Underground Aqueducts Handbook

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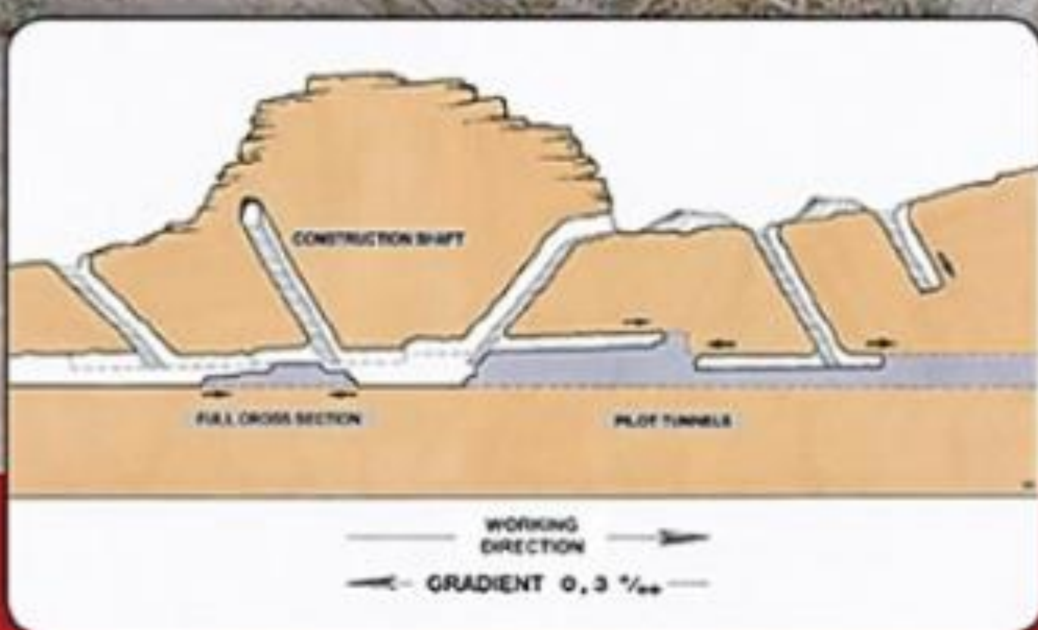

CRC Press
Taylor & Francis Group

2016

10 Spring Tunnels (Niqba')

The Jerusalem Hills Perspective, Israel

Azriel Yechezkel and Amos Frumkin

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10.1 HISTORICAL BACKGROUND

10.1.1 Development of Water Systems in Israel

The first development of water systems in Israel was at Atlit Yam, on Israel's northern shore (Galili and Nir 1993, 267). On this site, the first well was found, dated to the end of the Pre-Pottery Neolithic period (6100–5500 BCE). Well drilling continued on the Chalcolithic period, evidenced by a well found in Lahav (Burton and Levy 2012, 138). During the Early Bronze Age, fortified cities rose for the first time, concentrating large number of people. This allowed development of new methods for producing water because of the manpower involved in urban settlements. In Tel Arad, a great unplastered reservoir was used to collect runoff water from all over the city (Amiran and Ilan 1996, 106).

During the Middle Bronze Age (2200–1550 BCE), springs were included within the walls of cities (e.g., Tel Dan and Tel Kabri, see Kempinski 1992, 76). The most complex water system from this period was discovered in Jerusalem. It includes a tunnel that brought water from the Gihon Spring to a pool protected by a massive fortress. In addition, during this period, we have witnessed a new kind of water system—a carved, complex shaft tunnel, which was hewn downward into the groundwater. An example of such system can be seen at Tel Gezer (Macalister 1912, 256; Warner 2014, 6). During the Late Bronze Age (1550–1200 BCE), we have witnessed for the first time the existence of large, plastered reservoirs filled by runoff water (Hazor—Yadin 1975, 123; Ta'anach—Lapp 1969, 33).

During the Iron Age 2 (1000–586 BCE), water technology development reached a peak. Complicated and impressive water systems were found in Gibeon, Jerusalem, Hazor, Megiddo, Arad, Beit Shemesh, Be'er Sheva, and more. The main achievement of this period was to bring external water, from springs or runoff, into the city. This required exceptional engineering capability, good knowledge of hydrology and geology, recruitment of manual labor, excavation of thousands of cubic meters of rock, construction of retaining walls and staircases, plaster of large spaces, and more. In Hazor and Megiddo, it is possible that before building the water system, land in the city was expropriated, which indicates strong centralized government. At Megiddo, the people identified a water source outside the city, and by carving a shaft and an underground tunnel, they managed to channel the water to the bottom of the shaft and into the city. This testifies the high ability of measurement and navigation underground.

Water systems at Hazor and Gibeon did not aim their way to a water source outside of town but to the regional impermeable layer. This indicates an understanding that water gathers on layers spread regionally around the residential area and not in a single place or spring. Hezekiah's Tunnel is the first example in the ancient world of quarrying a long hidden water tunnel, from two different directions, without intermediate shafts, apparently under an approaching Assyrian campaign (Frumkin and Shimron 2006, 235).

During the Hellenistic period, water technology developed and long aqueducts were built for the first time in Israel—some as open channels (Jericho—Netzer and Garbrecht 2002, 367), some as hewn tunnels or built vaults (Akko—Frankel 2002, 83–86), and some with terracotta pipes (Sebaste—Frumkin 2002a, 267).

In the Roman period, there was another peak in technological development and water supply systems because of the engineering achievements of the Roman world. Romans were the first to use massive concrete vaults and arches in their building projects, building impressive aqueducts to many Roman cities throughout the empire in general and in Israel in particular. Some of these aqueducts are preserved until today along tens of kilometers, with minimal gradients, often using tunnels to shorten the route (Frumkin 2015a, 170). For example, Channel A, of the high aqueduct to Caesarea Maritima, used an underground 6.5 km long tunnel to catch groundwater and divert it along an impressive arched aqueduct to the city. Because the aqueduct had to overcome a "Kurkar" ridge before reaching the shore line, a 442 m long tunnel was hewn from both sides of the ridge by using 15 shafts for ventilation and measurements (Porath 2002, 112). The total gradient of Channel A is 16 cm per km, one of the lowest-gradient Roman aqueducts (Olami and Peleg 1977, 132).

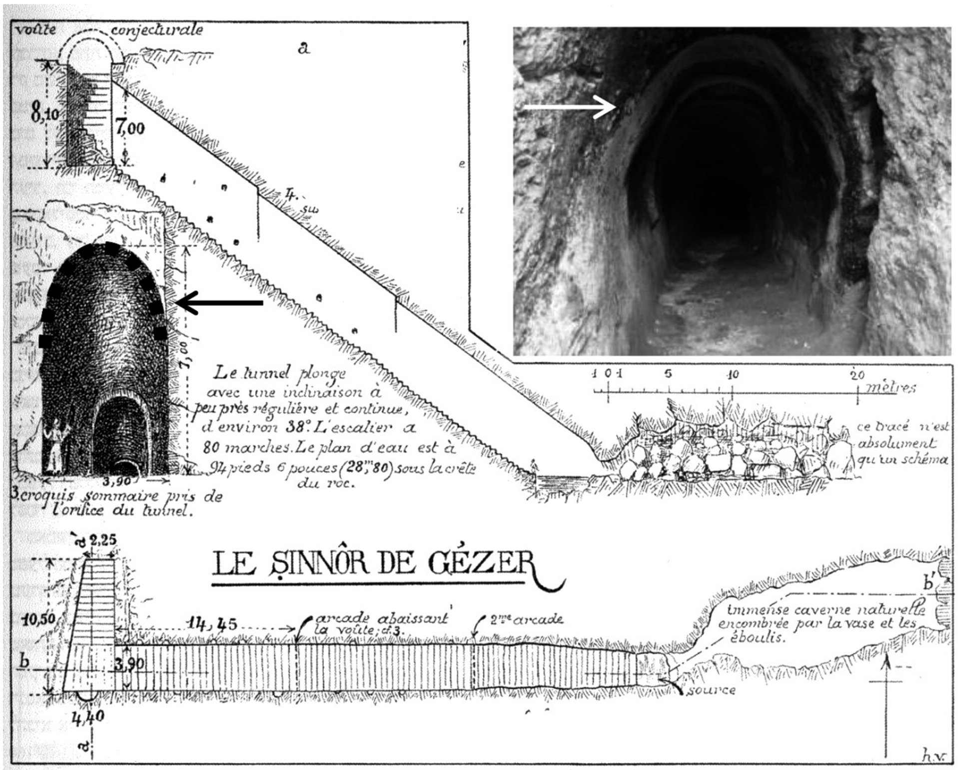

FIGURE 10.1 Water system at Gezer. Middle Bronze Age ceiling hewn as a barrel-shaped vault. (Based on Vincent, L.H. *Jérusalem recherches de topographie, d'archéologie et d'histoire- tome premier*, Librairie Victor Lecoffre, Paris, France, 1912, p. 158, figure 36. With Permission.)

10.1.2 Roofing Water Facilities Through Ancient History

During our study, we noticed that the roofing method for water facilities changes through history. Here, we offer a chronological typology for roofing methods and use this typology to date spring tunnels. During the Middle Bronze Age, the ceilings of water tunnels were hewn barrel-shaped vaults (e.g., Gezer—Figure 10.1) (Warner 2014, 2), and open channels were roofed with big unprocessed stones (boulders) (e.g., Jerusalem, see Reich and Shukron 2002, 3). In the Late Bronze Age, in a large water reservoir at Hazor, two forms of roofing are identified: a false arch vault, built of large stones without a keystone, and a barrel-shaped hewn vault (Ben Tor 1989, 18 Plan V). During the Iron Age 2, we have witnessed two forms of roofing water facilities: horizontal stone slabs (e.g., Arad, see Herzog 1997, 211, figure 61) and, for the first time, a tunnel with a square-cut hewn ceiling, at Hezekiah's Tunnel, Jerusalem (Figure 10.2), and in a water tunnel in Gibeon. Confirmation that a square-cut hewn ceiling began in the Iron Age 2 and is typical of this area and period was found in tunnel VI in Jerusalem (Figure 10.3) (Frumkin and Shimron 2006, 234).

The spring tunnels presented below became feasible owing to the hydrogeological and engineering knowledge developed in urban water installations.

10.2 GEOMORPHOLOGY AND CLIMATE OF THE STUDIED AREA

10.2.1 Geomorphological Properties

The studied area is within the Jerusalem hills (Figures 10.4 and 10.5), which are part of the Judean mountains, of the central mountain range of Israel. Its boundaries form a triangle between Jerusalem

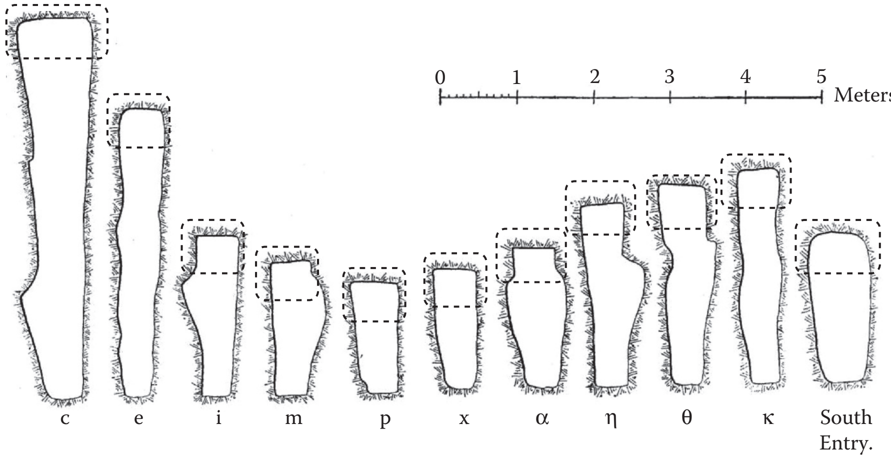

FIGURE 10.2 Hezekiah's Tunnel from the Iron Age 2. A square-cut hewn ceiling. (Based on Vincent, L.H. *JERUSALEM SOUS TERRE- les recnentes fouilles D'OPHEL*, Horace Cox, London, UK, 1911, figure 29. With Permission.)

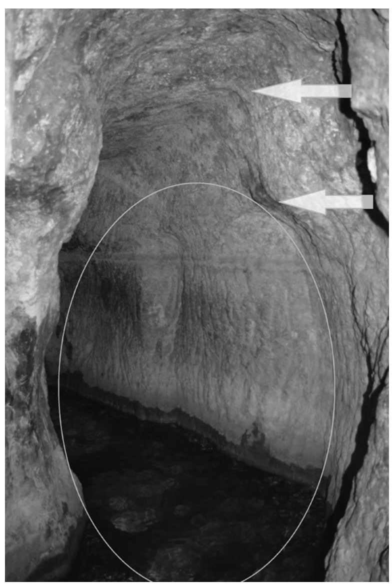

FIGURE 10.3 Tunnel VI at Jerusalem carried water from the Gihon Spring to the bottom of Warren's Shaft (Frumkin and Shimron 2006, 234), and it predated Hezekiah's Tunnel. This tunnel had a hewn barrel-shaped vault ceiling. At a later stage, the ceiling was raised and cut in a square style. (Photography by Frumkin.)

and the lowland hills in the West. Owing to several processes of folding, uplift, and erosion, the Judea Group of Albian, Cenomanian, and Turonian age is exposed in the Jerusalem hills (Sheffer et al. 2010, 4). The Mt. Scopus Group rocks of Senonian-Paleocene age overly the Judea Group rocks (Flexer et al. 1989, 350).

An erosional surface (termed the "Judean peneplain," see Frumkin 1992, 169), cuts the Judea- Mt. Scopus Groups, forming the skyline of the Jerusalem hills.

The Jerusalem hills are dissected by several valleys of ephemeral streams (wadies), such as Sorek and Refaim. These streams have formed seven major branches, in a dominantly east-west direction. Outcrops of hard limestone and dolomite commonly slope steeply (Kisalon, Aminadav, Veradim,

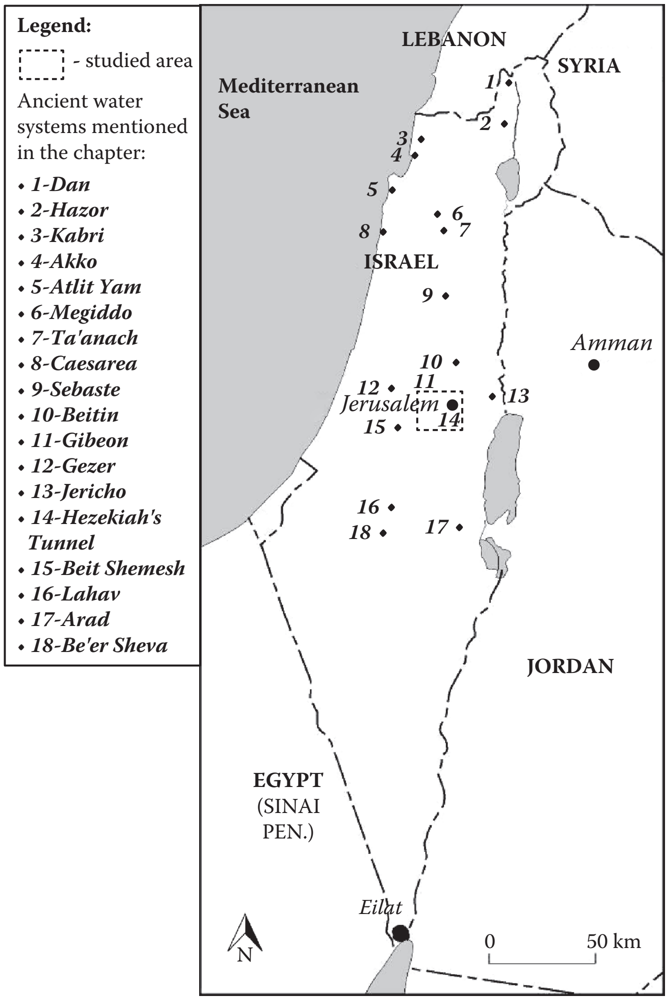

FIGURE 10.4 General map of Israel.

and Bina formations), while outcrops of marl and chalk are rounded and soft (Moza, Beit Meir, Kfar Shaul formations, etc.). In the Jerusalem hills, Karst phenomena such as caves are common in soluble cretaceous carbonate rocks (Frumkin and Fischhendler 2005, 459, figure 1; Frumkin 2013, 60).

10.2.2 Climate

Jerusalem mountains are in the dry Mediterranean climatic region (Csa) (Goldreich 2003, 13). The summer is hot and dry (Gvirtzman 2002, 14), and the rainy season lasts from October to May (Goldreich 2003, 63). Evaporation is high (due to high temperatures), causing negative effective precipitation over the entire year and positive effective precipitation only from December to February, when most precipitation falls (Gvirtzman 2002, 21; Goldreich 2003, 55). Rainfall is usually characterized by intense showers derived from cold fronts associated with Cyprus lows (Goldreich 2003, 26).

Temperature at Jerusalem hills averages 23°C and 8°C in the hottest and coldest months (August and January), respectively (Goldreich 2003, 101). Average annual precipitation is about 550 mm (Goldreich 2003, 67). Most precipitation is lost to evapotranspiration, and only 33% of the multi-annual precipitation infiltrates and recharges the aquifers (Dafny 2009, 104).

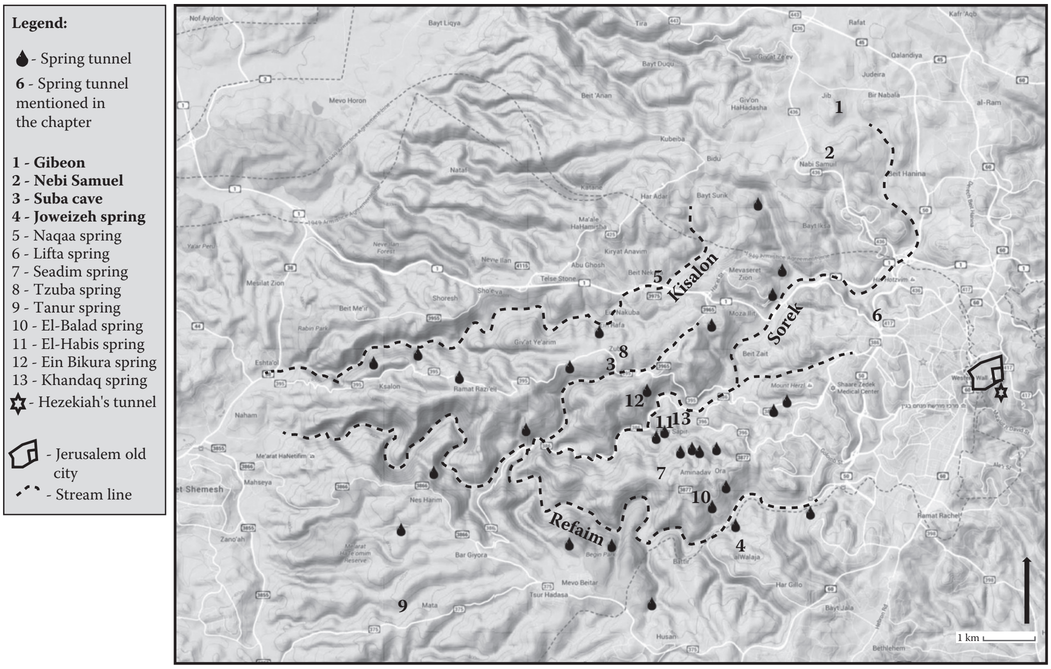

FIGURE 10.5 Studied area map of Jerusalem hills.

During the Holocene, that is, from the beginning of human settlement in permanent communities, there were a number of climatic changes in Israel (Frumkin et al. 1999, 680; Enzel et al. 2003, 272). Issar and Zohar (2012, 152) connected between the effect of climate change on water facilities and technology development in the Jerusalem area.

10.3 HYDROGEOLOGICAL BACKGROUND

10.3.1 Perched Springs—The Origin of Spring Tunnels

A perched spring is formed at the exposed interface between an aquifer and an underlying aquiclude layer (Figure 10.6). In some cases, a perched aquifer will not only feed a local spring, but water can seep down deeper, feeding additional perched springs or the regional aquifer. Many parameters affect the quantity and quality of water coming out from these springs. These include quantity and distribution of rainfall and the infiltration percentage (affected by soil moisture, evaporation and transpiration, runoff, etc.). Additional parameters are the size of the recharge area, the unsaturated zone depth, the characteristics of the soil and rock, and geological–geomorphological aspects (such as fractures and karst). In general, spring water quality in the Jerusalem hills is high, owing to the relatively slow infiltration and the length of seepage time through the rock.

Perched springs are very common in the Judea and Samaria hills. The larger springs discharge approximately 100,000 m^3yr^{-1} (Weiss and Gvirtzman 2007, 766 Table 1). A significant portion of the perched springs have low discharge rates, amounting to less than 10,000 m^3yr^{-1} (Cohen and Peyman 2011, Appendix 2), owing to their limited recharge area.

10.3.2 Annual and Seasonal Fluctuations of Discharge in Perched Springs

Burg (1998, 175) suggested that the perched springs in karstic carbonate areas (e.g., Jerusalem hills) have two sets of flow: slow matrix flow and quick flow in cracks and fissures. The first system feeds the springs through summer and the second feeds the springs through winter.

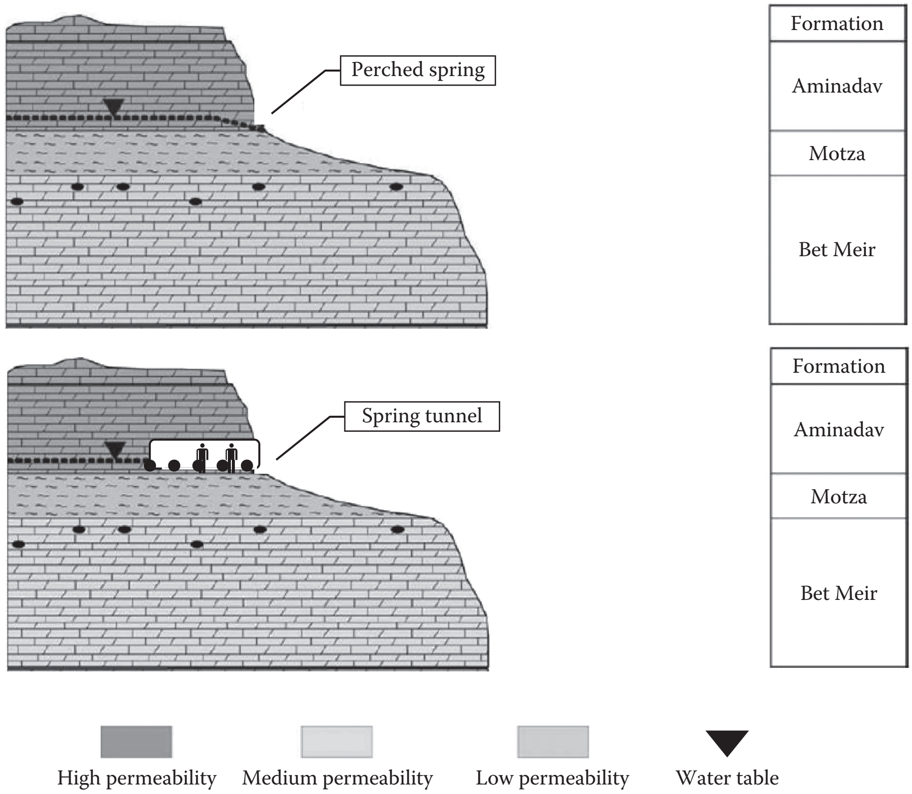

FIGURE 10.6 Perched spring and spring tunnel. (Based on Peleg, N. and Gvirtzman, H. *Journal of Hydrology* 388, 13–27, 2010, figure 3. With Permission.)

Our study of regional perched springs discharge was conducted on 36 perched springs in the mountains of Jerusalem and was based on photographs of the reservoirs of these springs over a period of 10 years. We have noticed that perched springs fed by a karstic aquifer were more affected by the fluctuations in annual precipitation than springs fed by non-karstic aquifers (Yechezkel 2015, 97). This is consistent with other studies (Peleg and Gvirtzman 2010, 24; Peleg et al. 2012, 782; Fiorillo 2009, 290).

10.4 SPRING TUNNELS

10.4.1 Description of the Phenomenon and Its Importance

Numerous perched springs in the Jerusalem hills emanate today from ancient tunnels, excavated sub-horizontally deep into the rock at the source of the spring. This technological development of the perched spring could achieve two goals: The first is to enhance spring discharge by increasing the saturated rock-air interface. The second is to renew the discharge of a spring that had dried out by tunneling into the retreating saturated zone. These excavations in the rock or earth are termed here spring tunnels (Hebrew: Niqba') (Figures 10.6 and 10.7).

Most spring tunnels we know are based on perched springs, while some of them have a karstic element (depending on the lithology of the aquifer). Spring tunnels can also be found carved into a karstic spring that is not perched, such as Ras Al Ein in Nablus (Frumkin 2015b). Quarrying spring tunnel is based on deep hydrogeological understanding: Water is perched on an aquiclude layer underground and can be reached by horizontal excavation from the surface and not just by digging vertically. The main significance of the spring tunnel is to develop water resources and increase the

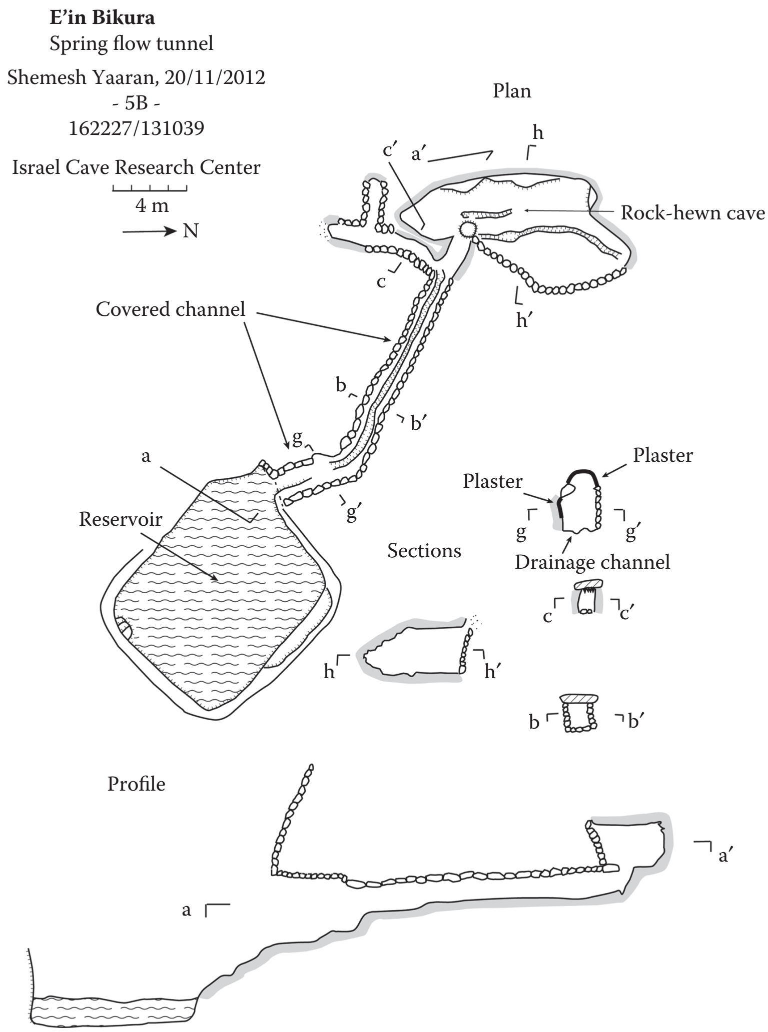

FIGURE 10.7 Ein Bikura Spring tunnel—plan and sections. Israel Cave Research Center.

economic security of rural agricultural communities. Perhaps, it even affected the distribution of habitation sites in different periods.

10.4.2 Types of Spring Tunnels

Depending on the topography, water level, and geology, we can identify two forms of spring tunnels.

1. Rock-hewn tunnel, cut directly to the bedrock, was excavated where a perched spring was seeping from a steep rocky slope. This is important from a technical and perhaps also from a chronological aspect (below). The width of a hewed spring tunnel is commonly less than 1 m but sometimes reach 4 m and more (e.g., El-Balad spring, Figure 10.8). Some of these tunnels are hewn partly in bedrock. In these cases, there is a built roof above a rock-carved tunnel (e.g., El-Habis spring, Figure 10.9)
2. Covered channel, dug where the water table was close to the surface and the mild topography did not allow excavation directly into the bedrock. First, an open channel was dug from the surface to the perched water layer. Later, the channel was covered using different

FIGURE 10.8 El-Balad spring. A hewn spring tunnel, 4 m wide. (Photography by Yechezkel.)

FIGURE 10.9 El-Habis spring. A hewn spring tunnel roofed with stone slabs. (Photography by Yechezkel.)

methods—stone slabs, barrel vault, pointed vault, and so on. When the spring tunnel was dug in loose sediment, casement walls were built to prevent collapse. The walls were constructed from either uncarved fieldstones (e.g., Lifta Spring and Naqaa Spring, Figure 10.10) or ashlar (e.g., Seadim Spring, Tzuba Spring, and Tanur Spring, Figure 10.11). Not all covered water channels are spring tunnels. Some were used only to carry water from one place to another. Therefore, we must investigate each water facility separately.

In many places, the terrain above the roofing was leveled by fillings of dirt, rocks, and soil. Subsequently, the area above the spring tunnel was restored as an agricultural area (Ron 1985, 155). Sometimes, the spring tunnel character changes as one moves inward, from a covered channel to

FIGURE 10.10 Naqaa spring. A built spring tunnel from field stones, roofed with stone slabs, and a drainage ditch. (Photography by Yechezkel.)

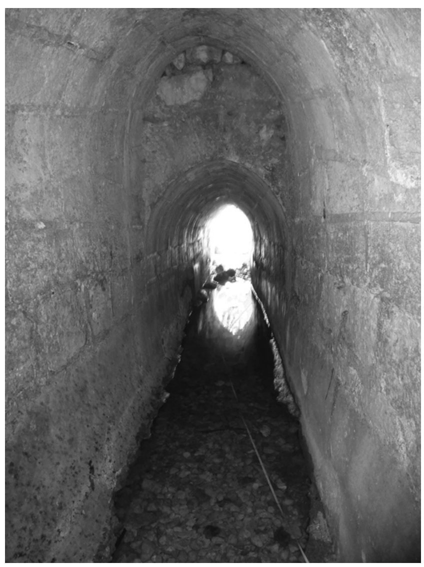

FIGURE 10.11 Tanur spring. A built spring tunnel from perfectly carved ashlar. (Photography by Yechezkel.)

a rock-hewn tunnel. In some cases, this reflects the additional stage(s) of pursuit after the receding groundwater level (Ron 1985, 154).

10.4.3 Spring Tunnels Setting

As noted, most spring tunnels are associated with perched springs. From a hydrological and/or climatic standpoint, spring tunnels may be found in areas where freshwater is scarce. These issues are met at hundreds of springs in Judea and Samaria, on the central mountain range of Israel. We suggest that spring tunnels may have originated in Israel.

10.4.4 Related Improvements and Associated Water Facilities

Increasing the saturated rock-air interface to increase spring discharge could be facilitated by quarrying at the end of the tunnel a large hall (Figure 10.7), by quarrying a twisting tunnel with sharp angles (e.g., Joweizeh Spring, Figure 10.12), or by splitting the tunnel into several branches.

In some spring tunnels, we can identify several points where water is emanating from the rock, along the tunnel. In the bottom of many spring tunnels, a drainage ditch was hewn with a small cross section, for times when discharge decreased. In long spring tunnels, sometimes, vertical shafts were constructed, connecting the tunnel with the surface, probably used as entry points, which facilitated easier access for excavation or maintenance. In some cases, a small shallow pool was dug at the output of the tunnel to filter the water before entering the main storage pool.

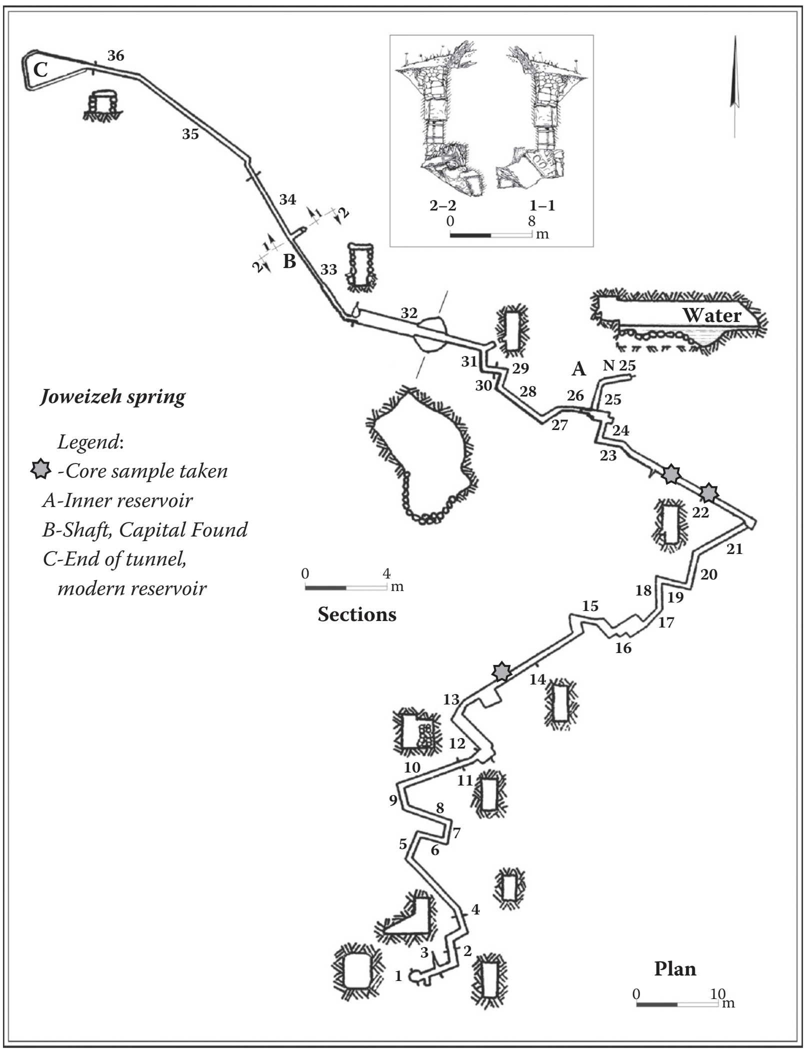

FIGURE 10.12 Joweizeh spring—plan and sections. (From Ein Mor, D. and Ron, Z. *New Studies in the Archaeology of Jerusalem and Its Region*, 85–109, 2013. [Hebrew], figure 3. With Permission.)

10.4.5 Environmental and Social Conditions That Accelerated Spring Tunnel Development

The most common type of settlement in the Jerusalem hills from ancient times to the Ottoman period is a small agricultural rural village. As perched springs are the only perennial water resources in this area, it is clear that increasing the discharge by spring tunnels was an important hydrogeological invention. It contributed to both the deployment of settlements in ancient times and their long-term resilience. In addition, since these springs are mostly located in mountain slopes, in many cases, the spring tunnel supplied water for irrigation agriculture, called "Shlachin" (Ron 1985, 149), based on gravity water channels. The high density of spring tunnels in a small area (Figure 10.5) indicates that these water resources were used as the basis for small agricultural villages. The scope of work needed for initial development is quite limited for most spring tunnels. It could rely on a small number of people for a season or two, such as for constructing cisterns. In some spring tunnels, one can identify that a large amount of work was done, possibly reflecting government-funded projects (such as Joweizeh spring and irrigated system of Khandaq spring) (Ein Mor and Ron 2013, 105; Ron 1985, 168).

10.4.6 Challenges in Dating Spring Tunnels

10.4.6.1 Complexity of Dating a Spring Tunnel

Various potential methods may be attempted to date a hydraulic structure/facility. Among them are stratigraphic dating of an archaeological excavation; dating hydraulic plaster and petrographic tests; dating with architectural typologies such as roof shape; and radiometric dating of calcium carbonate spring deposits. In practice, dating a specific spring tunnel is difficult for the following reasons: (1) Only few archeological excavations have been performed in spring tunnels. (2) The agricultural rural sector is not always represented in the archaeological record. (3) Dating plaster of water facilities in general and in spring tunnels in particular is complicated. Plaster is used mainly for sealing, so it was rarely used in spring tunnels, which were dug to increase the saturated rock-air interface.

10.4.6.2 Currently Accepted Age of Spring Tunnels

Several researchers have suggested that spring tunnels were first hewed in Israel during the Iron Age/Persian Period (Edelstein et al. 1983, 19; Ron 1985, 169; Shiloh 1992, 282; Issar and Zohar 2012, 161). This claim rarely relies on archaeological excavations of spring tunnels or on radiometric dating. Frumkin (2002b, 23) noted that the water source that feeds the water system in Gibeon, dating to the Iron Age, is a spring tunnel. Apart from this, many spring tunnels are associated with a high degree of probability to the Roman period (Patrich and Amit 2002, 10; Bull 1965, 227; Frumkin 2015b; Mazar 2002, 233; Zissu and Weiss 2008; Gibson et al 1991, 38). Because substantial evidence for dating the initial use of spring tunnels has hardly been presented, we analyze below a few selected cases.

10.5 FINDINGS FROM SELECTED SPRING TUNNELS

10.5.1 Joweizeh Spring Tunnel

Joweizeh Spring (Figure 10.12) is a few kilometers southwest from Jerusalem, toward the Refaim Valley, near the village of Walaja. This is the longest spring tunnel known in Jerusalem hills and Israel. The tunnel is hewn into the hard dolomite rock from the Aminadav formation and its path is twisting in sharp angles. The tunnel itself has two main parts, a built section and a hewn section. The total length of the tunnel is approximately 233 m.

The built section is accessed from a modern pool built on the surface. The first section of the built tunnel is approximately 30 m long, 60 cm high and 40 cm wide. Its walls are built of fieldstones covered with stone slabs (Markus and Ben Joseph 1983, 55). At the end of this section, a shaft connects it to the surface (described in detail later). The next section is 13 m long, approximately 1.5 m

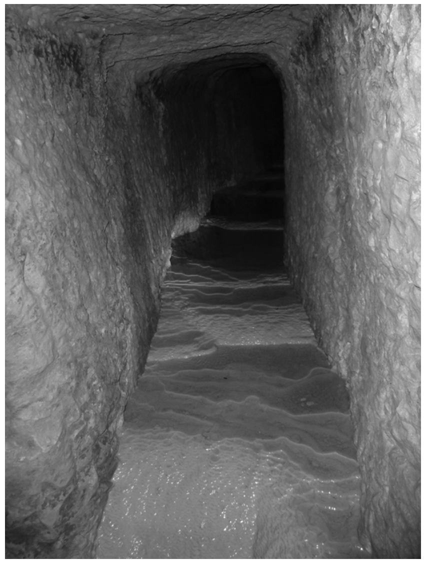

FIGURE 10.13 Joweizeh spring. Ceiling was cut in a square style. Notice the flowstone layers at the floor. (Photography by Yechezkel. With Permission.)

high and is built mainly from big ashlar. This part ends with a massive blocking wall, probably built as support against soil collapse. In its southern corner, there is a small breach, through which one can squeeze into the hewn part of the tunnel. A large vaulted hewn room leads into a narrow tunnel draining several small discharge points. This hewn part of the tunnel is more than 187 m long, 0.9–1.8 m high, and 0.6–1.5 m wide. The cross section is rectangular, and the walls and ceiling are carved in a professional way (Figure 10.13).

Along 124.5 m of the tunnel, there is a hewn and plastered drainage channel, approximately 10 cm wide and about 20 cm above the floor level of the main tunnel (Ein Mor and Ron 2013, 98). This channel probably led water during times of low discharge and is covered, like the floor of the tunnel, with a very thick layer of calcite flowstone. A short branch, 5 m long, splits from the main tunnel to the east. The floor level of this branch is lower by 1 m from the main tunnel floor, which makes this branch a small reservoir, may be for emergencies (Markus and Ben Joseph 1983, 57). The tunnel continues with sharp curves and angles up to 130° and ends with two small branches, each draining its own discharge point.

10.5.1.1 Dating the Water System—Proto-Aeolic Capital

After the discovery of this unique spring tunnel, a survey was conducted by Israel Cave Research Center in 1983 for mapping and measurements. During this survey, Frumkin noticed a carved stone that was stuck in the shaft described above (Markus and Ben Joseph 1983, 61). Only during a survey conducted in 2012, Ein Mor identified that the item is an architectural, monolithic, large capital, carved in a Proto-Aeolic style (Ein Mor and Ron 2013, 98). The quality of finish of the carving is excellent. Ein Mor and Ron suggest that this item served as half of the monumental entrance of the rock-cut water system.

So far, 27 Proto-Aeolic capitals have been found in the region of the Israel kingdom, 11 in the region of the Judea kingdom, and a few more in Transjordan. The capitals found in the kingdom of Israel are dated mainly to the ninth century BCE (Lipschits 2011, 205) and those in Judea and Jordan date back to the late eighth century or the beginning of the seventh century BCE (Lipschits 2011, 212–213).

The weight of the capital and the vast dimensions indicate that it is located close to its original location. Based on the parallels found, the researchers dated the capital and consequently the associated tunnel to the Iron Age 2 period and more precisely to the end of the eighth or beginning of the seventh century BCE. The engineers' skills and the impressive quarrying over more than 187 m leave no doubt that this is a state-funded water system. As noted in the introduction, knowledge of engineering and hydrology existed during the Iron Age 2, evidenced in water projects around the country. The nearest water system, geographically and chronologically, is the 530 m long Hezekiah's Tunnel.

Ein Mor and Ron suggest that there may have existed a nearby palace or estate similar to the one found at Ramat Rachel. They also note the possibility that the water system was built before the Iron Age.

10.5.1.2 Attempting Radiometric Dating of Flowstone

We drilled three cores for radiometric dating in the bottom of the spring tunnel (Figure 10.14). In the first core, there was stratification of flowstone overlying a piece of rock. Since it was not proved to be bedrock and could mean perhaps that it was a stone fallen from the ceiling, this sample was not used for dating. At the second core, the stratification of the flowstone was interrupted. The third core had uniform stratification of flowstone till bedrock to the depth of 30 cm. This sample was dated using U-Th at the Israel Geological Survey laboratories to 14,026–10,455 yr BP. This date is too ancient, indicating that the closed system assumption was violated, and Uranium was added during the years (Ford 2003, 556; Shopov 2003, 282).

10.5.2 Gibeon Spring Tunnel

Tel al-Jib, north of Jerusalem, is identified with the Biblical city of Gibeon. During the Iron Age, two water systems were constructed in Tel al-jib. One is a tunnel leading from the city to a reservoir room fed by a spring tunnel and the other is a large, deep, round shaft descending to the perched aquifer. Pritchard (1961, 1962) exposed both during two seasons of digging. We discuss here only the first system.

From the entrance hall, built within the Iron Age fortifications, you enter an inclined stepped tunnel approximately 45 m long (Pritchard 1961, 5). This tunnel does not intersect ancient layers. At the beginning, the tunnel is covered with stone slabs, soon becoming entirely hewn in the bedrock. The tunnel ends in a large reservoir chamber (12 m length and 3 m width). The chamber was supposedly open toward the surface in times of peace, but during times of war, a built stone wall 75 cm

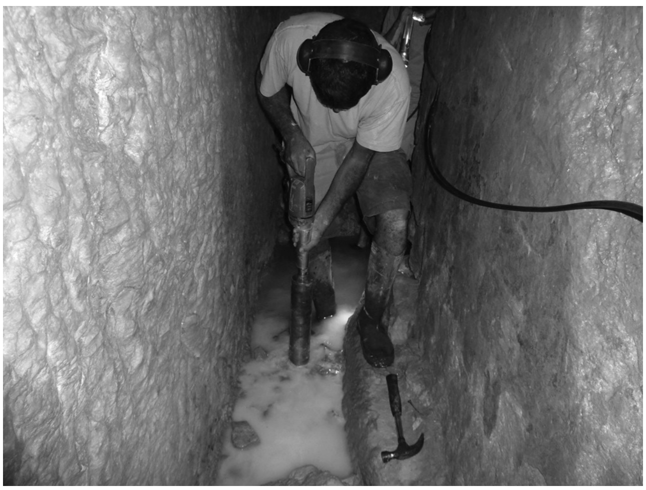

FIGURE 10.14 Joweizeh spring. Drilling a core at the bottom of the spring tunnel. (Photography by Yechezkel.)

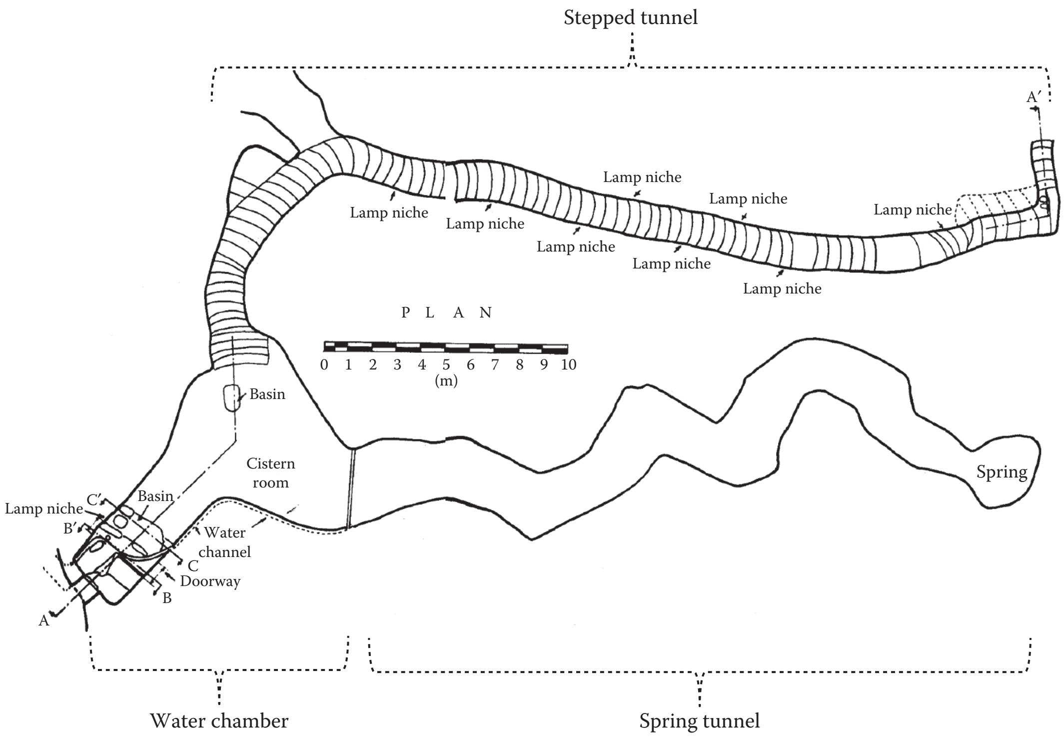

FIGURE 10.15 Gibeon water system and spring tunnel—plan. (Based on Pritchard, J.B. *The Water System of Gibeon*, The University Museum, Philadelphia, PA, 1961, figure 3. With Permission.)

thick prevented the entrance from outside the city. This wall was not preserved, but one can detect its rock-hewn foundation course.

A 47.5 m long hewn spring tunnel feeds water to the reservoir (Figure 10.15). There are nine turns in the spring tunnel, possibly reflecting pursuit after receding water (Ein Mor and Ron 2013, 103), or that the diggers had followed some karstic fissures in the limestone bedrock (Cole 1980, 25; Shiloh 1992, 282 footnote 21; Tsuk 2000, 125). A narrow channel was carved in the tunnel floor in order to maintain water flow during low discharge.

There are many different opinions in research regarding the relationship between the water systems in Gibeon, even though there is a consensus that both date to the Iron Age (Wright 1963, 211; Cole 1980, 27–29; Shiloh 1992, 291; Tsuk 2000, 127).

10.5.3 Suba Cave Water System

During 2003 and 2005–2006, Gibson (2009, 45) uncovered a sophisticated water system southwest of Kibbutz Tzuba, 9.5 km from Jerusalem. The water system, which was named by Gibson "Suba cave," or "Cave of John the Baptist," contains the following components: a spring tunnel, shaft, reservoir, canals, and pools (Figure 10.16). The entire system is fed by a spring tunnel directed S-N that is 11.5 m long and 0.5–1.0 m wide and is hewn in a rectangular cross section. The northern end of the tunnel was hewn in bedrock, with branches to the east and west in the form of a cross-like plan, while the southern part of the spring tunnel was open to the sky.

As explained earlier, splitting the tunnel was aimed to increase the saturated rock-air interface. Water lines high above the floor may indicate periods of more significant discharge. Today, only a small amount of water runs in the tunnel during winter. Water from the spring tunnel is directed

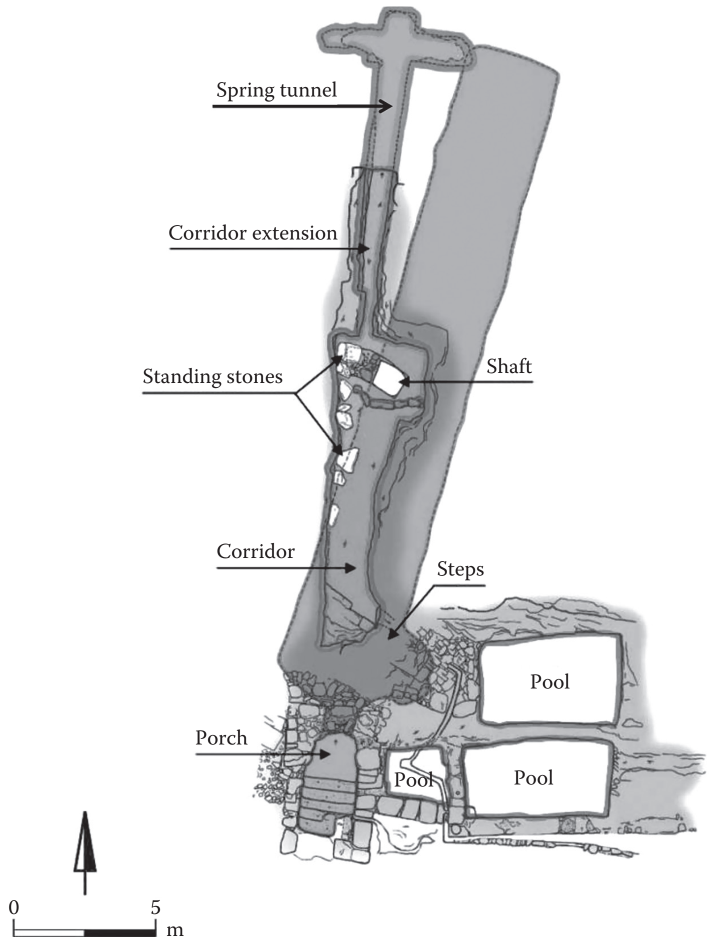

FIGURE 10.16 Suba cave—plan. (From Gibson, S., The Suba water system as a clay-production plant in the Iron Age II. In *Eretz Israel 29*, ed. J. Aviram, A. Ben-Tor, I. Ephal, Y. Aviram, S. Gitin, and R. Reich, pp. 45–55, The Israel Exploration Society, Jerusalem, 2009, figure 3. With Permission.)

both to a plastered reservoir through a shaft and to several small pools by shallow canals. Gibson assumes that these pools were evaporation ponds that were used for ceramic industry.

This water system, which begins with a spring tunnel, is well dated to the Iron Age 2, by several independent lines of evidence: (1) indicative hydraulic plaster from the reservoir, (2) speleothems accumulated over the plaster of the reservoir U-Th dated to ~598 BCE, (3) several complete vessels from the Iron Age 2, and (4) charcoal found inside one of the pools dated by carbon-14 to 770–400 BCE.

10.5.4 Nebi Samuel Spring Tunnel

Nebi Samuel, located NW of Jerusalem, is identified since medieval times as the burial place of Samuel the Prophet (Magen and Har-Even 2007, 38). Examination of 211 ceramic sherds collected during an archaeological survey resulted in negligible amount of sherds from the Iron Age 1 and from the Persian period, 36% potsherds from Iron Age 2, 15% from the Hellenistic period, 8% from the Roman period, 25% from the Byzantine period, and 15% from the Muslim period (Finkelstein 1993, 233).

Around the mosque of Nebi Samuel, built on the ruins of a Crusader castle, some archaeological excavations revealed no remains from the Iron Age 1. However, numerous Iron Age 2 pottery vessels were found, which dated to the seventh-eighth century BCE, including handles with “Lamelech” stamps that are commonly attributed to King Hezekiah (Magen and Har-Even 2007, 40). Apart from that, the site was inhabited in the Persian, Hellenistic, Byzantine periods and later.

The spring tunnel: On the northern part of the site, a spring discharges from two small caves (Yechezkel 2003, 11; Yechezkel and Yechezkel 2008, 24). The most significant flow comes out from a hewn spring tunnel 10 m long and approximately 0.6 m wide. The cross section of this tunnel is rectangular (Figure 10.17), it branches in the middle, and there is a shaft in the ceiling. Water runs through a small pit before being collected in a pool approximately 2 × 2 m in size. The pool also collects water from the second cave.

No excavations or surveys were done near the spring. We suggest that the spring tunnel is ancient and began to be used in Iron Age 2 for two reasons:

First reason is the technical characteristics of the spring tunnel. It is entirely hewn and resembles other water facilities and/or spring tunnels dated to the Iron Age. As noted, Hezekiah’s Tunnel, the Joweizeh spring tunnel, the Gibeon spring tunnel, and the Suba cave spring tunnel were quarried similarly, with a rectangular cross section and had similar dimensions.

Second, the main period represented by ceramic sherds at the site above the spring is from the eighth-seventh century BCE (36%). We have seen earlier in this chapter that there was considerable hydrogeological knowledge at that time. The dating of the “Lamelech” handles found in the site is consistent with the accepted chronological dating of Hezekiah’s Tunnel and the dating proposal of both the Joweizeh spring tunnel and the Suba cave spring tunnel. Most likely, the original residents of “Nebi Samuel” also made use of this important water source.

10.5.5 Beitin Spring Tunnel

Although this site is slightly beyond the natural boundaries of Jerusalem hills, north in the Benjamin hills, its geological-geomorphological properties and historical–archeological context are similar to the springs described above.

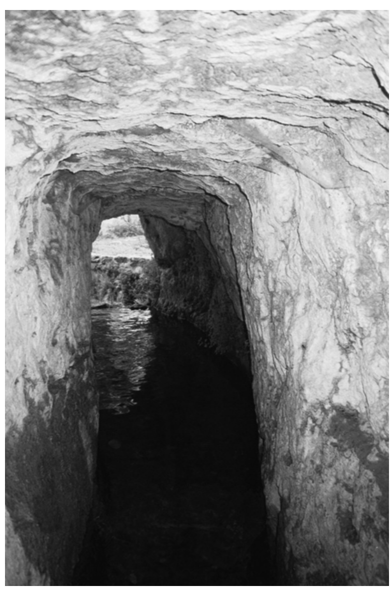

FIGURE 10.17 Nebi Samuel spring tunnel. Ceiling was cut in a square style. (Photography by Yechezkel.)

Most opinions tend to identify the village "Beitin," north of Ramallah, with Beth-El, mentioned many times in the Bible (Albright 1928, 9). Several seasons of archaeological excavations were conducted by Albright and Kelso between 1934 and 1960 (Kelso 1961, 16). The excavations uncovered findings from the Early Bronze Age up to the Byzantine period.

The spring of Beitin is at the southern edge of the site. A large pool drains water from a long covered channel more than 90 m long. It is hard to identify the original characteristics of the channel because it was recently coated with concrete.

The channel drains a hewn spring tunnel 15 m long. The spring tunnel line is not straight and has two zigzags. The far edge of the tunnel was enlarged to a small hewn hall, whose walls and floor are covered with thick flowstone. Rapid flowstone deposition rate is indicated by modern items such as pieces of iron and tree roots embedded in the flowstone. Erlich (2013, 99) assumes that from the western corner of the hall, the spring tunnel continued into the Bronze Age city area. If true, this continuation is now clogged and filled with mud and stone. Forty meters north of the hall, at the end of the purported extension of the spring tunnel, within the Bronze Age city limits, a deep ancient well was discovered. Erlich proposes that the well is the head of the water system, and the spring tunnel started from this well during the Late Bronze Age or Iron Age 1.

We drilled three cores for radiometric dating in the bottom of the tunnel, in and near the small hewn hall. The first core consisted of a very thin layer of flowstone, followed by 45 cm of plastic gray marl. The second core was composed of 19 cm layers of flowstone above 19 cm of gray marl. The third core had 12 cm of disturbed flowstone layers overlying gray and plastic marl. All three cores were unsuitable for dating because of the marl and dirt.

10.6 DISCUSSION AND CONCLUSIONS

When did the innovation of a spring tunnel occur? During the Iron Age 2, man had reached a peak in his abilities regarding water engineering, hydrological and hydrogeological knowledge, engineering capability, planning, and execution. This is reflected in highly sophisticated urban water systems. There is no doubt that city dwellers and government engineers during this period had the capability to measure height and distance difference between a spring outside the city and a certain point in the city and translate this information to construct a massive shaft coupled with a covered tunnel in order to reach precisely the source of the water. Moreover, in some water systems, such as in Hazor and Gibeon shaft, they did not even try to reach a water source outside the city but rather to reach the perched aquifer below the city. Hezekiah's Tunnel is the world's most ancient long hewn tunnel, constructed without any communication and ventilation shafts. This complicated engineering task was apparently executed by a small team of workers and under pressure of an approaching Assyrian siege.

In light of these considerations, we compare spring tunnels with Iron Age water systems. The technical competence required for excavating a spring tunnel, including a long one, is much less than the technical ability and the hydrological knowledge that existed during the Iron Age 2.

In recent years, as a result of new surveys and excavations, we can re-establish and claim that spring tunnels began to appear during the Iron Age 2 period, as we have seen in the Joweizeh spring, spring tunnel of Suba cave, the Gibeon spring, and perhaps also the spring tunnel at Nebi Samuel.

The evidence of spring tunnels from the Iron Age, which are the basis of prime agricultural or industrial enterprises, matches the results of the archaeological survey conducted in the Judean hills. The data of the Jerusalem hills' archaeological survey from the Bronze Age to the Persian period show that rural settlement reached an unprecedented peak in the eighth and seventh centuries BCE during Iron Age 2 (Broshi and Finkelstein 1992, 56; Faust 2005, 102). Hundreds of rural sites were found in the hills around Jerusalem, most of which are farms, as well as a few villages and satellite towns.

Based on this evidence, the presence of spring tunnels, and the flourishing of small agricultural sites on the countryside around Jerusalem during the Iron Age 2, we offer two alternative models for the development of the first spring tunnel:

1. It is likely that some of the manual labor for quarrying Hezekiah's Tunnel came from the rural area around Jerusalem. During excavation, some workers noticed water dripping from the walls of the tunnel. This observation taught them that it is possible to increase the discharge of a water source by increasing the saturated rock-air interface. From this point, the way to a local experiment and excavation of a spring tunnel is short. Recall that in ancient times, it was difficult to draw water from deep sources and bring large quantities of water to farmlands. This forced ancient farmers who lived in mountains to exploit water resources in mountains areas, even small perched springs. This model assumes a flow of labor, ideas, and information between the municipal/governmental sector and the rural sector.
2. While quarrying Hezekiah's Tunnel, the workers noticed water emanating from the walls. They realized that they were increasing the discharge of the spring by increasing the hewn space and passed this information to the municipal government. As a result, it was decided to develop state-funded spring tunnels in two springs near Jerusalem: One, Suba cave water system, for ceramic industry, and the second, Joweizeh spring, as a national irrigated garden. The conventional dating of Hezekiah's Tunnel to the end of the eighth century BCE and the dating of the spring tunnels described above fit this theory.

It is important to emphasize that the two models proposed above suggest local technological development rather than importing knowledge from various countries such as Persia, as claimed previously (Issar and Zohar 2012, 161).

In this study, for the first time, an attempt was made to date flowstone radiometrically in spring tunnels. Although the attempt was unsuccessful for flowstone under continuous flow of water, the method proved to be applicable in other water systems, such as dating dripping stalactites in Hezekiah's Tunnel (Frumkin et al. 2003, 169). Further attempts should be made to date spring tunnels that are not regularly flooded with water, by U-Th dating of dripstone speleothems. Perhaps, additional Iron Age spring tunnels are hidden in the hills of Jerusalem. We expect that these spring tunnels are hewn in bedrock and have a rectangular cross section.

ACKNOWLEDGMENTS

We would like to thank Dr. Raphael Yechezkel (AY's father) to help translating this article from Hebrew; Dr. Miryam Bar-Matthews from the Israel Geological Survey for dating the samples from the spring tunnels; And Zeev (Z'abo) Erlich, Shemesh Ya'aran, Reuel Kasel, Eran Meeiri, Iftach Raanan, Gideon Goldberg, Oded Hulzinger, and Elyashiv Videberg for their help in drilling cores in the spring tunnels.

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