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Brian Beckers, Jonas Berking and Brigitta Schütt

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Ancient Water Harvesting Methods in the Drylands of the Mediterranean and Western Asia

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Water harvesting methods were a vital part of the water supply system of many ancient settlements in the drylands of the Mediterranean region and Western Asia. Various water harvesting techniques evolved during the Bronze Age or earlier, and some of these remain in use even today. Based on literature we give a brief overview and present a tentative classification of these water harvesting methods and present the basic concepts behind these techniques supplemented with references to archaeological case studies.

Geoarchaeology; drylands; water supply; water harvesting; groundwater harvesting; runoff harvesting; floodwater harvesting.

Besonders in den mediterranen und westasiatischen Trockenräumen waren Methoden des „Water- Harvesting“ zum Wassersammeln schon früh ein wichtiger Bestandteil der Wasserversorgung antiker Siedlungen. Spätestens seit der Bronzezeit wurden dabei verschiedene Methoden entwickelt, die teilweise bis heute Bestand haben. Mittels einer Literaturanalyse soll hier versucht werden, eine Übersicht und vorsichtige Klassifizierung dieser Verfahren und Techniken zu geben und soweit möglich mit archäologischen Fallstudien zu belegen.

Geoarchäologie; Trockenräume; Wasserversorgung; *water harvesting*; *groundwater harvesting*; *runoff harvesting*; *floodwater harvesting*.

1 Introduction

Archaeological remains are abundant in the drylands[1] of the Mediterranean region and West Asia. Many of those show evidence of more or less elaborate water supply structures that allowed the existence of (semi-)permanent settlements at locations which nowadays are largely abandoned.[2] A great variety of ancient water supply techniques have been documented for the region, reflecting the historical evolution of these techniques and the specific hydrological conditions to which they had been adapted.[3] The natural water sources in drylands can broadly be classified into those which are generated in humid regions or inherited from wetter climate periods (*allogenic)* and those which are locally generated (*autogenic*).[4] *Allogenic* or perennial sources are predominantly fossil groundwater and major rivers which have their origin in humid areas and pass through drylands such as the Nile and the Euphrates.[5] *Autogenic* or intermittent sources are in general rainfall, local runoff and floods in intermittent streams (wadis) or shallow groundwater.[6]

1 Dryland is a term that comprises arid and semi-arid regions (Nicholson 2011).
2 Barker and Gilbertson 2000, 8.
3 See Wikander 1999, for a comprehensive introduction to past water supply systems.
4 Roberts 1977, 134, citing Goudie and Wilkinson 1977.
5 See e. g. Woodward 2009.
6 See Shanan 2000; Tooth 2000; Bull and Kirkby 2002; Wheater and Al-Weshah 2002, for overviews in dryland hydrology.

The focus of this paper lies on water techniques that harness autogenic water sources. These techniques are commonly grouped under the term *water harvesting systems.* Some of these techniques have regained attention in the past several decades especially in regard to their reimplementation to mitigate current food and water supply problems in drylands.[7] For this purpose, the study of ancient water harvesting technologies can not only give valuable information to engineers, planners, and local initiatives on technical aspects of those systems. It can also give indications of possible short- and long-term effects a reimplementation might have on the environment and the people involved.[8]

This paper will provide a brief introduction on water harvesting systems and intends to give a preliminary compendium for upcoming projects[9] which will study the diffusion of ancient water supply technologies in the "Old World" and assess the viability and reliability of such systems. Water supply techniques which rely on allogenic sources will be examined in an upcoming paper. Several books and papers exist on ancient water harvesting techniques[10] and this paper largely draws its information from these publications. The basic principles of the respective techniques will be explained and supplemented with references to archaeological case studies reaching from the Bronze Age to the Middle Ages.

2 Water Harvesting

Water harvesting is here understood as the process of harnessing water for beneficial use with any kind of device or technique that collects, stores, and/or increases the availability of intermittent surface runoff and groundwater in drylands.[11] Water harvesting is applied to irrigate crops and to supply water for animal and human consumption.[12] The basic principle of water harvesting, especially regarding agricultural purposes, can be illustrated by a hypothetical calculation. A region receiving 100 mm rainfall per year might not offer enough moisture for continuous vegetation cover or for crops to grow. If, however, these 100 mm of rainfall are collected and concentrated in a superpositional subarea a fourth of the total region's size, 400 mm of water column would be available in this subarea, which in turn would be sufficient for plants to grow on this area.[13] This process occurs naturally when rainfall is converted to runoff and collected by the topography, e. g. in a riverbed or at the foot of a hillslope. Water harvesting is the attempt to mimic and/or make use of these processes.

Commonly, water harvesting techniques are distinguished by the source of water they harvest and are called *groundwater harvesting, runoff harvesting* and *floodwater harvesting*[14] (Fig. 1). The specific device or technique applied is the water harvesting system.[15] Those systems range in their complexity from simple cultivated earth pits (section 2.2.2)

7 See Oweis, Prinz, and Hachum 2012, for a general introduction to water harvesting methods.
8 Cf. Barker and Gilbertson 2000, 9.
9 The authors are part of upcoming projects concerning ancient water management in cooperation with archaeologists and other disciplines within the Cluster of Excellence TOPOI.
10 E. g. Evenari et al. 1961; Bruins, Evenari, and Nessler 1986; Critchley, Reij, and Willcocks 1994; Prinz 1994; Wikander 1999; Ortloff 2009; Mays 2010a; Oweis, Prinz, and Hachum 2012.
11 Bruins, Evenari, and Nessler 1986; Prinz 1994; Oweis, Prinz, and Hachum 2012 for other definitions and reviews.
12 Prinz 1994, 2.
13 Cf. Evenari and Tadmor 1982.
14 The existence of ancient technologies which collected fog or dew is a controversial subject (Lightfoot 1996c; Shanan 2000; Beysens et al. 2006) and not part of this paper.
15 Frasier and Myers 1984, 1.

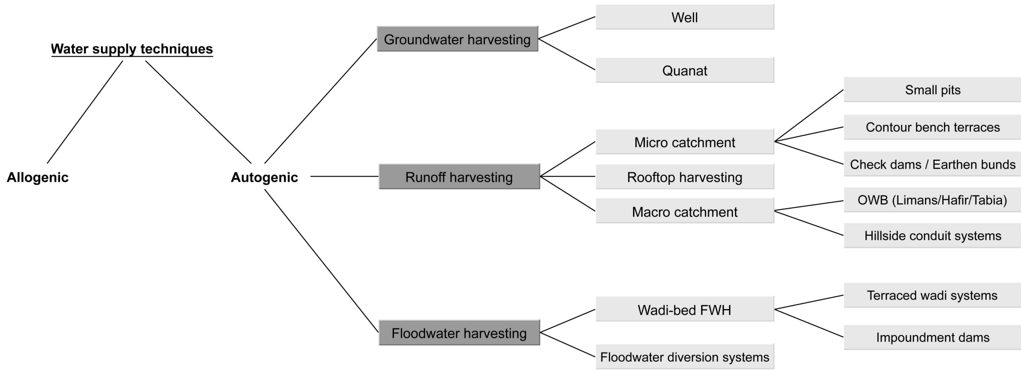

Fig. 1 | Classification of the aforementioned water harvesting systems. OWB: Open water basins; FWH: Flood water harvesting.

that collect local runoff to such elaborate systems as the irrigation system of Ma'rib in Yemen which relied on the floods of a large wadi (an Arabic denotation referring to a valley or an ephemeral channel).[16] In general, water harvesting systems consist of four (a-d) components:[17]

a. Catchment

The catchment is the area from which the water is collected. It may be the catchment of a wadi (section 2.3), parts of it like a hillside (section 2.2), or even just a few square meters (section 2.2.2). Suitable catchments are ones where surface and soil characteristics are such that runoff is generated regularly, i.e. that the infiltration rates are occasionally lower than rainfall intensities.[18] However, catchments may be modified to induce runoff and reduce infiltration rates as was e.g. done in the Negev in Israel by clearing the surface of the catchments from vegetation and stones.[19] Moreover, catchments can be artificially constructed by installing bunds or excavating a pit or a trench. Also the roofs of houses are catchments from where water can be collected after channeling it in drip moulding and drain pipes (=conveyance).

b. Conveyance or deflection device

Conveyance devices concentrate and channel collected runoff from catchments to the storage facilities. Commonly they consist of bunds or canals and may be equipped with control devices such as sluice gates and distribution systems. Conveyance devices are often installed in larger catchments or on long hillslopes where runoff would otherwise be lost due to infiltration or where the storage facilities are located at a great distance from the catchment. In small cultivated catchments conveyance devices are largely unnecessary as the catchments adjoin the storage device. In floodwater harvesting (section 2.3) deflection devices are built in wadi streams to tap occasional floods which were generated in remote catchments.

c. Storage facility

Storage facilities can be of many types including natural sediment bodies, (sub-)surface cisterns and open reservoirs which are e.g. formed by a dam or retaining wall. Storage facilities function as a buffer between the short rainfall and runoff events when natural

16 Brunner 2000.
17 Modified from Oweis, Prinz, and Hachum 2012, 6–7.
18 Bruins 2012, 29.
19 Evenari et al. 1961, 988.

water is provided and the long dry periods when water is required. Hence, their storage capacity has to meet the water demands during dry periods. When water harvesting is accompanied by farming, the storage devices often also act as the cropping area and the water is stored in the sediment column respectively, in the root zone of the crops. In areas where a sufficient sediment layer is lacking or prone to erosion, storage devices might be built to collect and conserve sediments. In those instances, the storage facilities are used to conserve both water and soil.[20]

In the evaluation and planning of water harvesting systems certain indices have been established that reflect a specific environmental regime and the particular demands of the end user.[21] Among the most important is the ratio between the *runoff area* (catchment) and the *run-on area* (retaining area). Because water harvesting is often associated with farming this index is commonly called the catchment to cropping area ratio (CCR).[22] The runoff area is always equal to or larger than the run-on area.[23] The lesser the rainfall and runoff yield and the larger the water demand, the larger the catchment has to be compared to the cropping area. The ratio varies from 1:1 in wetter regions to more than 30:1 in arid regions.[24] However, the efficiency (volume of runoff per unit area) of a catchment decreases with increasing size,[25] as does the frequency and predictability of harvestable runoff events.[26] This phenomenon is commonly attributed to the increasing infiltration losses due to downslope or downstream runoff, i. e. the farther a flood or runoff event flows on the surface, the lesser is the runoff yield at a specific point.[27]

The size of the catchment also has several implications for technical and organizational aspects of water harvesting systems. The character of runoff generated in small catchments tends to be moderate and manageable, flowing as sheet flow or along small rills. Thus, the water harvesting facilities can be of simple construction and can be implemented and maintained by individual non-expert households. Moreover, the runoff is usually generated locally, often within the borders of a farm or other small organizational units. Hence, the water distribution has only to be internally organized. In larger catchments, such as that of a high-order wadi, runoff can get the character a flash flood, torrential and unpredictable. In order to manage large water volumes that might occur at relatively short notice, harvesting facilities must be sophisticated, a factor that in return leads to high maintenance costs. Moreover, water distribution might have to be organized between different organizational units.[28]

d. Target

As depicted in Oweis et al.[29] the target is the user of the harvested water. Depending on the quality and quantity of the available water, the targets differ between either husbandry- and irrigation- or domestic- and drinking-water or both.

2.1 Groundwater harvesting

Water wells (artificial holes that reach the groundwater table) were probably the first structures that allowed the settlement of drylands beyond natural perennial surface water

20 Critchley, Reij, and Willcocks 1994, 297.
21 Prinz 1994, 4 ff.
22 Oweis, Prinz, and Hachum 2012, 124.
23 Oweis, Prinz, and Hachum 2012, 124.
24 Evenari and Tadmor 1982, 212.
25 Evenari et al. 1961, 985.
26 Shanan 2000, 90.
27 Yair and Raz-Yassif 2004, 156.
28 Cf. Oweis, Prinz, and Hachum 2012.
29 Oweis, Prinz, and Hachum 2012, 6.

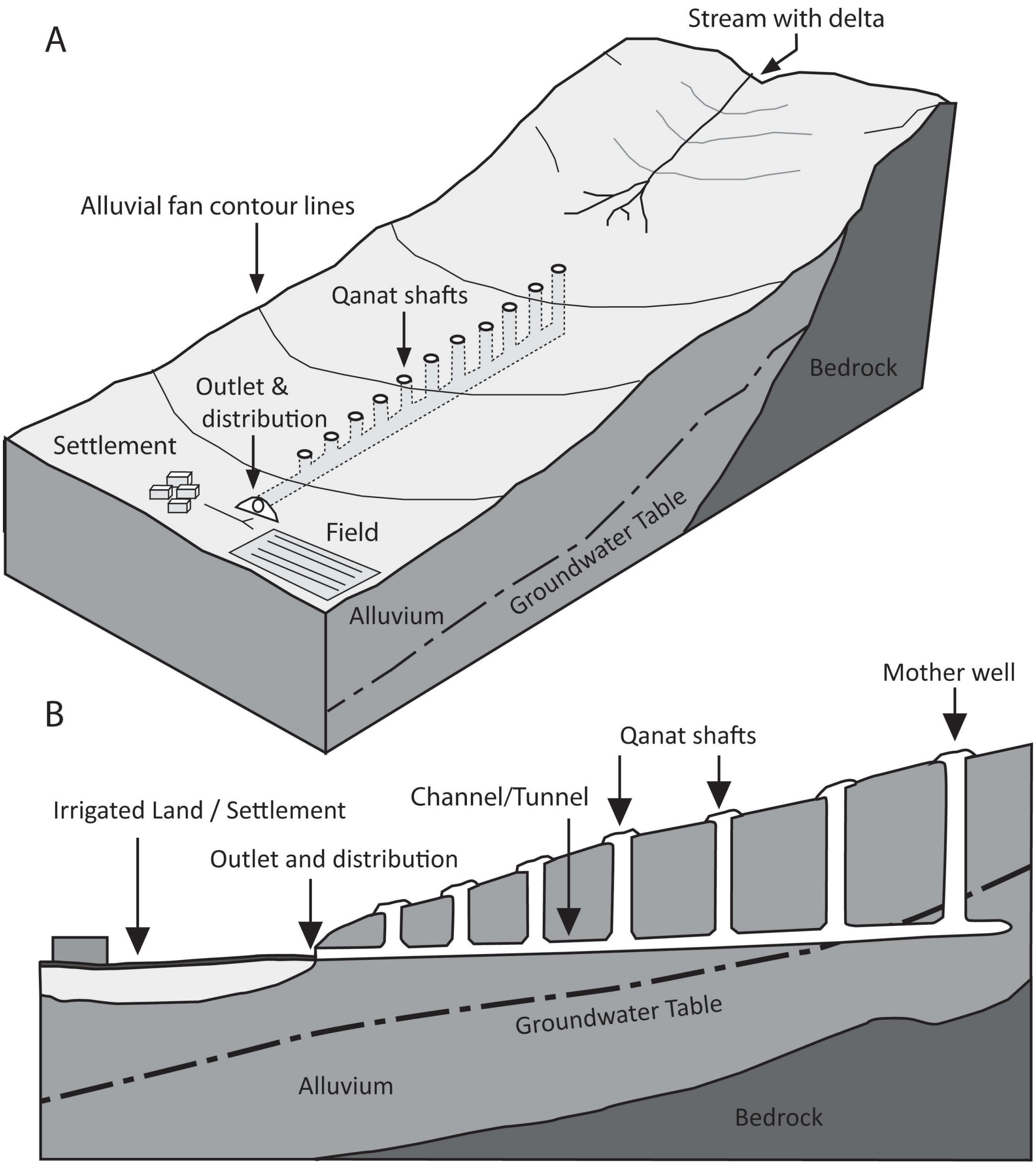

Fig. 2 | Sketches of a typical Qanat. For explanations see text. A: adapted from Cech 2009 B: adapted from Lightfoot 1996b.

sources.[30] Issar (ibid.) assumes that the first wells were temporary scoopholes (hand dug shallow wells) dug in beds of ephemeral streams (wadis). More sophisticated water wells which are lined and equipped with some kind of human or animal powered lifting device are abandoned at archeological sites in the study region.[31] If the tapped groundwater aquifer is prone to strong seasonal variations, water wells were sometimes combined with techniques that artificially recharged the groundwater, e. g. by channeling water from mountain streams to shallow aquifers in the lowlands as was e. g. done in Granada, Spain[32] or by building groundwater dams (section 2.3.1).

One of the most subtle techniques for harvesting groundwater is the *Qanat*. Qanats are subsurface conduits or tunnels tapping an upslope aquifer whose gathering ground

30 Issar 2001, 2.
31 Mays 2010b, 3.
32 Pulido-Bosch and Sbih 1995.

is naturally different from that of the area of usage. A tunnel connects the aquifer with a foreland outflow facility (Fig. 2). The tunnel is gently inclined towards the outlet. A dense series of vertical shafts, or wells, which connect the tunnel with the surface serve as construction and maintenance access shafts and regulate air pressure in the system; the uppermost part of these shafts is called the mother well. The tunnel usually channels the groundwater to a reservoir, frequently connected by a covered canal with the outlet of the tunnel. From the reservoir a system of canals distributes the water to fields or settlements. If a tunnel fails to deliver enough water, e. g. due to depletion of the groundwater, additional tunnels may be constructed which branch off from the main tunnel until the groundwater is tapped again.[33] To avoid infiltration of the water, frequently the tunnel beds are sealed with mortar. Qanats can often be found at the outlet of mountainous catchments, i. e. below the alluvial fans which bear reachable groundwater aquifers and workable sub- grounds. Qanats are abundant in Iran[34] and can also be found in Syria,[35] as well as in Morocco, where they are called *Khettara*,[36] in Spain where they are called *Galleria*[37] and in Oman, where they are called *Felaj*.[38]

2.2 Runoff (rainwater) harvesting

The term runoff (or rainwater) harvesting comprises the collection and storage of largely unconfined locally generated runoff from modified catchments.[39] Runoff flowing in rills and minor channels is included in this definition.[40] The term rainwater is often used interchangeable with runoff and signifies the water running off surfaces on which rain has directly fallen.[41] The collected runoff may be used for irrigation or domestic and animal consumption. Commonly two types of runoff harvesting are distinguished by the size of the harvested catchment: Micro and macro catchment runoff harvesting.[42] Runoff harvesting is often accompanied by runoff farming, the characteristic cultivation type.

2.2.1 Rooftop (courtyard) harvesting

Roofs, plastered courtyards and squares (sometimes roads) are especially suitable for the collection of runoff as their surfaces are often almost impermeable and relatively clean or easily cleaned of sediments and litter. The collected runoff is usually conveyed by a gutter system to cisterns or reservoirs and used for animal and domestic consumption and the small-scale irrigation of gardens. As the catchment area of roofs and courtyards are rather limited these systems usually provided water of high purity suitable for individual households or administrative and religious buildings (Fig. 3). There are many examples of the application of rooftop harvesting in ancient times. in the Minoan settlements in Crete, for example, rooftop and courtyard harvesting was an integral part of the water supply.[43] In Resafa, Syria, individual houses and churches harvested the rain falling on the roofs and stored it in bottle-shaped cisterns.[44]

33 Lightfoot 1996b, 322.
34 Motiee et al. 2006; Boustani 2009.
35 Lightfoot 1996b.
36 Lightfoot 1996a, 261.
37 Lightfoot 2000, 215.
38 Costa 1983, 274.
39 Prinz 1994, 1.
40 As opposed to runoff or floods flowing in larger channels and from remote catchments, section 2.3.
41 Bruins, Evenari, and Nessler 1986, 13.
42 Prinz 2002, 4.
43 Mays 2010a.
44 Brinker 1991, 124.

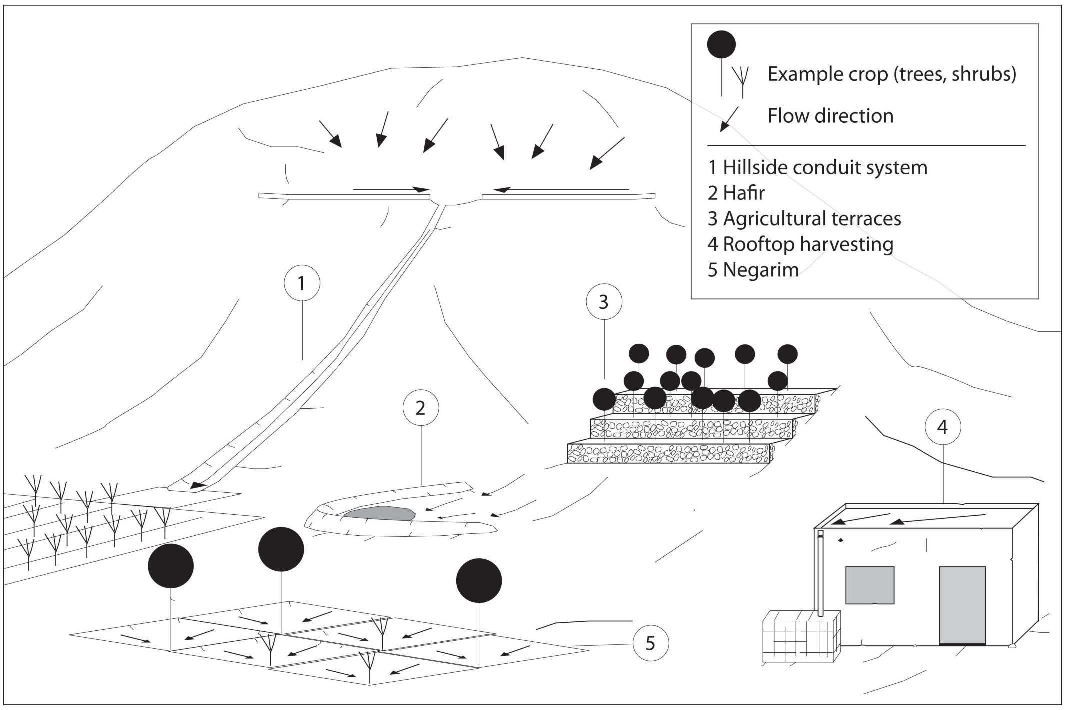

Fig. 3 | Examples of micro- and macro runoff harvesting techniques. Slopes are exaggerated.

Fig. 4 | A partly collapsed contour bench terrace at the foot of a low escarpment in the Petra region.

2.2.2 Micro catchment runoff harvesting

Micro catchment runoff farming is the collection of runoff on small (~ 1 – 1000 m^2) treated catchments to channel it to adjacent cropping areas or individual plants.[45] The catchments are either modified by some kind of special tillage technique, earthen embankments or masonry walls (Fig. 3). On steeper slopes the modifications might comprise the interception of those by building counter parallel individual or continuous bunds or agricultural terraces. An abundant agricultural terrace type in the Petra region is the contour bench terrace (Fig. 3 and 4). However, many other types of agricultural terraces built

45 Prinz 2002, 4.

on hillslopes fall within this classification.[46] In moderately steep to flat areas the systems might be constructed by building small runoff basins either by excavation (ditches, pits) or with bunds. Widely applied construction types are *Negarims* (Fig. 3), semi-circular micro catchments and contour bundings.[47] Negarims are diamond shaped earthen bunds a few square meters in area. They collect runoff and channel it to its lowest corner where the water is stored in the root zone of the plant. Agricultural terraces for water harvesting purposes are abundant in the Mediterranean region and West Asia.[48] Micro catchment runoff harvesting was applied e. g. in the Negev, Israel alongside other techniques[49] as well as in Tunisia.[50]

2.2.3 Macro catchment runoff harvesting

Systems which collect runoff in larger catchments such as hillsides with long slopes are commonly called *Macro catchment runoff harvesting* or *long-slope runoff farming* systems.[51] Often they necessitate the construction of elaborate structures and the maintenance is labor intensive.[52] One type is the hillside conduit system (Fig. 3).[53] Runoff which is induced in the upper parts of a hillside might percolate or evaporate before it can reach cultivated or settled areas. By building conduits (ditches or dikes) in the upper and middle parts of the slope, runoff loss can be greatly reduced.[54] Hillside conduit systems usually supply agricultural fields with water. On occasion the runoff is conveyed to neighboring wadis to supplement terraced wadi systems (section 2.3.1). *Hafirs* (Fig. 3) and *Tabias* (also called *Limans*) are large open reservoirs usually built by earth embankments at the foot of plan-concave slopes. Hafirs are semicircular open water basins for animal and human consumption (Fig. 5). Tabias are rectangular earthen bunds which store hillslope sediments and runoff. The sediment reservoirs of the Tabias are often used for cultivation.[55] Hafirs and Limans are sometimes also located in wide wadis or floodplains.

Hillside conduit systems can be found in the Negev,[56] Hafirs were widely applied in the Sudan e. g. in Musawwarat[57] and Naga,[58] Tabias in the Maghreb and on the Iberian Peninsula.[59] In Spain so called *Aljibe* systems channeled runoff from hillslope to fill cisterns.[60] In Petra, Jordan, the inhabitants found excellent conditions for runoff harvesting especially for drinking water purposes due to the abundance of outcropping bedrock. Here a multitude of rock carved conduit systems collected the runoff and channeled it to cisterns.[61]

46 Cf. Spencer and Hale 1961; Treacy and Denevan 1994; Frederick and Krahtopoulou 2000, for reviews on agricultural terraces.
47 Prinz 2002, 4.
48 Cf. Frederick and Krahtopoulou 2000.
49 Ashkenazi, Avni, and Avni 2012.
50 Nasri et al. 2004.
51 Prinz 2002, 4.
52 Prinz 2002, 13.
53 Bruins, Evenari, and Nessler 1986, 21.
54 Bruins, Evenari, and Nessler 1986, 23.
55 Oweis, Prinz, and Hachum 2012, 63.
56 Shanan 2000.
57 Näser 2010.
58 Berking, Beckers, and Schütt 2010.
59 Nasri et al. 2004.
60 Van Wesemael et al. 1998.
61 Ortloff 2005.

Fig. 5 | A desiccated hafir in the Sudan. Note the goats standing on the embankment to the left of the photo for scale. The hafir is filled from the right by a wadi.

2.3 Floodwater harvesting

Floodwater harvesting (or spate irrigation) is a technique that collects and stores water from ephemeral streams during flood events.[62] Floodwater harvesting usually requires the construction of elaborate hydraulic structures like large dams or dikes and distribution facilities.[63] Commonly, the harvested streams are of small or medium size as the regular floods occurring are more predictable and manageable than in larger streams. Two techniques are usually distinguished: floodwater harvesting within stream (wadi) beds and off wadi harvesting or floodwater diversion (Fig. 6).[64] The characteristic cultivation type for floodwater harvesting is called *floodwater farming*.

2.3.1 Wadi bed floodwater harvesting

Applying this method, structures are built across wadi beds to partially or completely dam flood water and to store it either in surface reservoirs or in channel sediments (Fig. 6). These structures might be walls built of masonry or earthen embankments.[65] A widespread type of this technique is called *terraced wadi system*.[66] These systems are commonly

62 Bruins, Evenari, and Nessler 1986, 24.
63 Prinz 2002, 13.
64 Bruins, Evenari, and Nessler 1986, 21.
65 Oweis, Prinz, and Hachum 2012, 36.
66 Bruins, Evenari, and Nessler 1986, 21.

built for agricultural purposes. Terraced wadi systems consist of a series of small dams (check dams) that intersect parts of a wadi course (Fig. 7). The check dams lower the runoff velocity of the floods and thereby their transport capacity. In consequence the transported sediments accumulate behind the dams and gradually build a terrace or sediment reservoir upstream. Excess water flows into the subsequent component of the system where the same process proceeds. After a few years (depending on the frequency and character of the flood events) when the volume of the accumulated sediment body is sufficient, the terraces might be cultivated.[67] The subsequently occurring floods now percolate into the terrace bodies where the water is stored and provide crops with water.[68] On occasion the check dams may be raised, thus enlarging the cropping area and the water storage capacity of the terraces. These systems are sometimes supplemented with hillside conduit systems (section 2.2.3). Examples of ancient terraced wadi systems can e. g. be found in the Negev in Israel,[69] in the Petra region in Jordan,[70] in the Matmata Mountain region in Tunisia where they are called *Jessour*,[71] in Libya[72] and in Andalucia in Spain where the system is locally called *Cultivo de cañada*.[73]

A variant of this technique are *groundwater dams* which predominantly collect and store flood water and intermediate flow for animal and human consumption.[74] Basically two types are distinguished: sand storage dams and subsurface dams. *Sand storage dams* function with the same principle as the terraced wadi system. However, the stored water in the sediment bodies is either withdrawn by water wells built in the sedimentary fill of the reservoir or by drainage devices built into the dam. *Subsurface dams* are built into the alluvial fill of streams by excavating a trench down to an impervious layer (e. g. bedrock, clay layer) and building a wall in the trench which is subsequently backfilled with the excavated material. Both techniques might also be combined. There are a number of advantages when implementing groundwater dams instead of surface reservoir storing systems, such as reducing evaporation losses or the risk of contamination. The problem of reservoir siltation is obviously avoided altogether. However, their relative water storage capacity is significantly lower.[75] Examples for ancient groundwater dams are said to be present e. g. in North Africa and Italy.[76]

2.3.2 Floodwater diversion systems

Floodwater diversion systems are built to deflect floods from a wadi channel to convey the water to adjacent storage devices or fields (Fig. 6).[77] This is either accomplished by damming parts of the wadi or blocking the entire channel. The retaining structures are called diversion dams. Those systems have been used to irrigate fields or for animal and human water consumption. Blocking the channel along its entire width might be necessary if the fields or storage devices are located considerably higher than the adjacent wadi channel floor. Thereby the water level of a flood can be raised to the appropriate

67 Cf. Evenari et al. 1961.
68 Critchley, Reij, and Willcocks 1994, 303.
69 Evenari et al. 1961.
70 Beckers et al. 2013.
71 Hill and Woodland 2003, 346.
72 Gale and Hunt 1986; Gilbertson 1986; Barker 1996.
73 Giráldez et al. 1988, 253.
74 Hanson and Nilsson 1986, 497 ff.
75 Hanson and Nilsson 1986.
76 Prinz 2002, 15 ff.
77 Prinz 2002, 10.

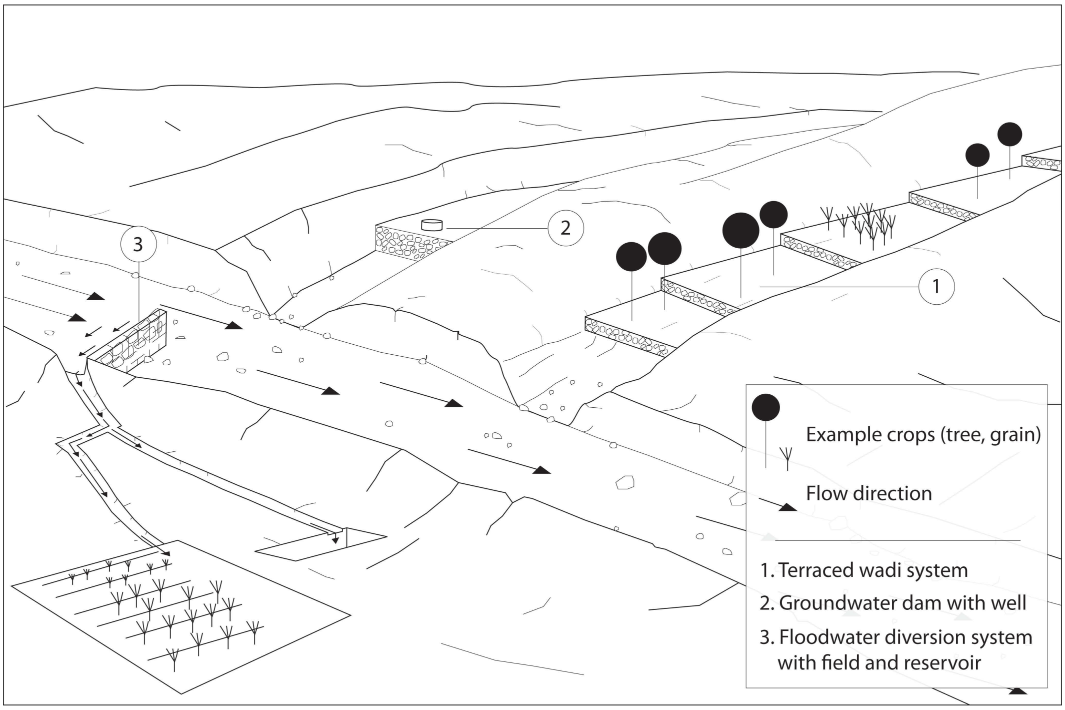

Fig. 6 | Examples of floodwater harvesting techniques. Slopes are exaggerated.

Fig. 7 | Abandoned and ruined terraced wadi system north of Petra, Jordan.

height.[78] An impressive example of such a system is the Great Dam in Ma'rib, Yemen.[79] Other examples of floodwater diversion systems are the floodwater harvesting system

78 Bruins, Evenari, and Nessler 1986, 25.
79 Brunner 2000.

Fig. 8 | The "large cistern" in Resafa, Syria. It was filled by channeling periodical floods from a wadi west of the city into the cisterns and had a capacity of ~ 18,000 m^3.

of Resafa in Syria (Fig. 8),[80] the Harbaqa dam in Syria,[81] the dam and pond system in Jawa, Jordan,[82] diversion systems in the runoff farms of the Negev,[83] in Oman,[84] and the *Boqueras* and *Acequiade cañon* systems in southeast Spain.[85]

3 Discussion and Conclusion

This paper gives an overview of ancient water harvesting techniques which were applied in the Mediterranean region and the Middle East; it refers to archaeological case studies for which the respective technology is documented. For most of the technologies case studies could be found throughout the study regions and for different cultural periods. However, the dating of water harvesting structures is notoriously difficult[86] and some of the case studies lack a reliable age determination or their chronologies are a subject of controversy.[87]

The case studies show that hardly any of the techniques were used for one purpose exclusively. For example floodwater harvesting served in Ma'rib, Yemen for the irrigation of fields, while in Resafa, Syria this technique was applied to supplement the drinking water supply of the city (Fig. 8). According to the listed case studies most settlements applied at least two water harvesting techniques: One for the drinking water supply—often with water wells or rooftop harvesting—and one to irrigate crops—often runoff and/or floodwater harvesting.

In conclusion, the study of the diffusion and reliability of ancient water supply systems will prove to be a challenging task. The age determination is often difficult and the reliability of water supply systems of settlements is affected by processes on various temporal and spatial scales. As shown by previous studies, the problem of age determination can be approached by applying new dating methods,[88] and climate and hydrological models make it possible to assess the reliability of the systems.[89]

80 Berking, Beckers, and Schütt 2010.
81 Genequand 2006.
82 Helms 1981; Whitehead et al. 2008.
83 Evenari et al. 1961.
84 Costa 1983.
85 Giráldez et al. 1988; Hooke and Mant 2002.
86 Cf. Treacy and Denevan 1994; Kamash 2012.
87 E. g. Rosen 2000.
88 Avni et al. 2006; Guralnik et al. 2011; Beckers et al. 2013.
89 Whitehead et al. 2008; Berking, Beckers, and Schütt 2010; Wade et al. 2012.

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Brian Beckers

2001–2008 Studied Geography, Geology and Meteorology at the Freie Universität Berlin; 2008 Diploma Degree (MSc equivalent) at Freie Universität Berlin; 2013 Dissertationat Freie Universität Berlin. Since 2013 he has been a lecturer for Landscape Archaeology at the Freie Universität Berlin, Department of Earth Sciences, Physical Geography. Research interests: Landscape Archaeology, Paleohydrology, GIS.

2001–2007 Studium der Geographie, Geologie und Meteorologie an der Freien Universität Berlin; 2008 Geographie-Diplom an der Freien Universität Berlin; 2013 Promotion an der Freien Universität Berlin. Seit 2013 Wissenschaftlicher Mitarbeiter für Landschaftsarchäologie an der Freien Universität Berlin. Forschungsinteressen: Landschaftsarchäologie, Paläohydrologie, GIS.

Brian Beckers
Freie Universität Berlin
Department of Earth Sciences, Physical Geography
Malteserstraße 74–100
12249 Berlin, Germany

brian@posteo.de

Jonas Berking

2001–2007 Studied Geography, Chemistry, Geology and Meteorology at the Freie Universität Berlin; 2003–2004 Exchange student at University of Wroclaw, Poland; 2007 Diploma Degree (MSc equivalent) at Freie Universität Berlin; 2011 Dissertation at Freie Universität Berlin. Since 2012 he has been a young research group leader in Topoi A3 which investigates historical water management. Research interests: Geoarchaeology (Drylands, Northern Africa and Central Asia); Quaternary landscape evolution and climate history; Water management, hydrology and water harvesting strategies in drylands.

2001–2007 Studium der Geographie, Chemie, Geologie und Meteorologie an der Freien Universität Berlin; 2003–2004 Auslandsemester an der Universität Wroclaw, Polen; 2007 Geographie-Diplom an der Freien Universität Berlin; 2011 Promotion an der Freien Universität Berlin. Seit 2012 Nachwuchsgruppenleiter in Topoi A3. Forschungsinteressen: Geoarchäologie (Nordafrika, Zentralasien); Quartäre Landschaftsentwicklung und Klimageschichte;Wassermanagement und Geschichte der Wassernutzung in Trockenräumen.

Jonas Berking
Freie Universität Berlin
Department of Earth Sciences, Physical Geography
Malteserstraße 74–100
12249 Berlin, Germany

Jonas.Berking@Fu-Berlin.de

Brigitta Schütt

2000–2001, Assistant Professor in Physical Geography, University of Trier; 2002, Substitute Extraordinary Professor in Physical Geography, Universität Bonn; since 2002 Professor, Institute of Geographical Sciences, Freie Universität Berlin, and since 2010 Vice President for Science at Freie Universität Berlin. Research interests: Past and present soil erosion, Late-Quaternary Paleoenvironments, Paleohydrology, Past and Present Morphodynamics, Drylands, Watershed Management.

2000–2001, Assistant Professor in Physischer Geographie, Universität Trier; 2002, Vertretung der Professur für Physische Geographie, Universität Bonn; seit Oktober 2002, Professur für Physische Geographie an der Freien Universität Berlin; seit 2010 Vizepräsidentin der Freien Universität Berlin. Arbeits- und Themenschwerpunkte: Bodenerosion, jungquartäres Paläoklima, Paläohydrologie, Morphodynamik, Trockengebietsmorphologie, Watershed Management.

Brigitta Schütt
Freie Universität Berlin
Department of Earth Sciences, Physical Geography
Malteserstraße 74–100
12249 Berlin, Germany

Brigitta.Schütt@Fu-Berlin.de