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Article *in* Lakes & Reservoirs Research & Management · May 2012

DOI: 10.1111/j.1440-1770.2012.00507.x

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Reservoir sedimentation and mitigation measures

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Abstract

The biggest threat to reservoirs after their construction, which can reduce their capacity, life cycle and water quality, is sediments carried inflowing streams. The sediment volumes in four reservoirs in Central Macedonia, Greece, were measured in this study. These measurements indicated the study reservoirs are under serious threat from sedimentation. Appropriate measures to protect these newly formed reservoirs from sedimentation also are proposed.

Key words

mitigation measures, reservoir, sedimentation.

INTRODUCTION

The increasing freshwater demands for water supply, irrigation, industrial use and the generation of hydroelectric power makes water a most valuable constituent of human well-being and of the financial development of a country. Climatic conditions in Greece are such that freshwater resources are present in excess quantities (i.e., flood disasters) when not really needed, yet are scarce when needed (Stefanidis 1995). To this end, a number of dams have recently been constructed in Greece, mainly earthen dams in hilly, semi-mountainous or mountainous areas, for the purpose of facilitating the utilization of surface waters.

A major threat to reservoirs in regard to reduction in their water capacity and their life cycle, as well as the quality of the water they contain, is the alluvium deposition in them resulting from the silts transported to them by the network of streams that supply them with water. This phenomenon constitutes increased reservoir sedimentation (Stefanidis 1988; Hrissanthou 2006; Psilovikos & Margoni 2010). Sedimentation is also a major threat to the biodiversity of the bedrock-controlled rivers that flow through the contributing watersheds (Rogers & Biggs 1999).

The production, transportation and deposition of sediments are extremely variable, both spatially and temporally (Zarris *et al.* 2002). Many researchers suggest several basic factors that strongly correlated with the erosion and deposition of sediments in areas with plains, namely climate, land surface relief, geological support, soil type and vegetation (D'Angelo *et al.* 2000; Descroix *et al.* 2001; Gatzojannis *et al.* 2001; Feoli *et al.* 2002; Montgomery & Brandon 2002; Renschler & Harbor 2002). Moreover, other researchers have examined the influence of rainfall intensity on erosion. The value of rainfall intensity for the start of the erosion phenomenon is 8 mm h^{-1} according to Margaropoulos (1963), 10 mm h^{-1} calculated from the USLE Method (Wischmeier & Smith 1978) and 0.3–0.5 mm min^{-1} according to Galevsky (1955).

By producing a quiescent or lentic water pool into which inflowing solids are deposited, reservoirs act as sediment traps (Hentati *et al.* 2010). Lacking measures to balance sediment inflows, therefore, the storage capacity of a reservoir can be significantly decreased (Fan & Morris 1992; Jain & Singh 2000; Verstraeten & Poesen 2000). In fact, Greece has recently been experiencing a reduction in the water levels in its reservoirs and artificial lakes, which some have attributed to increased sedimentation. Kotoulas (1988), for example, has estimated that 331.425 m^3 of sediment flow into Lake Orestikon (with an area of 175.64 km^2) each year. Further, it is estimated that artificial Lake Kerkini (area = 76 km^2) receives 12 335.771 m^3 of sediment each year (Kotoulas 1991). Other recent research in Greece also strongly suggests the threat from fluvial sedimentation to reservoirs is continuing to increase in severity (Kalinderis *et al.* 2009; Xanthakis *et al.* 2010; Stefanidis *et al.* 2011).

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Accepted for publication 23 April 2012.

Doi: 10.1111/j.1440-1770.2012.00507.x
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Construction of reservoirs represents infrastructure development, particularly in areas in which agriculture is the major activity. The impacts of fluvial sedimentation in such areas, therefore, can be both environmental and financial (Merz *et al.* 2010). Thus, facilitating the unhampered operation of reservoirs requires supplementary arrangement works to streams supplying the reservoirs, to reduce sedimentation (Koneatis 1974; Scheurlin 1987). In fact, the scientific literature contains many models for predicting erosion. These models generally only predict sheet erosion from lake basins, however, and do not normally consider either gully erosion or intense stream bank erosion. Further, these models typically only predict the quantity of sediments, rather than their volume.

The goal of this study is to define the volume of sedimentation for four reservoirs in Central Macedonia, Greece, utilizing actual measurements rather than a predictive model, to highlight the sedimentation threats to these reservoirs, as well as to propose appropriate measures for their protection.

MATERIAL AND METHODS

This study was conducted in the Kiki's Prefecture in Central Macedonia, Greece. A number of small earthen dams were previously constructed in this region for the purpose of creating reservoirs for the purpose of providing water for agricultural purposes. The range of alluvium reaching the four aforementioned dams via sediment transport was measured. The study reservoirs are Terpilo, Melanthio, Kato Theodorakia and Gerakona. Gerakona was depleted as a result of intensive pumping (Gerakona), Kato Theodorakia as a result of maintenance works, and Terpilo and Melanthio as a result of rock penetration.

The digital terrain model of the reservoir catchments in this study was drawn from past topographic maps of the region prior to the construction of the dams. After the reservoirs were depleted of water, a new digital terrain model of the catchment was developed, following the inflow of sediments into the reservoirs. Comparison of these two digital terrain models provides the opportunity to measure the thickness of sedimentation (cm) and the deposit area (m^2), and subsequently to calculate the total sedimentation volume (m^3). Based on the arrangement of the torrent control system, appropriate works are proposed to avoid alluvium deposition in the reservoirs, which would otherwise reduce their operational lives.

RESULTS

The torrent environment of an area is directly associated with the production and transportation of sediments. The torrent environment depends on four factors: namely climate, terrain, vegetation and geological support (Kotoulas 1972). The study area is characterized by hilly terrain, with altitudes between 200 and 600 m, and slopes between 5% and 50%. In regard to vegetation, forests comprise 17.03% of the area, while cultivable land, the prevailing land use, comprises 48.01%. Schists and granites are the most common rocks in the area. Further, the area receives ample precipitation, with an annual average rainfall of 550 mm. Based on these factors, the torrent environment of the study area clearly favours the emergence of intense torrential phenomena and subsequent intense transport of sediments.

The characteristics of the reservoirs comprising this study are summarized in Table 1. Although Table 1 indicates the dams are small, they are nevertheless adequate to satisfy agricultural irrigation water needs. Thus, it is important that their operation is not hindered by excessive alluvium.

As previous noted, the thickness (cm) and surface of the deposits (m^2) of the four reservoirs were measured in this study. By multiplying these two measurements, the total volume of sediment deposits (m^3) were calculated (Table 2).

Unfortunately, it was not possible to estimate the degradation of the four reservoir basin areas in km^2 per year, because their dams have been cleaned 2–3 times since their construction. Accordingly, it is difficult to determine the length of the time period during which the quantity

Table 1. Characteristics of reservoirs in sedimentation study

A/A	Position of dam	Height of dam (m)	Basin area (km^2)	Capacity of dam (m^3)	Operation time since construction (years)
1	Terpilou	4	3.5	3000	2
2	Melanthiou	5	2.0	5000	4
3	Gerakona	7	1.0	10 000	5
4	KatoTheodorakia	18	6.0	150 000	4

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Table 2. Sediment deposits in study reservoirs

A/A	Position of dam	Thickness of sediment deposits (cm)	Mean thickness of sediment deposits (cm)	Surface area of sediment deposits (m^2)	Sediment deposits (m^3)
1	Terpilou	5–15	10	3000	300
2	Melanthiou	5–40	22.5	900	202.5
3	Gerakona	5–30	17.5	7000	1225
4	Kato Theodorakia	5–50	27.5	30 000	8250

of alluvium calculated in this study was actually deposited in the study reservoirs.

A significant fact emerging from this study was the discovery of deposits of mainly fine-grained material in these small reservoirs. Moreover, although the dams were previously cleaned of their alluvium deposits, the reservoir sedimentation was still very high, compared to their capacity, over only a very short period of operation. On the basis of these findings, the inflowing sediment rate is clearly very important. To protect a reservoir from sedimentation, its construction also requires an arrangement of the torrents supplying it, noting they not only supply reservoirs with water, but also with sediments (deWolfre *et al.* 2008; Sharip & Jusoh 2010). A torrent control system of arrangement must be applied, the purpose of which is to prevent the production of, and control the transport of, sediments. Accordingly, the proposed works include:

- Agrotechnical works;
- Basic stability dams;
- Beam dams; and
- Deposit dams

The agrotechnical works include the re-establishment of vegetation at the sediment-producing eroded areas, from which rill and gully erosions occur. Further, basic stability dams must be constructed at the main streams beds and at the tributary streams, to stabilize the streambeds and reduce their slopes. An outcome of this activity will reduced sediment transport and protection against bank erosion. Further, beam dams must be constructed at appropriate stream cross-sections to retain the transported sediments and decrease their deposits in the plain areas. Further, because it is not effective to control sediments and debris materials in watersheds, deposits dams must be constructed at the cone of stream illuviation, upstream of the areas requiring protection. The results of this combination of works will include decreased sediment transport and avoidance of reservoir sedimentation.

CONCLUSIONS

As previously mentioned, sedimentation represents a major threat to the quality and operational life of reservoirs. Direct measurement of sediments in the study reservoir basins indicated that, despite that fact that the basins were relatively small, ranging from 1 to 6 km^2, they nevertheless supply the reservoirs with a significant quantity of sediments. The measured sediment volumes were between 300 and 8250 m^3, which are, these quantities are extraordinarily large values, considering the short period of the operation of the reservoirs (2–5 years). Further, the sediment deposits in the reservoirs were cleaned 2–3 times before measurements taken in this study. It is clear, therefore, that the total deposit of sediments in the reservoirs since the construction of the dams is incomparably higher than those measured in this study. As these reservoirs were cleaned of silt, it was not possible to measure the degradation of their basins. These study measurements indicated that the sedimentation rate in these four study reservoirs was very high.

A characteristic of torrents is that they remove silts from their basins, transporting them and depositing them in the plains (Kotoulas 1980). This phenomenon must be considered during reservoir construction activities. Planning for dam construction for the purpose of creating reservoirs must be accompanied by a study of the inflowing streams on the basis of torrent control works, to ensure their permanent operation and prevention of their siltation. If such actions are not undertaken, the reservoirs will ultimately become deposit dams.

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