Chapter 1: Water resources in the Near East

The geography of the Near East varies from well-watered coastal plains to arid and semi-arid plateaux. The problems related to harvesting water are not so much related to the amount of water available as to the distribution of that water over time and space. This chapter will present the data for the major water resources in the region, looking at climate and rainfall patterns, runoff patterns, aquifer zones, springs, rivers, and wadis. This should provide the necessary backdrop to understand the challenges faced by inhabitants of the Near East in gathering and accessing water supplies.

1.1 Climate and rainfall patterns

Studies reconstructing past climates in the Near East have often focussed on prehistoric sites rather than settlements of the Roman and late Roman periods.[1] A small number of studies have been undertaken in recent years, however, that may provide some useful information. Over the past few years Wadi Faynan, Jordan, has been the subject of intense investigation, focussing on the geoarchaeology of the area and climate reconstruction.[2] Preliminary analyses based on archaeological and environmental evidence suggest that major changes in climate were all pre-Roman. In particular it seems that there was a wetter environment in the early Holocene that lasted until the Chalcolithic period. Environmental degradation between the early Bronze Age and classical times probably reflected increasing aridity. From the Nabataean period onwards, further environmental degradation appears to have been due to the impact of human activity, rather than climate changes.

More research of this type is also being undertaken in Syria, for example Philip's survey of the settlement and landscape of the Homs region.[3] Preliminary analyses of pollen cores taken from Lake Qattine, to the south-west of Homs, have shown high potential for further research. Hirschfeld has also suggested, on the basis of archaeological data from Israel, that there was higher precipitation in the Levant from the 4th to the 6th century AD.[4] He claims that these climatic changes were responsible for the settlement of previously

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[1] Cf. for example Oates 1982 and Goldberg and Bar-Yosef 1982.

[2] Barker *et al*. 1997; Barker *et al.* 1998; Barker *et al.* 1999; Barker *et al.* 2000.

[3] Philip *et al.* 2002.

[4] Hirschfeld 2004.

unsettled areas, in particular in the Negev desert. More work is needed, however, to prove to what extent this settlement expansion was due to environmental or political factors. In addition, it is possible, given the geographical restrictions of Hirschfeld's data, that this possible climate change may not have made an impact on other areas of the Near East.

In the light of these data we must content ourselves with the reconstruction of the climate during the Roman and late Roman periods as 'comparable to the present day, perhaps warmer and drier',[5] possibly with higher levels of precipitation in the late Roman period in Israel. In spite of these uncertainties, there are, nevertheless, several climatic factors, in particular rainfall patterns, that are governed by topography and so we can assume that they were similar to the present situation.[6]

The highly varied relief of the Near East, in particular the Lebanon and Anti-Lebanon mountain ranges and Jebel Ansarieh (see below), have a strong effect on the spatial distribution of rainfall, which results in striking regional contrasts. Orographic effects, the uplift of cold air masses as they encounter mountain ranges, produce heavy rainfall on the windward side of mountain ranges, but reduced rainfall on the leeward side; most precipitation, therefore, tends to fall along the coastal regions. So, where Damascus typifies the open, arid interior, Beirut, behind which a range of mountains rises, typifies the damper, cloudier coastlands [Figs 1.1-2]. The action of the mountains is brought into sharp focus by the Homs-Tripoli gap: the region west of Homs is noticeably better watered than areas to the north and south that are in the lee of the Lebanon and Anti-Lebanon mountain ranges [Fig. 1.3].

The Near Eastern climate follows a characteristically Mediterranean rhythm of winter rain followed by summer drought. In general rainfall begins in early autumn with short showers in September and heavier more prolonged falls in October. A fine period then ensues until December when the rainy season starts. By the middle of June rain has ceased over the majority of the Middle East. The problem for water gathering is that much of this rain can fall in a very short space of time. The Levantine coastlands, for example, can receive higher annual falls than Britain, but this precipitation is concentrated in 6 months of

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[5] Bintliff 1982, 515-6.

[6] Information on the climate, topography and rainfall patterns comes from: Anderson 2000; Fisher 1971; Wigley and Framer 1982.

which only 14 to 18 days are rainy. In 1945 Damascus, which usually receives an average annual of 240 mm, received 100 mm in a single morning.

This basic pattern is subject to regional variation, again for topographic reasons [Figs 1.4-6]. The rainfall maximum occurs in January in the westernmost, coastal areas of Syria, for example, but in February elsewhere. Also, in Israel and the Palestinian Territories, the northern parts of the country receive between five and ten times more rainfall per annum than the south. This has an effect on where dry-farming is possible and where irrigation is necessary [Fig. 1.6]. Semiarid zones with less than 200 mm are classed as being outside the limit of rain-fed farming. This should be treated as a guideline as other factors can have an effect, for example soils along wadis may remain moist for greater parts of the year and therefore 'lobes' of rain-fed farming may extend into semiarid areas.[7]

As well as annual regional variations, interannual variations are also common (Table 1.1). In Baghdad, for example, annual rainfall from 1931-1960 varied from 336 mm to 72.3 mm, and similarly in Jerusalem it varied from 957.7 mm to 273.1 mm. The length and dates of the dry period and the unreliable rainfall regime are important considerations for understanding water storage solutions, for example cisterns. In addition, the structure of the climate is very similar to that found in North Africa. This would suggest that any differences found in water management may be primarily cultural.

Table 1.1: Annual precipitation in millimetres from 1931-1960[8]

Region	City	Mean	Maximum	Minimum	Ratio of maximum to minimum
Israel	Jerusalem	529	957.7	273.1	3.51
	Eilat	27	96.9	5.5	17.62
Jordan	Amman	273	476.5	128.3	3.71
Iraq	Mosul	390	585.5	208.2	2.81
	Baghdad	151	336.0	72.3	4.65

The impact of such interannual variations was certainly felt in the late Roman period in the Near East. In Antioch in AD 362, complaints were made to the emperor Julian about the high price of food. The arrival of the court and army had put pressure on food production that was already strained from a drought, which continued into the following

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[7] Wilkinson 2000b, 4.

[8] Based on data from Beaumont *et al*. 1998, 71, table 2.7.

year.[9] This event shows not only how unpredictable rainfall could affect food production, but also how that could be aggravated by additional factors, such as population pressure (see Chapter 5.8). Cyril of Scythopolis also describes in vivid detail the effect of five years of low rainfall on the water resources of Jerusalem in the 6th century AD (see Chapter 7.8.2):

> '…at the beginning of the 5th year of famine [September AD 520], so great was the lack of water that the poor of the Holy City were begging for water and dying of thirst. In fact, because of the long drought and lack of rain the water had disappeared from the Siloam Pool and the Lucillian Pool; moreover the springs of Colonia and Nephtho were much diminished.'[10]

Evapotranspiration and humidity are also important in studies of climate.[11] In hot, arid areas with low humidity a considerable percentage of precipitation is lost through evaporation. High evapotranspiration often causes soils to form into a dry crust (*caliche*) with high levels of salt, gypsum and calcium carbonate; this can lead to salinization and also means that water cannot penetrate into the ground so easily.[12] Large tracts of the Middle East suffer from high evaporation potential. Topography again plays a large determining factor in humidity levels. Low humidity values are typical of the majority of the Middle East with the exception of coastal plains, especially those backed by mountain ranges, and major inland water surfaces.[13] The evaporation values for the non-coastal regions of the Negev, for example, vary from 1700 - 2700 mm, in comparison to 1300 - 1600 mm further north in Israel and the Palestinian Territories.[14] As a corollary of this, the relative humidity values for the Negev are 40 - 60% in comparison to 65 - 75% further north, and thus the Negev suffers from high potential evapotranspiration, which must exacerbate the effects of the uneven rainfall distribution between the two areas as noted above.

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[9] Liebeschuetz 1972, 130. Effect of the army: Socrates *HE* 17.2-4. Poor harvest in winter AD 361-2: Libanius *Ep.* 699. Shortage of corn and drought in spring AD 363: Julian *Misop.* 369; Libanius *Ep.* 1351 (ἡ (γῆ) πέρυσι διφῶσα ούκ ἔπιεν.)

[10] Cyril of Scythopolis, *Life of Sabas*, chap. 54.

[11] Thornthwaite 1948.

[12] Beaumont *et al.* 1998, 34-5; Fisher 1971, 77; Schattner 1962, 23; Waugh 1990, 227.

[13] Anderson 2000, 45; Fisher 1971, 64.

[14] Evanari *et al*. 33.

1.2 Geology and runoff patterns[15]

The underlying geology also has a significant effect on whether water can penetrate into the ground. This has an impact on runoff patterns, and therefore on irrigation techniques (see Chapter 5) because where water can pass into the ground (e.g. in limestone areas) there will be less runoff than in areas where it cannot (e.g. basalt areas).

All the mountain ranges of the western Levant have a core of Jurassic or Cretaceous limestone and in many places are capped by later calcareous beds.[16] The Jebel Ansarieh in north-western Syria is a broad, gently-folded anticline with Jurassic limestone as a core and a later series of limestone and sandstone on its flanks. The most important fault structure in this is the Ghab: a lowland rift 80 km long and 16 km wide whose floor lies 1000 m below the summits of the Jebel Ansarieh and in which the Middle Orontes River runs (see Section 1.5) [Fig. 1.7].

On the Mediterranean side of the range are marine deposits that are less porous than the limestone substratum. Elsewhere, the permeability of the limestone has given rise to many karstic areas. To the east of the Ghab, the land rises to form an irregular plateau in which streams are entrenched in narrow, steep-sided valleys. On the Anti-Lebanon range, which rises east of the Beqaa Valley, impermeable rock is far less prevalent and limestone predominates; the greater part of the range comprises karstic uplands, similar to the Hermon range. Limestone formations also extend eastwards into the Arabian and Syrian deserts and into Iraq. The fold ranges of central Syria, for example the Jebel Kalamun, the Jebel ash-Sharqi, the Jebel at-Tar and Jebel Bishri, are comparable to the Anti-Lebanon system; they trend from south-west to north-east and die out towards the Euphrates.

The Lebanon range, which is the highest mountain massif in the Levant, consists of a single major upfold or anticlinal of Cretaceous and Jurassic series. Numerous faults occur in the range along which there have been some basaltic intrusions. There is also a developed area of generally impermeable Lower Cretaceous sandstones, marl and lignite in central Lebanon that lenses out to north and south.

In all these regions of limestone massif water cannot pass through the limestone itself, but because the formations are highly fissured, water can pass along the bedding

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[15] The information on the geology of the region is taken from Fisher 1971 with other supplementary references as indicated.

[16] Weulersse 1940a, 31.

planes and down the joints, which means that there will be more groundwater storage and less surface drainage water to contend with. The Terra Rossa soils, which occur on such hard limestones, have a high moisture-holding capacity, which makes them potentially useful for agriculture, but they are prone to the development of a bluish-grey sticky clay (gleying), which can prevent water penetration.[17]

There is no real topographical break between the Lebanon ranges and the extreme north of Galilee, but further south the altitude and intensity of relief decline further. Limestone still forms much of the surface, with increasing exposures of chalk as well as thin layers of basalt.[18] The Galilee region can be divided into Upper and Lower Galilee; the former has broken karst, deep gorges and distinct peaks, while the latter alternates between ridge or scarp and a broader alluvium-filled valley with occasional detached blocks, such as Mount Tabor. Further south is the Esdraelon lowland, to the south of which is Samaria: a zone of folds including the Carmel Ridge, the Irron Hills and the edge of the Jordan trough. To the south again, the limestone ridge of the Judean uplands becomes dominant.[19] To the west the Shefala, or western foothills, comprise low, rounded hills and to the east in the Wilderness of Judea, or eastern desert, chalk and marl replace limestone.

Water can easily penetrate certain marls either downwards or upwards; if upwards, a hardpan or crust can form. The marls in the southern part of the Lower Jordan Valley, however, are virtually impermeable which causes a high percentage of surface runoff that contributes to the formation of badlands along almost the entire length of this section of the river [Fig. 1.8].[20]

During the Pliocene and Pleistocene there was considerable volcanic activity in the region that gave rise to areas of basalt and basaltic tufa. This is particularly widespread on the borders of Syria and Jordan in the Hauran, Jebel Druze and the Upper Jordan Valley [Fig. 1.9]. The whole region south of Damascus and east of Hermon forms an irregular plateau dominated by extensive lava flows. Jebel Druze is the highest part of this plateau and is a dome of basalt capped by low volcanic cones. The volcanic activity originating in the Jordan valley or in the area bordering it has had a noticeable influence on the flow of

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[17] Fisher 1971, 81.
[18] Abel 1933, 139.
[19] Abel 1933, 147.
[20] Schattner 1962, 17 and 19.

the River Jordan and the lava flows have impounded the Sea of Galilee and (the former) Lake Huleh. Lava flows also feature in central Syria around Homs, as well as in the regions of Hama and Aleppo.[21]

To the far south, the Negev desert is mostly covered by thin layers of water-deposited sedimentaries and Aeolian strata. The northern Negev is split into the coastal region of dunes and alluvial deposits and the north-western plains and foothills, mostly comprising Eocene, Cenomanian and Senonian limestone as well as chalk. The central Negev is a mountainous sub-region whose exposed rock strata consist of Eocene limestone in the south-east as well as Mesozoic limestone and sandstone.[22] The southern Negev is different to the rest of the area as it comprises older igneous and metamorphic rocks such as granite and porphyry.[23]

1.3 Aquifers

Although there are some deep rock aquifers similar to those found in North Africa and the Arabian Peninsula, aquifers in the study region tend to be of the shallow alluvial type. This is particularly the case in Syria where the aquifers are situated in the areas with permeable rock [Fig. 1.10]. These shallow alluvial aquifers are recharged along broad gravel-floored valleys in the highlands or on the upper part of alluvial fans, where rivers leave the highland zone and divide into a number of smaller channels.[24] This occurs mostly during spring and summer at the time of maximum river discharge and percolation can be extremely rapid, with all river waters disappearing across the alluvial fan zone.[25]

The most relevant aquifers, for our purposes, in Jordan are the shallow aquifers [Fig. 1.11]. Firstly, there is a system that stretches southward from the Jebel Druze in Syria to Azraq and Wadi Dhuleil. Recharge occurs on the slopes of the Jebel Druze, the water flows radially away from the massif and is concentrated in the Upper Yarmuk basin, the Wadi Zerqa basin and the Azraq basin. The second shallow aquifer comprises alluvial and sedimentary deposits. There are widespread surface occurrences, but they are small in scale and recharge mostly takes place directly from precipitation.

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[21] Philip *et al.* 2002; Weulersse 1940a, 3.

[22] Evenari *et al.* 1982, 49.

[23] *Ibid.* 59.

[24] Beaumont *et al.* 1998, 84.

[25] *Ibid.*

In Israel and the Palestinian Territories there are four major aquifers [Fig. 1.12]. Firstly, there is the coastal aquifer. The lithologies vary, but in general terms the aquifer is formed of numerous layers of sands or gravels deposited under alluvial conditions and functions well. The northern aquifer is located in the highlands of eastern Israel in Mesozoic sediments with limestones forming the major water-bearing units. The other aquifers are located in the West Bank Palestinian Territories: the western and eastern aquifers that flow west and east respectively.

1.4 Springs

The geological structure of the region plays an important role in the formation of springs because permeable strata retain large quantities of water that can emerge as springs, for example in areas where limestone gives way to basalt. The extensive limestone outcrops to the south of the Anti-Taurus Mountains, for example, give rise to springs from which the Balikh, Khabour and Jagh-Jagh rivers originate.[26] There is a particular concentration of springs in northern Israel and the Palestinian territories. Abel attributes this concentration to the rains and mountains of Upper Galilee.[27] In addition, Abel has calculated that northern Palestine has 9 water sources per 100 km^2 in comparison to Samaria, which has 7 or 8 per 100 km^2 and Judea, which has only 2 or 3 in the same area.[28] Central Judea, as discussed above, does not possess large areas of permeable limestone and therefore water cannot infiltrate and emerge later as springs, hence the low density of water sources in the region.

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[26] Fisher 1971, 35.
[27] Abel 1933, 137.
[28] *Ibid.*

1.5 Wadis and rivers

One fundamental difference between regions in the Middle East is the location of rivers with perennial flow and those with seasonal or intermittent flow.[29] The intermittent flow zone is extensive and covers large expanses of the region. It is characterised by wadis: stream courses that are normally dry, but are sometimes subjected to large flows of water and sediment [Fig. 1.13].[30] Their characteristic process is the flash flood whose hydrograph (the expression of flow rate changes over time) has a steep, rapidly-rising limb, a sharp peak and an equally steep falling limb.[31]

Only two rivers in the study area are considered major by world standards: the Euphrates and the Tigris [Figs 1.14-15].[32] Both rivers rise in the highlands of Armenia and are fed chiefly by snowmelt.[33] After following an irregular course in a south-easterly direction through the Anatolian system, both rivers emerge on the lower plateau of northern Syria and continue their south-easterly path to the Persian Gulf. The Euphrates receives two important tributaries while crossing the Syrian steppe: the Balikh and the Khabour, both of which also rise in the hills of Asia Minor. The Khabour is the last tributary to enter the Euphrates and the river suffers from a large amount of evaporation as it crosses the hot Iraqi plains. Unlike the Euphrates, which has a single and relatively restricted catchment area whose water comes from the slow percolation of snowmelt, the Tigris draws water from a much larger catchment area. Lying close to the Zagros Mountains, the Tigris is subject to large fluctuations in level due to direct surface runoff from the mountains. Both the Tigris and Euphrates have a distinctly deep thalweg and are at their lowest in September and October. However, due to the differences in catchment area noted above, the Tigris is in maximum flood in April, whereas the Euphrates does not have its high waters until May. The effect of winter rainfall is less visible in the Euphrates because much of the precipitation percolates into the porous subsoil.

In addition to these major rivers, there are other smaller, but still significant rivers in the study area: the Orontes, the Litani, the Zerqa (or Yabbok), the Yarmuk, the Jordan and the Barada. Nearly all flow north to south, but the Orontes runs south to north from the

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[29] Anderson 2000, 73.
[30] Anderson 2000, 73.
[31] *Ibid.*
[32] Beaumont *et al.*1998 83; Anderson 2000, 74.
[33] Descriptions of these rivers and their tributaries are from Fisher 1971, 345-6.

Beqaa Valley, near Baalbek to the coast south-west of Antioch [Fig. 1.16].[34] The largest group of sources for the river is Ain Zerqa at its source in the Beqaa. The regime of the river is quite exceptional in the Levant since it does not suffer from the caprices of the Mediterranean climate. The regime is exclusively one of sources: in winter, the river valley acts as natural drainage from the permeable rocks, basalt and limestone and then in summer, the river is fed by the mountain reservoirs and the slow percolating waters from snowmelt. In general, high waters occur from February to May and low waters from November to January. The Orontes runs in a deep channel, which means that water needs to be raised artificially if it is to be used for irrigation. The Litani River also has its source in the Beqaa Valley near Baalbek, but unlike the Orontes it flows south and discharges into the sea near Tyre.[35] The total length of the river is c. 125 km. The river is perennial and has its maximum flow in the spring. Both of these rivers break through to the sea.

A major feature of the Middle East are the areas of endoreic or inland drainage, which are produced not only by low rainfall, but also by the land structure i.e. interior basins shut off from the sea by mountain ranges, lava flows across valleys and tectonic basins along fault lines.[36] At the lowest level of such areas there is usually an expanse of water, marsh or salt desert; in the case of the Jordan River this is the Dead Sea. The Barada River that runs through Damascus and the Jordan River collect in such endoreic areas.

The Jordan River has three principal sources: the Dan River, the Hasbani River and the Banias Spring/River. Lake Huleh and Lake Tiberias (or the Sea of Galilee) divide the valley into three major parts: firstly, the valley from the main river sources at the foot of the Hermon massif to Lake Huleh, secondly, the stretch from Lake Huleh to Lake Tiberias where the river reaches its maximum gradient and thirdly, the Lower Jordan Valley, which is 105 km long, from Lake Tiberias to the Dead Sea.[37] The gradient of the river is disproportionately steep in its northern- and southernmost parts. The drainage basin of the river is markedly asymmetrical with the catchment area on the east being three or four times that of the west. This is because the western affluents drain an arid to semi-arid

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[34] Description of the Orontes River is from Weulersse 1940a, 15, 20, 22, 31, 34 and 38.
[35] Abel 1933, 158.
[36] Anderson 2000, 76.
[37] Description of the Jordan River is from Schattner 1962, 24-26, 36-37.

region in a leeward position whereas the eastern affluents cross areas that are more Mediterranean in character and exposed to rain-bearing winds from the west.

The Yarmuk (or Seri'at al-Menadire) and Nahr az-Zerqa are the two major affluents on the east bank of the Jordan River. The Yarmuk is the most important affluent: its drainage basin is larger than the whole catchment area of the western side of the Jordan River and it supplies almost as much water as Lake Tiberias. It is the junction of three rivers that come together at al-Maqarin near Tell al-Gamid: Wadi al-Aweiret, Wadi as-Sallale and Wadi al-Ehreir.[38] In addition, the high discharge of the Yarmuk, which is raised by cloudbursts, is the primary cause of the flooding of the Jordan in January and February. The Nahr az-Zerqa, the second most important affluent, has a source in Amman, but its permanent source is at Wadi ad-Dleil; all the affluents of this river are on its right bank.[39] The Zerqa shows effects of direct runoff from rain superimposed on regular flow from springs as well as seasonal snow melt.[40]

Overall, the region suffers from annual and interannual variations in rainfall; this is less keenly felt in the Levantine coastlands, whose position on the windward side of the Lebanon and Anti-Lebanon mountain ranges and Jebel Ansarieh means that they are well-watered. The extent to which the landscape constrained or shaped water supply and management will be considered in the remainder of the study. How these variations might be countered may be largely dependent, for example, on what alternative water sources are available. In hard limestone and basalt areas with high levels of runoff, the effects might be countered by directing water using a system of walls and terraces to fields (see Chapter 5) or to reservoirs and cisterns for storage (see Chapters 6, 7 and 9). In aquifer zones, rainwater storage need not be so heavily relied upon, if access can be gained, in the form of qanats or wells (Chapter 5). Irrigation from rivers can be achieved using water-lifting devices or derivation channels (Chapters 4 and 5).

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[38] Abel 1933, 171-2.
[39] Abel 1933, 174-5.
[40] Fisher 1971, 35.