Thoughts on Flood Protection for the Settlement on a Small Island

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Abstract: This paper presents data from digital elevation models of the area around the settlement of the Greek island of Pserimos, based on which some thoughts are documented for the flood protection of the settlement. This paper aims to provide the impetus, data, and methodology for a thorough study. For this purpose, a digital elevation model of the area has been created with an accuracy of approximately two meters. Two watersheds are examined, one North of the settlement and one South/East. Our suggestions concern the creation of a retaining dam North of the settlement and the creation of small dams south and East of the settlement.

Key-Words: - Flood protection, water management, small island, small dams, open drainage channel.

Received: April 25, 2025. Revised: July 8, 2025. Accepted: August 6, 2025. Published: September 12, 2025.

1 Introduction

According to local press information, two floods occurred in the settlement of Pserimos [16] and [3]. The first one is mentioned: The damage on the island is incalculable (Fig. 1).

Fig. 1. A typical image of Pserimos from the floods on 11.25.2013. Source: Local press [16].

The second flood was reported on January 21, 2019 [3]: The island of Pserimos was flooded once again with today's downpour (Fig. 2).

There are many small Greek islands in the Aegean Sea, and Pserimos is a suitable example to use as a prototype for studying relevant problems and proposing solutions to support the local population. The focus of present thoughts is on water management and flood protection. These are some thoughts and recommendations based on scientific data from the island, but they are not the result of a comprehensive study.

Fig. 2. Flooding on the island of Pserimos from the morning downpour on Monday, January 21, 2019, with the island's only road turned into a river—source: Local press [3].

Therefore, a more detailed and funded study is needed to address the flooding problems of the island. Additionally, this work provides an extensive reference list for in-depth research.

1.1Literature review

Most of the literature focuses on the protection of settlements and deals with the social impact of natural disasters, such as flooding. According to the UN [1], emphasis must be placed on reducing the social and material losses caused by water disasters [20]. Community participation is crucial in mitigating the impact of flooding disasters [2], [19]. Flood damage modeling is used to estimate the global economic exposure to both river and coastal flooding [11], [14], [21]. An interesting study employs descriptive and exploratory analytical approaches to assess the trends of flood events and their potential risk management [4]. There are studies identifying how the low-income population responds to their flood risk [8]. Another essential factor to take into consideration about flooding is vulnerability [12], [18]. There are also national policies on urban development and disaster risk reduction that must also be taken into consideration [17].

2 Overview of the topography

Fig. 3 presents the relief of the entire island, along with its hydrographic network, which includes the streams [10].

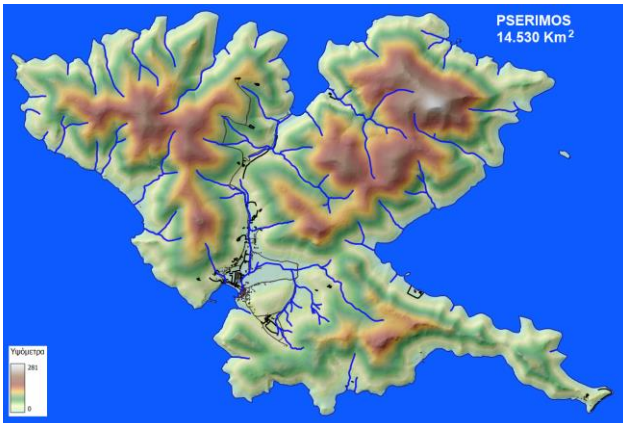

Fig. 3. The terrain relief from the digital elevation model [10]. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

The relief presents two main mountain ranges: Lakaniki to the West, with a maximum altitude of around 210 meters, and Patima to the East, with a maximum altitude of 267 meters. These ranges are separated by a small valley through which passes the road connecting the settlement of Pserimos with the beach of Marathoda on the North of the island. This road is around 2300 meters long. A smaller mountain range is located in the South of the island, Koriphi, with a maximum altitude of 179 meters. The total area of the island is approximately 14.530 square Kilometers, and the length of the coastline is around 31 kilometers.

Fig. 4. The topography of the area that affects flooding in the settlement. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

Fig. 4 shows the topography of the area around the settlement with contour lines having an interval of 4 meters. A careful study of the topography reveals the presence of two main catchments that influence flooding in the settlement of Pserimos, as shown in Fig. 5 as A (North) and B (South). Catchment A has quite steep slopes of around 30%, while catchment B has gentler slopes. An interesting observation is that the streams from both catchments converge within the settlement of Pserimos and almost coincide with the main road of the settlement, resulting in the situation depicted in Fig. 2 during a flood. Fig. 6 shows the union and identification of the streams with the main road in the settlement.

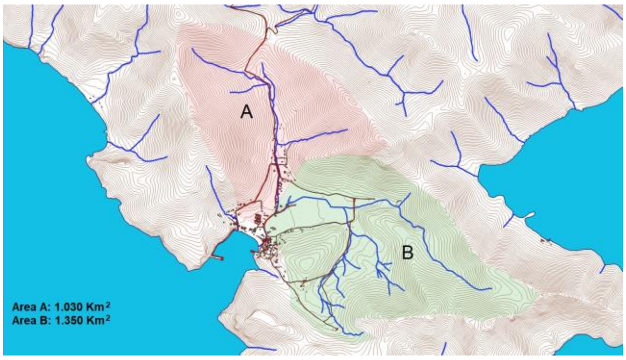

Fig. 5. The two watersheds that affect flooding in the settlement of Pserimos. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

Fig. 6. The identification of the two streams with the main road of the settlement. Source: Google Satellite, J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

Based on scientific data, including the digital elevation model (DEM) of Pserimos and the flooding issues in the settlement, the following Section will discuss the flood protection measures for the settlement.

3 Flood protection

Fig. 7 illustrates the relief of the area around the settlement that affects flooding, and Fig. 8 shows the same area with the catchment areas roughly demarcated. See also Figures 4 and 5 for comparison. Catchment A has an area of 1.030 Km^2, and Catchment B has 1.350 Km^2. An attempt will then be made to calculate the potential amount of water that will create a flood in the settlement.

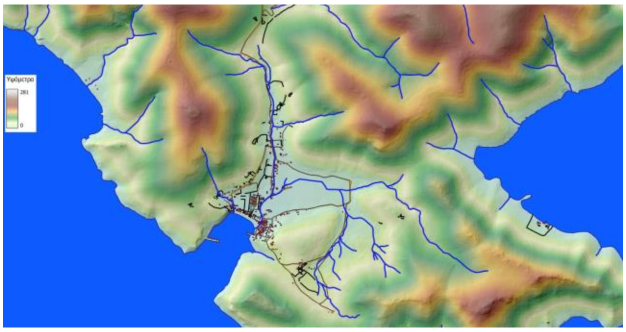

Fig. 7. The two watersheds that affect flooding in the settlement of Pserimos are visible in the relief form of the digital elevation model. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

For a 100 mm rainfall, which is an extreme rate [5], [15] within one hour (i=0.1 m/h) within a catchment area E, and assuming no evaporation and absorption from the soil or retention by vegetation (C=1), a quantity of water is generated:

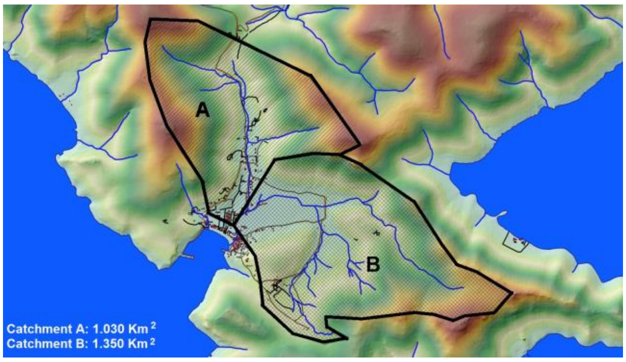

Fig. 8. The two watersheds are delineated on the relief map. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

$$Q = C * i * E/3600 \tag{1}$$

Where Q = flow rate (capacity) in m^3/sec

E = the catchment area in m^2

i = the rainfall rate in m per hour

C = runoff coefficient that depends on the catchment coverage

For catchment A we have: Q_A = 0.1 x 1030000/3600 = 28.61 m^3/sec

For catchment B we have: Q_B = 0.1 x 1350000/3600 = 37.50 m^3/sec

The trapezoidal cross-section of an open duct required to carry a capacity Q is given by Manning's formula [13]:

$$V = \frac{Q}{E} = \frac{1}{n} S^{1/2} R^{\frac{2}{3}} = \frac{1}{n} S^{1/2} \left(\frac{E}{\Pi}\right)^{\frac{2}{3}} = \frac{1}{n} S^{1/2} \left(\frac{by + my^2}{b + 2y\sqrt{1+m^2}}\right)^{\frac{2}{3}} \tag{2}$$

Where: V = flow velocity,
Q = capacity,
E = cross-section of the duct,
n = Manning coefficient,
S = duct slope,
R = hydraulic radius,
Π = wetted length,
y = flow depth,
m = side slope,
b = bottom width,
B = surface width.
These dimensions are shown in Fig. 9.

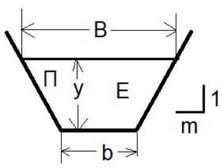

Fig. 9. Typical trapezoidal cross-section duct layout.

To avoid flooding based on the data above, which indicates that water accumulating within the settlement is 28.61+37.50 = 66.11 m^3/sec, a technical project should be carried out to create an artificial stream, i.e., an open conduit for the collection of rainwater to transport it to the sea. This conduit can have a trapezoidal cross-section, as shown in Fig. 9, and be made of concrete. To use Equation (2) and determine the cross-section of the duct: base, width, height, and slope, we make the following assumptions:

Flow rate Q = 66.11 m^3/sec (calculated)

Manning coefficient n = 0.011 [6], [22]

The slope of the duct S = 0.01215 (4.40/362 from the topographic map)

Base width b = 2.50 (assumption)

Slope m = 2/3 (assumption)

Height y = 1.80 (assumption)

We will use Equation (2) to solve for the flow rate, ensuring the height is less than 2 meters.

$$Q = \frac{by + my^2}{n} S^{1/2} \left(\frac{by + my^2}{b + 2y\sqrt{1+m^2}} \right)^{\frac{2}{3}} \tag{3}$$

A VB-6 computer program [10] was created for this purpose, and by appropriately adjusting the b and h values, the dimensions of the duct are calculated using Manning's formula for an open duct with a trapezoidal cross-section.

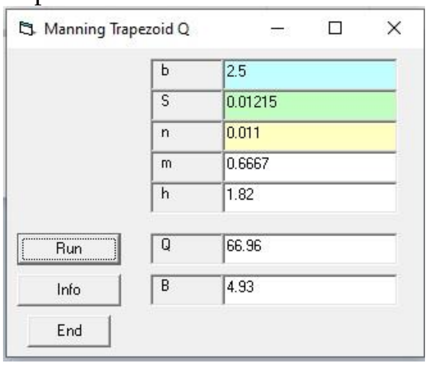

Fig. 10. The data and the result from Manning's formula for an open trapezoidal cross-section duct. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

Changing the assumptions a little and taking into account a side slope of 1:5, m = 0.2, and a rainfall of 100 mm in 6 hours instead of one hour, the rainfall intensity becomes 0.100/6 = 0.01667 m/h, so the flow rate given by formula (1) is calculated:

Q = 0.01667 x (1030000 + 1350000)/3600 = 11.02 m^3/sec

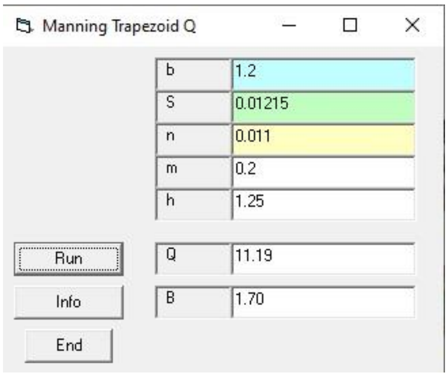

Fig. 11. The data and the result from Manning's formula for the second assumption. Source: J. N. Hatzopoulos, Remote Sensing and GIS Laboratory.

Running the BV-6 program, we obtain (see Fig. 11) the cross-section of the pipeline: b = 1.2m, B = 1.70m, m = 0.2 or a side slope of 1:5, y = 1.25m (See also Fig. 9).

As shown in Fig. 11, the second assumption appears more realistic; therefore, the dimensions of the open channel are 1.20 meters wide at the base, 1.25 meters high, and 1:5 channel side slope. This channel serves a flow of 11.19 m^3/sec. Therefore, to secure the settlement against a flood with a rainfall intensity of 100 mm in six hours, a technical project should be carried out, specifically a stormwater channel with the above-calculated dimensions.

4 The construction of dams

Based on the topographic data of the catchment area A (Figures 5 and 8), a retaining dam can be constructed within this basin. As shown in Fig. 12, the upper surface of the dam has an altitude of 28 meters, and its lowest point is at an altitude of 16 meters. Therefore, the facade will have an elevation difference of 12 meters, which will also be its height. The length at the top of the facade is 120 meters, and the area of the upper water surface is 27000 m^2.

The location of the dam in the broader area, concerning the settlement, is shown in Figure 13. Assuming an average depth of the dam of 5 meters, the approximate volume of water that will be retained is calculated to be 27000x5 = 135000 m^3. This volume will keep the water of the flood in question.

As a retention dam, it will allow the water to be held back before it floods the settlement and will enrich the underground horizon that feeds the springs and wells of the downstream area.

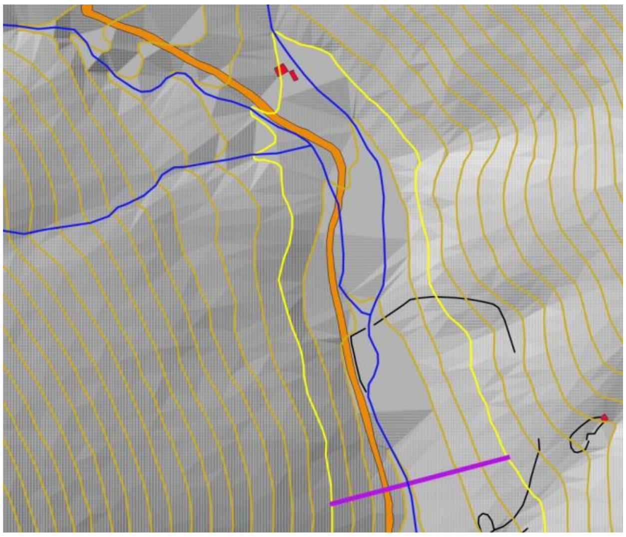

Figure 12. The proposed dam has a frontage of 120 meters and an area of 27000 m^2. Source: I. N. Hatzopoulos Remote Sensing and GIS Laboratory.

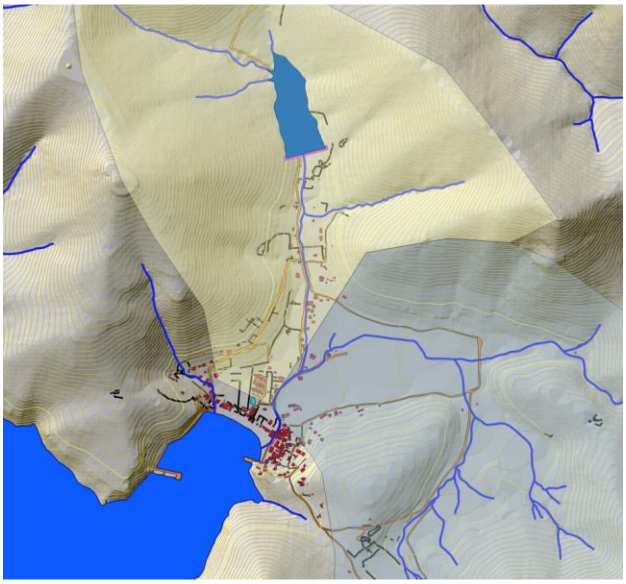

Fig. 13. The dam in the broader area. Source: J. N. Hatzopoulos Remote Sensing and GIS Laboratory.

The catchment area B (Figures 5 and 8) covers an extensive plain area with the surrounding hills having relatively gentle slopes. In the mountainous part of this area, small retention dams can be constructed, as has been done at Apeiranthos on the Greek island of Naxos [7].

In the European Comenius project "GEO-INFORMATION SYSTEMS AND ELECTRONIC COMMUNICATION NETWORKS AS INSTRUMENTS FOR ENVIRONMENTAL EDUCATION Trianet-Socrates-Comenius-course" in which the Remote Sensing and GIS Laboratory at the University of the Aegean coordinated a research team involving scientists from Germany, Italy, and Spain, we offered four seminar classes to 30 teachers from all over Europe in four different years. The first year we visited the small dams in Apeiranthos, Naxos, we were guided by the late Manolis Glezos. In Fig. 14, the small dams are depicted, along with the participating teachers in the Comenius project. Figure 15, from the following year, shows the result of aquifer enrichment by the small dams in Apeiranthos, Naxos, located on the mountain at an altitude of 650 m, as part of the same Comenius program, dated 7-15-2000.

Fig. 14. Small dams in Apeiranthos, Naxos [7]. Source: J. N. Hatzopoulos.

Cypriots have successfully employed the method of small dams for many years to retain water and prevent runoff to the sea.

Figure 15. Result of enrichment of the aquifer by the small dams in Apeiranthos, Naxos, at 650 m altitude, 7-15-2000. Source: I. N. Hatzopoulos.

At the Remote Sensing and GIS Laboratory of the University of the Aegean, a thesis on small dams was prepared by S. Karafyllis and D. Gitakou [9] on the use of Geographic Information Systems (GIS) to identify locations for small dams. For this purpose, basic specifications were developed for finding the locations where the dams will be designed, and according to Figure 16, they are:

1. The height h < 2 meters.
2. The width a <= 12 meters.
3. The ratio of depth to width b/a >1.
4. The volume of water in the dam is > 50 m^3.

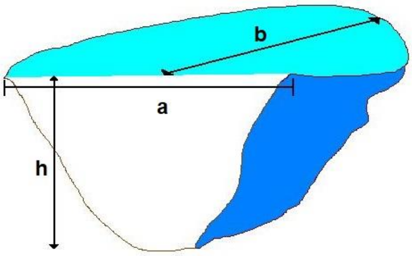

Fig. 16. Indicative specifications for locating a small dam [9].

An attempt was then made to automatically locate the stream places for small dams, as shown in Figure 17.

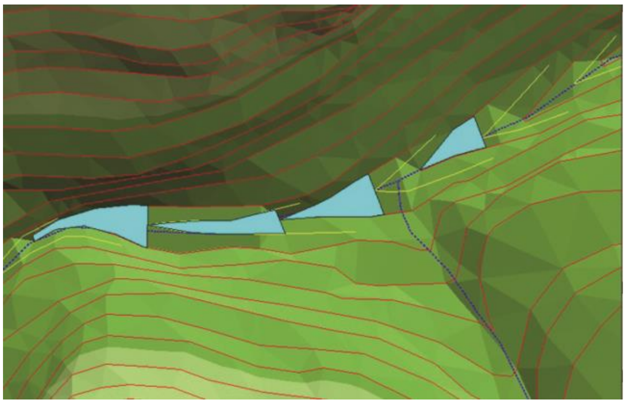

Figure 17. Identification of small dams [9] in a watershed in the Koronida area of Naxos, using ESRI ArcGis tools.

In catchment B, we did not attempt to locate small dams because it requires a contour interval of less than one meter, and the available digital elevation model was constructed from a contour map with a four-meter contour interval. Due to the gentle slopes in the B catchment area, small dams/reservoirs can be built to retain large quantities of water and solve the problem of flooding in the settlement.

5 Conclusion

Regarding the issue of protecting the settlement of Pserimos from flooding, two solutions were proposed, one of which involves the creation of a stormwater drain. Based on certain assumptions, two indicative examples were presented. The second solution also resulted in an outcome regarding the creation of a dam in the A catchment area, where it seems to retain the water that could flood the settlement on one hand, and on the other hand, it will feed the aquifer of the area, which provides water to the springs and wells. The same can happen with smaller dams in the B catchment area, where no results were given due to the lack of more accurate elevation data.

In addition to protecting the settlement from floods, other development projects can be carried out, such as a limited road network for cars that will connect the settlement with the various economic activities that will develop on the island. The island may be small, but its coastline is 31 kilometers long, and along it, pedestrian and cycle paths can be developed. Additionally, the Northern area of Marathoda could be designed to host facilities for high-tech companies.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The author contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The author has no conflict of interest to declare that is relevant to the content of this article.