Basin: Pedieos

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# Narrative

* 1. Description of the basin

The Pedieos River, similar to the majority of Cyprus rivers, is a non-perennial river, of ephemeral nature that only flows during the rainy winter months or after heavy rainfall events. The river originates in the north-eastern hillslopes of the Troodos mountain complex (Figure 1). The river basin has its highest elevation at 1,400 m above sea level and covers a population of 192,000 inhabitants. The forested upstream area hosts beautiful picnic sites and nature trails and forms an important Natura 2000 site (Department of Forestry, 2012). The fractured volcanic formations in the upstream area are mainly covered by conifers, with smaller areas of sclerophyllous and shrub woodlands and few plots of rainfed cereals, irrigated fruit trees, greenhouses and livestock farms.



Figure 1: The Pedieos River Basin in Cyprus.

At the bottom of the foothills, the Tamassos dam, which was completed in 2002, captures and stores the runoff of the 45-km2 upstream river basin in a 2.8-million m3 reservoir. The dam provides flood protection, groundwater recharge through the release of water to the downstream alluvial aquifer, and water supply for nearby communities.

Streamflow data just upstream from the dam, collected by the Cyprus Water Development Department, showed that the largest event in the past 40 years produced 3.1 million m3 of water in one day! This event occurred on 9 January 1989 and resulted from 57 mm rain over the upstream catchment on the preceding day and 108 mm on the day itself. Considering that there is always water in the reservoir in winter time, an enormous volume of water would have flown through the spillway of the dam. Thus, it is important to manage the water body behind the dam in such a way that sufficient storage is available to protect the nearby communities against floods.

Downstream from the dam, the river basin crosses about half a dozen rural communities, which grow rainfed and groundwater-irrigated crops. Barley, fresh vegetables and olives are the most common crops. Irrigation is the largest user of water in the rural areas of Pedieos consuming on average 4.5 Mm3/year (82%).

The river then flows into the urban agglomeration of the capital Nicosia and its adjacent municipalities. The Pedieos River in the urban areas of Nicosia is dry most of the year. However, during heavy rainfall events runoff from the surrounding paved areas flows to the river. A total of 38 floods were recorded in urban Nicosia, from 1960 to 2012, of which three were caused by flooding from the river (I.A.CO Ltd, 2011). Natural vegetation that grows in the dry river bed impedes the flow of the water. Garbage and branches that are dragged along by the flood get trapped at the low road crossings over the river, causing water to spill over the road. The Water Development Department has identified the urban area along the Pedieos as an area of potentially significant flood risk, for the European Flood Directive (2007/60/EC).

Along the river, a linear park with cycling path offers a quiet green corridor in the hectic urban environment of Nicosia. Many people visit the park in the early mornings and evenings during summer. Daily maximum temperatures in Nicosia average 37 degrees in July and August. A survey of the park visitors, conducted by intern students of the Cyprus Institute, showed that most people come for exercise or to enjoy nature (Poulou, 2014). The majority of the people indicated that they were happy with the services of the park. The park contributes to environmental awareness and creates an understanding of the functioning of ephemeral streams.

The river basin covers approximately 120-km2 at the green line in Nicosia, where it flows into the occupied areas of northern Cyprus.

Historical sources indicate the Pedieos River was important for the foundation and growth of Nicosia (Charalambous et al., in review). The river used to replenish the groundwater reserves that served the historical town and its nearby agricultural communities. However, floods occurred in the past too. The most well-known historical flood of 1330 caused the death of 3000 people. Around 1570, the river was diverted northwards around the town. The reasons for this diversion, under debate by various authors, could have been the protection of the city against flood or the supply of water to the moat around the walls (Charalambous et al., in review).

* 1. Global change

The Pedieos River Basin receives an average annual precipitation (1980-2010) ranging between 320 mm downstream to 670 mm upstream. Regional climate models indicate a drier and warmer Pedieos watershed in the near future (2020-2050) (Figures 2 & 3; Camera et al., 2013). In particular, it is projected that maximum and minimum temperatures may increase by an annual average of 1.5 ºC, indicating mainly hotter summers, while winter precipitation may decrease by an annual average of 7% (Hadjinicolaou et al., 2011). Changes in the number of hot days (Tmax ≥ 35 ºC) and tropical nights (Tmin ≥ 22.5 ºC) are also foreseen (Camera et al., 2013). The number of extreme precipitation events is also expected to increase in a warmer future (e.g., Russo and Sterl, 2012). No increases in precipitation extremes were found for Cyprus for three downscaled Regional Climate Models under the A1B scenario for 2020-2050, relative to 1980-2010 (Camera et al, in review). However, these 30-year periods may be too short to identify changes in precipitation extremes. These adverse changes can exert sizeable pressure on water supply and agriculture creating thus negative impacts on the local economy and the living standards of the residents.

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| Figure 2: Precipitation projections for the period 2021-2050 indicate a drier Pedieos Watershed in the future. *Source: Camera et al., in review.* | Figure 3: Average maximum and minimum temperature projections for the period 2021-2050 show a warmer future for Pedieos Watershed. *Source: Camera et al., 2013.* |

Population trends and the associated water demand are additional parameters that deserve attention. The population of both urban and rural communities of the Pedieos Basin follows an increasing trend over the past 30 years as shown in Figure 4. The population includes the rural communities Lazanias, Kampia, Politiko, Pera, Episkopio, Anageia, Ergates, Psimolofou, and Pano and Kato Deftera, which have their population centers in the basin. The urban Pedieos communities (municipalities) are Lakatameia with Anthopouli, Strovolos, Nicosia, Engomi and Agios Dometios. Some 94% of the total watershed population is located in urban communities, according to the 2011 Census (Cystat, 2014). Note that the total population of these communities and municipalities is shown. However, the administrative boundaries do not always coincide with the hydrological boundaries. Thus, part of the reported population lives outside the pictured boundaries of the watershed. According to the UN (2013) medium variant projection, the urban population of Cyprus will continue to grow over the next 35 years, while the rural population will follow a diminishing trend over the period 2015-2050 (Figure 5). Based on the annual population rate of change of these projections, the gross domestic water demand for the two population categories was estimated (Figures 6 and 7). It was assumed that people in urban communities consume 215 l/d per capita and people in rural communities 180 l/d per capita, following the assumptions of WDD (2011). Currently, the annual domestic water demand in urban communities is 15 Mm3/year and by 2050 is expected to increase by 28%. On the contrary, a 23% decrease by 2050 is expected in rural communities, from the current 0.85 Mm3/year domestic water demand. It should be noted domestic water supply in urban communities relies on desalination (outside the watershed), while groundwater and water from the Tamassos dam are the predominant water supply sources for rural communities.

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| Figure 4: Urban and rural population in Pedieos watershed, 1982-2011. *Source: Cystat (2014)* | Figure 5: Past and projected total urban and rural population in Cyprus. *Source: UN (2013)* |

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| Figure 6: Estimated gross domestic water demand in the urban communities of Pedieos watershed. | Figure 7: Estimated gross domestic water demand in the rural communities of Pedieos watershed. |

* 1. Challenges

Stakeholders identified three major challenges in the Pedieos River Basin, namely, quantitative and qualitative status of groundwater, quantitative and qualitative status of surface water and flooding from the river.

1.3.1 Quantitative and qualitative status of groundwater

A major challenge identified in the Pedieos River Basin is groundwater quantity and quality. The high temperatures and the increased variability of precipitation leads to an increased irrigation demand that will exacerbate the already high pressures on groundwater resources. A reduction in groundwater quantities will affect irrigated crop production and livestock farms. Overpumping of groundwater lowers water table and alters how water moves between the aquifers and the stream. Non-point source pollution poses an important threat to groundwater across the river basin. Croplands are a primary nonpoint source of contamination to groundwater due to the applications of agricultural chemicals such as fertilizers, pesticides and manure. Irrigated agriculture in the river basin has especially noteworthy effects on groundwater quality because excess irrigation water applications may leach agricultural chemicals into groundwater. Furthermore, overpumping of groundwater can also affect the groundwater quality.

Urbanisation has increased the sealed areas in the downstream part of the river basin, which implies modificiation of the hydrological cycle, especially the rate and volume of runoff. This can cause local flooding of roads and buildings during heavy rainfall events. The surface runoff from the urban areas of the watershed is drained into the Pedieos River and affects fluvial flooding.

1.3.2 Quantitative and qualitative status of surface water

The quantitative and qualitative status of surface water is the second major challenge identified by the stakeholders (Maes and Dude, 2014). The adverse climatic conditions (increase of temperature & precipitation decrease) will result in diminished surface water supplies. These changes affect the services and the functions of the dam water body. Tamassos dam contributes to groundwater recharge through the controlled release of water to the alluvial aquifer in the midstream area of Pedieos River Basin and provides water supply for the nearby rural communities. The reduction in surface water quantities will also affect irrigated farming and the riparian vegetation and biodiversity habitats of the streams.

Similarly to groundwater qualitative status, during peak precipitation events, agro-chemicals from irrigated agriculture and livestock manure are carried away to the river.

Forest ecosystem services have a positive impact on water (groundwater and surface) quality. The ability of forests to generate porous and filtering soils helps to regulate soil erosion and reduce sediment load.

Uncontrolled urban development has led to a significant degradation of riverbed and riparian area. Solid and liquid waste dumping has detrimental effects on the quality of the surface water. Urban sprawl is also a significant factor regarding soil sealing in suburban areas of Pedieos RB. Soil sealing contributes negatively to water quality as the rainwater is polluted by concentrations of heavy metals in sealed areas, which when washed into the river degrade its water quality.

1.3.3 Flooding from the river

The urban area along the Pedieos River has been identified as an area of potentially significant flood risk. Although the Pedieos River in its downstream part is dry most of the year, heavy rainfall events may lead to significant floods, as indicated by the latest flood risk assessment (WDD, 2014). Natural vegetation across the riverbed impedes the flow of the water, while illegal dumping of garbage is often blocking waterways and causes localised floods and spill overs of water in the roads. The restoration and maintenance of the riverbed was emphasized by the stakeholders (Maes and Dude, 2014).

The forests in the upstream area of the RB help to regulate relatively minor floods although they are not able to prevent major floods. Crop fields in good state have also a positive contribution to flood prevention in the midstream parts of the RB.

Tamassos dam provides significant flood protection to the midstream and downstream areas of the RB. The dam modifies the volume of water flowing downstream and alters the natural rates at which rivers rise and fall during extreme runoff events.

The high urban sprawl intensifies soil sealing which increases the risk of flooding. The disturbed land loses its ability to hold soil in place that increases the rate and the volume of runoff. Finally, flooding is partly caused by problems in the rainwater drainage systems in the urban area. Sustainable urban drainage systems are necessary to capture and store surface water run-off and control its release into Pedieos River.

* 1. Basin dynamics

A cognitive map of Pedieos RB is presented in Figure 1. Stakeholders identified three major climate variables, namely, precipitation decrease, increase in extreme precipitation events and temperature increase that affect either directly the aforementioned challenges in the basin (quantitative and qualitative status of groundwater, quantitative and qualitative status of surface water and flooding from the river) or indirectly through several (7) factors across the up-, mid- and downstream areas of the basin. These factors are: forest ecosystem services, riverbed and riparian area ecosystem services, livestock, rainfed and irrigated crop farming, rural communities water demand and urban runoff. The definitions and the interrelationships between the factors of the basin are presented in the Tables I1 & I2 of the Annex.



 **Figure 1**. Pedieos cognitive map

Precipitation decrease and high temperatures create strong negative effects on ecosystem services provided by forests including the provision of clean water, maintenance of soil quality, wildlife habitat, recreation and a variety of forest products. Forests also help to regulate water flows during extreme rainfall events preventing to some degree flooding. In addition, drought increases forest fire risk since dry trees and shrubs provide fuel to fires, while trees become more vulnerable to pests and diseases.

Precipitation is the major driver for the ecosystem services and functions provided by Tamassos dam water body, such as biodiversity, recreation, water storage and supply. Low precipitation affects the capacity of the dam water body to provide sufficient water supply to the nearby rural communities and to release water for recharge of groundwater resources downstream. Furthermore, the major function of the dam is flood protection during heavy rainfall events.

The rural communities of Kampia, Psimolofou and Episkopio (and Kapedes, outside the basin) receive water from Tamassos (interview with Pera Community leader, March 2014). Anthoupolis, Deftera and Ergates receive water from the seawater desalination plants from the Nicosia Water Board (interview with Deftera Community Leaders, March 2014; Director of Nicosia Water Board, Cyprus Mail, 2013). However, some of the rural communities also pump groundwater for their domestic supply. The urban communities receive their water supply from the Nicosia Water Board. As mentioned above, the water is predominantly sourced from the seawater desalination plants outside the basin, through the southern conveyor system.

The low precipitation and the high temperatures impact negatively on the ecosystem services provided by the riverbed and the riparian zone. The degradation of the above services creates negative impacts on the quantity and quality of groundwater resources. Groundwater resources are recharged through the riverbed, while ecosystem services of riparian zones, namely sediment filtering, water storage and release, bank stabilization and provision of habitat for biodiversity, affect positively water quality and water quantity. Furthermore, natural vegetation in the usually dry riverbed and across riparian area impedes the water flow reducing thus flood risk.

Local agriculture is the main user of the basin’s water resources and is significantly affected by climate conditions. Precipitation decrease exerts high pressures on the rainfed crops that rely on rainfall for water, while uncontrolled abstraction of groundwater resources for irrigation impact negatively on both the quantity and quality of groundwater resources. Higher production costs for groundwater-irrigated crops results in a further reduction of farm incomes. The performance and health of livestock is affected by the increase in temperature. This also increases the operational costs (energy and water for cooling) of intensive livestock units.

Although the Pedieos River is dry most of the year in its downstream part, extreme precipitation events increase urban runoff and lead to floods. The rapid urbanisation has increased drastically the sealed land in the suburban municipalities of Pedieos RB. The creation of impervious surfaces (e.g. roads, pavements etc.) results in the decrease of infiltration (groundwater recharge decrease) and an increase in surface runoff. The surface runoff flows through the sewer systems and drains to the Pedieos River, thereby increasing the risk of floods.

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# Annex

**Table I.1: documentation of the factors in the Pedieos cognitive map**

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| Number | Name of factor | Definition | Comment |
| F1 | Temperature increase | Overall increase in temperature (1-2 ⁰C), and more hot days (>35 ⁰C) and tropical nights (>22.5 ⁰C). | Climatic driver  |
| F2 | Precipitation decrease | Reduction in the average annual rainfall (1-12%) and more very dry years.  | Climatic driver  |
| F3 | Precipitation extreme events | Increase in the number of extreme precipitation events (days with more than 50 mm rain).  | Climatic driver  |
| F4 | Forest ecosystem services | Ecosystem services provided by forests, namely, ecological, sociocultural, scenic and landscape services and values, including the regulation of water flows and reduction of erosion  | Pine forests, a Natura 2000 site, cover the area upstream of Tamassos Dam.  |
| F5 | Dam waterbody ecosystem services | Quantitative and qualitative status of surface water, related to the ecosystem services provided by the Tamassos dam reservoir, including flood control, water supply, provision of habitat for biodiversity and recreation.  | Major challenge in Pedieos RB |
| F6 | Riverbed and riparian area ecosystem services | Ecosystem services of the river and riparian zones, including sediment and nutrient filtering, water storage and release, [aquifer](http://www.eoearth.org/article/Aquifer) recharge, bank stabilization and provision of habitat for biodiversity.  | The river and riparian zones downstream of the Tamassos Dam |
| F7 | Rainfed cropland | Land cultivated with crops that rely on rainfall for water, mainly barley grown during November-April and some olive orchards.  | Rainfed cropland covers an approximately similar area as irrigated cropland in the midstream part of Pedieos RB |
| F8 | Irrigated cropland | Land cultivated with irrigated crops such as vegetables, fruit trees and some olive orchards  | Irrigated cropland covers an approximately similar area as rainfed cropland in the midstream part of Pedieos RB |
| F9 | Livestock | Intensive livestock farms, mainly with sheep, goats, chickens, but also cows and horses. Occasional grazing of natural vegetation by sheep and goats in the lower upstream and upper midstream areas. | Sheep and goat are mainly found in the communities near the Tamassos Dam and poultry farms throughout the midstream area. |
| F10 | Rural communities (domestic water demand) | Water demand of rural households for drinking and gardens’ watering purposes  | Rural communities are found in the midstream area of Pedieos RB |
| F11 | Groundwater | Quantitative and qualitative status of groundwater | Major challenge in Pedieos RB |
| F12 | Urban runoff | Surface runoff of rainwater created by impervious surfaces (roofs, roads, sidewalks etc) and poor urban drainage systems. | The urbanized area covers the downstream part of Pedieos RB |
| F13 | Floods | Flooding from the Pedieos river | Major challenge in the downstream area of Pedieos RB |

**Table I.2: Relationships in the Pedieos cognitive map, showing the effect of the factor named in the top row on all other factors in the column below.**

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|  | **F1. TempIncr** | **F2. PrcpDecr** | **F3. Prcp\_Ext** | **F4. ForestEco** | **F5. DamEco** | **F6. RiverEco** | **F7. Rainfed** | **F8. Irrigated** | **F9. Livestock** | **F10. CommWD** | **F11. GroundW** | **F12. UrbanRof** | **F13. Flood** |
| **F1. TempIncr** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F2. PrcpDecr** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F3. Prcp\_Ext** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F4. ForestEco** | -0.2 | -0.5 | -0.2 | 0 | 0.2 | 0 | 0 | 0 | -0.2 | 0 | 0 | 0 | 0 |
| **F5. DamEco** | -0.2 | -0.5 | -0.2 | 0.5 | 0 | 0 | 0 | 0 | -0.2 | -0.2 | 0 | 0 | 0 |
| **F6. RiverEco** | -0.2 | -0.5 | -0.2 | 0 | -0.5 | 0 | 0 | -0.2 | -0.2 | 0 | 0 | -0.2 | -0.2 |
| **F7. Rainfed** | -0.5 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F8. Irrigated** | -0.2 | -0.2 | -0.5 | 0 | -0.2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **F9. Livestock** | -0.5 | 0 | 0 | 0.2 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0.2 | 0 | 0 |
| **F10. CommWD** | 0.5 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F11. GroundW** | 0 | -0.5 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | -1 | -0.2 | -0.5 | 0 | 0 | 0 |
| **F12. UrbanRof** | 0 | -0.2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **F13. Flood** | 0 | 0 | 1 | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | 0 | 0 | 0 | 1 | 0 |

Notes:

*0: indicates no effect, -0.2 indicates a small negative effect, 0.2 indicates a small positive effect, -0.5 indicates a medium negative effect, 0.5 indicates a medium positive effect; -1: indicates a strong negative effect; +1: indicates a strong positive effect.*