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Estimation of sedimentation rates under Mediterranean conditions deduced from the Mishmar Ayyalon Reservoir, Israel

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ABSTRACT

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The Mishmar Ayyalon Reservoir was constructed in 1955 and its watershed drains the upper basins of Nahal Ayyalon and Nahal Nachshon (160 km^2). It has a water storage capacity of 7.3×10^6 m^3 and is the only reservoir located within the western-flowing drainage basins that drains the mountain backbone of central Israel. Because the reservoir has never overflowed, the sediments that accumulated on its floor during the last 44 years provide a unique record of sedimentation rates and total sedimentation. A pit 3.3 m deep was dug into the sediment and variable-thickness layers, associated with specific years or flood events, were identified. Based on the sediment that was exposed in the pit and considering the original volume–elevation data of the reservoir, we have estimated the total sediment volume. Specific sediment layers were correlated with specific storms (and their resulting floods), based on three distinctive historical marker beds. The total sediment volume, which has been deposited by at least 22 significant floods, was calculated to be about 456,000 m^3. Approximately 30% of the sediment reached the reservoir during the two largest consecutive floods of the winter of 1963/4. Approximately 70% of the sediment was produced by a small number of very large floods. The mean annual specific suspended sediment yield for the catchment of the reservoir is 114 t km^{-2} year^{-1}, which is a typical sediment yield for land under minimal cultivation.

INTRODUCTION

Sediment yields in drainage basins experiencing Mediterranean climate are highly variable and influenced by climatic, physiographic, and land use factors (e.g., Langbein and Schumm, 1958; Young 1969; Naveh and Dan, 1973; Wilson, 1973; Inbar, 1982; Walling and Webb, 1983; Walling, 1986, 1988). Several attempts have been made to evaluate sediment yields in different areas of Israel (e.g., Negev, 1972; Av-Ron, 1973; Schick, 1977; Inbar, 1982, 1992; Inbar and Sivan, 1984; Larronne, 1989, 1991; Schick and Lekach, 1993; Lekach and Greenbaum, 1997). These attempts focused mainly on gathering sediment yield data from arid to semiarid southern Israel and from northern Israel (up to sub-humid Mediterranean climate). In the data collection two approaches were used: (1) suspended sediment sampling in rivers, and (2) measuring sedimentation in reservoirs. Due to the lack of monitored basins and the existence of few reservoirs, al-

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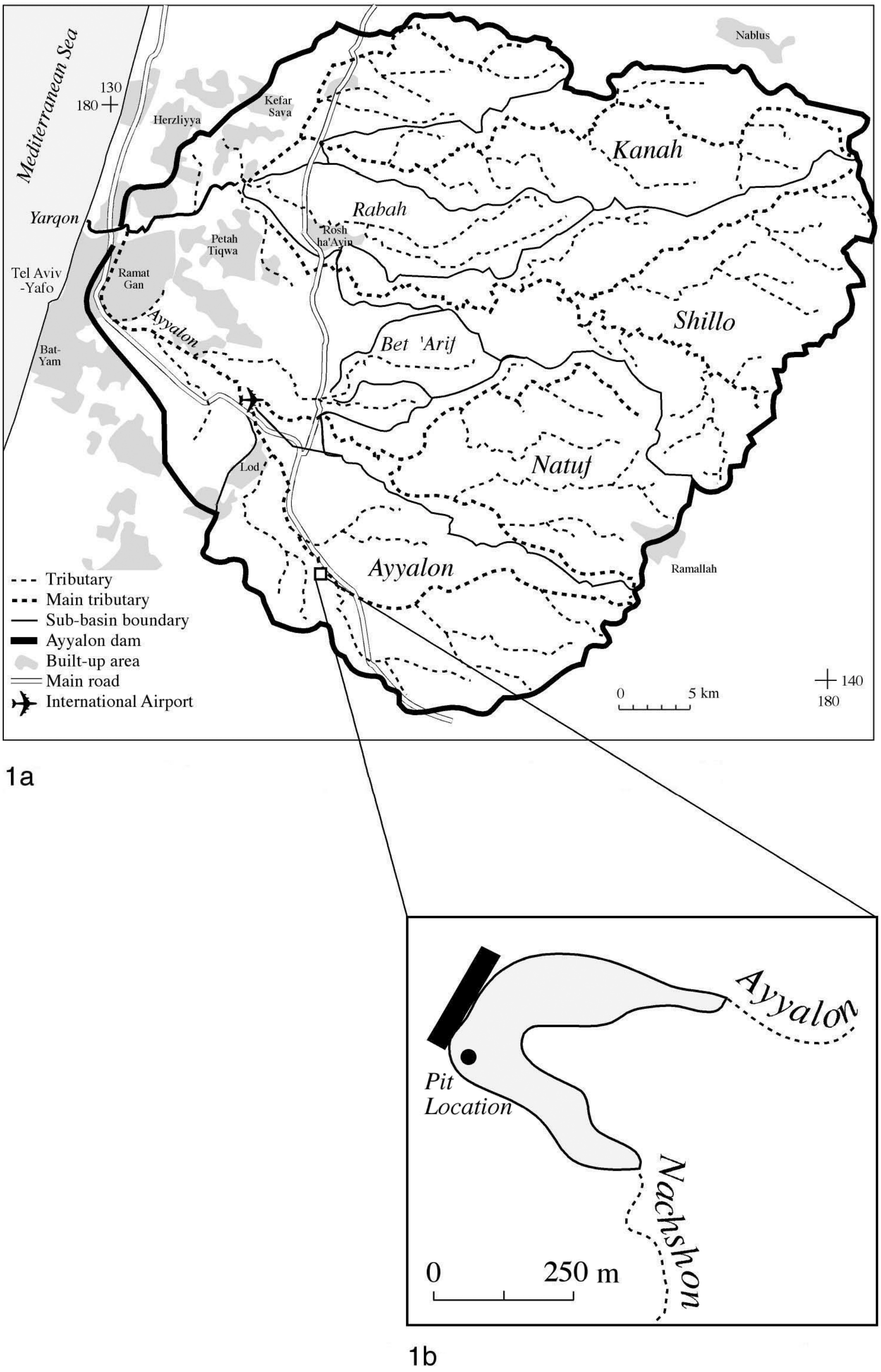

Fig. 1. (a) A location map of the Ayyalon–Yarqon watershed. (b) Zooming into the Mishmar Ayyalon Reservoir.

most no attempt was made to evaluate sedimentation rates along the western slopes of the central mountain backbone of Israel. Here we document sedimentation rates in the only existing reservoir, which lies within the Ayyalon drainage basin (Fig. 1). Although this basin may not characterize all the western slopes of the mountain backbone of central Israel, currently it presents the only data available.

In addition, following the 1991/2 flooding in the Ayyalon–Yarqon drainage basin, which caused damage in the Tel Aviv metropolitan area, the construction of a series of flood-control reservoirs (retention dams) in the upper parts of the basin was proposed (e.g., Rosentzweig and Sinai, 1993; Gvirtzman et al., 1994). The objectives were (a) to prevent damage by reducing discharge flow peaks, (b) to increase infiltration amounts into the regional aquifer by locating the reservoirs over fractured and karstic rocks, and (c) to provide water for local usage (agriculture and tourism). However, floods in this area carry considerable suspended loads that can accumulate on the bed of the reservoirs and cause two problems, namely (a) a decrease in the water storage capacity of the reservoirs, and (b) a dramatic reduction of infiltration rates into local aquifers. Due to the lack of data regarding sedimentation amounts and rates at this basin, it was impossible to evaluate the severity of these two problems, which often give rise to high costs in maintaining the reservoir. In this study, the single available record of sedimentation rate within the basin is analyzed in the Mishmar Ayyalon Reservoir.

The Mishmar Ayyalon Reservoir (Fig. 1a) is located at an altitude of 130 m above mean sea level. The drainage basin is characterized by a Mediterranean climate with 500–600 mm/year of precipitation during the late fall to early spring period, while the summers are hot and dry. Stream flow in Nahal Ayyalon and Nahal Nachshon (160 km^2; Fig. 1b) are characterized by occasional winter and early spring floods and no base flow. The maximum water storage capacity of the reservoir is 7.3×10^6 m^3 (Fig. 2). The dam that forms the reservoir was constructed in a small canyon that is incised into Turonian limestone. The reservoir itself is located on Cenomanian chalk covered by alluvium ranging from gravel to clay and clay soil. The reservoir has been operating since 1955 and has never overflowed or been filled to its full capacity. Therefore, the entire sediment load carried into the reservoir by the floods remains in storage. Furthermore, the reservoir is dry at the end of the summer and this allows sediment to cover its entire bed during the next flood rather than being deposited in a delta. As a first step, in this study we estimate both the total volume of sediment stored in the reservoir (during 1955–1994) and the average annual rate of sedimentation. In the second step, we make an effort to identify individual deposition layers, to correlate them with individual floods in specific years, and to estimate the sediment loads delivered by each event.

METHODS AND RESULTS

A 3.3-m-deep pit was dug into the sediments, down to the depth of the original pre-dam alluvial bed, which was easily recognized by its gravelly texture and alluvial sedimentary structures (Fig. 3). The pit location was chosen after excluding all sites of obvious and suspected human interference. Separation of

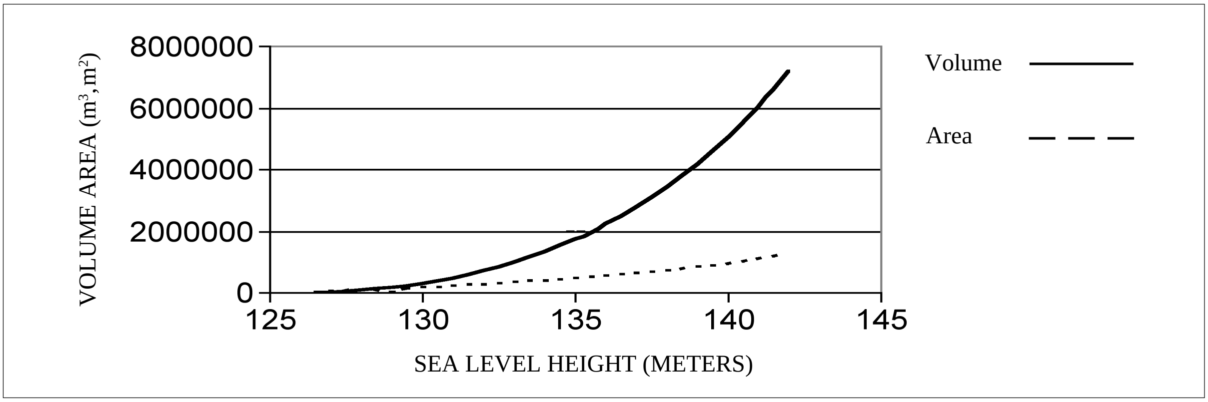

Fig. 2. Volume–Area–Depth curve of Mishmar Ayyalon Reservoir.

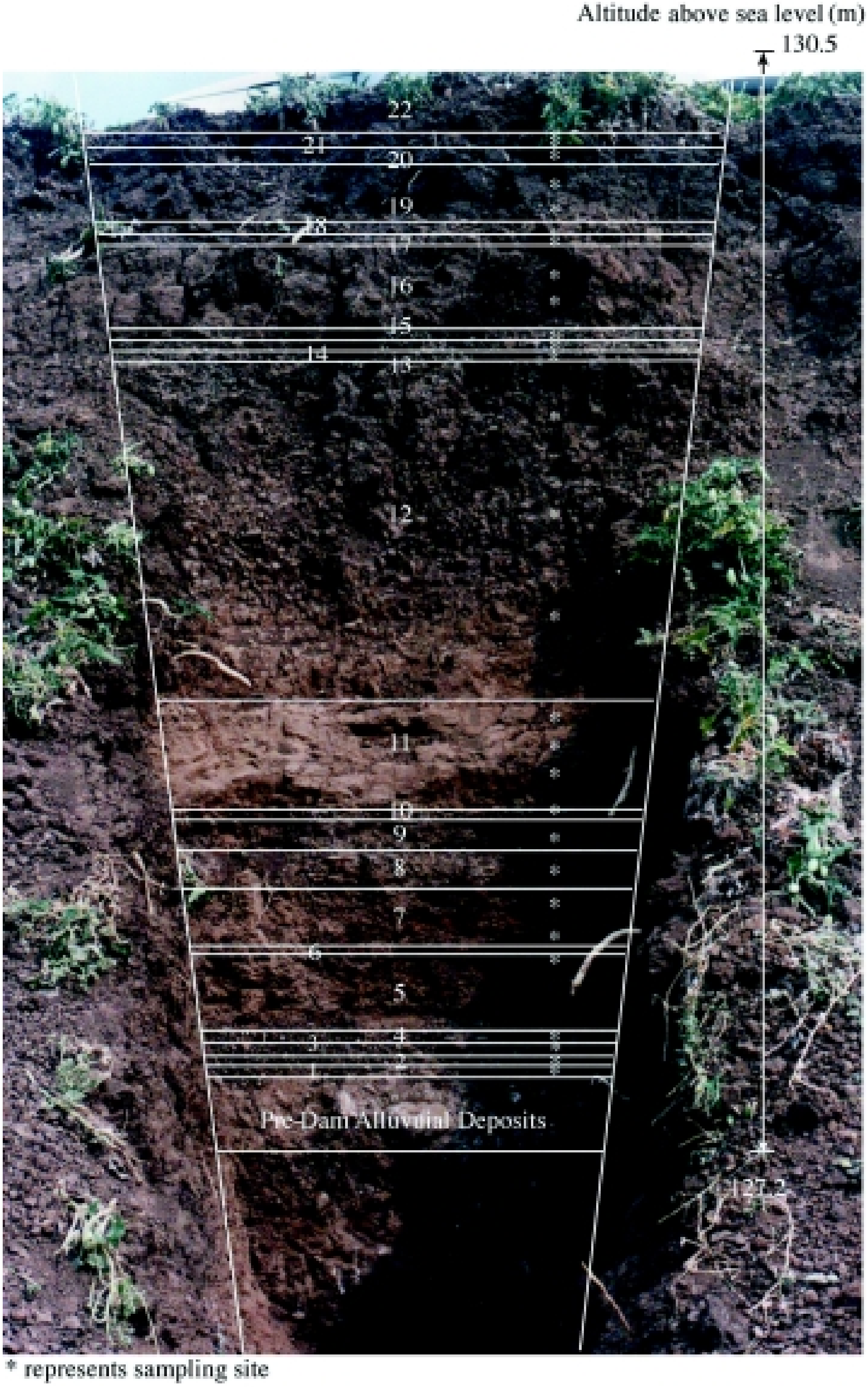

Fig. 3. The stratigraphic profile detected in the pit that was dug at the reservoir floor, exhibiting the various thicknesses of sediment accumulated during different flooding events and their elevation. The numbers correspond to the different layers as observed in the field.

stratigraphic beds in the field was based on the color and texture of the sediments. Samples were collected from each bed. Once a distinct bed was identified, it was sampled at 9-cm intervals (Fig. 3). Sediment samples were dried and analyzed for grain size distribution using wet sieving and a sedigraph. Assuming that sediments exhibit grain size fining upward within individual beds (Black, 1965), this sampling resolution allows identification of additional layers that were not easily distinguishable in the field and allocation of layers (that in the field seemed to represent two separate events) to one depositional event. This method also allows identification of the event layers described by Anderson (1986) and Larronne (1987) as rythmites comprising couplets, and, finally, correlation of the event layers to specific food events, which may shed light on the probability distribution of event sediment yields.

Following this procedure the beds were correlated with individual floods (Tables 1,2).

The following steps were applied:

1. Based on the hydrological record (Hydrological Service), all floods characterized by water volumes larger than 100,000 m^3 were selected. These are listed chronologically in Fig. 4. These floods would have filled the reservoir with 2 m or more of water (Fig. 2). This is the minimum depth of water that

Table 1
Correlation between deposition period, number of layers and floods, sediment thickness and volume, water volume, and sediment yield

Deposition period	Number of layers	Number of sedimentary events	Section thickness (m)	Sediment volume (10^{3}m^3)	Water volume (10^6 m^3)	Sediment yield (tons/km^2/year)
1955/6–1962/3	10	11	1.25	44	5.95	46.9
1963/4	2	2	1.55	147	5.95	931.3
1964/5–1967/8	4	5	0.40	55	6.40	98.4
1968/9–1985/6	4	3	0.50	77	13<	39.2
1986/7–1995/6	1<	1<	0.30	53	N.A.	45.6
40 years	21<	22<	4.00	456	31.3	114

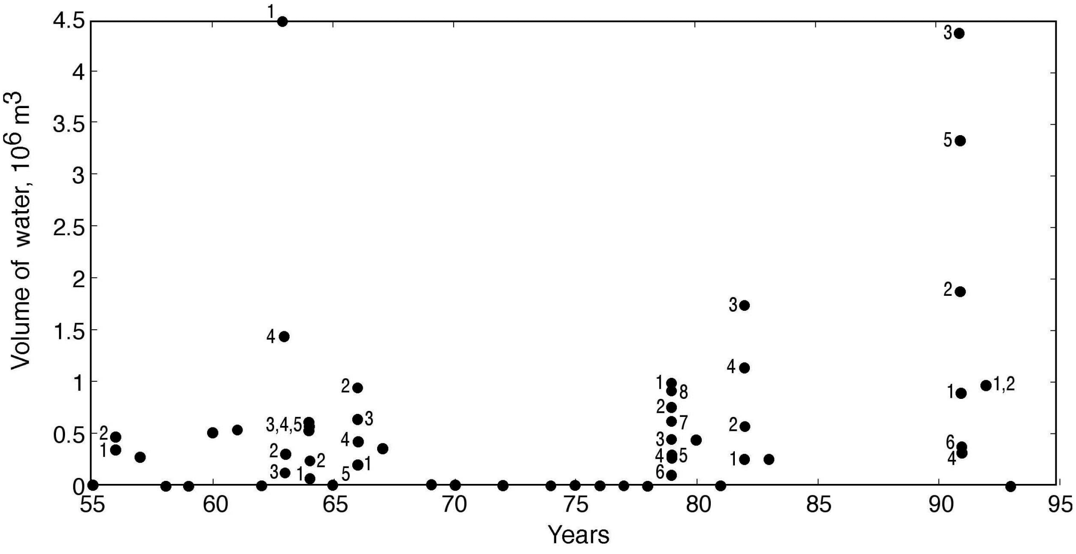

Fig. 4. Distribution of large flood-water volumes that have reached the Mishmar Ayyalon Reservoir during the period 1955–1995. Numbers represent the sequence of floods in a specific year.

Table 2
Summary of deposition sequence at the Mishmar Ayyalon Reservoir, and correlation between sediment layers and floods based on field observations and grain size distribution analysis

Number of samples	Layer number	Thickness (cm)	Number of floods	Sand %	Silt %	Clay %
1	1	2	1	0	26	74
2	2	2	2	0	60	40
3	3	3	3	0	42	58
4	4	3	4	0	52	48
5	5	7	5	0	45	55
6	5	7	6	0	51	49
7	6	4	7	0.6	74.7	24.7
8	7	4.5	8	0	45	55
9	7	4.5	8	0	25	75
10	8	8	9	0	46	54
11	9	8	10	0	45	55
12	10	2	11	4.9	24.5	60.5
13	11	20	12	3	71.5	25.5
14	11	20	12	6.2	19.9	73.9
15	11	20	12	0.7	81.7	17.6
16	12	32	12–13	0	55	45
17	12	32	13	0	47	53
18	12	31	13	0	40	60
19	13	1	14	0.1	45	54.9
20	14	2	15	0.1	52.9	47.9
21	15	2	16	0.4	54.8	44.8
22	16	18	17	0.7	45	57
23	16	18	18	0.3	60	39.7
24	17	1	19	0.4	37.5	62
25	18	2	19	0	35	65
26	19	18	20	0	52	48
27	19	18	20	0	45	55
28	20	10	21	0	98	2
29	21	4.5	22	0	62	38
30	21	4.5	22	0.7	54.6	44.7
	22	21				

would have resulted in significant and recognizable deposition at the pit site, which is located some distance from the stream inlet to the reservoir.

2. The original volume–elevation curve of the reservoir, prepared in 1955 (Fig. 2), was used to estimate the volume of sediment associated with the elevation of an identified layer in the pit.
3. The absolute elevations of layers throughout the vertical section were measured. The measurements were based on the absolute elevation of the dam (Iftach and Brown, 1968) and a detailed field survey using a reference station.
4. Four independent marker beds representing specific years/floods were used to separate the stratigraphic sequence into specific time zones of deposition, as is explained below.

Limitations of the method

A. No measurements of flood-water volumes reaching the reservoir were conducted during the winters of 1968/9, 1971/2, 1973/4, and from 1984/5 to 1991/2 (Fig. 4). However, it is likely that significant floods did occur during these winters.

B. Distinguishing between flood events using grain size distribution is reliable only when a single-peak flood enters the reservoir. However, when a flood has several discharge peaks or when two flooding events happened one shortly after the other, it is difficult to separate between layers, especially where the sand fraction is negligible as in this reservoir.

C. The original pre-dam map that was used for the construction of the dam could not be located. Therefore, it was impossible to verify the reported original elevation of the reservoir bed elevation.

D. The Nesher Cement Company currently divides the reservoir into two sub-reservoirs for clay mining that has taken place during the last few years. The connection between these sub-reservoirs might be blocked and thus, sites of continuous sedimentation might be disturbed. However, we overcame that with the help of the mining company, which provided us with a detailed topographic map of the reservoir from 1994 (scale of 1:2500).

E. Kibbutz Nachshon cultivated the reservoir floor during the last several years, which might have destroyed some of the layering and eroded the surface of the reservoir. Consequently, the intensive human interference excluded additional other pits to our analysis.

F. Given these limitations, the sedimentation rates discussed are estimations, especially the ones made for 1986/7–1995. During this period the magnitude of human interference was significant.

RESULTS AND DISCUSSION

Sedimentation amount and rates

The bottom and top of the pit are at elevations of 127.2 m and 130.5 m, respectively (3.3 m depth). When the reservoir was constructed, its lowest concave point was at 126.5 m (Fig. 2; Iftach and Brown, 1968). Our pit was dug to the pre-dam surface, but did not reach the lowest point, which is 0.7 m lower than the base of the pit. Therefore, an additional thickness of 0.7 m of deposits, which is not represented in the pit, exists in the reservoir. This total 4-m-thick layer of sediments represents a volume of 376,000 m^3 (Fig. 2). During large floods sediment was deposited also on the sides of the reservoir. Additional sediment is deposited in the two small sub-basins created by mining since 1990. Iftach and Brown (1968) estimated that 40,000 m^3 of sediment was deposited on the sides of the reservoir before the winter of 1967/8. We estimated that after that year, at least the same amount of sediment was deposited on the reservoir sides. Thus, the total sediment amount that reached the reservoir during 40 years of operation is approximately 456,000 m^3. These sediments were carried by at least 31×10^6 m^3 of water, which is the total water volume that reached the reservoir prior to 1984/5. Since 1985 no measurements were made in the Ayyalon Reservoir (Hydrological Year Book, 1992). The 456,000 m^3 of sediment occupies only 6.2% of the total reservoir capacity. Although this is a minimum estimate we believe that it is close to the total sediment deposition in the reservoir, as not much sediment accumulated in the two sub-basins that were dug in 1990.

The bulk density we measured for the sediment is 1.6 g/cm^3. Therefore, the total weight of sediment is 729,600 tons and the specific sediment yield of the upper Ayyalon drainage basin is 114 $tons/km^2/year$. This value is relatively low and is similar to those found in areas that experience limited cultivation in the United States (e.g., Wolman, 1967) or in Mediterranean areas (Av-Ron, 1973; Inbar, 1992; Bathurst et al., 2001) and considerably lower than the Langbein and Schumm curve for grassland sediment yield (Langbein and Schumm, 1958). Since it is often found that sediment yield tends to increase as basin-area decreases (e.g., Walling, 1983) this sediment yield is especially low in light of the small drainage area of the watershed studied here.

Most of the Ayyalon and Nachshon drainage basins are covered by negligible urban land use and by forested areas. This type of land use, with wide valleys and floodplains, is likely to be the cause of the relatively low sediment yield. In addition, the agricultural terraces characterizing the slope of the upper watershed combined with the low to moderate floods, which may have low capacity to transport the eroded soil downhill to the reservoir, may have further contributed to the low sediment yield found. This is support by the findings of Shanan (1999) that already identified the role of terraces in increasing infiltration and reducing the likelihood of erosion.

Correlation between specific beds and floods

As mentioned above, four marker beds enabled us to disaggregate the stratigraphic sequence into zones of deposition. The first marker was provided by the distinct gravelly pre-dam alluvial deposit at an elevation of 127.2 m. Iftach and Brown's (1968) research in the Ayyalon reservoir during the winter of 1967/8 estimated that 280,000 m^3 of sediment had reached the reservoir prior to that date. They concluded that the sediment reached a uniform elevation of 129.7 m. This time and elevation marker in our stratigraphic section corresponds with the upper boundary of layer number 16 (Fig. 3). These two markers indicate that 16 beds were deposited between the time that the reservoir was built (1955) and the winter of 1967/1968.

The grain size distribution within layers number 7 and 16 caused us to divide each into two distinct layers (Table 2). This produced at least 18 floods that reached the reservoir between 1955–1967. This is a minimum number of floods that reached the reservoir, since the additional 0.7 m of deposition (at the lower point of the reservoir) may represent several other small floods. In this sedimentary sequence there are only two significant thick beds that were deposited prior to that winter. These two beds probably were deposited in a sequence of two large floods as they are one on top of the other (layers 11 and 12 in Table 2 and in Fig. 3). The hydrological record (Fig. 4) shows that the two largest floods occurred during the winter of 1963/4. These floods carried 4.5×10^6 m^3 and 1.45×10^6 m^3 of water, respectively (Fig. 4). It is most likely that these two large floods deposited the two thickest layers. The first flood is represented by (a) the presence of a thick sandy layer (layer 11), which due to its color and the presence of a significant percentage of sand probably represents one flood, and (b) part of layer 12, which is composed of fine sediment and probably represents the slack-water deposition phase, following the flood entering a reservoir full to more than one half of its storage capacity. The second and smaller flood of 1963/4 (Fig. 4) is represented by a part of layer 12. These two floods account for 30% (137,000 m^3) of the total volume of sediment in the reservoir. These two large floods served as the third marker.

Lekach and Greenbaum (1997) have already described the 1963/4 storm as a large event (with a recurrence interval of 20 years) that caused extremely high sediment yield further to the south, on the western slopes of the Hebron Mountains.

The three markers indicated that floods 1–11 reached the reservoir before the end of winter 1962/3 and represent a few small-to-moderate floods that deposited only 44,000 m^3 of sediment (layers 1–10). During the time interval between the winter of 1964/5 and the survey by Iftach and Brown (1968) in the winter of 1967/8, 55,000 m^3 of sediments were deposited. This volume was deposited by three small floods (layers 13–15 depositing 8000 m^3) and by two moderate floods (layer 16) that together contributed 47,000 m^3 of sediment.

During the winter of 1986/1987 a pipeline was installed across the reservoir 30 cm above its bed (Y. Naor, personal communication, 1999). Today the pipeline rests on the bed of the reservoir with no gap between it and the ground. Therefore, the pipeline provided us with an estimation of the amount of sedimentation between 1968/9 and 1985/6 and between 1986/7 and 1995/6.

Despite the occurrence of several storms during 1968/9 and 1985/6, we have been able to discern only three floods during this period. These floods deposited approximately 77,000 m^3 of sediments from one small flood (layers 17,18), one large flood (layer 19), and one moderate flood (layer 20).

From 1986/7–1995/6 at least 53,000 m^3 of sediment was deposited. It is not possible to correlate the upper part of the section with specific flood events due to the mining activities of the Nesher Cement Company, which have resulted in some of the sediment concentrating into the two sub-basins that Nesher quarried in 1990. This human interference provides an explanation for the low sedimentation rate found for 1987–1996 on the reservoir. This low rate stands out in light of the major flood events of winter 1991/1992.

Table 1 summarizes the time and volume of sedimentation obtained by using the four markers and correlating the data with the volume of water reaching the reservoir during the corresponding years. In addition, the average annual sediment yield for the different time periods was estimated, which reveals that the annual sediment yield is highly variable. During most of the years the sediment yield values are 40 tons/km^2/year or less. However, when an exceptional rainstorm affects the drainage basin and causes a large flood the sediment yield rates rises dramatically. This finding, that the average sediment yield is significantly affected by the few largest events rather than by the annual rainfall and runoff totals, is consistent with many findings gathered in Mediterranean areas (Bathurst et al., 2001).

CONCLUSION

Between the years 1955–1994, approximately 456,000 m^3 of sediment was deposited in the Mishmar Ayyalon Reservoir. Most of the sediment was deposited by 22 significant floods. Additional amounts of sediment were also deposited on the sides of the reservoir and in the current mining site of Nesher Cement Company. The resulting average sediment yield in the watershed is 114 tons/km^2/year. This is a relatively low sediment yield and fits areas with minimal cultivation as the land use practiced. This is the practice in most of the upper Nahal Ayyalon basin.

Even if not perfect, partial correlation between floods and deposited layers was achieved. The correlation is based on four marker beds. Although a large number of significant floods reach the reservoir, two floods during one winter season (1963/1964) are responsible for 30% of the sediment. Furthermore, most of the sediment (70%) can be attributed to a small number of very large floods, while many of the small floods that reached the reservoir did not leave a distinct sediment mark.

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REFERENCES

Anderson, R.Y. 1986. The verve microcosm; propagator of cyclic bedding. Paleoseismography 1: 373–382.

Av-Ron, M. 1973. Sediment yield and rates of erosion in a few streams in Israel. MA thesis, The Hebrew Univ., Jerusalem, Israel (in Hebrew).

Bathurst, J., Sheffield, J., Vicente, C., White, S., Romando, N. 2001. Modeling large basin hydrology and sediment yield with sparse data: the Agri Basin Southern Italy. In: Geeson, N.A., Brandt, C.J., Thornes, J.B., eds. Mediterranean desertification a mosaic of processes and responses. Wiley, pp. 396–415.

Black, A. 1965. Methods of soil analysis, part 1. American Society of Agronomy, Monogr. 9, Madison, WI, pp. 545–566.

Gvirtzman, H., Sinai, G., Enzel, Y. 1994. Reservoir at the western slopes of Samaria for preventing floods at Dan regions. In: Erlich, Z.H., Ariel, Y.E., eds. Judea and Samaria research studies, pp. 315–328 (in Hebrew).

Hydrological Service. Reports on the height of water at time of floods in Ayyalon reservoir for the years 1955/56–1983/1984, 1991/92–1993/94. Jerusalem (in Hebrew).

Hydrological Year Book of Israel. 1992. Summary of records prior to October 1990. Jerusalem (in Hebrew).

Iftach, M., Brown, Y. 1968. Dams and reservoir built by Tahal, final report for the year 1967/68 (in Hebrew).

Inbar, M. 1982. Measurement of fluvial sediment transport compared with lacustrine sedimentation rates: the flow of the River Jordan into Lake Kinneret. Hydrol. Sci. J. pp. 439–449.

Inbar, M. 1992. Rates of fluvial erosion in basins with a Mediterranean type climate. Catana 19: 393–409.

Inbar, M., Sivan, D. 1984. Paleo-urban development and lake quaternary environment change in Akko area. Paleorient 9(2): 85–91.

Langbein, W.B., Schumm, S.A. 1958. Yield of sediment in relation to mean annual precipitation. Am. Geophys. Union Trans. 39: 1076–1084.

Larronne, Y. 1987. Rhythmic couplets: sedimentology and prediction of reservoir design periods in semiarid areas. In: Wurtele, M., Berkofsky, L., eds. Progress in desert research. Rowman and Littlefield, Totowa, New Jersey, USA.

Larronne, Y. 1989. Probability distribution of event sediment yield in the Northern Negev, Israel. In: Boardman, J., Foster, I., Dearing, J., eds. Soil erosion in agricultural land. Wiley, London, UK.

Larronne, Y. 1991. Sedimentotology of reservoir sediments and its use for the determination of event sediment yield. Israel Ministry of Energy and Infrastructure, Report ES-47–91, 100 pp. (in Hebrew).

Lekach,Y., Greenbaum, N. 1997. Water potential evaluation and sediment rates in Lahav Reservoir–Nahal Shikma. A special annual report to Mekorot Company.

Naveh, Z, Dan, J. 1973. The human degradation of Mediterranean landscape in Israel. In: Castri, F.D., Mooney, H.A., eds. Mediterranean type ecosystems. Springer-Verlag, Berlin, pp. 373–390.

Negev, M., 1972. Suspended sediment discharge in western watersheds of Israel. Hydrology Paper 14, Hydrological Service, Jerusalem (in Hebrew).

Rosentzweig, D., Sinai, G. 1993. Water reservoirs in the Ayyalon-Yarqon Basin to prevent floods. Internal Report, Israel Water Commission, 10 pp., 7 appendixes.

Schick, A.P. 1977. A tentative sediment budget for an extremely arid watershed in the southern Negev. In: Doehring, D.O., ed. Geomorphology in arid regions. State University of New York, Binghamton, pp. 139–163.

Schick, A.P, Lekach, J. 1993. An evaluation of two ten-year sediment budgets, Nahal Yael, Israel. Phys. Geogr. 14: 225–238.

Shanan, L. 1999. Runoff, erosion and the sustainability of ancient irrigation systems in the Central Negev desert. In: Hassan, M.A, Berkowicz, S.M., eds. The hydrology geomorphology interface: rainfall, floods, sedimentation, land use. IAHS Publication No. 261, pp. 75–106.

Walling, D.E. 1983. The sediment delivery problem. J. Hydrol. 65: 209–237.

Walling, D.E. 1986. Sediment yield and sediment delivery dynamics in Arab countries: some problems and research needs. J. Water Resourc. 5(1): 775–798.

Walling, D.E. 1988. Measuring sediment yield from river basin. Soil erosion research method. Soil Water Conserv. Soc. 39–73.

Walling, D.E., Webb, B.W. 1983. Parents of sediment yield. In: Gregory, K.J., ed. Background to palaeohydrology. Wiley, New York, pp. 69–100.

Wilson, L. 1973. Variations in mean annual sediment yield as a function of mean precipitation. Am. J. Sci. 273: 335–349.

Wolman, M.G. 1967. A cycle of sedimentation and erosion in urban rivers channels. Geografiska 49: 385–395.

Young, A. 1969. Present rate of land erosion. Nature 224: 851–852.