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Ancient Agriculture in the Negev

Archeological studies and experimental farms show how agriculture was possible in Israel's famous desert.

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The Negev desert of Israel, with its numerous, clearly visible traces of ancient civilizations dating back at least four to five thousand years, has attracted the attention of many scientists. Since Palmer (*1*) in 1871 described the general character of these civilizations as well as the intriguing agricultural remnants that he observed in the area, the Negev has become a field of research for many phases of science.

We have been working as a team in the Negev desert for five years with the specific aim of solving the enigma of the once flourishing agricultural civilizations in a now barren desert. This team covers the fields of botany, archeology, ecology, hydrology, and water engineering, and this combination of experience and interests enabled us to correlate widely differing fields of observation. In this article we present some of our conclusions as to how the ancient civilizations maintained a thriving agriculture in the desert and also indicate their possible application in the future.

Description of the area. The Negev is shaped like a triangle (Fig. 1). Its base line stretches in the north from an imaginary line drawn from Gaza on the Mediterranean Sea, through Beer Sheva, to Ein Gedi on the Dead Sea. Its two sides stretch from Gaza and from Ein Gedi down to Eilat on the Gulf of Aqaba. The 12,500 square kilometers of the Negev can be divided into the six following subregions: (i) the coastal strip; (ii) the lowlands and foothills; (iii) the central highlands; (iv) the sedimentary southern Negev, mostly consisting of rolling gravel plains; (v) the crystalline southern Negev representing the northeast corner of crystalline Sinai; and (vi) the Wadi Araba depression.

The physiographic and climatic conditions vary from subregion to subregion, and the various civilizations naturally adapted their agricultural projects to these differing features. The densest settled areas have been discovered in the lowlands and the highlands, and since most of our investigations have been concentrated in these subregions, we will describe them briefly.

The lowlands and foothills. This subregion is a strip about 10 to 25 kilometers wide, bounded by the coastal region on the west and the central highlands on the east and covering about 150,000 hectares. The morphological structure is made up mostly of Eocene limestone hills separating wide rolling plains, with the elevations ranging from 200 to 450 meters above sea level. This area contains the ancient towns of Nessanah, Sbeita, Ruheibeh, and Khalassah. A number of large wadis, whose sources are in the highlands, cut through the plains and drain towards the Mediterranean Sea. The hillsides are generally covered with a very shallow, gravelly, saline soil possessing an immature profile. The flora is dominated by the Zygophylletum dumosi association (*2*).

On the other hand, the Quaternary aeolian-fluviatile loess soils of the plains are relatively deep (2 to 3 meters) and only slightly saline. The Haloxylonetum articulati association is typical for these areas.

The highlands. This subregion covers some 200,000 hectares and contains the ancient towns of Mamshit (Kurnub) and Avdat (Abde). It is composed of a series of parallel anticlines, and the elevations vary between 450 and 1,000 meters above sea level. The anticlines are composed of Cenomanian Turonian limestones and cherts.

Between the high ridges, the main wadis drain to the Mediterranean and Dead seas. Adjacent to the wadis lie relatively narrow alluvial plains, and near the watershed divides where the wadis have not cut down to a stable base level, there are a number of expansive plains.

There are two principal plant habitats common to the area. On the rocky slopes (80 to 90 percent of the area) where the soil cover is shallow, gravelly, and saline, the Artemisietum herbae albae association prevails with transitions to the Zygophylletum dumosi.

On the loessian plains and in the wadi bottoms where loess has accumulated, the vegetation consists of sparsely distributed low shrubs of the Haloxylonetum articulati association.

Rainfall conditions. The rainfall records of our area have not been kept systematically for any long period of time. But even the few short records

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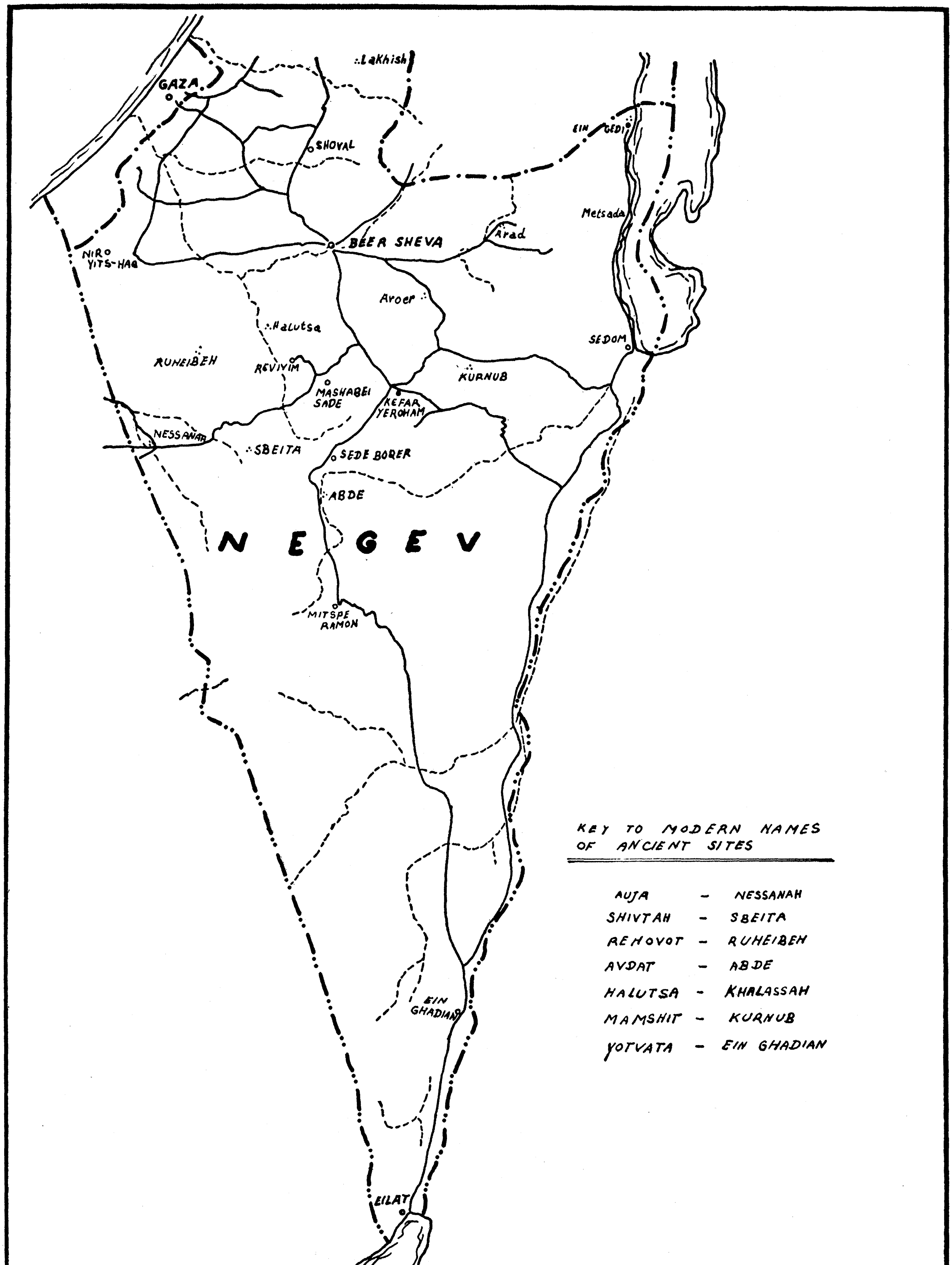
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MASHABEI SADE
KURNUB
KEFAR YEROHAM
NESSANAH
SBEITA
SEDE BOKER
ABDE
NEGEV
MITSPE RAMON
KEY TO MODERN NAMES OF ANCIENT SITES
AUJA - NESSANAH
SHIVTAH - SBEITA
REHOVOT - RUHEIBEH
AVDAT - ABDE
HALUTSA - KHALASSAH
MAMSHIT - KURNUB
YOTVATA - EIN GHADIAN
EIN GHADIAN
EILAT
0 10 20 30 40 50 KIL.

Fig. 1 (left). Map of the Negev. The key gives modern names at left, ancient names at right.

that have been published show that we deal here with that typical pattern of rainfall which is so characteristic for all deserts.

A study of Table 1 shows that the variations between maximum and minimum annual amounts of precipitation are large and that most of the rain falls in quick short showers of less than 10 millimeters. The difference between the average and median annual values should be noted, as, for agriculture, the median and not the average is significant.

The average number of rainy days with daily totals of precipitation of 0 to 3, 3 to 10, and more than 10 millimeters is another important figure, as it touches on the problem of the minimum "effective" rainfall (*3*).

Agricultural history of the Negev. The Northern Negev was, in historical times, first settled during the chalcolithic period (4th millennium B.C.). But up to now, no trace of this period has been found in the Central and Southern Negev (*4*).

During Middle Bronze I (21 to 19th century B.C.), the Negev was quite densely populated. The next period of sedentary settlement dates from the end of the 10th century B.C. to the beginning of the 6th—that is, the period of the Judaean Kingdom (Israelite periods II–III, or Iron Age II). However, the time between about 200 B.C. and A.D. 630 represents the longest and most flourishing period of almost continuous settlement in the Negev. During this time, the Nabataeans and Romans (about 200 B.C. to A.D. 330) and the Byzantines (A.D. 330 to 630) ruled the area (*5*). After the Arab conquest, from the 7th century A.D. up to our time, the Negev was occupied only by nomadic Bedouins (*6*).

As far as the *agricultural* history of the Negev is concerned, our own surveys and excavations of Israelite farms and settlements (*7*) and the surveys of Glueck (*8*) have shown that the Israelite period III settlers already carried out desert agriculture based on flood-water irrigation. We may men-

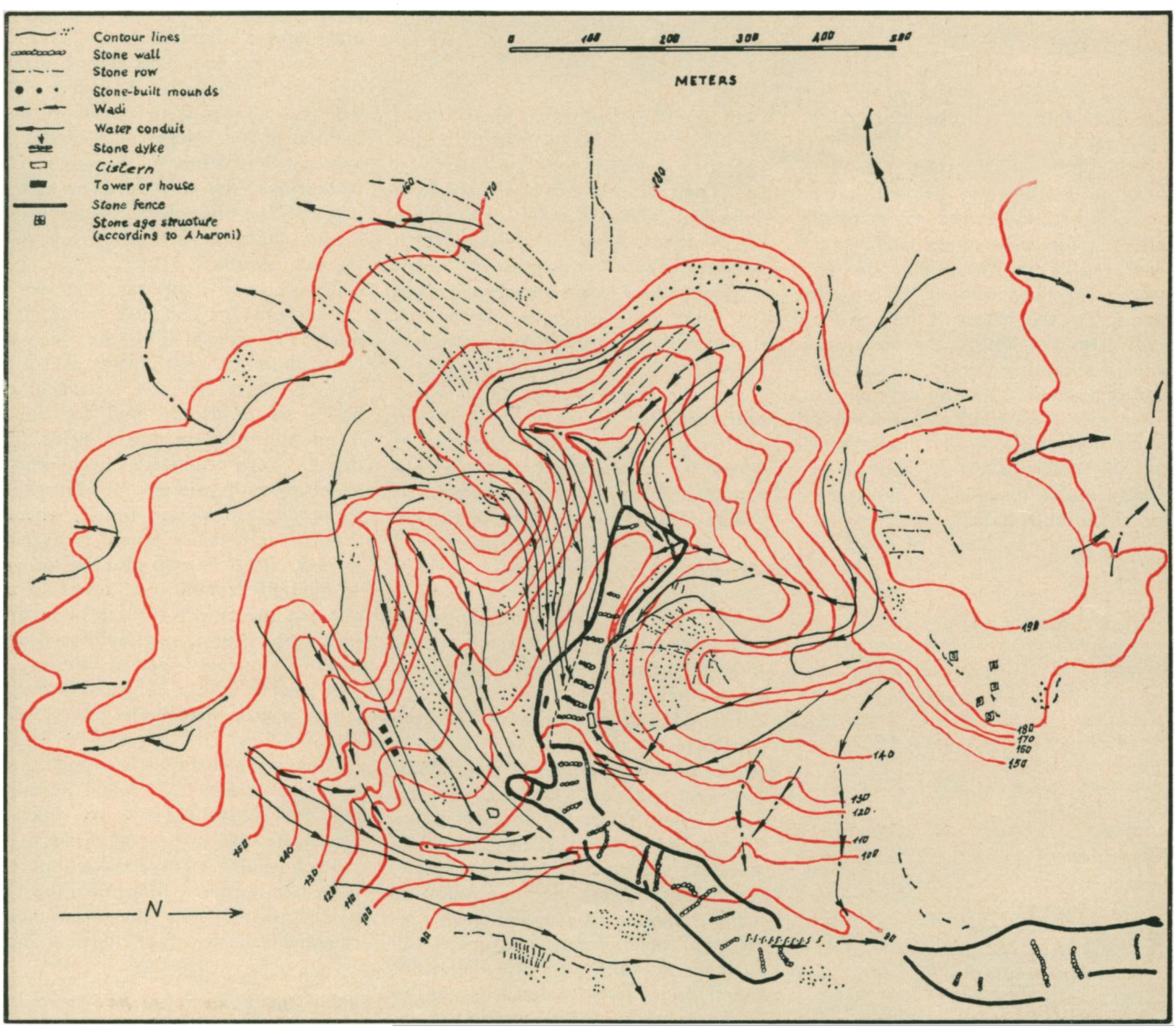


Fig. 2. Map of a runoff farm area near Avdat. Note the conduits and stone mounds.

Fig. 3. An oblique aerial photograph showing a number of ancient runoff farms near Shivtah.

tion that this is corroborated by the Bible (II Chron. 26:10), where it says of King Uzziah, who ruled the Negev down to Elath, "also he built towers in the desert, and hewed out many cisterns . . . for he loved the land." But it may even be that the Middle Bronze I people practiced run-off desert agriculture, as the Negev is full of their settlements (*9*). During the Nabataean-Roman-Byzantine period, desert agriculture reached its peak of development. After the Arab conquest, the ancient desert agriculture slowly disintegrated, and the Bedouins of the area at best merely utilize dilapidating old systems for patch cultivation.

Outside of the Negev of Israel, ancient desert agriculture is known from the following areas: (i) North Africa [Algeria, Tunisia, Lybia (*10–14*)], Syria (*15*), and Transjordan (*16*), where it flourished under Roman domination; (ii) Southern Arabia (*17*); (iii) North America, where it was practiced and is being practiced by the Indians (*18*); and (iv) South America, where it was carried out by the pre-Hispanic civilizations (*19*).

Table 1. Rainfall data (in millimeters).

Item	Station		
	Aslug	Auja	Mamshit
No. of years of record	13	14	9
Highest total annual recorded	170	285	171
Lowest total annual recorded	52	25	58
Average annual	100	89	98
Median annual	86	65	80
Av. No. of days per year with total of 0–3 mm	9	5	5
Av. No. of days per year with total of 3–10 mm	7	3	6
Av. No. of days per year with total of more than 10 mm	2	2	2

Ancient desert techniques of water utilization for agriculture. There are relatively large areas in the desert where the soils are suitable for cultivation and the only requirement is water. This is true for most of the not too steep wadis, the flood plains, and the depressions where loess soils have accumulated to a depth of 1 to 2 meters. The key to establishing sedentary agriculture in a desert is, therefore, maximum utilization of the meager rainfall.

For this reason, our work has been concentrated on studying the techniques used by the ancient civilizations to collect and exploit the meager water resources of the area. The techniques that we have so far studied in detail, and that are presented in this article, can be divided into the three following main categories: (i) exploitation of runoff from small watersheds (up to 100 hectares in size); (ii) exploitation of runoff from large watersheds (up to 10,000 hectares in size); and (iii) chainwell systems.

Exploitation of Runoff from Small Watersheds

The exploitation of runoff from small watersheds (*20*) is by far the most interesting of all the methods utilized by the ancients, since it made possible the very intensive development of the area.

The basic principle of the method was simple but nevertheless required a good understanding of the sciences of hydrology, soils, and meteorology. Table 1 shows that most of the rainfall in the desert falls in relatively light showers—3 to 10 millimeters at a time. These meager amounts of rainfall are generally regarded as ineffective—that is, they wet a very shallow depth of soil, which dries by evaporation before plants can utilize the moisture. However, the loess soils of the area have a characteristic of forming a crust when wet. This crustal formation was studied by D. Hillel (*21*), who has shown it to be an intrinsic feature of the Negev loess soil: the aggregated structure of the soil surface is destroyed by a wetting or slaking process. The crust decreases the water-intake rate of the soil and so increases the rate of runoff.

This phenomenon was observed by the ancients and exploited to the maximum. The loessial hillsides, which became more or less impermeable after wetting, were utilized as catchment basins to produce runoff for subsequent utilization in nearby fields. The desert farmer's aim was to prevent a penetration of rain on the slopes and so produce maximum runoff, whereas the farmer in more humid lands aims to soak all of the rain into the soil and so minimize runoff. The desert farmer directed the runoff from a large area on the slope to a small cultivated area in the bottomlands, and in this way he was able to collect sufficient water to ensure a crop even under adverse desert conditions.

This ingenious type of runoff agriculture we define as runoff farming, and the cultivated units to which it was related we call runoff farms.

Each runoff farm consisted of the farm area proper, containing the cultivated fields, and the surrounding catchment basin. The cultivated area

Fig. 4 (right). A vertical aerial photograph of a gravel mound and strip area near Shivtah.

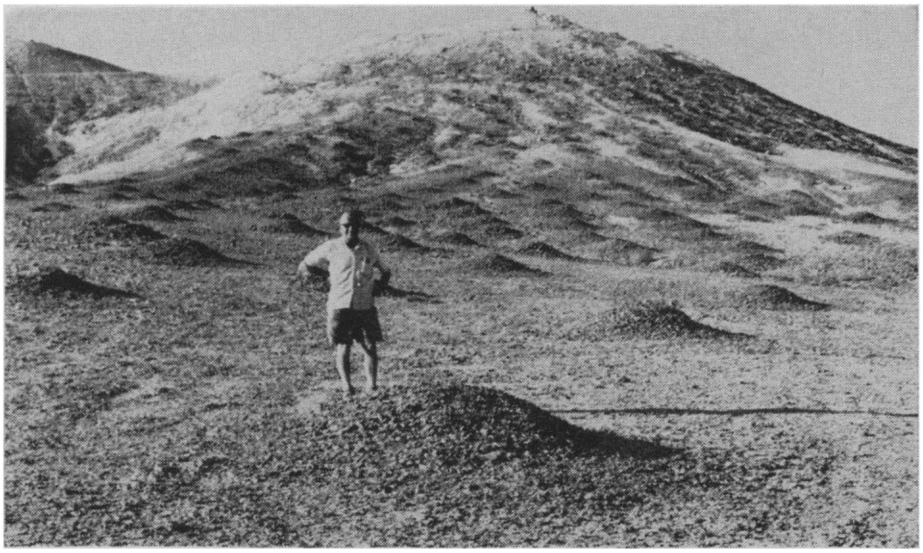


Fig. 5. A field of gravel mounds near Shivtah.

was subdivided into terraces by low terrace walls. The function of the terrace walls was to retain the flood water on the field, where it could soak into the soil and be stored for subsequent use by the crops. A number of terraced fields were surrounded by a stone wall, constituting a distinct unit (*22*). Within the area bounded by the wall there is very often a farmhouse or a watchtower. The hillsides surrounding the farm served as a catchment area from which water conduits channeled the runoff water onto the fields. Once the water was inside the farm, drop structures, ditches, and dividing boxes gave the farmer complete mastery over the distribution of the water. Figures 2 and 3 illustrate this very well. Figure 2 represents a system near Avdat. The whole catchment area comprises about 70 hectares and is artificially divided into a number of smaller catchment basins by several conduits, each leading to a specific terraced field in the narrow valley. Some of the conduits begin high on the plateau and collect runoff from there.

The 70 hectares of watershed of this system supplied water to about 2.2 hectares of cultivated land.

Figure 3 represents a number of runoff farms in the Shivtah area. Each farm received its runoff water from its own small wadi and from the many conduits which collected water from the small catchment basins on the hillside adjoining each farm.

Fig. 6. A field of gravel strips near Shivtah.

About 100 runoff farms, together with their catchment basins, have been studied in detail.

Each farm unit formed an entity comprising a catchment basin and cultivated land. The larger the catchment basin, the more the water yield and the greater the corresponding area that could be irrigated. The ancient farmers often extended their water-collecting conduits to the plateaus high above their fields in order to increase the available water supply, and sometimes conduits were led around the hillsides so as to increase artificially the natural drainage area of the runoff farm. These catchments were therefore "water rights," and each runoff farm possessed a water right on a definite portion of the slope. These water rights, which generally vary in size from 10 to 100 hectares, were no less important a part of the runoff farm than the cultivated land itself. The man who owned water rights on the slopes could always build himself a farm, but not vice versa.

The farm land and its catchment on the slope are thus a mutually balanced system of land and water. All the precious water collected from the slope was used. If there was any surplus water on the farm, the cultivated area was extended by adding a new terrace downstream. It was probably only in exceptionally rainy years that surplus water passed over the lowest spillway of a runoff farm and flowed to the next terrace. On the other hand, permanently "dry" terraces were of no avail, and the farmer only built a new terrace if his expectations of getting it wet were reasonably good. Catchment and cultivated area are thus seen as a clearly defined unit—an integral part of an over-all plan of watershed subdivision.

The conduits generally collected water from a relatively small area, sometimes as small as 0.1 to 0.3 hectare and generally not larger than 1.0 to 1.5 hectares. The result was that the overall runoff was always divided into small streams of water, preventing the occurrence of large flash floods. Such controlled flows are suited to the dry stone structures of the ancients; moreover, only such small flows could be handled by a farmer and allow him to control the flow during the flood period. Flows from even 1 hectare of catchment might reach a high peak intensity for short periods. For example, with a peak rain intensity of 30 millimeters per hour and a 60-percent (an extreme figure) runoff for a short period during a single rain storm, 1 hectare of slope might yield a peak flow of 180 cubic meters per hour, if only for a few minutes. This requires a ditch with a cross section of 0.05 to 0.10 square meter (depending on gradient), a requirement which readily fits observed ditch dimensions.

The farmer could therefore not allow the waters to collect from a larger area, as the resulting peak flow would have been unmanageable and would have destroyed his terrace structures. The over-all runoff was thus effectively broken up into small streams.

The crucial question that arises is the amount of runoff the ancient farmers received per unit area. Actual field measurements of runoff already initiated on our two reconstructed farms, discussed below, will have to be made for at least 10 years before a reliable estimate can be made. We approached this question indirectly by analyzing the ratio

$$R = \frac{\text{area of catchment basin of ancient farm}}{\text{area of cultivated area of ancient farm}}$$

About 100 farms in the Avdat, Shivtah, and Auja areas show that this ratio varies between 17:1 and 30:1, with an average value of about 20:1. This means that between 20 and 30 hectares of catchment area were needed to irrigate 1 hectare of cultivated field. Present-day agricultural experience has shown that flow of at least 3000 to 4000 cubic meters per hectare has to be applied as supplementary irrigation in order to insure any crop in this desert area. (Each 1000 cubic meters of water per hectare will wet about a meter of soil depth.) Taking these figures as a basis, we calculated that if 20 hectares on the slopes supplied the 3000 to 4000 cubic meters of water, every hectare of catchment supplied 150 to 200 cubic meters of water per year. If each hectare of catchment supplies 150 to 200 cubic meters of water (which is equivalent to 15 to 20 millimeters of rainfall), we can safely conclude that the coefficient of runoff was at least 15 to 20 percent of the total annual precipitation.

These runoff farms formed an important part of the desert settlements throughout the ages, and primitive but nevertheless well-defined runoff farms have been found dating from the 10th to the 8th centuries B.C. (*7*). This form of intensive sedentary agriculture was probably continuous throughout all the civilizations, reaching its peak in the Roman-Byzantine era. Interesting and conspicuous features related to the runoff farms are the gravel mounds and gravel strips (see Figs. 4–6) and stone mounds and strips. These man-made structures cover thousands of acres and are common in the vicinity of the ancient cities of Avdat and Shivtah. The gravel mounds are low heaps of gravel artificially arranged in long rows with a more or less uniform distance between the mounds. The strips are of the same material. Mounds and strips are often intermingled and form all kinds of intricate patterns. They are only found on hammadas (*23*) covered by small gravel and are made by raking together the gravel.

The stone mounds and strips are built of much bigger stone fragments and are typical for those areas where for geological reasons the slopes are covered with big stone fragments and not with gravel. Gravel mounds, gravel strips, stone mounds, and stone strips are found exclusively on slopes leading to farms or cisterns (*24*, *25*).

Since Palmer (*1*) first discovered these structures, all authors dealing with them agree that they are related to agriculture, and the following theories have been proposed concerning their function.

1) Palmer was told by his Bedouins that the arabic name for these structures is *teleilât el 'anab* or *rujum el Kurum*—that is, "grape mounds" or "vineyard heaps." "These sunny slopes," he concluded, "would have been admirably adapted to the growth of grapes and the black flint surface would radiate the solar heat, while these little mounds would allow vines to trail along them and would still keep the clusters off the ground."

A number of authors (*26*), and lately Mayerson (*27*), follow Palmer's theory. In our opinion, the slopes can never have been used for growing grapes because there is either no soil at all or only a very shallow superficial soil cover which is highly saline (2 to 5 percent total soluble salt). The naturally occurring plant associations on these slopes indicate the most difficult growing conditions for plants. As we have shown, the amount of rain water these slopes receive is insufficient for growing grapes, and since the ancient farmers never used all the good loess soils available, there was no reason for them to cultivate the worst soil to be found in all the desert (*28*).

2) Some authors (*10*, *29*, *30*) believe that the function of the mounds was to condense dew. But experiments have shown that no dew can be collected in the mounds and that the water relations of the soil below the mounds do not differ from those of the surrounding soil (*31*).

3) Kedar (*24*, *32*) put forward the theory that the main function of the mounds was to increase soil erosion from the slopes in order to accumulate more soil in the wadi bottoms ("accelerated erosion"), as in his opinion the main hindrance to agriculture was lack of suitable soil and not lack of water. There are a number of objections to this theory. First, there is and was plenty of good loess soil in the valley bottoms and flood plains close to the ancient agricultural systems. As today, lack of water and not lack of cultivable soil was the main problem of the ancients. It is hard to believe that the ancients, who knew so much about water spreading, would have endangered their elaborate systems by intentionally introducing silting, the arch enemy of any water-spreading system. Furthermore, some of the gravel-mound areas lead to water cisterns, where the accumulation of silt by erosion is most undesirable. The gradient of some of the collecting ditches varies from 0.5 to 1 percent. If they had been designed to carry silt, a much steeper gradient would have been necessary. But the main objection lies in a simple calculation. According to Kedar's experimental figures (*33*), an ancient farmer would have had to wait patiently for about 20 to 50 years after building an elaborate structure in the wadi before sufficient soil had accumulated to justify the planting of a crop (*34*).

4) We have proposed (*31*) that mounds and strips were established in order to increase the amount of surface runoff and gain more water for the fields below (*35*). Hillel (*21*) has shown that the infiltration capacity of the prevailing soil of the region decreases markedly with the formation of a characteristic surface crust through the physical slaking of the upper layer during the wetting-drying cycle. This

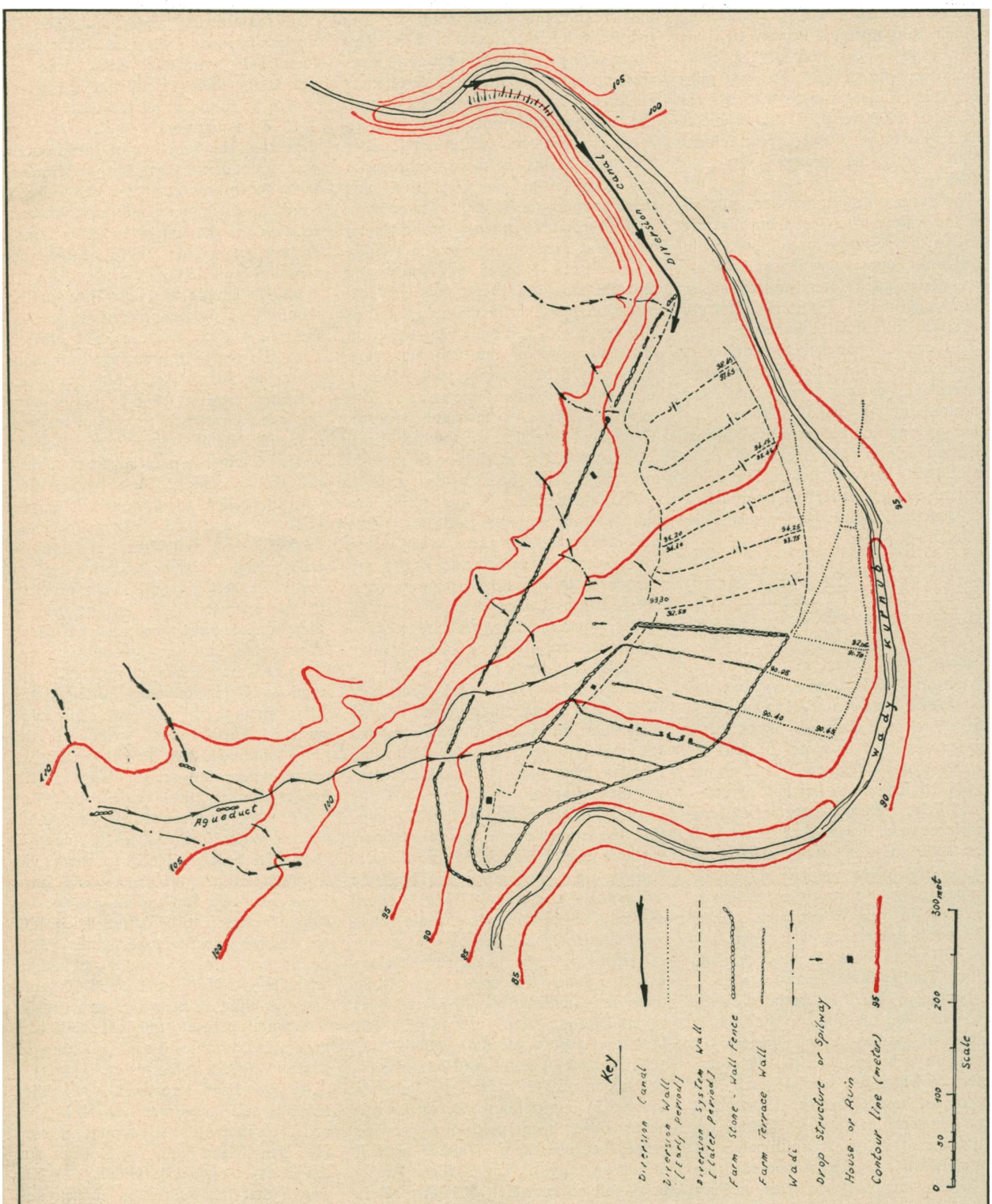


Fig. 7 (top). A map of the Mamshit system, which exploited runoff from a large watershed, showing the various periods of development. Fig. 8 (right). A vertical aerial photograph of the same system.

increases the runoff. Crust formation is prevented by the presence of a protective surface of gravel. Therefore, by clearing the slopes, the soil surface was exposed, crust formation was enhanced, and runoff was increased. This resulted in greater water yields from the slopes.

Thus, mounds were only a by-product of clearing the surface of stones. Strips sometimes fulfilled an additional function in channeling the water from the slopes to the fields. This is especially obvious in connection with the stone strips and conduits (see Fig. 2).

The fact that the mound and strip areas are always connected to the fields by channels (Fig. 2) is in conformity with this theory. Apparently this ingenious system was not restricted to the ancient desert agriculture of the Negev (*36*).

Exploitation of Runoff from Large Watersheds

For purposes of our work the term *large watersheds* is taken to mean watersheds greater than about 100 hectares in size. The hydrology of these large watersheds differs from that of small catchment areas. In the small catchment, runoff may begin after a small amount of rain (3 to 6 millimeters) has fallen, while on the other hand, a rainfall of at least 10 to 15 millimeters is required to cause a flow in the wadi of a large watershed (*37*, *38*). Furthermore, the percentage of runoff from a small catchment basin may be as high as 20 to 40 percent of the annual rainfall, but in the larger watershed it would not be greater than 3 to 6 percent. The small watersheds produce relatively small streams that can be handled easily by simple structures, whereas the flash-flood flows of the large wadis can destroy even the strongest of engineering structures. These factors led to the development of systems of water exploitation which differed both in form and extent from those described above for small watersheds. The Mamshit System is one of the best preserved. The ancient town of Mamshit is situated on a range of Turonian Cenomanian hills overlooking the Tureiba plain. Just south of the town, Wadi Kurnub cuts a narrow gorge through the Hatira anticline and enters the Tureiba plain. At the point where the gorge enters the Tureiba plain, the drainage basin has an area of about 27 square kilometers, and it was below this point that the flood waters from the large watershed were exploited.

Figure 7 is a map of this system and Fig. 8 is an aerial photograph of the area. A large diversion channel, about 400 meters in length, leads the diverted waters of Wadi Kurnub at a 2:1000 gradient to the flood plain. The original diversion dam has been completely destroyed but need only have been a simple rock structure to have raised the water level 30 to 50 centimeters in order to control the lower flood plain. This diversion channel leads the water to a series of broad terraces which are all in good condition. The terraces are more or less level in the transverse direction but have a slight gradient (2:1000 to 4:1000) in the direction of flow of the water. This arrangement made it possible to irrigate the area either in large basins or in small plots. The excess water from each terrace flowed to the next lower terrace through well-built drop structures.

The total area of the cultivated terraces is about 10 to 12 hectares. Agricultural experience has shown that about 3000 to 4000 cubic meters of water per hectare should be applied each year in order to insure an agricultural crop. This means that the watershed supplied about 40,000 to 50,000 cubic meters per year to the cultivated terraces. This represents less than 2 percent of the annual rainfall on the large watershed and could be expected every year as runoff. This quantity of water could have been carried by the diversion canal in 6 to 10 hours, according to the depth of flow (which probably did not exceed 40 to 60 centimeters).

A detailed examination of the area disclosed that the most ancient system was established when the wadi flowed in a shallow depression in the flood plain and before it had cut through the alluvial soils. The first walls were built primarily as stabilizing structures for the shallow depression, and only subsequently were they extended, in order to spread the water across the flood plain. Some of these walls can still be found on the opposite side of the wadi, showing that they predate the gulley stage of Wadi Kurnub. The most ancient potsherds found in the vicinity belong to the Middle Bronze and Iron ages, but there is still no certain evidence that this first system antedates the Nabataean period.

These stabilizing walls assisted in the deposition of alluvial silt in the terraces, and so their level was gradually raised. At some period, either through natural flood conditions or because the inhabitants abandoned the area for historical reasons, the wadi destroyed the stabilizing walls, and an ever-deepening gulley was cut through the system. The next users of the area were therefore faced with an entirely different problem: the runoff water no longer flowed in a shallow depression but concentrated in a wadi, one or two meters below the flood plain. They therefore had to base their system on a diversion structure which raised the water out of the wadi bottom and directed it to a diversion canal, which in turn led the water to the old terraces. The remains of this system stand out clearly on the aerial photographs and are the easiest to find in the field. Close inspection also revealed a number of diversions in the lower reaches of the wadi. These indicate that the elevations of the terraces were continually rising because of a silting process and that new diversion structures at higher elevations had to be built in order to control these new elevations.

Chronologically, the next system that is clearly discernible in the field seems to have been constructed when the diversion channel had become so silted that the whole system based on a diversion channel may have had to be abandoned. This system is based on a completely different principle. The main area with the diversion channel was not used, and only the lower terraces (about 3 to 4 hectares) were irrigated. This area was developed as a runoff farm and received its water from the relatively small watershed (3500 dunams) adjoining the area, not from Wadi Kurnub.

The system in Nahal Lavan (Wadi Abiad) (see Fig. 9) is much more complicated but nevertheless shows similar lines of development. Nahal Lavan is the largest wadi in the vicinity of the ancient town of Shivtah and drains from the high plateau of the Matrada through a large area of barren rocky Eocene hills. The torrential floods which have poured off these hillsides have cut a deep wadi through the alluvial plain. In the upper reaches, the plain is narrow (100 to 200 meters wide), but in the lower reaches the flood plain is more than a kilometer in width. Today the wadi is a gravel-bed watercourse typical of the area. All along these alluvial flood plains are

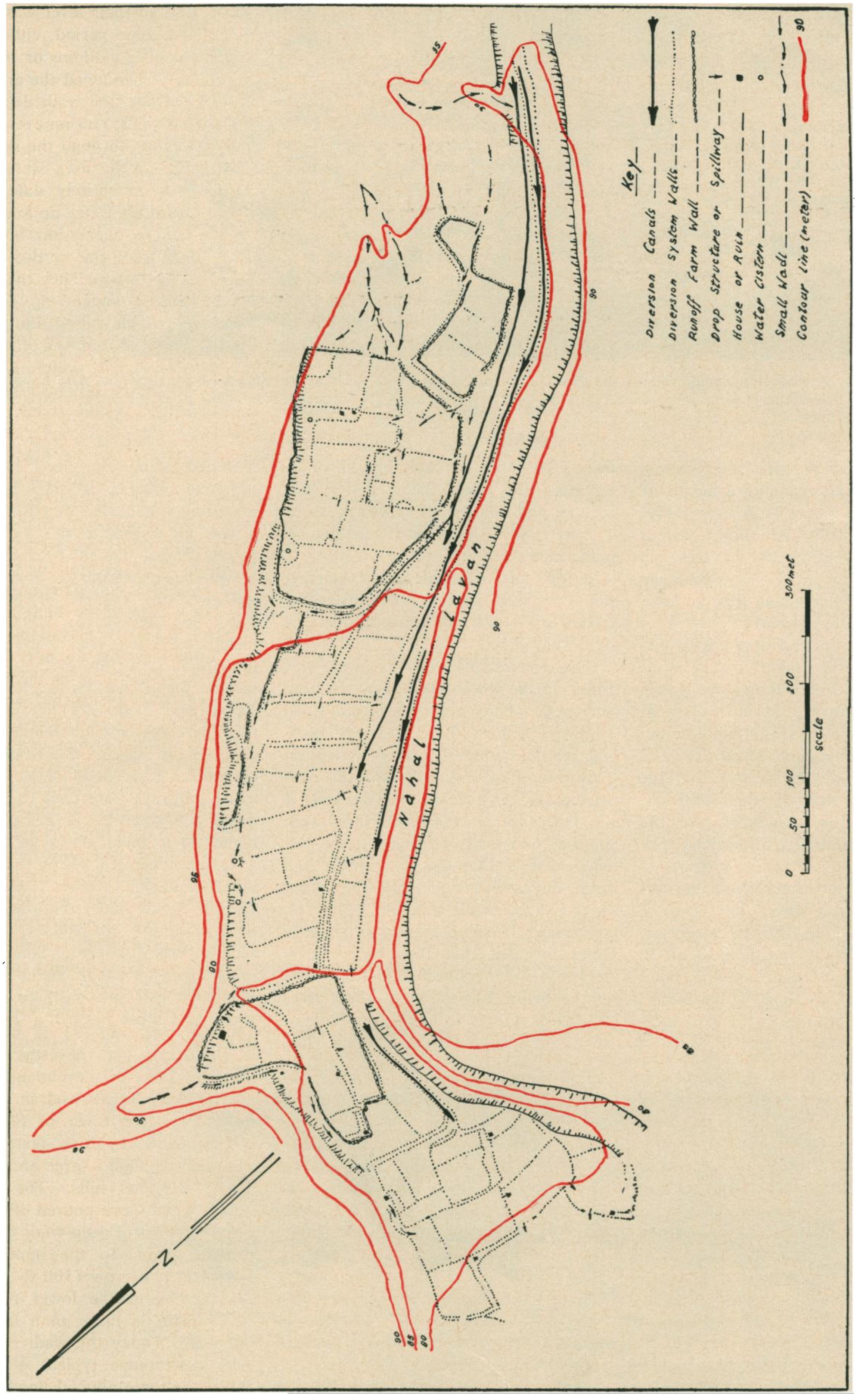


Fig. 9. Map of a section of the Nahal Lavan system.

Fig. 10 (above). A diversion canal wall of the Nahal Lavan system. Note the different stages of construction. The foundations are about 2 meters below the present soil surface. Fig. 11 (bottom of page). A large spillway with a crest length sufficient to allow passage of large floods.

remnants of ancient walls and terraces, some of the walls reaching a height of 4 to 5 meters. These high walls (Fig. 10) attracted our attention, and a specific area covering 200 hectares was studied in detail (*39*). The drainage area of Nahal Lavan at this point is about 53 square kilometers.

A close examination of the area disclosed again the superimposition of many systems. For a long time it was difficult to unravel the intricacies of each period or even to differentiate between the systems. Only toward the end of the survey did we realize that the capacity and size of the spillways, canals, and drop structures give the key to understanding the area. The spillways, which served as drop structures to carry the water from one terrace to the next lower one, can be classified into three distinct categories: (i) spillways with crest lengths of 30 to 60 meters, capable of handling flows in the range of 10 to 30 cubic meters per second (see Fig. 11); (ii) spillways with a crest length of 3 to 8 meters, capable of handling flows in the range of 1 to 5 cubic meters per second; and (iii) small spillways up to 1 meter wide for flows of less than 1 cubic meter per second.

Using this criterion as a starting point, we were able to differentiate between three different types and stages of development.

The earliest use of the area was found in the lower reaches of the area surveyed, where well-constructed stone spillways with a 30- to 60-meter opening are the common form of structure. However, these spillways were not connected to any stone walls, and it seemed as though these structures were all that remained of some ancient system—that is, that the stone walls had been dismantled and only the structures had been left standing. However, a special helicopter reconnaissance flight revealed that these wide stone spillways were connected to faint lines in the fields. Inspection of these lines disclosed them to be the remains of earth embankments which had stretched across the flood plain. The complete extent of this flood-plain spreading system was not surveyed, but it was clear that it was in use long before Nahal Lavan became a deep gravel-bed watercourse. Some of the spillways are capable of handling a flood flow of up to 100,000 cubic meters an hour (see Fig. 11). The topographic situation of this system indicated that it was in use when Nahal Lavan was a shallow depression and that the earth embankments were built in order to spread the runoff waters across the wide flood plain. The wide stone spillways were used to control or direct the water as it passed from a higher to a lower elevation.

In the upper reaches of the surveyed area, a second system based on diversion canals and structures (capable of handling 1 to 5 cubic meters a second) was discovered. Some of these main diversion canals are more than a kilometer in length and 5 to 10 meters wide, and most possess a gradient of 4 to 5 percent. All lead to diversion

structures which served to divide the canal flow into as many as seven secondary canals leading to leveled terraces. Some of these terraces are in good condition, but most of them are badly eroded by gulleys which join Nahal Lavan 5 meters or more below the level of the terraced fields. Each diversion canal serves an area of about 2 to 4 hectares.

Detailed investigation of the walls of the diversion canals and the terraced walls associated with them showed that these systems were also built in stages. Figure 10 shows one of the diversion canal walls and the three distinct periods of construction. Excavation alongside the terraced walls showed similar periods of construction. These observations indicated that the diversion system silted up during its operation and that the settlers were continually faced with the problem of raising the elevations of the terraced walls as well as the diversion structures. Potsherds in the area dated from the Nabataean-early Roman period.

The next use of the area was again as runoff farms connected to adjoining small watersheds (Fig. 9). These farms adapted the existing structures and stone walls of the diversion systems to their needs and did not exploit the runoff from Nahal Lavan. Potsherds in the vicinity of these farm units generally dated to the Byzantine era.

We were originally under the impression that diversion systems of this type were widely used by the ancient civilizations. Although we have traveled widely in the area and have studied hundreds of aerial photographs, we have now come to the conclusion that this method was used only in very special restricted areas, and furthermore no diversion canal has been found that served more than 3 to 5 hectares.

All the systems studied showed a remarkable similarity in their development. This development is characterized by three stages each related to the erosion that was taking place in the flood plains and wadis associated with the large watersheds (*40*). This development can be divided into three stages, as follows:

Stage 1: Flood-plain development. The major wadis were originally wide shallow depressions meandering in alluvial plains. Cultivation of these depressions necessitated the construction of stone walls in order to stabilize the cultivated fields. These walls were subsequently extended so as to spread the water over larger sections of the flood plain (*41*).

The main spillways of this system were characterized by wide openings (30 to 60 meters) for handling the whole flood flowing in the depression. The embankments in some cases were built of earth.

This flood-plain development period dates back at least to the Nabataean period and may be earlier.

Stage 2: Diversion systems. At some stage, these flood-plain spreading systems were abandoned and the system deteriorated through lack of maintenance. During or subsequent to this abandonment, the wadi cut a deep gulley through the flood plain. The next settlers in the area utilized the technique of raising the water from the wadi with the aid of a diversion structure and leading the water by means of a channel to the flood plain. These diversion channels generally served small areas, and in most cases the new settlers utilized the remnants of the previous flood-plain development walls and structures. During this period the wadi continued to erode, and at the same time silt from the large watershed (or from the eroding banks of the wadi itself) was deposited in the terraced fields. This silt raised the level of the fields until a stage was reached

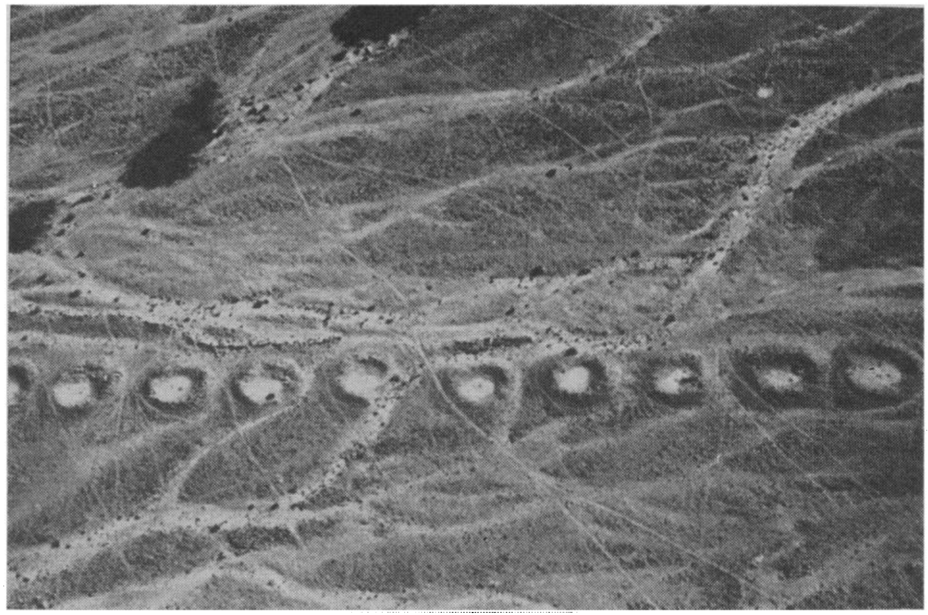
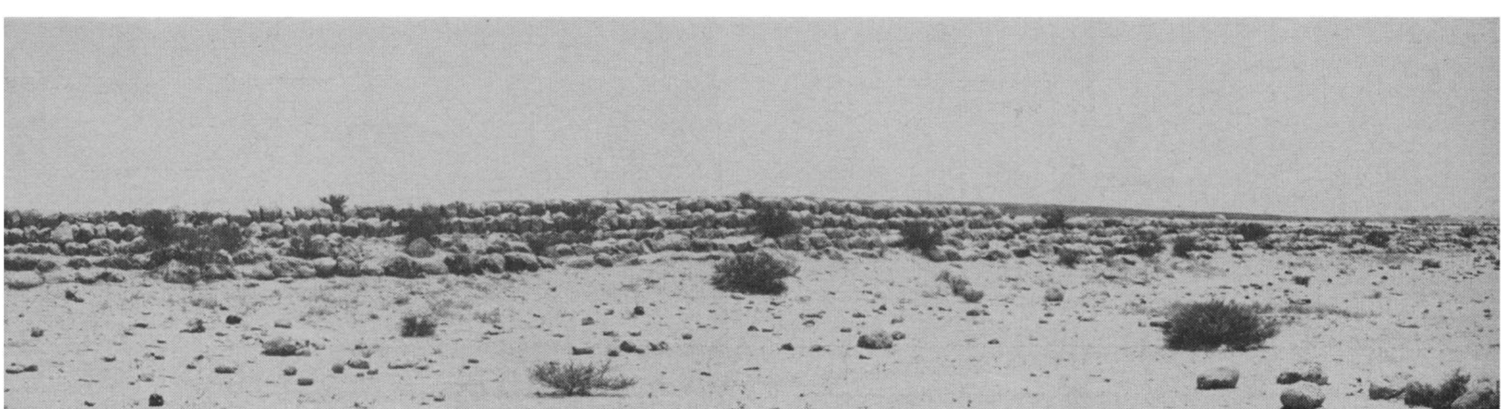


Fig. 12. An oblique aerial photograph of a chain-well system near Ein Ghadian.



that first necessitated raising the walls and later required the building of a new diversion structure higher up the wadi to raise the diversion canal.

The period of construction of these diversion systems must have been one in which the science of engineering was well developed, since all the structures required sound knowledge of hydrology and hydraulics. Furthermore, this period must have been one in which a central authority controlled the whole system and had the legal authority to distribute the flows during the short flood period that occurred in the ephemeral wadis. In both the Roman and Byzantine periods these conditions existed, and the Roman and Byzantine potsherds found in the area probably relate to this diversion-system period.

Stage 3: Runoff farms. The diversion system may have become unmanageable because of the silting problem, or serious flood conditions may have de-

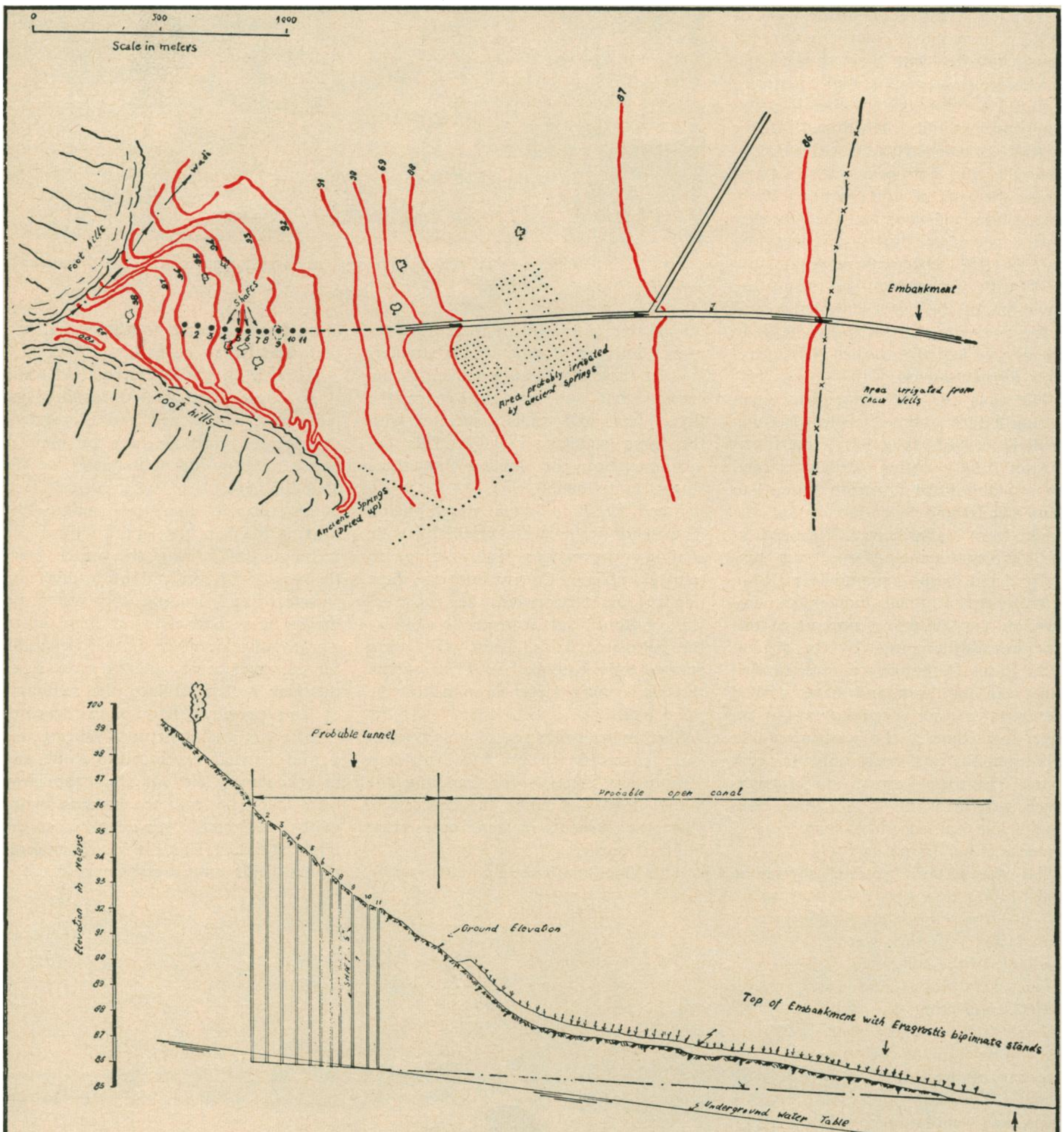


Fig. 13. Details of a chain-well system near Ein Ghadian.

stroyed the main diversion features, and the system was abandoned. The next system no longer relied on the main wadis but utilized the small watersheds adjoining the area in order to obtain the required runoff water. These runoff farms adapted existing walls and structures to their new requirements and generally utilized only part of the original diversion-system area (*42*).

Chain-Well Systems

In the Middle East and Central Asia, chain-well systems ("artificial springs") have been used since ancient Persian times and are still widely used today. Their construction and operation have been fully described in the literature (*43*).

While well digging was a common method of exploiting shallow groundwater resources in the ancient civilizations in Palestine, the more intricate chain-well systems have only been found in Jordan and the Arava Rift Valley (*37*, *44*). As the mean annual rainfall in the valley is only about 40 millimeters and this amount of rainfall is without agricultural value, the chain-well systems must have been the main source of irrigation water.

Chain-well systems have been located at three oases in the Wadi Arava Rift Valley. The largest and most intricate is near the Ein Ghadian (Yotvata) oasis. Other systems were discovered near Ein Zureib and near Ein Dafieh (Ein Evrona) (*45*). Since these systems are hardly discernible on aerial photographs and are difficult to discover from the air or even in the field, it is likely that a thorough investigation of the Wadi Arava would disclose many other systems.

A chain-well system is composed of three essential parts: (i) one or more wells (sometimes called "mother-wells") dug down to the water table; (ii) an almost horizontal underground tunnel leading the water, at small gradient, to the soil surface and ending in an open ditch; and (iii) vertical shafts connecting the tunnel to the ground surface. These shafts facilitate the construction of the tunnel and the disposal of excavated material in a molelike fashion and also provide access and ventilation to the tunnel for maintenance purposes. The surplus excavated material is deposited near the shafts, forming a circular mound around the shaft opening.

The oasis of Ein Ghadian, which was examined in detail, is presented as a typical example of a chain-well system of the Arava Valley. The oasis itself is of the playa type, and the central part, where the water table is 1 to 1.5 meters deep, is saline and sterile. It was natural that this oasis, the largest on the western side of the Arava valley floor, was constantly settled. There are several remnants of ancient settlements extending from Middle Bronze to Roman-Byzantine times. Ein Ghadian was also the first station on the Roman road from Eilath to the north of Palestine (*46*).

Figure 12 shows a part of one chain-well system at Ein Ghadian as seen from the air; Fig. 13 shows details of one of the systems.

The chain-well systems vary in length; some are 3 to 4 kilometers long, others seem to be only a few hundred meters long. The vertical shafts are spaced at distances of about 15 to 25 meters, center to center. In most systems, only relatively few of the original circular mounds and shafts are still intact, owing to the obliterating action of winter flash floods. In those sections where the danger of destruction by floods was greatest, remnants of stone protection walls are found on the upstream side of the line of shafts.

All systems apparently begin in the gravelly wadi-fans on the western edge of the Arava depression and may possibly be connected to a definite fault line. The tunnel part of the system always seems to terminate in an elevated earth ridge on which there is a thick growth of *Eragrostis bipinnata* ("love grass"). These ridges are probably the old irrigation channels.

The systems and their channels lead to the northwestern edge of the Ein Ghadian playa, which is covered by stands of *Eragrostis bipinnata* rooted in the water table. Closer inspection reveals that the individual tussocks of *Eragrostis bipinnata* form regular checkerboard patterns. It is possible that these stands indicate the area of ancient irrigation. Each tussock would then represent an irrigated basin, or possibly the point where a palm tree was rooted. However, if the water level in ancient times was different, the irrigable area would, of course, have changed correspondingly.

Practical application. Many authors (*47*), investigating the area, have suggested that the ancient and forgotten civilizations of the Negev could teach a practical lesson for the future. We, too, felt that some of the principles on which the ancient civilizations developed their desert agriculture could be applied today. The written records of ancient agriculture in the desert are limited principally to the Nessanah documents (*48*). But even the little information given in these publications encouraged us in this line of thinking.

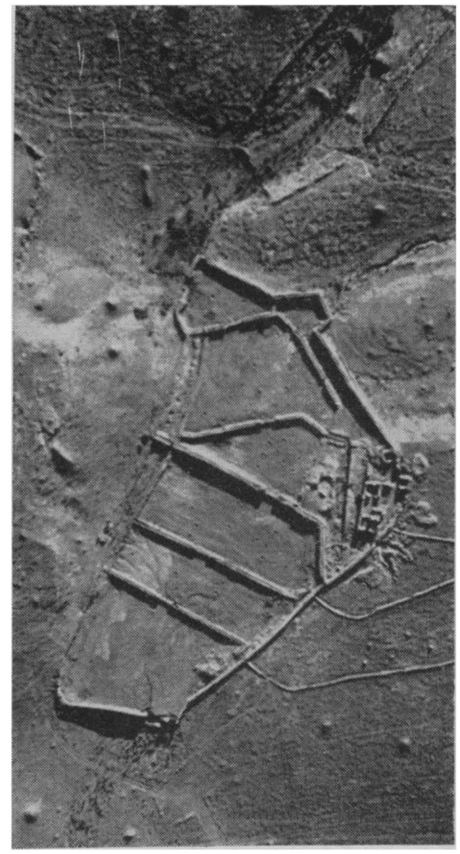


Fig. 14. An aerial photograph of the reconstructed Shivtah farm. Note one branch of one runoff conduit entering the farmhouse, bringing water to an underground cistern.

However, the first question that we had to decide was whether there had been any climatic changes during this period of time. We are of the opinion that there has been no major climatic change in the area—that is, that the Negev has always been a desert with an average annual rainfall of about 100 millimeters. If there had been a more humid climate in ancient times, there would have been no need to develop this ingenious desert agriculture based on maximum water conservation; necessity was the mother of invention. However, we are also of the opinion that there were definite variations in the average annual rainfall. The 20-year moving average may have fluctuated between 70 and 150 millimeters, but these differences would probably have evened out on a 100- to 200-year moving average.

Fig. 15. The reconstructed ancient farm near Avdat. Note the farmhouse on the hill. The reconstructed conduits leading runoff from the small watersheds may be seen in the background.

We then decided to reconstruct two ancient runoff farms, one near Shivtah and one near Avdat. In doing so, our aims were (i) to collect exact data about rainfall and runoff and, if possible, develop an analytical relationship between them, and (ii) to find out what, if any, agricultural crops and fruit trees could be grown by utilizing *only* the runoff from small watersheds.

After a careful survey, both farms were reconstructed with all their terraces, walls, and channels.

The Shivtah farm. The runoff farm shown in Fig. 14 was chosen for reconstruction (*49*). The reconstruction was started in the summer of 1958. Where a channel of the wadi led water into the farm, a weir and an automatic flood-recording gauge were built. A meteorological station was erected near the farm, and nine automatic and simple rain gauges were distributed over the whole catchment area. In February 1959, after the first flood, 250 fruit trees and vines were planted (grape, almond, apricot, peach, plum, carob, olive, pomegranate, and fig). During the summer of 1959 the young trees received small amounts of additional irrigation in order to insure their establishment. From then on, they received only runoff water from the small watersheds. The results by August 1960 were very encouraging, since during this short period the young saplings grew from a height of 40 to 50 centimeters into trees 2 to 2.50 meters high, despite the fact that both years were severe drought years, the season 1959–60 being the driest one since meteorological measurements were established in Palestine-Israel. During the coming rainy season (1960–61) we will plant another 50 fruit trees.

The Avdat farm. This reconstructed farm lies at the foot of the hill on which the ancient city of Avdat is situated. Its reconstruction was started in July 1959 after a careful topographic and soil survey.

The soil (as in the case of the Shivtah farm) is the typical aeolian-fluviatile loess of the Negev. It is uniform over the whole farm area with the exception of small strips in the upper part and along the sides of the farm. These parts will not be used for

Fig. 16. Harvesting barley on the Avdat farm in May 1960.

our agricultural experiments. The loess is uniformly 1.50 to 2.50 meters deep. A farmhouse (see Fig. 15) containing a laboratory, a kitchen, two sleeping rooms for the staff, and one sleeping room for visiting scientists was built on the hill overlooking the farm (*50*). Near the house there is a meteorological station more complete than that at the Shivtah farm. Two automatic and 17 simple rain gauges were distributed over the whole area. Eight weirs and automatic runoff recording gauges were set up as described for the Shivtah farm.

After the first rain of 16 to 22 millimeters, in November 1959, a heavy flood wetted the whole farm area down to a depth of 1 to 2.5 meters. Barley of the Beacher variety was sown. It sprouted quickly and was harvested in May 1960. On selected parts of the area, the yield was 125 kilograms per dunam (or 500 kilograms per acre) (Fig. 16). This is a quite astonishing yield for this most severe drought year, with only 40 millimeters of rain, when thousands of dunams of barley in the more northern area of Israel, with 80 millimeters and more of rain (but without additional runoff), failed utterly.

On the basis of the encouraging results of the first year, our agricultural committee has drawn up the following plan, which is now being carried out (*51*) for the coming rainy season.

1) Field crops: 80 plots (3 by 25 meters) will be established. The water-distribution system to these plots is so arranged that the plots will get equal, known quantities of runoff water and there will be full control of this distribution of the flood runoff. The plan provides for different field crops to be sown according to the time of year when the first flood occurs and according to the depth of penetration.

2) Pastures: 10 plots will be established as nursery areas. An additional 5 to 7 dunams will be used as observation areas which will receive only partially controlled quantities of runoff water.

3) Orchards: On 10 to 12 dunams, 200 fruit trees and vines will be planted (pistachio, cherry, peach, apricot, and grape).

References and Notes

1. E. H. Palmer, *The Desert of Exodus* (Cambridge, England, 1871).
2. For phytogeographical, phytosociological, and ecological data about the Negev, see H. Boyko, *Palestine J. Botany Rehovot Ser.* **7**, 17 (1949); D. Zohary, *Palestine J. Botany, Jerusalem Ser.*, **6**, 27 (1953); M. Zohary, *ibid.* **4**, 24 (1947); ——— and G. Orshan, *Végetatio* **5–6**, 341 (1954); M. Zohary, *Geobotany* (Sifriath Hapoalim, 1955) (in Hebrew).
3. The question of the minimum "effective" rainfall is a most important one for all desert areas. N. H. Tadmor and D. Hillel [Israel Agr. Research Sta. Rehovot, paper No. 38 (1957)] suggest that rainfall in amounts of less than 10 to 15 mm is "ineffective"—that is, has no or little effect on vegetation and runoff. Y. Kedar [*Econ. Quart.* **5**, 444 (1958) (in Hebrew)] estimates that 50 percent of the average yearly rainfall in the Negev is effective. However, our own first measurements showed that rainfalls much smaller than 10 to 15 mm are effective and start runoff.
4. For the history of the Negev, see the many publications of N. Glueck and especially his book *Rivers in the Desert* (Farrar, Straus, and Cudahy, New York, 1959). As for prehistoric times, there is much evidence of prehistoric settlement in the Negev, perhaps even reaching back to the Palaeolithicum [see N. Glueck, *Bull. Am. Schools Oriental Research* **142**, 17 (1956)]. Concerning the Chalcolithicum, we may have to change our opinion, as N. Glueck [*Biblical Archaeologist* **22**, 82 (1959)] reports that he found chalcolithic sites in the Central Negev.
5. An excellent historical sketch on the Nabataeans has lately been written by J. Starcky [*Biblical Archaeologist* **18**, 84 (1955)]; see also M. Evenari and D. Koller, *Sci. Am.* **194**, 39 (1956).
6. N. Glueck [*Biblical Archaeologist* **22**, 82 (1959)] writes of this period: "The Byzantine period in the Negev came to an end . . . as a result of the Mohammedan conquest. Darkness and disintegration and reversion to desert have characterized its history since then."
7. M. Evenari, Y. Aharoni, L. Shanan, N. H. Tadmor, *Israel Exploration J.* **8**, 231 (1959); Y. Aharoni, M. Evenari, L. Shanan, N. H. Tadmor, *ibid.* **10**, 23, 97 (1960).
8. N. Glueck has stressed this point in his surveys of the Negev published in many issues of the *Bulletin of the American Schools of Oriental Research*; see also N. Glueck, *Rivers in the Desert*. See also F. M. Cross and J. T. Milik [*Bull. Am. Schools Oriental Research* **142**, 5 (1956)], who reported Iron Age II sites and desert agriculture from the wilderness of Judaea (Wadi Buqeah, near Qumran). According to their description, they found what we call "runoff farms."
9. The Middle Bronze I period presents two main problems. To what ethnic group did the people of this period belong? N. Glueck [*Bibical Archaeologist* **18**, 2 (1955); *Bull. Am. Schools Oriental Research* **149**, 8 (1958)] calls this period in the Negev the "Abrahamitic age." But the scholars are not yet agreed on the date of Abraham's wandering through the Negev. Even if Glueck's date is right, the people of this period cannot be identified with Abraham's people. The second question arises in connection with the occupation of the people in the Middle Bronze I period. Were they cattlemen or agriculturists or both? Glueck [*Bull. Am. Schools Oriental Research* **138**, 7 (1955)] calls them "Tillers of the soil" and states in many of his publications that they practiced agriculture. However, no investigator has yet related ancient fields to any of these settlements.
10. R. Calder, *Man Against the Desert* (Allen and Unwin, London, 1951).
11. J. Baradez, *Fossatum Africae* (Arts et Métiers Graphiques, Paris, 1949).
12. Carton, *Rec. notes et mém. soc. archeol. Constantine* **43**, 193 (1909).
13. O. Brogan, *Illustrated London News* (22 Jan. 1955); M. Renaud, *Rev. agr. Afrique du Nord* **56**, 689 (1958).
14. Carton, in his excellent paper, was perhaps the first to recognize clearly the main principles of ancient desert agriculture—that is, the use of runoff from sterile hills and the storing of the runoff water in the soil. He writes: "Il s'agit ici d'ouvrages ayant pour but *non pas l'irrigation proprement dite, mais l'inondation ou la submersion*" (italics ours). The main aim of the system was "de faire pénétrer lentement et profondément l'eau dans le sol." He was the first, too, to point out "l'ingénuité et la prévoyance des Anciens qui, au lieu d'énormes barrages-réservoirs, coûteux et dangereux, destinés à l'irrigation, avaient préféré réserver l'eau dans ces immenses réservoirs-souterrains . . . ." We cite him verbatim because his paper is not easily available. Though this desert agriculture flourished most in Roman times, Carton is of the opinion that it may be older than the times of Carthage and Rome and dates perhaps back to the old Berber population.
15. A. de Poidebard, "La trace de Rome dans le désert de Syrie," (Librairie orientale P. Geuthner, Paris, 1934); S. Mazloum in R. Mouterde and A. de Poidebard, *Le limes de Chalcis* (Librairie orientale P. Geuthner, Paris, 1945).
16. N. Glueck, *Ann. Am. Schools Oriental Research* **14** (1934); **17-19** (1939); **25-28** (1951).
17. F. Stark, *Geograph, J.* **93**, 1 (1939); H. St. J. B. Philby, *Sheba's Daughters* (Methuen, London, 1939); W. Phillips, *Quataban and Sheba* (Harcourt, Brace, New York, (1955); R. L. Bowen, Jr., in *Archaeological Discoveries in South Arabia* (Johns Hopkins Press, Baltimore, 1958). Special mention must be made of the enormous ancient irrigation dam of Marib—possibly the biggest ever built in ancient times—constructed in the 8th century B.C., which broke down in the 6th century A.D. [E. Glaser, *Reise nach Marib* (Hölder, Vienna, 1913); A. Grohmann in *Encyclopedia of Islam* (Brill, Leiden, 1913)]. The oldest irrigation dam, which apparently broke immedately after it was finished, was found in Egypt, dating back to the IIIrd or IVth dynasty (about 3000 B.C.) [see B. Hellström, *Houille blanche* **1952**, No. 3, 424 (1952)].
18. E. F. Castetter and W. H. Bell, *Pima and Papago Agriculture* (Univ. of New Mexico Press, Albuquerque, 1942); *Yuman Indian Agriculture* (Univ. of New Mexico Press, Albuquerque, 1951).
19. G. de Reparaz, *El programa de estudios de la zona arida Peruana* (UNESCO, 1958).
20. See L. Shanan, N. Tadmore, M. Evenari, *Ktavim* **9**, 107 (1958); **10**, 23 (1960).
21. D. Hillel, *Bull. Israel Agr. Research Sta. Rehovot* **63**, 1 (1959) in Hebrew with English summary).
22. These farm fences apparently served two purposes. They are a symbol of property [Y. Kedar, *Israel Exploration J.* **7**, 178 (1957)] and, at the same time, a control structure. Most of them run around the farm at the base of the slopes preventing undesired material from the slopes from being carried into the fields and permitting the runoff water to enter the fields only at the places desired [see also N. Glueck, *Bull. Am. Schools Oriental Research* **149**, 8 (1958); **155**, 2 (1959).
23. In an earlier paper [M. Evenari and G. Orshansky, *Lloydia* **11**, 1 (1948)], hammadas were described as follows: "Hammadas are slightly rolling gravelly desert plains whose surfaces are strewn with vari-sized stone fragments and pebbles. Such fragments are brown or black, encased in the so called 'Schutzrinde' of the German authors, regardless of whether the core itself is composed of chalk, granite, flint, or schist. The brown and black surface of the pebbles shines brightly as it is covered by the 'desert lacquer' . . . . This black lacquer gave rise to the Arab legend that these stones were scorched by heavenly fires."
24. Y. Kedar, *Bull. Israel Exploration Soc.* **20**, 31 (1956) (in Hebrew with English summary).
25. Kedar was the first to point out the difference between stone and gravel mounds, according to the lithological material available.
26. A. Musil, *Arabia Petraea* (Hölder, Vienna, 1907); T. Wiegand, *Sinai* (Gruyter, Berlin and Leipzig, 1920); C. A. Woolley and T. E. Lawrence, "The wilderness of Zim," *Palestine Exploration Fund Annual* (1914–15).
27. P. Mayerson, *Bull. Am. Schools Oriental Research* **153**, 19 (1959).
28. Most of the arguments against this theory are discussed in N. H. Tadmor, M. Evenari, L. Shanan, D. Hillel, *Ktavim* **8**, 127 (1957).
29. N. Glueck [*Bull. Am. Schools Oriental Research* **149**, 8 (1958); **155**, 2 (1959)] and Y. Kedar [*Bull. Israel Exploration Soc.* **20**, 31 (1958); *Geograph. Rev.* **123**, 179 (1957)] also refute Palmer's (and Mayerson's) theory. There are only two points of Mayerson's which merit attention additional to that given by Glueck (1959). First, Mayerson presents a photograph of some stone heaps which were not on a slope but in a wadi bottom and uses this single observation as an argument against Kedar, Glueck, and ourselves. He fell victim to an error, as the rubble piles depicted in his photograph from Wadi Isderiyeh are the leftovers of a relatively recent excavation made by the Mandatory Government of

Palestine for a telephone cable which was laid along Wadi Isderiyeh. Second, Mayerson agrees that the vineyards planted on the slopes could not have existed on the available rainwater, but he believes that they were hand-irrigated from water stored in cisterns. A very simple calculation, already partly made by Kedar, shows that this is an impossibility. Kedar calculates that there are about 80 mounds per hectare (this is an underestimate; Mayerson talks about 600 per hectare) and that about 2300 hectares are covered by these mounds in the vicinity of Avdat. We estimate that each vine planted on or near a mound would require at least 0.5 cubic meter of additional water per year. The ancient farmers would, therefore, have had to supply 92,000 cubic meters as additional irrigation. Kedar has calculated that all the cisterns in the vicinity do not contain more than 4000 cubic meters altogether. The discrepancy between the figures is even more enormous if we assume that the people used some of the water from the cisterns for domestic purposes, and for cattle, as the Bedouins do today.

29. H. Boyko, *Proc. UNESCO Symposium on Plant Ecol.* (1955), pp. 1–8.
30. A. Reifenberg, *The Struggle between the Desert and the Sown* (Mossad Bialik, Jerusalem, 1955).
31. N. H. Tadmor, M. Evenari, L. Shanan, D. Hillel, *Ktavim* **8**, 127, 151 (1957).

Y. Kedar, *Geograph. Rev.* **123**, 179 (1957).

33. ———, in *Study in the Geography of Erets Israel* (1959), vol. 1, pp. 122–124 (in Hebrew).
34. D. Sharon, in an excellent experimental study, [see *Study in the Geography of Erets Israel* (1959), vol. 1, pp. 86–94], came to the following conclusions concerning soil erosion from the slopes: (i) The mounds were made by clearing the slopes of their dense stone cover. (ii) The soil beneath the mounds is undisturbed, but the clearance of ground between the mounds disturbed the natural equilibrium, exposed the slope to erosion, and through differential action on the soil-stone mixture led to the reformation of the stone cover between the mounds and the restoration of equilibrium. This explains why today the slopes between the stones are again covered by a stone pavement. As the difference in height between the old and "new" level of stone pavement is 10 to 15 cm only, only this amount of soil can have been washed down the slopes during the centuries (actually less, as the 10 to 15 cm contained a considerable number of stones, now left on the slopes). (iii) There were originally two types of strips—strips built of stones and strips made of soil. The latter type is the more frequent. As the soil from the soil strips has been eroded, only the original stone cover lying originally beneath the soil strips remains today. In Sharon's opinion, the function of the strips was to direct the water down slope. Therefore they were made of soil, as in this way their impermeability was greatly increased in comparsion with that of strips built of stone. All this tallies well with our own findings.

N. Glueck [*Bull. Am. Schools Oriental Research* **149**, 8 (1958)] came to the same conclusions.

36. G. Caton Thompson and E. W. Gardner [*Geograph. J.* **93**, 32 (1939)] report "evenly spaced stone-rubble heaps" tied up with ancient fields from Hadhramaut, a[illegible] W. J. H. King [*ibid.* **39**, 133 (1912)] reports similar findings from Lybia. Photographs in the book of Baradez (*11*) seem to show areas of mounds and strips on the slopes near ancient fields in Algeria. A most interesting observation was made by B. Hellström [*Roy. Inst. Technol. Stockholm, Inst. Hydraulics, Bull. No. 46* (1955)]. In the desert between Cairo and Alexandria he found numerous sand walls called today *kurum* (compare our *rujum el kurum*), dating from Roman times. His explanation is as follows: "When it was raining, the water ran quickly downwards along the sides of the walls . . . . The walls were constructed for the sole purpose of irrigating surrounding cultivated areas by means of the discharging water . . . . The areas along the walls were used for vineyards."
37. M. G. Jonides, "Report on the water resources of Transjordan and their development," *Publ. Govt. Transjordan* (London, 1939).
38. A. Schori and D. Krimgold, *Internal Rept. Dept. Agr. Israel* (1959) (in Hebrew).
39. Kedar [*Israel Exploration J.* **7**, 178 (1957)] studied part of this area. However, he did not differentiate between the various periods of development in the area, and hence he shows the system as having been built and operated all at one time.
40. Kedar (*24, 32*) indicates a different erosion cycle. We feel that he did not notice the superimposition of earlier structures on later ones.
41. Examples of this flood-plain development were mentioned in our work on the Matrada plain and Sahel-El Hawa (*7*) and are common in all those flood plains where the main wadi has not yet eroded down below the flood plain. In these areas the process of active head gulley growth can be seen even today. A deep gulley (2 to 4 m deep) is cutting into the flood plain, progressing at a rate of tens of meters per year and so changing the base level of the area.
42. The cultivation of shallow depressions (stage 1) probably also occurred in the small watersheds, and the simple terraces and cultivation of wadis found in these areas may relate to this stage. But we have not yet studied in detail either the hydrology or the historic development of this type of desert agriculture. Moreover, we have only begun an investigation of the role the numerous water cisterns played in collecting runoff from small watersheds for domestic purposes. It should also be pointed out that, although the final use of the diversion areas was as runoff farms, the runoff farms occur mainly in areas which were never related to diversion projects.
43. See, for exam[illegible] M. Cressey [*Geograph. Rev.* **48**, 27 (1958)], A. Smith [*Blind White Fish in Persia* (Allen and Unwin, London, 1953)], and A. Reifenberg (*30*).
44. B. Aisenstein, *J. Assoc. Engrs. and Architects in Palestine* **8**, 5 (1947).
45. M. Evenari, L. Shanan, N. Tadmor, *Ktavim* **9**, 223 (1959).
46. Y. Aharoni, *Eretz-Israel* (1953), vol. 2, p. 112 (in Hebrew); F. Franck, *Z. deut. Pal. Ver.* **57**, 191 (1934).
47. N. Glueck, in many of his papers cited in these notes; Y. Kedar, *Econ. Quart.* **5**, 444 (1958) (in Hebrew); Carton (see *12*), who writes: "Il peut être . . . intéressant de montrer que les études archéologiques méritent d'être favorisées *en raison des enseignements utiles* qu'elles peuvent donner" (italics ours); Woolley and Lawrence [*Palestine Exploration Fund Annual* (1914–15)], who write: "We believe that today . . . the Negev could be made as fertile as it ever was in Byzantine times."
48. C. J. Kraemer, Jr., *Excavations at Nessanah* (Princeton Univ. Press, Princeton, N.J., 1958), vol. 3.
49. Jossi Feldmann, then a member of *kibbutz* Revivim, carried out the reconstruction work at the Shivtah farm. The agricultural planning for both farms is done by an agricultural committee headed by Dr. J. Carmon. Its members are Dr. Samish (fruit trees) and Dr. R. Fraenkel (field crops), both from the National and University Institute of Agriculture; M. Hilb, Government Minister of Agriculture; J. Dekel, Jewish Agency; and M. Eshel, Government Department of Soil Conservation. Joel de Angeles, from Revivim, is responsible for carrying out the agricultural planning.
50. The farmhouse is called "The Lauterman Negev House" and is a gift of Rose Annie Lauterman, Montreal, Canada. We hope that scientists interested in animal or plant ecology of deserts will use this opportunity to study desert fauna and flora *in situ*. We ourselves, in addition to pursuing the hydrological and agricultural aims of the project, are carrying out an ecological-physiological investigation of the main desert plants, based on fixed observation plots around the two farms.

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