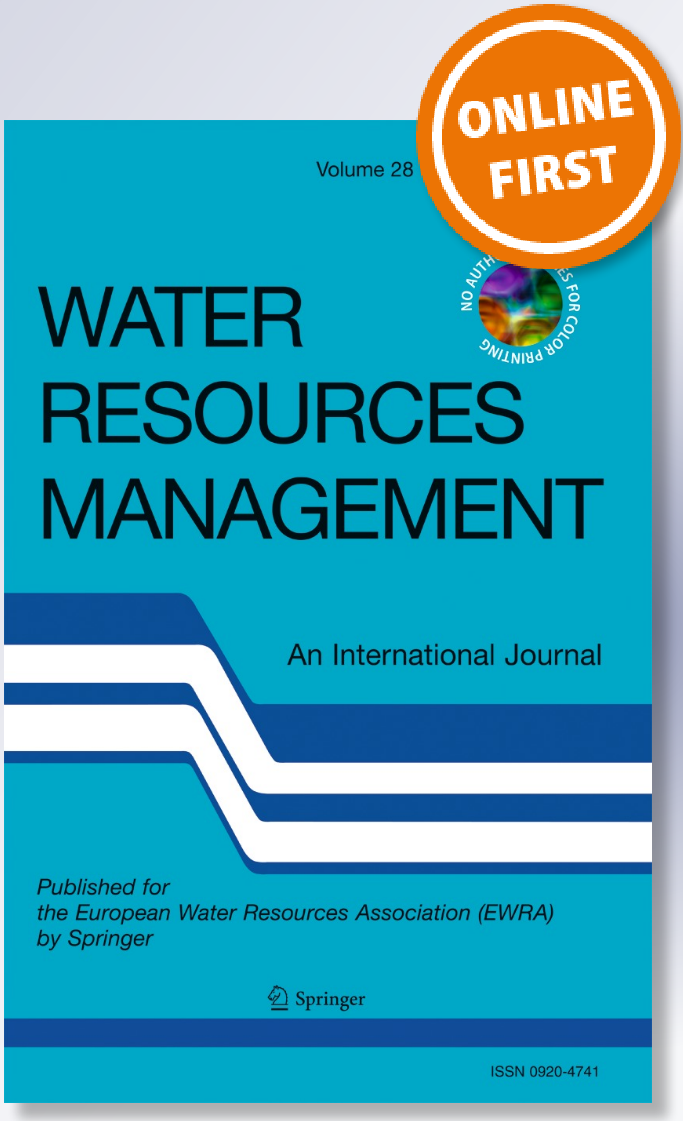
A new MONERIS in-Stream Retention Module to Account Nutrient Budget of a Temporary River in Cyprus

O. Tzoraki, D. Cooper, G. Dörflinger & P. Panagos

Water Resources Management
An International Journal - Published for the European Water Resources Association (EWRA)

ISSN 0920-4741

Water Resour Manage
DOI 10.1007/s11269-014-0646-7



Springer

Your article is protected by copyright and all rights are held exclusively by Springer Science +Business Media Dordrecht. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com”.

Springer

Author's personal copy

Water Resour Manage
DOI 10.1007/s11269-014-0646-7

A new MONERIS in-Stream Retention Module to Account Nutrient Budget of a Temporary River in Cyprus

O. Tzoraki · D. Cooper · G. Dörflinger · P. Panagos

Received: 19 February 2013 / Accepted: 24 April 2014
© Springer Science+Business Media Dordrecht 2014

Abstract 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. MONERIS in-stream retention module was modified to account for a 1-dimensional advection - dispersion pollutants transport rather than the general mass balance equation for mixed reactors. TRS plot classified Kryos stream as an Intermittent flow – Dry (I-D) stream (hydrologically altered) and Kouris and Limnatis as Intermittent – Pool (I-P) streams that need different lumped parameterization in MONERIS simulation. Point sources are important for nitrogen (64 %) and phosphorous emissions (22 %), and diffuse sources for nitrogen via erosion (15 %) and free grazing (12 %) and for phosphorous via free grazing (8 %). We estimate that around 40 % of N and 88 % of P entering streams is retained in the stream. An analysis of the model uncertainty and sensitivity to input data indicates that MONERIS model, even in semi-arid areas, may be used for the purpose of managing river basins.

Keywords Temporary streams · Intermittent flow · Kouris river · MONERIS model · In-stream retention · Cyprus · Loads · Nutrients · Nitrogen · Phosphorous · Hydrologic index

O. Tzoraki (✉)
Marine Sciences Department, University of Aegean, Mytilene, Greece
e-mail: rania.tzoraki@aegean.gr

D. Cooper
Centre for Ecology and Hydrology, ECW Building, Deiniol Rd, Bangor, Gwynedd, UK
e-mail: cooper@ceh.ac.uk

G. Dörflinger
Water Development Department, Ministry of Agriculture, Natural Resources and Environment, Nicosia, Cyprus
e-mail: gdorflinger@wdd.moa.gov.cy

P. Panagos
European Commission, Joint Research Centre, Ispra, Italy
e-mail: panos.panagos@jrc.ec.europa.eu

Published online: 11 May 2014

Author's personal copy

1 Introduction

Intermittent flow rivers (temporary streams) found in California and other Mediterranean climate semi-arid areas (Moyle 2013) are sensitive to climate seasonality resulting in prolonged dry periods interrupted by flash floods. Intermittent (or temporary) rivers cease to flow every year or at least twice every 5 years (Tzoraki and Nikolaidis 2007). Such rivers drain large arid and semi-arid areas covering approximately a third of the world's surface. The extent of temporary rivers is increasing, as many formerly perennial rivers are becoming temporary because of increasing water demand, particularly for irrigation (De Girolamo, Calabrese et al. 2012). The combination of dry crusted soils and high intensity and erosivity of the rain cause sediment resuspension and transport to coastal areas (Tzoraki, Nikolaidis et al. 2009). These areas among the aquatic habitats most altered by human activities (Moyle 2013). During the summer even when there is no flow point sources are still active releasing wastewater effluents (Perrin and Tournoud 2009; Chahinian, Bancon-Montigny et al. 2013) resulting in nutrients and organic pollutant accumulation in bed sediments. Sediment operates as a pollution inventory and pollutants are moved successively downstream from pool to pool during flush events (Bernal, von Schiller et al. 2013). The vulnerability of intermittent rivers is intensified by the conflict between water use demand and aquatic ecosystem conservation (Webb, Nichols et al. 2012).

High nutrient fluxes into streams 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. 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). 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.

Author's personal copy

2 Study Area

The Kouris catchment (360 km^2) is mountainous with elevation ranging from sea level to 2,000 m. 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). The main vegetation cover are deciduous trees (631 ha), vines (118 ha), citrus (36 ha) and olives (49 ha), with small areas of potatoes (7 ha) and vegetables (12 ha). The main water-using vegetation cover 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 650 mm (1997–2009). Evapotranspiration accounts for around 85 % of the precipitation (555 mm). The surface runoff is around 50 mm and infiltration to groundwater 50 mm (7.5 %). We analyse data for three main headwaters in the catchment, the Kouris itself (100 km^2), and two tributaries, the Kryos (67 km^2) and Limnatis (120 km^2), all flowing into the Kouris reservoir (Fig. 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. The Kouris, Limnatis and Kryos have a total mean outflow of 31.7 $Mm^3 years^{-1}$ (1966–2009). The respective contributions are 14.0 $Mm^3 years^{-1}$ (1966–2009), 12.8 $Mm^3 years^{-1}$ (1966–2009) and 4.9 $Mm^3 years^{-1}$ (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 (after 1989) river outflow decreased to 3.8 Mm^3 annually (mean value of 1990–2008 hydrologic years) (Nikolaidis 2010).

2.1 Hydrological Classification

2.1.1 Intermittency Based on Precipitation Pattern

We used various indices to characterize the seasonality of precipitation pattern affecting the intermittent character of the flow. According to Collwell (1974) three parameters, which he called them – predictability, constancy and contingency, are sufficient to describe periodic changes in biological and climatic processes. Predictability (P) is a function of Constancy (C) and Contingency (M), each of which has profoundly different implications for the ecology and evolution of biological systems (Gallart, Prat et al. 2012). Maximum predictability can be attained as a consequence of either complete constancy, complete contingency or a combination of constancy and contingency with respect to time. In the case of complete contingency, the state is the same for all seasons for all years. The state could be the wet and dry period of a hydrologic year in terms of precipitation or the flow, no-flow period in terms of discharge. In the case of complete contingency, the state is different for each season, but the pattern is the same for all years. Contingency is minimal when the probability of occurrence of each state is independent of the season. Constancy is minimal when the state fluctuates to the greatest degree possible during the course of an average year.

We have estimated the PCM (Predictability/Constancy/Contingency) index for the 11 stations that operate in Kouris river basin using monthly precipitation records for the period 1997–2009. We assume that the wet period lasts from November to April and the dry period

Author's personal copy

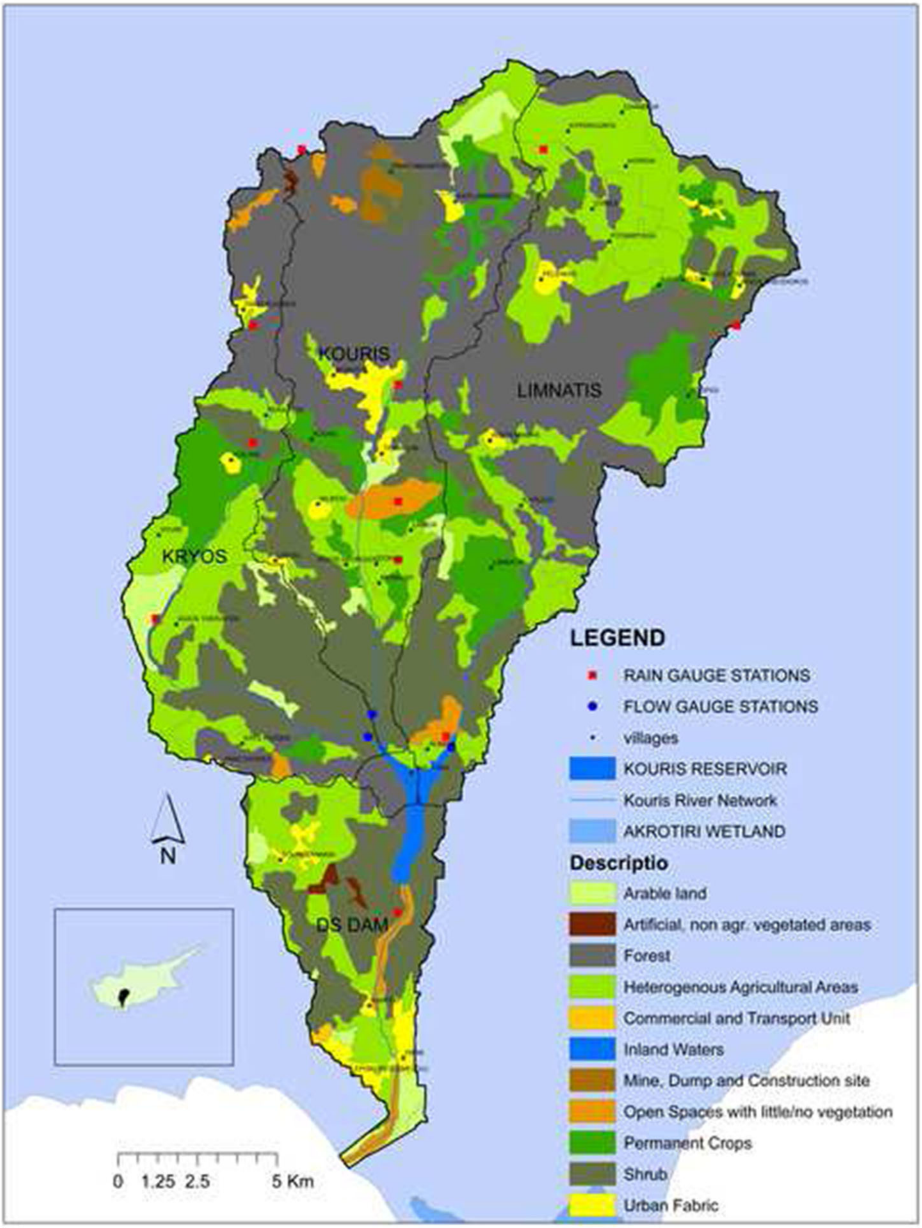


Fig. 1 Kouris river basin stream network, rain and flow gauge station and main landuses

from May to October. The Predictability index ranges between 0.40 and 0.63 (average 0.53) indicating a precipitation pattern with moderate seasonal variability and high prediction uncertainty.

McKee et al. (1993) developed the Standardized Precipitation Index (SPI) to define and monitor drought. He fitted a gamma probability density function to a given frequency

Author's personal copy

distribution of precipitation totals for a station. The maximum likelihood solutions are used to optimally estimate *a* and *b* parameters for each time scale of interest (3 months, 6 months, 9 months, etc.). The estimates of these parameters are then used to estimate the cumulative distribution of an observed event for the given month and time-scale for the station in question. The cumulative probability is then transformed to the standard normal random variable Z with mean zero and variance one, which is the value of SPI. Conceptually, the SPI represents a z-score, of the number of standard deviations an event deviates from the mean. Even though various categorizations have been suggested, the initial classification shown in Table 2 is generally used (Tsakiris and Vangelis 2004). The SPI was estimated for the Kouris station for a time scale of 3 months over the period 1999–2009. The hydrological status of the Kouris basin according to the SPI value range from extreme wet to extremely dry, dominated by mild drought (40.1 % probability) and mild wet (31.3 % probability) conditions, with extremes of 1.4 % probability of extreme drought and 2.7 % of severe drought in basin. The probability of extreme and severe drought is therefore 4.1 %, a figure which is at the lower end of severe and extreme drought probability estimated in China for 10 river basins (mean value 7.03 %) (Zhai, Su et al. 2010) lower than the probability in Portugal (between 8.4 and 15.4) (Santos, Portela et al. 2011) and along the southern coast of the Caspian Sea (mean value 7.25) (Ramazanipour, Roshani et al. 2011).

2.1.2 Intermittency Based on Flow Regime

Base flow has been separated from daily stream flow time-series using the SWAT (Soil and Water Assessment Tool) base flow filter program (Arnold and Allen 1999) which uses a modification of the recession curve displacement method. The minimum number of days used to calculate the parameter a of the groundwater recession equation was 10 days. Daily flow data were used for Kouris and Limnatis covering the period 1 January 2006 to 30 September 2009 and for the Kryos 1 January 2007 to 30 September 2009. The average fraction of "quick flow" contributed by each rainfall event to the reaches estimated to be 54 % for Kouris, 67 % for Limnatis and 80 % for Kryos (results of 3nd filter pass), showing a limited water retention capacity in the basin. The baseflow component ranges between 20 up to 46 % in agreement with previous hydrological studies in the area that have estimated a baseflow ratio of around 25–31 % (Boronina, Renard et al. 2003; Boronina, Balderer et al. 2005).

Other hydrologic metrics have been reported in order to classify temporary stream regimes, based on the distribution of lengths of dry period. An analysis of the stream flow 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^3s^{-1} with a standard deviation of 3.8 m^3s^{-1} (mean value of 1976–1993 hydrologic years' maximum instant flow) but the mean annual flow is only 0.473 m^3s^{-1}.

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

Author's personal copy

length of the dry period. A different classification is suggested by Gallart et al. (2012) who define four (4) main conceptual types of temporary streams:

(1) P (permanent): perennial streams characterized by continuous surface flow.
(2) I-P (intermittent–pools): similar to perennial streams in the wet season but in the dry season the flow is discontinuous with characteristic formation of pools along the river bed.
(3) I-D (intermittent-dry): streams usually having a dry river bed in summer.
(4) E (episodic - ephemeral): streams which flow only during rain events and pools and water flow are irregular and short lived.

The P and IP stream types are recharged continuously during the whole year by base flow while for ID type rivers the base flow component ceases during dry months. For the E stream type base flow is almost absent for the whole year. One index for characterizing the seasonality of the dry conditions in a stream is the 6-month seasonal predictability of dry periods (Sd_6) defined in Eq. (1). This index has been used to determine threshold boundaries between the various aquatic states. The equation for seasonal predictability (Gallart, Prat et al. 2012) is:

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

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 6 months by the average of the following 6 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 between 0 and 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 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 Fig. 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 2006–2012. 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 stream flow characteristics refer to the river reaches just upstream of the Kouris Reservoir, while all three rivers have

Author's personal copy

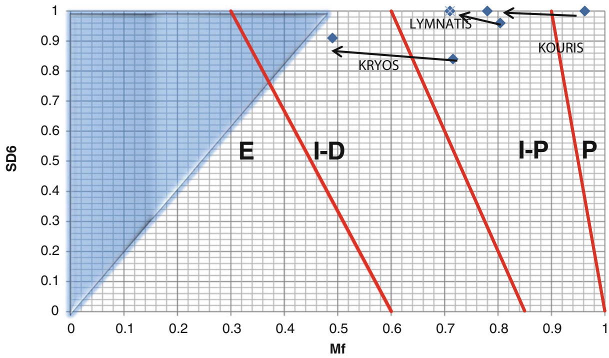


Fig. 2 TRP of Kouris streams

continuous flow in their upper and upper-middle reaches. The boundaries between perennial and intermittent reaches move every year depending on rainfall and subsequent stream flow (Uys and O'Keeffe 1997).

2.2 Catchment Nutrient Budget

We use the MONERIS model as an aid to estimating the nutrient budget of the catchment. MONERIS considers nutrient losses through seven different pathways: diffuse nutrient emissions such as overland flow (related to different land uses), erosion (based on soil loss, soil slope and land use and nutrient content of topsoils), tile drainage (estimated by drained area and nutrient concentration and rate of drain flow), groundwater (nitrogen residence time is the dominant parameter in groundwater emissions), sealed urban areas (connected or not to sewer systems and households not connected), atmospheric deposition on surface waters (based on area specific atmospheric deposition of nutrients) and point sources via municipal wastewater treatment plants and industrial discharges. MONERIS calculates separately for each pathway the nutrient fluxes including transformation processes in soils and groundwater and the total resulting net emissions entering surface water. 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

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

Author's personal copy

In Eq. 2 $C_{x,t}$ is the nutrient concentration mg L^{-1}, at time t and location x. E is the dispersion coefficient (m^2s^{-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 stream flow, cross sectional area, a constant dispersion coefficient and first order kinetics Eq. 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 = Q/A.

3 MONERIS Application with 1D Retention Component

Nutrient loads calculated by catchment characteristics and land use are input to the model, and simulations of downstream concentrations are generated by MONERIS. Measurements of these downstream concentrations can be used as a partial test of the performance of MONERIS, and for calibration. In the Kouris catchment, 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

Author's personal copy

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

MONERIS nutrient load calculation is dependent on a number of catchment characteristics, including land use, soils, geology, elevation and slope. A Digital Elevation Model (DEM) (30 m spatial resolution) was used to estimate the mean subbasin 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, Renard et al. (2003) which distinguishes five zones: Zone 1 - mantle rocks (harzburgites, serpentinites, dunites); Zone 2 - plutonic and intrusive rocks (sheeted dykes and gabbros); Zone 3 – volcanogenic rocks (pillow lavas); Zone 4 – sedimentary rocks (chalks, marls, calcarenites) and Zone 5 – sedimentary rocks (alluvium in the river bed). 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 the soil by the European Soil Data Centre (ESDAC) (Panagos et al. 2012) in the Kouris basin. Kryos soils are characterized as clay loam soils, Kouris and Limnatis as sandy loam. The Phosphorous content in topsoils was lower than 10 mg kg^{-1} and the Nitrogen 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 t year^{-1} N and 20 t year^{-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. For Cyprus a nitrogen surplus of agricultural soils (the difference between all nutrients inputs and outputs on agricultural land) of 40 kg N ha^{-1} year^{-1} was used for MONERIS simulations. It equals to the average nitrogen surplus of agricultural soils at European scale when the nitrogen application rate ranges between 8 and 179 kg ha^{-1} (Grizzetti, Bouraoui et al. 2008; Bouraoui, Grizzetti et al. 2009). Nitrogen surplus corresponds to 37.4 % of applied nitrogen in Kouris agricultural soils, almost equal to the regional average nitrogen surplus of 38 % (European average) (Tsakiris and Vangelis 2004). With an input rate of 22.0 kg P ha^{-1} year^{-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} year^{-1}.

Bouraoui et al.(2009) estimate an atmospheric deposition rate of 3.7 kg N ha^{-1} year^{-1} for Cyprus. Total phosphorus deposition was set similar to other Mediterranean countries equal to 0.99 kg P ha^{-1} year^{-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

Author's personal copy

subcatchments. The livestock annual nutrient production rates (kg P and N ha^{-1} year^{-1}) were estimated with reference to the native livestock breed characteristics such as animal weight (OECD 2007). Livestock production contributed 490 t N year^{-1} and 147 t P year^{-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} year^{-1} respectively. For a soil pH of 8.1, a median value of denitrification rate can estimated as 5 kg ha^{-1} year^{-1} for grassland areas (Hofstra and Bouwman 2005), giving a final N loss rate of 42 kg ha^{-1} year^{-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} year^{-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 plants. 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 t N year^{-1} and 0.2 t P year^{-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 (5,320 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 t year^{-1} and 0.64 t year^{-1} of N and P respectively. The remainder of the population (11,955) is served by individual septic tanks or by sewers drainage system not connected to WWTP. 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). Considering 35 % Nitrogen reduction (Rosado, Morais et al. 2012) (by denitrification, ammonia volatilization and removal of solids as septage) in the underground tanks and that almost in the half areas there is still direct discharge of septic tank effluent to adjacent streams, it is assumed that only 2 % of P (De Girolamo, Calabrese et al. 2012) and 30 % of N (Moyle 2013) of human emissions reaches the river. Thus the diffuse sources exports into the river were estimated to be 0.8 t P year^{-1} and 30.3 t year^{-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 10 mm 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).

Author's personal copy

Table 1 Calibration and verification period Moneris input data

	KRYOS	KOURIS	LIMNATIS
Calibration period 2008–2010			
Mean Flow m^3s^{-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			
Mean Flow m^3s^{-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			
Mean Flow m^3s^{-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

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 Eq. 4 was calibrated for TN retention (0.98–2.3 days^{-1}). The NSE value between modeled 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 t 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 estimated by MONERIS from the three river basins are 47.6 t of nitrogen and 1.8 t of phosphorus (Table 2). Pollution generated by WWTP effluent, sewers not connected to WWTP and individuals septic tanks is estimated to generate most nutrient loss (Table 2) (63.7 % of total N, 43.8 % of total P). Erosion processes appear to be a serious environmental threat, since significant amounts of nitrogen (15 %) and phosphorus

Author's personal copy

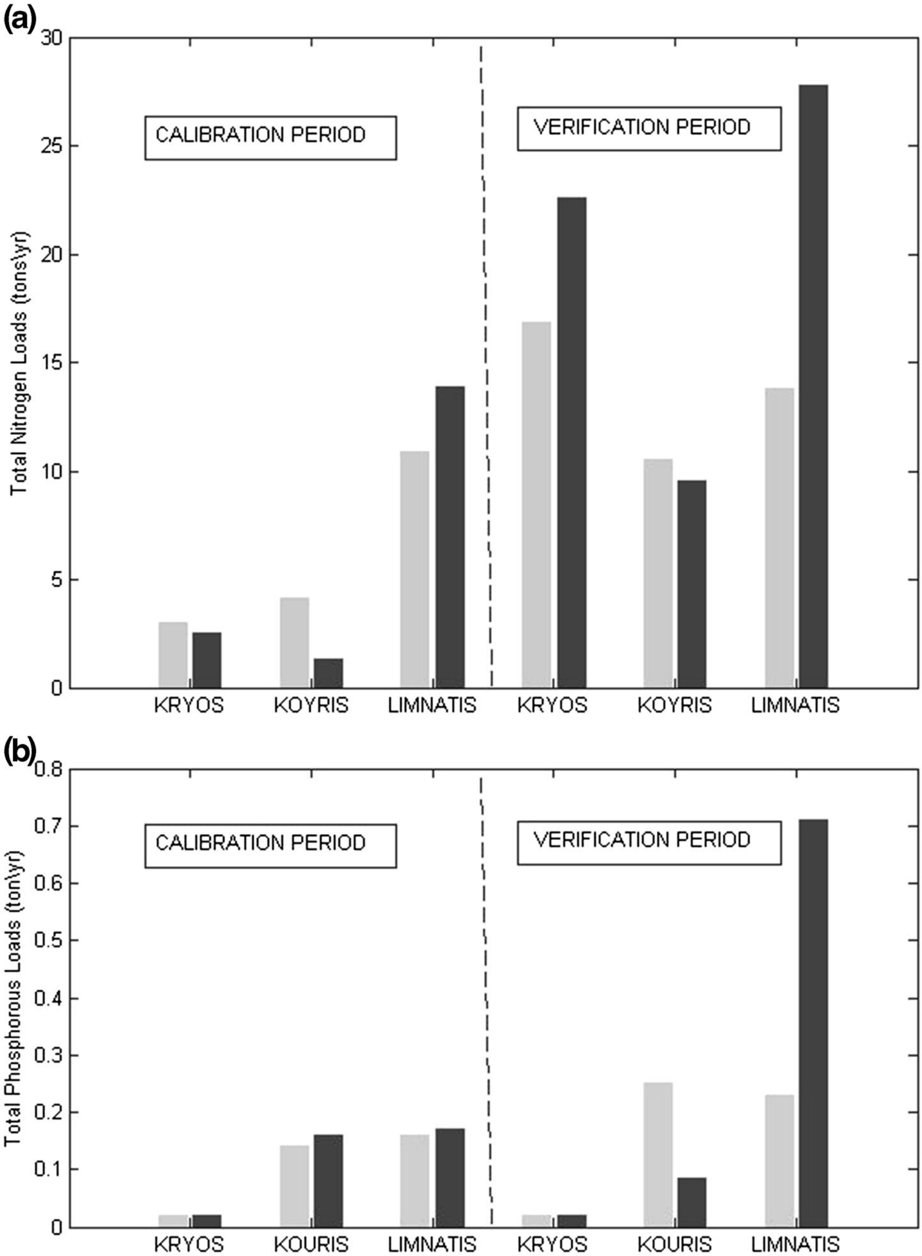


Fig. 3 Modelled (*grue bars*) versus observed values (*black bars*) of Total Nitrogen (*left figure*) and Total Phosphorus (*right figure*) for the calibration and verification period

Author's personal copy

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

Pathways	Nitrogen Emissions					Phosphorus Emissions				
	Kryos [t yr^{-1}]	Kouris [t yr^{-1}]	Limnatis [t yr^{-1}]	Total [t yr^{-1}]	[%]	Kryos [t yr^{-1}]	Kouris [t yr^{-1}]	Limnatis [t yr^{-1}]	Total [t yr^{-1}]	[%]
Atmospheric Deposition	0.15	0.26	0.96	1.37	2.88	0.03	0.04	0.17	0.24	13.48
Overland flow- (impact of free grazing)	0.74	3.26	1.51	5.51	11.57	0.02	0.08	0.04	0.14	7.87
Erosion	2.24	2.67	2.17	7.08	14.87	0.04	0.02	0.03	0.09	5.06
Groundwater	0.13	0.92	0.27	1.32	2.77	0.03	0.12	0.07	0.22	12.36
Septic Tanks/not connected sewers	5.6	12.81	7.5	25.91	54.42	0.12	0.10	0.16	0.38	21.35
WWTPs effluent	–	–	4.4	4.40	9.24	–	–	0.40	0.40	22.47
Urban Runoff	0.34	0.53	0.85	1.72	3.61	0.02	0.03	0.06	0.11	6.18
In-Stream Secondary Sources[b]	0.1	0.1	0.1	0.30	0.63	0.08	0.06	0.06	0.20	11.24
Total Emissions[c]	9.30	20.55	17.76	47.61		0.34	0.45	0.99	1.78	
In – Stream Retention[d]	6.60	5.75	6.86	19.21		0.33	0.38	0.85	1.56	
Estimated Load[e]	2.70	14.80	10.90	28.40		0.01	0.07	0.14	0.22	
Observed Load[f]	2.54	13.83	9.57	25.94		0.02	0.15	0.17	0.34	

[a] Septic Tanks effluent disposed into the adjacent streams and sewers not connected to WWTP

[b] In stream Secondary sources originated by unmanaged disposal into the river of wastewater, wastes etc

[c] Emissions by the various pathways as estimated by MONERIS model

[d] Nutrients retention by the stream processes as estimated by 1D MONERIS Retention Module

[e] Final Emissions to the surface water as estimated by MONERIS

[f] Nutrient load measured by regular sampling in the streams

Author's personal copy

(5 %) are subject to detachment and transportation. Erosion processes are promoted by steep slopes, scarce vegetation and dry mobilisable soils. Groundwater is estimated to contribute 1.32 t of N (2.85 %) and 0.22 t of P (12.36 %). The Kouris subcatchment has the highest domestic wastewater loads, since it does not include a WWTP. Grazing is a serious environmental pressure (the origin of 11.89 % of N and 7.87 % of P) especially in the Kouris catchment. Emissions of P by groundwater and overland flow are significant in the Kouris subcatchment and strongly related to the hydro geologic conditions of the subbasin. In the Limnatis subcatchment atmospheric deposition and wastewater effluents generate the highest P loads. The agricultural area in the basin has no tile drainage, only surface drainage.

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) who 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 topsoil TP content in the Kouris catchment is lower than 10 $mgkg^{-1}$, the TP content of the sediment was measured to be 3,432 $mgkg^{-1}$ (±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, Hirt et al. (2011). With respect to nitrogen simulation the most sensitive parameter was the coefficient (a_n) of the erosion equation. A second group of influential parameters were coefficients of surface runoff (a and b) and parameters k1 and k2 in groundwater for consolidated bedrock of high porosity and the parameters k1 and k2 in groundwater for consolidated impermeable bedrock. Phosphorus simulation was most sensitive to the parameter (a) in the clay-P model of phosphorus surplus and less sensitive the parameters (a_P and b) in the erosion equation. Finally the parameter (a) of surface runoff was identified as of similar importance for phosphorus losses.

The N and P retention Eq. 5 is strongly dependent on the retention parameter (*K*) 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 1,000 random values of K. Monte Carlo analysis of K_{TN} value (0.98 $days^{-1}$) in the Kouris gave a median value of TN in-stream loads of 14.40 t TN, ranging between 14.17 and 14.65 tonne and a K_{TP} value (4.0 day^{-1}) gave a median value of TP in-stream loads of 0.135 t TP, ranging between 0.133 and 0.137 tonne.

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

Author's personal copy

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 ceases to flow 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 desiccation.

Because the Limnatis shows a permanent hydrologic pattern that has only slightly changed recently, MONERIS appears suitable for estimating nutrient losses. Essential components of the hydrologic cycle including base flow and surface runoff contribute to flow for most of the year. A weak point in the performance of MONERIS is its treatment of the effect of 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 base flow 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 base flow. 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 with long period with no flow the average flow actually is the average of the individuals flood events and is overestimated. The base flow 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.

The total N emissions of the Kouris streams (28.4 t yr^{-1}) (Table 2) for the calibration period 2006–8 and for a drainage area of three streams of 287 km^2 corresponds to an average N export of 99 kg N km^{-2}. By using the in-stream retention module of MONERIS it was estimated that the stream N retention capacity reaches 40 %. Phosphorus total emissions were estimated to reach 1.78 t yr^{-1} (Table 2) or equivalently 6.2 kg P km^{-2} while entering into the stream is decreased further up to 88 % by sorption and other processes and the final P emission specific ratio is reduced to 0.49 kg P km^{-2}. N and P loads were estimated by the use of MONERIS for the period 2000–2 for a Mediterranean catchment, in Spain (La Tordera, 877 km^2) 681 kg N km^{-2} and 81 kg P km^{-2} accounting for in-stream retention of 45–55 %, slightly higher than Kouris stream retention capacity (Caille, Riera et al. 2012). For a trans boundary Mediterranean river, Axios river, Greece (drainage area 25,000 km^2) for the period 1995–2000 N and P loads were estimated of approximately 198 and 64 kg km^{-2} by MONERIS model, implying a retention fraction of 61 % of N and 73 % of P (Nikolaidis, Karageorgis et al. 2009). Since the studied streams are located in highland areas, with low density population and the absence of any industrial activity they may be considered pristine with nitrogen specific emission (99 kg N km¯2) much lower than other Mediterranean areas such as the Axios (198 kg N km¯2) or La Tordera (681 kg N km¯2). Kouris P losses on an area

Author's personal copy

basis (0.49 kg P km^{-2}) are much lower than for the Axios (64 kg P km¯2) and Lardera catchments (81 kg P km-2) although very close to the P export estimated by export coefficient approach of Matias and Johnes (2012) for four intermittent flow subbasins (drainage areas 2,108–3,511 km^{2}) of the Sado river basin (Portugal) ranging from 1.7 to 2.3 kg P km^{-2} and within the range of specific P emission of 892 Hungarian sub-catchments (0.01–7.5 kg P km^{-2}) (McKee, Doesken et al. 1993).

The MONERIS model estimated higher N emissions (7.08 t year^{-1}) than P (0.09 t year^{-1}) due to erosion. The quantification of N and P emissions, via erosion, into surface waters depends on N and P content in topsoils (Venohr, Hirt et al. 2011). The small erosion capacity of Kouris basin (mean value 1.5 t ha^{-1} year^{-1} estimated by Universal Soil Loss Equation) in combination with the high content of Nitrogen (N) in Cyprus topsoil (800–1,700 mg/kg) and low P content (10 mg/kg) results in smaller loads of P into surface waters via erosion than N loads. Similar differences in N and P content are observed in Mediterranean semi-arid topsoils as evidenced by the Lucas Topsoil Survey (Rosado, Morais et al. 2012). Almost 55 % of shrubland soils in Mediterranean semi-arid climate have a N content in the range 1,000–2,000 mg kg^{-1} and 55 % a P content less than 20 mg kg^{-1}. Kouris soils are in the range of 50 % of Mediterranean semi-arid climate soils.

In Kouris almost 63.7 % of N and 43.8 % of P emissions are derived from the point source and septic tank discharges. In Cyprus, the design and location of many septic tank systems in rural areas visualize the historical legacy of the wastewater disposal infrastructure during periods when regulations and environmental awareness were not so rigorously defined or implemented. Field surveys in the basin indicated that numerous households either are served by a sewerage drainage system that is not connected to WWTP, with raw wastewater discharged directly to a stream, or use septic tanks to store permanently the wastewater that is later discharged to adjacent streams. In contrast to findings for North Temperate European catchments (for instance for the Vistula WWTP N emissions are restricted to 4.5 %(Kowalkowski 2009)) and large Mediterranean catchments (Axios 14.1 % N and 65.2 % P WWTP emissions) (Nikolaidis, Karageorgis et al. 2009), the dominant source of nutrient loading in these small scale semi-arid catchements is effluent discharge from point sources (WWTPs) and diffuse leakage from septic tank systems (Matias and Johnes 2012).

Groundwater is a lesser contributor of N emissions (2.77 %), explained by the proportion of the catchment having consolidated impermeable rock (83.9 %) in comparison to consolidated high porosity (11.6 %) and unconsolidated shallow groundwater (4.5 %), so that channeling or lateral flow occur rather than percolation to groundwater. In contrast in North Temperate European catchments the high geologic fraction of unconsolidated bedrock (59.3 % of Vistula and 72 % of Oder) explains the high percentage contribution of groundwater pathway to nitrogen emission (Vistula, 40 % and Oder 24 %) (Pastuszak, Stålnacke et al. 2012).

Livestock generates important nutrient load (11.57 % of N and 7.87 % of P) (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 and by promoting maintenance of the public sewage system. It is important to reduce the total amount of pollution load from causative agents in urban runoff derived from cooking, washing and other activities by controlling detergent use or prohibiting the disposal of edible waste oil in the drainage system

Author's personal copy

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 to recent highly modified conditions, but also to visualize the stream interannual changes. The position of a stream in the TRS plot is essential for the calibration procedure to be followed. The Limnatis and Kouris streams show limited hydrologic change in 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 is effective only with the prerequisite of continuous public participation, technologies awareness of stakeholders and economic efficiency of adapted measures.

Acknowledgments The authors wish to thank Dr. Charles Demetriou from the Cyprus Water Development Department for the data contribution and his valuable comments towards the improvement of this manuscript. This work is partly funded by the SoilTrEC 7th FP (Grant Agreement No. 244118).

References

Arnold J, Allen P (1999) Automated methods for estimating base flow and ground water recharge from stream flow records. J Am Water Resour Assoc 35(2):411–424

Arnold JG, Srinivasan R et al (1998) Large area hydrologic modelling and assessment part I: model development. J Am Water Res Assoc 34(1):73–89

Baker DB, Richards RP, Loftus TT, Kramer JW (2004) A new flashiness index: Characteristics and applications to Midwestern rivers and streams. Journal of the American Water Resources Association 40(2):503-22

Bernal S, von Schiller D et al (2013) Hydrological extremes modulate nutrient dynamics in Mediterranean climate streams across different spatial scales. Hydrobiologia 719(1):31–42

Bicknell B R, Imhoff J C et al (2001) “Hydrological Simulation Program-Fortran, HSPF, Version 12, User’s Manual.” (March 2001, Athens: National Exposure Research Laboratory, Office of Research and Development)

Boronina A, Renard P et al (2003) Groundwater resources in the Kouris catchment (Cyprus): data analysis and numerical modelling. J Hydrol 271(1–4):130–149

Boronina A, Balderer W et al (2005) Study of stable isotopes in the Kouris catchment (Cyprus) for the description of the regional groundwater flow. J Hydrol 308(1–4):214–226

Bouraoui F, Grizzetti B et al (2009) “Nutrient discharge from rivers to seas for year 2000.” JRC Scientific and Technical Reports 54459

Caille F, Riera JL et al (2012) Modelling nitrogen and phosphorus loads in a Mediterranean river catchment (La Tordera, NE Spain). Hydrol Earth Syst Sci 16(8):2417–2435

Camargo JA, Alonso Á (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environ Int 32(6):831–849

Chahinian N, Bancon-Montigny C et al (2013) Temporal and spatial variability of organotins in an intermittent Mediterranean river. J Environ Manag 128:173–181

Colwell RK (1974) Predictability, constancy and contingency of periodic phenomena Ecology 55: 1148-1153

De Girolamo AM, Calabrese A et al (2012) Impact of anthropogenic activities on a temporary river. Fresenius Environ Bull 21(11):3278–3286

Author's personal copy

Fleskens L, Graaff JD (2010) Conserving natural resources in olive orchards on sloping land: Alternative goal programming approaches towards effective design of cross-compliance and agri-environmental measures. Agricultural Systems 103(8):521-34

Gallart F, Prat N et al (2012) A novel approach to analysing the regimes of temporary streams in relation to their controls on the composition and structure of aquatic biota. Hydrol Earth Syst Sci 16(9):3165–3182

Grizzetti B, Bouraoui F et al (2008) “Assessing nitrogen pressures on European surface water.” Global Biogeochemical Cycles 22(4)

Hirt U, Venohr M et al (2008) Modelling nutrient emissions and the impact of nutrient reduction measures in the Weser river basin, Germany. 58: 2251–2258

Hirt U, Kreins P et al (2012) Management options to reduce future nitrogen emissions into rivers: a case study of the Weser river basin, Germany. Agric Water Manag 115:118–131

Hofstra N, Bouwman AF (2005) “Denitrification in agricultural soils: summarizing published data and estimating global annual rates.”. Nutr Cycl Agroecosyst 72:267–278

Kowalkowski T (2009) Classification of nutrient emission sources in the Vistula River system. Environ Pollut 157(6):1867–1872

Kowalkowski T, Pastuszak M et al (2012) Differences in emission of nitrogen and phosphorus into the Vistula and Oder basins in 1995–2008 - natural and anthropogenic causes (MONERIS model). J Mar Syst 89(1):48–60

Matias NG, Johnes PJ (2012) Catchment phosphorous losses: an export coefficient modelling approach with scenario analysis for water management. Water Resour Manag 26(5):1041–1064

McKee T B, Doesken N J et al (1993) “The relationship of drought frequency and duration to time scales.” 8th Conference on Applied Climatology, Anaheim, CA. 17–22 January(179–184)

Medis (2005) “Institutional analysis of water management practices Majorca-Corcia-Sicily-Crete-Cyprus.” Project No. EVK1-CT-2001-0009

Moyle P B (2013) “NOVEL AQUATIC ECOSYSTEMS: THE NEW REALITY FOR STREAMS IN CALIFORNIA AND OTHER MEDITERRANEAN CLIMATE REGIONS.” River Research and Applications

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I-A discussion of principles. J Hydrol 10:282–290

Nikolaidis C (2010) “Update of the project of the environmental impact assessment of the Akrotiri aquifer replenishment with recycled wastewater of Limassol – Amathountos” TAY 74/2009

Nikolaidis NP, Karageorgis AP et al (2009) Management of nutrient emissions of Axios River catchment: their effect in the coastal zone of Thermaikos Gulf, Greece. Ecol Model 220(3):383–396

Nikolaidis NP (2011) Human impacts on soils: Tipping points and knowledge gaps. Applied Geochemistry 26(SUPPL.):S230-S3

OECD (2007) “Environmental indicators for agriculture.” Volume 4(Paris, France.)

Pastuszak M, Stålnacke P et al (2012) Response of Polish Rivers (Vistula, Oder) to reduced pressure from point sources and agriculture during the transition period (1988–2008). J Mar Syst 94:157–173

Panagos P, Van Liedekerke M, Jones A, Montanarella L (2012) European Soil Data Centre: response to European policy support and public data requirements. Land Use Policy 29(2):329–338

Perrin J L, Tournoud M G (2009) “Hydrological processes controlling flow generation in a small Mediterranean catchment under karstic influence.” Processus hydrologiques contrôlant la génération des débits dans un petit bassin versant Méditerranéen sous influence karstique 54(6): 1125–1140

Ragab R, Bromley J (2010) IHMS-integrated hydrological modelling system. Part 1. Hydrological processes and general structure. Hydrol Process 24(19):2663–2680

Ramazanipour M, Roshani M et al (2011) The relationship of drought intensity, duration and frequency in the southern coast of Caspian Sea. World Appl Sci J 15(8):1176–1180

Richter BD, Baumgartner JV, Braun DP, Powell J (1998) A spatial assessment of hydrologic alteration within a river network. River Research and Applications 14(4):329-40

Rosado J, Morais M et al (2012) Key Factors in the Management and Conservation of Temporary Mediterranean Streams: A Case Study of the Pardiela River, Southern Portugal: 273–283

Santos JF, Portela MM et al (2011) Regional frequency analysis of droughts in Portugal. Water Resour Manag 25(14):3537–3558

Smil V (2001) “Enriching the Earth: Fritz Haber, Carl Bosch, and the transformation of world food production.”. MIT Press, Cambridge, p xvii338

Tsakiris G, Vangelis H (2004) Towards a Drought watch system based on spatial SPI. Water Resour Manag 18(1):1–12

Tzoraki O, Nikolaidis NP (2007) A generalized framework for modeling the hydrologic and biogeochemical response of a Mediterranean temporary river basin. J Hydrol 346(3–4):112–121

Tzoraki O, Nikolaidis NP et al (2009) A reach-scale biogeochemical model for temporary rivers. Hydrol Process 23(2):272–283

Author's personal copy

Tzoraki O, Dörflinger G et al. (2012) "Controlling Pollution Risk of an important Drinking Water Reservoir in a strongly human altered and climatically induced semi-arid environment." 3nd International Conference on Industrial and Hazardous Waste Management, 10–14 September 2012 (Chania, Crete)
Uys MC, O'Keeffe JH (1997) Simple words and fuzzy zones: early directions for temporary river research in South Africa. Environ Manag 21(4):517–531
Venohr M, Hirt U et al (2011) Modelling of nutrient emissions in river systems - MONERIS - methods and background. Int Rev Hydrobiol 96(5):435–483
Von Schiller D, Martí E et al (2008) Inter-annual, annual, and seasonal variation of P and N retention in a perennial and an intermittent stream. Ecosystems 11(5):670–687
Waschbusch R J, Selbig W R et al (1999) "Sources of Phosphorus in Stormwater and Street Dirt from Two Urban Residential Basins In Madison, Wisconsin, 1994–95"
Webb JA, Nichols SJ et al (2012) Ecological responses to flow alteration: assessing causal relationships with eco evidence. Wetlands 32(2):203–213
Zessner M, Kovacs A et al (2011) Enhancement of the MONERIS model for application in alpine catchments in Austria. Int Rev Hydrobiol 96(5):541–560
Zhai J, Su B et al (2010) Spatial variation and trends in PDSI and SPI indices and their relation to stream flow in 10 large regions of China. J Clim 23(3):649–663