Some Ancient Water Systems and Patterns of Land Degradation

Michael Kenneth Cowan

(This research was made possible through a grant from the Centre for Plant and Water Science at the University of Central Queensland)

In Memory of William Culican – Archaeologist…Scholar…Teacher

Preface page 2
Introduction page 5
A brief history of some ancient water systems page 6
Runoff farming in the Near East page 26
Old Dryland Dams and Diversion Systems page 40
Cisterns page 46
Qanats page 50
(see also pp. 84-86)

Patterns of ecological degradation page 53
Patterns of land degradation in dryland regions page 63
Modern interventions and traditional systems page 72
Evenari’s runoff farms page 87
(see also pp. 35-40, 44-46, 48-50)

Some concluding remarks page 110
Appendix – Forestry page 123
Bibliography page 133
Preface

A piece of research like this can be problematic as it presents an overview of some very old water delivery systems and attempts to place them in a modern context which mainly takes the form of degraded landscapes. No fault however can be attributed to the texts used in putting together the research from which I have quoted freely, some of which are described below.

*The Negev. The Challenge of a Desert* (1982) is a central text in this research. The book was written by Michael Evenari, Leslie Shanan and Naphtali Tadmor. Evenari was a Professor of Botany at the Hebrew University in Jerusalem and lived for a number of years in the bare desert terrain above the runoff farm at Avdat. The research covered in the book is largely a team effort shared by scientists and workers from very many different disciplines. Aside from the important research on the Nabatean/Byzantine water systems, the book is a classic study of desert ecology.

Alan Grainger’s book (Dr Grainger is at the School of Geography, University of Leeds) *The Threatening Desert* is a also a fine piece of research which arose out of the United Nations Conference on Desertification (UNCOD 29 August - 9 September 1977). The UNCOD was supposed to serve as a wake-up call to increasing patterns of land degradation particularly in Africa. Grainer’s comprehensive work looks at the various man-made processes that contribute towards desertification as well as many sensible ways of tackling this problem.

Thorkild Jacobsen contributes three sources namely: *Salt and Silt in Ancient Mesopotamian Agriculture*, (1958), *Sennacherib’s Aqueduct At Jerwan* (1935) and *Before Philosophy: The Intellectual Adventure of Ancient Man. An Essay on Speculative Thought In The Ancient Near East* (first published in 1946). Though he is possibly best known for *The Sumerian King List* (1939) Jacobsen knew Iraq well having worked there for many years as a Field Officer for The Oriental Institute at the University of Chicago. He later went on to become director of that institute and a Professor of Assyriology at Harvard.
A. Leo Oppenheim’s book *Ancient Mesopotamia Portrait of a Dead Civilization* (first published in 1964) also came out of the University of Chicago where Oppenheim was a Professor of Oriental Studies. He was a world expert on cuneiform script.

S. N. Kramer’s text *The Sumerians* (first published in 1963) came out of work at The Oriental Studies Department of the University of Pennsylvania. Kramer was a world expert on both Sumerian history and the language of that remarkable culture.

*Ancient Mesopotamia* (1999) by Susan Pollock is a more modern work on Ancient Mesopotamia and takes an anthropological approach to the subject.

*Water, Life and Civilization. Climate, Environment and Society in the Jordan Valley* (2011) is an entirely modern, scientific and ambitious approach to a subject which was traditionally covered by historians. The perspective is interdisciplinary and covers subjects such as history, climate and hydrology over a very long period (*20,000 years ago to 100 years into the future*). It is edited by Professor Steven Mithen and Dr. Emily Black both from the University of Reading with a host of contributing scientists.

*The Wilderness of Zin* by C. Leonard Woolley and T.E. Lawrence was first published by the Palestine Exploration Fund in 1914 and has recently been republished (2003). Woolley is best known for his excavations at Ur. Lawrence famously went on to work for British Intelligence in the First World War. It is generally forgotten that he was also an archaeologist with field experience in the region. The book is a well-documented account of the Negev and surrounding deserts from the early part of the last century.

*The Future of Drylands* (2008) edited by Cathy Lee and Thomas Schaaf is a collection of papers from the *International Scientific Conference on Desertification and Drylands Research Tunis, Tunisia, 19-21 June 2006* with numerous contributions from around the world on this important subject. The year of this conference (2006) was the International Year of Deserts and Desertification (declared by the United Nations).
Heartland of Cities: Surveys of Ancient Settlement and Land Use on the Central Floodplain of the Euphrates (1981) Robert McC. Adams was also Director of the Oriental Institute of the University of Chicago. The book looks in detail at ancient Mesopotamian patterns of settlements around the old river and canal systems and covers field work between 1968 until 1975. It is regarded as the most comprehensive study of its type.

From Provincia Arabia to Palaestina Tertia: The Impact of Geography, Economy, and Religion on Sedentary and Nomadic Communities in the Latter Roman Province of Third Palestine is a most informative PhD (Walter David Ward 2008) thesis covering an area which is little studied namely Byzantine settlement in the Negev and Sinai regions.

Peter Andrews’s book Back from the Brink (2007) and his concept of ‘Natural Sequence Farming’ have attracted the attention of farmers around Australia some of whom are putting his ideas into practice.

Sir William Willcocks’s Ancient Systems of Irrigation in Bengal And Its Application to Modern Problems is a series of lectures given at the University of Calcutta between 1928 and 1930. Willcocks was well known for designing the first Aswan Dam which was completed in 1904 and was also regarded as an authority on irrigation schemes in Mesopotamia, South Africa, the United States and Turkey.

Fred Pearce’s When The Rivers Run Dry (2007) provides a very good insight into the way water resources are being squandered in different regions of the world. Pearce is a science writer and travelled extensively to compile the data in the book.

Mountfort’s book The story of an Expedition to Jordan (1966) is a unique account of a party of British scientists in Jordan almost half a century ago.

Handbook of Ancient Water Technology (2000) edited by Örjan Wikander who was a Professor at Lund University (Sweden). The book has many good chapters by different authors on some of the ancient water systems.
Introduction

This research covers several areas. Firstly it is a partial history of some old water systems which were used to successfully provide useful quantities of water for past human cultures.

The research also looks at how these old systems could be of some use as for example in the dryland areas of the Middle East or Africa and generally in regions where lack of water is a critical issue.

Processes of ecological degradation are also looked at in terms of misuse of water resources, soil degradation and loss of forest cover.
Quite a few of the old water systems were to be found in the drier parts of the planet where human ingenuity produced runoff harvesting systems in regions without perennial water sources other than occasional springs. In Mesopotamia early river irrigation systems allowed an astonishing culture to flourish in a climate with limited rainfall over five thousand years ago. Many of the regions where these systems had made farming possible are now either deserts or degraded landscapes prone to desertification.

It is important to record the historical background of these old water systems thus establishing their place in human cultures over long historical periods of time. The historical background also establishes their worth. Technological change and perceptions of worth may vary over time and notions of quality and value have become somewhat blurred in modern cultures. Philosophical questions involving epistemology and ontology are subjects that are rarely mentioned and rarely studied nowadays yet these disciplines questioned the human tendency towards imbedded assumptions about the world around us. It is often such assumptions that prevent recognition of worth.

**A brief history of some ancient water systems**

Much of human history is a mystery. The emergence of *Homo sapiens* is little understood as is much of the interaction with the previous dominant species *Homo neanderthalis*. The Pleistocene era spanning 600,000 years saw four ice ages of tens of thousands of years’ duration with interglacial periods between. *Homo sapiens* lived through the peak of the Last Great Ice Age to go on and develop farming, the domestication of useful animals, monumental architecture and writing around 5,000 years ago. These early human populations settled around river systems and springs and developed cultures that have shaped society until the present.

Looking at periods of human culture going back ten or twelve thousand years presents different challenges. Often there is the tendency to apply concepts that are familiar to situations that are entirely unfamiliar which can lead to perceptions that are probably misleading. At best we can distinguish patterns. Around 10,000 years ago cultures in
the Near East began living in relatively large settlements. Metallurgy appears to have stimulated trade and much of this increasingly widespread interaction was by sea as well as by overland routes and river systems.

Metallurgy also facilitated forest clearing and increased patterns of warfare as well as the development of agriculture traditionally dated to the beginning of the Holocene period which saw good rainfall levels and warmer temperatures throughout the Near East in stark contrast to the much colder end of the Pleistocene period.¹

Early Neolithic farming communities in the Near East probably had relatively small cropping areas which were supplemented by hunting, domestic animals and wild food collection. Plant remains detected in early sites indicate cultivation of wheat, barley and lentils with tools such as sickles and quern stones also found.²

Patterns of hunter gathering merged with periods of early agricultural settlement. Some anthropologists have suggested that nomads surrendered to permanent settlement encouraged by discoveries of yeasts and beer-making and the need for a more sedentary lifestyle in order to cultivate barley. We do not really know what led nomadic lifestyles of long duration to develop into sophisticated literate urban cultures about 5000 years ago but by this time, fruit and nut trees including olives, ¹

---

¹ The Pleistocene period was a much colder and drier period with the last Ice Age peaking at about 20,000 BC. See Graeme Barker, “Farmers, Herders and Miners in the Wadi Faynan, Southern Jordan: a 10,000-Year Landscape Archaeology” in The Archaeology of Drylands: Living at the Margin, ed. G. Barker and D. Gilbertson (London and New York: Routledge, 2000), 69.

² B. Finlayson et al., “The archaeology of water management in the Jordan Valley from the Epipalaeolithic to the Nabatean, 21,000 BP (19,000 BC) to AD 106,” in Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley, ed. S. Mithen and E. Black (New York: Cambridge University Press, 2011), 201-202. Cereal species grown at Jeitun regarded as one of the oldest known agricultural settlements in the world were einkorn wheat (Triticum monococcum), emmer (T. dicoccum) and a type of barley (Hordeum sativum). It is not known how these crops were irrigated. M. Nesbitt and S. O’Hara, ”Irrigation Agriculture in Central Asia: A Long-Term Perspective from Turkmenistan,” in The Archaeology of Drylands: Living at the Margin, ed. G. Barker and D. Gilbertson (London and New York: Routledge, 2000), 107. There was also early cultivation of einkorn and wild rye for example at Abu Hureyra on the Euphrates. Emmer, barley, rye, chickpeas, and lentils were early crops. See G. Willcox, Sandra Fornite, and Linda Herveux, “Early Holocene Cultivation Before Domestication in Northern Syria”, Vegetation History and Archaeobotany, 17, no. 3 (2008), 313-325. Tell Abu Hureyra in Syria saw Gordon Hillman and his team identify hundreds of seeds from over 70 plant species that locals were harvesting. See J. Diamond, Guns, Germs and Steel: A Short History of Everybody for the Last 13,000 Years (London: Vintage Books, 2005), 145.
figs, dates, pomegranates, and grapes had long been domesticated and irrigated farming systems had spread throughout the Near East and to India.  

Earlier evidence of water distribution systems for crops can be found, though many of the Neolithic constructions to dam, store or channel water have long disappeared through floods or have been buried under post-Neolithic alluvium and traces that do survive are difficult to date. 

Some examples however can be found. Neolithic wells on Cyprus at Mylouthkia and Shillourokambos are from about 9,000 to 10,000 years ago and very old wells have also been discovered at Sha’ar Hagolan in the Jordan Valley dating to about 8,000 years. The nearby Carmel coast has a long settlement period beginning over 9,000 years ago including earlier Neanderthal sites.

Irrigation systems at Jericho taking spring fed water to fields can be dated to around 8000 years ago and from a culture known as Samarran, located in the centre of the Tigris valley. By around 4000 B.C. farmers in Turkmenistan were constructing canals to divert floodwater using small feeder channels to take water to cultivated areas with Syria having earlier systems which used stone and terracotta drainage channels from the 6th millennium onwards.

---

3 Diamond, Guns, Germs and Steel, 124.

4 B. Finlayson et al., 195. Water systems do not usually have pottery and coin remains for dating purposes. Some later complex systems had inscriptions allowing precise dating (see Sennacheryb’s Aqueduct At Jerwan below). Early Egypt and Mesopotamia saw various inscriptions, letters and law codes mentioning agricultural procedures and irrigation systems detailing dikes, barrages, inlet openings, basins and reservoirs. See J.P. Oleson, "Irrigation" in Handbook of Ancient Water Technology, ed. Örjan Wikander (Leiden; Boston: Brill, 2000), 193.

5 B. Finlayson et al., The Archaeology of Water Management, 200. Elsewhere, Finlayson makes mention of the discovery of ritual depositions in several wells suggesting the possibility of a significance beyond their function as irrigation systems.

6 P. L. Viollet, Water Engineering in Ancient Civilizations: 5,000 Years of History, IAHR International Association of Hydraulic Engineering and Research, (CRC Press, 2007), 8. Canals discovered here at Choga Mami connected to the river were apparently used to take spring floodwater to fields.

Early civilizations developed around river systems exploiting the availability of water for domestic and farming needs as well as using these waterways for transportation. The proximity of good water supplies for increasingly large farming areas would have been a primary criteria for site selection.\(^9\)

In ancient Egypt the regular flooding of the Nile meant that early agriculture probably consisted of putting out seed in soils which had been recently covered and fertilized by flood water and silt deposits. Natural basins on both sides of the river were used permitting water storage of sufficient duration to allow sediment deposition and then drainage back into the river or to another cultivated basin. At later periods dikes and canals were used to store water in *artificial retention basins*.\(^10\) This is usually referred to as *basin irrigation* with earthen banks around fields fed by sluice water which saturated soils and water then being led to a lower basin or an irrigation canal.

This simple but effective method also occurs in Mesopotamia and India. Ancient farmers could simply breach levees allowing water to gravity feed into cropping areas and gardens. Yearly flood events in Egypt would inundate the floodplain with a metre or more of water which would recede leaving drained valley soils which had been fertilized by nutrient rich silt from the mountains of Ethiopia. Wheat and other crops were planted out at the beginning of the mild winter (November) with harvests in spring (April-May)\(^11\)

---

\(^8\) Ö. Wikander, "The Neolithic and Bronze Ages" in *Handbook of Ancient Water Technology*, ed. Ö. Wikander (Leiden; Boston: Brill, 2000), p 609. The terracotta pipes at Habuba Kabira in Syria had *flanges and sockets to make the joints more efficient* with long ceramic pipe systems in use by about 3500 BC. Terracotta pipes were used to channel waste water into *stone-lined sewers in the streets*. It is not part of this study to examine in detail some of the fine urban water delivery systems that can be found throughout the ancient world. *Ancient Water Technologies* by Larry W. May (Ed) contains good discussions of some of these systems.


Flooding periods in ancient Mesopotamia were much less favourable for crop cultivation. The Tigris and Euphrates rising in the Armenian mountains could produce destructive episodic flooding in April and May with receding waters by June through to October being too late for seasonal plantings. There were early construction of dikes and levees which served as crucial flood mitigation strategies to protect already planted fields with systems in place to distribute flood waters.  

By the 3rd millennium BC urban centres were well established in Southern Mesopotamia along water courses some of which were river branches and some artificial canals. Early towns had sophisticated wastewater and stormwater drainage with canal systems used for both irrigation and carriage which included long-distance commerce and the transport of harvested crops into the cities from outlying estates and villages. The slower flow of the Euphrates allowed navigation further upstream which was important for trade.

Wikander talks about a vast irrigation network which he suggests began to expand around 2500 BC. At Mari different irrigation canals were put in for crops one of which has been estimated to have been 35 km long.

---


15 Oppenheim, *Ancient Mesopotamia*, 41. McC. Adams describes the Tigris as more turbulent and unpredictable than the Euphrates as a source of irrigation though the right bank of the Tigris was eventually canalized fairly extensively. See McC. Adams, 7. Extending irrigation to the Tigris appears to have led to the salinity problems described below.

Patterns of trade saw contact between Egyptian, Mesopotamian and Indian cultures and these trade patterns would have seen the diffusion and spread of ideas. The development of large-scale irrigation systems possibly spread from Mesopotamia to the Indian sub-continent, though this is unclear. Certainly the water systems of India are complex and diverse and of all the ancient cultures that emerged about 5,000 years ago the Harappan civilization on the Indus floodplains is probably the most mysterious as enough is known to suggest great sophistication but much remains unknown. Violett describes these early Indus valley cultures as the great “hydraulic” civilization of Harappa which developed around the 3rd and 2nd millennium BC.18 The estimated annual rainfall for this region at the time was 15-125 mm. Wikander states that in spite of these conditions, the high level of water technology at Mohenjo Daro remains inexplicable 19 with the city having an estimated population of over 40,000 and dwellings with bathrooms and latrines as well as street drainage channels lined with bricks 20 and flanged terracotta pipes of standardized dimensions.21 By the second half of the third millennium Mohenjo Daro had sophisticated water systems including a large bathing area suggesting ritualized cleansing was important.22

17 Violett, Water Engineering in Ancient Civilizations, 36-38. Mari was founded around 2900 BC by the Sumerians or a culture influenced by them on the Middle Euphrates at a site near trade routes to the Syrian coast. Violett describes Mari as a center of bronze metallurgy. It was certainly built on important trade routes with commerce up and down the Euphrates in wood, metals and stone. The city had a circular shape and was encircled by a dike and wall and was linked to the Euphrates by a 30 meter wide canal which provided water for the city and boat access. See Violett pages 36-37. Charlotte Wikander laments that very little research has been done on canal systems, ancient canal building, different canal uses and their important role within the transport systems of the ancient world. Canal construction and use would have been an important element of the economic systems of Mesopotamia and Egypt. See Charlotte Wikander in Wikander 2000, 321-322.

18 Violett, Water Engineering in Ancient Civilizations, 187.

19 Wikander, The Neolithic And Bronze Ages, 612.


21 Wikander, The Neolithic And Bronze Ages, 611. Mohenjo-Daro had about 700 cylindrical wells going down 15m with many being located within homes which had bathing rooms and sometimes latrines and sophisticated drainage systems using clay pipes. The city also had covered gutters. See Violett, 16.

22 Scarborough, Water Management Adaptations, 106. The Harappan port city of Lothal has a constructed basin structure which measures 219 m by 37 m with sidewalls which drop down to 4.5 m. The structure dates to the late 1st millennium BC and appears to have been used to capture fresh water.
Similarly much is unknown about the kingdom of Uratu in the mountains of Armenia which is first mentioned in Assyrian inscriptions around 1250 BC. Its capital Tushpa on Lake Van had large-scale water diversion schemes from about 800 BC. Garbrecht states that the Urartians were the only people in Anatolia to evolve a concept of elaborate and well-planned water management systems which are reminiscent of modern hydraulic works. Garbrecht compares water delivery and irrigation systems here to those in Egypt and Mesopotamia though Oppenheim describes Urartian culture as a Mesopotamian satellite civilization. However the fact remains that Urartian water systems around Tuspa used for irrigation contained all the elements that are used in modern systems such as dams and transferring water from different catchment areas through canals and river diversions.

These old irrigation systems appear to have been highly productive and we have some evidence of agricultural practises from both Egypt and Mesopotamia. In Egypt 18th-dynasty tombs reveal a selection of cultivated plants including vines, fruit trees and vegetables. Oppenheim describes ancient Mesopotamia as the land of barley, beer and sesame oil and barley, emmer-wheat, wheat and millet were mainstream crops. Large herds of sheep, goats, cattle, donkeys and other species were central to the economy. One temple record for around the time of Cambyses (530-22 B.C.) reveals estimated animal holdings of 150,000 beasts. Babylonian texts reveal an economy.

---

23 G. Garbrecht, "Water Management for Irrigation in Antiquity (Urartu 850 to 650 BC)" in Historical Dams: Foundation of the Future Rests on the Achievements of the Past, ed. H. Fahlbusch (New Delhi, India: International Commission On Irrigation And Drainage, 1988), 185. A canal brought water over 50 km to the capital from a good source of spring water to the southeast which was in use for 2,500 years with modern renovations to the system in 1950. The kingdom was centred around Lake Van but also incorporated Lakes Sevan and Urmia around the present-day borders of Turkey, Iran and Russia. See P. L. Violett, 50.

24 Ibid., 186.


26 Garbrecht, Water Management for Irrigation in Antiquity, 59.

27 Wikander, The Neolithic And Bronze Ages, 614.

28 Oppenheim, Ancient Mesopotamia, 42-44. In southern Mesopotamia barley was grown as a source of fodder with the mature crop being used for bread and beer production. Emmer and different varieties of wheat and millet were also planted. Vegetables included onions, beans, garlic, chickpeas and other pulses plus other vegetable crops and fruits. Date palms were grown with date and grape wine consumed. The date is seen as being ideal for the region of southern Mesopotamia. See McC. Adams, Heartland of Cities, 86.
which reflected an essential balance of cultivation with husbandry. Oppenheim talks about immense herds of cattle, sheep, and goats which were kept for milk, meat and leather products. Cattle were also used as draft animals and supplied hides. Donkeys were used for transportation and pigs kept for meat. Birds, fish and hunted game were also common and flax was a useful crop grown for both linen and oil production. Geese, chickens and ducks were highly regarded and there are records of fish breeding in designated ponds.

There appears to have been a high regard for botanically rich systems from the early Mesopotamian periods. Later Assyrian cultures appear to have inherited this tradition. Both Tigalp-pilezer and Ashurnasirpal II (883-859 BC) dug canals to service gardens and orchards around palaces. The Assyrian ruler Sennacherib had a great love of nature, gardens and irrigation systems. He describes how he cut through the difficult places with pickaxes and directed their outflow on to the plain of Nineveh...I strengthened their channels...I had all the orchards watered in the hot (season). In winter a thousand fields of alluvium above and below the city I had them water every year. To arrest the flow of these waters I made a swamp...wild swine I turned loose therein...within the orchards more than in their (native) habitat the vine, every fruit, sirdu-trees, and herbs grew luxuriantly. The cypress and the mulberry, all kinds of trees, grew large and sent out many shoots.

---


32 McC. Adams, *Heartland of Cities*, 204.


34 Thorkild Jacobsen and Seton Lloyd, *Sennacherib’s Aqueduct at Jerwan* (The University of Chicago Press, 1935), 35. The *sirdu* tree is possibly the bitter almond. See R. Campbell Thomson, *The Assyrian Herbal* (London, 1924) 131-32 (p. 35 footnote 21) The time frame for the construction of the water systems is roughly 690-702 BC. Jacobsen and Lloyd’s work on Sennacherib’s aqueduct at Jerwan is interesting as it is both based on discoveries by the authors and on the inscriptions found at the site. This is possibly the oldest example of an intact aqueduct system.
Viollet describes water taken from springs in the hills to the northeast of Nineveh with weir construction designed to handle flooding by channeling floodwaters into a canal leading to constructed marsh areas (artificial lakes) stocked with imported plants, animals and birds from the marshes of southern Mesopotamia. Postel refers to Sennacherib’s canal at Jerwan as one of the most impressive works of hydraulic engineering until Roman times. Jacobsen and Lloyd say that this aqueduct is part of an astounding succession of hydraulic engineering works by which Sennacherib transformed the barren environment of his new capital into a garden of almost paradisiac fertility. Sennacherib massively extended his water systems and in an inscription from 690 BC talks about digging a further eighteen canals into the Khosr River possibly because of drought. In this inscription the Assyrian ruler suggests that the local people of Nineveh were ignorant of artificial irrigation but through this large-scale program with flow diverted from the river and springs in the high mountain border country of Armenia, irrigation water was taken through various villages to Nineveh allowing the establishment of neighbourhood gardens...vineyards, the fruits of all lands and grain and sesame seed cultivation.

The Assyrians were also a rather war-like culture and some mention should be made of the links between complex engineered water systems and security. Water supplies can be disrupted by warfare and social dislocation. Finlayson et al. mention sophisticated well systems at Lachish, Meggido and Hazor which were all engineered to provide these cities with a guaranteed water supply in times of siege.

35 Viollet, Water Engineering in Ancient Civilizations, 48.
36 Postel, Pillars of Sand, 23.
37 Jacobsen and Lloyd, 31. Included with the text, Sennacherib’s Aqueduct At Jerwan is an enlarged fold-out with a detailed plan for the aqueduct plus an analysis of the concrete used in the water channel (provided by the British Building Research Station, Dept. of Scientific and Industrial Research. (15-16)
38 Jacobsen and Lloyd, 35
39 Finlayson et al., 210. Assyria’s southern campaigns into Palestine were devastating with the destruction of towns and cities and the removal of whole populations. According to Assyrian records over about a forty-year period 450,000 people were transported into exile at the end of the 8th century B.C. See McC. Adams, 154. The Assyrians incorporated cavalry into their military after the ninth century B.C. See Oppenheim, 46.
suggests that water security was vital in order for a city to have a chance of survival. Though survival was not always a possibility, Kenyon states how

\[
\text{on a number of sites archaeological evidence has been found of these events, for their effect was so cataclysmic that there is seldom much doubt in the correlation of the archaeological and historical evidence.}^{40}
\]

Kenyon makes the case that the water supply system at Megiddo involved engineering that \textit{would be no light task even today}.\textsuperscript{41} The secure well had a very large vertical shaft tunnelled 35 m deep into the ground with the lower part going through solid rock. At the bottom of the shaft a 63 m long horizontal tunnel was constructed which led to the spring with access from the outside being prevented by the construction of an enclosing wall. Kenyon remarks that

\[
\text{the women of Megiddo were now able to walk down the staircase round the side of the great shaft and along the gallery to fill their jars at the spring in complete safety.}^{42}
\]

There were other threats as farming and irrigation systems eventually led to the perennial problem of salination and this has been an ancient and recurring pattern on the old Mesopotamian lands and elsewhere in the Middle East.

The spread of irrigation systems around the world particularly in the 20\textsuperscript{th} century saw salinity concerns and the abandonment of once fertile land in different regions, a process which had already occurred over 4000 years ago in the once flourishing alluvial soils of Sumer and Akkad. Beaumont suggests that

\begin{footnotesize}
\begin{itemize}
  \item\textsuperscript{40} Kathleem M. Kenyon, \textit{Archaeology in the Holy Land}, 3rd ed. (London: Ernest Benn Limited, 1970), 284. Lachish is a good example with graphic pictorial inscriptions of the destruction of the city.
  \item\textsuperscript{41} Ibid., 234.
  \item\textsuperscript{42} Ibid., 234-235. Kenyon also describes the famous Megiddo water system which is dated to 12\textsuperscript{th} century BC in \textit{Royal Cities of the Old Testament} 1971.
\end{itemize}
\end{footnotesize}
throughout the irrigated lands of the Middle East perhaps the most important single cause of the abandonment of land is the build up of salinity within the soil.\footnote{P. Beaumont, "Desertification in the Middle East" in Arid Land Development and the Combat against Desertification: An Integrated Approach (Moscow: United Nations Environmental Programme, UNEP1986), 83.}

Ancient Mesopotamia is instructive here.\footnote{Salinization was also much less of a problem in Egypt. The summer water table was around 3-4 meters below the surface of planting areas and weeks of inundation before planting pushed whatever salts had accumulated in the upper soil layers down below the root zones. See Postel, Pillars of Sand, 32.} The Tigris and Euphrates river basin saw successive rich cultures, Sumerian, Akkadian, Assyrian, Babylonian and Sassanian over a 4000-year period. The Sumerians as we have seen had a flourishing culture in the southern part of the river basin by 3000 BC. Canal systems were constructed and different crops grown on the rich alluvial soils.\footnote{Some artificially constructed canals were more than 100 kilometers long. See McC. Adams, 158.} Irrigation transformed the landscape of what was essentially a drylands region. Wikander suggests that the alluvial lands of southern Mesopotamia were too arid for large human populations before \textit{efficient irrigation techniques} were established.\footnote{Wikander, \textit{The Neolithic And Bronze Ages}, 608.} Pollock states that rainfall levels in the area could never have sustained large populations with local crops without irrigation systems as annual rainfall of more than 200 mm a year occurred perhaps once every four years.\footnote{Pollock, \textit{Ancient Mesopotamia}, 30 -31. Southern Mesopotamia has a hot summer from May to October with no rain. Winter rains are unpredictable and as we have seen do not necessarily fall to coincide with planting. Thus despite the two rivers (Tigris and Euphrates) urban settlement would not have been possible without irrigation.}

McC. Adams is also clear here and states that

\begin{quote}
\textit{it seems incontestable that agriculture was introduced into lower Mesopotamia only on the basis of irrigation and that the region has remained a classic example of irrigation agriculture ever since}\footnote{McC. Adams, \textit{Heartland of Cities}, 13.}
\end{quote}
Various factors contribute to radically change what was once a flourishing region and home to the oldest urban, literate civilization in the world into largely abandoned wilderness. The vast network of tributary canals of the Euphrates where barges used to take produce to docking areas within cities is now largely desert.

Pollock quotes William Kennett Loftus who dug and explored Uruk.

In former days the vast plains of Babylonia were nourished by a complicated system of canals and watercourses, which spread over the surface of the country like net-work. The wants of a teeming population were supplied by a rich soil, not less bountiful than that on the banks of the Egyptian Nile. Like islands, rising from a golden sea of waving corn, stood frequent groves of palms and pleasant gardens, affording to the idler or traveller their grateful and highly valued shade.

then

how changed is the aspect of that region at the present day! Long lines of mounds, it is true, mark the courses of those main arteries which formerly diffused life and vegetation along their banks, but their channels are now bereft of moisture and choke with drifted sand; the smaller offshoots are wholly effaced.

Jacobsen and Adams in their classic study suggest three major episodes of salinity with the earliest and most serious being from 2400 BC possibly down to 1700 BC in

49 McC. Adams, Heartland of Cities, xvii Preface.

50 Pollock, Ancient Mesopotamia, 28. Postel quotes Leonard Woolley who had excavated Ur in a desolate dry landscape Why, if Ur was an empire’s capital, if Sumer was once a vast granary, has the population dwindled to nothing, the very soil lost its virtue? See Postel, Pillars of Sand, 21. Frankfort et al. talk about a civilization whose monuments perished, whose cities – in the words of the prophet – ‘have become heaps’. There is scant reminder of ancient grandeur in the low grey mounds which represent Mesopotamia’s past. See Frankfort, Before Philosophy, 137.

southern Iraq. Documents from central Iraq from between 1300-900 BC indicate salinity concerns but less acute than the earlier period. Large-scale problems appear to have occurred when a new canal was constructed taking water from the Tigris for irrigation purposes on land that had formerly been irrigated by the Euphrates only. This new supply of *copious Tigris water* saw a rise in *seepage, flooding, and overirrigation*, creating *all the conditions for a decisive rise in ground water level*. Records from the period after the reign of Entemenak (C 2100 BC) from ancient temple surveyors document outbreaks of salinity with archival material mentioning *individual fields which at that time were recorded as salt-free.*

Wikander describes increases in agricultural production but a rising water table, evaporation and *inadequate drainage* leading to increasingly saline prone soils. Agricultural yields dropped and the period after 2000 BC saw the abandonment of large tracts of farming land.

McC. Adams suggests that salinity problems are *endemic on semiarid, subtropical alluviums where high evaporation and slow drainage gradually concentrate even the very low salt levels that are present in rivers like the Tigris and Euphrates.*

Roux stresses the dangers to these complex irrigation works of the accumulation of salt in the soils and water table and remarks that *fertile fields can become sterile in a comparatively short time* and revert to desert.

---

52 Ibid., 1252. A dispute over fertile cropping land around 2400 BC between the cities of Girsu (Lagash) and Umma both of which are situated on a watercourse of the Euphrates led to fighting. As part of this conflict water courses suffered *breaching and obstructing* of the branch canals that served the border fields. Kramer has a more detailed account of this conflict. Entemenak the ruler of Girsu put in a new canal which took large quantities of water from the much faster flowing Tigris. See Kramer, *The Sumerians*, 54-57.


54 McC. Adams, *Heartland of Cities*, 20. Salts in the alluvial soils could have arrived as a result of long periods of irrigation with the water containing sediment from the mountainous country to the north. Some of it could also be wind borne from the Persian Gulf. See Jacobsen and Adams, *Salt and Silt*, 1251. Late flooding could also lead to a greater propensity towards salinity with *rapid evaporation in the increasing heat*. See Oppenheim, *Ancient Mesopotamia*, 41.
Increasing patterns of salinity over time saw crops selected for their salt tolerance. Evidence of grains in pottery from southern Iraq from about 3500 BC suggest that equal amounts of wheat and barley were being sown out however just over 1000 years later wheat production had declined substantially to about one-sixth of the grain crop. By 1700 BC wheat cultivation had been abandoned in southern Iraq and the more salt tolerant barley was being planted out instead. 56

There is no question that ancient Mesopotamia suffered from a saline groundwater table and saline soils. Though there are differing views on how this problem was dealt with. Wilson makes the interesting point that while ancient irrigation schemes have been documented, the systems that were used for drainage have been little looked at possibly through lack of archaeological research. 57

Importantly, fallow systems appear to have been a critical element in farming systems in the third Millennium Mesopotamia. Jacobsen and Adams describes harvest records from the Early Dynastic Period which indicate fields in production only every other year with the suggestion that

\[
\text{in spite of the almost proverbial fertility of Mesopotamia in antiquity, ancient control of the water table was based only on avoidance of overirrigation and on the practice of weed-fallow in alternate years} \ 58
\]

McC. Adams proposes that fields left fallow but still irrigated could have also contributed a fodder crop of deep-rooted perennial weeds with root systems that could penetrate the surface water table. 59 Jacobsen and Adams have fallow plots

55 G. Roux, Ancient Iraq (Suffolk: Pelican Books, 1972) 22. Oppenheim suggests that the progressive salinization of the intensely irrigated soil in Babylonia, the silting-up of the canals (carriers and distributors alike), and the weakening of the dikes necessitated constant surveillance. See Oppenheim, 84.

56 Jacobsen and Adams, Salt and Silt, 1252.


58 Jacobsen and Adams, Salt and Silt, 1251-52.

59 McC. Adams, Heartland of Cities, 136.
planted out to *Proserpina stephanis* and *Alhagi maurorum* to create a deep-lying dry zone against the rise of salts through capillary action with the suggestion that long fallow periods might have been necessary but through evapotranspiration and some slow draining they could eventually reduce an artificially raised water table to safe levels.  

McC. Adams talks about salinity being *inextricably intertwined with the intensity of land use and the irrigation practices that are followed*.  

There were steep rises in population between Early Dynastic and the Ur III period with the suggestion that population pressures could have led to a decline in fallow systems and *widespread violations of the system of alternate years in fallow would have further intensified the salinity problem* with subsequent catastrophic effects. By about the end of the Third Dynasty of Ur (21st – 20th century BC) populations levels could have risen beyond half-million people but by about 1700 B.C. crop yields around Larsa had substantially dropped to be followed by *extensive abandonment of southern Babylonia*.  

Later settlement patterns saw greater exploitation of land and water resources and by the twelfth century, farming and human populations had significantly declined. Jacobsen and Adams suggests that

*the southern part of the alluvial plain appears never to have recovered fully from the disastrous general decline which accompanied the salinization process...many of the great Sumerian cities dwindled to villages or were left in ruins.*

Silting was also a problem with both the Tigris and Euphrates.

---

60 Jacobsen and Adams *Salt and Silt*, 1252. The idea that plants can be used to combat salinity problems is looked at below.

61 McC. Adams, *Heartland of Cities*, 151 -152. There is no question that salinity problems over time led to a significant drop in crop yield. McC. Adams says *Early Dynastic crop yields averaged over 2,030 liters per hectare whereas under the Third Dynasty of Ur that impressively high figure fell sharply to 1,134 liters.*


Early tablet inscriptions talk about the importance of maintaining the irrigation system and there is evidence the early Mesopotamian water systems needed some form of cooperative contribution and depended on such efforts for its existence. Roux talks about the cooperation of many demographic groups being necessary to maintain the complex system of canals, reservoirs, dykes (and) regulator sluices as without this effort the whole system would have succumbed to silt.

Jacobsen and Adams describe sedimentation in the region as a massive, continuing process. Silt build-up in canals would have to be removed periodically and probably was placed around the canal banks from where it could be spread by rain or wind to nearby fields. Sediment would have also entered cultivated areas through irrigation water. Pollock talks about water deposition which accumulated to depths of up to 10 metres particularly in the northern part of the river plain. The Ubaid mound of Ras al-Amiya was covered by 7000 years of alluvial sediment and many traces of ancient settlement are no longer visible.

---


65 Roux, *Ancient Iraq*, 22. Kramer suggests that the Sumerian irrigation systems fostered a strong spirit of co-operation among individuals and communities alike. Sumerian culture depended on water and irrigation systems. Water systems had to be maintained and repaired after floods. Water allocations to cropping areas must have been of crucial importance. Kramer maintains that authorities set up to organize these critical social needs evolved into governmental institutions and the rise of the Sumerian state. See Kramer, 4 ff. Irrigation is mentioned in the Code of Hammurabi (C1770 BC) which details numerous regulations involving agriculture and water usage. Inscriptions from around 1845 BC recording the dredging of the Tigris by king Sin-Iddinam of Larsa using paid workers. *I grandly dug out the Tigris...I raised the top of the slope, the old embankment...I transformed the Tigris into a freely flowing water.* Many tablets containing inscriptions concerning canal maintenance have also been found at Mari. Silt was certainly a problem with water intakes having to be cleared from sediment and vegetation annually by hundreds and possibly thousands of workers though slave populations would have been high. Dredging operations seem to have been on-going to keep the waterways clear. See Viollet, *Water Engineering*, 29 and 39-40.

66 The authors estimate that perhaps ten meters of silt has been laid down at least near the northern end of the alluvium during the last 5000 years. See Jacobsen and Adams, *Salt and Silt*, 1252.

67 Pollock, *Ancient Mesopotamia*, 46. Ras al-Amiya was only discovered by accident after a canal was built through it. The Tigris and Euphrates in flood can carry daily around 3 million tons of suspended sediment. See Postel, *Pillars of Sand*, 24. McC. Adams says that in flood, the Tigris bed load may reach twenty thousand parts of silt per million, five times that of the Nile and more than three times the highest level known for the Euphrates. Tigris water appears to have been used to as a supplement when major flooding was not a problem. In modern times the 1954 flood down the Tigris saw a raging, uncontrollable crest of 16,000 cubic meters per second (cumecs) below Baghdad. See McC. Adams, *Heartland of Cities*, 6-7.
The later Sassanid period (226-637 AD) saw the further construction of sophisticated irrigation systems which lasted until the Islamic invasion of the eighth century. The later Mongol invasions under Hulagu Khan in the 13th century have been blamed for putting an end to these once flourishing irrigation systems. But increasingly saline soils and silt build-up were also major factors for the decline of this rich culture.

Jacobsen and Adams describe how the

*silt banks left from Parthian, Sassanian, and Islamic canal cleaning are today a major topographical feature not only in the Diyala region but all over the northern part of the Mesopotamian alluvium; frequently they run for great distance and tower over all but the highest mounds built up by ancient towns and cities.*

69

Some parallels can be drawn here between ancient Bengal and early Mesopotamian cultures. Both used canal and river systems for food, transport, irrigation and importantly to manage the hydrology of the large flood plain river systems on which they were based.

---

68 In 1258 Hulagu destroyed Baghdad and irreversibly damages the Mesopotamian irrigation system. See Viollet, *Water Engineering*, 209. Similarly the region around Merv was devastated by Gengis Khan’s forces around AD 1221. Merv was well known centre for culture, commerce and religion for very long periods of history and was already a large oasis settlement during the Bronze Age with a variety of domesticated plants and animals. Fields appear to have been irrigated by a system of ditches which sourced water from nearby streams which were part of the Murgab river which rises in Afghanistan and flows north into the Kara Kum Desert. Nesbitt and O’Hara cite the Arab historians and geographers Muqaddasi, Al-Biruni and Yakut who left good accounts of the old irrigation systems. Water was accepted as being a *gift from God* and was not controlled or owned by any one individual suggesting the possibility of a community based system of organizing what were scarce water resources. The geographer Yakut lived in Merv in the early 13th century when the city was at its height of culture and prosperity just before the Mongol conquests and relates how water gauges were placed at the head of each canal within the city. The entire hydrological system was the responsibility of the *mirab bashi* or ‘chief water master’ who received hourly reports on water levels in the canal main allowing sluice gates to be opened or closed accordingly. Elections were held for senior water officials and the whole system was maintained by a labour force of 12,000 workers whose wages were paid for by water consumers. There was an annual maintenance program which all users were expected to participate plus help with construction projects. See Nesbitt and O’Hara, *Irrigation Agriculture in Central Asia: a long-term perspective from Turkmenistan*, 109-114.

69 Jacobsen and Adams, *Salt and Silt*, 1257. The Nahrwan Canal had been constructed to take water from the Tigris. It ran for a length of 300 kilometers and was built with technical proficiency that still excites admiration. The canal had weirs and thousands of brick sluice gates along its branches. But by the end of the 12th century only a trickle of water passed down the upper section of the main canal to supply a few dying towns in the now hostile desert. See Jacobsen and Adams, *Salt and Silt*, 1257.
Oppenheim suggests that Mesopotamian farming systems and related technological practices could have emanated from the region around the Gulf of Bengal. Trading patterns would certainly have contributed to the exchange of technologies. Kramer suggests that by the 3rd millennium BC there were trading relationships between Mesopotamia, India, the Mediterranean and as far south as ancient Ethiopia and as far north as the Caspian.

McC. Adams describes the use of the two Mesopotamian rivers as a scheme of extraordinary comprehensiveness, entailing the artificial reshaping of the relationship between major rivers and their many effluents and much the same appears to have been true of river management in ancient Bengal.

The 19th century British hydrologist William Willcocks gives us some idea of the great productivity of the old Bengali irrigation systems and how they might have functioned. Willcocks describes the behavior of deltaic rivers in raising the levels of areas where flooding has occurred with some rivers changing courses down secondary channels.

In Mesopotamia McC. Adams talks about an anastomosing pattern where the river regularly overtops its banks and maintains an elevated bed on a natural levee made up of sediments. Pollock describes the importance of the meandering flow of the Euphrates across the alluvial plains which saw the river bed being raised over time

---

70 Oppenheim, Ancient Mesopotamia, 63.
71 Kramer, The Sumerians, 5. Oppenheim describes trade items such as copper, ivory and precious stones plus there was trade in leather, wool, hair, silver, textiles, metals, stone, lumber, spices and perfumes. See Oppenheim, 63, 87 and 91.
72 McC. Adams, Heartland of Cities, 7.
73 Sir W. Willcocks, Ancient Systems of Irrigation in Bengal and Its Application to Modern Problems (Delhi: B. R. Publishing Corporation, 1984), 37. First published in 1930 as a series of lectures from the University of Calcutta. Willcocks was one of the pre-eminent irrigation engineers of his time. He supervised the construction of the first Aswan Dam in Egypt and was head of the Ottoman Irrigation Department.
74 McC. Adams, Heartland of Cities, 7. See Peter Andrews p117ff below for an account of similar patterns in Australia.
until flow was above the level of the surrounding land. Postel suggests that the Euphrates was relatively easy to extract water from as the river bed was higher than the surrounding plain. This is a characteristic of river systems carrying large quantities of silt and allows irrigation to be carried out by breaching levees allowing water into fields and diversion channels.

Willcocks describes this system of providing water for crops as overflow irrigation which was practiced in Bengal 3000 years ago utilizing overflow canals which had regulating heads and sluices. Breaches were made yearly at approved sites when dangerous flooding events had passed. These approved sites were higher than the surrounding countryside. Canals were regularly cleared of silt which was used to strengthen and create new banks. Sengupta talks about the construction of weirs on rivers with irrigation being simply a matter of making a cut in a bank.

Canal breaches were made simultaneously and breaches were often the sites of future canals. Water flow was distributed carefully through canals and water-courses with fish eggs spread over the fields and kept alive in the rice fields full of rain and river water. Central Bengal had tens of thousands of ponded field areas and thousands of overflow canals which fertilized fields with the rich muddy deposits of the river floods. (Willcocks does not mention the manurial contribution of the fish to the fertility of the fields but it must have been substantial).

---

75 Pollock, *Ancient Mesopotamia*, 32. This is an important point looked at in more detail below.

76 Postel, *Pillars of Sand*, 19.


78 Ibid., 38-39.


80 Willcocks, *Ancient Systems of Irrigation*, 72. Willcocks quotes peasant lore…though no one would care to cut the river bank across the head of a single canal, still when they had agreed to cut the river banks at thirty places simultaneously there was no great risk. See Willcocks, 61.

81 Ibid., 69. Similar systems employing fish were used in China where fallow rice paddies were irrigated with river water full of carp.
In Mesopotamia the slight elevation of the Euphrates as we have seen saw similar irrigation methods. McC. Adams says *yet at least the upper surface of the stream itself is generally elevated in relation to this land surface. Fairly short, shallow cuts in its banks are sufficient, therefore, to bring water out onto the backslopes at or above the land’s level, establishing “command” of it for irrigation.*  

Both the Euphrates and later the faster flowing Tigris were used for irrigation in this way. McC. Adams describes how openings could be cut into the banks of the Tigris *if the canals themselves were extended far enough down the backslope of the Tigris levee to provide a water level higher than the adjacent fields to be irrigated.* 

Willcocks suggests that what is perceived as the natural drainage systems of the Ganges-Brahmaputra delta is in fact the result of ancient irrigation systems. Willcocks believed that some Bengali rivers, for example, the Bhagirathi River were originally engineered as drainage channels. The canals were dug in straight courses but over time developed winding patterns and increasingly resembled river systems. 

McC. Adams in describing the old Mesopotamian systems suggests a similar pattern where natural watercourses and channels *assumed an increasingly canal like regime as the inhabitants of the area undertook to dike, straighten, and deepen them, primarily to assure the passage into the cities of barges with bulk foodstuffs and other riverine commerce.* 

In discussing the Mesopotamian systems, Jacobsen and Adams make the same point that both ancient and present day distinctions between *canals* and *rivers* is 

---

83 Ibid., *Heartland of Cities*, 7.  
85McC. Adams, *Heartland of Cities*, 245. Canals were usually excavated in reasonably straight lines but later they frequently show the same propensity as rivers to develop meandering courses over time. See McC. Adams, 19.
meaningless or impossible as large canal systems would develop an ecology of their own over time (a natural regime).  

In both Bengal and Mesopotamia the rivers that often travelled above the plains around them were managed for irrigation and transport. Artificial canals were put in that could travel for hundreds of kilometres often in time becoming indistinguishable from the natural waterways around them. Fields that were diked with mudbrick or earthen walls with drainage canals were all part of vast irrigation systems. These systems were also managed for flood mitigation with excess waters diverted to allow cultivation of the fertile alluvial soils. By all accounts these were productive systems that were integrated into the natural hydrology of the region.

Runoff farming in the Near East

Ancient water systems in the dry areas of the Near East made use of perennial springs and seasonal runoff under circumstances altogether different from the river civilizations of Mesopotamia, Egypt and India.

Early remains of dryland runoff farming systems suggest irrigation employing runoff methods was taking place in Neolithic times. Finlayson et al. propose that harvesting and manipulating runoff water led to an expansion of Neolithic settlements in Jordan. Increases in patterns of settlement would have continued north and east into Syria, Turkey and the Iranian Plateau. Viollet makes the point that the hydrological expertise found for example at Jawa in southern Jordan was not an isolated example.

Jacobsen and Adams, Salt and Silt, 1254.

Oleson talks about irrigation systems that enhance the natural hydrology being characteristic of the more arid regions of the Near East. Both the Bengali and Mesopotamian irrigation systems integrated the natural hydrology of floodplains with their own water supply networks. Elsewhere Oleson suggests that most of the Mesopotamian hydrological works have been obliterated by continued exploitation and by migration of the river channels. See J. P. Oleson, Irrigation, 187-189.

Finlayson et al., The archaeology of water management, 200-206. Finlayson et al. suggest that the Neolithic period was characterized by the development and growth of sedentary communities with complex social organizations, monumental architecture and religious institutions all based upon the new economic practice of cultivating domestic plants and herding animals. See Finlayson et al., 195.

Viollet, Water Engineering, 32.
Sites in Jordan do however have good early examples of drylands irrigation. By around the middle of the 4th millennium BC farmers at Jawa had put in stone-lined canals running for several kilometers to take water to ten reservoirs with sluice gates capturing water from runoff flood from winter and spring rains. The captured water was used for crop irrigation with three of the reservoirs devoted to supplying the city of Jawa with an estimated total capacity of 42,000 m³. ⁹⁰

Other possible early examples of runoff farming are ascribed to the Natufian culture where at Jericho sufficient food was produced to allow permanent settlement probably around 7000-8000 BC. Kenyon talks about settlement here being based upon a successful system of agriculture and she surmises that an expanding population requiring larger cultivated areas could not have been serviced by unmanaged spring water alone as the bigger field areas would have needed irrigation channels to transport water and cultivated areas were some distance from the town. ⁹¹

The Bronze Age period at Wadi Faynan has good evidence of field systems, small cisterns (circular or oval cisterns 30-50 cm deep) and check dams constructed across wadis. These systems were designed to harvest seasonal (wadi) floods in storage cisterns as well as directing water to terraced fields. ⁹² Rainfall patterns in these regions can be as little as 100 ml or less a year. One author remarks that it is ironic that intensive agriculture developed early in areas that received very little

---


⁹¹ Kenyon, Archaeology in the Holy Land, 45. Jericho is sited near the Ain el Sultan spring with its historically famous abundant flow of water of about 26 m per second. Natufian culture has been described as semi-sedentary complex hunter-gatherer groups, exploiting resources such as wild cereals and the products of hunting. See C. Rambeau et al. "Palaeoenvironmental Reconstruction at Beidha, Southern Jordan (C. 18,000-8,500 Bp): Implications for Human Occupation during the Natufian and Pre-Pottery Neolithic" in Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley ed. S. Mithen and E. Black (New York: Cambridge University Press, 2011), 249.

⁹² Barker, Farmers, Herders, 72-75. Early Bronze Age sites such as Tell el-Handaquq (southern Jordan) reveal heavy stone retaining walls though the origin of these systems remains obscure. See Oleson, Irrigation, 185.
precipitation.\textsuperscript{93} Viollet talks about \textit{wadis} being exploited for their periodic water resources and structures making use of \textit{wadi} floods dating from around the 3\textsuperscript{rd} millennium BC.

Similar systems can also be found in Yemen \textit{along the wadis of Dura, Dhana and Markha} and from the 2\textsuperscript{nd} millennium BC from \textit{wadis} in the Hadramawt on the Arabian Peninsula.\textsuperscript{94} By the time of the Iron Age (C1200-300 BC) more advanced systems had been laid out at Wadi Faynan to harvest water from the surrounding hillsides and by means of channels and sluice gates to divert this water to terraced fields below.\textsuperscript{95} Oleson suggests that these early settlements and their dryland crop irrigation systems \textit{had transformed the landscape of Palestine and Transjordan} by the Early Iron Age.\textsuperscript{96}

However it is the sophistication of the dryland runoff systems that emerge between c.300 BC to around 700 AD that are of particular importance and it is these systems, particularly those of the Nabatean-Byzantine era in Southern Jordan and the Negev Desert that have rekindled interest in what were once highly productive farming systems in some of the driest regions of the planet.

Some early examples from this period can be found in the Syrian Desert region. At Ad-Diyatheh a runoff agricultural system dates probably from the late 3rd century AD and includes leats (millstreams) running to watermills and extensive cultivated areas. (The watermills were probably utilized for processing cereals that were grown extensively in the Roman period also testifying to the useful functionality of these managed \textit{wadi} diversion systems.) Average annual rainfall here is 100 mm. The same period also saw settlement to the east on another Syrian Desert plateau named the al-Harra (referred to as the Black Desert by European visitors to the region) with

\textsuperscript{93} Oleson, \textit{Irrigation}, 188

\textsuperscript{94} Viollet, \textit{Water Engineering}, 74.

\textsuperscript{95} Barker, \textit{Farmers, Herders}, 76. Barker suggests that Iron Age farmers at Wadi Faynan had learned to construct substantial and rather sophisticated walls to divert the flow of floodwaters. Greater quantities of water could be collected and sent down a field system than was possible with Bronze Age technology.

\textsuperscript{96} Oleson, \textit{Irrigation}, 184.
average rainfall of about 150 mm in the north and around 50 mm in the south. Here various *wadis* drop down in an easterly direction from the Jebel al-Arab plateau providing sources of water for human settlement based on runoff farming. 97

Nabatean settlements in the 3rd century BC are established around Petra based on caravan trade into Arabia, Africa and the Eastern Mediterranean and by the end of the 3rd century AD much of the northern Negev Desert was settled by Nabateans and later Roman Byzantine cultures.98 By the second century BC the Nabateans had established a monopoly over the Arabian-Mediterranean trade routes which lasted until Roman annexation in 106 AD when sea routes began to dominate the traditional overland camel caravans.99 Their origins remain obscure though the region of the central

97 Paul Newson, "Differing Strategies for Water Supply and Farming in the Syrian Black Desert," in *The Archaeology of Drylands: Living at the Margin*, ed. Graeme Barker and David Gilbertson (London and New York: 2000), 88-92. The first to the third centuries of the Roman period in Syria saw large scale patterns of settlement of the Jebel al-Arab in Syria. The region has an average rainfall of around 200 mm and geographically is a high altitude plateau region. (86) These water harvesting systems were sophisticated. (Newson reports the ruins of eight mills which have been found *usually located along short mill-race canal sections leading off from the secondary canals*) Wadi Sham has a series of *stone-lined* wells which tap into subterranean flow. The agricultural layout here comprises several diversion systems across the *wadi* bed situated over a 3 km stretch. These systems were constructed of medium sized stones forming a *long, low* barrage running across the *wadi* at an oblique angle to the runoff flow. These low dams only partially blocked the floodwater flow thus avoiding destruction by the force of the water in a major flood event. The barrages diverted water into canals with a series of tributary canals lower down taking water to cultivated areas. The main canal was built on a shallow gradient allowing floodwater to overflow thus compensating for the height discrepancy between cultivated areas on the plain and the *wadi* bed some metres below. Channels were usually 1-2 m wide with low walls 0.5-1 m in height constructed out of medium-sized boulders along the downside of each channel which ran along the contour of the terraced bank. Waterproofing of walls was achieved with earth and small stones being packed into the gaps between the boulders. Channels led to *rock-cleared fields scattered at intervals across the gently sloping plateau*. It is estimated that over 1000 ha of farm land were supplied with water from this system with one canal flowing into another so that there was little wastage of water and little or no ponding. The system would have been well maintained. Evenari found that when the ancient water harvesting systems of the Negev were abandoned serious erosion patterns occurred and the situation is similar at Ad-Diyatheh where much of the old system has been ruined by severe erosion after settlement here was abandoned probably in the 5th - 7th century AD. Newson maintains that these eroded ruins testify to the functionality of the system in managing the flood water when they were properly maintained. The *Wadi Sham* has caused erosion in the plain below (Harra plain) to a depth of 15 m a channel which in places is wider than 200 m see pp. 86-93. *Differing strategies for water supply and farming in the Syrian Black Desert*. Paul Newson.

98 Finlayson et al., *The archaeology of water management*, 211.
Arabian Peninsula is a possibility and parallels have been drawn between the Sabeans (see below) and the Nabateans in terms of their great skills in harvesting water for agricultural and settlement purposes. Viollet suggests that Nabatean prosperity was both based on the spice trade and techniques of growing crops in a desert environment. This was a culture that was able to create arable land in the mineral wasteland of rocks and stones of the Negev desert. Under the Nabateans, the Negev becomes a land of immense orchards, farms, and villages. Seasonal (winter) rainfall was harvested to provide water for crop cultivation as well as storage for urban populations.

Nabatean skills in managing scarce water resources can be seen in the considerable trouble they went to artificially establish perennial water sources for their towns. The Nabatean capital of Petra was built in the valleys of wadis allowing both the harvest of water from springs plus runoff flood water with sophisticated water distribution systems incorporating above and below ground cisterns, aqueducts, storage reservoirs, dams and tunnels.

---

99 W. D. Ward, From Provincia Arabia to Palaestina Tertia: The Impact of Geography, Economy, and Religion on Sedentary and Nomadic Communities in the Later Roman Province of Third Palestine (Los Angeles: University of California, 2008), 144. Aila, modern Aqaba, and the island of Iotabe in the Red Sea saw exotic goods conveyed into the Roman Empire plus the ancient port of Gaza would have been important. Another port was Leuke Kome which was probably situated near Aynunah in Saudi Arabia. In the third century, Clyysma (modern port of Suez) became part of Roman trade and shipping routes. See Ward, 145, 153 and 315. Sir Frederick Kenyon describes the Nabateans as the great carrying merchants. See Woolley and Lawrence, The Wilderness of Zin, 14.

100 Ward, From Provincia Arabia, 144 and 120.

101 Viollet, Water Engineering, 120.


103 Viollet, Water Engineering, 122. Lawrence maintained that Petra was not the Nabatean centre for their trading empire but more a religious and residential centre. Prosperous Nabatean traders and officials, priests could live in comfort and civilization, sufficiently near to but above the very uncomfortable highway from Akaba to Gaza. See Woolley and Lawrence, The Wilderness of Zin, 14.
These systems

acted to capture every conceivable amount of the meagre seasonal rainfalls, distribute water throughout the city and provide protection from seasonal and potentially destructive floods.¹⁰⁴

Viollet makes the point that weirs or dams were utilized to partially block wadi watercourses to make use of annual floodwaters but also and perhaps more importantly, they retain the silt conveyed by the floodwaters. This accumulated silt provided a good growing medium for crop cultivation.¹⁰⁵ Rock channels using stone blocks were also constructed to take water from springs and aqueducts were later used to transport water over longer distances possibly influenced by Hellenistic and Roman systems.¹⁰⁶

The water harvesting systems at the Nabatean city of Humayma although less well known than those at Petra were also based on spring and runoff floodwater. Oleson talks about the hostile desert environment being the key to understanding this town as the Nabateans would have used all their skills in applied hydrology and hydraulic engineering to ensure the survival and growth of the urban center. Cisterns were to be found throughout the town as well as earthen and stone walls some of which are still employed to harvest runoff from hillsides or small wadis.¹⁰⁷ The Nabateans brought

¹⁰⁴ Finlayson et al., The Archaeology of Water Management, 213. Terracotta pipes were also used to distribute water.

¹⁰⁵ Viollet, Water Engineering, 120. Viollet suggests that these methods were later employed by the Romans in North Africa. The main access to Petra is a narrow gorge called the Siq which is linked to Wadi Musa which has its source some kilometres to the east. The Siq is 1500 m long but only a few metres wide. This is a dry wadi which winter floods can change rapidly. The Nabateans built a dam (14 m high and 43 m long) across Wadi Musa where it enters the narrowest part of the gorge. As part of this system they also built a tunnel 9 m high, 6 m wide and 88 m long which served to channel flood waters towards another wadi (Wadi Mudhim) and then on to Wadi el Metaha where flood waters would rejoin their natural course in the centre of Petra. Rainfall here falls in winter and can lead to a strong flow of water which is dramatically enhanced by the steepness of the gullies. See Viollet, 121.

¹⁰⁶ Finlayson et al., The archaeology of water management in the Jordan Valley, 212. The main entrance to Petra had one aqueduct taking the spring water of the Wadi Musa valley along the right wall of the Siq and another aqueduct transporting water was carved along the left wall of the Siq. This work was probably done around the beginning of the 1st century BC coinciding with construction of the city. Wadi Musa as it flows into the Siq has a slope (drop) of about 40 m per kilometre. Hydrological data suggests a maximum discharge of Wadi Musa in flood to be about 200m³/sec., a flow rate reached in one hour. See Viollet, Water Engineering, 121-122.
water to the settlement from two spring systems (The Qana and Jaman Springs) with two aqueducts each over 16 kilometres in length. In places the aqueducts are cut into the sandstone bedrock and in one location the open conduit makes a vertical ascent of ca. 100 m where the average slope is 40 percent and in places 60 percent. The authors state that it is difficult to see how any significant amount of water can have remained in the channel as it turned corners or levelled off at the bottom but calcium carbonate deposits show that the branch line did indeed function as intended. 108

The establishment of Constantinople in AD 330 saw the Negev region becoming increasingly important to the Eastern Roman world with the Byzantine Empire serving as a buffer zone against nomads in the surrounding desert regions. Nabatean settlements were Romanized with Christian Byzantine settlers who built churches and thousands of kilometres of terraced walls. 109

The Christian era saw monks in increasing numbers attracted to settle in the Negev Desert and Sinai Peninsula because of its barren terrain and historical association with events in the Old and New Testaments. Byzantine farming systems based on Nabatean hydrological technique led to agriculture prosperity in the dry Negev and surrounding areas of southern Jordan and the southern Sinai mountain allowing an explosion of inhabited sites in the province. 110 Ward talks of a burgeoning Christian

107 Eadie and Oleson, Water Supply Systems, 53. The authors state that the plans for supplying Humayma with water were regional in scope and sophisticated in their execution. (See 61-68 for a discussion of their construction). Humayma has an annual rainfall average of 100 mm and gets seasonal runoff from the al-Shera escarpment plus a spring about a kilometre from the site takes water from winter rains and melted snow from the Jibāl Humayma. Average rainfall in the Humayma catchment is 95 mm but this can go down to 40 mm in a dry year with 150 mm in a wet year. (Rain falls between October and May). See Eadie & J Oleson 1986, p 50-54.

108 Ibid., 66. The Qana aqueduct has a fall of about 450 m over 17 km with an overall slope of 2.65 percent. The Jamam conduit has an average slope of 3.67 percent but the slope of the descent from the plateau is an astonishing 28 percent. See Eadie and Oleson 1986, 68.

109 Evenari, Shanan and Tadmor, The Negev, 22. Previously in AD 106, one of Trajan’s generals (Cornelius Palma) had annexed the Nabatean kingdom to Rome with the new name of Provincia Arabia Petraea though Nabatean towns and settlements were not destroyed.
monastic movement in the region and it is possible that Byzantine monks made up a proportion of the manual labour that went into the expanded runoff water farming systems. There is also probable ecclesiastical involvement in regional winemaking and transactions involving agricultural products to other monastic sites.\footnote{111} All the Negev towns of the period had olive and wine presses sufficient for what has been described as industrial production levels.\footnote{112} Evenari describes how

\begin{quote}
the intensely cultivated farms and water collecting systems reached a peak of development during the Byzantine era, and their engineers fully exploited every drop of runoff water either for agriculture or for domestic purposes.\footnote{113}
\end{quote}

Shivta and Avdat were important Byzantine towns as evidenced by the construction of many contemporary churches and other religious buildings suggesting a large ecclesiastical population. Avdat has two beautifully constructed churches as well as a good sized fortress with hundreds of houses and storerooms cut into the hillside testifying to an affluent culture. Shivta displays similar prosperity with three large churches with walls lined with marble.\footnote{114} Ward suggests that the area of Sinai, the Negev and Southern Jordan through the Nabatean-Roman-Byzantine period had unified economic conditions, homogeneous population, and shared culture.

\footnote{110} Ward, From Provincia Arabia, 14 and 126. The edict of Theodosius in A.D. 392 established Christianity and led to Palestine becoming the ‘Holy Land’ and the centre of worship for the Christian world of the time. The journey of Constantine’s mother Helena to the region and the construction of new churches led to the beginnings of large-scale pilgrimage to the Holy Land. Ward says after Helena, pilgrims traveled to the holy land in ever increasing numbers. Athanasius’ work Life of Antony had widespread popularity in the Mediterranean region and appears to have created enthusiasm for the monastic life. Ward also mentions the powerful influence of religious leaders such as Paul, Pachomius and Hilarion. See Ward, 306 and 269.

\footnote{111} Ibid., 262.


\footnote{113} Evenari, Shanan and Tadmor, The Negev, 26. Interestingly Ward (From Provincia Arabia) describes the expansion of ecclesiastical settlement in the Negev as urban monasticism (269). Elsewhere he states that there were a number of urban monastic communities in the Negev plus individual monkish cells were to be found throughout southern Jordan and the Sinai Peninsula. See Ward, From Province Arabia, 269 and 301 Wooley and Lawrence in their trek and archaeological survey through the region just prior to the First World War make the observation that in addition to their corn and wine and silks, the people of Syria had a second commerce in their unlimited holy places, and indeed, in their sanctified air (49). Woolley and Lawrence, The Wilderness of Zin, 49.

\footnote{114} Evenari, Shanan and Tadmor, The Negev, 26.
They also had a shared system of agriculture based on harvesting and storing rainwater in a region with relatively meagre rainfall using terraced systems and dams constructed across wadis, the remains of which can still be found throughout the region. Cultivated crops included cereals, olive trees and vineyards and as we have seen supported relatively large populations with food and commerce.

Some idea of the functional nature of these old dryland water systems comes from Evenari’s study of old Nabatean and Byzantine farms in the Negev Desert. The study conducted over many years identified three types of harvesting structures.

The first and oldest remnants were *individual terraced wadis* which comprised stone terraces of 5 to 7 layers of rocks constructed at right angles to a wadi with accumulations of *silted loess soil* behind them. The walls were separated by a distance of around 12-15 metres and in length varied from 6 to 20 metres depending on the slope of the gully. Walls were 60-80 centimetres high measured from the lower terrace which was about 10-20 centimetres above the surface of the higher terrace.

Rain events produced runoff and some of this flow penetrated the soil areas between walls and some ponded behind the walls to slowly enter the ground. Walls also

---

115 Ward, *From Province Arabia*, 69 and 140. At least ten wadi systems in the Sinai were exploited for runoff during the Byzantine era with most sites supplying water to orchards on sloping hillsides rather than on wadi floors. A winepress found at Wadi Tubuq several kilometres southwest of Santa Katarina, one of the earliest monasteries, suggests grape production. See Ward 116.

116 Evenari, Shanan and Tadmor, *The Negev*, 97. Accumulated silt provides soils that can eventually be used to cultivate crops. See Viollet, *Water Engineering*, 120. Viollet’s use of the word *weir* here merely refers to a stone barrage, essentially a terraced wall. Another term used is *bund*. But more important is the principle behind such structures which involves slowing down water flow allowing it to spread in cropping areas. As mentioned above terraces across wadi systems have been found in many areas of southern Jordan at Jebel Haroun, Phaino, Humayma, Nakhl, and Gharandal as well as in the Sinai Mountains close by ecclesiastical settlements. Ward suggests that monkish communities adopted regional agricultural practises. See Ward, 112. Some of these systems are still used by local Bedouin to put out useful barley crops after floods at the beginning of winter. See Evenari, Shanan and Tadmor, *The Negev*, 97. This is not uncommon. Oleson reports good quantities of cereal crops and large herds of sheep and goats around Humayma from 1983 presumably making use of the old water harvesting systems. See Eadie and Oleson, *Water Supply Systems*, 50.

117 Oleson makes the point that the stone terraced walls also trapped eroding soils and these soils served as *a sponge to hold the water for agricultural purposes*. See Oleson, *Irrigation*, 185. He describes how runoff farming can involve large quantities of water from major wadi systems often containing alluvial sediments useful for crop cultivation. See Finlayson et al., *The Archaeology of Water Management*, 192.
served the purpose of erosion and flood control, silt collection as well as providing well defined planting areas.

The second type of system found by Evenari was larger and described as *groups of terraced fields with farmsteads* and these were situated close to the ancient towns in the Negev. Evenari describes the farmhouses as having 3 or 4 rooms with underground cisterns and storage facilities strategically located *in small tributary wadis surrounded by barren hillsides* on which were the runoff-collection channels which led the water to cropping areas. Evenari and his team discovered thousands of these old farms all containing two main features, namely a cultivated terraced area in the wadi bottom and a catchment area divided up into subcatchments by water conduits. These channels harvested runoff water from the surrounding hillsides to the fields below.

Evenari examined one of these farms in some detail describing it as a *simple and uncomplicated example of a runoff farm*. This farm (*Yoram’s farm*) was located roughly 3 kilometres from Avdat in a small wadi that begins about 500 metres higher than its entry point into the farm. Nine conduits or runoff channels are visible on one side of the farm with other conduits on the other side of the wadi slope harvesting water over about 17.5 hectares. Overall the farm comprised an area of 0.6 hectares bordered by a rough stone wall with designated openings to allow runoff water to enter ten terraced areas of about equal size. Terraced walls of 1.5 – 1.8 metres separate the different areas and water was allowed into each field via a well-built drop structure allowing surplus runoff to flow from the upper to lower terraced areas. The lowest terraced wall was of more substantial construction than the other walls.

---


119 Ibid., 99. *The Negev: The Challenge of a Desert* has good aerial photographs of these well engineered systems systems.

120 Ibid., 99 and 104. The conduits appear to have been first built using unhewn rocks to construct a loose embankment not more than 15 centimetres high. Gaps between the stones were packed with smaller rocks and the soil scraped off the shallow ground. The water entry points where the conduits and wadi reached the farm were well built gates (no mention of material used in construction) or purpose built drop structures (stone steps) built into the wall.
Viollet describes similar systems in Yemen with walls which would deflect flow (deflector walls), weirs, terraces, and small dams built in wadi beds which would take silt-laden floodwaters through systems of branching canals to cultivated areas. Sluice gates were used to regulate flow and fields were often surrounded by earth banks. The canals had less of an incline or fall than the wadis so water flow rates were reduced and only fine sediment particles made it to the fields. Planting would take place when the floodwaters soaked into the soils or were directed to other field areas. Sediment deposits helped maintain soil fertility.\footnote{Viollet, Water Engineering, 74-75.}

Evenari describes another runoff farm also near Avdat which had a more complex design. The terraced areas here were roughly 2.2 hectares and the catchment supplying runoff water was about 70 hectares. This catchment area had been divided into smaller watersheds by several runoff conduits and each of these conduits or runoff channels led to a specific field on the farm. Some of the cultivated areas were situated above the main farm on a plateau supplied by other conduits. Evenari speculates that the ancient farmers originally divided the slope to capture water and funnel it into fields and later conduits on the plateau were added to harvest further supplies of water. Each field in effect had its own catchment area and so during a good rain event water flow was led naturally to individual fields.\footnote{Evenari, Shanan and Tadmor, The Negev, 104. The effect of (thousands) of these dryland water harvesting farming systems in bare desert must have been quite spectacular with trees and cropping areas which would have stood out clearly against the desert background.}

Each of the farm units studied by Evenari’s team (around 100 in total) had both well defined cropping and water harvesting areas with the ratio between catchment to cultivated fields varying between 17:1 to 30:1 with an average ratio of around 20:1.\footnote{Ibid., 104. Rosen has the standard ratio of catchment area to cultivated field areas at about 21:1 and runoff is calculated at about 15 percent of actual rainfall. Thus an annual rainfall average of 100 mm can be turned into over 400 mm of water for field areas. See Rosen, The Decline of Desert Agriculture, 51. Pacey and Cullis talk about availability of water being much influenced by this ratio of catchment area to cropping areas which in a drylands region may be from 10:1 to 30:1. In areas where average annual rainfall is around 500 mm the ratio may be as low as 5:1. See Pacey and Cullis, Rainwater Harvesting, 144. The farms described by Evenari had much lower rainfall averages.}
These farms were adapted to relatively light rainfall events and harvesting runoff was made possible by the nature of the loess soils which characterize this desert region. When it rains these soils form a crusted surface which quickly becomes impermeable to rain allowing runoff to proceed with minimal rainfall.\textsuperscript{124} Yearly rainfall in this region can be as low as 25 mm with an annual fall of 150 mm being considered a good average year. But the formation of soil crusts allows even a minimal rainfall event to supply large quantities of water harvested from a catchment area many times the size of the cropping area.\textsuperscript{125}

Evenari calculated that total runoff was the equivalent of about 15-20 percent of total yearly rainfall with some variation depending on the intensity of rain events and the nature of the catchment area. Thus according to Evenari’s calculations 10-20mm of annual rainfall of 100mm could be utilized as water for plant production. This translates into each hectare of catchment potentially yielding 100-200 cubic metres of runoff water with 1mm of rainfall across a catchment area of one hectare providing in total an average of 10 cubic metres of water. With a ratio of 20:1 a hectare of farmland harvesting water from a sloping area of 20 hectares would receive 2000-4000 cubic metres of runoff water as well as 1000 cubic metres in the form of direct rainfall. Theoretically this means that cultivated fields would have a total water supply equivalent to 300-500mm of annual rainfall despite rainfall only measuring 100mm for the year.\textsuperscript{126}

\textsuperscript{124} Ibid., 109. The loess forms a cryptogamic soil crust. Warren describes regions with limited rainfall as having enhanced runoff potential as surfaces and slopes have little vegetative cover and are prone to crusting and so shed more rainwater than wetter climate surfaces with considerable vegetative ground cover. See Warren, \textit{Land Degradation}, 452-453. Pacey and Cullis suggest that clay soils are well suited to runoff systems. Sandy soils may allow rapid soil infiltration without sufficient moisture storage to grow a crop. See Pacey and Cullis, \textit{Rainwater Harvesting}, 141.

\textsuperscript{125} Other authors propose that runoff farming is practicable in regions with average winter rains of around 100 mm and summer rains of 250 mm with the suggestion that water harvesting can be used in dryland areas with rainfall averages of 100-300 mm. See Theib Oweis, Ahmed Hachum, and Jacob Kijne, \textit{Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas} (Colombo, Sri Lanka: ICARDA, IWMI, 1999), 2. But Evenari’s research would seem to suggest that dryland regions with biological soil crusts can see productive water harvesting at much lower rainfall rates.

\textsuperscript{126} Evenari, Shanan and Tadmor, \textit{The Negev}, 109. These calculations are again also based on the runoff characteristics of loess soils and their ability to form rapid crusts so enhancing runoff flow. Oleson makes the point that the drylands of Provincia Arabia saw grain production with annual rainfall of 75-100 mm through the use of water harvesting techniques designed to harvest infrequent precipitation. See Oleson, \textit{Irrigation}, 183.
Evenari distinguishes the third type of system namely *diversion systems*, as being larger and more complex to engineer than the two systems already mentioned.\(^{127}\) Diversion systems dealt with flash floods down large *wadis*. Evenari located fewer of these larger engineered systems which were sited *only adjacent to the few main wadis*. One such system was found at *Wadi Kurnub* about two kilometres south of the ancient town of Kurnub. Ancient farmers here put in a series of terraced fields around 10 to 12 hectares in size and a large diversion channel was built where the *wadi* came out onto flatter land (*the Tureibe plain*) which took part of the floodwater to the fields. The drainage basin of this system measured 27 square kilometers. The original diversion dam across the *wadi* has long disappeared but Evenari speculates about its construction suggesting that it could *have been a simple rock structure which raised the water 30-50 centimeters into the channel*. The field systems however were relatively well preserved and the diversion channel which led to them was constructed out of solid stone with a width of 9.5 metres and a total length of 400 meters following a gradient of 1:2000. The terraced fields had a gentle gradient of 2:1000 to 4:1000 with surplus water from each terraced field flowing to the next lowest field through drop structures.\(^{128}\)

Despite the size of their catchments Evenari suggests that the water harvesting efficiency of these larger systems was quite low. The watershed area at Kurnab at 27 square kilometers would have produced roughly 20,000 to 30,000 cubic meters of water in an average year to cultivated areas of about 10-12 hectares. This amount constitutes *less than 2 percent runoff of the annual rainfall on the large watershed since 100 millimeters of rain on the 27 square kilometers gives 2,700,000 cubic meters of water and this was spread over the 10-12 hectares*.\(^ {129}\)

---

\(^{127}\) *diversion systems necessitated the building of large, intricate structures*, Evenari, Shanan and Tadmor, *The Negev*, 110.

\(^{128}\) Ibid., 110. A diversion system takes water to terraced areas using a dam to divert flow to conduits which conveyed water to cropping areas. Spillways able to handle large flows of water were part of such systems with dams constructed to raise part of the floodwater out of the *wadi* to *diversion canals* leading this water to cultivated areas. Ibid., 118.
The conduit systems here closely resemble the earlier Nabatean systems mentioned at both Petra and Humayma. At Wadi Kurnub runoff water was transported over very difficult rocky terrain and where the conduits traversed the wadis small stone diversion dams diverted additional runoff...into the conduits leading to the terraced fields below. In one area a stone aqueduct was found which took water over a tributary wadi. In later times nomadic Bedouin made use of the fields between the dilapidated terrace walls probably for opportunistic barley crops.

Evenari comes to the conclusion that the ancient agricultural practises of exploiting large catchments was a miscalculation leading to erosion, silting up, and destruction because this approach to cultivation of the desert was over ambitious.

There is no question that maintenance would have been an issue with such large systems. Evenari makes the point that the total size of a diversion system could comprise an area of hundreds of hectares. Prinz proposes that such systems were labour intensive because of initial construction of the system and the maintenance of

129 Ibid.,112. The large diversion system at Ma’rib (described below) was certainly efficient and endured for hundreds of years but Evenari’s main point is that the smaller watershed systems are more efficient with a 10-20 percent runoff average compared to the 2 percent from the larger system. Nevertheless the main diversion channel at Kurnab would have been able to transport very large quantities of water. Evenari calculates that over a 10-hour period this channel could carry a depth of flow of 40 to 60 centimeters and that the Kurnab system having a watershed of 27 square kilometers would supply about 20,000 to 30,000 cubic meters per year to the 10 to 12 hectares of cultivated terraces. Ibid., 112. As we have seen with the early Mesopotamian systems, unmanaged silt here also could be problematic. The Kurnab system appears to have been worked over a considerable period of time with traces of three distinct sets of walls superimposed on each other. The oldest of these systems was put in prior to the wadi eroding into a gully cutting through the alluvial soils. Thus the original walls served to manage water flowing through a relatively shallow entrance onto the flat plain. These walls would have held back accumulations of alluvial silt in the terraces areas raising them over time. Early wall construction here appears to have been to merely spread water through cultivated areas on the floodplain. However at some subsequent period possibly because of flooding or perhaps the site being abandoned, the walls were destroyed leading to further erosion and the wadi becoming much deeper probably up to several metres below the floodplain. Subsequent farmers had to put in walls to dam the wadi so raising water levels and flow into terraces areas. Evenari found that the elevations of the terraces were continually rising and this was due to silt accumulation forcing farmers to begin using the lower sections of the diversion system itself as fields which comprised about 3 hectares supplied by water from two small watersheds 35 hectares in size, situated on the ridge adjoining the farm and no longer from the original water source of Wadi Kurnab. Ibid., 112-113.

130 Ibid.,113.

131 Ibid., 414-415.

132 Ibid.,110.
conduits and dams and suggests that contemporary labour was cheap. Though it is probable that Nabatean farming systems relied on slave labour and capital from their extensive trading networks.

**Old Dryland Dams and Diversion Systems**

Despite Evenari’s appraisal of the possible inefficiency of the large systems looked at in the Negev Desert, the fact remains that many of the large water harvesting systems in dry regions of the Middle East were once used to capture useful quantities of water from ephemeral *wadi* runoff and furnished good water supplies for agriculture. Dams were used to hold up rather than store water and in this sense they were also diversion systems.

The region of modern Yemen has a long tradition of irrigation. During the period of the British Protectorate the British Department of Antiquities based in Aden looked at many of these old water systems which consisted of canals, sluices and distribution systems and there is no question that the Sabean farming system at Ma’rib is unique. Much of it has been preserved and the large cultivated areas were irrigated from a single dam located at the edge of *Wadi Dhana*. The dam had the function of raising flood water to the same level as the main outlet sluices which took water to large cultivated areas of around 9,600 hectares divided into a northern and southern sector. *Wadi Dhana* has a catchment area of 8,300 km² and is situated within the

---

133 Dieter Prinz and Amir H. Malik, *Runoff Farming*, Karlsruhe, Germany, 2000, 14. Oleson also points out that aside from the cultivation of crops and building and maintaining water distribution systems there was always the unpredictability of serious flooding events from which crops had to be protected. See Oleson, *Irrigation*, 188-189.


135 The first recorded dam built in this region was the Sadd-el-Kafara dam which appears to have been built in *Wadi Garawi* which is a dry tributary of the Nile around 2650 BC to probably protect cultivated areas and settlements in the lower parts of the *wadi* and in the Nile valley from large scale flooding. It was constructed out of rubble, gravel, rocks and large blocks and the fully constructed dam would have been stable even by modern standards but it was hit by a major flood event probably before completion which could have generated a catastrophic flood wave down stream. Garbrecht estimates that the construction of the dam would have taken between 10-12 years and suggests that the loss of the dam due to a major flood event so devastated contemporary Egyptian engineers that another such dam was not built for about 1,000 years when the Quatinah Dam was built on the Orontes probably by Sethi I (1305-1290 BC). See Garbrecht, *The Sadd-El-Kafara*, 6 -16.

eastern Yemeni Mountains and has been described as one of the largest wadis watering into the South Arabian desert Ramlat as-Sab’atayn. 137

This was a large sophisticated system with water in distribution canals kept moving by excess flow being directed to the edge of the cultivated areas and then directed back into the wadi by means of well-built drop structures which protected the cultivated land from erosion. Brunner describes the main northern canal as being still visible for a length of over one kilometre to the beginning of the cultivated area. (Northern Oasis.) This canal has 15 outlets leading to secondary canals with solid stone structures serving to divert water to other smaller tertiary canals with smaller distributors in the canal sides taking water into the cropping areas. 138

A massive flood event which probably occurred at the beginning of the 7th century AD destroyed much of the dam leaving the extensive cultivated areas above the level of the wadi and in effect knocking out the whole water distribution system. (The cataclysmic nature of the event saw it mentioned in the Koran.) The farming sectors described as gardens and oasis had been in use for hundreds of years but as we have seen with other systems, maintenance and silting would have been problematic. 139

There is evidence of increasing repair work in the 5th and 6th centuries AD with the

137 Brunner, The Great Dam, 169-175. There is good evidence for other ancient cultivated areas in the region. In the Hadramauth and Wadi Beihan large areas have the remnants of large scale desert agricultural system and images produced by a US shuttle flight in 1984 reveal an area of 44,500 ha of ancient irrigated fields belonging to at least ten different systems plus two other large irrigated areas based on wadi systems have been located at Jawf and Hadramawt. See ibid., 170 and Evenari, Shanan and Tadmor, The Negev, 351. Earliest sources of information on southern Arabia are to be found in Herodotus, Strabo, Pliny the Elder and Ptolemy. See Wolfrum and Wolfrum, Dams, 74.

138 Brunner, The Great Dam, 172-176. Scarborough describes these systems as dams which together with reservoirs are employed to slow the flow of water particularly in a flood event. These systems can also raise water levels and allow flow into canals for water distribution into fields. See Scarborough, Water Management Adaptions, 110. Irrigation was critical to the region because geomorphological conditions meant extremely limited water supply. It is unclear if these irrigation techniques were indigenous developments or borrowed from another civilization or culture. See Wolfrum and Wolfrum, Dams, 80. Evenari refers to Ma’rib as a complex water distribution system. Evenari has the 700 metre long dam holding up to 400 million cubic metres of floodwater from Wadi Dhana which he suggests could have irrigated about 20,000 hectares. See Evenari, Shanan and Tadmor, The Negev, 350.

139 Brunner suggests that although dating for the construction of the South Sluice goes back to the sixth century BC, an analysis of silt sediment in the irrigated areas reveals a history of irrigation of the area going back at least to the early second millennium BC. See Brunner, The Great Dam, 174. The relatively well preserved topography of the area means that until recently it was still possible to make out traces of the ancient farming system with signs of ploughing rows, tree rings, tree mounds, roots of former trees or graves well preserved until the 1970s. The region around Ma’rib has average annual rainfall at less than 100 mm. Ibid., 170.
possibility that the southern sluice was closed around the middle of the 6th century and thereafter served only as an overflow. Brunner also suggests that by the late 6th century the dam was partially washed away and had to be rebuilt with the northern cultivated sector also experiencing silting-up near the sluice.\textsuperscript{140}

Elsewhere in this dry region other dams have been discovered near Taif in Saudi-Arabia with very old dam structures found near Medina.\textsuperscript{141} Mohammed al-Hamdan, a medieval scholar of the 10th century lists 80 dams in Yemen some around Zafar, the capital of the Himyarites. Another Arab writer, Hamdani, lists 27 dams mentioned by name and other old water systems can be found at Bainun about 40 km east of Damar where a dam was constructed of cyclopic masonry with the remains still clearly visible today and at Wadi Taiy As-Sabisa, 20 km north-west of San’a, the modern Yemini capital.

Ancient dam structures have also been found at Damar and Yarim and in the Wadi Adra’a situated east of Damar. In Wadi Dodan, situated about 20 km north-west of San’a the ruins of a chain of three dams have been discovered and north-east of San’a at Wadi Ghailan another dam system has also been located.\textsuperscript{142} A substantial number of ruins of old irrigation systems are also found in the Wadi Baihan which was the old Kingdom of Qataban.\textsuperscript{143}

\textsuperscript{140} Ibid., 177. An inscription dated from 449 AD reveals extensive repair work carried out with 14,000 camels, 200,000 (?) sheep, 217,000 pounds of flour as well as 630 camel loads of beverages...needed to satisfy the demands of the labourers. Over two thousand different animals were slaughtered in religious ceremonies. Diminishing economic returns from trade meant that monumental repairs could not be carried out possibly also because of a reduced population. Under these circumstances the final destruction of the dam was probably inevitable. The Sabean culture at this point was in decline with trade patterns (incense) shifting from land to sea routes.

\textsuperscript{141} Henning Fahlbusch, “Ancient Dams in the Kingdom of Saudi Arabia” in Historical Dams: Foundation of the Future Rests on the Achievements of the Past, ed. H. Fahlbusch ( New Delhi, India: International Commission On Irrigation And Drainage, 2001), 245. Some of these dams appear to have been constructed by the Umayyads for farming purposes in the 7th century AD and could have served as storage for irrigation. Though this is not clear. Many of the dams could also have been built for flood protection following heavy rains. Ibid., 271.

\textsuperscript{142} Wolfrum and Wolfrun, Dams,80-85. In the region of Mukeiras about 240 km north-east of Aden on the Audhilla Plateau can be found many inscriptions praising the fertility of the region with mention of irrigation and farming. Ibid., 100.

\textsuperscript{143} Ibid., 101. Both the Qataban and Himyarite cultures flourished in ancient Yemen. Qataban in the second half of the first millennium BC and the Himyarites from the 2nd century to the 6th century AD. Yemen has a very long and interesting history little studied in the West.
The ruins of numerous large reservoirs have been found in Sudan mainly in wadis dating from the Kushite period between the 9th century BC and the 4th century AD. Many Kushite settlements appear to have been formed around wadi systems. Large reservoirs were constructed to harvest runoff during the brief wet season. One example is the reservoir of Musawwarat-es Sufra situated 30 km from the Nile valley in the Wadi-es Sufra. 144

We know very little about many of these old dryland irrigation and farming systems and can only speculate about how they were used and what happened to them. The Southern Arabian kingdoms went into decline through the 4th and 7th centuries AD in large part because of the collapse of the incense trade after 323 AD with the adoption of Christianity by Rome. The Christian Roman world saw a reduction in incense use, a development that would have meant fewer resources available for maintenance of large irrigation installations. Wolfrum and Wolfrum point out that little research has been carried out into these farming systems. They remark that we have scarcely succeeded in fathoming the mysteries of these civilizations. 145

Evenari’s research provides some idea of how these large diversion systems might have worked. Nahal Lavan (Wadi Abiad) had water delivery systems considerably bigger and more complex than at Kurnub described above.

The Nahal Lavan system was according to Evenari possibly the largest of all such systems in the Negev highlands and was located near Shivta. Its drainage basin was

144 Kleinschroth, L. A., "Dams in the Old Sudanese Empire of Kush (Nubia)," in Historical Dams: Foundation of the Future Rests on the Achievements of the Past, ed. H. Fahlbusch (New Delhi, India: International Commission On Irrigation And Drainage, 2001), 221-227. The northern Kushite Kingdom is arid desert with an average of about 30 mm per year though the southern Kushite region can receive up to 200 mm per year. Rain falls in summer leading to flooding in the wadi systems and in the Kushite period this water was used to irrigate fields. Large areas of the uplands of Saudi Arabia can remain without rainfall for years at a time. See Fritz Hartung and Gh. R. Kuros, “Historical Dams in Iran,” in Historical Dams: Foundation of the Future Rests on the Achievements of the Past, ed. H. Fahlbusch, (New Delhi, India: International Commission On Irrigation And Drainage, 2001), 131. See also their discussion of old Iranian dams, ibid., 108-164.

145 Wolfrum and Wolfrum, Dams, 82 and 103. The authors suggest that in this dry region the technological base of hydraulic engineering gradually fell into oblivion.
high up on a plateau but the whole system had fallen into disrepair and unmanaged flooding over time had led to the deep *wadi* cutting into the alluvial flatlands where the old farming areas had been and which contained the remains of *ancient walls, terraces, and canals*. Some of the *canals* ran for more than a kilometre and were 5-10 meters wide and 2-3 meters deep. Evenari studied a 200-hectare section of this large system with a catchment area of about 53 square kilometers.\(^{146}\) He found that different spillways were used as *drop structures* to transport runoff water from the upper to lower terraces and these spillways were of three different types. Some spillways had *crest lengths* of 30-60 meters which could handle water flow *in the range of 10-30 cubic meters per second*. Other spillways of 3-8 meters could have handled flows of 1.5 cubic meters per second with smaller spillways up to one meter wide for flows of less than 1 cubic meter per second.\(^{147}\)

The larger spillways (probable flow of between 10-30 cubic meters per second) appear to date to an early period before the erosive effect of flood impacted the *wadi*. The extent and size of this system only became clear from aerial observation which revealed that large stone spillways *were connected to faint lines* on the ground which had once been earth embankments constructed *to spread the runoff water across the wide floodplain* with field areas located between the embankments. Evenari makes the point that these spillways were capable of handling floods of up to 100,000 cubic meters per hour.\(^{148}\)

There is no question that silt from the extremely large catchment area together with erosion in the *wadi* would have ended up in cropping areas. Subsequent increases in soil levels necessitated higher terrace walls. Evenari puts the case that farmers here *were perpetually faced with the problem of erosion and deposition* with walls having to be continuously raised to combat both *wadi* erosion and silt deposition in

---

\(^{146}\) Evenari *et al* 1982, p 114. Like *Wadi Kurnub* this system has been changed and adapted over different historical periods. Evenari describes this as *the super-imposition of many systems one upon another*. Woolley and Lawrence observed that *the whole plain showed traces of ancient cultivation*. See Woolley and Lawrence, *The Wilderness of Zin*, 8.

\(^{147}\) Evenari, Shanan and Tadmor, *The Negev*, 114-118. Evenari says here that all these *canals* *led to ingeniously devised distribution structures which divided the flow into as many as seven secondary canals*.

\(^{148}\) Ibid., 118-119. These large volumes of water were directed to the cropping areas on the plain. Evenari refers to this as *waterspreading in wide floodplains*. 

---
terraces.\textsuperscript{149} Evenari’s team found evidence of 6-metre high walls constructed along the \textit{wadi} banks almost certainly built to mitigate against damaging flood waters. Evenari records that this task appeared fruitless over time leading to the systems final stage where smaller \textit{runoff farm units were superimposed on the diversion systems}.\textsuperscript{150}

Evenari suggests that the middle stage of this large system dated to the Nabatean and early Byzantine period because of the quality of wall construction and \textit{the high engineering skill required to design and construct these diversion systems}\textsuperscript{151} and this is consistent with Nabatean expertise at blocking the entire width of a \textit{wadi} or valley across a water course to make use of large flows during flooding periods.\textsuperscript{152}

Woolley and Lawrence had been impressed with the solid dam structures at \textit{Wadi Kurnub} which were almost certainly Nabatean in origin.

\textit{The two upper dams, serving their purpose, are buried in the soil that they have retained...the lowest dam is 24 metres long, and 11 metres high; its front is strongly battered, but even so, the width at the top is 7.80 metres. The face is of finely-cut aslar stone, set in hard lime, packed behind with lime and boulders; the top, over which crossed the road, was paved with layer upon layer of flints set in lime, a concrete as hard as the rock itself. A few stones have been dislodged from its edge, and the masonry of the front is deeply}

\textsuperscript{149} \textit{Wadis} here suffer from an erosion process sometimes referred to as “down-cutting” with high velocity flow levels over time leading to \textit{wadi} entrances to flatter plains being metres below field levels. This also occurred at \textit{Ma’rib}.

\textsuperscript{150} Ibid., 118-119. Evenari’s archaeologists did not \textit{excavate} these systems \textit{in situ}. Evenari though offers some evidence for dating based on potsherds found in the vicinity of the diversion systems. Potsherd finds came from four periods, namely \textit{M.B.1} (Middle Bronze One), \textit{Israelite, Nabatean-Roman-early Byzantine and late Byzantine}; roughly a period covering 1000 BC to around the 7\textsuperscript{th} century AD.

\textsuperscript{151} Ibid., 119.

channeled by the falling water, but the dam is still almost as solid as when it was built.153

But there are many imponderables with these large systems. We do not know the size of the labour force necessary to maintain them in good working order though evidence from Ma’rib suggests a large number of workers were critical. (see footnote 140 above) If Shivta was a religious centre indicated by the number of churches and religious buildings found there then there may well have been a communal labour force of monks.154 Elsewhere slave labour when available would probably have been important. There is no disputing however that these large water-harvesting systems provided substantial quantities of water for human populations and for crop production in what are extremely arid regions.

Cisterns

Ancient cultures often made use of cisterns to store water with collection at the point of use obviating the need for transport systems. In dryland regions the storage capacity of cisterns extended water availability for farming and human needs. Covered or sealed cisterns minimized loss to evaporation, a critical element in a hot desert climate.

153 Woolley and Lawrence, The Wilderness of Zin, 165. The second dam was situated 51 meters upstream and was 20 meters long and 5 metres across at the top and was buried in silt and built in a similar fashion to the one described above. The third dam was 53 meters long and 3.4 meters wide at the top.

154 There is some evidence that these water systems were communally maintained. Potsherd inscriptions discovered at Shivta reveal that inhabitants contributing to the upkeep of the water systems were presented with a receipt testifying to their efforts by the local governing body. One such example states to Flavius Gormsson of Zachariah, You have completed one corvée (turn of duty) for the reservoir. Written on the 25th Dios in the 9th Indication. See Evenari, Shanan and Tadmor, The Negev, 171.
Construction was usually of masonry which could be lined with waterproof cement and ancient design sometimes had stone steps descending to the cistern bottom facilitating maintenance and allowing access when water levels dropped. The early Bronze Age (c 5000 BC) period saw cisterns being used in Wadi Faynan for water storage as part of larger systems which made use of check dams, deflection walls, field systems and terraces used for the purpose of floodwater farming. Cisterns were in effect integrated into larger systems. Cisterns could also be lined with an impermeable coat of lime mortar which began to be used near the end of the second millennium with increased possibilities of settlement independence.

The earliest open cisterns in the Negev had runoff water inlets at the top of the structures with later cisterns having roofs that had inlets on the side of the excavation. Evenari suggests that this was due to these cisterns being sited usually at the junction between two different geological strata which was composed of roughly a one meter hard limestone stratum overlying a soft chalk layer. Some of these early open cisterns had stone steps to allow extraction of water by hand when levels dropped and some had overflow channels which would take excess water from a full cistern to terraced fields.

In a wadi near Avdat, Evenari discovered thirteen cisterns next to each other which were connected to a large catchment area of about 60 hectares and serviced from channels that came down and around the hillside to the cisterns. Cisterns here were of different sizes and shapes with water holding capacities varying from 10-20 cubic meters up to 100 cubic meters. Evenari suggests that the primitive construction here

---


157 Kenyon, Archaeology in the Holy Land, 242. Some cisterns were sealed with plaster. In the Negev, cracks in cistern walls and floors were packed with small stones and pebbles and then walls were plastered with mortar. See Evenari, Shanan and Tadmor, The Negev, 159.

158 Evenari, Shanan and Tadmor, The Negev, 159. Stone lined ancient Israelite open cisterns with silt traps are the earliest large scale water holding systems in the Negev and scores of open cisterns of this type have been discovered here.
predate Nabatean settlement and estimated that total water holding capacity of these thirteen cisterns was around 1000-1200 cubic meters.159 (Some of these structures still filled with water despite their poor condition and were used by the Bedouin).

Roofed cisterns constructed out of rock are classified by Evenari into hillside cisterns, public town cisterns and private domestic cisterns. All of these cisterns were quarried out of soft limestone and had runoff collection conduits leading to them with silt traps at inlet points.

Roofed cisterns are a later development and were excavated out of rock using metal tools and date from the Nabatean period when the population of the Negev region substantially increased.160 Finlayson et al. describe how Nabatean settlements were serviced by such cisterns which were cleverly cut into bedrock near natural catchments with rock channels used to collect runoff water.161 At Petra the Nabateans used these cut-stone reservoirs to store water with later Nabatean cisterns at Humayma often cut into the sandstone bedrock.162

Altogether Evenari found hundreds of hillside cisterns in the Negev with the majority of them being filled with runoff from small watersheds and not from main wadis. Some of these pillars had heads carved into them, often bull heads, which enabled dating to the Nabatean period. Size and storage capacity varied with a usual floor area

159 Ibid., 166

160 Ibid.,159 and 166. The actual excavation of these roofed cisterns was out of the soft chalk with the harder limestone layer acting as the roof with the inlet inserted through the side wall composed of the softer rock.

161 Finlayson et al., Archaeology of Water Management, 211.

162 Eadie and Oleson, Water Supply Systems, 56. See also Abdulla and Al-Shareef, Roof Rainwater Harvesting Systems, 197. Umayyad desert palaces used below-ground cisterns as did crusader castles and traditional village homes in the Middle East. It has been speculated that Nabatean merchants could have studied Greek cistern design in the Aegean islands such as Delos which led to similar Nabatean designs with transverse arches supporting roofs for much larger sized cisterns. See Finlayson et al., Archaeology of Water Management, 212. Delos has a dry climate where the central courtyard of homes had large cisterns under them taking runoff from roofs. Water could be easily obtained from a well-head in a corner of the courtyard. Ampuria founded in 575 BC by Greek colonists out of Phocaea had many household cisterns for domestic water supply. See Wikander, 22. Minoan palaces and villages made use of rainwater harvested from roofs and courtyards into cisterns. See Sklivaniotis and Angelakis, Water for Human Consumption, 660.
covering 36 square meters and a depth of 4-6 meters. Larger cisterns had roof supports made from leaving pillars of the soft chalk of 1-2 square meters.

Evenari cites an example of one such cistern located about a mile from Avdat. The cistern could be filled with water either from the adjoining wadi (Nahal Zin) or the slopes surrounding the site. A large flood in this wadi could see water levels 1.5 meters above the wadi floor allowing water to enter through the cistern inlet plus a long runoff-collecting conduit constructed on the adjoining hillside also took water to the cistern.\footnote{Evenari, Shanan and Tadmor, \textit{The Negev}, 159-166}

Town cisterns in the Negev were also usually excavated out of rock supporting a limestone roof held up by pillars. Water was harvested both within the town and from surrounding catchment areas and transported through the streets to silting basins to then enter cisterns through an opening in the cistern roof. Cisterns were found attached to the Byzantine churches at Avdat and Shivta. Evenari describes the North Church in Shivta where a water conduit conveyed runoff from catchment areas outside the town to a series of division boxes, underground channels, and cisterns. This conduit was constructed over approximately a 4-kilometer length outside the town walls.\footnote{Ibid., \textit{The Negev}, p166.}

Woolley and Lawrence in their discussion of Shivta describe large reservoirs in the middle of the town with countless cisterns and everywhere were runnels and long banks of earth and stone to catch the rainwater and to carry it to the tanks. One reservoir in the centre of the town is described as a great double reservoir of irregular shape open to the air, with sides of mason and of rubble concrete; each of the two basins has steps leading down into it. The northern streets drained into the reservoir.\footnote{Woolley and Lawrence, \textit{The Wilderness of Zin}, 91. The largest town cistern discovered in Shivta did not appear to be covered with a roof. Evenari refers to it as an open resevoir which had area of about 300-400 square meters with a 4 meter depth level. See Evenari, Shanan and Tadmor, \textit{The Negev}, 166. Segal in describing a private dwelling at Shivta talks about a sophisticated system of runoff channels which drains water from the entire exterior of the house and its different levels into a}
Cisterns connected to private homes were also fairly common. These were always built within the home itself and in towns took their water from the roofs and streets. Individual homes outside towns (Evenari refers to them as farmsteads) had cisterns which harvested water from hillside catchments. Most of these were dug out below the floor and were bottle shaped having a narrow throat about 1 meter in diameter and widening at the bottom to 3 to 4 meters suggesting a Nabatean design. The individual house cisterns found by Evenari had an average storage capacity of 5-10 cubic meters which was probably sufficient for the domestic requirements of a family for a period of one year.

Qanats

Qanats are a historically rich and old traditional method of moving water and using it productively for farming and domestic human use in dryland regions when rain often falls in winter only. Over very long historical periods of time qanats have functioned as water delivery systems and although the original history of these systems appears to be lost, a Persian source is often attributed to their invention. Hartung suggests that the Iranians appear to have invented qanat systems in the Late Neolithic Period


166 Evenari, Shanan and Tadmor, The Negev, 171. Nabateans rock-cut cisterns were often constructed in a bottle shape with a diameter of 3-4 m, the narrow entrance hole acting to minimize evaporation and the risk of pollution, such as from animal faeces entering the water. See Finlayson et al., Archaeology of Water Management, 211.

167 Evenari, Shanan and Tadmor, The Negev, 171. Masada provides an illustrative example of the storage capacity of large cisterns in an essentially bare desert environment. It would seem likely that the ingenious water systems here were much influenced by older Nabatean hydrological expertise. Two quite small wadis to the north and south of the plateau where Masada is situated, had dams with open channels allowing dam water to gravity flow to the extremely large cisterns. Two cisterns were served here with an estimated capacity of over a million cubic feet. When periodic flooding down the wadis occurred these cisterns would fill quite rapidly providing ample water storage for dry periods. Yigael Yadin (Professor of Archaeology at the Hebrew University of Jerusalem) describes floods down the wadi systems after drought years. Torrential rains which burst from the skies without warning filled the ravines in a flash…we witnessed a rare natural spectacle when the two wadis which had supplied the water to the Herodian channels serving the cisterns suddenly filled up and burst their banks…If the aqueducts had been in good repair, all the cisterns excavated in the slope of the Masada rock would have filled up in only a few hours. See Yigael Yadin Masada Herod’s Fortress and the Zealots’ Last Stand pp.21-32 CARDINAL ed. pub. 1973, Sphere Books Ltd.
because of a lack of water resources. Groundwater supplies were tapped and this clever system spread throughout the region.\textsuperscript{168} Though it is possible the qanat technique could also have derived from ancient mining operations in the mountainous regions of Kurdistan. Hussain describes qanats as \textit{historically vital sources of water for multiple uses in the driest parts of the planet}\textsuperscript{169} and many old qanat systems are concentrated on the Iranian plateau around the Iranian Central Desert with some possibly over 3000 years old.\textsuperscript{170} The Achaemenian period (c.625 BC) in Iran (Persia) saw this water technology being exported to Egypt and qanats were deliberately destroyed during the Parthian period (205-212 BC) to hinder Roman advances.\textsuperscript{171}

As an ancient hydrological system qanats have many fine attributes. Evaporation is minimal and water flow does not diminish groundwater supplies. In Iran qanats traditionally transported water from the base of a mountainous area or from an aquifer. Often an underground tunnel or a series of tunnels would bring the water to

\begin{itemize}
  \item \textsuperscript{168} Hartung and Kuros 2001, p109 in Fahlbusch. Qanat systems are a paradox in that they are quite widely known and are ancient in origin but are still being used in parts of Central Asia and Iran (see below pp. 83-83) though their use has been reduced somewhat over the last 50 years largely because of lower ground tables, water, pump technology, rapid population growth and centralized water management policies. Hussain et al suggest that qanat systems have suffered decline particularly over the past 50-60 years because of various physical, social, economic and environmental reasons. See Hussain et al, 337. With regard to the decline of qanat systems in Iran, Professor Fred Ghassemi states \textit{my general understanding is that because of the significant drop in groundwater levels all around Iran, since the Iranian Revolution in 1979, there should not be too many qanats left active. (Email correspondence from Professor Fred Ghassemi.)}
  \item \textsuperscript{169} Intizar Hussain et al., "Revitalizing a Traditional Dryland Water Supply System: The Karezes in Afghanistan, Iran, Pakistan and the Kingdom of Saudi Arabia," \textit{Water International,} 33, no. 3 (2008): 333. \textit{Qanat} is an Arabic word, the Persian term is \textit{karez}. Documents from 6\textsuperscript{th} century BC Persepolis clearly mention a \textit{karez} system. See Scarborough, \textit{Water Management Adoptions}, 199, 109. Though the word \textit{qanat} appears to come from an ancient Semitic word meaning \textit{to dig}. See Seyed Ali Hosseini et al., "Effect of Urban Sprawl on a Traditional Water System (Qanat) in the City of Mashad, NE Iran," \textit{Urban Water Journal,} 7 no. 5 (2010): 310.
  \item \textsuperscript{170} Hartung and Kuros, \textit{Historical Dams in Iran}, 116. The qanat of Jopar near Kernan (south east Iran) is thought to have been in use in 1200 BC. Qanats in north-western Iran date to around 800 BC. See Mahmoud Jomehpour, “Qanat Irrigation Systems as Important and Ingenious Agricultural Heritage: Case Study of the Qanats of Kashan, Iran,” \textit{International Journal of Environmental Studies,} 66, no. 3 (2009): 297.
  \item \textsuperscript{171} Jomehpour, 297. The Median capital Ecbatana in the seventh century BC had its water system based on qanats as did Persepolis.
\end{itemize}
an oasis. Subterranean tunnels could run over several kilometers to cropping areas with water flow being gravity fed so duplicating natural flow hydraulics. Qanat design incorporated local rainfall patterns with longer tunnels in drier regions with deep wells and shorter tunnels in regions with high rainfall and shallow wells. Considerable infrastructure was invested in these systems with vertical well shafts put into tap flowing groundwater which could be up to 30 metres below the surface level. These shafts also functioned as air passages and were used for repair work. A qanat system ends with a horizontal tunnel on a slight inclining slope which transports the water to the surface.

Qanats could facilitate the supply of water over potentially large tracts of land in a dry climate for cropping and other purposes. Water was available throughout the year with variance in the flow regime in different seasons. Small reservoirs could be constructed to store water for periods of scarcity and many of these systems could be found in Iranian dryland regions where annual rainfall is no more than 150 mm. Jomehpour suggests that qanats were the only means of using water for several centuries, and have contributed to the forming of civilizations in these harsh climatic conditions.

Viollet describes old qanat systems around Palmyra, Damascus, Homs, Hama and Aleppo. These water systems appear to have been highly regulated with water allocations for users with ten-day irrigation schedules being common in the Muslim

\[\text{\cite[172]{Hussain et al., Revitalizing a Traditional Water Supply, 333-334. Authors also distinguish between mountain qanats taking water from mountainous areas and plain qanats which take water from a river system. A qanat source of water resources can be in local hills or mountains several hundred miles distant. But a critical factor here is the ability of the source system to recharge. Annual use cannot be in excess of annual recharge or the qanat system will dry up. This critical principle can also be applied to other hydrological systems where water is extracted without knowledge or due care about recharge rates which will often fluctuate annually depending on rainfall.}}\]

\[\text{\cite[173]{Jomehpour, Qanat Irrigation Systems, 299. Qanats were also used to power water mills for milling flour. The qanats of Bagh-e-Fin (Fin Garden) in Kashan have 75 water mills along the length of the qanat system. Water mills could be constructed when there was a fall of about 5-6 m between the point of collection...and the point of water discharge. Kashan is one of the oldest settled areas of Iran with archaeological evidence for some of the oldest qanats. The qanat at Yazd appears to have the greatest length of 120 km. The Kaykhosroo Qanat of Gonabad has a mother well going down 400 m and the qanat of Ardestan has two stories and an underground dam. History in Kashan goes back to the Sialk civilization of 7000 years ago. See Jomehpour 2009, 298.}}\]

\[\text{\cite[174]{Ibid., 298.}}\]

52
world. However qanats have been found in many other dry regions of the planet including China (the Turfan oasis in the Xinjiang region), Baluchistan, southwest Afghanistan, Turkmenistan, Libya, Saudi Arabia, Jordan, Egypt, Syria, Tunisia, Algeria, Morocco, southern Spain and in other countries. The introduction of this system into Spain through the Muslim conquests almost certainly explains the systems later use in Mexico, Peru and Northern Chile. Evenari and his team found qanat systems in the dry desert region about 30 kilometres north of the Israeli port city of Eilat with other qanat sites on the Jordanian side of the border. Potsherds from these sites indicate both Persian and Roman sources suggesting that at least some of these systems were put in place during the Persian occupation of Palestine (537-332 BC). There is also the possibility that Jewish exiles returning from Mesopotamia brought the technology with them.

Patterns of ecological degradation

It is important to provide the land context of some of these old water systems with patterns of deforestation, land degradation and inappropriate water supply schemes in regions that once had flourishing farming cultures made possible by clever water harvesting systems. Many of these regions are now barren and knowledge of the old water harvesting systems has either been forgotten or marginalized by modern central water authorities.

175 Violett, Water Engineering, 203. In Syria qanats were called foggaras. Violett remarks that qanats are costly devices that provide copious quantities of water. Qanat systems to the north of Damascus had irrigation periods every 12 days with two-hour water allocations before dawn and two hours after sunset. At Hama weekly schedules were employed with water distributed to cropland, mosque fountains and public baths.

176 Hussain et al., Revitalizing a Traditional Water Supply, 336. In China there are about 100 qanat systems in the Turpan region with a total length of 5000 km dating back to the Han Dynasty (206 BC-220 AD). The oasis at Turpan was a well established trade centre on the northern Silk Route. Qanat technology appears to have spread out from Iran to North Africa, Spain, Cyprus, Sicily and elsewhere in the region. See Jomehpour Qanat, Irrigation Systems, 298- 299.

177 Scarborough, Water Management Adaptions, 109.

178 Evenari, Shanan and Tadmor, The Negev, 178.
The dryland regions of the Middle East and Africa can be quite fragile and can suffer dramatic declines with the removal of tree cover and the establishment of large irrigation schemes which may be appropriate in temperate zones but are less so in dryland regions.

Old methodologies of water harvesting seen in this important context could be useful in restoring what were once biologically diverse ecologies which often supported productive human cultures over long historical periods of time.

It is perhaps difficult to quantify the great loss of forest cover across many areas of the planet. Old mixed forests are biologically rich in plant, animal, bird and insect species and traditionally provided a variety of resources to human populations. There is debate about the extent of rainfall variations over the Holocene period. There is however no debate about human activities dramatically changing landscapes with deforestation probably leading to reduced rainfall levels in the Middle East.

We still know relatively little about what are sometimes regarded as the large hierarchical systems on our planet but it seems probable that forested regions can also impact on climate, rainfall patterns and so availability of water. Certainly early Holocene forests were widespread and were later to be impacted by settled human populations, tree felling and grazing animals.\textsuperscript{179}

In the region of the Mediterranean land degradation and loss of tree cover goes back thousands of years. The Phoenicians appear to have deforested large tracts of land including hill country for timber used in ship building, temple construction and ore smelters. Though records have the cutting of Lebanese cedars (*Cedrus libani*) dating back to 2600 BC with Egypt importing this valuable timber for temple construction and for resins employed in the mummification process. Little of the once great stands of Lebanese cedar now remain.\(^{180}\)

In different parts of the Near East tree pollen analysis from around 6,000 years ago indicates a range of species were to be found including *Juniperus, Pinnus, Ulmus, Olea* and *Quercus* but much of this was soon to disappear.\(^{181}\) Kenyon suggests that the countryside of Palestine has never recovered from deforestation which began with the introduction of bronze tools used for the cultivation of expanded crop areas and tree felling. Kenyon goes on to suggest there is evidence that very considerable deforestation had taken place during the Early Bronze Age. At Jericho and Tell el Far‘ah there is evidence of good supplies of timber once being available with many examples of burnt roofing of wood construction as well as timber having been used in lacing town walls over several periods.\(^{182}\)

Smith *et al* describes the impact of Roman-Byzantine copper mining in what is now Jordan which occurred around 2,000 years ago when millions of tonnes of wood would have been needed to support smelting activity in Wadi Faynan with the suggestion

---

\(^{180}\) H. E. Dregne, "Magnitude and Spread of the Desertification Process," in *Arid Land Development And The Combat Against Desertification: An Integrated Approach* (Moscow: United Nations Environmental Programme, UNEP, 1986), 12. The Phoenician port of Byblos on the Syrian coast had an important harbour for Near East Trade. Lebanese cedar was traded down to Egypt from the port in the 4th millennium BC. See Kenyon, *Archaeology in the Holy Land*, 66. Quite a few old inscriptions record the trade. Cedar was cut and the timber was left to season in the mountains of Lebanon. One such inscription reads *and he put supervisors at their head, to have them cut down the timber. So they cut them down, and they spent the second season lying there.* Another inscription talks about wood being imported from Phoenicia into Egypt for the ceremonial barge of the gods. See James B. Pritchard, *The Ancient Near East, An Anthology of Texts and Pictures*, ed. James B. Pritchard (Princeton University Press: 1958), 21-22 and 16 ff.

\(^{181}\) Smith *et al.*, *From Global Climate Change*, 228.

\(^{182}\) Kenyon, *Archaeology in the Holy Land*, 133-134. Kenyon suggests that timber was scarce in Palestine at the time of Solomon since timber for the construction of the Temple came from Hiram, King of Tyre, though the choice of timber here could also have had something to do with the quality and status of this particular wood (*Cedrus libani*) in the construction of such a building. Overall Kenyon puts deforestation in the region down to the expansion of cleared areas for farming and the expansion of human settlements.
that fuel timber would have been brought from further afield because local sources were severely depleted.\textsuperscript{183} Many sites have been found where there was mining and smelting of copper on both sides of \textit{Wadi Arabah}. These mines would have been of major economic importance. Some of these locations are from the Early Iron Age and Nabatean period and some appear to have been built around large fortified enclosures possibly holding slaves as the main labour force. Kenyon says that \textit{the only source of the fuel for the smelting that can be suggested is that of the forests of Edom, plentiful till comparatively modern times}.\textsuperscript{184}

The Romans annexed Palestine in 63 BC and this period saw Wadi Faynan transformed into a large industrial copper mine complex (ancient \textit{Phaino}) with importation of large numbers of slaves to work the mines. Barker talks of an \textit{imperial landscape} which was \textit{highly organized, with large-scale industrial processing sustained by an integrated agricultural and hydraulic system}.\textsuperscript{185} It was also a highly destructive system. The area was increasingly stripped bare of its tree cover as smelting fuel needs increased. Barker suggests that \textit{by the time of Christ the landscape consisted of very degraded steppe land}. The main \textit{wadi} is now 5 meters below the parallel conduits that took floodwater to the ancient terraced fields that would probably have supplied food for the mines.\textsuperscript{186}

\textsuperscript{183} Smith et al., \textit{From Global Climate Change}, 229. Tree pollen counts at Wadi Faynan suggest that the area was probably forested around 7 to 8 thousand years ago. See Stuart Robinson et al., "A Review of Palaeoclimates and Palaeoenvironments in the Levant and Eastern Mediterranean \textit{from 25,000 to 5000 Years BP: Setting the Environmental Background for the Evolution of Human Civilization}," in \textit{Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley}, ed. S. Mithen and E. Black (New York: Cambridge University Press, 2011), 79.

\textsuperscript{184} Kenyon, \textit{Archaeology in the Holy Land}, 256-257. The Edomites would have traded in copper.

\textsuperscript{185} Barker, \textit{Farmers, Herders}, 78-79. It seems likely that Christian slaves were employed here and there is evidence that they were deliberately crippled or even blinded to prevent escape. The Romans are known to have harnessed the power of water in some of their mining installations using reservoirs built on hillsides above mines. These \textit{hushing tanks} had sluices at one side which could be opened allowing the water to descend rapidly and wash through \textit{large quantities of spoil}. Water flow could also be regulated to a slow trickle for washing ores. The holding tanks were serviced by long aqueducts. See J. G. Landels, \textit{Engineering in the Ancient World}, (London: Constable, 1998), 25-26.

\textsuperscript{186} Barker, \textit{Farmers, Herders}, 79-80. These are the same erosive processes we have seen at \textit{Wadi Karnub} and \textit{Wadi Abiad}. Copper mining and smelting was also highly toxic and would have been a problem for locals. Barker cites the geochemical evidence that this toxicity is still present today.
The Near East is somewhat unique here as we have documentation for the region over very long historical periods of time. *The Epic of Gilgamesh* well records the importance of cedar forests from around 5,000 years ago. Alexander the Great used Mediterranean timber for fleet construction and during the time of the Mamelukes (1250-1517 A.D.) timber in the eastern Mediterranean was considered a *scarce strategic material*. Grainger talks about how many years of tree clearance, grazing and fire have seen the widespread reduction in oak woodlands in Mediterranean regions to be replaced with a *low, shrubby vegetation called maquis*.

The beginning of the 20th century in the region saw trees removed for railroad construction and fuel with the period between 1908-1917 seeing large reductions in forest cover as a result of the building of the Hijaz railway by the Ottomans. Smith et al. describes the construction of the Hejaz rail line in terms of *massive, industrial scale removal of trees by humans*. All of these events contributed to landscapes which are today largely barren desert.

In 1963, Guy Montfort led a British scientific expedition to Jordan. This now little known expedition comprised ecologists, botanists and ornithologists who prepared a report for the then Jordanian government with a focus on *the problems of the ecology and conservation of desert and semi-desert areas*. The expedition found massive loss of forest cover of both oak (probably *Quercus haliprinis*) and pistacia (*Pistachia atlantica*) forests. Mountfort recounts how around the time of WW1 there had been with local Bedouin goat herds containing *significant levels of heavy metals from grazing the polluted ground* and the suggestion that cereal crops grown near the smelting sites are also affected. See Barker in Barker and Gilbertson, 82. Kenyon remarks that *erosion is almost always the result of deforestation*. See Kenyon, *Archaeology in the Holy Land*, 133.

---


189 Smith et al., *From Global Climate Change*, 229.
great oak forests at Shaubak, but the Turks built a special branch-line from the Hejaz railway expressly to remove every tree in the region for fuelling their locomotives.\textsuperscript{190} Montfort records a conversation between expedition member, Sir Julian Huxley and the Mayor of Karak who describes the wildlife which had been plentiful in the region at the early part of the 20\textsuperscript{th} century.

\begin{quote}

in those days we had large forested areas near Karak, but the Turks cut them all down for fuel for their accursed Hejaz railway. One plot of pistacias alone covered 150 square miles. Today- just stumps! When I was a young man the average rainfall here was 600 millimetres. Now we are lucky if we get 100.\textsuperscript{191}
\end{quote}

On a broader regional level, deforestation can reduce biological diversity and accelerate extinction of both flora and fauna\textsuperscript{192} and certainly the British expedition found very high levels of extinction in animal and bird populations. Hunting practices stretching over centuries had eliminated many wild species. The Asiatic lion had gone by the early 15\textsuperscript{th} century and by 1900, Roe Deer, Addax Antelope and crocodiles had disappeared. In the 1920’s The Wild Ass and Fallow Deer had been killed off and the Syrian Bear followed in the 1930s. Jordan’s last ostrich was observed near Jebel Tubaiq in 1932. Oryx were all hunted out by 1950 and there were few if any cheetah left. The Arabian Gazelle (\textit{Gazela arabica}) and the Dorcas Gazelle (\textit{G. dorcas}) had also been hunted to the point of extinction.\textsuperscript{193}

\begin{footnotes}
\item[190] Guy Mountfort, \textit{The Story of an Expedition to Jordan: Portrait of a Desert} (London: Readers Union; Collins, 1966), 102. The expedition employed birds as ecological indicators. Sir Julian Huxley was part of the team which had the blessing and interest of the then King Hussein who believed that \textit{something should be done to arrest the extermination of the unique wild animals of Jordan and their habitats}. Ibid., 19.
\item[191] Ibid., 89. Probably \textit{Pistacia Atlantica}. Mountfort remarks that such a loss of biological capital cannot be restored in less than a hundred years and then only at gigantic cost in labour. Ibid., 102.
\item[193] Mountfort, \textit{Story of an Expedition}, 59. Populations of Long-Horned Arabian Oryx had been severely reduced with animals slaughtered with machine guns and automatic rifles. Cheetah could be found in Jordan and the surrounding region until around the middle of the last century. The ancient Assyrians trained these superb creatures to hunt and regarded them as far superior to hunting dogs.
\end{footnotes}
The region abounds in such episodes. One third of the tree cover in Cyprus had been removed in the 20 years previous to the island being placed under British administration in 1878 through over-grazing and removal of trees for fuel, wood and timber. At the time it is estimated that there were 250,000 goats on the island. Seventy years was required for the Forestry Department to control the goat population through establishing goat-free villages on the forest margins and providing compensation for loss of grazing areas.\textsuperscript{194}

Over the past half century there has been a much greater awareness about losses to the forest systems that once covered the planet. The British forester Percy Stebbing was raising concern in the 1930’s about large-scale deforestation in the Sahel and Sudan\textsuperscript{195} but patterns of forest clearance accelerated throughout the 20\textsuperscript{th} century with consequences that are still not fully understood. Deforestation can have local and regional impacts involving different countries. Tree clearance on important watershed areas can lead to greater flooding intensities, erosion and siltation. Large scale clearing of trees in hill country can have significant impacts downstream.

Gregersen et al. writing in the 1980’s warns that forests are being over-exploited and are disappearing in many countries. The soils in deforested areas are being degraded through improper land use. The impacts of these problems are cumulative and can affect entire regions and nations.\textsuperscript{196}

In the drier regions of the planet loss of tree cover can see land areas reverting to desert. Around six percent of forested areas in the world constituting roughly 230

\textsuperscript{194}Grainger, The Threatening Desert, 98.

\textsuperscript{195}Dregne, 1986, 13.

\textsuperscript{196}Gregersen, Draper and Elz, People and Trees, 14-15. The book is dated and ‘social forestry’ appears to have lost fashion but the text is still an extremely useful account of the different functions of trees and how local communities can benefit from being involved in local forestry projects with the important idea that trees should be integrated more into mainstream farming. Ibid.,11. Grainger suggests that community forestry projects have not been overly successful in dryland regions and suggests as an alternative farm forestry projects. Though such projects in India have come in for criticism for benefiting wealthy farmers at the expense of poorer rural folk. See Grainger, The Threatening Desert, 245-246. According to Malagnoux, Local people should be involved all through the process from conception to the management of the new resources. See Malagnoux, Sene and Atzmon, Forests, Trees and Water, 27.
million hectares can be found in dryland regions.\(^{197}\) Loss of forests in these regions can lead to large-scale reductions in biological capital built up over many thousands of years. Loss of tree cover can also lead to productive farming landscapes being more exposed to the elements.

In dryland areas, wooded areas can help with soil stabilization, provide shade and help manage valuable underground water resources by maintaining water tables. Tree canopy can buffer the impact of heavy rain easing erosion pressures on fragile landscapes. Grainger makes the point that *trees play a crucial protective role in drylands because they prevent the soil from being blown away by wind, and their roots lend cohesion to the soil and protect it from erosion by water.*\(^{198}\)

Deforestation in dry regions is often caused by land clearing for commercial operations such as agriculture and livestock production and demand for forestry products.\(^{199}\) Tree clearing for cash crops is also a major factor with regions in Africa in recent times seeing large areas of land cleared for export crops. Grainger writing in the late 1980s talks about Burkina Faso losing 50,000 hectares of woodland annually, with 60,000 hectares removed in Senegal. In the Kordofan and Darfur provinces of Sudan, 88,000 hectares of woodlands were being removed each year for conversion to mechanized agriculture. An estimated 42,000 hectares of this land had been put out to sorghum continuously for up to 3-4 years and had become degraded and barren, and

---

\(^{197}\) Ibid., 24.

\(^{198}\) Grainger, *The Threatening Desert*, 35. Australia has lost much of its tree cover. The short period of European influence on this continent has seen very large loss of rainforest including temperate rainforest, sub-tropical and tropical species. The rate of destruction has been so rapid that little historical record now remains. The 19\(^{th}\) century Australian poet, Henry Kendall recounts a trip he took on the Clarence River. The extract is from an essay he wrote from the *Grafton Independent* in 1868. *We have since visited many of the most beautiful of the South Sea Islands, but nothing about these far-famed gardens of the world impressed us as what we here beheld. In one or two places, where the channel is contracted, huge Moreton Bay Fig Trees interlaced with gigantic creepers overhang the water, their dark green foliage glittering underneath the day in such masses that only glimpses of sunlight, here and there, can find their way between. Beneath and behind these stately monarchs of the forest, rich clusters of evergreen undergrowth embower a land of fruitfulness that perhaps neither sun nor wind has ever kissed since day first dawned... Through this barrier of leaves and vines the boughs of the larger trees shoot upwards, forming far aloft, a second edition of heavy umbrage... He goes on to describe the great profusion of bird life. Rod Ritchie, *Seeing The Rainforests in 19\(^{th}\) century Australia*. Rainforest Publishing. Sydney. 1989. 85

then been abandoned. Similarly in Mozambique, Tanzania, Zimbabwe and elsewhere in East Africa woodlands have been cleared for tobacco cropping and for fuelwood. Thick stands of *Acacia* woodlands were common around Khartoum in the 1950s but had been reduced to isolated woodlots.

Deforestation causes patterns of fragility in landscapes but also in local cultures. Rural communities can be impacted by lack of fuelwood, timber and a range of other products. Livestock can suffer from lack of shade or browsing when grass is scarce because of drought or the onset of dry weather. At the same time, patterns of natural regrowth are little understood or exploited. A reforestation project in the Abéché protected area in Chad in the early 1960s saw a degraded area comprising just over 300 hectares fenced off with barbed wire. The area had a few existing trees made up of *Acacia radiana*, *A. senegal* and *A. mellifera*. After 45 years of almost continuous protection forested areas could be clearly seen in satellite images.

Grainger proposes the establishment of natural woodlands as opposed to plantations of fast-growing forestry trees with the suggestion that the potential yields from natural woodlands have been underestimated. Natural woodlands can provide a great many harvestable products and this makes them far more attractive to local people than village woodlots. Natural wooded areas can provide fuelwood, poles, fodder, food products, medicines, gums.

---


201 Ibid., p 101. Grainger gives a figure of around 734 million ha of open woodlands on the planet with over 480 million ha in Africa and suggests that this type of forest is being lost at a rate of just under 4 million ha each year. Ibid., 96.


204 Grainger, *The Threatening Desert*, 269-270. Grainger suggests that lack of plantings of tree-based foods possibly lies in the perception of trees being the province specialty of foresters and
Research from Africa shows the extent of harvest possible from a forest system for local households. Yields can include fuel woods, construction materials and wild food including medicinal plants. The Center for International Forestry Research (CIFOR) defined such products as non-timber forest products (NTFPs) which can include fruits, nuts, vegetables, fish and game animals, medicinal plants, resins, fibre plants, bamboo, palms and grasses. Wood is also available as fuel and some species will provide fodder for livestock as well as providing shelter and shade. Trees can also improve farmland productivity by being planted out to fix nitrogen, provide green manure and shelter belts and as windbreaks. Tree plantings can also slow down surface runoff and thus increase rainfall infiltration into soils as well as reducing erosion.

Through the 20th century reforestation schemes occurred in different parts of the world with early projects in France and Germany going back to the 18th and 19th centuries. The United States launched major tree planting projects after the ‘Dust Bowl Crisis’ in the mid - 1930’s and various schemes have been implemented to halt the spread of the Sahara Desert often using Pinus halepensis as the dominant planting species. Millions of hectares of trees have been planted out in China with some of this work aiming to reduce dust storms over Beijing. Such schemes have had differing rates of success with various factors such as species selection, maintenance regimes and protection from browsers impacting on survival rates.

---


206 Gregersen, Draper and Elz, People and Trees, 39. The perspective here is that trees can have multiple functions in the farming systems of nearly all countries.

207 Malagnoux, Sene and Atzmon, Forests, Trees and Water, 27. Mono-cultures of one species have often been the norm in such plantings where mixed species selection is probably more suitable. Grainger writing in the mid-1980s suggests that rates of afforestation have been small compared to the removal of 4 million ha of woodland cleared in the world’s dryland regions each year. See Grainger, The Threatening Desert, 96.
In dryland areas water availability can be critical in establishing young trees and water delivery systems can make major differences to survival and growth patterns. In dry regions tree cover can often be found where runoff accumulates or where groundwater is present. Water availability which includes ground and surface water as well as air moisture can limit the spread of tree cover. Other important factors are rainfall levels, temperatures and wind.

The utilization of water-harvesting systems based on the old systems for the establishment of tree cover in dryland regions could be an important element in any ecological restoration process.

**Patterns of land degradation in dryland regions**

We have seen that in many dryland regions, human cultures once flourished in what are now relatively barren areas, by the utilization of clever water harvesting systems and a knowledge base of the worth of such hydrological systems built up over thousands of years.

Land degradation in these regions can come about from a variety of causes ranging from deforestation to ancient military conquest that can involve abandonment of farming settlements including important maintenance of water supply systems. Land degradation can also involve inappropriate irrigation methods which can lead to salinity.

Landscapes can also become barren and degraded through the overgrazing of livestock and the removal of trees and areas that were once productive can turn into desert. Increasing patterns of sinking relatively low cost tube-wells has seen a lowering of ground water tables in many dryland regions.

---

About 40 percent of the land mass of the planet is considered to be drylands incorporating farming regions, grasslands, forests and urban centres.\(^{209}\) This is an area of about 60 million square kilometers with about ten million square kilometers made up of hyper-arid deserts. More than a third of the world’s population lives in these either arid or semi-arid drylands\(^ {210}\) with Eurasia and North Africa having the largest and most complex belt of arid lands on earth, comprising an entirely interconnected ensemble of hot deserts, cold deserts, semi-deserts.\(^ {211}\)

Landscapes are all too often defined with a climate type that restricts perception of what the area was once like and ignores potential in terms of what the area could resemble after rehabilitation.

Degraded landscapes can be characterized by their low biological diversity which also includes soil life and the myriad different soil bacteria which inhabit land systems. Deterioration in soils is compounded by rain falling onto bare ground without the protective cover of vegetation, mulch systems, crop residues or buffering by tree canopy. Such patterns of land degradation can lead to desertification. It is less important here to debate whether this process is actual than to accept that historically once productive land is now barren desert.

Long term climate change and its impact on such regions is still largely an unknown factor. But the history of the Near East has shown that productive landscapes can become desert-like if rainfall diminishes or water resources are over exploited.\(^ {212}\)


\(^{212}\) Grainger, *The Threatening Desert*, 128. Desertification is described by Grainger as a *global phenomenon which afflicts drylands in more than 100 countries* with the most affected areas being in Asia and Africa comprising between them over 70% of desertified land. Grainger’s research in the 1980s has more than 80% of Africa’s drylands...moderately or severely desertified. The United Nations details the Sudano-Sahelian region as being most impacted by desertification. This is an area stretching from the southern borders of the Sahara Desert (the Sahel) Mauritania, Cape Verde Islands,
Essahli and Sokona offers what seems to be a widely accepted definition of this process which views desertification as land degradation in arid, semi-arid and dry, sub-humid areas due to the combined effects of human activities and climatic variables.\textsuperscript{213}

Dar suggests that loss of vegetative cover can lead to loss of topsoils leaving impoverished soils that make it much more difficult for vegetation to recover leading to permanent degradation.\textsuperscript{214} Grainger lists the main causes of desertification as deforestation, overgrazing, over cultivation and inadequate management of irrigated cropland. All of these elements are compounded by rapidly increasing populations, development patterns and policy decisions by governments.\textsuperscript{215} Dregne categorizes the different impacts of desertification and mentions the loss of vegetative cover for grazing, soil erosion and irrigated farming land being impacted by salinization and waterlogging.\textsuperscript{216} Oweis et al. suggest that degraded dryland landscapes are characterized by overgrazing and removal of tree cover or bushes for fuelwood.\textsuperscript{217}

The patterns are similar and widespread.

Land degradation can also lead to insecurity among dryland populations with increased competition and exploitation of valuable resources such as timber and

\textsuperscript{213} Essahli and Sokona, Policy Requirements, 59.


\textsuperscript{215} Grainger, The Threatening Desert, 105-106.

\textsuperscript{216} Dregne, Magnitude and Spread, 10.

\textsuperscript{217} Oweis, Hachum and Kijne, Water Harvesting, 2.
fuelwood which in turn leads to further land degradation. Social impacts can affect hundreds of millions of people. Essahli and Sokona talk about a *vicious cycle of desertification and poverty*. Dar makes the point that *dryland degradation breaks out in patches where droughts, overgrazing and overtillage strip away the vegetation. This loss of land cover is the central cause of desertification*. Episodes of drought in dryland regions can accelerate these patterns of degradation. Briceno states that

*drought is one of the most serious transboundary and regional natural risks. Often several countries are at risk of drought and famine when hit by severe climate variability. The threat of climate change only increases the need to reduce risk and vulnerability as rapidly as possible.*

During a drought episode overgrazing can lead to the removal of vegetative ground cover in already fragile eco-systems. In the dryland areas of Libya, Tunisia, Iran, Syria, Iraq and the Sahel regions of Africa, overgrazing is a major problem.

---


219 Essahli and Sokona, *Policy Requirements*, 57. The link between desertification and poverty is well established. Essahli *et al.*, writing in 2006 estimated 480 million people across the planet affected by desertification *and one billion who are threatened* with over 3,500 million hectares of degraded land and a further 10 million hectares of arable land deteriorating each year. The authors suggest that the situation of encroaching deserts is particularly bad in Africa where they describe the problem as a *complex multi-dimensional phenomenon with diverse political, social and economic implications that are in perpetual mutation*. Ibid., 57-58. In India desertification impacts on over 100 million ha or over 30% of the country’s total land mass. Durgadas Mukhopadhyay, “Indigenous Knowledge and Sustainable Natural Resource Management in the Indian Desert,” in *The Future of Drylands: International Scientific Conference on Desertification and Drylands Research*, ed. Cathy Lee and Thomas Schaaf (Paris; Dordrecht, Netherlands: UNESCO; Springer, 2008), 162.


222 Koohafkan and Stewart, *Water and Cereals*, 14. Koohafkan and Stewart make the point that *the challenge will be to identify the technologies and policies that enable sustained growth to satisfy the increased demand for meat and milk*. Overgrazing also negatively impacts on soils and eco-systems in Australia, Central Asia, Brazil, Argentina and western areas of the USA. Grainger suggests
impacting negatively on soils and the health of animals and leading to erosion by exposing fragile soils to wind and compaction.\textsuperscript{223}

Many of these fragile dryland areas have seen large-scale irrigation projects in relatively recent times. In 1800 the total irrigated areas around the world was about 8 million hectares which by the late 1990s had increased to around 240 million hectares.\textsuperscript{224} Dryland regions have abundant sunshine and temperatures that suit a diverse range of crops making such schemes attractive. Dar suggests that \textit{some of the most productive agriculture in the world is in dryland areas}\textsuperscript{225} and this has attracted large irrigation schemes often for cash crops such as cotton or groundnuts (\textit{Arachis hypogaea}) which can form important components of national economies. Grainger maintains that extensive groundnut production contributed to desertification in Niger and Sudan through the 1960s with farmers having to grow more nuts to maintain living standards which led to a reduction in the use of fallows.\textsuperscript{226} Traditional pastoral

\begin{flushleft}
that around 150 definitions of drought have been put forward. See Grainger, \textit{The Threatening Desert}, 39. Grainger also puts the case that \textit{poor land use is accelerated by drought} and a drought event which can last for many seasons can be impacted upon by social, economic and political influences. See ibid., 64-65.
\end{flushleft}

\begin{flushright}
\textsuperscript{223} Ibid., 79. Mountfort’s expedition into Jordan found large scale browse impacts from local goats with the goat population around Karak alone being around 30,000 animals. Sir Julian Huxley is quoted as saying that they reminded him of \textit{an invasion of black aphids on a cherished garden}. See Mountfort, \textit{Story of an Expedition}, 104. The Kermes Oak, \textit{Quercus calliprinos} found in this region resembles a bush rather than a tree under browsing pressure and develops long prickles at goat level as a defense mechanism. Grainger observes that browsing can kill a tree and over-browsing in an area can alter the species composition to less useful species. See Grainger, \textit{The Threatening Desert}, 98.
\end{flushright}

\begin{flushright}
\textsuperscript{224} Postel, \textit{Pillars of Sand}, 5. The global growth in irrigated farming areas has slowed from a peak of 2.2 percent expansion in the 1970’s which has been attributed to fluctuations in cereal prices, the recognition of problems with irrigated systems, cost increases in setting up infrastructure for such projects and lastly concerns about the ecological damage and social problems (dislocation) involved with large dam projects. See Koohafkan and Stewart, \textit{Water and Cereals}, 22.
\end{flushright}

\begin{flushright}
\textsuperscript{225} Dar, \textit{Interventions and Implementation}, 67. Dar proposes that plantings in dryland regions should form a polyculture of different crops, trees and livestock.
\end{flushright}

\begin{flushright}
\textsuperscript{226} See quote on p75 by Jacobsen and Adams testifying to the ancient tradition of fallow systems. This is a productive system that goes back many thousands of years. See also footnotes 249-250.
\end{flushright}
uses were reduced and demands put on sparsely vegetated lands most vulnerable to desertification.  

Dryland soils and eco-systems are fragile and depend on variegated rainfall patterns. Cash crops on fragile dryland regions can make substantial demands from soils and their cultivation can lead to degraded landscapes. Beaumont describes a pattern where such projects often lead to improved crop yields followed by reduced yields as a response to rising water tables and the build up of salt in the surrounding soils.

Koohafkan and Stewart estimate that over 40 million hectares of irrigated land in dryland areas are affected by degradation which can include waterlogging and salt affected soils. They suggest that decades of poor water management have caused large tracts of irrigated land to be abandoned or cultivated at lower levels of productivity due to salinization.

---

227 Grainger, *The Threatening Desert*, 74-75. Groundnut or peanut cultivation saw rapid expansion in the Sahel region (Niger, Mauritania, Mali, Chad) beginning in the 1950s and 1960s.

228 Grainger, *The Threatening Desert*, 1990, p73. Grainger suggests that the patterns of expansion in irrigated cash crops in dryland areas indirectly causes desertification by displacing subsistence cropping and pastoralism on to more marginal lands which later become degraded. See ibid., 74.

229 Beaumont, *Desertification*, 83. Beaumont also makes the point that with some of these irrigation projects, problems can arise within a period of several months of project completion though problems can also occur after several years. See ibid., 80. Grainger says that there are many examples of irrigation projects designed to supply food for growing populations or cash crops for export with poor management procedures often causing productivity to fall after a few years operation which can lead to saline or alkaline soils and waterlogging leading to land which is no longer productive. See Grainger, *The Threatening Desert*, 91.

230 Koohafkan and Stewart, *Water and Cereals*, 13. Out of a total of around 230 million hectares of irrigated crop land 45 million hectares are impacted by salt with 32 million hectares being salt affected in dryland regions with the main cause here being human-induced processes. Problems with salinity are endemic. Postel gives a figure of one in five hectares of irrigated cropland around the world being impacted by salt levels in soils in countries such as China, India, Pakistan, Central Asia and the United States. See Postel, *Pillars of Sand*, 92. Grainger describes major salinity and waterlogging problems in Egypt, Algeria, Tunisia, and some regions of Sudan, Ethiopia and Somalia. This problem is not confined to developing countries. Australia has problems with salinity and different uses of subterrenean water. In the US the large-scale irrigation projects in the Colorado River basin have seen major problems with salinity. Countries such as Syria, Jordan, Iraq have waterlogging and salinization problems as does the Arabian Peninsula and the drylands of Central Asia comprising China, Mongolia and the old Soviet lands. Iran, Afghanistan and Iran are also affected as well as Rajasthan and elsewhere in India and Pakistan with large areas of irrigated cropland on the Indo-Gangetic Plain. See Grainger, *Threatening Desert*, 130.

Salinity once established can be difficult to remedy. Salt crusts can form on soil surfaces and high temperatures during dry periods increase surface evaporation causing a *pumping action and bringing* more saline water up to the surface leading to reduced crop yields and ultimately the end of crop cultivation.232

Such degraded ecosystems are often the result of tree cover removal for cash crop systems as well as the removal of trees for fuelwood.233 Grainger talks about the introduction of mechanical agricultural techniques from developed temperate countries being poorly suited to *fragile drylands soils* and although such farming methods can lead to increased production in the temperate areas of the planet this type of cultivation may not be as appropriate for dryland soils. He cites the example of southern Tunisia bordering the Sahara with average rainfall at 100-200 mm. Areas of land under cultivation more than tripled between 1948-1975 and the use of tractors and disk ploughs during this period led to wind erosion of the local soils. Similar processes have occurred in other parts of Tunisia.234 Koohafkan and Stewart highlight a number of problems here which can include loss of organic matter in soils, wind and water erosion, loss of good soil structure, salinity and acidification. They suggest that

> whenever an ecosystem such as a grassland prairie in a semi-arid region is transformed into an arable system for food and fibre production, several soil degradation processes are set in motion 235

Increasingly large irrigation schemes have been called into question. In Turkmenistan water is taken from the Amu Darya for the Karakum Canal which is described as the *largest irrigation canal in the world* and which is up to a kilometre wide running

---

232 Grainger, *Threatening Desert*, 91. The heavily cropped and irrigated areas of the Murray-Darling Basin are susceptible to salinity problems and waterlogging. Grainger puts this down to *poor irrigation management*. Ibid., 131.


234 Grainger, *Threatening Desert*, 66-73. Grainger describes how 100 million tonnes of dust are blown into the Atlantic every summer from West Africa. Soil compaction can also be problematic through use of machinery leading to hard soils which hinder the infiltration of rainfall. Plant life struggles to put down roots and little or no germination occurs. Soils in effect become less permeable and help promote destructive runoff. Ibid., 32.

through the length of southern part of the country. The 50 year old Soviet built canal carries somewhere between 20-30 cubic kilometres of water a year which is channeled off to smaller irrigation canals for cotton production on dryland soils. Siltation problems are endemic to this system and much of its water is lost to seepage and evaporation. Pearce remarks that *the waterway leaks so much from its bed that the desert for ten kilometres either side is waterlogged.*

Increasing patterns of sinking relatively low cost tube-wells has seen a lowering of ground water tables in many dryland regions. This technology allows farmers to put in two or more crops a year making this type of water delivery system an attractive option. This relatively cheap tubewell technology has seen many millions of farmers in developing nations pumping ground water and severely reducing water tables with large imbalances between amounts of water pumped from aquifers and natural recharge. Pearce states that up to a tenth of the world’s food is produced using subterranean water resources that are not being replenished by rainfall. He suggests that India, China and Pakistan alone *probably pump out around 400 cubic kilometres of underground water a year from the new tubewells.*

Kowsar cites the Gareh Bygone Plain in Iran which was *once a healthy scrubland* *teaming with wildlife* with large herds of gazelle. This region has suffered from prolonged drought, population pressures and development patterns on a fragile

---


237 Pearce, *When the Rivers*, 78-79. Pearce suggests that *every year, perhaps 100 million Chinese eat food grown with underground water that rains are not replacing.* Another 200 million people are doing the same in India. Water tables in Pakistan’s Punjab province are being lowered by around one to two metres a year. The Punjab produces around 90% of Pakistan’s wheat crop. Pearce gives a figure of 150-200 cubic kilometres as being the amount of water taken from subterranean sources through pumping by India, China and Pakistan in excess of natural recharge. He gives a figure of around $12 billion spent by Indian farmers on pump technology and boreholes in the two decades before he wrote his book. See ibid., 58. Groundwater depletion from over pumping of aquifers for irrigated crops is becoming problematic in many regions of the world. The Ogalla aquifer in the Great Plains region of the USA provides more than one-quarter of US irrigation needs. But in less than 50 years of extraction a great many of the wells have become unproductive with land reverting to dryland management regimes. See Koohafkan and Stewart, *Water and Cereals*, 21.
ecological landscape. The author suggests that the advent of diesel pumps and moldboard ploughs hitched to powerful tractors delivered the coup de grâce to this productive land with a substantial lowering of the ground water table.\textsuperscript{238}

In China, India and Pakistan the growth in ground wells has led to large-scale expansion in irrigated cropland. Postel suggests that the over-pumping of groundwater may be the single biggest threat to irrigated agriculture, exceeding even the buildup of salts in the soil.\textsuperscript{239} One estimate with regard to groundwater management in Syria suggests there is a deficit of between 60-70 percent of groundwater recharge in agricultural areas. Over-pumping around Aleppo has led to a lowering of the water table and consequently to increases in pumping depth. Oweis \textit{et al.} report that \textit{deep non-flowing artesian wells are degrading the good quality water of shallow wells, and most of the shallow wells are running dry.}\textsuperscript{240}

Crops such as rice, sugar cane, alfalfa and cotton require large amounts of water with little in the way of enforced regulations as to how much water can be extracted and \textit{no reliable statistics on how much water the farmers pump from beneath the ground.} Pearce cites estimates of 250 cubic kilometres of water a year taken from underground water resources for irrigation purposes which is approximately 100 cubic kilometres more than rainfall replenishment.\textsuperscript{241}

\textsuperscript{238} Sayyed Ahang Kowsar, "Desertification Control through Floodwater Harvesting: The Current State of Know-How," in \textit{The Future of Drylands: International Scientific Conference on Desertification and Drylands Research}, ed. Cathy Lee and Thomas Schaaf. (Paris; Dordrecht, Netherlands: UNESCO; Springer, 2008), 231. The water table which had been at a depth of 10 meters before pumps were introduced had dropped to 26 meters in a well dug in 1982 and water stopped flowing after about 10 minutes of pumping.

\textsuperscript{239} Postel, \textit{Pillars of Sand}, 66. Postel describes the problems of removing groundwater at a rate greater than natural recharge and describes it as \textit{pervasive in most major areas of irrigated agriculture.} Ibid., 255. India’s National Environmental Engineering Research Institute (NEERI) put out research in 1996 stating that \textit{over exploitation of ground water resources is widespread across the country} with water tables sinking at an alarming rate. Postel describes North China as having severe water deficits and gives an annual figure of 30 billion cubic meters of groundwater overpumping with similar situations in Pakistan, (Punjab) the USA (Ogallala aquifer, Central Valley in California) Similar situation in North Africa and the Arabian Peninsula. Ibid., 73 and 76-78.

\textsuperscript{240} Oweis, Hachum and Kijne, \textit{Water Harvesting}, 7.

\textsuperscript{241} Pearce, \textit{When the Rivers}, 58.
The entire Mediterranean region has witnessed large scale depletion of aquifers through over-pumping. Countries such as Algeria, Israel, Malta, Cyprus and Tunisia are heavily reliant on groundwater sources and many aquifers in the region have slow replenishment rates. Periods of prolonged drought can also contribute to the degradation of these underground systems with agriculture increasingly demanding larger shares of a diminishing resource.242

Patterns of reduced water availability, degraded soils and loss of tree cover in many of the dryland regions of the world would appear to be increasing. There is the probability that climate change and greater incidence of drought events will only serve to compound the situation. Well engineered dryland water harvesting systems based on traditional models could help alleviate some of these problems.

Modern interventions and traditional systems

Ancient cultures leave behind evidence of some of their history through written and archaeological records. It is also probable that traditional cultures retain elements of much older cultures. Qanats are ancient water systems that have survived as functional systems until the present. Terraces in Yemen which appear to date from the 3rd millennium BC may have been in use continuously since this time.243 However throughout much of the 20th century there has been a large dichotomy between traditional knowledge systems and what is sometimes referred to as the rationale scientific model with old knowledge systems ignored or disregarded for the sake of expert knowledge.

242 Juan Cánovas Cuenca, and Andrés del Campo García, Study on Irrigation Water Management in the Mediterranean Region (Spain: Funded by European Union, April 2006) 9-101. Coastal aquifers are fragile and overpumping allows the entry of sea water with local groundwater becoming saline limiting its usage. This has already occurred with over-pumping in Cyprus, Greece, Israel, Italy, Spain, Turkey and Algeria. Ibid., 15. Cultivated areas can be impacted by the entry of seawater into the water table in low-lying areas near the sea. Some cities such as Mexico City, Beijing, Amman, Bangkok, Tianjin, Tuscon are much reliant on aquifers for their water. Overpumping in excess of natural recharge appears to be the norm.

Turnbull talks about

the illusory nature of one of the core tenets of modernity – that the technoscientific knowledge, upon which the concept of modernity is based, epitomises planning, rationality and order.244

Rapid patterns of change in the 20th century saw the role of the expert elevated and traditional local knowledge based systems involving irrigation and farming marginalized. Postel quotes E.H. Carrier stating in 1928 that disturbing factors have already begun to be manifest in Egyptian farming. Carrier was concerned about waterlogging which in Egypt’s climate would lead to problems with salinity. Carrier also warned that silt that had maintained fertility in the Egyptian floodplains for thousands of years was now being trapped behind the Aswan Dam.245

Traditional Nile Valley farming was based on a single annual crop followed by the Nile flood which washed out accumulated salts and provided alluvial silt to enrich soils. Over a hundred million tons of silt comes down the Nile each year with about 10 per cent historically deposited on the floodplains which had significantly contributed to fertile soils for Egyptian farmers. The new dam at Aswan was completed in 1970 further changing this situation with perennial irrigation systems, rising water tables and the Nile Delta retreating at least two kilometres out to sea. 246

Similar patterns can be observed in Iraq. In 1957 the Oriental Institute of the University of Chicago together with the Iraqi government undertook a large archaeological based project to look at the early irrigation systems of the southern Mesopotamian plains. A year later Jacobsen and Adams were already warning of the risks of the rapid expansion of dryland farming in Iraq with projects often backed by

244 David Turnbull, Masons, Tricksters and Cartographers (London: Routledge, 2003), 1. Turnbull says that technoscience has become the authoritative form of knowledge in the world today. Ibid., 7.

245 Postel, Pillars of Sand, 53. Carrier wrote The Thirsty Earth; a study in Irrigation published in 1928.

246 Ibid., 72. Annual evaporation on the Aswan dam is measured in cubic kilometers. Local farmers now use artificial fertilizers.
funds from the new oil industries allowing government monies for expanded irrigation projects to grow successive winter and summer crops. They pointed out that irrigation projects which could be feasible in Europe or North America could have disconcerting effects in a semiarid, subtropical zone. The two scholars proposed a cautionary approach with the suggestion that the systems of irrigation used by the ancient Mesopotamians should be closely examined as

old canal banks and thickly scattered ruins of former settlements testify to former periods of successful cultivation in most of the desert areas now being reopened.

Jacobsen and Adams pointed out that new irrigation water in large volumes could raise the water table unless there were provisions for adequate drainage. They also suggested that good studies showed that salinity has a long past in the region and that only the modern means to combat it are new. They went on to say that

the cultural pre-imminence of the alluvial plains of central and southern Iraq through much of their recorded history provides still further evidence of the effectiveness of the traditional agricultural regime in spite of its prevailing reliance on a similar system of fallow in alternative years. Accordingly, the entire 6000-year record of irrigation agriculture in the Tigris-Euphrates flood plain furnishes an indispensable background for formulating plans for future development.

Their observations however were largely ignored. Already in 1953 the Iraqi government had instituted the Greater Mussayeb Irrigation Project. Poor planning and

247 Jacobsen and Adams, Salt and Silt, 1958, 1251. The authors were part of a comprehensive assessment of ancient agricultural sponsored at the time by the Government of Iraq Development Board.

248 Ibid., 1251. They pointed out that the looming problems of salinity were in part due to the semiarid climate and generally low permeability of the soils of central and southern Iraq.

249 Ibid., 1251. Ancient Mesopotamian farming and flood irrigation appear to have been largely based on fields being left fallow in conjunction with plant and tree cover. Beaumont describes the fallow process simply as allowing soils to recover by employing a fallow period with salts being leached away allowing cultivation and agriculture to continue. See Beaumont, Desertification, 83.
inadequate drainage measures resulted in irrigation canals clogged with silt and soils reduced by severe salinity. Grainger remarks that

there were no field trials to determine the water requirements of different crops; managerial staff were inadequate; irrigation canals silted up; and drains were badly maintained. By 1969 waterlogging was common and two thirds of the soil was saline.\textsuperscript{250}

Other similar patterns can be found in India with the British East India Company becoming increasing active in irrigation schemes from the 1820’s with subsequent problems with salinity and waterlogging. Local knowledge was usually ignored and local authorities who had important roles in water maintenance systems were dismissed to be replaced with Company employees.\textsuperscript{251} British engineers viewed embankment systems which ran for kilometres along river systems as old flood protection measures whereas they had traditionally been used for overflow irrigation where levees had been breached in a deliberate and systematic way to irrigate and fertilize fields and also produce good harvests of mosquito eating carp.\textsuperscript{252} Overflow irrigation came to an end and the result was that large tracts of land became waterlogged leading to health problems in local populations. Willcocks describes how these canals were once living streams full of vitality but had become nothing but long chains of stagnant pools of water, breeding malaria and poverty.\textsuperscript{253}

\textsuperscript{250} Grainger, \textit{The Threatening Desert}, 94. Quite a few farmers went back to traditional nirin cropping where cereal crops were put out using flood irrigation until salinity meant leaving cropping areas fallow allowing rainfall to leach out the salts which is the historical system mentioned by Jacobsen and Adams.

\textsuperscript{251} Sengupta, \textit{Irrigation}, 1923-1924. The British began canal construction in India in 1817 with expansions particularly in the Punjab after the famine of 1837-38. See Postel, \textit{Pillars of Sand}, 43-44. British irrigation schemes in Pakistan dating from the latter part of the 19th century were huge. The Lower Chenab Canal irrigated an area the size of Yorkshire. Pearce suggests that the British in the Indian sub-continent spent more money on digging canals than on laying the famous railways of India. By 1947 100,000 kilometres of canals had been constructed. See Pearce, \textit{When the Rivers}, 42. During the period between 1870-1900 irrigated cropland in the Punjab tripled to 3 million hectares. See Postel, \textit{Pillars of Sand}, 45.

\textsuperscript{252} Sengupta, \textit{Irrigation}, 1925. Sengupta remarks that when they first arrived in India the British were altogether ignorant about the importance of the (local) irrigation systems. Ibid., 1923.

\textsuperscript{253} Willcocks, \textit{Ancient Systems}, 8. Early British traders and sailors came across neglected waterways and mistook the canals for rivers which were used for navigational purposes only. Ibid., 21. Jacobsen and Adams make the point that both ancient and present day distinctions between ‘canals’ and ‘rivers’ is meaningless or impossible as large canal systems would develop an ecology of their own over time (a natural regime). See Jacobsen and Adams, \textit{Salt and Silt}, 1254. They are referring to Mesopotamia but the same was true of Bengal.
The modern systems did not allow for the spread of fish eggs into fields and so contributed to malarial outbreaks. (Fish hatching in flooded ponds and fields would eat mosquitoes.) Sengupta has the new British engineered canals resulting in declines in soil fertility and salinity and describes how canal seepage and water-logging problems reached alarming proportions. He gives the example of the Krishna delta which the British took over in 1776 in a fairly prosperous condition however by the end of the eighteenth century the irrigation system was in a miserable state and the area was largely depopulated.\textsuperscript{254} Willcocks remarks that British colonial water engineers were either not aware of the efficacy of overflow irrigation or were not interested in an old (ancient) system which could be superseded by modern method.\textsuperscript{255} New canal irrigation schemes were extended in areas which were already well irrigated by traditional systems with rapid increases in water availability and crop production in the first few years. Subsequently however soil quality started deteriorating with hardening of upper soils and formation of saline crust in the subsoil.\textsuperscript{256}

Traditional well systems such as \textit{kaccha} and \textit{pakka wells} in the permeable Gangic soils had not suffered from such problems. These shallow well systems collected water near rivers (or canals) and often served for one or two years but were easily constructed at little cost. Manual water lifting was used and also animal power. \textit{Kaccha} wells irrigated one or two acres each season and the \textit{pakka} wells could supply water for up to 5 acres.\textsuperscript{257}

The East India Irrigation and Canal Company was formed in 1857 which Willcocks believes probably accelerated the destruction of the old irrigation systems. Solid banks were put in on Bengali rivers with no cuts for irrigation allowed. Willcocks

\begin{flushright}
\textsuperscript{254} Sengupta, \textit{Irrigation}, 1923.
\end{flushright}

\begin{flushright}
\textsuperscript{255} Willcocks, \textit{Ancient Systems}, 27. Sengupta says the massive and vastly complex works were never understood by the colonial rulers. See Sengupta, \textit{Irrigation}, 1925.
\end{flushright}

\begin{flushright}
\textsuperscript{256} Sengupta, \textit{Irrigation}, 1925.
\end{flushright}

\begin{flushright}
\textsuperscript{257} Sengupta, \textit{Irrigation}, 1925. Sengupta suggests that the decline in irrigation systems had a role in provoking disaffection with the Company’s rule and contributed directly to the rebellion of 1857. Ibid., 1924.
\end{flushright}
describes water engineers blocking off traditional waterways used for irrigation with local farmers despairing of being deprived of their fish supply.  

The vast subcontinent that once made up India, Pakistan and Bangladesh has many examples of traditional water harvesting systems. Scarborough suggests that the celebrated tank systems of western and southern India as well as northern Sri Lanka represent the largest non-Western reservoirs known. These tank systems utilize small reservoirs to store runoff water during the wet season for use during the dry season. Postel estimates about 2 million of these systems of varying sizes in India providing irrigation for about 3.5 million hectares. In Tamil Nadu very old tank systems known as eris are used extensively and these systems also help with flood mitigation and soil erosion as well as providing good quantities of water for groundwater recharge.

Some of these tanka systems are being resurrected. The Indian village of Rajsamadhiya in Gujarat harvests its own water while villages around rely on water tankers for drinking water. Water harvested into ponds is allowed to percolate into soils so replenishing subterranean resources including village wells. These ponds harvest rain from monsoonal falls with the ponds constructed along the routes that the monsoon water takes as it drains through the village. Some of these structures harvest water from 4 kilometres away. Crops are chosen for their suitability for a low water regime. Pearce describes how

farmers scooped the water from the tanks, diverted it down channels onto fields, or left it to sink into the soil and refill their wells. The tanks served

---

258 Willcocks, *Ancient Systems*, 37,40,99. The construction of rail networks on high embankments by the East Indian Railway Company also led to drainage problems and disruption of the old irrigation systems. Ibid., 65.


260 Postel, *Pillars of Sand*, 223. In large watershed these tanks may be arranged in a cascade fashion, with the overflow from one feeding the next one downstream. Tamil Nadu has almost 40,000 tanka still providing irrigated water to around a million hectares of land. According to Pearce there around 140,000 tanka either abandoned or still being used across India. See Pearce, *When the Rivers*, 301. Pearce describes these systems as shallow mud-walled reservoirs in valley bottoms which are designed to capture seasonal monsoonal rainfall.

261 Ibid., 300-301.
other functions, too. Some were stocked with fish. All were prized for the silt brought into them by the rainwater. Farmers guarded the slimy-nutrient-rich mud in their tanks almost as much as the water. They dug it out to put onto their land, and turned silted-up former tanks into new farmland.262

Other old systems include Ahars which are traditional reservoirs where water is ponded within a bund system which can be released into other ahars downslope. Water trapped in such a system can also be pumped for irrigation purposes or directed to irrigate cropland by gravity flow using pipes which pass through the bund.263 Postel describes a traditional water harvesting system from the upper part of the Narmada River valley in Central India. This haveli system is still being used in the region where monsoonal rainfall is held by earthen embankments which border fields on all sides. These systems are also referred to as bundhands. Fields vary in size from 2 to 12 hectares and good rainfall allows cultivated areas to fill with water which is allowed to soak into the soil with farmers then draining the fields and planting out crops. Soil moisture ensures crop growth until harvest time.264 These traditional systems managed water resources without depletion of water sources. Mukhopadhyay talks about intelligent and sustainable use of land, water and soil without causing damage to the resilience of the surrounding ecosystem.265

Other examples can be found in Rajasthan which has a dry climate and sandy soils with khadins placed in proximity to low eroded hills and ridges of sandstone and

262 Ibid., 301.

263 Pacey and Cullis, Rainwater Harvesting, 136. These large bund systems (ahars or khadins) which can cover hundreds of hectares are usually divided between a number of farmers. Pacey and Cullis cite a khadin of 150 ha which is cultivated by 25-30 farmers some with blocks of 1 hectare with the largest holding being 7 hectares with co-ordinated maintenance and opening of sluices. Ahars are sometimes used to grow a variety of rice before the bunded area fills up with water. This is a type of ‘floating rice’which can grow in relatively deep water. Often this crop will be followed by a winter wheat crop after the ahar is drained. Some of the traditional Indian bund systems can be as small as one hectare but other cover large areas from 500 ha up to 4000 ha with bunds wandering along contours for 10 kms or more. Ibid., 139-141.

264 Postel, Pillars of Sand, 222. Postel laments the fact that these traditional haveli systems are being superseded by sprinkler irrigation using groundwater to grow soya beans as a cash crop with declining water tables now common in the region.

265 Mukhopadhyay, Indigenous Knowledge, 161-162. Mukhopadhyay has desertification in India impacting on over 100 million hectares or over 30% of the country’s total land mass.
limestone which serve as catchment area for runoff into valleys with bund construction to harvest and hold back runoff water and sediment. In western Rajasthan submerged areas behind traditional bunds (khadins) can vary from 20 hectares to 500 hectares. Koohafkan and Stewart describe how near Alwar, removal of trees led to slope erosion, dried up river beds and dry wells with a subsequent disruption to local food production. In 1985 local villagers began constructing johads or small dams to harvest rainfall.

By 1986, the results were already visible. The rains filled the johads, and the riverbed retained water for a much longer period. Within just a few years, the region once labelled a “black zone” by the Rajasthan government (meaning to dry to grow anything) again had a stable groundwater level, the five rivers in the region were again flowing continuously, and the villagers had returned to growing crops in the area.

Check dams were also once used across India. As we have seen these dams were constructed across small streams and gullies to hold up water long enough for it to soak into soils. In Limbadia a village in western Gujarat villagers brought back this old system and constructed dams in an attempt to stop a falling water table. Pearce reports that soon afterwards several wells began spurting water at the surface.

Elsewhere in India there has also been interest in the old irrigation systems. In flat country west of Bangalore, the BAIF Development Research Foundation has helped

---

266 Pacey and Cullis, Rainwater Harvesting, 139. The area behind the embankment is referred to as a tank or dhar or a khadin in Rajasthan where wheat and pulses are sown in November to be harvested in April. Bund or embankment construction involves maximizing the infiltration of runoff into soils. The top of each bund needs to be level with base of the bund upslope with the distance between bunds closer on steep slopes. Ibid., 172. This is similar to some of the systems described by Evenari.


268 Koohafkan and Stewart, Water and Cereals, 35.

269 Pearce, When the Rivers, 302. According to Pearce, the International Water Management Institute in Gujarat estimates that around 6,500 square kilometres in Rajasthan is being managed to harvest rainwater. Pearce quotes Tushaar Shah at the IWMI that that these check dams have had a dramatic impact on groundwater recharge and the revival of dried up-springs and rivulets with five old river systems that had previously been dry now flowing once more. (The Ruparel, Arvari, Sarsa, Bhagani and Jahajwali Rivers)
local farmers put in 350 ponds spanning four valleys close to the town of Adihalli. Pearce describes the new system with water cascading slowly from one pond to another resulting in more water in village wells, year-round farming of grains and improved yields of cash crops like coconuts and chillies, cashews, and mulberries, vegetables and rice. Instead of having scant water resources for farming these farmers now have useable water all year round.²⁷⁰

Old traditional water harvesting systems can still be found in the Yemeni highlands with many areas covered in terraced fields and diversion systems still being used with local farmers using gravel and stones to create artificial berms which channel water onto terraced fields. Farmers grow crops such as coffee, bananas, sorghum, vegetable crops and qat (khat) in regions with low rainfall. However, sparse rainfall, population pressures and economic changes have put enormous pressures on the sustainability of terrace agriculture in this country. Farmers struggle with poor income levels and labour intensive work. Al-Ghulaibi makes the point that neglect of these water harvesting systems...as a result of relatively poor economic return, threatens to destroy the entire ecosystem and increasingly there is a pattern of farmers and their children abandoning this type of work.²⁷¹

Remnants of traditional runoff systems can also be found in Africa. These are termed remnant to the extent that they still retain pre-industrial irrigation technique as well as retaining elements of much older traditions which were once widespread.

South of the Sahara there are some descriptors of runoff farming with simple techniques described such as cultivation in depressions (cuvettes in West Africa and teras in Sudan). Pacey and Cullis suggests that agricultural specialists and water engineers working in sub-Saharan Africa often seem unclear...as to how the traditional systems should be regarded.²⁷²

²⁷⁰Ibid., 302-303. This network of ponds has also seen rises in the local water table.

²⁷¹Al-Ghulaibi, Traditional Water Harvesting, 22-35.

Malagnoux proposes that in the dry Sahelian zones local populations over thousands of years have developed methods of rainwater harvesting for the benefit of their crops and trees. He gives an example from Sudan (teras) with small plots of land enclosed by earth barriers on three sides which captures runoff. This method is employed for food crops but also to combat erosion and conserve soil fertility. There is a downstream soil barrier on contour which can be 50-300 meters in length with an area of the system uncultivated and used for water harvesting purposes only. Pacey and Cullis describe another system in Sudan on relatively flat undulating land east of the Nile with clay soils and gentle slopes where sheet-water runoff is trapped by constructed embankments (bunds) and planted out to crops of quick maturing millet after the water has subsided. The crop matures in about 80 days utilizing soil moisture left behind by the floods.

Grainger cites a project funded by the World Bank in 1970 on eroded slopes in the Kenyan Rift Valley where farmers and livestock owners were encouraged to put in earth walls or bunds to minimize soil erosion in an area that had already lost much of its fragile soil through overgrazing and deforestation. Check dams were also constructed to prevent further gully erosion. The bunds were put out every 1.5 - 3 metres permitting farmers to take better advantage of rainfall. Crops were only planted out in the lower terraced areas behind each bund to maximize uptake of water runoff. Grainger observes that once the bunds were functioning less labour was needed than in the traditional hand cultivation of soil.

---


274 Ibid., 270. This area is 2-3 times the cropping area. The plots are usually about 0.2-3 hectares with the bunds or earth walls having a height of 50 cm but a base width of 2 m.

275 Pacey and Cullis, Rainwater Harvesting,131.

276 Grainger, The Threatening Desert,170.
Elsewhere in Africa remnants of these old water systems in use can still be found in Mauritania, Niger and Somalia all employing techniques which harvest rainwater for farming systems.278

Some further mention here should be made about Qanats. These clever water delivery systems are unusual in that they are a very old traditional method of providing water for human cultures and farming systems which can still be found in a surprisingly large number of regions such as Iran, Baluchistan, Afghanistan, Saudi Arabia and China and importantly a considerable number of them are still fully or partially functional.279

Traditionally communities formed around qanat systems and evolved laws regulating their construction, maintenance and use with communal participation in their

---

277 Grainger, *The Threatening Desert*, 171. Yields also appeared to benefit from the use of improved varieties of sorghum, cowpeas and tepary beans (*Phaseolus acutifolia*). Grainger say that *care was taken to ensure that these were locally adapted so that farmers would actually want to grow them*. Nurseries were also established to grow out tree seedlings with the locals favouring *Leucaena, Prosopis and Cassia*. Other measures were also adopted such as structures for tapping water from rivers. Sorghum yields were *two to three times those obtained before*. Bunds are described by Pacey and Cullis as *embankments, earth-banks, low dams, terrace walls and stone walls without mortar*. These walls are constructed on contours and can have spillways at 20m intervals in order to regulate water flow to cultivated areas. Dimensions are determined by volume of water flow taking into consideration major flood events. A typical size built on a plot of 0.1 ha on a 1% slope is a wall of 0.4m high and 0.5-1m wide at the base. Bunds should be spaced at 15-20m intervals on a slope. Bunds are constructed on contours and control of water depth is facilitated by dividing up cultivated areas into small walled areas with individual stone spillways. Discharged water from one plot enters another lower plot. Dimensions are determined by volume of water flow taking into consideration major flood events. See Pacey and Cullis, *Rainwater Harvesting*, 143. Similar systems were used in the Negev.

278 Pacey and Cullis, *Rainwater Harvesting*, 154. In Somalia stone barriers were used across dry riverbeds.

279 Hussain et al, *Revitalizing a Traditional*, 336. In Iran there are differing opinions about the number of functioning qanats with estimates varying from 30,000 to 40,000 and many that have survived have been abandoned as working water supply systems. Though in recent years more interest has been shown within Iran about qanats as awareness of sustainability and climate change issues have portrayed them as sustainable water management systems. Hussain et al, *Revitalizing a Traditional*, has over 7000 Iranian qanats being rehabilitated between 1998 and 2003. Ibid., 340. According to Jomehpour until about 40 years ago, part or most of the water in larger cities, such as Yazd, Kazeroun, Esfahan, Tabriz, Shiraz, Ghazvin, Zanjan and Kashan was provided solely or significantly by qanats, thus demonstrating that they are not uniquely a rural phenomenon, but have also had an important role in the formation of cities. See Jomehpour, *Qanat Irrigation Systems*, 299. UNESCO statistics for Iran have 38,000 qanat tunnels being used in the 1950s. See Hosseini et al, *Effect of Urban Sprawl*, 311. Hussain et al estimates that in Iran out of 70 billion cubic metres of total groundwater supply about 10-12% (8.6 billion cubic metres) is supplied from existing qanat systems. They give figures from Khorassan province from 1990 (which borders Afghanistan and is the largest province in Iran) as having over 7000 working qanat systems delivering an annual withdrawal of 2.5 BCM (billion cubic metres). See Hussain et al., *Revitalizing a Traditional*, 339.
In Iran local water distribution rights were established over time with complex rotational systems to distribute water to owners in different seasons. Traditionally land was divided up into ploughing units and each unit of land had about 10-15 members with added shareholders involved in the final production stages. Payment was involved for the amount of water used and usage also based on ownership share with the rights to water varying from a few minutes to a few hours per year. Critical to this process was a profession called Muqannis who had the knowledge and skills employed in qanat construction and operation. Jomehpour suggests that the knowledge base built up over centuries by the Muqannis was unique and that their expertise and experience is irreplaceable.

Functioning qanat systems found in Baluchistan are described as being the most ancient and indigenous source of irrigation in the province. Though pumping technology employing deep tubewells in valleys in this region has seen lowering of the water table with many qanat systems drying up and large reductions in flow rates. Lack of maintenance on systems is also a problem with wells collapsing due to excessive rains or simply through aging. This is a common pattern in regions such as the Middle East and North Africa where qanats were once part of productive agricultural systems with many now either drying up or abandoned.

---

280 Hussain et al., Revitalizing a Traditional, 334.

281 Jomehpour, Qanat Irrigation System, 302-303. Hussain et al., Revitalizing a Traditional, talks about intricate relationships that evolved over time to manage karez water and distribute it according to each individual shareholder’s inputs of land, labour, tools and money. Ibid., 334. Jomehpour proposes that such collaborative work can be observed not only in the irrigation system but also in other activities related to agriculture and rural societies. In general there are strong relationships between people of the same tagh (irrigation unit) which also affects their daily life together. Ibid., 308.

282 Jomehpour, Qanat Irrigation System, 300. The shift from traditional decision-making systems to a centralized water bureaucracy has largely seen traditional expert knowledge in the form of the muqannis marginalized and lost. See Jomehpour, Qanat Irrigation System, 313.


284 Hussain et al., Revitalizing a Traditional, 340. The authors go on to say that qanat systems in Baluchistan are dying a slow death creating social problems of water coming into the hands of a few powerful landlords. The exact number of qanat systems in Baluchistan is unknown. Though the authors quote figures suggesting that in 1971-72, 43% of all irrigated cropland in Baluchistan came from qanats watering 208,000 hectares which by 1996-97 had dropped to 9% of qanat irrigated land, an area of 78,550 hectares. The authors also quote a report from the Water and Power Development Authority (WAPDA) from 1992 in which it states that of 1000 karezes, 464 are in good running condition, 266 have declining flows and 270 have gone dry. See Hussain et al., Revitalizing a Traditional, 340.
However some functional systems can still be found in Syria around Damascus and Homs which are still used for irrigating cropland. Viollet has around 600 qanats in Morocco hundreds of which were still being used around the middle of the 20th century. These were quite shallow systems as the water table coming from the Atlas mountains is about 20 metres below ground level. There are over 6000 qanat systems in Afghanistan with an estimate of 163,000 hectares being irrigated from these systems in the south and southwest of the country. It is also estimated that 60-70% of qanats here are not being used, in need of maintenance, dried-up or having very low flow rates from drought conditions and low groundwater recharge. In northwest China there are over 1000 qanats in Turpan and possibly over 1500 systems in the Xinjiang region with indications that this number has been severely reduced in recent years. In Saudi Arabia springs and qanats have been important traditional sources of water but numbers of qanats are not known though a figure of 4,000-5,000 is mentioned. It is also unknown how many of these systems are still in working order.

There is no question that modern pump or tubewell technology and centralized water systems have led to these old systems being largely marginalized in many regions. This is unfortunate. Qanats are an ancient system with little or no adverse ecological impacts. They did not impact adversely on subterranean water systems and during

285 Wessels 2008 in Zafar et al., 13-14. Farmers here have developed their own local systems of water use based on households having an irrigation share based on a duration of time measured in minutes or days worth of water flow depending on the amount of land and household water entitlements. In Qara the author witnessed qanat systems working in combination with drip irrigation to water fruit trees. See Joshka Wessels, "Assessment of Three Collective Renovations of Traditional Qanat Systems in Syria," in What Makes Traditional Technologies Tick? A Review of Traditional Approaches for Water Management in Drylands, ed. Zafar Adeel, Brigitte Schuster and Harriet Bigas (UNU-INWEH: 2008), 15. These comments were written before the current conflict in Syria.

286 Violett, Water Engineering, 213. Violett gives the average flow of a qanat system at Marrakesh at around 40 m³/hour.

287 Hussain et al., Revitalizinga traditional, 339.

288 Ibid., 336. The authors quote the Chinese Hydraulic Engineering Society (1991) and unpublished sources.

289 Ibid., 342. Saudi Arabia is described as one of the most water-scarce countries in the Middle East with no permanent rivers or lake systems. Water is obtained from limited annual rainfall (average annual rainfall of 100 mm except for mountainous areas in the southwest of the country but some areas of the country will have no rainfall over several years) and scarce surface water resources plus expensive desalination technologies using seawater. The authors cite ‘Agricultural Statistics of Saudi Arabia 2002’ which record almost 100,000 private tubewells for a variety of purposes. Increasingly desalination plants are being looked at as a solution to the region’s water problems.
drought periods qanat systems do not dry up as quickly as wells. Jomehpour puts forward the idea that water flowing over long distance in qanats, results in sedimentation of suspended matter, and therefore self-purification. In other words water quality can improve as it travels down the qanat. Jomehpour suggests that crops irrigated with qanat water have been found to be of better quality and more resistant to drought. He also suggests that qanat irrigation systems have a relatively low rate of water usage for cropping areas.\textsuperscript{290}

We have seen how many old water systems have been abandoned in relatively recent times. By all accounts the Bengali irrigation systems were highly productive and not recognized by British water engineers who had their own ideas about how irrigation should work. The same pattern occurs in modern Iraq and with qanat and other traditional irrigation systems and it is often the case that old water systems used for productive farming cultures were simply either ignored, not understood or little studied. Hodge gives the example of Timgad in Roman North Africa which is a dry region where Berber peoples harvested

\begin{quote}

   every drop of the rainfall...for the subsistence crops on which their livelihood depended; and they then had to stand by and watch it all be channeled off to a local town where colonial settlers and pensioned ex-servicemen used it daily for nothing better than to splash around in.\textsuperscript{291}
\end{quote}

There is no doubt that dryland regions saw large scale increases in water consumption from the 1950s particularly for agriculture with rapid exploitation of groundwater sources from this period increasing between 1960-1980. Water was treated as an abundant resource and wastage was common with emphasis on immediate returns on investments and not sustainability. Little attention was paid to ecological

---

\textsuperscript{290} Jomehpour, \textit{Qanat Irrigation System}, 304. Jomehpour suggests that development projects and the perception of qanats as obsolete systems together with the introduction of deep wells using pumps which can extract greater volumes of water at a higher speed than qanats plus the introduction of pipelines which are relatively simple and cheap to put out over long distances for water distribution have all impacted negatively on qanat infrastructure. Ibid., 313. This is consistent with the observations of Professor Fred Ghassemi. See footnote 168.

consequences, impacts on local communities or on water efficiency measures. Inputs increasingly began to include artificial fertilizers and various chemical biocides with only an incomplete knowledge of their ecological impact as was well documented in Rachel Carson’s *Silent Spring*.

Little attention was paid to the older irrigation systems which had sustained populations for thousands of years and had themselves been sustainable. These systems did not deplete water resources and made use of either floodwaters or as in the case of qanats, clever use of subterranean water without depleting the source of that water.

A recent edition of *The Hindu* had the Vice-Chancellor of Mangalore University, B. Hanumaiah, deplore the tendency to discredit ancient water harvesting methods in favour of major irrigation projects and in India and elsewhere recognition of the worth of these old systems has led to some schemes of resurrection.

In relatively modern times there have been plans to rebuild the ancient Sabean system at Ma’rib (Yemen). The Ottomans were keen on the idea for a while but nothing came of it, however in 1976 a feasibility study was embarked upon which led to the *Ma’rib Dam and Irrigation Project* and a dam was built and inaugurated in 1986. Brunner describes subsequent developments which have included the development of nearby oilfields at Safir, relatively large scale migration to the area because of the oil industry, tribal conflict over selling local land and the sinking of thousands of wells with diesel pumps catering to field areas of fruit and vegetables for the markets of Sana. In more recent times there have been increasing patterns of conflict. The new dam remains largely un-utilized with high levels of evaporation and increasing local cases of water borne diseases such as malaria and bilharzia. Brunner writing in 2000 remarks that *almost the only positive effect is the recharging of the aquifer by the leaking reservoir.*

---


**Evenari’s runoff farms**

The most comprehensive research to date in resurrecting an old dryland water harvesting system was carried out by Professor Michael Evenari in the Negev Desert over a twenty-year period. Evenari’s work appears to have acted as a catalyst for further examination of the old dryland water harvesting systems which as we have seen were once more common in the Middle East. Prinz and Malik make the point that

> after 1950 water harvesting received renewed interest on the research level as well as in the implementation sector, partly due to the successful reconstruction of ancient water harvesting farms in the Negev by Evenari and colleagues. 295

Pacey and Cullins state that *Evenari’s work has a particular authority because of the runoff farming models established in the Negev, the thoroughness of the research and the historical origins of the models established.* 296

However Evenari’s work appears little studied or understood.

Following publication of the results of their findings a large 70,000-hectare site was established in Afghanistan by a German team together with the Afghan Ministry of Agriculture with reports that the project was producing good results.

> We imitated the microcatchment method with good success to grow fruit trees and other useful trees. We advised the local peasants to use these methods. We used these systems, which we call the Israeli systems, especially to improve the pastures and to install, on a large scale, basins for storing water. I am firmly convinced that this system can be of great economic importance in


developing countries with arid conditions. I see in these projects the possibility – and I have demonstrated this myself – to plant, with a minimal capital outlay, trees and bushes in steppical areas endangered by erosion, and to use these regions for agriculture.  

The project appears to have come to an end because of the disruptions caused by the Russian invasion of Afghanistan in 1980.

Pacey and Cullis describe another project in northern Burkina Faso in the early 1970s near Ouahigouya where soil erosion had led to barren areas without vegetation which were encroaching on cultivated areas. A staff member of Oxfam at this time visited the Negev runoff farms and on returning to Burkina Faso he organized the construction of 200 microcatchment plots which were distributed among seven villages near Ouahigouya with farmers using their most badly eroded land for the experiments. The constructed catchment plots measured 10m$^2$. Trees were put out in 2m$^2$ basins in the lowest part of each microcatchment with some farmers also sowing out cereals. On some plots sorghum was inadvertently introduced in manure mixes. At harvest the sorghum had massive heads, comparable to the best in adjacent fields.

Evenari had become intrigued by the widespread remains in the Negev Desert of what had once been flourishing agricultural systems supporting a relatively large population in an area that had become mostly abandoned desert. He remarks

\[\text{297 See Evenari, Shanan, and Tadmor, The Negev, 337. Extract from a letter by the project leader Dr. Haselbarth. This was in Paktia Province which has seen much recent conflict. Projects in runoff agriculture were also launched in Botswana (Tschin, Tabiskin in the Aire mountains), Niger, Upper Volta (Ouagadougou, Titao), Kenya (Lokitaung, Lakori near Lotubai, Maralal in Samburu district), and in some of our neighbouring Arab countries.}\\
\[\text{299 The late Professor Michael Evenari was a botanist at the Hebrew University of Jerusalem.}\]
as our work proceeded we found that there was not a square meter of soil, including the barren hillside, that had not been put into the service of agriculture in the 200,000 hectare area between Kurnub and Nitzana.\footnote{Evenari, Shanan, and Tadmor, \textit{The Negev}, 97.}

A half a century earlier Lawrence and Wooley had made a similar observation.

\textit{Every flat stretch of valley or upland was put under cultivation. Across every wady, not only in the broader water-courses, but where the rain torrent had cut channels far up on the rocky hill-side, low walls were built to catch the flood-borne earth in a staircase of terraced fields, and later to fan out the rush of the torrent over a great space, that the gathered soil might not be carried away, but might retain...such moisture as it received.}\footnote{Woolley and Lawrence, \textit{The Wilderness of Zin}, 50. The two authors describe their main objectives as tracing the ancient inland caravan route to Egypt through central Palestine and to identify some of the sites mentioned in the Old Testament. Upon entering the Negev south of Beersheba they found the countryside to be desolate but were impressed by numerous abandoned terraced walls \textit{even in the narrowest wadies...evidence of a more industrious husbandry in the past.} Ibid., 24.}

Evenari’s group of researchers set out to study and understand how dryland Nabateans and Byzantine farming systems functioned through the reconstruction of their runoff farms at Shivta and Avdat in the central Negev Desert. Construction on both farms was based around the on-site ruins of Nabatean / Byzantine farms. A third larger area was later added at Wadi Shamash.

Average rainfall in the Negev varies between 25 to 200 ml and with no other major sources of water the old desert cultures of the Negev managed the rain when it fell and used it to grow a range of crops. Evenari called them \textit{runoff farmers.}\footnote{Evenari, Shanan, and Tadmor, \textit{The Negev}, 2. Evenari’s team comprised botanists, hydrologists, engineers, archaeologists, geologists, photogrammetrists, agronomists and soil scientists and covered about 20 years of study in the Negev desert. The team selection reflected a multi-disciplinary approach combining the efforts of many different disciplines – history, archaeology, botany, geology, hydrology, (and) agriculture. Ibid., 6-7 and preface vii.}

Evenari states the main research objectives set by his team in resurrecting the ancient runoff farms. They wished to test their own theories about these old farming methods...
and to monitor and collect data on runoff from different sized watersheds and to examine the elements involved. They also wished to explore how various field crops including vegetables, fruit trees and pasture plants could be grown successfully under conditions of runoff agriculture and to examine how a range of different plants would survive under a runoff water regime in a desert and to develop methods of applying runoff farming to modern desert agriculture.\footnote{Ibid., 179. An important corollary of these objectives soon developed which was the study of plant and animal life in their natural desert environment. Ibid.,179-180. Evenari, Tadmor and Shanan had formed a research team in 1954 and until 1959 had surveyed and studied more than 100 ancient farming systems and irrigation projects all based on harvesting runoff from small and large catchments. See Leslie Shanan, “The Hydrology-Geomorphology Interface: Rainfall, Sedimentation, Land Use” in Runoff, erosion, and the sustainability of ancient irrigation systems in the Central Negev Desert (Jerusalem: IAHS, 2000), 77.}

Work on resurrecting the runoff systems at Shivta began in 1958 and in 1959 work was also started on resurrecting the second farm situated in a small tributary wadi 540 m above sea level not far to the south of the Nabatean - Byzantine town of Avdat.\footnote{Michael Evenari, Leslie Shanan, and Naphtali H. Tadmor, Runoff-Farming in the Negev Desert of Israel (II) Progress Report on the Avdat and Shivta Farm Projects 1962/3 Season ( Rehovot: 1964), 11.}

The Shivta farm had a complex system of terraces and water channels together with the remains of an ancient house. Evenari and his team re-built the terrace walls to create a total cultivable area of 0.70 hectares with runoff water coming from four different watersheds. A wadi system supplied the bulk of the runoff and water was directed to the different terraces through a series of drop structures 4-5 meters wide.\footnote{Evenari, Shanan, and Tadmor, The Negev,180.}

Soils in the terraced areas were sandy loess with average soil depth of 2.5-3m at the centre of terraced plots with a more shallow depth of 1-1.5m at the edges of cultivated areas. Evenari describes these soils as being well drained, relatively free of salts, and weakly alkaline. Conduits, channels, drop structures and channels were reconstructed and monitoring devices installed to measure the runoff entering the farm.\footnote{Ibid., 181. Evenari describes how a meteorological hut with instruments to measure temperature, relative humidity, and evaporation was placed at the lower end of the farm, and 10 rain gauges, including one automatic recorder, were distributed throughout the farm catchment area.} The actual

---

303 Ibid., 179. An important corollary of these objectives soon developed which was the study of plant and animal life in their natural desert environment. Ibid.,179-180. Evenari, Tadmor and Shanan had formed a research team in 1954 and until 1959 had surveyed and studied more than 100 ancient farming systems and irrigation projects all based on harvesting runoff from small and large catchments. See Leslie Shanan, “The Hydrology-Geomorphology Interface: Rainfall, Sedimentation, Land Use” in Runoff, erosion, and the sustainability of ancient irrigation systems in the Central Negev Desert (Jerusalem: IAHS, 2000), 77.


306 Ibid., 181. Evenari describes how a meteorological hut with instruments to measure temperature, relative humidity, and evaporation was placed at the lower end of the farm, and 10 rain gauges, including one automatic recorder, were distributed throughout the farm catchment area.
terraced fields were not levelled and Evenari makes the point that this *led to uneven distribution of flood water.*

The second farm at Avdat had a larger cultivated area as well as a larger catchment than the Shivta farm. A major focus of reconstruction work here was on setting up experimental plots to measure water use, plant and tree responses to a runoff water regime and slope and catchment measurements to determine the optimal way in which runoff could be harvested. At Avdat Evenari’s team experienced their first flooding rain in November 1959 and although construction of terraced walls was incomplete, a barley crop was planted with the help of a local Bedouin Sheik who supplied camels and plows. This initial crop produced 1250 kilos of grain per hectare.

Reconstruction at this second farm utilized existing terraces and water conduits with fields divided into experimental plots each of which received *controlled quantities of flood water* through the use of a water distribution system which was *superimposed on the ancient layout.* The catchment basin of the farm comprised a southern area of 30.7 hectares which in ancient times had been divided into *seven smaller watersheds by channels which collected runoff from the hillsides and led the water to terraced fields.* Evenari’s team rebuilt these channels and where they entered the farm

---

307 Ibid., 181. Pacey and Cullis discuss artificial levelling by machinery to allow water to flow evenly to cropping areas though this increase the cost of establishing such systems. They suggest that if land is not levelled flows of runoff can be unevenly distributed to cropping areas though arguably even non-engineered systems can function quite well as demonstrated by the site at Shivta. See Pacey and Cullis, *Rainwater Harvesting,* 140.


309 Ibid., 4.

310 Evenari, Shanan, and Tadmor, *Runoff-Farming in the Negev Desert of Israel (II),* 11. In effect Evenari’s team placed onto this ancient runoff farm *a modern floodwater distribution system* employing *concrete channels, steel pipes, risers, and distribution outlets.* See Evenari, Shanan, and Tadmor, *The Negev,* 182. When field plots were saturated the main outlet pipe could be closed using a *simple gate* with surplus water then channeled to other terraces through a *division block* to the main concrete conduit to combine with other runoff flow. Drop structures allowed the water to flow to fields below. All of these flows were monitored with strategically placed water meters. (Some of these fields were levelled, some were not). Water from the eastern catchment was also monitored and diverted into various fields using a division box and pipes. Surplus water here flowed over a concrete spillway into *an earth distribution channel* and then to another field area. Not all water flow was measured or managed on this eastern catchment area with water being *lost downstream in the wadi.*
measuring weirs and flood recorders were set up.\textsuperscript{311} At Avdat greater care was taken in the reconstruction effort using \textit{well-cut stones} in repairing the terraces instead of the \textit{roughly hewn rocks} they had used at Shivta. Concrete was employed to strengthen spillways and drop structures and water conduits on the hillsides which conveyed runoff to the fields were also rebuilt. Fourteen terraces were reconstructed providing an area suitable for cultivation of 2.6 hectares.\textsuperscript{312}

In early 1960 Evenari’s team completed the rebuilding of the farms at both Avdat and Shivta and commenced planting out crops in the winter season of 1960-61 which turned out to be an extremely dry period. The following seasons (1961-62 and 1962-63) were also unusually dry years with the latter period seeing extreme drought.

Evenari describes the period as

\textit{the most extreme drought ever recorded in the Negev.}\textsuperscript{313}

However he makes the point that

\textit{we were out to discover whether runoff farming worked under desert conditions – and this included the erratic rainfall patterns.}\textsuperscript{314}

\footnote{\textsuperscript{311} Evenari, Shanan, and Tadmor, \textit{The Negev}, 182. The second catchment to the east comprised an area of 345 hectares which also included around 10 hectares of ancient terraced fields situated at the bottom of the valley. These terraced areas were not rebuilt as the force of the unmanaged water over the years had damaged the stone walls and the terrain as it entered the farm area had turned into a \textit{fairly shallow, wide wadi} but monitoring equipment was installed where this \textit{wadi} entered the rebuilt farm. See previous footnote.}

\footnote{\textsuperscript{312} The Avdat farm also had loess soils which were measured at 2.5-3 meters deep above the \textit{wadi} gravel beds though the loess soils on the eastern area of the lower farm were shallower with gravel beds at a depth of 0.9-1.5 meters. Ibid., 186.}

\footnote{\textsuperscript{313} Evenari, Shanan, and Tadmor, \textit{The Negev}, 191. The 1962/63 drought season had been preceded by five successive drought years. Evenari talks about a 15-year average of 100 mm for the Central Negev Highland region but the 1962/63 season at Avdat recorded 27.7 mm with 28.0 mm at Shivta. Beer Sheva to the north with a 64-year average of 200 mm, recorded 42.0 mm (1962/3) which was the lowest yearly fall since records were first kept in 1898. Winter and summer temperatures in 1962/3 were above average compounding the effects of the drought. See Evenari, Shanan, and Tadmor, \textit{Runoff-Farming in the Negev Desert of Israel (II)}, 1 and Evenari, Shanan, and Tadmor, \textit{The Negev}, 191.}

\footnote{\textsuperscript{314} Ibid., 191. Shanan talks about the region having \textit{spotty, erratic, and unequal distribution} of rainfall events. See Shanan, \textit{The Hydrology-Geomorphology Interface}, 88.
The 1963-64 and 1964-65 seasons provided reasonable rains and some good floods (flow down the wadis) following the previous drought period. These contrasting weather periods allowed Evenari’s team to study plant growth of different species under extremely variable conditions and so determining their suitability for runoff agriculture.\(^{315}\) It became clear that slope was critical in determining the quantity of runoff with steeper slopes generally having less runoff. Evenari describes this as

*a most astonishing result and is the reverse of most observations made hitherto on other runoff plots all over the world.*\(^{316}\)

It was also found that these runoff farms could harvest water from the typically light rainfall events of the Central Negev of between 3-10mm with runoff made possible by the nature of the loess soils which characterize this desert region. When it rains these soils form a cryptogamic crust which allows runoff with relatively meagre falls.\(^{317}\)

It also became apparent that size of catchment area had a significant effect on water yield with larger catchment areas producing a smaller proportional water harvest than smaller catchments. Variations could also occur due to differences in topography with areas composed largely of a flat plateau with very few stones…the most efficient

\[\text{315} \text{ Evenari, Shanan, and Tadmor, *The Negev*, 197. At Avdat and Shivta the majority of rain events usually occur in December and January. Mid summer sees very high rates of evaporation with Avdat having a drier climate than Shivta although the distance between the two farms is only 18 kilometers. Ibid., 338.}\]

\[\text{316} \text{ Ibid., 141. Evenari’s team measured slope in terms of soil depth, stone cover, rock outcrops, and microvegetation of the area as well as fall. It was found that slopes with a greater incline had a shallow layer of soil. Slopes with a more gradual incline had deeper soils and fewer rocky outcrops. On the steep slopes the shallow soils did not form crusts with rainfall and water penetration was greater due to the many fissures and cracks at the junctures between soil and stone surfaces as well as the rock formations breaking the flow of water. Ibid., 142. Shanan refers to studies on the Avdat runoff plots showing that slope gradient was an important factor affecting runoff. Shanan describes how a 10% gradient will provide about 60% more total annual runoff than a 20% gradient. See Shanan, *The Hydrology-Geomorphology Interface*, 90.}\]

\[\text{317} \text{ Cryptogamic crusts are common in semiarid and arid areas of Australia. Eldridge et al. talk about these biological crusts in terms of complex associations of mosses, lichens, liverworts, cyanobacteria, fungi and bacteria that are intimately bound onto surficial soils. These crusts, sometimes referred to as microphytic or cryptobiotic crusts, stabilize soil surfaces against water and wind erosion and contain organisms that can fix atmospheric nitrogen. See D. J. Eldridge, W. S. Semple, and T. B. Koen. “Dynamics of Cryptogamic Soil Crusts in a Derived Grassland in South-Eastern Australia,” *Austral Ecology* 25 (2000): 232. Evenari describes the impact of rain, even little rain, on this type of soil…the colloids and very fine soil particles on the surface loess layer swell and increase in size. The wetted layer slakes and the fine particles clog the surface layer to form an almost impenetrable crust. See Evenari, Shanan, and Tadmor, *The Negev*, 136. Warren observes that a region with limited rainfall can enhance runoff potential as surfaces and slopes with little vegetative cover are prone to crusting and so shed more rainwater than wetter climate surfaces with considerable vegetative ground cover. See Warren, *Land Degradation*, 453.}\]
producers of water. Evenari also found that stone removal could improve water yield in dry years by about 40 cubic meters per hectare. However in years of greater rainfall (more than 130mm) the increased yield may be as little as 10-20 cubic meters per hectare.

Terraces once flooded with runoff even for relatively short periods of time provided an opportunity for both plant growth and storage of sub-surface water where plants could make best use of it. Choice of crops was critical with three broad categories selected including a range of orchard trees, field crops and pasture plants. Aside from some initial watering for establishment all plantings had to survive on runoff water only.

Evenari’s team included pasture plants in their experiments because grazing has been practised in the Negev since ancient times. Evenari also makes the point here of the importance of trialling pasture crops as in all arid lands, the natural pastures have been largely destroyed by heavy overgrazing. The expectation was that good yields could be had through the use of harvested runoff and choice of perennial and annual drought resistant plants. Cash crops were also planted (artichokes and asparagus) as well as medicinal plants, bulbs and rhizomes for flower production and biological experiments with wild desert species.

---

318 Evenari, Shanan, and Tadmor, *The Negev*, 145. At Avdat the large catchment produced about 52,000 cubic metres of runoff in 27 flood events between 1960 and 1967 which averages out to 7,500 cubic meters per year or about 24 cubic meters per hectare. The smaller catchments comprising 30 hectares produced almost 17,000 cubic meters in 46 floods over the same period which is annually about 79 cubic meters per hectare. The smaller catchments could flood with very light falls of rain. See microcatchments below. Annual production here (flat plateaus with few stones) was 100 cubic meters per hectare over the same 7 year period (ibid., Table 12 p 145). Evenari’s model suggests that a small catchment with a 10-percent incline and typical surface cover will yield 160 cubic meters per hectare of water in a year of rainfall totalling 105mm. A larger catchment of 20 hectares with a similar incline will produce only about 100 cubic meters per hectare and a catchment area of 300 hectares will produce only 50 cubic meters a hectare. Ibid., 146-147.

319 Evenari, Shanan, and Tadmor, *The Negev*, 146. Evenari’s team factored in annual rainfall, size of catchment area, incline variations on slopes and surface stone cover to produce a model nomogram based on water harvested over the 7 year period. As an example, with annual rainfall of 105mm a microcatchment of up to 0.1 hectare in size with natural stone cover and a 10-percent slope could be expected to produce about 16 cubic meters per year of runoff water in a small catchment area of this size stone clearing can increase yields to 21 cubic meters a year which is 30-percent increase in harvestable water. If this area (0.1 hectare of catchment) had an incline of 20 percent then annual water harvest would amount to around 6 meters but stone clearing would increase this to 12 cubic meters, a 100-percent increase. See Evenari, Shanan, and Tadmor, *The Negev*, Fig 91, 146-147.)
The final decision to plant out fruit trees on the resurrected farms seems to have been taken because of mention of orchard trees in the Nitzana papyri\textsuperscript{321} as well the various trees mentioned in the Old Testament. Fruit trees were planted out at both the Shivta and Avdat farms with a main difference in planting conditions being the \textit{unleveled terraces} at Shivta created a situation of \textit{wild natural flooding of the trees} as opposed to the levelled terraces at Avdat. The Avdat orchard was also much bigger than the one at Shivta and covered an area of 2.6 hectares with systems in place measuring incoming runoff flow and growth rate of trees.\textsuperscript{322}

Trees that did well at Shivta included pomegranate, olive, figs and also grapevines. Carob trees did exceptionally well and Evenari observes that

\textsuperscript{320} Evenari, Shanan, and Tadmor, \textit{The Negev}, 189. The various agricultural practices of the time were pursued, such as cultivation for the terraced fields, insecticides and fertilizers. Manure from Bedouin sheep and goats was harvested and applied as fertilizer. See ibid., 191. Four \textit{columbarium} towers found at Shivta dated to the 4\textsuperscript{th} and 5\textsuperscript{th} centuries is a possible indication of a source of rich fertilizer on the original farmlands. The remains of pigeon bones and quantities of fertilizer were found inside with estimates of each tower housing about 1200 pigeons which would have served as a good source of food as well as providing about 15 tons of fertilizer each year which would be sufficient to fertilize about 1500 orchard trees or vines. Shivta is surrounded by remains of animal enclosures which could have been another source of fertilizer. See Ward, \textit{From Provincia Arabia}, 111.

\textsuperscript{321} Part of series papyri documents discovered by H.D. Colt who excavated at Shivta in 1935. The archaeological dig soon moved to Nitzana because of water problems with drought in the region at this time (1935-36) and uncovered the papyri. The Nitzana Papyri suggests three different classes of land owned by the church, farmers and \textit{limitanei}, a local military group who also managed farm land. The Papyri reveal some of the crops and yields from this period and region that include fruit trees, barley and wheat crops plus a legume referred to as \textit{arakos}. The papyri documents also mention figs, grapes, olives, dates and almonds. (The nuts are mentioned rather than the trees however the trees were much valued in these times and it is likely that almond production was local.) Pomegranate and peach seeds were found at Nitzana during the Colt archaeological dig of 1935 suggesting that the trees were grown locally. See Evenari, Shanan and Tadmor, \textit{The Negev}, 121-122. Many ancient industrial wine presses had been discovered near Avdat and Shivta and Saint Jerome (c.340-420) had remarked that a quality wine had been made in Khalutza. Ibid., 207.

\textsuperscript{322} Evenari says \textit{from the moment of planting we carefully followed the development of all the trees at Avdat, observed their phenological behaviour, regularly measured their height, and counted the number of new branches}. In 1963 a specially constructed dendrometer was obtained and tree trunk measurements (width) were regularly taken to \textit{an accuracy of 0.01 millimeter at the same marked points 20-30 centimeters above the ground}. Observations indicated that the maximal growth rate of trees measured on a yearly basis was less interesting than the actual growth periods – \textit{the time interval during which this rate is kept up and the length of the yearly growing period}. Drought had an impact on growth rates. Evenari refers to the 1963 drought when maximal growth for all the orchard trees were \textit{but fractions of those of the two following years, and the growing period was very short} with some trees putting on almost no growth at all. Evenari’s team observed that a drought year could also affect the growth patterns of the following year. In 1964 following severe drought all the trees had shorter growing periods with growth patterns accelerating in 1965 despite both years having similar rainfall. Evenari proposes this as \textit{an after-effect of the drought year, since 1964 was at least as favorable for growth and development as 1965}. Most of the trees needed 12 months to recover from the severe drought conditions of 1963. See Evenari, Shanan, and Tadmor, \textit{The Negev}, 213 -214.
after seven years one of the carob tree planted more or less in the center of the farm had reached 6.50 meters in height and 1.20 meters in trunk circumference and dwarfed the less successful almonds, peaches, and apricots...even during the drought of 1962-63 they stayed green and sustained their growth.\textsuperscript{323}

Other orchard trees also did well on the runoff regime. Evenari relates how \textit{in 1965 and 1966 the abundant fig yield...compelled us to experiment with drying the fruit by various methods, which proved highly successful.} Olive trees grew slowly as would be expected and pomegranates described as \textit{drought and salt resistant} appeared to suffer from a trace element deficiency but responded well to manure treatment. Evenari describes the most successful trees and shrubs at Avdat as being \textit{peaches, apricots, almonds, and loganberries}. All of the trees put on growth during the drought periods with even minimal rain events generating flood in the terraces.

Grape vines planted at Shivta produced good harvests in 1965 and 1966 though some difficulty was encountered with initial establishment but subsequent growth and development was fine. Pistachios despite early slow growth did very well. Evenari observes that these trees \textit{seem well adapted to their arid environment...since a related species (Pistacia atlantica) grows wild in the Negev}.\textsuperscript{324} Almond trees were very successful and were \textit{the first to flower and bud, have the highest maximal rate and longest period of growth, and shed their leaves last of all}. Peach cultivars grafted onto almond rootstock outperformed peach trees grafted onto apricot rootstock. Evenari says \textit{the advantage of the almond over the other rootstocks was also most pronounced during the drought of 1963}.\textsuperscript{325}

\textsuperscript{323} Evenari, Shanan, and Tadmor, \textit{The Negev}, 208. Carobs sustained some drought related damage in the 1964 season with loss of leaf cover but recovered fully the following spring. Figs (\textit{Ficus carica}) initially succumbed to drought stress but went on to perform well.

\textsuperscript{324} Ibid., 208-216. Apples planted out did not apparently do well during drought years but recovered when runoff events became more productive. Apple trees were late to bud and flower compared to other trees planted out and this was observed as being a disadvantage. \textit{Pistacia atlantica} is probably the tree species cut down by Ottoman railway construction mentioned above. See pp. 58-59 and quote from the Mayor of Karak (Jordan).
A variety of field crops were trialed with both wheat and barley planted as winter crops with good results. Cultivars for both these cereals were sought that could deal with a seasonally late planting date as the first floods of the year often occurred in December. These cultivars provided good yields even in dry years with crops of 2 tons per hectare for wheat and 2.7 tons per hectare for barley during the drought season of 1963-64.

Carrots, radishes and onions were planted out in the winter season with the actual seeds harvested as a good cash crop when the shift in desert temperatures in March saw the well developed vegetables produce a good seed crop. Winter peas were sown out as a leguminous crop. Sunflowers were found to be successful with early plantings and various other crops trialed such as safflower.

Summer crops were less successful with poor results in the 1961-62 season of cotton, sorghum and sesame. Safflower proved to be the only successful summer crop here. Plantings of asparagus and artichokes, both perennials are described as being outstanding. Evenari and his team had already identified a wild desert species of asparagus (Asparagus stipularis) growing well in the area and found their own plantings of this highly drought resistant and deep rooted plant to have produced exceptionally well. (It yielded well and the plants were green and healthy throughout the year).

325 Evenari, Shanan, and Tadmor, The Negev, 214-216. Almonds and pistachios yielded about 1.4 tons per hectare. Olives yielded up to 10 tons per hectare See Michael Evenari, The Awakening Desert (Jerusalem: Magnes Press, Hebrew University, 1988), 154. In order to monitor soil moisture and water use of the orchard trees at Avdat, Evenari’s team employed the neutron-moderation method with 20 access tubes placed in four concentric circles around the trees. Measurements were recorded at 30-cm depth intervals with the deepest at 1.65m and the shallowest at 15cm from the surface. Three peach trees and three apricots were selected for this procedure with these trees being planted in a 5 X 7-meter spacing in circular basins, 15centimeters deep and 3 meters in diameter with water coming into the basins from a delivery channel during small floods. Trunk growth was also measured using a dendrometer on a weekly or biweekly basis. Measurements indicated an annual average water usage for these trees of the equivalent of 2700 cubic meters of water per hectare. These figures factored in water loss caused by evaporation and drainage. Evenari observed that trees planted out in commercial orchards have closer spacings and calculations based on figures obtained from this study would suggest under a closer spacing regime trees should not require more than 3000 to 4000 cubic meters per hectare of irrigation water. Evenari suggests that by employing the spacing regime used at Avdat moisture use should be 3600 cubic meters per hectare. He gives the figures of nearby commercial orchards with trees of a comparable age to the Avdat trees as about 7000 cubic meters per hectare for peaches and about 3500 for apricots and comments that this leads us to ask whether our trees in Avdat require less water, or whether the farmers overirrigate. Experience all over the world has shown that farmers always overirrigate. See Evenari, Shanan, and Tadmor, The Negev, 216-219.

Medicinal plants were also trialed with the arid conditions accentuating the *pharmacologically active alkaloids*. Desert henbane and thorn-apple (*Datura metel*) were successfully grown out with Evenari describing *a high production of medicinal components.*

Flower production was also looked at with *hyacinths, narcissi, daffodils, gladioli and Vrieseas* with good flowering behaviour, quality bulbs and rhizomes. Evenari observes that these plants do well in regions with a lengthy dry summer season with sprouting after early seasonal rains and the rhizomes and bulbs becoming dormant at the beginning of the dry season. These flower crops have shallow root systems and do well under dry seasons even with only enough water to *wet the upper 30-50 centimeters of soil.*

Interestingly Evenari relates how

> in 1963-64 the cereals were a complete failure in the northern Negev and the southern coastal plain of Israel. The drought damage to agriculture in these areas amounted to many millions of Israeli pounds. But our Avdat farm provided the only green field of cereals in the whole area and the yield was not bad: 2 tons per hectare for wheat and 2.7 tons per hectare for barley.

Unexpected problems arose with predator pests as the green cultivated areas would have stood out in the dry desert. Evenari remarks that *our green fields attracted all the plant-eating population in the region* including different insects, beetles, hares, (*Lepus capensis and possibly L. arabicus*) gazelle (*Gazella gazellai* and *G. dorcas*), porcupines (*Hystrix indica*) plus desert partridges (*Alectoris graeca sinaica*). In the end the farms at Shivta and Avdat had to be fenced *with low wire netting.*

---

327 Ibid., 193-194. Dar makes the observation that drylands have abundant sunshine and temperatures that suit a diverse range of crops and suggests that *some of the most productive agriculture in the world is in dryland areas.* See Dar, *Interventions and Implementations*, 67.


329 Ibid., 193.

330 Ibid., 192.
Yields for pasture plants were very good with different varieties monitored for performance and plants harvested in the May-June 1965 season comparable or better than in unirrigated pastures in the sub-tropical Mediterranean region.331

The use of microcatchments followed from Evenari’s unexpected discovery of large catchments being less efficient at harvesting water in comparison to smaller catchments areas. Evenari’s team also appears to have been inspired by the use of such systems in North Africa. Microcatchments have been described as collecting basins and where runoff is led to a small catchment plot allowing water to infiltrate the soils with storage in the root zone of the crop, tree or bush.332

331 Ibid., 197. Evenari’s team grew out pasture-plants in both a nursery situation and in a water-use trial. In the nursery over a hundred species and ecotypes of annual and perennial pasture plants were seeded with the idea that several years observation would provide good data on plants that would survive the alternately wet and dry conditions of the floodwater regime. Very high survival rates were recorded even during extreme and extended drought periods with some years providing very brief growing seasons due to lack of rain events and runoff water. Ibid., 196. Some good performing varieties of perennial pasture plants were Alfalfa (Medicago sativa), Smilo grass (Oryzopsis miliacea), Harding grass (Phalaris tuberosa), Canary grass (Phalaris arundinacea, Ph. trunciata, Ph.caerulescens), Hairy beard grass (Andropogon hirtus), Erhart’s grass (Erhartia calycina), Tall fescue (Festuca arundinacea), Broad fescue (Festuca elatior), Bulbous barley (Hordeum bulbosum), Tall wheat grass, (Agropyrum elongatum), Burnet (Poterium sanguisorba ) Ibid., 196. Table 20. Poor results with other plants such as Medicago sp., clover and vetches (Trifolium pilulare and V.monantha) and various legumes (Hymenocarpus, Onobrychis) were put down to the imperfect establishment of appropriate symbiotic soil bacteria. It was observed that some of the legumes, vetches and medickes took 4 years to develop a well-adapted symbiotic system. Ibid., 196. Table 20. Some good yielding varieties of annual pasture plants were Wild oats (Avena sterilis), Wild barley (Hordeum spontaneum), Spiny medick (Medicago hispida, M. tribuloides), Pea (Pisum sativum), Hirsute clover (Trifolium pilurare), Purple clovet (Trifolium purpureum), Arabic fenugreek (trigonella arabica), Narrow-leaved vetch (Vicia dasyarpa), Short-beaked vetch (Vicia dasyarpa), Syrian vetch (Vicia monantha) Ibid., 199. Table 22. See also Table 21, 197. Impressive results were obtained from native wild oats (Avena sterilis) which gave high yields under water spreading in fertilized seed beds – yields equaling those of seeded hay crops in a humid region. Ibid., 200.

332 The first modern record of the use of micro-catchments comes from French travellers in Tunisia in the 19th century with olive trees observed growing in small microcatchment plots bordered by low earth bunds of about 0.2-0.3m high. See Pacey and Cullis, Rainwater Harvesting, 149. See also Prinz and Malik, Runoff Farming, 4. Olives have been grown in microcatchments in Southern Tunisia for very long periods of time and was possibly a technique introduced by the Phoenicians. See Evenari, The Awakening Desert, 156. These micro-catchment systems can be put in cheaply and are simple to design. They demonstrate a runoff efficiency greater than larger water harvesting systems. These simple systems can also enhance erosion control and can be put in on slopes on flat terrain with a slight fall. See Prinz and Malik, Runoff Farming, 5.
Evenari’s research had indicated that smaller catchment areas could harvest good quantities of water and that within certain limits the smaller the catchment, the higher the relative water yield per unit surface area. At Avdat it was found that there was great disparity between runoff percentages at the farm’s seven smaller watersheds with average runoff here at less than 10 percent compared to 45-50 percent average runoff from the microcatchment plots. They also found that insignificant rainfall events of light rain flooded the microcatchments when a similar fall would not engender runoff on the farm.333

In 1961 Evenari and his team selected an area of just under two hectares near the Avdat farm for the establishment of microcatchment plots. Evenari describes the area as part of a loessial plain with a slight slope of about 1.5 percent; the soil is shallow, saline, and gravelly. This was difficult terrain as the average content of total soluble salts of the whole soil profile was 1.02 percent. Gypsum was present in all layers. The soils also had a high lime content.334

The area was subdivided into 117 microcatchments with the biggest plots at 1000 m² and the smallest at 15.6 m² with earth border of 15-20 centimeters in height raised around each plot (catchment area).

Evenari says that:

to collect the runoff water, we dug a square basin at the lowest point of each microcatchment and shaped it in the form of a flat inverted truncated pyramid to ensure the flow of water to the center. The size of each basin is matched to the water

333 Evenari, Shanan, and Tadmor, The Negev, 224. Evenari says that Rainfalls too light and ineffective to provide runoff on the farm were effective on the microcatchments. He describes how in the 1966-67 season they had one flooding event on the farm and eight such events on microcatchment plots. See Evenari, The Awakening Desert, 156. Evenari gives an example of a flood event in (December 10, 1963) which produced 1238 cubic meters of runoff water from 340 hectares of catchment which is 3.6 cubic meters of water per hectare. Corresponding amounts from a three hectare catchment equalled 156 cubic meters of runoff which is 52 cubic meters per hectare. This is attributed to a hydrological phenomena called overland flow which means the distance the runoff water travels diminishes volumes due to loss in depressions and other irregularities of the surface of the catchment. This phenomena means that flooding of small catchments can occur with moderate rainfall events whereas the same rainfall in a large catchment area will produce no flooding. Ibid., 155. One rainfall event provided a runoff yield of 100 percent as the surface was still wet from a previous rain. Evenari, Shanan, and Tadmor, The Negev, 224.

334 Ibid., 220-222.
harvest expected from each microcatchment. The trees and shrubs were planted at the lowest point of such basins...and no runoff water could enter from the outside.  

Plantings in the microcatchment plots included: pomegranates, grapevines, apricots, almonds, carobs, olives, and saltbush (*Atriplex halimus*) which was put out in 15.6-250 m² plots with fruiting trees planted out in larger 125-1000 m² plots. Organic manure was used as a fertilizer and plantings were initially mulched with straw.

Some plants proved harder to establish than others. The less salt resistant vine cultivars struggled and some of the apricot trees did not put out root systems. Other plants were more successful with overall good first year establishment rates, though growth through the second year proved to be more difficult after trees budded in spring with the explanation offered that root systems had begun entering a more saline soil profile. However most of the plantings recovered and measurements of salinity over the period 1961-1967 saw a decrease

*throughout the whole soil profile of the microcatchments of various sizes and actually reached a point where it no longer presents a serious hazard to the growth of moderately salt-sensitive crops.*

---

335 Ibid., 222. Evenari’s team here added no design components for the collection of hydrological data but they roughly measured the volume runoff of some rainfalls from each microcatchment by noting the high-water marks in the collecting basins after heavy rainfalls. In the summer of 1962 with aim of collecting more data on these small water harvesting systems two further microcatchment plots were put in *each with a collecting surface of 20m² draining into 300-liter asbestos-cement barrels.* During the 1967-68 season these smaller microcatchment plots produced nearly three times as much runoff as the farm’s control plots. Ibid., 224
In 1970-1971 a new runoff farm area was established at Wadi Mashash. Evenari relates how

after nine years of runoff farming in Avdat and Shivta, we were reasonably certain that fruit trees, field crops, pasture plants, and vegetables could be grown successfully under desert conditions without any additional irrigation.\(^{337}\)

In establishing the farm at Wadi Mashash, Evenari and his team wished to expand their original experiment at Shivta and Avdat to a larger scaled project. They reasoned that the cultivated areas at Shivta and Avdat were too small to be applicable to the broader situation of arid land agriculture and land usage. Evenari remarks that they had yet to apply our method to a large overgrazed area, and most important, we had yet to carry out a real grazing experiment, with sheep, on this improved pasture.\(^{338}\)

The Wadi Mashash area had been farmed in ancient times and had many long abandoned terraced walls, cisterns, wells and ancient houses. The area consisted of about 25 square kilometers with sloping hills and flat areas suitable for grazing.

\(^{336}\) Evenari, Shanan, and Tadmor, *The Negev*, 224. Salinity is not usually a problem in runoff systems because of the quality of runoff water from quite small catchment areas. See Pacey and Cullis, *Rainwater Harvesting*, 184. The 1962/63 season at Avdat saw salt build-up in in the microcatchment plots in soils which were already saline The drought over the years 1961-63 had seen minimal runoff with leaching of salts from the collection basins only partly achieved. Evenari, Shanan, and Tadmor, *Runoff-Farming in the Negev Desert of Israel (II)*, 28. The trees, vines and shrubs in the microcatchment plots were each given 180-200 liters of water in two installments to help with establishment at the time of planting. Evenari, Shanan, and Tadmor, *The Negev*, 224. The saltbush received no water when being planted out and did not appear to be affected by the presence of salt. In West Africa another method known as *Zai* employs small constructed basins which vary in size according to soil types but are usually 20-30cm in diameter with a depth of 10-15 cm. A hectare of land will take between 12,000 to 15,000 of these basins. Interestingly thorny branches are placed on top of the basin to protect individual crops against herbivores mainly goats. Foresters in this region are using individual micro-catchment basins for single and small groups of trees. Malagnoux suggests that water harvesting is particularly important for establishing young trees. (Evenari’s team ‘delivered’ water for some early tree establishment because of lack of runoff in their first season.) See Malagnoux, *Degraded Arid Land Restoration*, 272. At Avdat Evenari found that the best microcatchment size for fruit trees was 200 to 300 square meters, for vines 150-200 square meters and for salt bush 100-125 square meters. See Evenari, *The Awakening Desert*, 156. Evenari suggests that in other dryland regions with loess soils with higher rainfall the microcatchment area would be smaller. Evenari also makes the point that such systems would have a much lower installation and operating cost compared to runoff farms.

\(^{337}\) Evenari, Shanan, and Tadmor, *The Negev*, 324. Evenari remarks that this kind of farming, well adapted to its environment allows at least part of the desert to become productive without destroying the delicate balance of nature.

\(^{338}\) Ibid., 324. Evenari wanted to find out if runoff farming could be profitably used to restore overgrazed pastures of desert areas and to increase considerably their carrying capacity.
Some of the ancient dams at Wadi Mashash were resurrected and used as limans and planted out with fruit trees.\textsuperscript{339}

The 1970-71 season saw good rain events producing floods on 13 separate occasions which on six established runoff plots filled each basin of the microcatchments we had prepared for the trees with 16.3 cubic meters of water.

Rainfall over the year was also well spread over the season (November to April) allowing further plantings in the microcatchments of 2000 almond trees with various selected cultivars, 130 pistachio trees as well as 65 olives trees.\textsuperscript{340}

The pasture management plan had several objectives including perennial pasture plants grown out in contour catchments\textsuperscript{341} and limans as well as improvement to some of the natural grazing land in the wadi bottom. This latter objective involved putting out perennial pasture plants, seeding out annual plants, applying fertilizers and removing already established wild plants that were unsuitable for grazing sheep.\textsuperscript{342}

In the upper part of the proposed sheep grazing area a variety of perennial pasture plants were grown out and the seed of annual pasture plants broadcasted with the

\textsuperscript{339} Ibid., 327. Limans are constructed in a small wadi dry riverbed with a compact check dam constructed to hold water flow which is channeled to trees. The word \textit{liman} is from the Greek limne.

\textsuperscript{340} Evenari, Shanan, and Tadmor, \textit{The Negev}, 330. The 1971-72 season at Wadi Mashash saw 207 mm of rain falling from 25 wet days. Runoff here was measured at 84.4mm (40.8 percent of the rainfall). The olives were Manzanilla.

\textsuperscript{341} The contour catchments involved the construction of a low earthen wall along the contour lines of a slightly inclined slope, planting two or three rows of pasture plants behind the wall and leaving an area 5-10 m wide above the planted rows as a catchment providing runoff to the planted pasture plants below. We would then have another contour catchment above this on a higher contour line. Ibid., 327.

\textsuperscript{342} Where the sheep were going to be introduced many shrubs of \textit{Thymelana hirsuta} were located within the 50 ha of fenced wadi lowlands. This plant was seen as being in competition for scarce water resources and Evenari observes that it was not eaten by any wild or domesticated grazing animal, not even by the omnivorous goat. \textit{Thymelana hirsuta} is a fast growing plant with a deep root system that uses useful quantities of water; it was removed by hand and then the land was manured and fertilized. Ibid., 330.
expectation that these latter seeds would be spread downwards by the floods, thus improving the whole length of the pasture in the wadi bottom.\textsuperscript{343}

Water was organized for the local Bedouin and their sheep who grazed in the area by resurrecting an abandoned well on the site and later as water became critical during drought periods another ancient well, probably last used during Ottoman times was resurrected and \textit{at the end of the long and dry summer the well delivered daily enough water for 500 sheep, goats, donkeys, and camels.}\textsuperscript{344}

The following season (1972-73) saw an extended dry period with total rainfall for the year of only 55mm. More abandoned wells were sought and \textit{another ancient silted-up well was found} and cleaned out requiring the removal of about 100 m$^3$ of debris consisting of stones, soil and mud. These wells had \textit{been carefully walled with stones by the ancient builders}. An additional 40 ha of the area around the wells was fenced to protect water sources. Evenari’s team also rebuilt two ancient cisterns and their conduits with each cistern having the capacity to store about 200 m$^3$ of runoff water.\textsuperscript{345}

Various observations were made during this dry season. There were no \textit{wadi} floods and only one small flood was recorded in the microcatchment areas. Snow fell which was also measured as precipitation but was useless as runoff. However despite the extremely dry conditions \textit{all the fruit trees developed well and grew an average of 1.20 to 2 m.} Evenari observes that the drought saw the trees being impacted much less from pests and diseases that year than during the better rainy years.

\textsuperscript{343} Ibid., 330. The perennial pasture plants put out were three species of Atripex namely \textit{A.halimus, A.nummularia, A.vesicaria} plus \textit{Medicago sativa} (alfalfa) \textit{Agropyrum elongatum} (tall wheat grass), \textit{Phalaris bulbosa, Phalaris tuberosa} (Harding Grass), \textit{Hordeum bulbosum} (bulbous barley), \textit{Oryzopsis miliacea}, (smilo grass) and \textit{Cassia sturti}. Annual pasture plants included \textit{Medicago hispida, Vičia dasyarpa, Sorghum sudanese} and \textit{Trigonella arabica}. Ibid., 329. Interestingly a technique of establishing perennial pasture plants was by employing \textit{thirty thousand plastic sacks} filled with a mixture of \textit{sand, loess and compost} into which the seeds of the plants were sown. These plants were given due care allowing them to germinate and grow in the bags making them ready for planting after the first flooding. Prior to planting an Australian made tensile wire fence was erected around a 500-hectare area which contained the microcatchment areas and the contour catchments, limans and pasture areas. Ibid., 330.

\textsuperscript{344} Ibid., 332.

\textsuperscript{345} Ibid., 332-334. The second well produced \textit{about 1 m$^3$ of water per day}. Evenari’s team installed a generator and a pump with water from both wells were pumped through a plastic line 2.4 km long which served to deliver water to watering points for the sheep. The 400m$^3$ of water from the two cisterns produced critical water supplies during drought periods.
Evenari surmised that the lack of rainfall meant sparse wild vegetation hence less habitation and food for pests. During this year, despite the drought, the improved pasture areas did well with one flood only while the natural, unimproved pasture was in a most deplorable state.

The contour catchment areas did not do well with the majority of the pasture plants succumbing to lack of water. However Evenari remarks here

in spite of our failure we are still convinced that contour catchments can be very successful if they are more carefully prepared: ours had not been properly leveled.346

The pasture improvement plan at Wadi Mashash involved using runoff water to improve wild grazing land. Two hundred Awassi sheep347 plus 10 rams were purchased from local Bedouin herders and let loose in the areas where pasture plants had been established. Evenari records how

throughout the dry summer the sheep grazed in the improved pasture which provided enough food. Lambing started in November and our ewes dropped 165 lambs: by 1974 we had 450 sheep.348

During the period 1970-80, three seasons were extremely dry with two seasons recording no flooding events in the wadi or liman systems. However olive and almond trees in the liman systems did well despite the dry years and produced good harvests. Throughout the decade water always flooded the microcatchments though some years this was minimal 349 and plantings here were not as successful with 150

346 Ibid., 334.

347 The Awassi sheep is described by Evenari as an ancient Middle Eastern breed that has long been accustomed to desert conditions. Evenari remarks that these sheep need less water, are more frugal in their eating habits, and are easier to keep than other, more vulnerable breeds. Ibid., 335.

348 Ibid., 335.

349 Ibid., 334. The 1973-74 season recorded 180.5 mm of rain but only two small flooding events down the wadi and two small floods in the microcatchments plots. The 1979-80 season saw 166.0 mm of rainfall with six flooding events down the wadi, 3 large, 2 medium and one small flood plus nine floods into the microcatchments (4 large, 3 medium and 2 small floods). The total amount of flood water entering the wadi and liman (check dam see footnote 338) systems in the 1973-74 season equalled 4000 m$^{3}$/ha whereas the 1979-80 season saw 16,500 m$^{3}$/ha. Similarly, the 1975-76 rainy season with 79.5 mm of rain had no flooding events with zero quantities of water into the catchment areas, while only 75mm fell at Wadi Mashash over the 1977-78 season there were three small flooding events with a combined harvest of 1500 m$^{3}$/ha down the wadi and into the microcatchments and limanim. Ibid., 334-335.
trees dying over the drought years. Trees recovered during the two seasons spanning 1978-80 with wetter conditions but were *still smaller than the trees of the same age in the limans*. Evenari suggests probable causes here could have been lack of runoff water, salinity in the soils or soils that were too shallow or possibly *a combination of all three factors.*

Fruit trees under the runoff farming regime grew slowly and had late fruiting. Some fruit trees like cherries, apples, loganberries and plums seemed to grow well but yielded only small quantities of fruit. Apricot and peach trees did much better and were not much affected by drought conditions though there was variation here between cultivars but overall yields were below product coming from commercial irrigated orchards. However these trees according to Evenari yielded sufficient fruit to *justify the growing of apricots and peaches under runoff conditions in developing countries.* Evenari also remarks that *in quality, judged by taste, flavor, and sugar content, our peaches are far superior to any others we have ever tasted.*

Evenari proposes that almonds and pistachios *are in all respects ideally suited to runoff conditions and their yields are quantitatively competitive with trees grown anywhere else.* *Pistacia atlantica* was used as a rootstock with some cultivars. This tree grows wild in the Negev and elsewhere in the region and is an important wild tree in Iran.

Peaches, olive trees and apricots also did well. Mixed results were obtained from grapevines. The locally protected *Chukar* partridge (*hordes*) had a heavy impact on yields and the site chosen at Avdat for grapes was poor in terms of receiving runoff water. The most promising field crop appears to have been onions grown for seed

---

350 Ibid., 335.

351 Ibid., 361-362. Evenari remarks that *one of our friends to whom we had sent some samples wrote to say that she was sorry that she had tasted them, because from then on no other peach could possibly taste good again.* Ibid., 362.

352 Ibid., 362. Even in significant drought years good yields of nuts were produced by the pistachios. It was also found that yield was not impacted by drought conditions of a previous year which was the case with almond trees. Ibid., 369- 370. Cherry trees, both sweet and sour, were uprooted in 1971-1972 because of poor results and replaced with almond trees.

353 Ibid., 364.
production although the yields of the other crops are not bad and are certainly economically feasible in comparison with non-irrigated crops in Israel and for desert areas of developing countries.\textsuperscript{354}

Pasture plants, both annual and perennial were trialled over a nine-year period from 1961-1970. Over this period the perennials had four good years, three years of average water supply and two dry years (one caused by a blocked inlet pipe). The best yielding plants were alfalfa, smilo and Harding grass with all of these plants displaying marked drought resistance and good yields. Of the annual pasture plants Evenari observes that

\textit{the annual plants had to pass a very different test from that of the perennial pasture plants. In order to be of practical value they must propagate themselves satisfactorily from year to year, must be able to build up a reserve of seed population in the soil large enough to survive long drought periods, and to germinate well when a year with good water conditions occurs after the drought.}\textsuperscript{355}

In 1977 a desert runoff park was begun at Wadi Mashash with the planting of 350 ornamental trees and shrubs with thousands of ornamental herbs put in as herbaceous ground cover. Altogether trees, shrubs, ground cover, climbing plants and flowers did very well. The ground-covers kept the area green during the dry summer months.\textsuperscript{356}

Evenari’s research would seem to indicate that the old dryland systems to harvest runoff in \textit{wadis} or sloping land in dry zones is a viable option in regions where water

\textsuperscript{354} Ibid., 371.

\textsuperscript{355} Ibid., 374. \textit{Avena sterilis} proved to be very successful as were the other annuals (see Table 52, p. 357) These plants were deemed to be well adapted to desert runoff agriculture and are of practical value for the development of desert pasture.

\textsuperscript{356} Ibid., 377-378. Evenari and his team also planted out a new area at Avdat to almonds and pistachios. This area was designed as a combination of a runoff farm and a diversion system with reconstructed ancient runoff channels of about 300-350 meters bringing water to the new area from the hillsides and a large new diversion channel of about 750 meters which took flood runoff in the main wadi to the upper part of the new orchard plots. A small dam allowed some manipulation of water flow into one of the channels with a gate allowing the channel to be closed in a major flood event. A nursery was established at Avdat and trees grown here for the new area. Male and female cultivars of \textit{Pistacia atlantica} and \textit{P. vera} were put out with one of the plots having pistachios and almonds in\textit{ alternating rows}. The idea here being as the almond only produced nuts after 4-5 years and pistachios began yielding only after 8 years, the mixed plantings could be more economically viable. The trees seemed to be doing well. Ibid., 375-376.
shortages are common. The bacterial soil crusts found in the Negev which allow runoff to proceed with only light falls of rain could be a limiting factor in regions where cryptogamic crusts are not present. But the widespread use of runoff farming technique in the Middle East in ancient times would suggest that the techniques could have a larger application.\textsuperscript{357}

Oweis et al. suggest that water harvesting can be used in dryland areas with rainfall averages of 100-300 mm as crops in these regions may not grow if dependent on rainfall alone.\textsuperscript{358} Prinz and Malik propose that regions with an average rainfall of 300-600 mm with few but intensive rainfall events are well suited to runoff farming.\textsuperscript{359}

However Evenari’s research would seem to indicate that rainfall events of under 10mm can generate flood episodes which can be channeled into field areas or microcatchment plots when cryptogamic soil crusts are present. Shanan talks about a threshold rainfall event of 8mm being enough to instigate a runoff event. He cites research from Jordan in 1939 indicating that falls of 8mm were needed to initiate flood flows in the watersheds of Transjordan.\textsuperscript{360}

Measurements taken between 1961-1977 show maximum yearly falls at Avdat of 161mm to a minimum yearly fall of just 18mm and Shivta recording a maximal yearly fall over this period of 167mm and a minimal yearly fall of 26 mm throughout which period runoff floods were generated and a variety of plants successfully grown out.\textsuperscript{361}

\textsuperscript{357} Abdulla and Al-Shareef make the point \textit{that from ancient times, farmers and herders in the Mediterranean have, under widely varying ecological conditions, attempted to ‘harvest’ water to secure or increase agricultural production. A wide range of indigenous techniques can be found in areas between 100 and 1000 mm annual precipitation and with population densities varying from 10 - 300 persons/km$^2$.} See Abdulla and Al-Shareef, \textit{Roof Rainwater Harvesting}, 197.

\textsuperscript{358} Oweis, Hachum and Kijne, \textit{Water Harvesting}, 2.

\textsuperscript{359} Prinz and Malik, \textit{Runoff Farming}, 3.


\textsuperscript{361} Evenari, Shanan, and Tadmor, \textit{The Negev}, 341. Evenari’s nomogram suggests that dry periods with annual falls of less than 50mm in catchment areas bigger than 50 hectares \textit{will not produce any appreciable water yield} but smaller natural watersheds can produce 20-40 cubic meters a hectare and \textit{microcatchments as much as 80-100 cubic meters per hectare}. Evenari, Shanan, and Tadmor, \textit{The Negev}, 147.
There is no question that floodwater can be dammed and led to valley bottoms and used for cropping or pasture improvement. Flow from *wadis* can also be diverted to cultivated terraced areas. Pacey and Cullis suggest that during periods of drought *the extra soil moisture from retained runoff might make all the difference between the production of a reasonable crop and a catastrophically poor harvest* particularly when runoff can be introduced into cultivated areas just prior to planting or seeding out of crop.362

Evenari makes the observation that

*runoff agriculture therefore seems to be more effective than agriculture under a comparable rainfall, since it directly stores available moisture in the root zone, very little water is wasted by ineffective rains, and most of the rainfall is used effectively for growth and development.*363

Grainger suggests that the productivity of rainfed farming could be substantially increased with subsequent reductions in soil erosion *by the introduction on to farms of water-harvesting systems which retain rainfall for a longer time on the soil surface so that more of it percolates through to crop roots.*364

Some final remarks here are from Koohafkan and Stewart who propose that

*the time may be right to rethink investment in water-harvesting practises. There is sufficient rainfall and soil information in most dryland regions, coupled with models that can analyse and determine probabilities, to design water-harvesting schemes that will improve crop production in the majority of years. These schemes may be more cost effective than developing additional irrigated lands where water resources are*

---

362 Pacey and Cullis, *Rainwater Harvesting*, 1. Pacey and Cullis also suggest that floodwater mitigation could involve the construction of contour bunds being built in high catchments closer to where the rain falls and at the same time allow cropping in these areas. Ibid., 186.

363 Ibid., 197. Whereas brief ephemeral rain episodes (10-20mm) falling on this landscape would hardly sustain productive farming without the water harvesting systems being in place thereby exploiting what would be insignificant rainfall for crop production.

limited. More importantly, these schemes can be developed in areas where there is no water available for irrigation.\textsuperscript{365}

\textbf{Some Concluding Remarks}

This research attempts to establish a link between degraded ecologies and some of the ancient water systems which once allowed these areas to flourish. Modern landscapes have been treated as industries to be mined and exploited. The ancient water systems appear to have complimented the natural systems around them by enhancing biodiversity with the creation of rich ecologies of plants, animals and farming systems.

Kuhn’s idea notion of periodic \textit{paradigm shift} is perhaps more relevant now than when he published the idea in the early 1960s. Kuhn’s description of scientific revolutions that encompass often a reluctant change in worldview describes well the sort of shifts occurring at present.\textsuperscript{366} Increasingly scientists such as Lovelock are looking at the planet as one living entity with interlinked systems. Odum’s ideas on \textit{whole systems ecology} have also been influential.\textsuperscript{367}

A greater appreciation of the natural systems around us has gone hand in hand with greater awareness of the multiple impacts of degrading landscapes and the extent of these impact on once healthy and rich ecologies.

Data from various agencies all suggest that unless change occurs various biological processes on the planet will continue to decline with implications for the future which

\begin{footnotes}
\textsuperscript{367} Odum has probably been more influential than is realized. Mollison and Holmgren’s work in looking at integrated food production systems with tree and water components as part of a design equation has also had considerable influence. See Odum’s \textit{Fundamentals of Ecology}, 1953 and Mollison’s \textit{Permaculture A Designers’ Manual}, 1988.
\end{footnotes}
do not bode well. There is always a margin of error for poor choices. However choices made become more critical when the sectors involved are themselves in crisis.

Turnbull questions the assumption that modern science is the *embodiment of the highest form of rationality and objectivity* and asks the important question of how can we have technoscience that does not dominate nature but is compatible with it, that does not exploit and demean people but enhances their lives. These are legitimate considerations.

At the beginning of the 21st century our planet as a complex biological entity is faced with multiple crisis indicators no least of which is the great loss of natural diversity. This pattern has accelerated over the last 100 years with increases in human populations and the marginalization of wilderness areas.

Drought conditions would appear to be occurring with greater regularity and access to water resources in some regions has become critical with increasingly diminished supplies for agriculture and human populations.

---

368 There are no shortages of such reports. The 2012 report *Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change* talks about the global food system being unsustainable and does not provide adequate nutrition to everyone on the planet and, at the same time, changes to our climate threaten the future of farming as we know it (from the foreword), and further that extreme weather events such as droughts and floods are predicted to become more frequent, adding to the global burden of hunger caused by poverty, weak governance, conflict and poor market access. These weather events and climate change will exacerbate the fragility of food production systems and the natural resource base — particularly in environments prone to degradation and desertification, in areas of widespread or intense water stress. See J. Beddington et al., *Achieving Food Security in the Face of Climate Change: Final Report from the Commission on Sustainable Agriculture and Climate Change* (Copenhagen, Denmark: 2012), 7-15. A 2012 report from the United Nations Secretary-General’s High-Level Panel on Global Sustainability suggests that by about 2030, the world will need at least 50 per cent more food, 45 per cent more energy and 30 per cent more water — all at a time when environmental boundaries are throwing up new limits to supply. This is true not least for climate change, which affects all aspects of human and planetary health. The document also pays tribute to the Brundtland Report of 1987 which introduced the concept of sustainable development to the international community as a new paradigm for economic growth, social equality and environmental sustainability. However more than a quarter of a century later, sustainable development remains a generally agreed concept, rather than a day-to-day, on-the-ground, practical reality. The report suggests that it is critical that we embrace a new nexus between food, water and energy. See United Nations Secretary-General’s High-Level Panel on Global Sustainability, *Resilient people, resilient planet: A future worth choosing. Overview* (New York: United Nations, 2012), 4-6.

Around a billion people do not have access to clean drinking water. At the same time the world is in the midst of rapid change. Past history would suggest change at a much slower pace. A human population of around one billion in 1830 had doubled a hundred years later and is now around 7 billion putting enormous pressures on ecosystems in many regions. This growth pattern has seen a parallel decline in other life forms on the planet which scientists such as Tim Flannery are describing as a mass extinction only paralleled by the extinction of the mega-fauna of about 55 million years ago.

The early periods discussed in this paper had much smaller populations. Many of the dryland regions had abundant wildlife and human cultures had adapted to landscapes where water was in short supply. Nabatean-Byzantine towns seemed to have been designed around water in what is a very dry region of the world. Evenari observes that if one wanders through the ruins of Shivta or Avdat, one gets the impression that the whole planning of the towns was based on water collection and storage. The flat roofs of the houses and the paved streets all served as catchment for rainwater. Water was led carefully from the roofs through clay pipes built into the walls to the cisterns dug

---

370 Steven Mithen and Emily Black, "Introduction: An Interdisciplinary Approach to Water, Life and Civilization," in Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley, ed. Steven Mithen and Emily Black (New York: Cambridge University Press, 2011), 1. Mithen and Black cite a UN Water report from 2007 suggesting that by 2025 almost one fifth of the global population is likely to be living in countries or regions with absolute water scarcity while two-thirds of the population will probably live under conditions of water stress. A report from the United Nations Development Programme from 2011 suggests that although one third of humanity lives in drylands, they enjoy just 8 percent of the world's renewable water supply. N. Middleton et al., The Forgotten Billion: MDG Achievement in the Drylands (New York, USA and Bonn, Germany, 2011), 17. Pollution of waterways is increasingly common with build up of plastics and other contaminants. Spring systems have disappeared. Ground water aquifers are being depleted faster than natural recharge and ground water contamination is a concern. Modern science has yet to come up with a way of cleaning these old natural water storages (aquifers) which can hold good quality water that can be thousands of years old. Interestingly Pokhrel et al suggest that groundwater depletion has contributed to rises in sea levels because much of the water taken from groundwater aquifers eventually reaches the oceans. They estimate a total of around 359 km³ of annual unsustainable groundwater use over the period 1951-200 with the assumption that 97% of this groundwater ends up in the world's oceans Model Estimates of sea-level change due to anthropogenic impacts on terrestrial water storage. See Yadu N. Pokhrel et al., "Model Estimates of Sea-Level Change Due to Anthropogenic Impacts on Terrestrial Water Storage," Nature Geoscience, 5, June (2012), 389-390.

371 According to Devillers and Beudels-Jamar the planet is going through a period of large-scale extinction on a parallel with any other such event in the past. See Pierre Devillers and Roseline C. Beudels-Jamar, The Role of Megafauna in Dryland, Natural and Cultural Heritage Conservation, 103.
under the floors of the houses. It seems that building regulations demanded provision for a catchment and cistern in every structure so that no citizen would be a burden on the community.\textsuperscript{372}

Western culture would seem to take water for granted. In ancient times attitudes were different with old cultures being in awe of water and its powers of regeneration with water venerated for its power to transform landscapes and engender life. Herodotus observes a Persian tradition where

\textit{they never pass water into a river or spit into it; neither do they wash their hands in it nor tolerate another doing so. Rather they show the deepest reverence for their rivers}\textsuperscript{373}

The human species has given rise to historically rich and diverse cultures across the planet however the same species has also universally altered landscapes usually with little understanding of consequence.

Forests would seem to be important to the health of the planet and there can be no question that patterns of deforestation over thousands of years have radically changed whole ecologies with subsequent reductions in once biologically rich regions.

Once tree cover is removed it becomes difficult to re-establish. The Outer Hebridean islands of Scotland were forested until relatively recent times but the forests were cut and burnt by feuding Norwegians leaving a treeless windswept landscape relatively unchanged to this day.\textsuperscript{374} Regions which now have relatively barren landscapes had

\textsuperscript{372} Evenari, Shanan, and Tadmor, \textit{The Negev}, 171. Evenari’s research deserves to be better known and understood. The overlay of the old Avdat system with sophisticated water monitoring equipment provided interesting results. Modern day equipment running on solar power would provide good back up data.

\textsuperscript{373} Hartung and Kuros, \textit{Historical Dams}, 112. Pockets of this practise still exist with some anecdotal evidence from Mongolia, a country that still preserves elements of very old traditions.
biologically rich ecologies in recent historical periods. Mountfort’s expedition into Jordan looked at the Qasr al Amara, an 8th century Umayyad hunting lodge situated about 20 kilometres west of Azraq with rooms displaying frescoes depicting gazelles, bustards, cranes, a bear, a lion and various hunting scenes. The surrounding area now is arid with little or no vegetation or game. There are many such examples.

Jacobsen and Adams were correct when they warned of the dangers of a rapidly expanding cropping sector in Iraq. They were pointing to an irrigation tradition around them of many thousands of years’ duration that was being ignored and they in turn were also ignored. Grainger laments the lack of policy change when the evidence for that change is compelling. Grainger almost certainly had expected that something would have come out of his own prodigious research into drylands degradation. He had proposed a variety of interesting strategies and his research had been sponsored

374 See John Macleod, Highlanders: A History of the Gaels (London: Hodder & Stoughton, 1996), 68-69. The war between Vikings or Norsemen in their Hebrides Islands kingdom and mainland Norwegian Norsemen in the 11th century led to the deforestation of the Outer Hebridean Islands. Macleod says The very landscape of the isles today is a silent witness to that awful campaign. Today the Outer Hebrides are bare and treeless. Then they were densely wooded, with acres of low scrub and coppice. Cripplehand mentions fig trees; he was no botanist, but there was certainly abundant, if scruffy, tree cover on Lewis in his day. At any rate, Magnus Bareleg destroyed these forests, which had hitherto survived the needs of the population for wood and charcoal. They never recovered. An expanding population rapidly consumed what remained. The climate grew damper, colder, and the peat deposits thickened fast, and the trees did not grow again. Bjon Cripplehand was a witness to the conflict and skaid to Magnus Bareleg (Magnus Olafsson), the king of Norway.

375 Mountfort, The Story of an Expedition, 79. Jordan falls into the category of a water-scarce country with less than 1,000 cubic metres of fresh water per person per year and is ranked as one of the 10 most water-deprived countries of the world. See Stephen, Emily Black, and Robert Potter. "Current Water Demands and Future Strategies under Changing Climatic Conditions,” in Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley, ed. Steven Mithen and Emily Black (New York: Cambridge University Press, 2011), 406. Jordan lies in a region where the strength and duration of the old traditions of water harvesting have widespread cultural acceptance and where rainwater collection is still used despite conventional water distribution infrastructure. To some extent this can be explained by a culture accustomed to periodic water shortages and periods of drought in what is now an extremely dry climate. Though as we have seen, it may not have been as dry prior to the Ottoman removal of tree cover in the region. But the old water harvesting systems could perhaps be more easily reintroduced to dryland regions where the tradition was a common part of everyday life in past cultures. See F Abdulla and Al-Shareef, Roof rainwater harvesting systems for household water supply in Jordan, 197. The Intergovernmental Panel on Climate Change ((IPCC) has provided data suggesting that the region of the Middle East will become much drier with the rise in greenhouse gas levels with potentially devastating consequences. E. Black et al., "Future Climate of the Middle East," in Water, Life and Civilization: Climate, Environment and Society in the Jordan Valley, ed. S. Mithen and E. Black (New York: Cambridge University Press, 2011), 51.
by the UN Environmental Programme. But little changed and if anything the patterns he describes in West Africa have worsened.\textsuperscript{376}

Jacobsen and Adams were concerned about salinity and the disregard for a rich farming and irrigation tradition going back thousands of years. Current thinking on this perennial problem revolves around the principle that good drainage is important in irrigation schemes otherwise soils can readily become waterlogged and salts accumulate. Modern and ancient patterns of irrigation saw problems occurring when excessive water was added to cropping lands. It would seem however that very early irrigation and farming systems in Mesopotamia used plants to manage salinity in conjunction with fallow periods.

There is some recent evidence for the use of plants in preventing salinity. Andrews puts the case that artificial disruptions to the natural hydrology of a region in particular the removal of vegetative cover, can also lead to problems with salt accumulation in soils. Andrews is suggesting that hydrology, fertility and biodiversity are connected and that plants used to run terrestrial hydrological systems until they were removed. Andrews proposes that the Australian landscape used to cope with salt perfectly well but vegetation removal, dam building and inappropriate drainage systems have altered patterns of subterranean water flow which has disrupted natural

\textsuperscript{376} The Threatening Desert was funded by the UN Environment Programme (UNEP). Grainger wrote a paper called The Role of Science In Implementing International Environmental Agreement: The Case Of Desertification. The UN Conference on Desertification (UNCOD) took place in Nairobi in 1977 and approved a Plan of Action to Combat Desertification. Grainger’s research came out of that plan. But little progress was made in implementing the plan despite its comprehensive scope and grounding in science. There are hundreds of international environmental agreements (IEAs). Granger suggests an effectiveness index to compare the implementation of such agreements. He also says that scientists and policy makers construct a boundary around the science domain to enhance its stature and distinguish scientific knowledge from other forms. See Granger, “The Role of Science in Implementing International Environmental Agreement: The Case of Desertification.” Land Degradation & Development 20, (2009): 412- 415. Essahli and Sokona, point out the differences between political discourse and the actions taken in the field to combat desertification. See Policy Requirements to Combat Desertification, 60-61.
patterns of salt distribution and storage in soils. These ideas cannot be dismissed easily.

The old cultures of Mesopotamia and India put in place irrigation systems that spread water flow allowing it to pond in cultivated areas. In the dryland regions of Jordan, Israel and Yemen *wadi* floods were managed to direct water on to flatter lands for use in cropping areas. Floodwaters were managed by spreading potentially destructive flow into productive crop systems benefitting from the slow penetration of nutrient rich water into soils. In Mesopotamia and India this form of irrigation could be adapted to harvest both fish and food crops planted out after waters had receded.

The old irrigation systems on broad flooding plains saw the development of highly productive farming systems with diversion canals and embankments allowing water to be directed and impounded in cultivated areas. Potentially damaging floodwaters were channeled into farming systems.

The Euphrates was relatively easy to extract water from as the river bed was higher than the surrounding plain. This is a characteristic of river systems carrying large quantities of silt. Irrigation was simply carried out by breaching levees allowing water into fields and diversion channels. Sediment load in these river systems raised their beds above the surrounding floodplains.378

377 See Peter Andrews, *Back from the Brink*, (ABC Books, 2007), 20 and 84. Andrews’s primary concern is with natural hydrological systems in the Australian landscape. Andrews observes that few Australian farmers *make any attempt to understand the hydrology of the land they own*. See Andrews, 2. Andrews describes the Australian landscape as having a *layer of salt water in the ground at varying distances beneath the surface*. This salt water cannot possibly surface as long as there’s a layer, or lens, of fresh water above it – that is just below the surface. The fresh water will always keep the salt water suppressed and according to Andrews salt levels were kept in balance in this way in the Australian landscape and that importantly this fresh water lens was created and maintained by plant life. Andrews is referring to a natural regime of trees and grasses. Ibid., 2-13.

378 Postel, *Pillars of Sand*, 19. Slow river speed causes flood plain rivers to drop their sediment load which over time raises river beds and their banks above the surrounding lands which means that rivers can flood easily and change courses. Ibid., 19 and 25. The Yellow River sits about 4-7 metres above the surrounding plains. The Chinese government have had to strengthen dikes along more than a 1,000 kilometres of river banks plus build flood control dams upstream. This river carries an annual load of 1.6 billion tons of sediment most of which is carried to the sea but 200 million tons is dropped as the river slows with the river bed rising about 10 centimetres a year. See Postel, *Pillars of Sand*, 68. The Ganges and Brahmaputra Rivers deposit about a billion tons of sediment each year into the densely populated Bengal Basin, See Kuehl et al., “The Ganges-Brahmaputra Delta: River Deltas—Concepts, Models, and Examples,” *Special Publication 83: SEPM Society for Sedimentary Geology* (2005), 413.
These were productive systems. Willcocks describes the monsoonal rains wetting the soils for crop planting in Bengal and the accumulation of surface water allowing mosquito larvae to breed up and then the muddy waters of the rivers come down with millions of eggs of the finest carp at first, later of inferior fish, and finally of shrimps. These fish fed on the mosquito larvae and soon all the canals, watercourses, fields and tanks became full of fish.\textsuperscript{379}

Andrews in his quest to understand hydrological systems in the Australian landscape maintains that in the past many Australian rivers and creeks were elevated above the surrounding sediment with periodic flooding causing these water systems to spread across plains permitting water to soak into soils.\textsuperscript{380} Andrews says the idea that in the Australian landscape water ran naturally on elevated ground is completely foreign to most people.\textsuperscript{381} He quotes the explorer Thomas Mitchell who travelled through north-west New South Wales in 1851.

\textit{At length we reached an open tract across which we travelled in a south-west direction about eight miles, when we arrived at one of those watercourses or chains of ponds which always have the appearance of being on the highest parts of the plains and further}

\textsuperscript{379} Willcocks, \textit{Ancient Systems}, 60. Floodplain systems are species rich with great habitat complexity. Sparks talks about a flood pulse which engenders a slowly spreading waters into marsh areas which can be occupied by different fish types that have adapted physiologically and anatomically to a low oxygen environment (for example, the tropical lungfish species, Dipnoi). In these large flood plain systems fish yields per acre can be very high. Sparks talks about flood plain river systems being characterized by seasonal flooding that promote the exchange of nutrients and organisms among a mosaic of habitats and thus enhance biological productivity. Richard E. Sparks, "Need for Ecosystem Management of Large Rivers and Their Floodplains" in \textit{BioScience} 45, Mar 3 (1995): 168 and 170-171. Human activities have altered the majority of the world’s large river-floodplain systems which once constituted very large biologically rich systems. There are 79 of these large eco-systems. Colonial records from the 17th and 18th centuries suggest that the lower delta plain of the Ganges-Brahmaputra Delta was mainly mangrove forest with only remnants remaining mainly in the Sunderbans marsh areas. See Kuehl et al., \textit{The Ganges-Brahmaputra Delta}, 413 and 422.

\textsuperscript{380} Andrews, \textit{Back from the Brink}, 47 and 53. Andrews is describing rivers like the Paroo which comes down from south-west Queensland and has a floodplain more than 100 kilometres wide.

\textsuperscript{381} Ibid., 173. As opposed to the present situation where rivers and creeks run through deep eroded channels that are lower than the surrounding land. Ibid., 48.
We found these ponds in situations which seemed rather elevated above the adjacent plains, at least their immediate banks were higher; hence we usually came upon them where we least expected to see water before we were acquainted with this peculiarity of the country.382

Andrews maintains that these early explorers merely saw remnants of an ancient natural system that had largely been destroyed by the burning practices of indigenous Aboriginal populations and later by European settlement.

All too often the great flooding patterns of such landscapes are seen in modern times as a problem to be dealt with through the construction of extensive barriers across or along waterways. Certainly there is no question that flood events can be catastrophic it would seem however that ancient cultures managed their floodplains for farming.383 Systems in place to spread floodwater onto basins where cropping can occur once water recedes was a productive methodology used in Egypt, Mesopotamia and India. The construction of diversion systems along waterways which can be opened simultaneously when required as described by Willcocks, to release flood water onto cropping basins means productive use of a water resources which could otherwise be destructive downstream. Ancient cultures saw flooding as an opportunity to capture

382 Ibid., 173-174. Andrews also cites John Oxley travelling around the Lachlan River in 1817. During our whole journey, we have never discovered in what manner any additional supply of water could be conveyed to it [the river], as the back lands (with the exception of the ranges) were always lower than the immediate banks of the river itself. Ibid., 174. Andrews also cites Aboriginal paintings which depict floodplain steps. Andrews refers to these paintings as quite accurate illustrations of an ancient floodplain system, complete with separate steps, ponds, wetlands and watercourses running through the middle. According to Andrews in the past water moved down from the higher country through a series of floodplain steps, diffusing through each floodplain and filling the ground with nutrient-laden water. The further water moved down, the richer in nutrients it became. The plants grew and flourished in this slowly moving inground water. Ibid., 49.

383 The ancient Mesopotamians were well aware of the devastation that could about through flood episodes. The Tigris and Euphrates were much more unpredictable than the Nile and could overflow to destroy dikes and crops. One inscription relates:

Rising waters, grievous to eyes of man
All-powerful flood, which forces the embankments
And Mows mighty mesu-trees,
(Frenzied) storm, tearing all things in massed confusion
With it (in hurtling speedy)

H Frankfort et al., Before Philosophy, 138-139. (The mesu tree has not been identified but appears to have been fairly common occurring in both mythical and administrative texts.)
large quantities of a precious resource. Storage or holding structures were built to conserve supply.

Evenari’s work serves as a testimony to the productivity of dryland water harvesting systems for food production in regions where water resources are limited. The research covered spanned many years of work in growing out a variety of plants using runoff water. The research successfully duplicated the old Nabatean and Byzantine systems of harvesting floodwater from dry wadi systems. A later stage saw the introduction of sheep by first using runoff to establish a good cover of pasture plants. Watering of animals was achieved by the use of ancient stone-lined wells.

One major difficulty with dryland crop systems can be great variation in rainfall patterns over different years which can affect yields. Ancient systems took this factor into account with the construction of good water storage systems for local farming and human needs. Ancient farmers stopped seasonal floodwater pouring down gullies from being an erosive force by putting in place systems which allowed water to percolate gently into cropping areas. When these systems were abandoned and natural deterioration occurred, floodwaters in time broke through the old dams and terraces leading to destructive erosion patterns in what were once productive agricultural areas.Degraded landscapes emerged in their place. Evenari cites the evidence of Baradez who was a colonel in the French Air force during French colonial days in North Africa whose photographs from the air revealed terraced wadis, diversion systems, large runoff fields, runoff cisterns and villages, in an area that is completely barren today.

---


385 Evenari, Shanan, and Tadmor, The Negev 353. See J. Baradez, Vue aérienne de l’organisation romaine dans le sud algérien Fossatum africæ (Arts et métiers, Paris, 1948). Evenari also describes a location called Nahel Bakara where floodwaters were controlled by ancient terraced walls which had the effect of allowing flow to be dispersed to a width of 30-50 meters over the valley floor. The system has long been abandoned for agricultural purposes but the dispersal of floodwaters had allowed relatively lush perennial and annual vegetation to grow. Evenari witnessed the destruction of the last downstream wall and saw how over a 20-year period unchecked floodwaters led to the wadi growing deeper and wider into the flood plain with the resultant destruction of upstream walls. He relates how in 1951 the gully at the lower end was about 1 meter wide and 1 meter deep. Fifteen years later it had become a wadi 50 metres wide with vertical loessial banks 3 metres high and had cut back some 300 meters into the original stable floodplain. Ibid., 70.
Evenari’s research would seem to suggest that dryland regions with biological soil crusts can see productive water harvesting at much lower rainfall rates than would be expected. Oweis suggests that *the worldwide potential for the introduction of water harvesting techniques has not been fully assessed.*

The idea of using small micro-catchment plots or *limans* which harvest their own water to grow out a range of useful trees in areas where there is little or no tree cover would appear to have considerable merit.

Runoff harvesting systems could deliver supplies of water to restore degraded ecosystems. Traditional dryland water harvesting systems have the potential to help establish forests in areas that are now sparsely vegetated. This is sometimes described as restorative ecology.

Tree cover is used by many different creatures as habitat and their combined waste products are significant in changing soil types in combination with rotting wood in the form of fallen branches and leaf litter. The exclusion of browsing impacts encourages understory species to move in usually through bird droppings and other seed dispersal mechanisms. The important bacterial and other biological interactions that make up the forest floor are reconstituted.

---


387 Forest floors are complex and little studied. Chris Maser made some interesting discoveries when studying the processes involved in the breakdown of fallen timber on a forest floor. Maser examined the role of small mammals that fed on the spores of mycorrhizal fungi. In the U.S., the deer mouse (*Peromyscus*) carries the nitrogen-fixing bacteria *Clostridium butyricum* which is important in the inoculation of Douglas-fir seedlings (*Pseudotsuga menziesii*). Maser’s research found that when these small mammals fed on fungi each faecal pellet dropped contained between 500,000 to 800,000 viable spores. This data astonished local U.S. foresters as millions of dollars were being spent each year poisoning these same animals. The Red-backed vole (*Clethrionomys*) has about 300,000 such spores and one deer pellet contains up to ten million spores. Rotting wood under trees will produce fungi and later different mushrooms and toadstools which are consumed by various creatures and these animals almost certainly disperse mycorrhiza spores which can form associations with tree root endings in an important process where they contribute and enhance nutrient uptake in trees. Australia has over 50 known species of native rats and mice as well as various marsupials and the more recent arrival of several deer species all of which will utilize mushrooms and toadstools as food so spreading fungi and encouraging the complexity that makes up a forest floor. These associations are little studied or understood. *Ancient Forests, Priceless Treasures* Chris Maser in *Restoration Forestry. An International Guide to Sustainable Forestry Practices*. Michael Pilarsky. Kivaki Press 1994. 76 ff.
This can be an important process in restoring degraded landscapes. Trees can also fix nitrogen in poor soils and shade becomes a possibility. Shade is best described as indirect or diffused light and various life forms including beneficial mycorrhizal fungi will grow and flourish in shaded areas when they will not survive in open sunlight. These processes are important in ecological restoration and can only occur in the presence of water.

Forests can also supply abundant resources to human populations in the form of wood and edibles which can include fruit, berries, root crops and game. Forests rehumidify the surrounding atmosphere and seem to create moisture systems that are imperfectly understood. These moisture systems harbour life and also seem to enhance cloud formation and so rainfall. The capacity of nature to heal itself is immense if water, plants and wildlife are present.

In dryland regions runoff systems could also be used to grow out a range of commercial herbs, flower, hemp or tree crops. Evenari’s research, which appears to be now little known, also demonstrated that a large variety of important pasture plants can be grown out by using runoff technique. Such plants are of great importance in maintaining livestock and improving soils. The placement of above or preferably below ground, storage cisterns to hold excess runoff in dry regions is well within the capacity of modern construction technology.

In recent times there has been greater realization that community based processes can facilitate solutions towards local responsibility for local landscapes which could be based on watersheds. It may be appropriate for local communities particularly in dry regions to be involved in decisions on storage and use of water with the option of establishing local food and tree polycultures.

In this way local knowledge systems are built up. This is an extremely important old tradition where local cultures always had individuals who were highly skilled in a

---

388 It has been argued that restoring tree cover in dryland areas could help mitigate climate change by increasing carbon uptake and storage, even if only a small amount of carbon per unit area will be sequestered. See Malagnoux, Sene and Atzmon, Forests, Trees and Water, 26.
number of fields, a tradition which to a large extent has been disenfranchised by modern economic processes.

Sir William Fairbairn’s description of a millwright in 1861 is interesting.

The millwright of former days was to a great extent the sole representative of mechanical art...he was an itinerant engineer and mechanic of high reputation. He could handle the axe, the hammer and the plane with equal skill and precision; he could turn, bore or forge with the despatch of one brought up to the trades and he could set out and cut furrows of a millstone with an accuracy equal or superior to that of the miller himself...Generally he was a fair mathematician, knew something of geometry, levelling and mensuration, and in some cases possessed a very competent knowledge of practical mathematics. He could calculate the velocities, strength and power of machines, could draw in plan and section and could construct buildings, conduits, or water course in all forms and under all conditions required in his professional practice. He could build bridges, cut canals and perform a variety of work now done by civil engineers.389

Solutions to water shortages are critical to farming systems and human populations. Drought patterns can seriously impact on food production and different elements such as population growth, agricultural, industry and tourism combine to place ever greater strains on available water resources. At the same time all of these factors have seen declines in the availability of water despite large-scale exploitation of surface and groundwater resources. Possible reductions in rainfall and increases in evaporation rates over the next century are likely to compound shortages of this critical resource in some regions.

---

389 Cooley, M. "The Fragmentation of Skills," in On the Social Analysis of Science, ed. David Wade Chambers (Victoria: Deakin University Press, 1984), 76. Cooley talks about the fragmentation of skills a process which since the industrial revolution is accepted as being normal with traditional knowledge systems being marginalized. Popper says that Certain types of tradition of great importance are local, and cannot easily be transplanted. These traditions are precious things, and it is very difficult to restore them once they are lost. Karl R. Popper, Conjectures and Refutations: The Growth of Scientific Knowledge, (London: Routledge & Kegan Paul, 1963) 121.
Ancient water systems were well engineered to harvest useful quantities of water for farming and other human needs. Such systems should not be dismissed as mere historical curiosities. The old hydrological engineering systems were clever and could be replicated to sustain productive farming systems. Replicas of these old systems could also be used for ecological restoration. It is time to look at new solutions to the way water is perceived, collected and used before a precarious situation becomes increasingly a threat to the biological systems of the planet.

..........................

Appendix - Forestry

This section looks at a few dryland species only and also refers to some traditional use of trees in drylands regions in Africa, India and the Middle East.

The prospect of using historically productive dryland water harvesting systems to grow out trees in regions where water resources are scarce would seem to have merit.

In many regions of the Near East and elsewhere on the planet, patterns of deforestation have been devastating with loss of once rich biologically diverse ecologies and human cultures. It is probable that the removal of large tracts of forest can also affect regional rainfall patterns and negatively impact ground water tables. The concept of restoration ecology is perhaps made all the more pertinent by the uncertainties of climate change and rapid population growth.

Dryland water harvesting technique could provide water systems for reforestation projects in regions where lack of water resources usually precludes such projects or limits survival rates of species planted. There are different perspectives on how best to establish tree cover which involve planting technique, protection from browsing animals and maintenance regimes.

Water is seen here as a critical element.
Different tree species have adaption mechanisms to certain conditions and choice of species is important. Farm forestry projects where agriculture and forestry can be combined can bring benefits such as higher crop yields and reductions in soil erosion with fodder, fuelwood, poles and other potential yields.\(^{390}\)

Fodder trees planted out in deep hedgerows in dryland regions could furnish a good nutrient source for various farm animals particularly in times of drought. The research indicated above would seem to indicate the viability of such a design element in regions where water can be scarce and the need for fodder is critical to prevent loss of animals and/or the need to ‘import’ expensive feed.

Bee fodder systems should not be excluded here nor the use of water harvesting to put out a range of perennial pasture plants. Evenari’s experience with the Awassi sheep would appear to testify to the utility of such a strategy. Hedgerows traditionally formed living field borders and had a rich diversity of plants which served as both nutrient rich fodder and medicine to browsing farm animals. These same hedges also attracted bees and provided nectar for these important insects. The traditional ‘herbal ley’ is little mentioned these days but once provided a botanically rich assortment of pasture plants many of which were of benefit to animals and soils.

Rainwater harvesting systems could also be used to establish commercial plantings of various medicinal herbs. These plants often do exceptionally well in a dry environment. Evenari’s mention of the pharmaceutically active alkaloids in the herbs trialled at Wadi Shamash (see p. 100 above) is an indication of the effect of abundant sunshine and dry conditions which would appear to concentrate these medicinally important alkaloids.\(^{391}\)

---

\(^{390}\) Norman Hall, *The Use of Trees and Shrubs in the Dry Country of Australia*, Australian Government Publication Service: Canberra, 1972), 1, is a very good starting point although published 40 years ago. This classic text begins with the admonition that *the more severe the climate in any region the greater is the need for trees and shrubs to ameliorate the extremes of temperature or to reduce the effect of strong winds*. The author talks about dryland management strategies in Australia which involve water harvesting, production of commercial timber and the provision of some recreational facilities. See ibid., 24.

\(^{391}\) The author has taken slides of *artemesia* sp., planted out in the bare desert near the Red Sea (where there is no average rainfall) for commercial purpose. The irrigation system had been removed from these plants three years prior to his visit and the plants were thriving.
Grainger advocates much more research into multi-purpose trees if such trees are to attain their full potential in making drylands more productive. Work has been done in this area by The US National Academy of Science plus a short lived journal the International Tree Crops Journal, which was established in 1980, but the idea does not appear to have caught on within agricultural bodies around the world.392

Research from Africa, which appears to have been based on good knowledge of traditional farming system, shows the extent of harvest possible from a forest system for local households. Yields can include fuel woods, construction materials, and wild food including medicinal plants. The Center for International Forestry Research (CIFOR) defined such products (NTFPs non-timber forest products) to include fruits, nuts, vegetables, fish and game animals, medicinal plants, resins, fiber plants, bamboo, palms and grasses.393

In Australia, the seed of some acacia sp. have provided food for Aboriginals in dryland areas for thousands of years with many of these trees traditionally being a significant seasonal component of Australian Aboriginal diets.394 Many Australian Acacias produce seed with high nutritional value and have lower toxicity levels compared to many African Acacia species. Quite a few Australian acacias yield edible green seed pods which can be eaten raw or processed into a flour and baked.

Some examples are Acacia colei which will tolerate drought conditions and produces an abundant crop of seed. This tree also has rapid growth rates and will coppice well and can be used for wind breaks, land rehabilitation and fuelwood production. (A. colei produces a dense wood suitable for fuelwood or charcoal). Acacia tumida is very fast growing with an average growth rate of over 1 meter per year. This tree can


also be coppiced and dry mature seed is edible either dry or green. Some other Australian acacias in this category are *A. acradenia*, *A. adsurgens*, *A. ampliceps*, *A. citrinoviridis*. Many of these trees could be used for land rehabilitation, windbreaks, soil restoration, fuelwoods.\[^{395}\]

There are many recorded traditional uses of *Acacias* in Africa. Grainger describes farmers in Chad locating their cattle in compounds through the rainy season where they are fed acacia pods (*Acacia Albida*) and manure is taken from the compound for use as crop fertilizer. In dryland regions of Africa this tree is intercropped with other crops such as millet and sorghum and its foliage used as fodder. *A. albida* is drought resistant and fixes nitrogen and has an open canopy which means it can be grown out with field crops.\[^{396}\]

Fodder trees as mentioned above can be of great importance in dryland regions where drought periods are increasingly common. Mukhopadhyay suggests *Azadirachta indica* and *Ailanthus excelsa* as good dryland species.\[^{397}\] These trees can be lopped for leaf fodder in winter when dormancy means they are not damaged.\[^{398}\]

The carob tree *Ceratonia siliqua* has very good potential as a fodder tree and will do well on dry soils and rocky hillsides. Carob pods are rich in sugars and in the Middle East are also turned into a high value honey-like product. Carobs also fix nitrogen into soils are exceptionally hardy and will recover from fire damage. Smith in his classic work *Tree Crops: A Permanent Agriculture* has a chapter on the use of carob trees as

---

\[^{395}\] See pages 5-34 for a discussion of promising species and their attributes, A.P.N. House, *Australian Dry-Zone Acacias For Human Food.*

\[^{396}\] Grainger, *The Threatening Desert*, 199. Over a hundred years ago, the Sultan of Zinder issued an edict threatening to remove the head of anyone cutting down an *Acacia albida*. One possible legacy is the high number of field trees throughout the farming areas of the Zinder region of Niger. See Grainger 248-249. Africa has a great variety of indigenous trees and shrubs which have multiple uses, for example, the Mopane. (*Colophospermum mopane).*

\[^{397}\] *Melia azadirachta* is found in Australian rainforests and as been planted out in the Middle East as a drylands tree.

a fodder and food tree. Smith relates how the carob was used as fodder for Allenby’s cavalry (Australian Light Horse) in Palestine during the First World War.399

Many Mediterranean species are drought resistant as can be seen from Evenari’s research. One traditional technique from the Middle East is to plant an olive tree and a fig in the same hole or very close together. The fig will produce fruit long before the olive but is removed after 7 years just before the olive tree begins to bear.400

In Africa *Acacia senegal* and *Acacia seyal* are harvested for gum arabic which has been traded and sold over thousands of years and is traditionally used as a medicine and food as well as being a valued product for food and pharmaceutical industries.401 *Acacia senegal* is also allowed to colonize fallow plots and the tree is then tapped for gum Arabic after five years. Tree cover here protects soils from erosion plus provides leaf litter for soil improvement. Short-lived *acacias* can be used in this way and then cut as fuel wood.402

Malagnoux describes how *Acacias* used in sub-Saharan dryland regions provide *gum, fodder and fuelwood production which diversifies household income*. These trees also protect crops against rain and wind erosion, alleviating climatic extremes and, above all, restoring soil fertility.403


401 Gum arabic is produced in 17 African countries. World demand for gum arabic in 2010 was about 100,000 tons with a supply shortfall of roughly 70,000 tons. The EU is the biggest market for this product. *Guidelines on Sustainable forest management in drylands of sub-Saharan Africa. Arid Zone Forests and Forestry Working Paper No. 1.* (Romes: FAO, 2010) 3.

402 Grainger, *The Threatening Desert*, 67. This fallow system was a popular tradition in the west Kordofan region of Sudan. Grainger suggests that population pressures have seen this tradition disappearing. Ibid., 68.

Eucalyptus sp. are well suited to dryland regions and have been planted out in many such regions throughout the world. There is no question that this species can provide good quality timber but there is also disquiet about water requirements. Eucalyptus camaldulensis planted near Bangalore in India and monitored for water uptake used considerable water resources taking up more water than rainfall over a three-year study period. Root growth was greater than 2.5 m a year. The two other species in the same trial namely Tectona grandis (Teak) and Artocarpus heterophyllus (Jackfruit) used much less water. Eucalyptus camaldulensis planted out at 3 x 3 m spacing on the Gareh Bygone Plain in Iran were also seen to be using large amounts of water with each tree consuming about 50 liters of water a day in summer. Kowsar calculated that E. camaldulensis planted out at this spacing would deprive a community of 1,000 residents of domestic water for every hectare planted. In India Eucalypts have been described as a species which harms the soil without providing fuel, fodder, green mulch or shade.

Prosopis cineraria grows in the dryland regions of India and this species has been traditionally used in rural economies in the northwestern dryland areas of the Indian sub-continent. The tree is leguminous and can be managed as a coppice system. P. cineraria has a very deep tap root so does not compete with other crops and the large root system is useful in dune stabilization and also used as a windbreak and shelterbelt and in the afforestation of dryland areas. Leaf litter drop is also useful for

404 Ian R. Calder et al., Eucalyptus water use greater than rainfall input – a possible explanation from southern India, Hydrology and Earth System Sciences 1, 2 (1997): 253-255.


406 Grainger, The Threatening Desert, 246-247. Eucalyptus have now been planted out in many countries around the world. As a tree species they have a tendency to become a weed pest, a problem compounded by the great flammability of this species. In Australia eucalyptus have colonized vast areas where once rainforest flourished. Rainforest species are largely fire-retardant while crown fires in eucalyptus are well documented.
organic matter into soils. This tree can also provide wood for house construction, rafters, doors, windows and posts as well as different agricultural tools plus it can supply green fodder for animals in winter when little or no other fodder is available with the leaves being highly nutritious to stock.

The Bishnoi culture in Rajasthan regards *Prosopis cineraria* as a sacred tree. Its leaves are used for fodder, fallen branches as fuel and the fruit as food and also used to stabilize sand dunes. Local tradition has it that *P. cineraria* will increase crop yields if planted nearby. Groves of these trees (*orans*) provide habitat for the Indian gazelle and other wildlife. *Orans* also help to recharge rainfall into aquifers. It has been estimated that there are over 400 *orans* in Rajasthan covering an area of over 100,000 hectares. Mukhopadhyay talks about these systems in terms of intelligent and sustainable use of land, water and soil without causing damage to the resilience of the surrounding ecosystem.

Traditional use of trees in Africa is well documented. In Burkina Faso local women collect shea nuts (*Vitellaria paradoxa*) and turn it into a cooking oil. The baobab (*Adansonia digitata*) is a source of food with small animals being hunted in the trees undergrowth. *Cissus* fruits are also eaten. Africa has a long tradition of seeds, pods and leaves being used as a source of fodder which can be a vital source of nutrition for livestock at the end of the dry season when ground cover vegetation is scarce.

---

407 Mukhopadhyay, *Indigenous Knowledge and Sustainable Natural Resource Management in the Indian Desert*, 166-168. Mukhopadhyay describes *P. cineraria* as being able to withstand the rigorous and exacting conditions of the Rajasthan desert. The *Prosopis* genus comprises 44 species and can be described as ‘multi-purpose’ trees which are drought resistant and saline tolerant with pods that can contain up to 14% protein. Most of these trees fix nitrogen into soils and will grow in regions with less than 100 mm of rain. Both the pods and leaves can be used as fodder. See Grainger, 198.

408 Ibid., 166 *Indigenous Knowledge and Sustainable Natural Resource Management in the Indian Desert*. The tree has also various medicinal qualities. The flowers mixed with sugar is given against miscarriage. An extract from the bark has anti-inflammatory properties. The tree also produces gum plus the bark has anthelmintic properties and is also used to treat *rheumatism, cough colds, asthma and scorpion stings*. See Mukhopadhyay, p 168. Elsewhere in the dryland regions of India *Prosopis juliflora* and *P. cineraria* are lopped for fodder during winter without damaging the trees growth patterns and can support sheep and cattle. Plantations featuring *Prosopis nigra* and *P. alba* in Chile produced an annual fodder crop of between 1-2 tonnes from 50-105 trees per hectare. See Grainger, *The Threatening Desert*, 198.


In Africa various vegetative propagation techniques are also employed such as root suckering techniques using suckers, stolons and rhizomes. Bellefontaine makes the point that in parts of Africa the traditional know-how of the population have hardly been investigated with regard to these useful techniques. This is despite locals in Burkina Faso, Niger, northern Cameroon and Uganda making use of these propagation techniques. For example in Uganda root suckering is employed to improve the hectare density of ligneous medicinal trees threatened with extinction (Spathodea campanulata is mentioned). The authors suggest that these propagation techniques are inexpensive and can play a useful role in land regeneration.\(^{411}\)

This is by no means an exhaustive list of dryland species which can be planted out for a variety of productive use. Evenari’s work led to plantings of some forestry trees in the late 1970’s including: \textit{Acacia victoria}, \textit{A. horrida}, \textit{A. pendula}, \textit{A. ciliata}, \textit{A. loderi}, \textit{Eucalyptus sticklandii} and \textit{E. torquata}, \textit{E. woodwardi} as well as \textit{Ceratonia siliqua} (carob) and \textit{Prosopis tamarugo}. Some of these trees had reached 3-4 m after three years.\(^{412}\)

There is a range of diverse dryland plants worthy of consideration. Salt tolerant species like Tamarisk or \textit{Prosopis} can be put out to combat salinity problems.

\[\ldots\]

\(^{411}\) Ronald Bellefontaine, and Michel Malagnoux, \textit{Vegetative Propagation at Low Cost: A Method to Restore Degraded Lands}, 425-428. In Burkina Faso bunds are used as a technique for increasing crop yields and reducing drought risk with trees planted on contour lines producing leaf fall for mulch purposes and acacias planted out on cropped land because of their ability (as leguminous plants) to restore soil fertility. See Pacey and Cullis, \textit{Rainwater Harvesting}, 172.

\(^{412}\) See Evenari, Shanan, and Tadmor, \textit{The Negev}, 378.

\[\ldots\]
Bibliography


Malagnoux, M. "Degraded Arid Land Restoration for Afforestation and Agro-
Silvo-Pastoral Production through New Water Harvesting Mechanized
Technology." In International Scientific Conference on Desertification
and Drylands Research, Tunis, Tunisia, 19-21 June 2006, edited by


Maradi-Jalal, Mahdi, Siamak Arianfar, Bryan Karney, and Andrew Colombo.


Mays, Larry W., ed. Ancient Water Technologies: Springer Science +

Mays, Larry W. "A Brief History of Water Technology During Antiquity: Before

________. "Water Technology in Ancient Egypt." In Ancient Water

McC. Adams, Robert. Heartland of Cities: Surveys of Ancient Settlement and
Land Use on the Central Floodplain of the Euphrates. Chicago and


Mithen, S. and E. Black. "Introduction: An Interdisciplinary Approach to Water,


Ridley, R.T. *The Unification of Egypt*.


Ward, Walter David. From Provincia Arabia to Palaestina Tertia: The Impact of Geography, Economy, and Religion on Sedentary and Nomadic Communities in the Latter Roman Province of Third Palestine, University of California


Yigael Yadin Masada Herod’s Fortress and the Zealots’ Last Stand pp.21-32 CARDINAL ed. pub. 1973, Sphere Books Ltd.

Michael Kenneth Cowan
michaelkcowan@gmail.com
June 2014