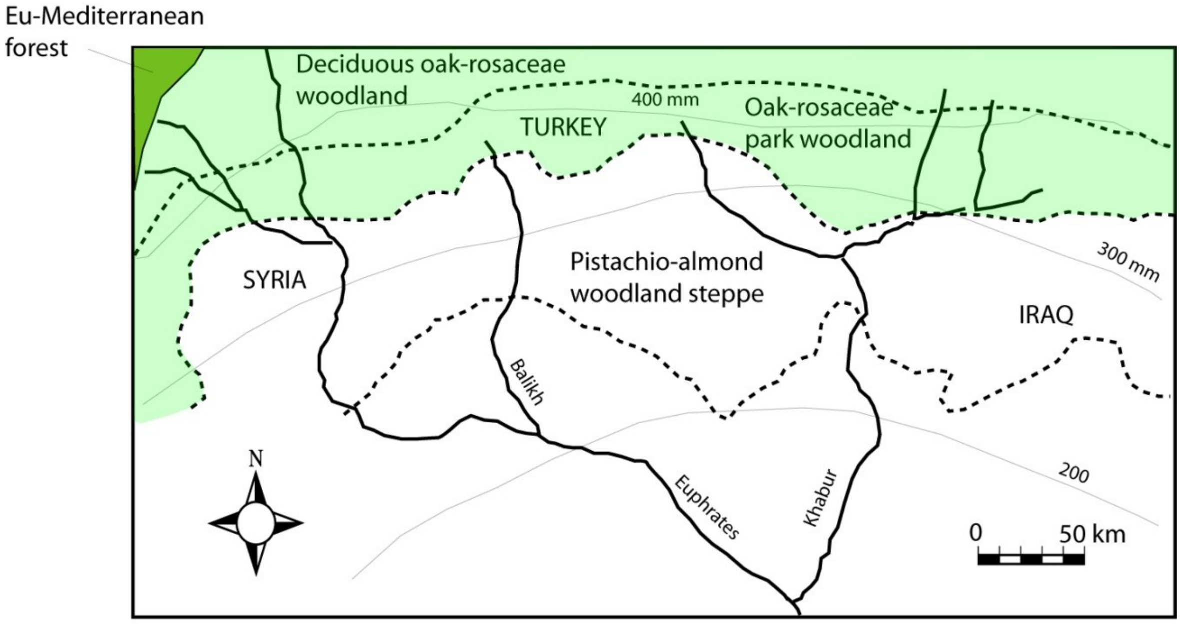

Fig. 2.6 Map of potential early Holocene vegetation in northern Syria, Iraq and southern Turkey (based upon Hillman, in Moore et al. (2000), and Deckers & Pessin (2011): fig. 1). Approximate rainfall isohyets are superimposed as thin grey lines.

In the Jazira the extensive areas of cultivated land compensate for the relatively low yields per hectare to supply relatively high total production, which during the Early Bronze Age must have rivaled the total production of the irrigated south (Weiss 1986). Although there is no unambiguous evidence for the use of canals for irrigation before the Middle Assyrian period[3], cuneiform texts from the Yorgun Tepe (Nuzi), to the east of the Tigris, suggest that as much as 20% of the land was irrigated in the mid-second millennium BC (Zaccagnini 1979; this volume Chapter 4). However, given the lack of field evidence for Bronze Age canals in the areas of Tells al-Hawa and Beydar, we are treating the land use systems of the Jazira as being wholly rain-fed in the period ca.

[3] Except for the area of Mari, which is not considered in this research.

5000-2000 BC (the period of interest here). This provides a marked contrast with southern Mesopotamia where approaching 100% of the cultivated land was irrigated.

The Syrian Jazira has been subdivided into six 'agro-ecological zones' by agronomists (Cocks et al. 1988; Jones 1993), but for archaeological purposes it is more realistic to recognize two broad zones:

1) a region with greater than ca. 300mm mean annual rainfall, where Late Chalcolithic settlement was relatively common and which today is dominated by wheat, lentil and grape cultivation (Zones 1 and 2 of Cocks et al. 1988); this is also the zone where Oak-rosaceae park-woodland predominated in the early Holocene.
2) the 'zone of uncertainty', with mean annual rainfall of between 300mm and 180mm per annum, in which barley is the most successful crop and sheep and goats are particularly important to the local agro-pastoral economy (Zones 3-5 of Cocks et al. 1988); this is the area of the former pistachio-almond wooded steppe. Here Late Chalcolithic settlements are rare, but there was a boom in EBA settlement during the late fourth and much of the third millennium BC (Wilkinson et al. 2012).

The above zones encompass a wide range of uncertainty in crop production, and Van Liere (n.d.: 27) suggests that even in good wheat land such as in zones 1 or 2, crops may fail one out of every three to six years. Under modern conditions of commercialized agriculture, harvest failure is regarded as a yield of less than 500kg/ha, which in neighboring parts of Turkey would occur one year in six or seven (Jas 2000: 256-7).

Under present-day social and economic conditions, defining a climatic limit to agriculture is difficult, and Van Liere has pointed out that today this is very much determined by modern economic circumstances as well as climate (Van Liere n.d.: 49). For example, when cereal prices are low, only the best and more well-watered soil can be sown, whereas with high prices, even marginal lands achieve profit. Because prices rise during times of short supply (and dry conditions) and fall during times of abundance (wet years), there may be a greater incentive to cultivate the marginal steppe during dry years, thereby risking crop failure. Although such conditions of commercialized production did not prevail in the ancient Near East, this case illustrates that the margin of cultivation is very much dependent upon both economic and environmental factors as well as human perceptions of risk and supply.

In northern Syria many Uruk and Bronze Age period towns fall within a 'zone of uncertainty' (Fig. 2.1) that is marginal today for cultivation and which receives a mean annual rainfall of 180-250mm (Wachholtz 1996; Wilkinson 2000, fig. 2) (Table 2.1). Although some of these sites, such as Emar and Bi'a, probably benefited from irrigation, others such as Sweyhat and Tell Malhat did not. This distribution illustrates that large-scale urban settlements do not simply develop in moister areas where crop yields are optimal, but rather that settlements can develop and thrive, at least for a while, where other conditions, perhaps pastoral production or trade, are more significant (Chapters 7 and 9; Wilkinson et al. 2012).

Table 2.1 The location of major Early Bronze Age sites in northern Syria, southern Turkey and northwestern Iraq according to rainfall zones (rainfall, in mm per annum, is approximate).

Zone	**Rainfall**	**Sites**
Moister, sub-marginal	> 250mm	Brak, Beydar, Leilan, Mozan, Hamoukar, Chuera, Titriş, Samsat, Kazana, Carchemish, Banat/Bazi, Mardikh, Nineveh, Til Beshar, Hawa, Khanzir, Abu Shakhat, Mabtuh al-Sharqi
Marginal	180-250mm	Sweyhat, Hadidi, Tell es-Seman, Khoshi, Bi'a, Umm al-Marra, Emar, Malhat ed-Deru.

As demonstrated by Wirth, the frequency of drought does not simply increase towards the southern desert: wet years can result in most of the Jazira receiving sufficient rainfall for cultivation, whereas during dry years a much larger part of the Jazira registered rainfall less than 200mm per annum, with only the northeastern Khabur basin receiving sufficient rainfall for successful cereal crops. However, absolute levels of rainfall are not the only factors that determine a successful harvest; inter-annual variability is also extremely important (Wallén 1967). In other words, even if the average rainfall seems sufficient for successful cropping (ca. 250mm for wheat, slightly less for barley), if the rainfall variability is too great there will be an increased frequency of dry years with crop failures. Grain reserves would then be insufficient to tide a community over for a large number of deficit years (Wilkinson 2000; Rosen 2007: 7).

Although cereals may be grown every year in the moister northern areas, the characteristic practice is for fields to be fallowed every second year (i.e. biennial fallow; see below and Chapter 4). Farther south, the number of years under fallow increases until crops (mainly barley) are only planted if it is perceived that rainfall will be sufficient that year. In addition to this marked geographical zoning of crops, analysis of carbonized plant remains suggests that during the drier Middle Bronze Age certain crop plants with high moisture requirements, such as lentils, garden peas and grapes, ceased to be cultivated throughout much of the Jazira; in contrast, the hardy bitter vetch and barley continued to be grown with the latter often becoming the dominant crop (Riehl & Bryson 2007: 531). Hence, during periods of apparently dry conditions, cropping can be seen to have continued, although there appears to have been some adjustment to the types of crop grown (Riehl 2010; Charles et al. 2010).

THE SOUTHERN ALLUVIAL PLAINS AND THE ROLE OF WATER

At first glance, the plains of southern Mesopotamia appear flat, bleak and relentlessly arid, the vista broken only by alignments of palm gardens, occasional fields of dunes and upstanding canal banks or archaeological mounds. On careful viewing, however, it is possible to discern low alluvial ridges which have built up over the millennia as a result of the preferential deposition of sand and silt along river channels and canals. These ancient river levees form substantial features in the landscape, rising as much as 5m above the surrounding flood basins and being up to 5km in width (Fig. 2.7; Wilkinson 2003: fig. 5.4). The presence of the main river channel along the levee crest provided a focus for settlement sites and associated palm gardens, as well as a source for irrigation: water would be transported down the levee slopes, often along a branching or herringbone system of canals (Fig. 2.8; Chapter 4). Archaeological surveys demonstrate how ancient sites are preferentially distributed along the levees (Ur: Chapter 3); since many levees are associated with sites ranging in date from Ubaid to Islamic, it is clear that they form long-term features of the landscape, but are especially significant during the third millennium BC and later (Ur: Chapter 3). Even if a river channel shifted abruptly from the levee crest to a more convenient course, it would have been advantageous for kings and ancient engineers to redirect its flow back into the vacated channel or to dig new canals along this course, thereby taking advantage of the existing topography (Cole & Gasche 1998: 14). In the language of complex systems, the Mesopotamian plains provide an excellent example of 'path dependence', in which initial conditions can determine later phases of development.

The irrigated landscapes of southern Mesopotamia can be regarded as giant 'sediment traps' because each part of the system – irrigation channels, fields and flood basins, as well as marshes beyond – became loci for the deposition of silt and clay. This sedimentary landscape is differentiated topographically into levees, levee slopes and flood basins (Chapter 4) and according to sediment type into sandy/silt, silts and clays, with the finer clays accumulating at the maximum distance from the levee crest (Fig. 2.7).

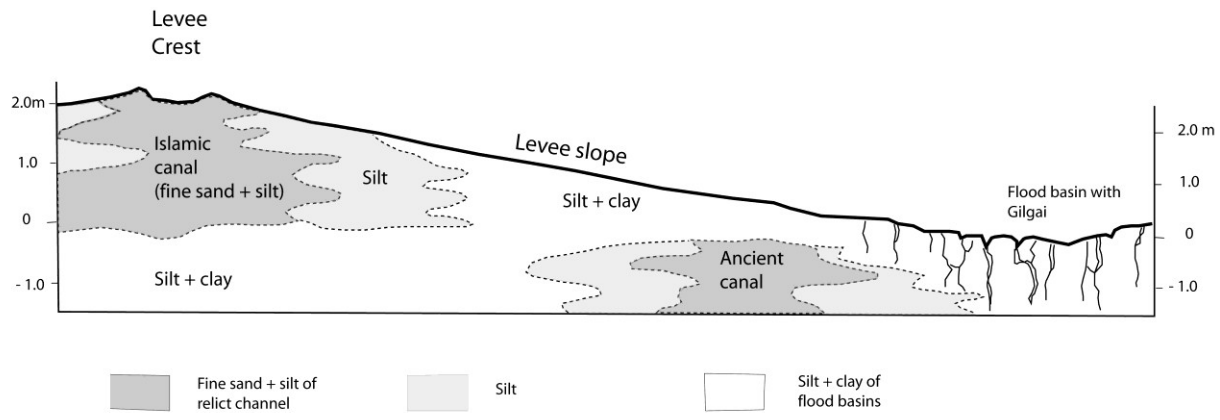

Fig. 2.7 Cross-section of a levee in the Diyala region of Iraq showing the deposits of buried canals and the distribution of sediment types down-levee. (Based upon a section in a consultant's report of the Diyala region).

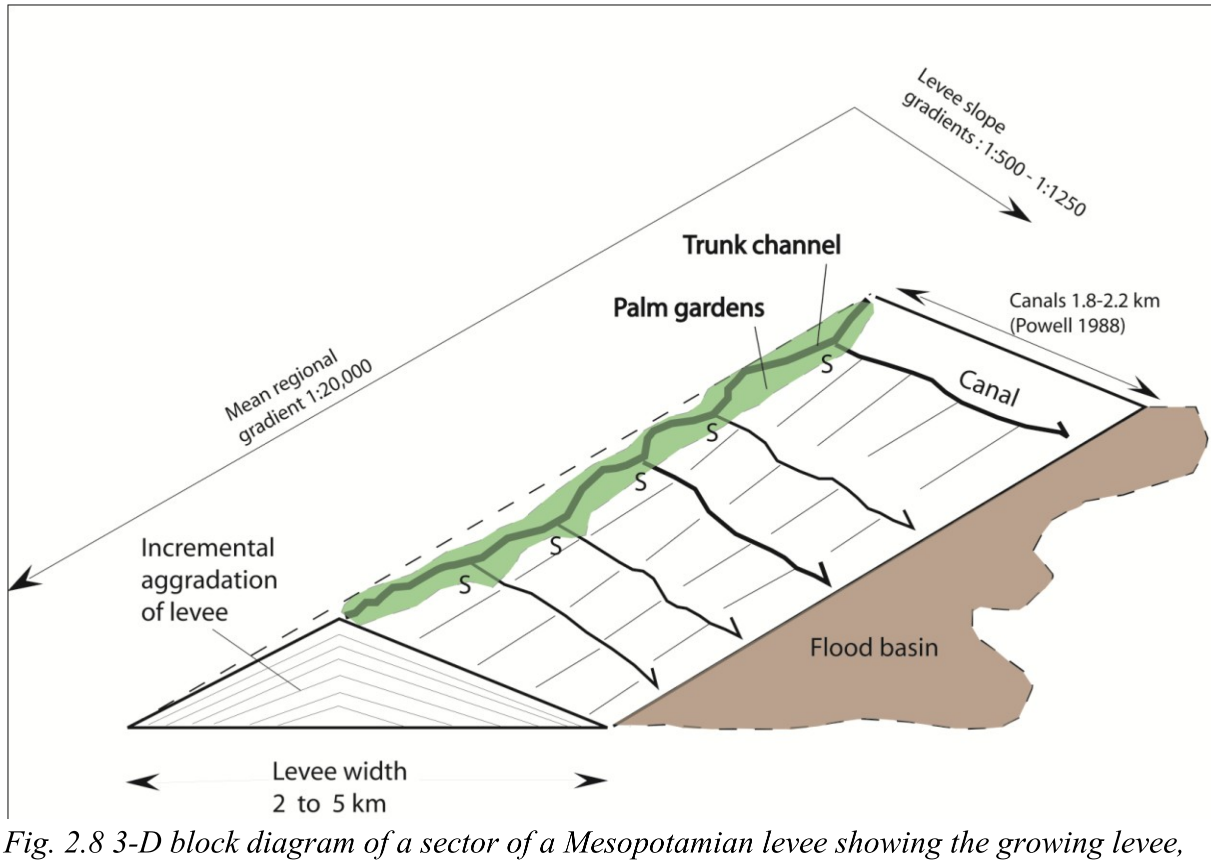

Fig. 2.8 3-D block diagram of a sector of a Mesopotamian levee showing the growing levee, levee-top palm gardens, the herringbone pattern of lateral canals discussed further in Chapter 4, and the flood basins. The length of canals is based upon information derived from cuneiform texts; gradients relate to figures derived from consultants reports (tabulated in Wilkinson 2013: table 2.1 and references therein).

During the twentieth century AD, the detention of water behind hydroelectric dams in Turkey, Syria and northern Iraq, together with drainage schemes in the south, resulted in the loss of many of the extensive and interlocking deltaic wetlands. Nevertheless, even today marshes continue to form a conspicuous feature of the landscape, and we know from both cuneiform texts and the texts of Islamic geographers that such wetlands contributed a verdant element to the landscape and formed a crucial component of the Mesopotamian economy during both historic and prehistoric times (Cole 1994; Pournelle 2003). The higher ambient rainfall, increased river discharge and raised sea level ca. 4000 BC must all have contributed to an increasingly marshy setting for the development of the earliest Ubaid communities (Pournelle 2003). Moreover, the ever-present threat of major floods from the Euphrates and (especially) the Tigris made flood basins and swamps an ideal safety valve for excess water.

The alluvial plains accumulated over the Quaternary period of geological history, and most of the fine clay, silt and sand was deposited over the past 10,000 years (i.e. the Holocene; see Buringh & Edelman 1955 versus Buringh 1960: 162; Yacoub 2011). However, parts of the plain may be significantly older, and Pleistocene surfaces have been recognized in the south near Tell Oueli and Larsa (Geyer & Sanlaville 1996) and possibly as ‘turtle backs’ to the north and east of Uruk (Pournelle 2003). The processes of sediment accumulation and loss are extremely and spatio-temporally complex. Sediments preferentially accumulate along the river channels, which naturally agrade as a result so that eventually the channel is raised, perhaps several meters above plain level. Both floods and irrigation water run-off then cause the intervening basins to become sumps for clay deposition, sometimes in fresh or brackish marshes. If a river should shift its channel or if the protective cover of vegetation is lost (because of lack of soil moisture), the soils can dry out and become vulnerable to wind erosion, so that the topsoil is eroded away and incorporated into 'sand' dunes, many of which, strictly speaking, are mainly composed of silt-clay aggregates. As a result of the two contrasting processes of alluvial accumulation and aeolian degradation, parts of the landscape, often in close proximity, can build up (i.e. agrade) whereas others erode (degrade). Consequently, parts of the archaeological record may become buried and elsewhere, in degrading areas, the more robust parts of archaeological sites are revealed (Wilkinson 2003: chapter 5). Therefore, a major difference between the north and south is that in the north most major sites rest on a relatively stable soil surface or are associated with localized alluvial deposition, whereas in the south most sites are contained within a widespread aggrading sedimentary environment or remain within degrading alluvial landscapes that are constantly scoured by aeolian activity.

The above summary does not simply supply the 'environmental background' or the stage upon which the 'actors' of the ancient world played out their lives. Rather, these geomorphological features and process both shaped the everyday lives of the inhabitants and were produced by the local inhabitants, who, by cleaning out silt from canals, constructing bunds (soil ridges) around fields, diverting rivers and digging canals contributed to landscape development themselves. The landscape of southern Mesopotamia is therefore very much a cultural product (Algaze 2008).

The Tigris and Euphrates rivers vary in form from upstream to downstream as follows (Wilkinson 2003: 82):

- in the upper reaches of Turkey, Syria and northern Iraq, the rivers have multiple (braided) channels and their beds are generally coarse sediments of gravel and sand

- within the upper alluvial plains of Mesopotamia around Baghdad, where the sediments are fine silts and clay, the rivers possess 'single thread' channels that are meandering or sinuous

- in the lowermost reaches of the alluvial plain, the single thread channels show a tendency to split into subordinate branching channels (anastomosing) which, although not straight, are considerably less sinuous than those in the middle reaches of the plain. This is a common situation on alluvial plains where channel sinuosity is lowest where valley slope is also very low (Schumm 1977).

During the Holocene there has been a tendency for Mesopotamian rivers to adopt anastomosing patterns, presumably because extremely low gradients and very low stream power result in a tendency for channels to accumulate sediments, a situation that is enhanced by the construction of networks of canals, sluices and other devices which slow and raise water levels. As a result, breaks in levees are more likely and new channels are formed as a result.

The development of branching channel systems in the lower parts of the alluvial plain appears to result from the tendency of the rivers to occasionally abandon their long-established course and adopt a new one, often at a lower elevation (Allen 1965). Such abrupt channel shifts, known as avulsions, are well known from the geological literature and may be a fundamental process in the development of the Tigris and Euphrates rivers as discussed below.

Satellite images and air photographs suggest that relict meanders are common features on the plain, but recent analyses show that many of these may date to the earlier Holocene or even the Pleistocene. For example, Adams suggests that relict meanders northeast of Nippur probably date to the fourth millennium BC (Adams 1981: 61-62), and Hritz (2004, 2010) has demonstrated that relict meanders can be recognized on the alluvial plains between levees that post date to the fourth millennium BC. The latter evidence implies that the meandering channels are earlier than the fourth millennium BC and were formed when the Euphrates was a less managed river and had not been diminished by significant abstraction of irrigation water.

The Mesopotamian plains are dominated by the Euphrates River to the west and the Tigris to the east. The Euphrates flows at a slightly higher elevation than the Tigris, and conducts less water, the level of which peaks in May. On the other hand, the Tigris, which receives a considerable flow from the left bank tributaries draining the Zagros mountains, carries a significantly higher discharge that peaks in April, and is regarded as a more unruly river that is difficult to manage.[4] The reputation of the Tigris is hardly surprising, given that it not only conducts a higher annual discharge, but also that the discharge flows along what is a considerably steeper long profile upstream of Baghdad, which then leads into a more gently sloping flood plain district. In contrast, upstream of Ramadi the long profile of the Euphrates is gentler than that of the Tigris, but it discharges water into a rather steeper and more elevated flood plain zone (Gibson 1972; Knappen et al. plate IV-2 and 3). In other words, the power of the Tigris is the greater of the two, but it drops dramatically as it enters the flood plain; that of the Euphrates goes through a much less abrupt transition. The massive shift in power that occurs where the Tigris enters the Mesopotamian alluvium may therefore be expected to result in increased sediment deposition and a greater propensity for the river to flood and break its banks, which are pre-conditions for abrupt channel shifts or avulsions.

In fact flooding, rather than lack of water, is one of the perennial problems for the inhabitants of the Mesopotamian plains. In the nineteenth century AD the Tigris flooded Baghdad at intervals of every one to nine years, often with devastating results and sometimes with ensuing plague (Issawi 1988: 101-5). Because of the tendency of both rivers to flood, the irrigation engineer Sir William Willcocks declared that it is the first task of the engineer to protect the population from floods. Willcocks suggested that flood protection would be ensured by allowing the waters of the Euphrates to flood into the Lake Habbaniya basin (near Ramadi) and the Tigris into the Tharthar depression (near Samarra; Willcocks 1910); both these low areas are near the abrupt break in slopes of the rivers' long profiles.

The marshy lower Mesopotamian plain near the head of the Gulf provided abundant resources for everyday life. In addition, smaller-scale marshes were formed in the upstream regions as a result of the overflowing of floods from the channels, so that water accumulated in flood basins to form reed-fringed long-term swamps. These, in turn, would have been reinforced by the tendency of irrigation canals to discharge excess water into flood basins, thereby creating temporary marshes. Such swamps and marshes would have provided ideal grazing area for the flocks and herds of the nearby settlements as well as sources of sustenance for fish, reeds, and aquatic birds (Postgate 1992; Pournelle 2007). Nevertheless, because of their poor drainage such areas were prone to salinization and therefore could not be used for grain cultivation (this volume: Chapter 13).

Today the Tigris occupies a rather entrenched channel through the Mesopotamian plains, and its bed is at a significantly lower altitude than the Euphrates (Adams 1981: 6); this makes it difficult to use for irrigation

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[4] The mean flow of the two rivers during the first half of the twentieth century, when there was little control of the flow, was 4000m^3/sec (Tigris) and 2200m^3/sec (Euphrates) at Baghdad and Hit respectively (Knappen *et al*. n.d. Pl. III 6 and III 12).

except by means of water-lifting devices such as water sweeps or dalia (in Iraq; equivalent to the shaduf of Egypt. Rost & Hamdani 2011: 208). However, because both the Euphrates and Tigris have been prone to frequent channel shifts, there is no reason to assume that in antiquity the river occupied a similar course as it does today.

River channel movements relate to a number of factors:

- tectonics, although Larsen and Evans (1978) have suggested that in Mesopotamia there is little evidence for significant tectonic subsidence during the Holocene

- the bounding solid rocks of the plains: Miocene limestone to the west and the outer hills of the Zagros to the east

- the developing alluvial fans of a number of rivers that discharge water and sediment from the Zagros to the northeast (including the Diyala River near Baghdad) and from the Arabian and Iraqi plateaus to the west. Near the head of the Gulf, the combined fans of the Karun (to the east) and the Wadi al-Batin (to the west) constrain the courses of the Tigris/Euphrates to a zone a mere 30-50km wide.

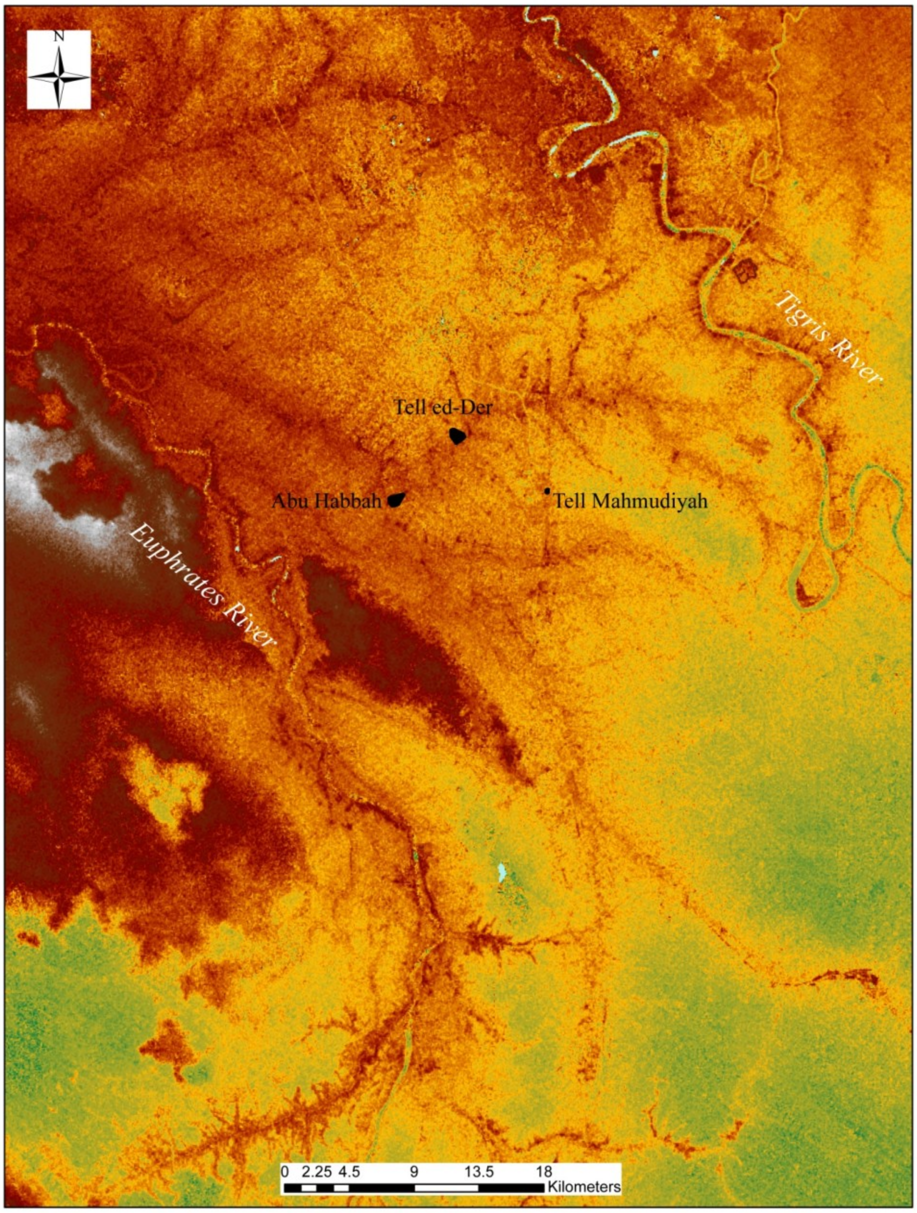
- the topography of the plain resulting from earlier episodes of riverine deposition. Sediment accumulation falls into two classes: higher areas resulting from aggradation along river levees, and lower areas that have been starved of sediment. If there is any impediment to flow, such as relict river channels or canal levees along their accustomed courses, the rivers flow into these basins thereby increasing the rate of sedimentation.

The nature of the micro-topography of relict levees provides considerable insights into the development of the river systems and the complexity of channel re-use. For example, when a Belgian team plotted contours from large scale maps for the area near Sippar (in the northern alluvium), several branches of the former Euphrates were revealed. When these were compared with the textual record it was possible to infer which branches corresponded to named channels in the texts. Thus south of modern Baghdad, in the second millennium BC, the Euphrates (Purratum) and Tigris (Digli or Zubi) rivers were shown to have been separated by only a single field (Cole & Gasche 1998). A virtually identical pattern of relict levees is revealed by Shuttle Radar Topographic Mission (SRTM) images that indicate a remarkable series of dendritic levees, which flow primarily from northwest to southeast to follow the topographic grade of the alluvium (Fig. 2.9a; Hritz & Wilkinson 2006; Hritz 2010).

The topographic signature of levee development can also restrict water flow and encourage the reuse of parts of relict channel lines, resulting in the superimposition of features from different chronological periods. For example, SRTM images show that the Sasanian-Islamic period Nahrawan canal, apparent as a long, narrow and straight canal, cuts into and reuses a portion of a presumed earlier, wider and more sinuous levee, perhaps representing an ancient Tigris channel (Hritz 2010). The path of both channels follows the natural gradient of the plains and is constricted by other relict levees. Such re-use is common (Hritz & Wilkinson 2006) and frequently resulted in the combination of hybrid, artificial and natural channels throughout antiquity.

Channel shifts (avulsions), an ever-present threat to the populations of ancient Mesopotamia, are caused by several factors, including unusually high floods, tectonics, earthquakes, and the breaching of levees by animals and humans. The best-documented avulsion in recent history is that recorded to the southwest of Baghdad when the Euphrates flowed along the branch of the Hindiyeh canal, leaving the Hilla branch of the river empty (Cadoux 1906; Gibson 1972). Despite attempts by the Ottoman government to construct a barrage to divert one-third of the flow down the Hilla branch, the flow down the Hindiyeh canal predominated, again leaving the Hilla branch dry. Cadoux (1906) points out that the Euphrates adopted a canal (the Hindiyeh canal) for its course. He also blamed the increased diversion of water into irrigation canals, as well as the presence of temporary dams for water diversion, for the increased amount of sedimentation within the channels, a factor that contributed to the tendency of the clogged channel to shift to a more advantageous course (Cadoux 1906: 271).

Other avulsions have been documented at Kut (Verhoeven 1998; Hritz 2004), near Sippar (Haevert & Baetemen 2008), and Samarra (Adams 1965), and, in general, the branching nature of the lower Tigris and Euphrates rivers suggests that avulsion and channel anastomosis may have been the dominant process in the development of Mesopotamian rivers and a significant factor in the cyclical change of Mesopotamian civilizations (Gibson 1973; Schumm 1977; Wilkinson 2003: 83-89; Morozova 2005). Certainly, the branching of several subordinate channels on the Euphrates near Falujja provides a good example of a node of avulsion, from which at various times in the third, second and first millennia BC, the Irnina, Purattum (main branch) and Purattum (Kish branch) of the Euphrates (Purattum) branched off (Fig. 2.9b) Cole & Gasche 1998; Haevert et al. 2008). For avulsions to take place, it is necessary for a weakness or gap to be present in the bank of the levee. Canal off-takes provide an ideal opportunity for channel diversions, and these would have been especially vulnerable during times of high flood. Overall, therefore, landscape and channel management by humans are significant factors in the development of the Mesopotamian plains.



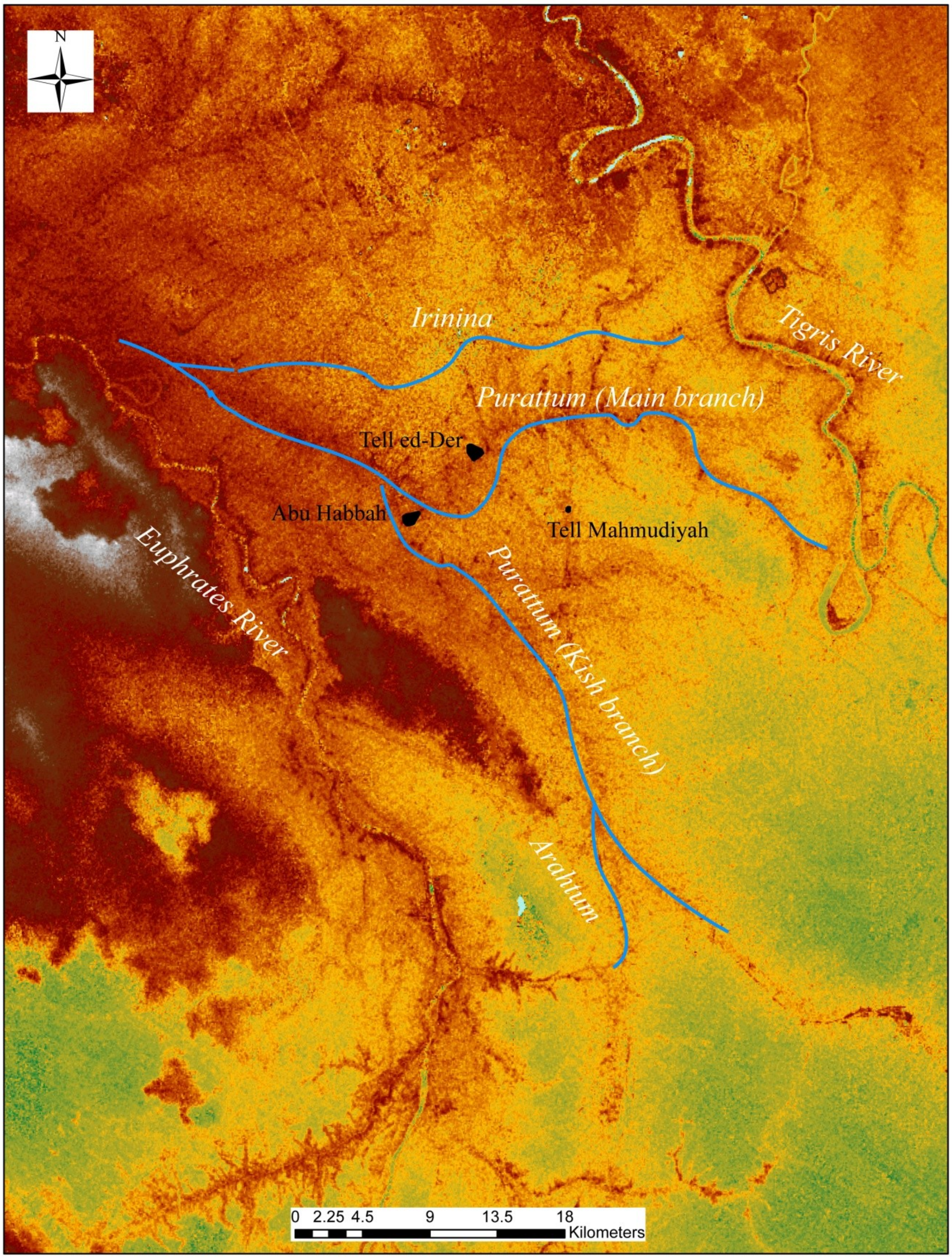


Fig. 2.9 a) Micro-topographic map of part of the northern Mesopotamian plains near Sippar derived from SRTM data; b) showing some of the main second millennium BC branches of the Euphrates (from Cole & Gasche 1998). (map compiled by C. Hritz).

As the Mesopotamian plains became more settled and populated, there was an increasing tendency to manipulate the natural characteristics of the channel systems to suit the needs of food production and pasturage. As a result of the following management processes, the 'natural' alluvial landscape of Mesopotamia was transformed into a cultural landscape.

- Throughout the Holocene, soil erosion in the agricultural headwaters of the rain-fed north increased the tendency for Mesopotamian rivers to accumulate sediment within their channels (Cole & Gasche 1998: 10) and for levees to agrade, so that the rivers became more elevated above the surrounding plain.

- Where the Holocene rivers had developed meanders, gradients would decrease, thereby encouraging sedimentation and the clogging of channels. Therefore, to maintain flow, the channel tended to shift progressively from sinuous (meandering) to straight (i.e. with lower sinuosity). This straightening tendency would have been enhanced by the periodic cleaning out of the channels by agricultural communities, so that the rivers effectively became canals.

- The development of levees provided a lateral gradient so that small channels could be led down the levee slope for irrigation (Chapter 4). By providing breaks in the levees, these small gaps could become enlarged by occasional high flows, thereby initially resulting in so-called crevasse splays and, in turn, providing opportunities for avulsion. The small crevasse splay channels could then develop into new river channels (Wilkinson 2003: 88).

- The annual flood of the Tigris and Euphrates comes in the spring, when the autumn- or winter-sown cereals have reached maturity and are virtually ready to harvest. Irrigation is both unnecessary and harmful to the mature crops at this time, but is necessary just after sowing and during the early stages of growth, which for autumn-sown cereals is when the river level is relatively low. If off-takes were sufficiently deep to allow water through at the time of the relatively low autumn flood stage, they would have allowed too much flow through during the spring floods, thereby increasing the risk of a catastrophic flood through any off-takes and into the canals. The Sumerian farmer would therefore experience least risk to his canal, but would receive the least amount of water, if off-takes were kept high; alternatively, a larger amount of water could be allowed through, but at greater risk to the irrigation infrastructure by constructing larger and deeper off-takes.

- To avoid this problem, a common traditional practice was to construct temporary reed dams in the main channel, thereby raising the water level so that it could flow into the canal off-takes (Naval Intelligence Division 1944: 439; fig. 161, 162; see also Rost & Hamdani 2011 and Chapter 4).

- It would therefore have been the task of the Sumerian water managers to create off-takes, sluices and temporary dams that would deflect the main flow, raise the water level sufficiently and allow the optimum amount of water into the irrigation systems (Rost & Hamdani 2011; Wilkinson 2013). The need to monitor flow into the canals is illustrated by a Sargonic text, probably from the city of Umma, that recorded water levels at midnight and noon on successive days (Steinkeller 1988: 85). By the third millennium BC, the nature and composition of water management devices may have become more sophisticated and permanent to match the needs of growing cities and their agricultural hinterlands. For example, the 'construction enigmatique' (Barrelet 1965) at the site of Girsu/Telloh may have served a dual role: first, to direct water from the main channel of the Tigris River to the north to agricultural fields and production sites at the fringes of the city, and second, to control water levels in this area, where the water table was high and prone to salinization and where marshes tended to develop.

- The down-levee decrease in the grain size of sediments is only the long-term norm for natural or quasi-natural situations. As channel flow was manipulated to suit the needs of irrigated agriculture, the sedimentary deposits themselves became more uniform and included more silt and clay, until they could be termed irrigation deposits. This is because canals and their attendant distributary channels try to maintain a constant flow of water, which, in turn, maintains silt and fine sand in suspension until the water reaches the irrigated lands, which therefore results in the preferential accumulation of silt and clay on the land.

- In addition to the preferential accumulation of silt and clay, so called agro-irrigation soil horizons can also be recognized in Mesopotamia. These soils, in addition to being enriched in silt and clay, display a columnar structure and contain occasional inclusions of artefacts from the application of household wastes used for fertilizer as well as shells from the irrigation canals. Brief investigations of soils in the region of Nippur and Abu Salabikh suggest that agro-irrigation soils frequently form an undulating cover over the pre-existing landscapes.

In the long term, Mesopotamian channels probably shifted from a braided state during the Pleistocene cold phases to an earlier Holocene meandering pattern. Later, during the Holocene, there was a probable shift from a landscape dominated by meandering rivers towards less sinuous but anastomosing channels, raised upon levees, as well as dug canals and their artificially raised mounds of clean-out spoil. However, this suggested sequence needs to be tested by rigorous field investigations.

The Development of Irrigation and canals in Southern Mesopotamia

Although canals were probably dug as early as the Ubaid period, it was not until Early Dynastic or Akkadian times that we have good evidence for the excavation of major canals (Adams 1981: 134-135; Adams & Nissen 1972:12). Whereas some major canals appear to have followed the hydraulic gradient, others may have cut across the topography, thereby creating features that were hybrids between natural rivers and canals. That canals were increasingly dug from the Old Babylonian period is demonstrated by numerous Akkadian texts referring to the excavation of canals and the opening up of new lands, as in this example dating from the reign of king Rim-Sîn of Larsa (1822-1763):

> 'The year the righteous shepherd Rim-Sîn, under the order of An, Enlil, and Enki, had the Euphrates, the holy cup of Nanna, which brings the first fruits to the Ekur, the sanctuary of life, dug (ba-al) from Uruk/Larsa (disagreement in the texts) towards the sea (a-ab-ba), making available large areas of land on its banks and he had sweet water brought to Ur.'
> (summarized from Rengers 1990: 31-46; Tenney MASS report 2003-04)

Not only were such channels dug to irrigate new lands, as indicated above, they also carried 'half the waters of the Tigris and Euphrates and poured them into the sea' (Sollberger & Kupper 1971: 205-6; cited in Postgate 1992: 179). In other words, by the early second millennium BC, engineering works were used to evacuate surplus floods as well as for irrigation, and were of a scale that was capable of diverting significant amounts of water from the Tigris and/or Euphrates rivers. However, detailed analysis of cuneiform texts suggests that shorter canals were the dominant feature of the southern Mesopotamian hydraulic landscape, where they appear to have formed the lateral components of herringbone irrigation systems (Fig. 2.8; Wilkinson 2013). Further details on the practice of irrigation, the administration of water, the size of canals and the layout of fields is provided in Chapter 4.

Studies of branching river systems suggests that many abrupt channel shifts (avulsions) do not adopt virgin areas of flood plain, but instead use pre-existing river channels or even flow back to the original channel (Hritz 2010 for the Nahrwan). In antiquity this process is echoed by the action of another King of Larsa, Sin-iddinam (c. 1849-1843 BC):

> 'In order to provide sweet water for the cities of my country …. (An and Enlil) commissioned me to excavate the Tigris (and) to restore it (to its original bed).'
>
> Frayne 1990: 158-160 (also Cole & Gasche 1998: 32 for a similar instance near Tell ed-Der).

Mesopotamian channel development therefore depends partly upon the history of earlier river courses. For example, it is common for river floodplains in general to exhibit a variety of active, partially active, and abandoned channels away from the dominant channel (Slingerland & Smith 2004). In Mesopotamia, many of these relict channels take the form of abandoned canals or irrigation channels, and these provide potential new routes along which rivers can flow. In other words, the long history of canal digging and channel management increases the number of relict channels that provide weak points along which the rivers can escape if circumstances warrant it.

HUMAN ECOLOGY: STRESSES AND INSTABILITIES

The above synthesis of environmental conditions in northern and southern Mesopotamia suggests that the local inhabitants had to deal with a wide range of circumstances that both provided constraints on and opened up new opportunities for agricultural production. We now summarize some of the environmental stresses that operated on society in both the north and south and discuss their contributions to everyday life or the ways in which they were dealt with by inhabitants. Several of these challenges are developed further in the simulations presented later in the book.

North

Although there is a tendency to focus on drought-induced crop failure, historical records from the medieval period in northern Syria emphasize that the inhabitants had to cope with a wide range of crises (Widell 2007: table 2), some of which included:

> severe winters (resulting in the death of sheep); hordes of locusts; drought and crop failure; floods; plague; loss of crops as a result of mildew, rats and weevils.

As if the above list were not sufficient to contend with, there was also the problem of coupled disasters. In the Near East, cold winters tend to be associated with higher winter rainfall (Neumann & Sigrist 1978) and, as a result, the loss of flocks was frequently associated with a good harvest the following summer (Widell 2007: 13,15). Conversely, dry winters tend to be relatively warm, so that although animal survival would be good, there would be an increased risk of crop failure (Widell 2007). For farmers with optimal holdings of cereal lands and animals, these problems might balance out, although in some dry years there can also be catastrophic loss of animals during drought due to the desiccation of pastures. Drought is particularly devastating to farmers, who cannot provide supplementary straw when crops fail, so that they are deprived of draft animals for plowing (Hütteroth 1982, cited in Jas 2000). Alternatively, if a run of dry years resulted in farmers with poor crops exchanging surplus animals for cereals, some successful farmers would accumulate large flocks, which could then be wiped out by a cold winter. If this were followed by a warm but dry year, the same farmer might then experience severe crop losses, compounding the earlier loss of sheep. Because cycles of wet/cold and warm/dry winters will vary considerably through time, households will be affected differently in terms of their personal circumstances. Nevertheless, in order to maintain a good level of subsistence production, the optimum arrangement would have been for farmers to maintain a balance of livestock and cereal cultivation, although as discussed in Chapters 11 and 12, this was not always possible.

Overall, it is therefore overly simplistic to perceive farmers in the Jazira as being vulnerable to drought alone, because not only were there many types of environmental 'events', the same event could have had different impacts on households, especially if they were followed by other types of crises such as plague, rats and so on. If droughts or cold winters were widespread throughout the Jazira, then populations would be severely stressed because of the difficulty of exchanging bulk cereals between communities in different areas. When the rainfall amounts (in mm per annum) at different stations in Upper Mesopotamia are compared, the correlation between stations varies significantly. For example, a high correlation implies that roughly the same conditions of drought or moisture prevail over large areas, whereas lower correlations indicate that high rainfall years will, in certain cases, correspond with low rainfall years in other places. The latter case increases the possibility of the exchange of food between regions (bearing in mind the difficulty of transporting grain overland in bulk). Alternatively, people might choose to migrate to places where more grain was available, if that was possible. As indicated on Figures 2.10-12, there is a moderate correlation of rainfall between Aleppo and Kamishli (0.35), but a much lower correlation between Aleppo and Mosul (0.05); Urfa also shows a relatively low correlation with Aleppo (0.135; Fig. 2.12). Therefore, there would have been a high likelihood that a harvest failure in the Urfa region could be offset by grain from Aleppo, but less chance between Aleppo and Kamishli. Not only would the manifestations of regional disparities of production be very complex; they would also depend very much upon political relations between the local kings or rulers. Overall, these simple statistics demonstrate that local variations in climate do matter today, and probably did in the past as well.

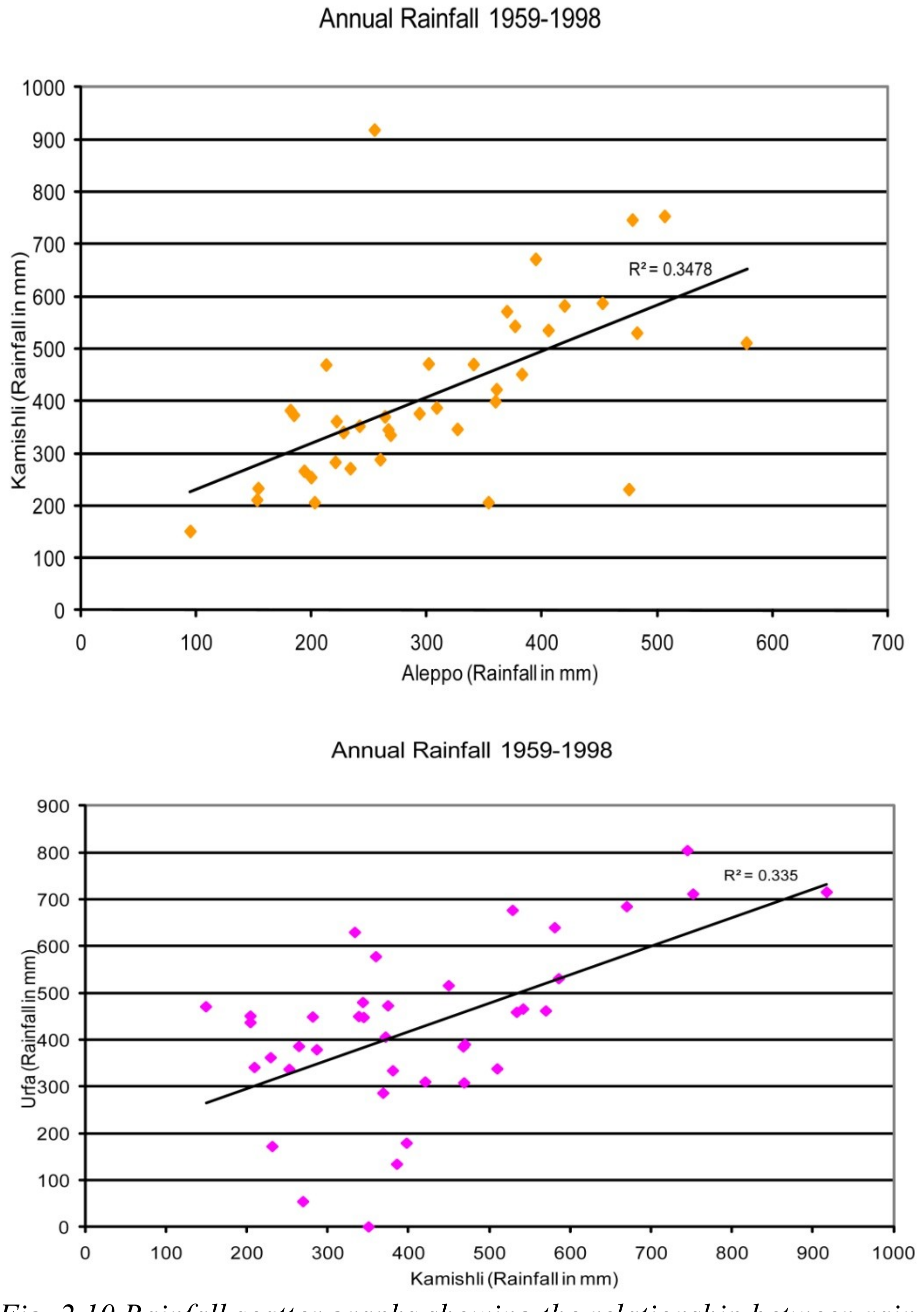
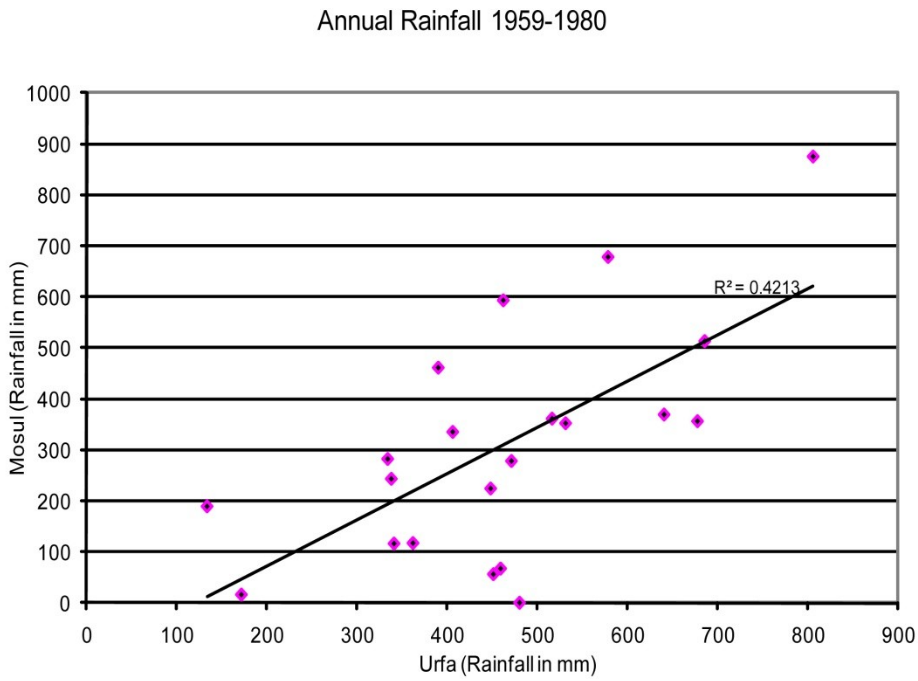


Fig. 2.10 Rainfall scatter graphs showing the relationship between rainfall at: top, Kamishli and Aleppo, and below, Urfa and Kamishli (data compiled by Colleen Coyle for the MASS Project). Linear trend lines are superimposed, together with correlations (R^2 figures). In both these cases, the moderate correlations, suggest that droughts in one area would tend to correspond to droughts in the other.



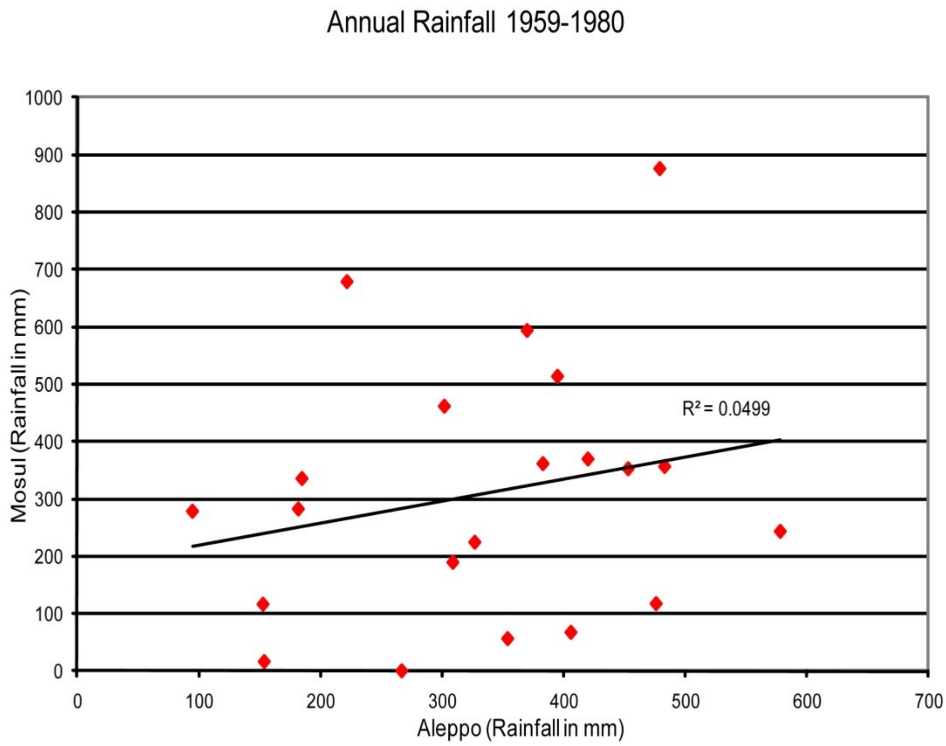


Fig. 2.11 Rainfall scatter graphs showing the relationship between rainfall at: top, Mosul and Urfa, and below, Mosul and Aleppo. Note the very low correlation between Mosul and Aleppo readings implies that a drought at one place would not necessarily correspond to a drought in another (data compiled by Colleen Coyle for the MASS Project).

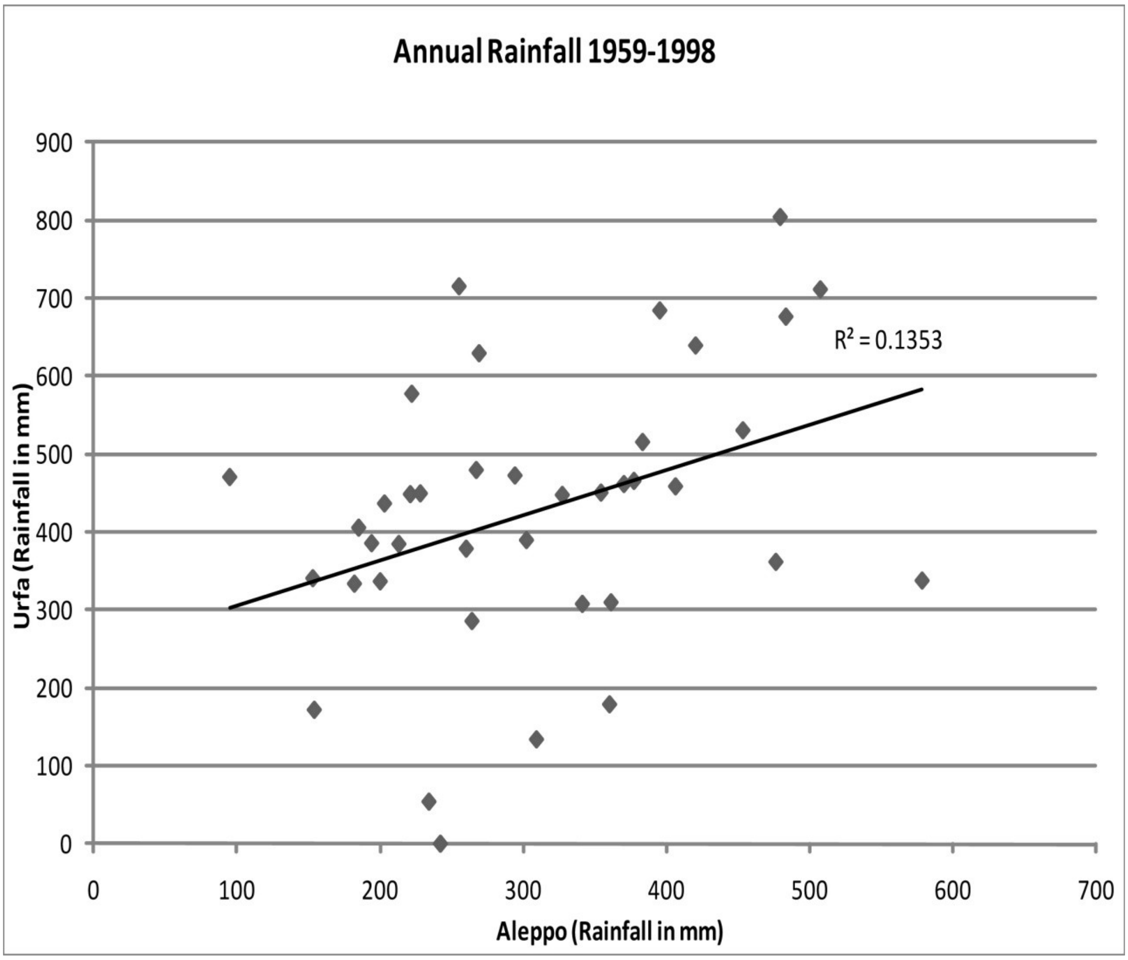


Fig. 2.12 Rainfall scatter graph showing the relationship between rainfall at Urfa and Aleppo (data compiled by Colleen Coyle for the MASS Project).

In the Jazira of northern Mesopotamia, there is a positive correlation between rainfall and crop yield, so that for any one location wet years result in higher yields than dry years.[5] Similarly, crop yields are lower in areas where there is a lower average rainfall or where there is a greater inter-annual variability of rainfall (Wallén 1967). Nevertheless, successful cropping seasons do not simply correspond to years of high rainfall because, in reality, human practices as well as soil moisture are a key determining factor of crop yield. If rainfall is diminished, crops will experience moisture stress and suffer accordingly. To a small but significant degree, soil moisture also depends on the amount of water that remains in the soil from the previous wet season. Because of this, and to provide supplementary pasture for the village flocks, the normal pattern of cropping for northern Mesopotamia is to incorporate an alternate year of fallow. In cuneiform texts this system can be traced back to the Middle or Late Assyrian period (Fales 1990; Renger 1995). Biennial fallow stores soil moisture for use in the following growing season, and although small, this bonus is often critical in a dry year. However, if population increases to a certain level or if there are greater demands on the cropping system for taxation purposes (or sharecropping), it becomes necessary to crop annually. The result of such violation of fallow is the associated loss of soil moisture carry-over from season to season and can result in crop failure in drier years (Wilkinson 1994; 2000). Traditional communities, for which reliable cropping rather than maximum yields is more important for survival, therefore tend to use the rather inefficient system of biennial fallow.

[5] In fact, more important than annual precipitation is the amount of rain received during the autumn-winter 'growing season'. Although statistics on the growing season rainfall were compiled and analyzed around 1999 by the MASS project, these results are not presented here; for a more recent analysis of the relationship between growing season and annual rainfall see Kalayci (2013: 198-201).

The Fertile Crescent is one of the centers for the development of agriculture, and so the cultivation of domesticated crops there has an extremely long history. For example, the Khabur and Balikh valleys have been farmed for some 8000 years or more, during which time plant nutrients have been progressively removed from the soil (see above). This resultant loss of plant nutrients, if not replaced, would have had a detrimental effect on the long-term productivity of the land and associated crop yields.

Another resource that appears to have been depleted through long-term human use of land is woodland cover. The loss of trees and bushes as inferred by palaeobotany (Miller 1998; Deckers & Riehl 2007; McCorriston 1992; Deckers & Pessin 2011) was, in part, the result of the removal of wood for fuel. Once this resource was gone it became necessary for alternative fuel sources to be found. Animal dung, suitably dried and prepared, is the most common natural fuel source in the region today, but the use of dung as fuel deprived the soil of manure. Such measures would have reduced crop yields, and as a result farmers either resorted to cropping every year to compensate for the lower yields (with detrimental effects on soil moisture as noted above), or to returning the ash derived from burnt dung to the fields as fertilizer.

The interrelated nature of Upper Mesopotamian farming is also illustrated by the response to crop failure. Some losses from a crop failure can be recouped by grazing flocks of sheep on the 'failed' crop, which then leads to a bountiful year for the sheep as well as those households with large holdings of sheep (Nordbloom 1983). This process was clearly evident in northern Syria in spring 2008, where there was region-wide drought and associated crop failure (Trigo et al. 2010). In the Euphrates region near Carchemish fields of green wheat and barley were rented out as grazing land to visiting Bedouin during March and April; although crops were lost, some income was retrieved, and the sheep experienced an unanticipated Christmas (Fig. 2.13). Further east, however, in the Khabur basin crop failure was so catastrophic that there was little available grazing at all.[6] Because such conditions of crop failure reflect similar variations in local climate as discussed above, they vary spatially. Consequently, over the entire Jazira, a wide range of cropping and grazing strategies will have applied during years of so-called crop failure. Another example of a problem being turned into an opportunity is the practice of harvesting green grain prematurely in order to avoid payment of tax (which normally is levied at the threshing floor when the grain is fully ripe). The green grain, known today as frika, provides both an excellent and slightly sweet grain course to a meal (Hubbard & al-Azm 1990). Overall, the various decisions taken by the farmers were interlinked by a network of ecological and human decisions that not only had an impact on the vegetation cover, but also on the management of flocks, plowing strategies, agricultural sustainability and soil moisture (Wilkinson 2000).

In addition, some areas may have been dominated by agro-pastoral strategies in which levels of risk were raised above those normal for subsistence farming. For example, instead of using the landscape to produce a diversified range of staple crops and livestock (for which it was not really suited), Early Bronze Age inhabitants of the zone of uncertainty may have perceived it as being ideal for the 'opportunistic stocking' of sheep and goats. Such herding strategies allow the number of livestock to increase in accordance with the availability of forage so that the growing herd can then be converted into 'capital' in years of good rainfall (Stein 2005: 143; after Sandford 1983), whereas bad years can entail herd numbers being reduced as necessary (Stein 2005: 143). Such high-risk strategies can only be applied where a sufficient economic buffer already exists, as perhaps exemplified by wealthy states such as Ebla and Mari during the later third millennium BC (Wilkinson et al. 2012). When compared with the economies of moister areas further north, such stocking strategies must have resulted in very different levels of resilience.

[6] Mike Charles, pers. comm. 2008.

Fig. 2.13 Sheep grazing on a failed cereal crop at Jerablus on the Syrian Euphrates in spring 2008 (T.J.Wilkinson).

Other seemingly innocent decisions must have also had an impact on everyday life in both the north and south. The high demand for soil to make mud-brick for domestic and public buildings resulted in the excavation of brick pits in close proximity to settlements (Wilkinson 2003: 119). Once filled with winter run-off, these must have remained for part of the year as ponds. Under ideal circumstances such ponds would have supplied a valuable supplementary source of water, but their location adjacent to the town would have made them the recipient of effluent and other pollutants: many settlements may have been surrounded by foetid pools that would have been the ideal breeding grounds for insects and infectious disease. Moreover, the high demand for chaff for mud-brick manufactures means that during periods when major public buildings were built there would have been competition for chaff between those involved in building construction and those in charge of flocks.

South

The inhabitants of the irrigated south suffered an equivalent number, though slightly different range, of challenges.

First is the total amount of water available for irrigation. In the irrigated south the total discharge of the Euphrates and Tigris rivers provide an upper limit to the total cropped area (and therefore the population that could be supported). Adams has convincingly demonstrated that the autumn and early winter discharge, which is critical for the cereal harvest, provided such a limiting factor. Consequently, no more than 12000km^2, or more realistically 8000km^2, of land could have been irrigated under modern flow conditions (Adams 1981: 5-6). The potential cultivated area would therefore have to be adjusted downward to allow for conditions of moisture decline that prevailed during the second and first millennia BC. It is only possible to speculate how these changes affected settlement in the south, but a decrease in the discharge of the Euphrates may have contributed to the decline in settlement that is suggested to have taken place in the southern plains during the Kassite and Middle Babylonian periods (Adams 1981: 142, figs 31-35). In addition, the shift of the Euphrates to the western part of the plain, as well as the increased use of the Tigris for irrigation during the Seleucid, Parthian and Sasanian empires, must both have contributed to the changing relationship between cultivated land and water supply.

Salinization was a significant problem in the south because the salt content of the river waters,[7] high levels of evaporation, low soil permeability, high water tables and low gradient of the land all encouraged the build-up of salts in the soil (Jacobsen and Adams 1958; Gibson 1974; this volume Chapter 13). Torrential rains can have a significant impact due to the high water table. For example, several days of heavy rains in spring 2013 brought salts to the surface of agricultural fields, as well as archaeological sites such as Ur, Girsu and Lagash. The uniquely wet spring quickly transformed uniform agricultural field systems into a landscape characterised by deep basins of standing water below levee crests and islands of fields. The copious application of irrigation water, especially to lower terrain where soil drainage is poor, consistently results in the build-up of salts, which both reduces crop yields and necessitates a shift to more salt-tolerant cereals such as barley (Jacobsen & Adams 1958; Gibson 1974). However, in theory, such salinization could be held in check by the expedient of fallowing the land every second year: with this method the developed vegetation lowers the water table, thereby allowing the accumulated salts to be leached out of the soil by the next flush of irrigation waters (see also Chapters 4 and 13). Therefore, as in the north, annual cropping would result in a long-term decline in crop yields by violating fallow (see Gibson 1972; Poyck 1962: 19; 38). However, studies of soils and land use in the Diyala region have highlighted that there is often no simple correlation between, for example, crop yield and salinity or soil type (MacDonald 1958: 171-172). As a result, it is not always possible to infer under what conditions crop failure and agricultural decline will take place. Although salinization may not have resulted in the collapse of the Ur III state, it was clearly a major problem for agriculture in southern Iraq, especially in those areas of raised water tables (for alternative views see Jacobsen and Adams 1958; Gibson 1972 vs. Powell 1985). This is an area where modeling can provide insights into early agricultural practice (Chapter 13).

As noted above, the irrigation systems of southern Mesopotamia acted as a giant sediment trap, and one of the main tasks of the inhabitants must have been to keep the canals and off-takes free of sediment. This was a perpetual problem in the very low gradient canals and was observed by Strabo in the Parthian irrigation systems (Geography XVI:1.9-10). If not attended to regularly, canals and other channels tend to clog, thereby leading to a decrease in the flow of water to fields and the backing up of water in channels during floods. Such clogging could also contribute to the breaking of banks and the initiation of avulsions.

Floods affected both northern and southern Mesopotamia, although rarely do we have information as to their true scale. During the third millennium BC, high magnitude floods attaining heights of 8m to15m above normal levels have been recorded in the Upper Euphrates in northern Syria and Turkey (Kuzucuoğlu 2007: 472). Parts of Upper Mesopotamia did not only experience substantial landscape degradation and forest removal during the fourth and third millennia BC; the considerable amount of overland transport also resulted in the development and growth of thousands of hollow way roads (Chapter 4). By acting as enhanced overland flow paths for runoff, as well as extending the drainage network, these would have expedited the discharge of overland flow into the rivers, thereby exacerbating floods (Wilkinson et al. 2010). The increased silt load resulting from such landscape degradation would also have made the rivers muddier and led to greater problems of channel clogging in the south. Although such coupled degradation systems have not been modeled in the MASS Project, it is evident that settlement growth in the northern steppe must have had some unintended affects on the irrigated south.

[7] Both the Euphrates and Tigris near Baghdad had salt levels of around 30-33 parts per 100,000, which increased to ca. 90 parts per 100,000 in the lower reaches (Fisher 1978: 366).

OVERVIEW

From the above synthesis, the Mesopotamian plains evidently experienced a range of instabilities that created problems for the inhabitants of the alluvial lands.

- It was in the interest of the inhabitants to maintain lateral canals on their levees to take advantage of the gradients down which irrigation channels could be led. As levees were raised by in-channel sedimentation, the resultant potential energy represented by the elevation of the levees meant that if a channel break did occur, the consequent flooding could be devastating.
- Greater food demand from higher populations would have increased the need for water to be led off into irrigation canals, thereby increasing the number of levee breaks or weak points in the channels and the risk of avulsion.
- Population growth would have pushed agricultural communities towards violating fallow. In the south this would have encouraged salinization, whereas in the north it would have resulted in less dependable crop yields.
- Increased population, and especially population concentration in urban areas, would have led to loss of woodland, a shift towards dung as fuel, a decrease in soil fertility, and either a tendency for cropping to take place every year (with its ensuing problems), or for yields to be lower.

The above-mentioned range of challenges should not be used to imply that the agricultural outlook in ancient Mesopotamia was perpetually bleak. This is unlikely to have been the case, because otherwise it is difficult to see how the region could have become the hearth of early civilization. Nevertheless, the processes listed above demonstrate that although the fertility of the levee soils provided good opportunities for initial cultivation and settlement, with time, as population increased and the landscape became more mature, the number of constraints or potential instabilities increased. Although it was possible to overcome some of these limitations by building bigger and longer canals, these often resulted in novel and bigger problems in themselves. Hence, by the time of the Sasanian and Early Islamic empires, not only had the scale of irrigation systems increased but also, arguably, the scale of the catastrophes and abandonments may also have increased, with the result that large areas of the southern plains were progressively abandoned (Chapter 4; Adams 1981).

It is the above range of possibilities and constraints that provided the 'opportunity landscape' for the southern Mesopotamian communities. As has been demonstrated, the Mesopotamian plains did not simply provide a range of excellent opportunities; it was the management of these opportunities that increased the potential for farming and pastoralism, as well as population growth, trade and urbanization. However, the constraints imposed by the natural environment were also increased by human management of the landscape, with the result that the human communities of the plains must have been confronted by numerous potential disasters, the management of which was the responsibility of the king and his officials.

The agricultural ecology of greater Mesopotamia therefore encompasses a wide range of inter-linked processes ranging from the Machiavellian politics of river management, to upstream-downstream water competition, loss of soil nutrients, salinization, crop instability, death of livestock, and landscape degradation. The problem for the archaeologist and ancient historian, however, is that these processes do not occur in isolation: if a cold spell killed off livestock, this did not only mean a loss of wealth on the hoof; it would also include the loss of draft animals, which would be crucial for plowing the land following the summer’s bumper harvest. In some cases these crises would have occurred in such an order that one counteracted the effect of the other. At other times they would have reinforced each other, thereby amplifying the scale of any problem. This is precisely where agent-based modeling comes into its own, as it is able to suggest within a simulation environment the ways in which one scenario can play out under a range of different circumstances.

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