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# Nutrient budget of a temporary river in Cyprus

Ourania A. Tzoraki, PhD

David M Cooper, Ph.D.

Gerald Dörflinger

Panos Panagos

University of Aegean

Lesvos, Greece

# 1. Introduction

The sustainability of aquatic and terrestrial ecosystems is threatened by pressures due to population increase, land use change and the irreversible effects of Climate Change (CC). Particularly in semiarid areas where there is heavy and conflicting demand for water, water stress is a key issue for sustainable development. Water scarcity is addressed through the reservoir construction as a common solution to the pressure from river and groundwater abstraction (Mimikou, Baltas et al. 2000; Krol, de Vries et al. 2011). Reservoirs provide water for human supply, irrigation, industrial water needs, fishing and recreational purposes. Nevertheless they may also generate water quality problems. Cyanotoxins released by cyanobacteria (CB) blooms in freshwater reservoirs have long been a serious problem, affecting a variety of organisms including humans. High nutrient fluxes into freshwater lakes and reservoirs stimulate cyanobacteria (CB) in suitable weather conditions. Although nutrient loadings have changed in recent decades due to improvements in wastewater treatment and the efficiency of fertilizer usage, excessive N and P loads still pose a serious threat to the freshwater environment. Nutrient runoff from intensively cultivated areas, forest burning, industrial and municipal sewage effluents have been identified in several studies as a cause of deterioration in water quality (Perrin and Tournoud 2009) and ecology (Smil 2001; Camargo and Alonso 2006) and increased input loads to lakes and reservoirs. Even waters classified as mesotrophic or oligotrophic, with a Redfield ratio of 16N:1P, can be considered as eutrophic based on the dominance of CBs (Galvão, Reis et al. 2008) and many recent blooms are attributed to increasing nutrient concentrations (Winter, Desellas et al. 2011).

Once a eutrophication risk by anthropogenic nutrient enrichment has been identified, management strategies should consider the long-term control of the relationship between nutrient loading and freshwater runoff, which regulates nutrient delivery and residence time (Grizzetti, Bouraoui et al. 2008). For reservoirs fed by intermittent flow there may be periods when there is a complete absence of freshwater input, but the presence of point sources continues to influence water quality. A river is characterized as intermittent (or temporary) if it ceases to flow every year or at least twice every five years ((Tzoraki and Nikolaidis 2007). Such rivers drain large areas not only in the Mediterranean region but also in other arid and semi-arid areas covering approximately a third of the world's surface (Thornes, 1977). The extent of temporary rivers is increasing, as many formerly perennial rivers are becoming temporary because of increasing water demand, particularly for irrigation (Tzoraki and Nikolaidis 2007)(Tzoraki and Nikolaidis, 2007). The nature of the nutrient budget for temporary rivers differs from that for permanent rivers because of the restricted nature of flow, the lack of adequate dilution, and weather conditions which are conducive to the development of algal blooms. We analyse the nutrient budget of three tributaries of a temporary river in Cyprus, the Kouris, with the aid of the MONERIS model

The MONERIS model (MOdelling Nutrient Emissions in River Systems; (Venohr, Hirt et al. 2011)) has been extensively used to estimate river nutrients losses in many parts of the world. The model is relatively simple, while producing acceptable results in comparison to other models such as SWAT (Arnold, Srinivasan et al. 1998)(Arnold et al., 1998) or HSPF (Bicknell, Imhoff et al. 2001) which require data with high spatial resolution and temporal frequency. MONERIS has been applied to numerous European rivers including the Weser (Hirt, Venohr et al. 2008; Hirt, Kreins et al. 2012), Oder and Vistula (Kowalkowski, Pastuszak et al. 2012), Axios in Greece

(Nikolaidis, Karageorgis et al. 2009), alpine catchments (Zessner, Kovacs et al. 2011), rivers in Portugal (Caille, Riera et al. 2012).

While MONERIS is widely used in temperate latitudes, applications in intermittent flow rural catchments are limited. We modify MONERIS for application in semi-arid regions, notably to account for the runoff dynamics of intermittent flow rivers. In-stream nutrient retention is estimated using a 1-dimensional advection - dispersion model rather than the general mass balance equation for mixed reactors. Metrics for characterizing the aquatic regime of intermittent rivers were selected to establish the limits of MONERIS application in intermittent river environments.

## 2. Study area

The Kouris catchment (360 km$^2$) is mountainous with elevation ranging from sea level to 2000m. Some 63% is covered by forest and other natural land cover, 1% is surface water bodies, 31% is agriculture and 5% is urban and similar developed land use. The geology of the catchment consists of an ophiolite complex in the north and an overlying sedimentary complex in the south (Boronina, Balderer et al. 2005; Ragab and Bromley 2010)(Ragab et al., 2010, Boronina et al., 2005). The main crops are deciduous trees (631ha), vines (118ha), citrus (36ha) and olives (49ha), with small areas of potatoes (7ha) and vegetables (12ha). The main water-using crop in the catchment are deciduous trees (4.34 Mm$^3$ per year); the remaining crops use comparatively small amounts of water, taking the total water demand to 5.1 Mm$^3$ per year (Medis 2005).

There are 11 precipitation stations in the catchment (Fig. 1) with an estimated mean annual precipitation of 650mm (1997-2009). Evapotranspiration accounts for around 85% of the precipitation (555mm). The surface runoff is around 50mm and infiltration to groundwater 50mm (7.5%). The PCM Index, (Predictability(P)-Constancy(C)-

Contingency(M)) can be used to indicate the ecosystem's characterization in terms of intermittency (Colwell 1974). The analysis of monthly precipitation records of the eleven stations revealed that the PCM Index ranges between 0.40-0.63 indicating a precipitation pattern with moderate seasonal variability. Monthly precipitation records of Kouris station for the period 1997-2009 were used to estimate the Standardised Precipitation Index (SPI) (Tsakiris and Vangelis 2004). The states of the meteorological drought according to the SPI value range from extremely wet to extremely dry, dominated by mild drought (40.1% probability) and mild wet (31.3% probability) conditions.

We analyse data for three main headwaters in the catchment, the Kouris itself (100km$^2$), and two tributaries, the Kryos (67km$^2$) and Limnatis (120km$^2$), all flowing into the Kouris reservoir (Figure 1). The Kouris delta is located in the Akrotiri peninsula, the southernmost part of Cyprus and forms the west boundary of the Akrotiri wetland. The construction of the dam has directly altered the flow regime in the river and consequently reduced the natural recharge of the delta aquifer and the indirect recharge of the Akrotiri wetland.

## 2.1 Catchment hydrological status

The Kouris , Limnatis and Kryos have a total mean outflow of 31.7 Mm$^3$yr$^{-1}$ (1966-2009). The respective contributions are 14.0 Mm$^3$yr$^{-1}$ (1966-2009), 12.8 Mm$^3$yr$^{-1}$ (1966-2009) and 4.9 Mm$^3$yr$^{-1}$ (1977-1997) with corresponding coefficients of variation of annual flows of 0.6, 0.8 and 0.9. indicating the differences in inter-annual flow variability between the three streams. In post dam period river outflow decreased to 3.8 Mm$^3$ annually (mean value of 1990-2008 hydrologic years) (Nikolaidis 2010).

Baseflow has been separated from daily stream flow time-series using the SWAT (Soil and Water Assessment Tool) baseflow filter program (Arnold and Allen 1999) which uses a modification of the recession curve displacement method. The average fraction of “quick flow” contributed by each rainfall event to the reaches estimated to be 30% is in agreement with previous hydrological studies in the area that have estimated a baseflow ratio about 25-31% (Boronina, Renard et al. 2003; Boronina, Balderer et al. 2005).

An analysis of the streamflow data of the three tributaries using the IHA software, which is described in a number of papers by Richter et al. (1998), allows differentiation between their respective hydrological regimes. Near their inflow to the Kouris Reservoir, the Kouris, Limnatis and Kryos rivers have a median number of days with no flow of 29 (1986-2009), 124 (1986-2007) and 159 (1985-1997) respectively. This demonstrates that the Kouris river is almost permanent, while the Limnatis shows an intermittent flow regime with a dry period of about 3 months and the Kryos is also an intermittent stream but with a prolonged dry period of about 5 months. In addition the Kryos stream hydrograph has higher peak flow values, indicating higher flood risk and higher erosion and sediment transport potential. The mean annual maximum flow of the Kryos is 4.2 $m^3sec^{-1}$ with a standard deviation of 3.8 $m^3sec^{-1}$ (mean value of 1976-1993 hydrologic years maximum instant flow) but the mean annual flow is only 0.473 $m^3sec^{-1}$.

## 2.2 Basin hydrological classification

Various hydrologic metrics have been reported in order to classify temporary stream regimes, based on the distribution of lengths of dry period. The values of the Richards–Baker flashiness index (Baker et al., 2004) are estimated as 0.21 (1986-2009), 0.25 (1986-2007) and 0.34 (1985-1997) for the Kouris, Limnatis and Kryos rivers near their inflow to the Kouris reservoir, indicating that flashiness increases with the length of the dry period. A different classification is suggested by Uys and O’Keeffe (1997) and Gallart et al. (2012) who define three main conceptual types of temporary streams

(1) P (permanent): perennial streams

(2) IP (intermittent – pools): in the dry season the flow is discontinuous with characteristic formation of pools along the river bed.

(3) ID (Intermittent): streams usually having a dry river bed in summer;

(4) E (Ephemeral): streams which flow only during rain events.

The P the IP stream types are recharged continuously during the whole year by baseflow while for ID type rivers the baseflow component ceases during dry months. For the E stream type baseflow is almost absent for the whole year. One index for characterizing the seasonality of the dry conditions in a stream is the six-month seasonal predictability of dry periods ($Sd_6$) defined in Eq. (1). This index has been used to establish threshold lines between the various aquatic states. The equation for seasonal predictability (Gallart, Prat et al. 2012) is:

$$Sd_6 = 1 - \left( \sum_1^6 Fd_i \Big/ \sum_1^6 Fd_j \right) \qquad (1)$$

where:

$Sd_6$ = seasonal predictability

$Fd_i$ = multi-annual frequencies of 6 contiguous wetter months with zero flow

$Fd_j$ = multi-annual frequencies of the remaining 6 contiguous drier months with 0–flow.

The $Sd_6$ index uses the probability that the stream falls dry for each month and divides the average of six months by the average of the following six months. This is performed for all sets of consecutive months. The index $Sd_6$ is dimensionless and takes the value of 0 when zero flows occur equally throughout the year in the long run and 1 when all the zero flows occur in the same 6-month period every year. When the regime is fully permanent, this metric cannot be computed, so the value of 1 is set to indicate full predictability. The flow occurrence index, $M_f$, takes values from 0 up to 1, calculated as the proportion of time the stream is flowing and may be used as an indicator describing the extent of complete drying. The seasonality and flow occurrence indexes are may be plotted on a single graph, called a Temporal Stream Regime Plot (TSR). In the TSR the four river regime types are differentiated as described by Gallart *et al*. (2012). The regime of a stream is determined by searching the coordinates of the two metrics in the TSR plot (Plot of $M_f$ and $Sd_6$, as shown in Figure 2).

Flow in the Kouris tributaries was examined for a historic period of 1965-1985 and recent years (2006-2012). The historic period hydrologic regime is assumed to be the Reference Condition regime (RC). In this period the Limnatis, Kryos and Kouris flowed for 9.7, 8.6 and 11.6 months per year respectively. The corresponding values for 2008-2012 are 8.5, 5.9 and 9.5 month per year. These values suggest a decrease in the $M_f$ index on three tributaries in recent years. The $SD_6$ is estimated 0.96, 0.84 and 1.0 for the Limnatis, Kryos and Kouris respectively for the historic period and 1.0, 0.91 and 1.0 for 2008-2012. The difference between Kryos historic and recent $SD_6$ values strengthens the hypothesis that the Kryos tributary has experienced the greatest regime shift of the three streams. The TSR plot for the Kouris tributaries indicates that the Kryos stream is classified as I-D and the Limnatis and Kouris as I-P (Fig. 2). It is important to keep in mind that these streamflow characteristics refer to the river reaches just upstream of the Kouris Reservoir, while all three rivers have continuous flow in their upper and upper-middle reaches. The boundaries between perennial and intermittent reaches move every year depending on rainfall and subsequent streamflow (Uys and O'Keeffe 1997).

## 2.3 Catchment nutrient budget

We estimate the nutrient load to the three tributaries, and the subsequent fate of these nutrients. We use the MONERIS model as an aid to understanding the budget. MONERIS considers nutrient losses through seven different pathways from six different sources, and also identifies tsuitable nutrient management options. Downstream nutrient loads are computed as the difference between catchment losses (ie inputs to the river) and changes due to in-stream retention processes. Nutrient retention is modeled as a function of specific runoff (discharge divided by catchment area) or hydraulic load (specific runoff divided by water surface area) based on the assumption of steady state solution of the general mass balance equation for mixed reactors. Nutrient retention, especially in temporary environments is strongly affected by in-stream transport phenomena (Von Schiller, Martí et al. 2008). We have modified the in-stream retention component of MONERIS to allow for advection and dispersion.

In a one dimensional (1D) river model such as MONERIS, there is assumed to be complete mixing in the vertical and lateral (width) directions. Nutrient concentration is a function of the rate of input and output of the constituents (sources and sinks), the dispersion and advection of the constituents and a range of in-stream physical, chemical, biological reaction rates. Change in concentration of any constituent under the assumption of 1-dimensional flow is defined by the partial differential equation

$$\frac{\partial C_{x,t}}{\partial t} = \frac{1}{A}\frac{\partial}{\partial x}\left( EA\frac{\partial C_{x,t}}{\partial x} - UAC_{x,t} \pm \sum_{k} S_{k} \right) \tag{2}$$

In equation 2 $C_{x,t}$ is the nutrient concentration mg $L^{-1}$, at time t and location x. E is the dispersion coefficient ($m^2sec^{-1}$), U is velocity (m $sec^{-1}$), A is the stream cross sectional area ($m^2$) and $S_k$ is a source or sink of the nutrient. Equation 2 states that at particular site in the river system, the change in concentration with respect to time depends on the change in the constituent flux due to advection and dispersion, plus or minus any sources. The source/sink term includes the various reactions that increase or decrease the concentration of a constituent. The flux due to dispersion is assumed to be proportional to the concentration gradient, allowing constituents to be transferred from zones of higher concentration to zones of lower. Dispersion is assumed to be responsible for any change of concentration that cannot be accounted for by advective transport. Many of the reactions affecting decrease or increase of the constituent concentrations are often represented by first order kinetics, often acceptable in natural aquatic systems. For steady-state conditions in reaches treated as one dimensional, assuming constant streamflow, cross sectional area, a constant dispersion coefficient and first order kinetics equation 2 becomes

$$\frac{\partial C_{x,t}}{\partial t} = E\frac{\partial^2 C_{x,t}}{\partial x^2} - U\frac{\partial C_{x,t}}{\partial x} - KC_{x,t} \tag{3}$$

where $K$ is a reaction or decay rate coefficient ($day^{-1}$). For nitrogen decay $K$ is symbolized as $K_{TN}$ and for phosphorus $K_{TP}$. This steady-state equation may apply to many flow conditions in river systems, including low-flow conditions often found in late summer in temperate environments or late spring in semi-arid. Considering long sections of the river where $K$, $E$, $A$ and $U$ are constant, the pollutant concentration at any point X resulting from a discharge of the constituent at a constant rate $W_0$ the point X=0 is

$$C_x = \frac{W_0}{Q_m} \exp\left( \frac{U}{2E}(1-m)x \right) \quad x > 0 \tag{4}$$

where $m = \sqrt{1 + \frac{4KE}{U^2}}$ . Equation 4 assumes that there are no sources or sinks of the constituent, other than the natural decay governed by K and the constant discharge at x=0. In freshwater rivers, the dispersion coefficient E is often small and, after taking a Taylor series expansion of m, we can approximate as

$$C_x = \frac{W_0}{Q} \exp\left( -\frac{Kx}{U} \right) \tag{5}$$

Equations 4 and 5 may be used as the basis for the 1D steady-state nitrogen and phosphorus water quality retention model for a river. In the MONERIS model it is assumed that $W_0$ is the input load in surface water. The velocity U is estimated based on field measurements or using the Manning equation. If flow (Q) measurements are available then $U = A / Q$.

## 3 MONERIS application with retention component

In MONERIS, nutrient loads are estimated in each of the three streams entering the Kouris reservoir. Water samples have been collected monthly since October 2007 and analysed for twelve water quality variables. Three stations (one in each stream) were selected for monthly measurement of Total Nitrogen (TN), Dissolved Inorganic Nitrogen (DIN), Total Phosphorous (TP) and Dissolved Inorganic Phosphorus (DIP) concentrations. Nutrient loads were estimated as the product of mean monthly concentration and instantaneous flow. We have calibrated MONERIS for the period

2008-2010 and validated the model for 2011-2012. Model performance was evaluated by the Nash-Sutcliffe efficiency (NSE)(Nash and Sutcliffe 1970).

### 3.1 Spatial data

A Digital Elevation Model (DEM) (30m spatial resolution) was used to estimate the mean sub-basin slope, required for erosion estimation in MONERIS. The land use types present in the study area were extracted from the Corine Land Cover map (2006). The hydrogeology of the subcatchments is defined within MONERIS as four classes according to porosity and depth of groundwater. The hydrogeology of the catchment was based on the transmissivity classification of Boronina et al. (2003) which distinguishes five zones: Zone 1-mantle rocks Zone 2- plutonic and intrusive rocks; Zone 3 – volcanogenic rocks; Zone 4 – sedimentary rocks The thickness of the main aquifers was assessed indirectly from geological observations. For MONERIS, zones 1 and 2 were characterized as bedrock, consolidated of high porosity, zones 3 and 4 as bedrock consolidated impermeable and zone 5 as unconsolidated soil with a shallow groundwater. The topsoil classification in the study area was derived from a soil survey by the EC Joint Research Centre (JRC) in the Kouris basin. Kryos soils are characterized as clay loam soils, Kouris and Limnatis as sandy loam. The nitrogen content in topsoils was lower than 10 mg kg$^{-1}$ and the percentage content was estimated to be 0.12% in Kryos and Kouris soils and 0.08% in Limnatis.

### 3.2 Diffuse pollution

In estimating the diffuse pollution load, the recommended fertilizer application rates provided by the Cyprus Ministry of Agriculture were applied for the estimation of the nutrient load from agriculture. These rates were estimated as 90 tonne yr$^{-1}$ N and

20 tonne yr$^{-1}$ P. The annual fertilizer application divided by the agricultural area was gave N and P application rates of 107 kg ha$^{-1}$ and 22.0 kg ha$^{-1}$ respectively. An average nitrogen surplus of agricultural soils of 40 kg N ha$^{-1}$yr$^{-1}$ is estimated at European scale when the nitrogen application rate ranges between 8-179 kg ha$^{-1}$(Grizzetti, Bouraoui et al. 2008; Bouraoui, Grizzetti et al. 2009). Since the Kouris basin application rate falls close to the middle of this range the nitrogen surplus value of 40 kg N ha$^{-1}$yr$^{-1}$ was used for MONERIS simulations. With an input rate of 22.0 kg P ha$^{-1}$yr$^{-1}$ and an export coefficient of 4% (Matias and Johnes 2012), then the P surplus in agricultural soils amounts to 0.88 kg P ha$^{-1}$yr$^{-1}$.

Bouraoui *et al.*(2009) estimate an atmospheric deposition rate of 3.7 kg N ha$^{-1}$yr$^{-1}$ for Cyprus. Total phosphorus deposition was set similar to other Mediterranean countries equal to 0.99kg P ha$^{-1}$yr$^{-1}$. The summer rainfall amount was estimated to be 19% of the total by the analysis of the 11 precipitation stations records (1997-2009).

In addition to fertilizer application, a major source of nutrient pollution is livestock farming. There are some 200 pigs, 4,600 sheep and 28,000 goats in the total area of the three subcatchments (WDD, 2011). The livestock annual nutrient production rates (kg P and N ha$^{-1}$yr$^{-1}$) were estimated with reference to the native livestock breed characteristics such as animal weight (OECD 2007). Livestock production contributed 490 tonne N y$^{-1}$ and 147 tonne P y$^{-1}$. Based on local information it was assumed that goats and sheep are grazed outside all the year on the upland fallow/pasture/rangeland areas resulting in N and P input rates of 47.3 and 14.3 kg ha$^{-1}$yr$^{-1}$ respectively. For a soil pH of 8.1, a median value of denitrification rate can estimated as 5 kg ha$^{-1}$ yr$^{-1}$ for grassland areas (Hofstra and Bouwman 2005), giving a final N loss rate of 42 kg ha$^{-1}$yr$^{-1}$. The export coefficient of 0.007% for grasslands soils (Matias and Johnes 2012) was used for P, giving a final P loss rate of 0.016 kg ha$^{-1}$yr$^{-1}$.

### 3.3 Point source pollution

Point source pollution in the subcatchments is mainly generated by olive oil mills and in some cases by malfunctions of domestic wastewater treatment plans. In the basin there are 486 acres of olive trees. Assuming semi-intensive agricultural practices that corresponds to 12 trees per acre and 375 kg of olive fruits per acre (Fleskens and Graaf, 2010), the olive oil mill wastewater volume generated annually corresponds to 0.3 tonne N $yr^{-1}$ and 0.2 tonne P $yr^{-1}$ (Nikolaidis, 2011). The olive mill waste (OMW) emissions are assumed to be discharged without any pretreatment directly to the river.

The permanent population in the basin is 20,442 people (Statistical Service, 2012) and only 8,487 are served by waste water treatment plans (WWP). In the Limnatis subcatchment there are waste water treatment plants (WWTPs) at the villages of Alassa, Pelentri and Kyperounta (5320 persons). These have discharged secondary treated effluent into the river since 2011. The reclaimed wastewater has a mean concentration of total nitrogen of 15 mg $L^{-1}$ and phosphorus of 1.37 mg $L^{-1}$ resulting in annual total discharges of 6.97 tonne $yr^{-1}$ and 0.64 tonne $yr^{-1}$ of N and P respectively. The remainder of the population (11,955) is served by individual septic tanks. In order to estimate the nutrients load generated by septic tanks, the human production rates of N and P for Cyprus were estimated as 13.7 g N $person^{-1}day^{-1}$ and 2.9 g P $person^{-1}day^{-1}$(Bouraoui, Grizzetti et al. 2009). It is assumed that only 5% of P and 7% of N reaches the river, thus the diffuse sources exports into the river were estimated to be 1.1 tonne P $yr^{-1}$ and 75.3 tonne $yr^{-1}$N.

The urban runoff generation component of MONERIS model uses an equation that relates the monthly precipitation depth to the number of generated rain events. This equation was estimated for the Kouris basin for the period 1991-2005, using the number of events exceeding 10mm of rain. The derived equation is

$$N_{RE} = 0.039 N_j^{0.93} \tag{6}$$

where $N_{RE}$ is the number of rain events and $N_j$ is the monthly precipitation record. The urban runoff total phosphorus concentration was set to 0.275 mgL$^{-1}$ based on studies in the Harper basin (Waschbusch;, Selbig; et al. 1999).

## 4. Results

### 4.1 MONERIS calibration and validation

The MONERIS model was calibrated for the period 2008-10 and verified for 2011-2012. Table 1 shows the data used in the model simulation and the estimated nutrients loads for goodness of fit analysis. The MONERIS model was calibrated to account for in-stream nutrient retention of total N and P (TN and TP). The velocity was derived for each stream by the equations that relate mean instantaneous flow to mean velocity. The exponent coefficient *K* of equation 4 was calibrated for TN retention (0.98-2.3 days$^{-1}$). The NSE value between modelled and simulated loads for the calibration period was 0.97. In the validation process the NSE value was estimated as 0.53 for 2011 and 0.4 for 2012. The lower NSE value of the 2012 verification year may be explained by the fact that 2012 is an “extreme wet” year and annual TN loads were estimated to be 50.15 tonne in the Limnatis in comparison to 5.5 ton of the previous year.  Figure 3 shows the observed (black bars) against modelled TN loads (grey bars) for the calibration and verification periods on the left figure and TP loads on the right figure. For TP retention the coefficient *K* was calibrated (4.0-9.0 days$^{-1}$) to achieve NSE value of 0.99. In the validation process the NSE value was estimated as 0.99 for 2011-2012 period. The model fit to interannual variation in the three subcatchments showed good overall agreement between model and observed loads. But interannual catchment hydrology variability in Cyprus and in general in semi-arid climates affects MONERIS model efficiency.

The total annual nutrient losses from the three rivers are 46.5 tonnes of nitrogen, 1.8 tonnes of phosphorus (Table 2). Pollution generated by WWTP and individuals septic tanks generates most nutrient loss (Table 2) (64.7% of total N, 43.9% of total P). Erosion processes appear to be a serious environmental threat, since significant amounts of nitrogen (15.2%) and phosphorus (0.7%) are subject to detachment and transportation. Erosion processes are promoted by steep slopes, scarce vegetation and dry mobilisable soils. Groundwater is estimated to contribute 1.8 tonne of N (3.8%) and 0.29 tonne of P (8.4%). The Kouris subcatchment has the highest domestic wastewater loads, since it does not include a WWP. Grazing is a serious environmental pressure (the origin of 11.8% of N and 16.4% of P) especially in the Kouris catchment. Losses of P by groundwater and from urban sources are significant in the Kouris subcatchment and in the Limnatis atmospheric deposition and urban sources generate the highest P loads.

We estimate that around 40% of N and 85% of P entering streams is retained in the stream. Nitrogen retention is similar to the study of Caille et al. (2012) that estimated N and P retention of the order of 45-55%. The high P retention of Kouris sediments (85%) is explained by their high phosphorus sorption capacity (Tzoraki et al., 2012). Although the soil TP content in the Kouris catchment is lower than 10, the TP content of the sediment was measured to be 3432 mgkg$^{-1}$ (±169.7 mgkg$^{-1}$) (Tzoraki, Dörflinger et al. 2012).

### 4.2 MONERIS sensitivity analysis

Sensitivity analysis provides information on the relative influence of different model inputs or parameters on model outputs. Sensitivity is expressed by a dimensionless index I, which is calculated as the ratio between the relative change of model output and the relative change of a parameter (±10% change). We used sensitivity analysis of the MONERIS model parameters to identify the parameters to which the simulation results are most sensitive. A detailed description of MONERIS equations can be found in Venohr et al. (2011). Concerning nitrogen simulation the most sensitive parameter was the coefficient ($a_n$) of the erosion equation. A second group of parameters with similar significance were coefficients of surface runoff (a and b) and k1 and k2 coefficients in groundwater for consolidate bedrock of high porosity and k1 and k2 coefficients in groundwater for consolidated impermeable bedrock. Phosphorus simulation was most sensitive to the coefficient (a) in clay-P model of phosphorus surplus and less sensitive the coefficients ($a_P$ and b) in the erosion equation. Finally the coefficient (a) of surface runoff was identified as of similar importance for phosphorus losses.

The N and P retention equation 5 is strongly dependent on the retention coefficient ($K$) value since the remaining parameters are affected by water velocity and stream length. Performing Monte Carlo analysis for this parameter, the in-stream TN and TP load were estimated for 1000 K random values. Monte Carlo analysis of $K_{TN}$ value (0.98 $d^{-1}$) in Kouris has given a median value of TN in-stream loads 14.40 tonne TN, ranging between 14.17 and 14.65 and a $K_{TP}$ value (4.0 $d^{-1}$) has given a median value of TP in-stream loads of 0.135 tonne TP, ranging between 0.133 and 0.137.

## 5 Discussion

The TN and TP in-stream retention module of the MONERIS model using the transport mechanism approach of dispersion and advection in one dimension can adequately simulate the field data. It considers the stream velocity and constituents transport distance, important variables in intermittent flow rivers. MONERIS gives a general quantification the main pressures at basin scale and is an easy tool for use by catchment managers.

TRP plots are a useful tool for visualizing the major changes of flow pattern due to human intervention or climate change effect. There is no evidence that the flow status of the Limnatis has changed from I-P in recent decades. In contrast, the Kouris has changed from P to I-P and both $Sd_6$ and $M_f$ values are now lower than in the historic period. The river stops flowing for longer periods than in the past. But the greatest change in hydrological pattern has occurred in the Kryos, from I-P type in the past, to I-D, with long periods of dessication.

Because the Limnatis stream shows a permanent hydrologic pattern that has only slightly altered recently, MONERIS appears suitable for estimating nutrient losses. Essential components of the hydrologic cycle including baseflow and surface runoff contribute to flow for most of the year. A weak point in MONERIS efficiency is the effect of the interannual hydrological variability and we suggest the use of TRS plots to estimate any hydrologic alteration from year to year. Where a stream has changed its hydrologic regime and especially if it is moved from P or P-IP to IP-D or E then the MONERIS model should be recalibrated for the new regime conditions.

Since groundwater emissions are very significant we suggest that different calibration parameters should be used in MONERIS for ephemeral (E) and intermittent dry (I-D) streams rather than Permanent (P) and Intermittent Pools (I-P). For I-P steams there is a baseflow component recharging the stream or pools during the summer months. In contrast in the ephemeral streams the river bed dries out completely and there is neither surface flow nor baseflow. In the latter case the groundwater table is very low, the stream loses water and dries out, only sustaining water during rainfall events. For these streams essential components of the MONERIS model such as groundwater, or surface runoff should be calibrated very carefully in order not to overestimate the real hydrologic mass balance.  We suggest that if the hydrologic status classification of a stream (as defined by TRS plot) belongs to P or I-P, its water quality can be adequately simulated using MONERIS, since in-stream retention is strongly related to stream mean velocity and geomorphology. But if a stream belongs to I-D or E regime then a separate calibration procedure should be followed. For those stream regimes due to long dry period of zero flows the average flow actually is the average of the individuals flood events and is overestimated. The baseflow component is almost zero for the majority of the year and the lowering of the river bed enhances the transmission losses, a component that is not accounted for by the MONERIS model. Stream intermittency results in high uncertainty in the hydrological cycle because flow occurs during rainfall events, and the resulting flash floods are characterized by high erosion and nutrient transport capacity (Tzoraki, Nikolaidis et al. 2009), while during much of the year the only flow is from point discharges, which are often the only flow component.

Measures to reduce nutrient losses need to account for the need to maintain agricultural productivity. Unfortunately, the adoption of good agricultural practice is becoming increasingly difficult due to the splitting of the land into numerous small farms. Sustainability objectives in agriculture have to take the form of restrictive management thresholds such as specific fertilization rates, buffer strip establishment, crops rotation, irrigation with reclaimed wastewater (Matias and Johnes 2012). Livestock generates most of the basin nutrient load (Table 2), and livestock production in Kouris upland areas results in land degradation, deforestation and nutrients losses into streams. Even though livestock are extremely important to the livelihoods of Kouris smallholder farmers, the adaptation of modern farming practices such as enclosures or rotational grazing should help significantly in the direction of river sustainability. Also, composting process of animal manure/excreta may produce high additive value bio-fertilizer, which instead of reducing the ecological quality of the water resources, would cover the N, P, K demands of the agricultural sector. Further improvement to water quality is to be expected if villages are connected to the central wastewater treatment plant.

## 6 CONCLUSION

MONERIS is a valuable modeling tool, helping in the monitoring and quantifying nutrients mitigation and to the application of suitable remediation technologies, whenever it is required. The in-stream phosphorus and nitrogen module using the approach of 1-D advection and dispersion transport process can adequately simulate the in-stream processes of such intermittent flow streams. The use of TRS plots is a useful tool to understand the flow regime alteration not only from the unaltered conditions to recent highly changed but also to visualize the stream interannual alteration. The position of a stream in the TRS plot is essential for the calibration procedure to be followed. The Limnatis and Kouris streams showed limited hydrologic alteration the recent years in contrast to the Kryos, where there has been a significant regime shift. In the Kouris subcatchment high N and P losses are attributable to grazing livestock, erosion processes and the absence of wastewater treatment plants. Therefore the in-stream nutrient retention processes are very significant and in particular P sorption onto sediments and the loss of N through denitrification. Potential measures that are suggested are the adaption of modern farming practices and the use of central wastewater treatments plants. Recommended management technologies to reduce both point and non-point source pollution are effective only with the prerequisite of continuous public participation, technologies awareness of stakeholders and economic efficiency of adapted measures.

Table 1. Calibration and verification period Moneris input data

Table 2 Total Emissions and proportion of the different pathways in the streams for the calibration period 2008-2010

Figure 1. Kouris river basin stream network, rain and flow gauge station and main landuses.

Figure 2. TRP of Kouris streams

Figure 3. Modelled (grue bars) versus observed values (black bars) of Total Nitrogen (left figure) and Total Phosphorous (right figure) for the calibration and verification period.

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table 1

| **Calibration period 2008-2010** | | | |
|---|---|---|---|
| | **KRYOS** | **KOURIS** | **LIMNATIS** |
| **Mean Flow m$^3$sec$^{-1}$** | 0.067 | 0.271 | 0.152 |
| **Precipitation, mm** | 509.2 | 575.7 | 528.1 |
| **TN, ton/year** | 2.538 | 13.825 | 9.568 |
| **TP, ton/year** | 0.016 | 0.155 | 0.169 |
| **Verification period 2011** | | | |
| | **KRYOS** | **KOURIS** | **LIMNATIS** |
| **Mean Flow m$^3$sec$^{-1}$** | 0.069 | 0.414 | 0.126 |
| **Precipitation, mm** | 772 | 838 | 791 |
| **TN, ton/year** | 0.478 | 12.940 | 5.531 |
| **TP, ton/year** | 0.006 | 0.022 | 0.031 |
| **Verification period 2012** | | | |
| | **KRYOS** | **KOURIS** | **LIMNATIS** |
| **Mean Flow m$^3$sec$^{-1}$** | 0.203 | 0.783 | 0.537 |
| **Precipitation, mm** | 802 | 868 | 821 |
| **TN, ton/year** | 2.152 | 32.200 | 50.150 |
| **TP, ton/year** | 0.036 | 0.216 | 1.389 |

table 2

| Pathways | Nitrogen Emissions | | | | | Phosphorus Emissions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Kryos | Kouris | Limnatis | [t yr-1] | [%] | Kryos | Kouris | Limnatis | [t yr-1] | [%] |
| Atmospheric Deposition | 0.01 | 0.02 | 0.06 | 0.1 | 0.2 | 0.03 | 0.04 | 0.17 | 0.24 | 13.4 |
| Overland flow-(impact of free grazing) | 0.74 | 3.26 | 1.51 | 5.5 | 11.8 | 0.02 | 0.08 | 0.04 | 0.29 | 16.4 |
| Erosion | 2.24 | 2.67 | 2.17 | 7.1 | 15.2 | 0.05 | 0.04 | 0.06 | 0.01 | 0.7 |
| Groundwater | 0.16 | 1.26 | 0.33 | 1.8 | 3.8 | 0.04 | 0.16 | 0.09 | 0.15 | 8.4 |
| WWTP-SEPTIC TANKS | 5.58 | 12.81 | 11.71 | 30.1 | 64.7 | 0.12 | 0.1 | 0.55 | 0.77 | 43.9 |
| Urban Runoff | 0.34 | 0.53 | 0.85 | 1.7 | 3.7 | 0.02 | 0.03 | 0.06 | 0.2 | 11.3 |
| In-stream Secondary Sources | 0.1 | 0.1 | 0.1 | 0.3 | 0.6 | 0.08 | 0.06 | 0.06 | 0.11 | 5.9 |
| **Total Emissions** | **9.2** | **20.6** | **16.7** | **46.5** | **100** | **0.35** | **0.52** | **1.02** | **1.8** | **100** |
| **Retention** | **6.5** | **5.9** | **6.3** | **18.7** | | **0.33** | **0.38** | **0.85** | **1.56** | |
| **Estimated Load** | **2.7** | **14.7** | **10.4** | **27.8** | | **0.02** | **0.14** | **0.17** | **0.33** | |
| **Observed Load** | **2.6** | **13.8** | **9.6** | **26** | | **0.02** | **0.15** | **0.17** | **0.34** | |

figure 1

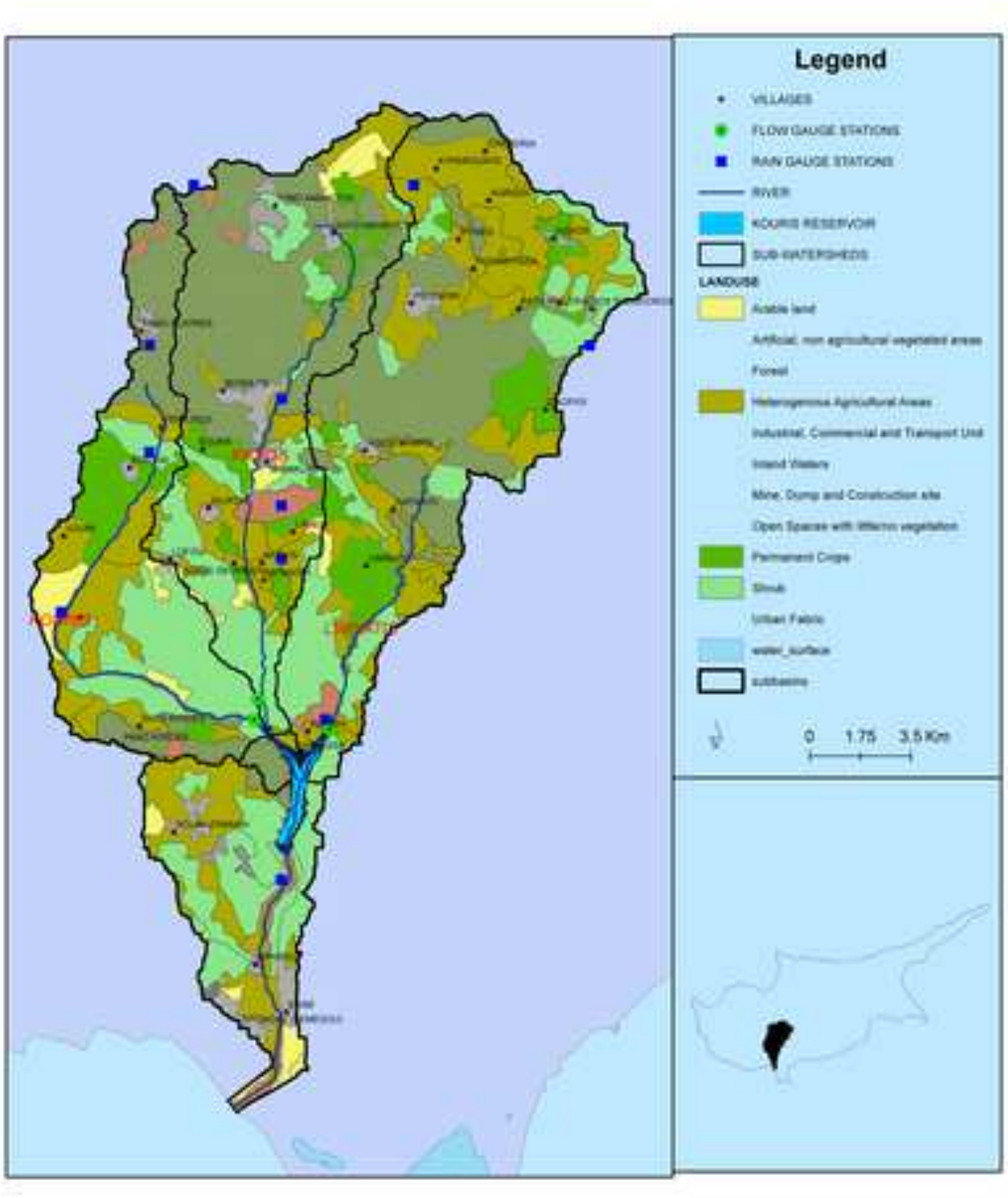
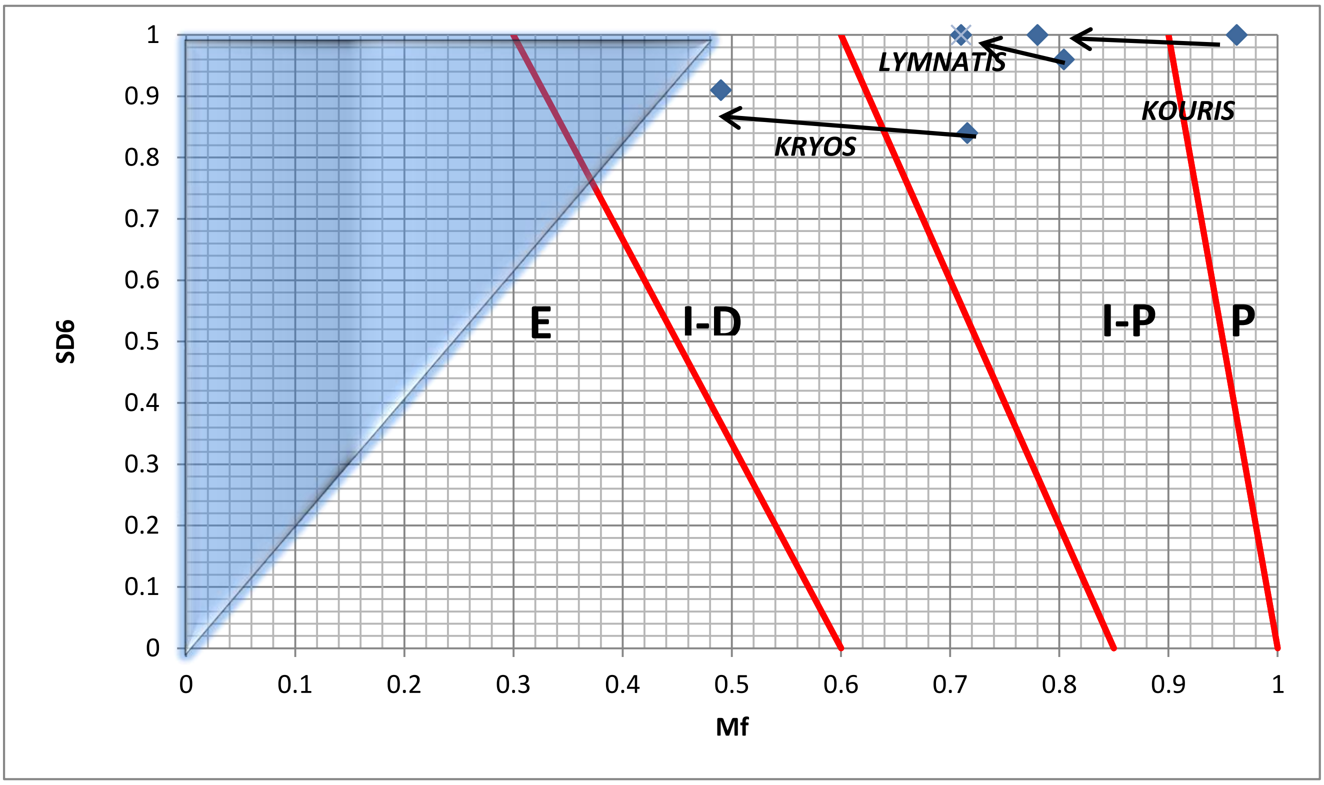

Legend
VILLAGES
FLOW GAUGE STATIONS
RAIN GAUGE STATIONS
RIVER
KOURIS RESERVOIR
SUB-WATERSHEDS
LANDUSE
Arable land
Artificial, non agricultural vegetated areas
Forest
Heterogenous Agricultural Areas
Industrial, Commercial and Transport Unit
Inland Waters
Mine, Dump and Construction site
Open Spaces with little/no vegetation
Permanent Crops
Shrub
Urban Fabric
water_surface
subbasins
0
1.75
3.5 Km

figure 2


1
0.9
0.8
0.7
0.6
0.5
0.4
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0.1
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0
0.1
0.2
0.3
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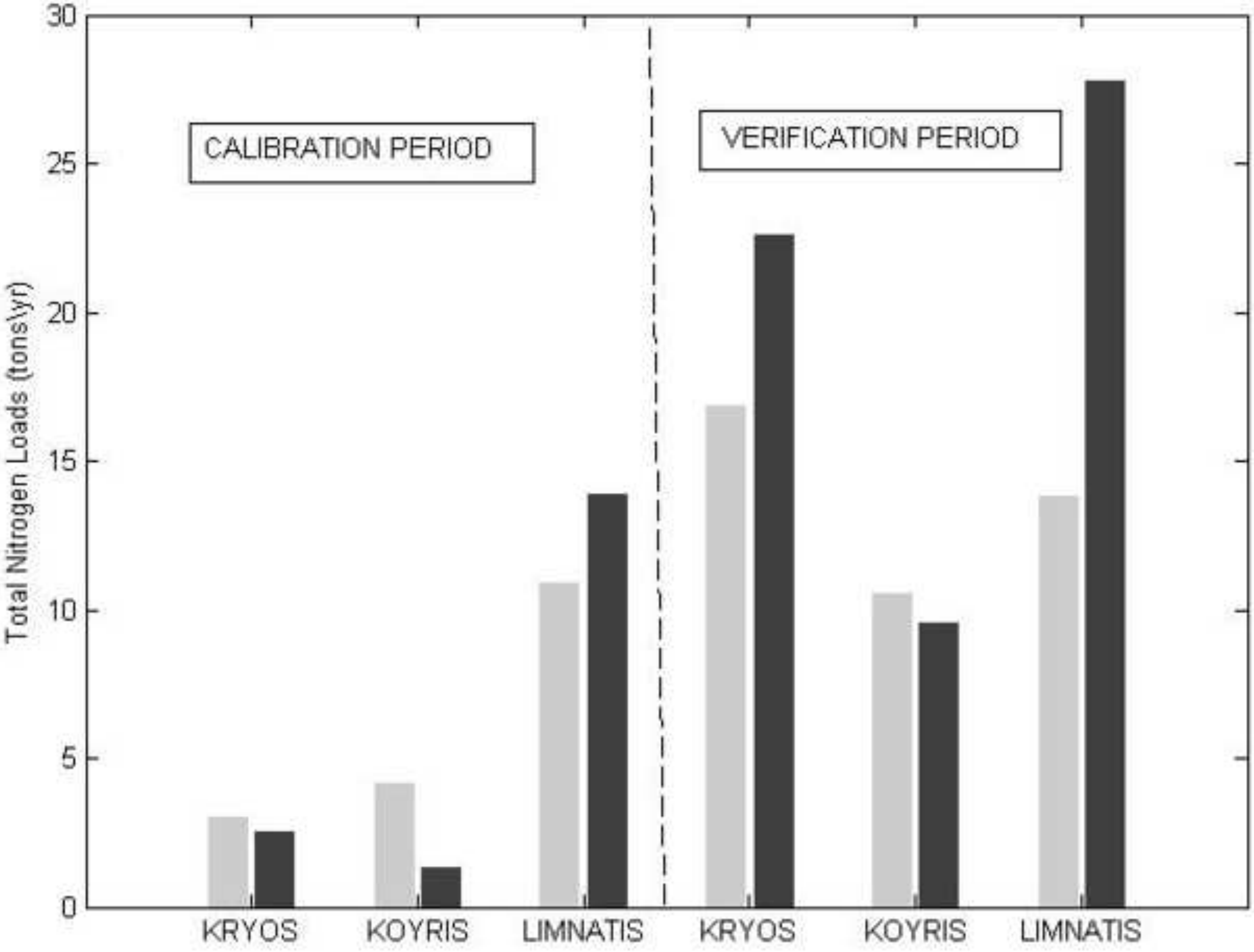
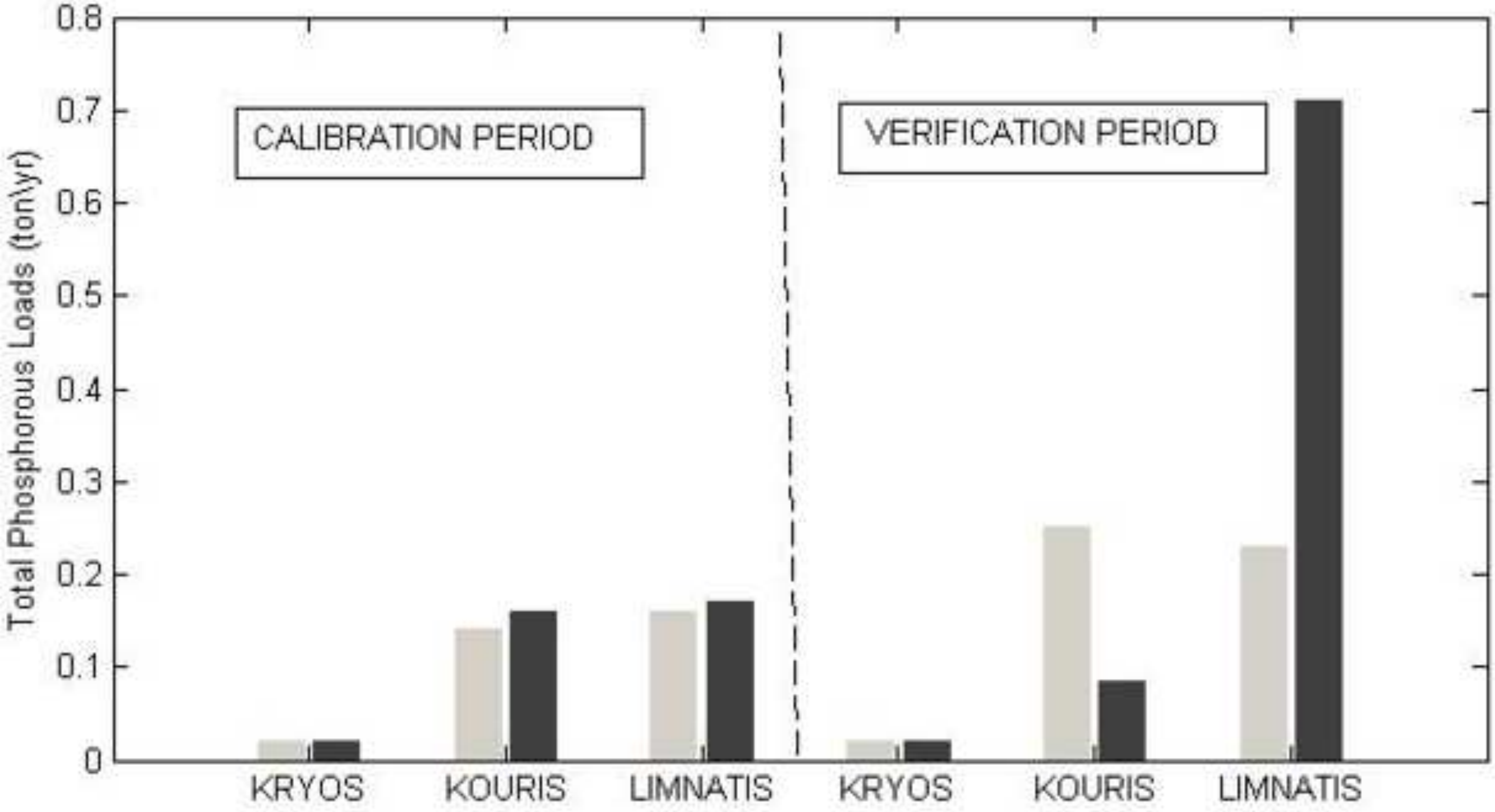
0.5
0.6
0.7
0.8
0.9
1
Mf
LYMNATIS
KOURIS
KRYOS
E
I-D
I-P
P

figure 3A



Total Nitrogen Loads (tons/yr)
30
25
20
15
10
5
0
CALIBRATION PERIOD
VERIFICATION PERIOD
KRYOS
KOYRIS
LIMNATIS
KRYOS
KOYRIS
LIMNATIS

figure 3B


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Total Phosphorous Loads (ton\yr)
CALIBRATION PERIOD
VERIFICATION PERIOD
KRYOS
KOURIS
LIMNATIS
KRYOS
KOURIS
LIMNATIS