Pre-reservoirs: a sustainable solution for eroding beaches/deltas of dammed rivers

A. Toumazis[1], K. Kyrou[2], N. Iacovou[3], J. Sophos[3], S. Zervos[3] & G. Anastasakis[4]
[1] *Koronida Research & Development Centre, University of Cyprus*
[2] *Water Development Department, Cyprus*
[3] *Public Works Department, Cyprus*
[4] *University of Athens, Greece*

Abstract

Dams have as their main objective the storage of storm water. The arrest of sediments in the reservoirs is an indirect impact of the water storage. The trapping of sediments in the reservoirs reduces the storage capacity of the dam and arrests the sediment supply to the river mouth/delta. This starvation of sediment supply to the coastal environment results in the termination of the development of the river delta. Depending on the coastal hydrodynamics, recess of the delta and erosion of the coastline are initiated. This problem is acute in Cyprus, where almost all rivers have been dammed and erosion of the beaches is experienced in numerous areas. A sustainable solution has been developed which addresses the restoration of the sediment cycle and at the same time it minimises the risk of pollution to the water stored in the reservoir and of pollution of the sediments deposited on the beach.

The construction of a small dam, called pre-reservoir, within the main dam reservoir causes the temporary storage of the impounding water and the deposition of sediments within its reservoir. The stored water is allowed to drain to the main reservoir, if the water is of acceptable quality, whilst the collected sediments are evacuated once a year. After segregation, suitable sediments are transported to the beach. This system achieves sustainable management of sediments currently trapped in dams, restoration of sediment supply to the coastal environment and assurance of water quality of the dams.
Keywords: dams, sediments, erosion, river delta, coastal management, Cyprus, pre-reservoir, water quality.

WIT Transactions on The Built Environment, Vol 99,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CENV080171

1 Introduction

1.1 Dams in the World

In accordance with the international bibliography (White [1]) there are more than 40 000 large dams in the world. The main function of these dams is to store water for later use for irrigation, power generation and flood protection. Sediments trapped in dams reduce the storage capacity of the dams. The annual loss of storage capacity is estimated to be between ½% and 1% of the total storage capacity. This corresponds to a loss of 300 to 400 large dams per year, a loss that is enormous for dam operators. In order to alleviate this problem either the sediments need to be evacuated from the dams or more dams have to be constructed.

1.2 Erosion on land

The rate of land erosion varies significantly from place to place. The rate of erosion depends on:

- The climate in the catchment area
- The geology of the catchment area
- The topography of the catchment area
- The human activity in the catchment area

Erosion requires two mechanisms to act simultaneously:

1. Water flow capable to transport sediments
2. Sediments on the land surface that can be transported

If there is rainfall but the surface is rocky or with vegetation then there is no erosion. Similarly, if there is abundance of sediments but no rainfall to carry the sediments away, then there is again no erosion.

The world average rate of erosion is of the order of 65 m^3/km^2/year (Walling [2]), or 65mm per 1000 years. The largest erosion rates are encountered in China and the Middle East and the least in South America and North Africa.

An additional problem associated with the sediments trapped in the dams is the starvation of the sediment supply to the coastal zone.

2 The case of Cyprus

2.1 The damming of rivers

The island of Cyprus is situated in the eastern Mediterranean Sea (figure 1). Cyprus is the third largest island in the Mediterranean Sea, with an area of 9.251 km^2. The most significant geomorphologic features, shown in figure 2, are: the Troodos mountains, having peak elevation of 1.950m, on the south-west of the island, the longitudinal Pentadaktylos/Kyrenia mountain-range, with peak elevation of 1.000m, on the north part and the Mesaoria plain which lies in-between the two mountain ranges. Forests, of mainly pine trees, cover about 1/5th of the total area of Cyprus.

Figure 1: The Mediterranean Sea.

The climate is semi-arid, with mild and relatively wet winters and hot, dry summers. Rainfall is variable having a mean intensity of the order of 500 mm per year. Continuous droughts are becoming more frequent, whilst in the last 30 years the mean rainfall has been reduced. All rivers are seasonal rivers, which flow only after rain storms.

Figure 2: Topographical map of the Island of Cyprus.

The population of the island, in the areas under the control of the Republic of Cyprus is about 750 thousand people, of which about two thirds (2/3) live in urban areas. Urbanisation took place over a very short period of time, the urban population being doubled in just 30 years (1960 to 1990).

www.witpress.com, ISSN 1743-3509 (on-line)

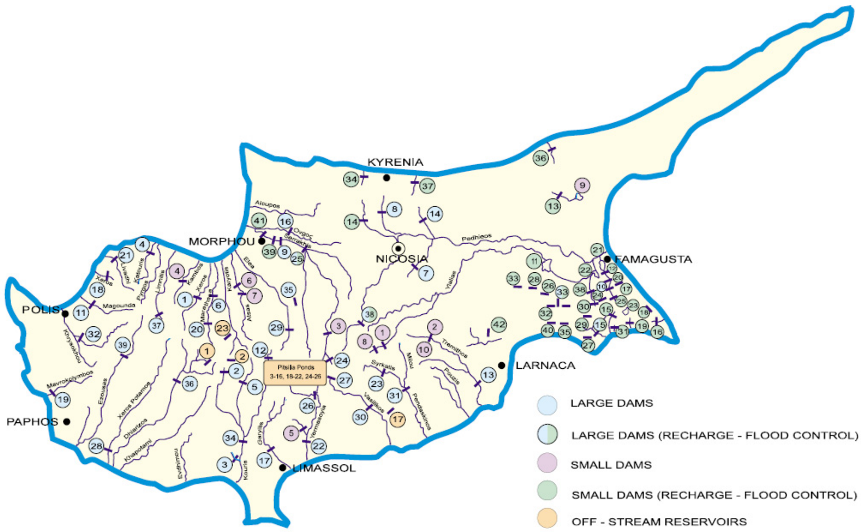

Figure 3: The dams of Cyprus.

Water shortage is a major problem. In order to address this problem, the Republic of Cyprus adopted the slogan “Not a drop of water to be wasted to the sea”. A series of dams has been constructed in recent years, and today almost all (seasonal) rivers are dammed. The rivers and the dams of Cyprus are shown on figure 3. It is noted that Cyprus has the largest number of dams per area in Europe.

The majority of the large dams are located close to the river delta in order to maximise the size of the catchment area and hence maximise the potential quantity of stored water. An example of such a dam is shown in figure 4.

Since the rivers that are dammed are seasonal ones, the dams are usually not full. Their primary role is to store water. The use of water is carefully managed and monitored. In exceptional cases some dams experienced overflow in the past, which however was controlled.

2.2 Erosion on land

Land erosion is significant due to the adverse contributing factors of:

- Climate: The rain is seasonal and hence vegetation is limited. Rainfall, which is sporadic and intense, erodes the susceptible soil surface.
- The geology of the mountains is ophiolitic easily erodible
- The topography is characterised by steep slopes which are erodible
- Human activity is most intense both in urbanisation and in agricultural use

All these factors contribute towards the erosion of sediments and their transport by storm water and deposition in the reservoirs.

The problem of sediments trapped in the reservoirs was identified from the start of the dam construction programme. Evacuation of the sediments from the reservoirs using dredging or sluice gates were evaluated and found as non-viable due to the large cost and due to the loss of precious water respectively. The solution adopted at the time was to build the dams larger than required, providing additional/dead storage.

The sediment yield in four dams is presented in table 1 (Konteatis [3]).

Figure 4: Dam of Asprokremmos damming the Xeros River, Paphos area.

Table 1: Sediments in dams in Cyprus.

DAM	Capacity $M\ m^3$	Catchment Area km^2	Erosion Rate of Catchment Area $m^3/yr/km^2$	Sediment yield/Year m^3/yr
Asprokremmos	52.4	224	940	210,560
Evretou	24	91	480	43,680
Kourris	115	308	910	280,280
Kiti	1.6	130	590	16,800

2.3 Effects of river sediment supply on the coastal morphology

The geomorphology of the island has been influenced by the sediments carried by its rivers. Archaeological and historical evidence is widespread about coastal cities on river mouths now located 3 km inland (such as Engomi), lakes being formed behind offshore islands due to sediments deposited by rivers on either side of the island (Akrotiri lake) and beaches formed from sand carried by rivers.

Figure 5: Kouris River Delta showing the recess of the coastline over a period of 20 years.

Since the damming of the rivers, the sediment supply to the coastal zone ceased. The river deltas stopped expanding and in a number of cases the deltas are receding at significant rates, as illustrated in figure 5. The coastline at the Chrysochos river dammed by the Evretou dam receded by 50m in the period 1973 to 1993. Similar observations were made to various deltas of dammed rivers.

Figure 6: Yermasoyeia Dam and River Delta. Breakwaters as a means of arresting coastal erosion.

In order to combat the problem of coastal erosion a number of breakwaters have been constructed over the past years, such as the ones in Yermasoyeia, Limassol (figure 6). These structures cure the symptoms of the problem and not the cause of the problem.

2.4 Problem definition

2.4.1 Coastal erosion

The problem of coastal erosion has been studied extensively over the last 30 years. Main causes of the erosion have been identified as the damming of rivers, beach material mining (now stopped), and construction of not-licensed coastal structures, coupled with the prevailing natural potential sediment transport due to wave action.

Beach nourishment has been evaluated and rejected as a non-viable solution due to the lack of sediments. The adopted strategy is the construction of sea defence works, such as beach revetments and breakwaters (offshore detached, groynes, etc) in urban/developed areas and the retreat of the coastline in rural/non-developed areas.

2.4.2 Reduction in dam storage capacity

The problem of sediment accumulation in the dams has not yet caused any serious problems to the water industry. As mentioned earlier, the dams have been constructed to allow for sediment accumulation over the life time of the dams. However, at some time in future, this problem will have to be addressed.

2.4.3 Risk of pollution of water in dam

Two further problems that are becoming increasingly important are the quality of the water entering the dams and the quality of the sediments on the beach. Recent fires in the woods have highlighted the risk of polluting the water stored in the dams. Although the pollution from burned trees might not be so damaging, the risk of pollution due to the burning of industrial, commercial or even housing units might pollute the water in the dams. Although the water from the dams is treated before its distribution for domestic consumption, not all pollutants are removed from the water.

Further risks of pollution include accidents such as road accidents adjacent to the reservoirs, fertilisers and pesticides being carried by surface or ground water.

2.4.4 Risk of sediment pollution

Regarding sediment quality, pollutants accumulated on sediments should be treated before returning to the natural environment. Sediments in dams are more susceptible to pollution than sediments being transported by the surface river flow. Testing of sediments is therefore required and the relevant measures need to be taken depending on the test results.

3 Pre-reservoir

3.1 Main characteristics

During the course of a research programme, funded by the Cyprus Research Promotion Foundation, a new proposal has been developed which addresses holistically the problems of sediment management <u>and</u> water quality. This proposal refers to a small dam, called pre-reservoir with the following characteristics:

- It is constructed in the entrance of the main dam reservoir
- Storm water is temporarily stored
- The water quality is checked after the storm:
  - If the quality is acceptable, then the water is allowed to enter the reservoir through a pipeline
  - If it is not acceptable, then the appropriate measures are taken (e.g. collection and treatment, diversion downstream)
- The sediments are collected once a year and their quality is tested:
  - If their quality is acceptable, sieving takes place and suitable material is transported and deposited at the river mouth/beach.
  - If their quality is not acceptable, then suitable measures are taken (e.g. treatment, burial etc).

The flow chart of the pre-reservoir operation is shown in figure 7 and a typical cross-section and plan are shown in figures 8 and 9 respectively.

3.2 Construction of the pre-reservoir

The pre-reservoir is wholly constructed within the land already allocated to the main dam and hence no additional cost for land purchase is required. The exact

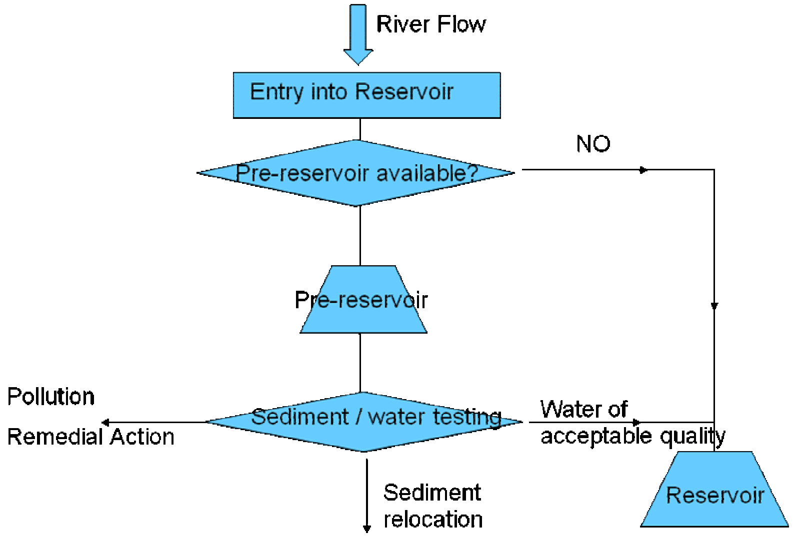

Figure 7: Flow chart of pre-reservoir operation.

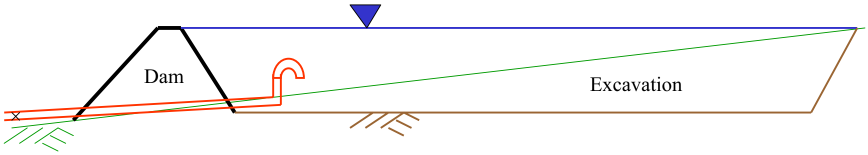

Figure 8: Cross-section of pre-reservoir.

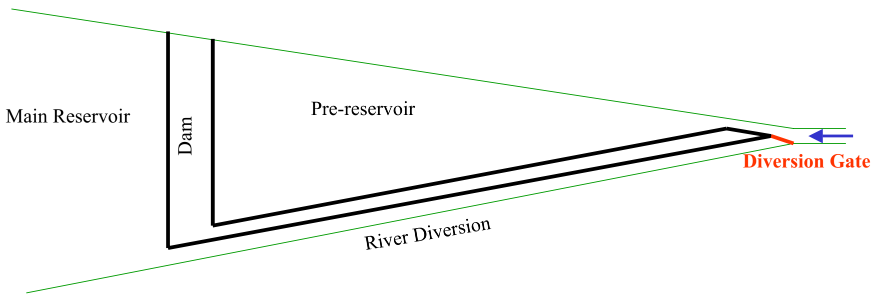

Figure 9: Plan of pre-reservoir.

location of the small dam is selected so that it has good access for road vehicles. The materials used for the construction of this small dam are to be obtained from the local area minimising thus the environmental impact of this project.

The pre-reservoir overall dimensions are such that it can accommodate the flow occurring once a year. The pre-reservoir will be overflowed over a spillway made of again local materials. It is proposed to build it with gabions, using gravels from the river bed.

3.3 Operation of the pre-reservoir

The dams are regularly monitored, having permanent staff in each dam. The pre-reservoir will therefore need no additional staffing. The river, being seasonal, is normally not flowing and the pre-reservoir is normally empty and the valve draining the water to the main reservoir is normally closed. Accidents, fires and other events are notified and the dam inspectors are alerted.

Under normal circumstances the water flowing after a storm event carries sediments and both the water and the sediments are of acceptable quality. The water and sediments are trapped in the pre-reservoir. The dam inspector will verify (through visual inspection) that the water is not adversely polluted and the valve will be opened and the water drained into the main reservoir. The sediments, other than the fine suspended sediments within the water, will be not be transported to the main reservoir.

Once a year, during the dry summer season, the sediments, which are dry, will be excavated and relocated outside the pre-reservoir using land equipment. Conventional sieves will be used to segregate the sediments. Organic material will be used for use in fields for agricultural purposes. Material suitable for the coastal environment will be transported to the beach using road vehicles.

In the unlikely/extreme event of an accident such as fire, the polluted storm water will not be allowed to enter the reservoir. It will be either collected and treated (e.g. in case of oil pollution) or be diverted outside the reservoir (e.g. ashes from wood fire).

Similarly, contaminated sediments, unsuitable for bathing beaches, will not be transported to the coast. These sediments will be treated in accordance with the extent of their pollution.

3.4 Beach nourishment

The sediments collected in the pre-reservoirs and transported to the coast will be used for beach nourishment in eroding river deltas and beaches. This is a precious source of sediments and the management of these sediments needs particular attention. Nature would have deposited these sediments, together with the fine suspended sediments that inevitably end up in the main reservoirs and the organic matter (tree branches, leaves, etc) that are placed in the fields, at the river delta. The wave action would sort the sediments and would also cause the rounding/smoothing of the edges of the material.

4 Conclusions

The disruption of nature's cycle of sediments by the construction of dams is associated with the reduction of the storage capacity of dams and the starvation of sediment supply to the coastal environment. A sustainable solution to this problem is the construction of a small dam, pre-reservoir, at the entrance of the river to the main dam reservoir, which acts as a temporary water storage structure and a sediment trap. Water is drained, free from most sediments, in the main reservoir after each storm, whilst the sediments are transported once a year to the coast. This temporary trap of water and sediments is also effective in the assurance of the quality of the water of the main reservoir and the quality of the sediments on the beach.

Acknowledgement

The authors would like to express their appreciation for the financial support of their work from the Cyprus Research Promotion Foundation.

References

[1] White, R., *Evacuation of Sediments from reservoirs*, Thomas Telford, UK, 2001.
[2] Walling, D.E., The erosion problem. *International Journal of sediment Research*, 14, No. 1, 1-11, 1984.
[3] Konteatis C., *Dams of Cyprus*, Republic of Cyprus, 1974.