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Feasibility study of the application of the LOICZ budget to the Mediterranean Sea

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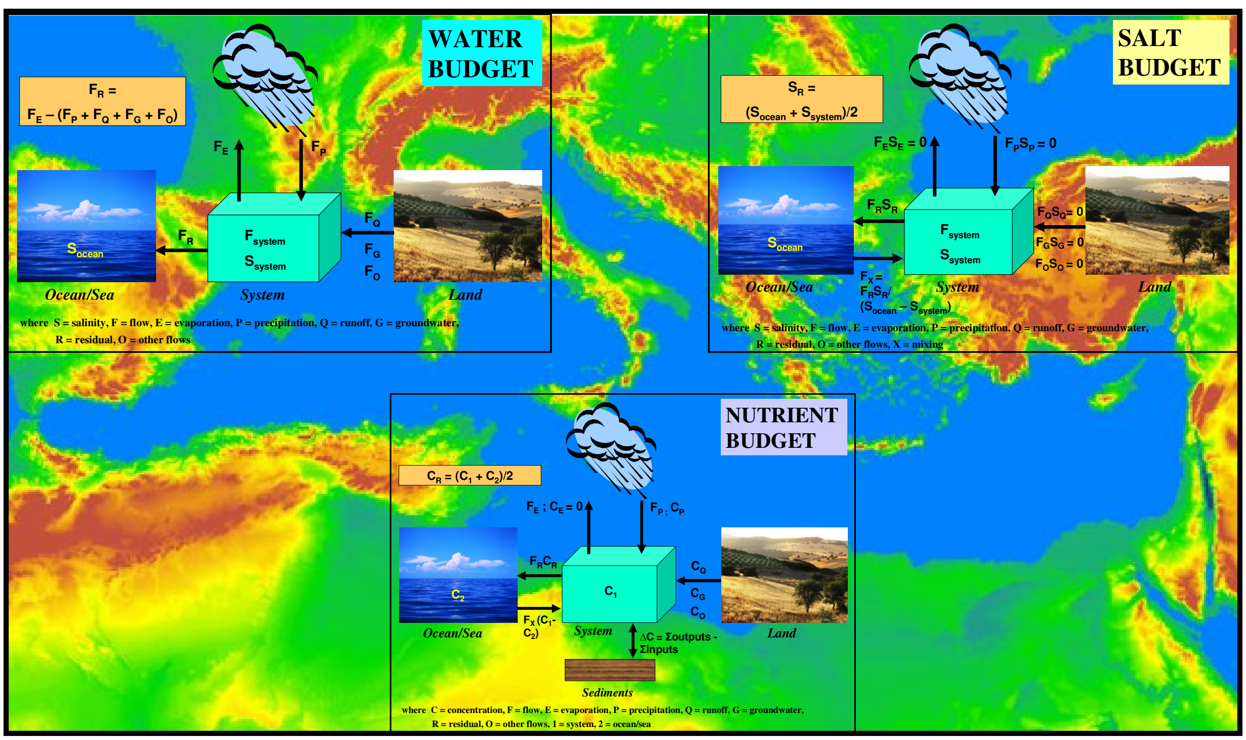

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1. Introduction

Although it only makes up about 1% of the total world ocean surface, the Mediterranean Sea is often used as a representative model of the world's oceans. Due to its practically enclosed character, it is also often used to assess the global change of the environment. Area-wise the Mediterranean Sea covers approximately 2.5 Mkm^2 and stretches at its widest cross-sections about 4,000 km from west to east and 900 km from south to north (Laubier, 2005). The Mediterranean Sea is connected to the Black Sea via the Strait of Dardanelles (7 km width and 55 m average depth) and to the Atlantic Ocean via the Strait of Gibraltar (15 km width and 290 m depth at sill). An artificial connection to the Red Sea is given through the Suez Canal. The average depth of the Mediterranean Sea is approximately 1.5 km. The biggest rivers flowing into the Mediterranean Sea are the Nile, Rhône, Po and Ebro. The riverine input to the Mediterranean Sea has been roughly estimated at 15,000 m^3/s (EEA/UNEP, 1999). More than 130 million people live on a permanent basis along the Mediterranean coastline, this figure doubling during the summer tourist season (EEA, 2005).

The Mediterranean climate is marked by high winter and low summer precipitation, the latter accounting for less than 10% of the annual total. A north to south gradient of the mean annual precipitation is evident, with precipitation increasing towards the north. High precipitation (1,500 – 2,000 mm/yr) can be encountered, especially in the Alpine and Pyrenean headwater areas. In the northern Mediterranean, the principal rivers are recharged via rather large basins, while the smaller basins usually experience floods. In the southern Mediterranean, on the other hand, flash floods are generally common (Laubier, 2005). In addition, the Mediterranean region is considered as one of the most sensitive regions on Earth in the context of climate change as a consequence of its position between two different climate regimes in the North and the South (Somot et al., 2006).

For the Mediterranean Sea, evaporation exceeds the precipitation and river runoff inputs. Thus, the Mediterranean Sea is often called an "evaporation basin". Theoretically, if the Strait of Gibraltar became closed, the sea level in the Mediterranean would decrease at a rate of about 0.5-1.0 m/yr (Laubier, 2005). High evaporation causes an increase in water salinity, leading in turn a decrease in water temperature. Consequently, the drivers responsible for the exchange of water at the Strait of Gibraltar are the evaporation in the Mediterranean and salinity gradient. Generally speaking, the exchange between the Mediterranean Sea and the Atlantic Ocean occurs as the more saline and denser Mediterranean deep waters go out to the Atlantic Ocean, while the lighter Atlantic surface waters enter, with a positive net inflow towards the Mediterranean Sea (Bryden and Kynder, 1991). The turnover period for water entering through the Strait of Gibraltar is estimated to be between 80 and 200 years (Hopkins, 1999).

In the Mediterranean Sea, there are relatively strong vertical and lateral currents, enabling relatively rapid mixing of introduced contaminants from the air, land or water compartments. The residence time for a basin is considered to be one of the indicators of how long contaminants may amass in a basin before mixing and then exiting a basin. The residence time for the entire Mediterranean basin is estimated to range between 200 and 300 years (UNEP/MAP/MED POL, 2004).

Contaminants that enter the Mediterranean basin are principally originating from the sectors of agriculture, animal husbandry and municipal sewerage. In other words, anthropogenic activities have contributed significantly to the existing nutrient enrichment and consequent eutrophication problems in the Mediterranean Sea. At the present, however, mainly due to the favourable circumstances regarding the hydrology, morphology as well as absence of significant upwelling of the Mediterranean basin as a whole, severe eutrophication cases is limited to specific coastal areas (UNEP, 2003). An estimation of the percentage of each major anthropogenic factor contributing to the eutrophication problem has been made by the EEA (1999). It was observed that the nonpoint sources of agricultural runoff and eroded soil are the root causes of nutrient enrichment in the Mediterranean, mostly from areas having a high degree of soil erosion (e.g. the Po and Rhône river basins). The total area of the basins draining into the Mediterranean comprises 3.91 million km^2. In addition, urban and domestic activities are partially responsible for nutrient enrichment. In the eastern Mediterranean Sea, nutrients are also being added via the receiving waters from the Black Sea. The net inflow from the Black Sea is approximately 163 km^3/yr (UNEP, 2003).

Another possible source of nutrient input into the Mediterranean Sea is via seepage from coastal aquifers, of unconfined sedimentary or karstic nature. It is estimated that approximately 25% of the total freshwater inflow into the Mediterranean Sea comes from seepage via coastal aquifers. However, there is no data available on nutrient concentrations/loads entering by means of this pathway. Such coastal aquifers are known to be especially susceptible to pollution originating from the surface (UNEP/MAP/MED POL, 2004).

Average dissolved nutrient concentrations in more than 30 Mediterranean rivers are presented in table 1 (UNEP/MAP/MED POL, 2004). Average total phosphorus concentrations greater than 1.0 mg/l are found in several Spanish and Turkish rivers (e.g. Besos, Llobregat, Ter, Ceyhan and Goksu rivers). Average total nitrogen values are not available for many rivers. From the available average N-NO_3 concentration data it is evident that the intensely cultivated areas in Spain, Italy and Greece exhibit higher values (e.g. Pinios, Ebro, Po, Axios, etc. rivers). Additionally, the Nile river reveals an elevated N-NO_3 value. However, this value needs to be taken with a grain of caution, as it has been derived from a few available values. Lower nitrate values are often found in the less intensely cultivated areas or where less fertilizer are effectively applied, such as in the French rivers Var and Tavignano.

For various streams in Croatia, Italy and Greece, monitoring studies on the evolution of average total phosphorus and nitrate concentrations in the time period 1981-95 have been undertaken and disclose the following: for rivers where measures have been taken to reduce total phosphorus, concentrations decreased over time, from 0.4 mg P/l to approximately 0.01-0.15 mg P/l. Nitrate concentrations, on the other hand, increased from 0.1-1 to 0.3-2.0mg N-NO_3/l (Bethoux *et al.*, 2005).

Bethoux *et al.* (2005) have estimated the total nutrient loads entering the Mediterranean Sea from stream discharges for approximately the last 30 years.

It was estimated that about $36x10^3$ ton/yr for total phosphorus, $14x10^3$ ton P/yr for P-PO_4 and $333x10^3$ ton N/yr for N-NO_3 were discharges into the sea before 1975. For the time period between 1985-90, the loads increased, namely to 94 $x10^3$ ton/yr for total phosphorus, $38x10^3$ ton P/yr for P-PO_4 and $469x10^3$ ton N/yr for N-NO_3. After 1995 a strong decline in phosphorus to pre-1975 figures could be observed, namely to $36x10^3$ t/yr for total phosphorus and $14x10^3$ ton P/yr for P-PO_4. The total estimated nitrate load, on the other hand, increased to $605x10^3$ ton N/yr for N-NO_3. The total estimated loads were reported as ca. 304,000 ton/yr N and 22,000 ton/yr P (EEA/UNEP, 1999).

Table 1. Average dissolved nutrient concentrations in some Mediterranean rivers (UNEP/MAP/MED POL, 2004)

Rivers	Discharge (km^3/yr)	N-NO_3 (mg/l)	N-NO_2 (mg/l)	N-NH^+ (mg/l)	N_{TOT} (mg/l)	P-PO_4^{-3} (mg/l)	P_{TOT} (mg/l)
ADIGE	7.29	1.25		0.111		0.03	0.1126
AKHELOOS	5.67	0.60		0.035		0.02	0.0151
ALIAKMON	1.168	0.395		0.05		0.10	0.0168
ARGENS	0.38	0.74	0.02	0.09	0.5	0.11	0.22
ARNO	2.10	0.912		0.042		0.500	0.01
AUDE	1.31	1.42	0.03	0.09	1.2	0.09	0.49
AXIOS	4.90	1.584		0.0658		0.48	0.48
BESOS	0.130	1.9	0.3	31			12.7
BUYUK MENDER	4.70	1.44				0.55	
CEYHAN	7.10						8.68
EBRO	9.24	2.3		0.1672		0.029	0.243
EVROS	6.80	1.9		0.05		0.36	
PLUVIA	0.36			0.054			0.35
GEDIZ	1.87	1.65		0.05		0.19	
GOKSU	2.50						8.87
HERAULT	0.92	0.61	0.012	0.06		0.045	0.22
KISHON	0.063						20
KRKA	1.61	0.45	0.001	0.031		0.029	
LLOBREGAT	0.466	1.9	0.5	3.2		1.2	1.53
METAURO	0.43	1.366		0.0		0.005	0.119
NERETVA	11.01	0.269		0.029			0.050
NESTOS	1.03	1.24		0.071			0.127
ORE	0.86	0.67	0.045	0.44	0.9	0.14	0.45
PINIOS	0.672	2.323		0.167			0.2431
PO	48.90	2.03		0.21		0.084	0.2393
RHONE	48.07	1.48	0.033	0.124	0.80	0.101	0.14
SEMANI	3.02	0.24					0.002
SEYHAN	7.20	0.59		0.31	0.27	0.0.1	
SHKUMBINI	1.94	0.73					0.01
STRYMON	2.59	1.236		0.053		0.11	0.125
TAVIGNANO	0.06	0.34	0.045	[0.003]		[0.005]	
TER	0.84			1.2			2.15
TET	0.40	1.8	0.18	1.5	2.7	0.47	0.8
TEVERE	7.38	1.37		1.04		0.26	0.355
VAR	1.57	0.18	0.003	0.031	1.5	0.006	0.13

In another study by UNEP/FAO/WHO (1996), the total loads of total nitrogen and total phosphorus have been estimated, based on fertilizer use, population density, land-use and livestock populations for three different scenarios. From the undertaken calculations, it could be roughly estimated that the most probable total nitrogen load from land-based sources lies between 1.5 and 2.5 M ton/yr, while for total phosphorus it is probably in the range of 0.15 and 0.25 M ton/yr.

From a socio-economic viewpoint, the consequences due to the introduction of excess nutrient loads into the Mediterranean have been recapitulated by the following (UNEP/MAP/MED POL, 2004):

- Reduced fish production due to eutrophication events causing fish kills that consequently lead to income loss
- aesthetic value loss of the water body due to algal blooms/overproduction
- loss of cultural heritage
- loss of income and employment related to reduced tourism
- increase in unemployment due to the decline in fishery activity
- possible increase in social instability due to livelihood loss

2. Objectives

Assessment of the environmental and economic impact of the implementation of European directives (Water Framework Directive, Marine Strategy) on the Mediterranean Sea entails a detailed knowledge of biogeochemical processes taking place at sea. A budget approach was adopted, as proposed by the LOICZ (Land Ocean Interactions in the Coastal Zone) programme. The LOICZ budget approach represents the estimation of the present fluxes of carbon, nitrogen and phosphorous in particular coastal systems on the local scale. As part of the input to the LOICZ budget, the nutrient loads from the adjacent surfaces need to be estimated. In fact, an evaluation of the nutrient loads from the adjacent land surfaces lends itself to be used to interpret past, existing and future legislation using scenario analyses, reflecting different expected or known events.

3. LOICZ budget

The initial LOICZ project (Land Ocean Interactions in the Coastal Zone) priority is on the estimation of the present fluxes of carbon, nitrogen and phosphorous in particular coastal systems on the local scale. For constructing biogeochemical budgets for coastal waters, LOICZ has developed a set of Guidelines (Gordon *et al*., 1996) which concentrate on the simplest case where an estuary or embayment is treated as a single box which is well-mixed both vertically and horizontally, and at steady state.

The sequence of budgets follows four steps: water budget, salt budgets, non-conservative materials and stoichiometric linkages among non-conservative budgets.

3.1. WATER BUDGET

Figure 1 illustrates the contributions of different sources in the water balance of a coastal system, which can be summarised as freshwater inflows: runoff, precipitation, groundwater; and evaporation from the system. Assuming either that the coastal volume is constant or its derivative (dF_{system}/dt) known, then the net water outflow from the system can be estimated by difference.

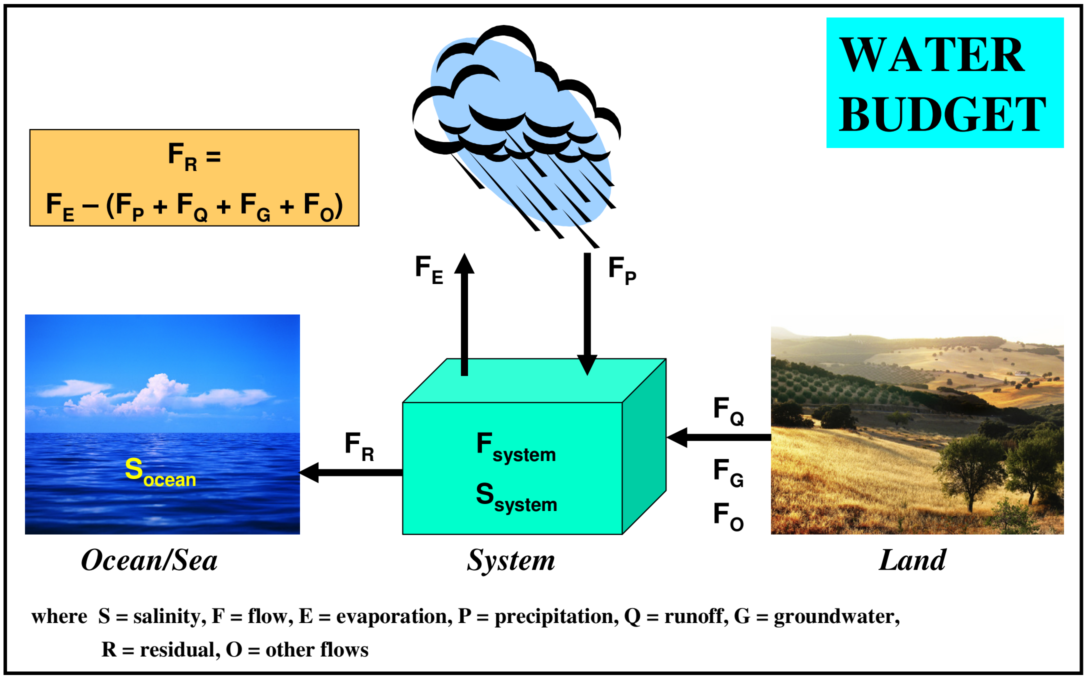

Figure 1. Water budget for a coastal water body of volume F_{system} (adapted from Gordon *et al.*, 1996).

3.2. SALT BUDGETS

Because salt, in principle, is not being either produced or consumed in the system, salinity is said to be conservative with respect to water within the system. Hence, a salt budget (see figure 2) will allow to estimate the flow across the system boundaries, which is used afterwards for the calculation of non-conservative compounds as nitrogen and phosphorous.

3.3. BUDGETS OF NON-CONSERVATIVE MATERIALS

LOICZ concentrates on balances among the essential plant nutrients elements C, N and P. In these budgets (see figure 3), there will be a residual element which is not balanced in the calculations. These residual values are a measure of the net internal fluxes of these materials, which should be interpreted as a function of the internal dynamics of the system.

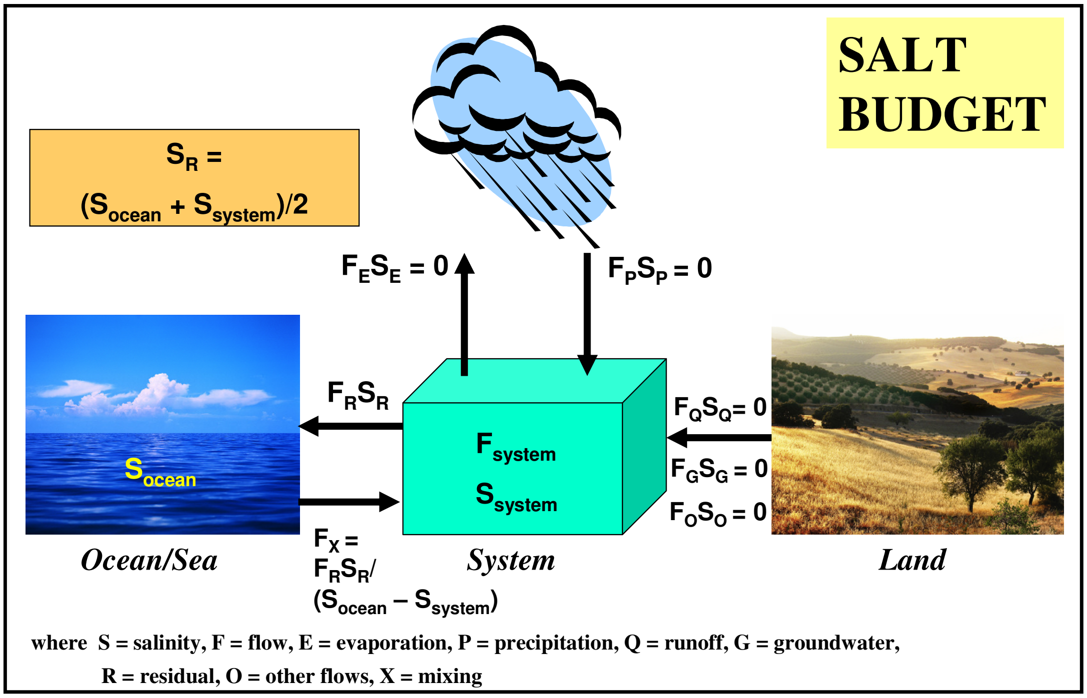

Figure 2. The salt budget for a coastal water body (adapted from Gordon *et al.*, 1996)

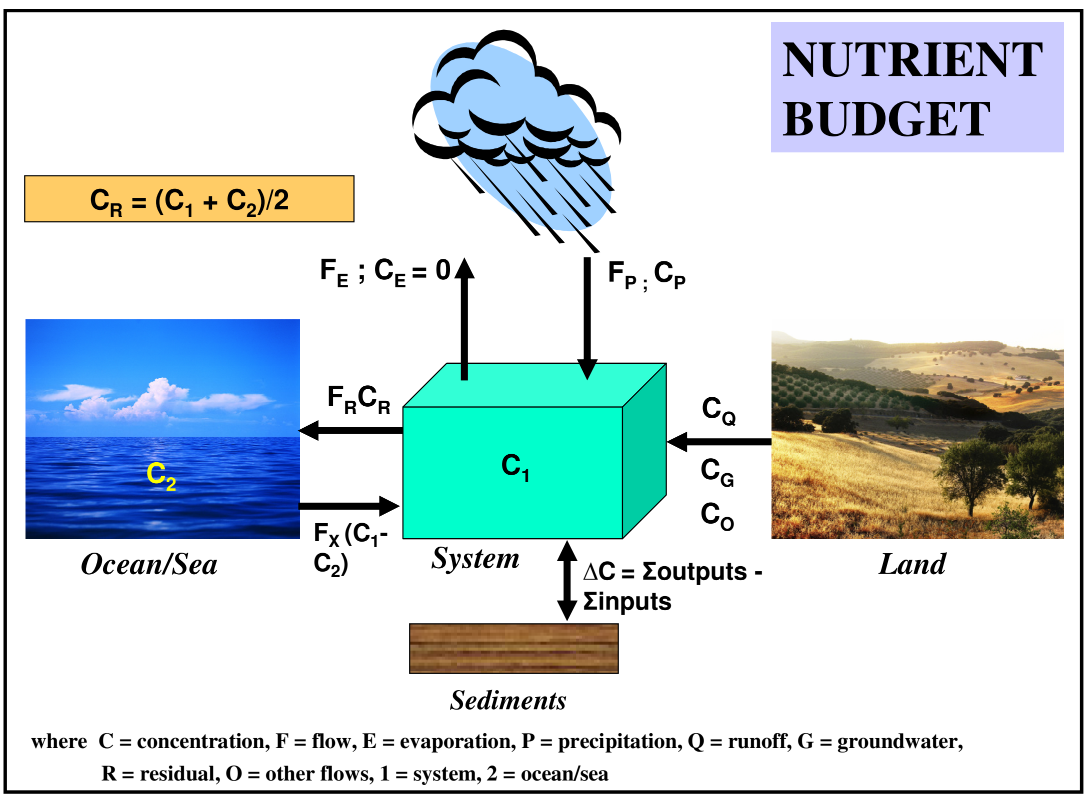

Figure 3. The nutrient budget in a coastal water body (adapted from Gordon *et al.*, 1996)

3.4. STOICHIOMETRIC LINKAGES AMONG NON-CONSERVATIVE BUDGETS

The last step in the LOICZ budget approach involves developing the stoichiometric linkages among nonconservative budgets. The basic assumptions are that biogeochemical cycles of C, N and P are intimately linked and that the approximate stoichiometric relationships among these elements can be written. For instance, in a plankton metabolism dominated ecosystem, the well-established "Redfield Ratio" is considered to be a reasonable approximation of the C:N:P ratio of locally produced (or consumed) organic matter. If the ecosystem is dominated by macrophytes or shellfish then some other composition (ratios) may be more appropriate.

Nitrogen-Phosphorous stoichiometry: Nitrogen is predominantly present in seawater in the gaseous from. Conversion of N_2 gas to organic nitrogen is termed nitrogen fixation (*nfix*) whereas conversion from NO_3^- to N_2 is termed denitrification (*denit*). Both of these processes require biotic mediation (bacteria) and usually require anaerobic conditions to proceed in aqueous ecosystems. Significant amounts of nitrogen are transferred between the so-called fixed nitrogen (DIN _Dissolved Innorganic Nitrogen-, DON -Dissolved Organic Nitrogen-, PN -Particulate Nitrogen-), which is normally measured and gaseous nitrogen (N_2), which is not. The net effect of this transfer has been termed by LOICZ as (*nfix-denit*). This value is often significant for the nitrogen budget, for this reason the LOICZ methodology has proposed the following methodology to calculate it (Webb, 1981):

$$(nfix - denit) = \Delta N - \Delta P \cdot (N:P)_{part} \qquad (1)$$

Assuming that the N:P ratio of particulate material in the system $(N:P)_{part}$ is known, the dissolved flux associated with production and decomposition of particulate material is the dissolved phosphorous flux *($\Delta P = \Delta DIP + \Delta DOP$)* multiplied by $(N:P)_{part}$ minus the measured dissolved nitrogen flux ($\Delta N = \Delta NO_3^- + \Delta NH_4^+ + \Delta DON$) is the net effect of the nitrogen transfer (*nfix-denit*). As DOP and DON tend to be small when compared to DIN and DIP, it is possible to carry out the evaluation without these values (Gordon *et al*., 1986).

Phosphorous-carbon stoichiometry: According to LOICZ methodology (Gordon et al., 1986) the ΔDIP scaled by $(C:P)_{part}$ ratio becomes a measure of net ecosystem metabolism NEM or (p-r).

$$(p - r) = -\Delta DIP \cdot (C:P)_{part} \qquad (2)$$

A system with ΔDIP>0 is interpreted to be producing DIC (Dissolved Inorganic Carbon) via net respiration (*p-r<0*), whereas a system with ΔDIP<0 is interpreted to be consuming DIC via net organic production (*p-r>0*). This assumption is most likely not to work in systems with an anaerobic water column, or with sediments anaerobic to the sediment-water interface. Under either of these conditions, redox-mediated phosphorous desorption from inorganic particles is likely to occur.

4. LOICZ budget: setting up the components

4.1. PRECIPITATION AND EVAPORATION OVER THE MEDITERRANEAN SEA

Gridded precipitation-data sets are an essential base for many applications in the geosciences and especially in climate research, as for instance global and regional studies on the hydrological cycle and on climate variability, verification and calibration of satellite based climate data or the evaluation of global circulation models (GCMs). As all applications require reliable high quality precipitation fields the underlying station data have to meet high demands concerning the quality of the observed precipitation data as well as the correctness of station meta data and also with respect to sufficient spatial station density and distribution. Concerning the use of regionally or globally gridded climate data for analyses of long-term climate variability it has to be ensured that station data used for gridding are as continuous and homogeneous as possible.
In recent years various globally gridded data-sets of monthly terrestrial precipitation observations have been developed for example at the European Centre for Medium Range Weather Forecast (ECMWF), the National Center for Environmental Prediction (NCEP) or the Global Precipitation Centre (GPCC). For research purposes most of these data sets are available free of charge.

For the purpose of this feasibility study we focused on the data from ECMWF, but later on also a detailed comparison to the others products, specifically to the measured data from GPCC must be done.
Precipitation and evaporation estimates for the entire Mediterranean Sea were derived from the ERA-40 reanalysis datasets. Such datasets are the results of a collective effort based on the ERA-40 re-analysis project, carried out by the (ECMWF), in collaboration with a number of institutions in Europe, Asia and North America.

Meteorological observation from a number of different sources (satellite, aircraft, radiosondes, ocean-buoys and other surface platforms), covering the period from September 1957 to August 2002, were collected and a global data assimilation system was set up and operated during the full period.
These data are now available from the Meteorological Archival and Retrieval System (MARS), which is the main data repository at ECMWF.
From the available global data in spectral representation we selected an area covering the European area (25W-45E, 30S-67N) and interpolated it to a grid with unique resolution of 0.5x0.5 degrees. Large Scale Precipitation (LSP) and Convective Precipitation (CP) where both downloaded and aggregated to calculate Total Precipitation (TP). Evaporation (E) comprises evaporation and condensation. The sign convention used here for the data conversion, is so that precipitation and condensation are positive (water accumulation on land or sea), whereas real evaporation is negative (loss of water to the atmosphere). This is opposite to the typical sign convention in meteorology, where precipitation is considered a water loss of the atmosphere.

Precipitation and evaporation data as retrieved from MARS were accumulated into annual totals from the 6-hourly data (0:00, 6:00, 12:00, 18:00) for the period 1996-2002. For the remainder of the period (September 2002 to December 2005), pure model data derived from the operational model (IFS) of ECMWF were used.

It should mentioned that specifically the global modelling of precipitation contains large uncertainties (see e.g. Troccoli and Kallberg, 2004) and even the measured data are not completely satisfactory. A recent model intercomparison of GCM's demonstrated that differences of up to 100% occurred (SCOR working group on fluxes). Fortunately for us the most severe problems are apparent in the tropics and the southern hemisphere, whereas the arid climate of the Mediterranean Sea gives much more reliable precipitation estimates. Nevertheless a detailed data intercomparison, specifically with the GPCC dataset should be carried out, in order to provide more quantitative error bounds.

4.2. COASTAL INPUTS

Coastal inputs estimates were calculated using the AVGWLF model (Evans et al., 2008), composed of the watershed model GWLF (Generalized Watershed Loading Functions, Haith and Shoemaker 1987), and integrated with an ArcView interface to allow for easier and more accurate extraction of input data to the model. AVGWLF has been tested extensively in the US and elsewhere. The model does not explicitly include the spatial aspect of parameters, but instead averages spatial heterogeneity. In other words, the source areas are not spatially distributed throughout the watershed and as such no spatial routing is performed. Instead the model assumes that each source area is located near the watershed outlet and independent of the other source areas. The loads from each source area are then aggregated into a watershed total.

Although the surface loading component of the model can be considered a distributed parameter model because it permits multiple source areas, it assumes that the land cover and soil characteristics are homogeneous within each source area. On the other hand, the subsurface loading component is a lumped parameter model and applies a water balance approach for the unsaturated and saturated subsurface zones. Groundwater is treated as one source in the model. Daily time steps are used for the input weather data and the subsequent water balance computations. GWLF is a continuous simulation model and daily values are accumulated to express monthly and annual values for the final output (Haith and Shoemaker, 1987; Haith et al., 1992).

The Soil Conservation Service Curve Number (SCS-CN) method is employed to partition surface runoff and infiltration. Accordingly, each source area is designated a curve number that determines the amount of direct surface runoff. The precipitation that enters the soil is assigned to the unsaturated zone and may be lost to evapotranspiration processes. Evapotranspiration is estimated from a cover coefficient, the available moisture in the unsaturated zone, and potential evapotranspiration, which is estimated from the number of daylight hours and mean daily temperature. Further infiltration to the shallow saturated zone occurs once the unsaturated zone is filled. The shallow saturated zone functions as a linear reservoir that either transmits the infiltrated water to the stream or to deep seepage. On the other hand, erosion and sediment yield is computed by the Universal Soil Loss Equation (USLE) for each source area. In order to predict the sediment yield originating from each source area, a sediment delivery ratio as a function of watershed size is first calculated and subsequently a transport capacity linked to the average daily runoff is applied. The transport capacity refers to capacity of surface runoff to transport sediment. During a given month, the sediment yield is proportional to the total transport capacity of that month's daily runoff. In turn, evaporation losses are estimated using daily weather data and involve applying an evaporation cover factor to each existing land cover. Dissolved nutrient loads are computed from rural runoff, groundwater, septic systems, and point sources. Solid-phase nutrient loads may originate from rural runoff, urban runoff, as well as the recently included streambank erosion component in the AVGWLF version of the model. The streambank erosion routine is based on a technique often applied in the field of geomorphology where monthly stream-bank erosion is computed via a watershed-specific lateral erosion rate, average stream-bank height, total stream length in the watershed and average soil bulk density.

One of the major advantages of the model is its ease of use as well as its reliance on input datasets that are less complex than those required by other hydrologic/water quality models, such as SWAT, HSPF, etc. (Deliman *et al.*, 1999). Furthermore, the GWLF model has been used in various geographically diverse watersheds, including watersheds in the United States, Mexico, Ecuador and Chile (Haith *et al.*, 1992; Lee et al., 2000; Izurieta *et al.*, 2001; Strobl et al., 2007). In addition, the U.S. EPA has in fact officially endorsed the model as a good "mid-level" model incorporating algorithms for simulating most of the main mechanisms influencing nutrient fluxes within a watershed (U.S. EPA, 1999). For a more detailed description of the model, the reader is referred to Evans et al. (2008).

4.2.1. *Model data requirements*

Model data requirements (mandatory and optional) are listed in table 2, along with the data actually used to perform the simulation.

Land use: The land use/cover data used for the Mediterranean area came from the Corine Land Cover 2000 and Global Land Cover 2000. These two data sets had different classification schemes which needed to be adapted to the AVGWLF land use categories.

Soils: The soils layer for the AVGWLF model was constructed using the soil databases ESDB and ISRIC-WISE. In order to arrive at an accurate K-factor (from the Universal Soil Loss Equation (USLE)), a textural triangle (see http://www.pedosphere.com/resources/bulkdensity/triangle_us.cfm) and average values for K (http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm#tab2) were used along with the dominant surface texture information provided within the ESDB. Using the dominant surface texture information provided within the ESDB, the K factor values were estimated. The AVGWLF soils layer also requires information on the available water capacity (AWC). The topsoil available water capacity and the depth to rock parameters from the ESDB were utilized**.** The hydrologic soil group (HSG) value for the soil layer was obtained by using the soil textures given in the ESDB along with the classification given in table 3. Therefore, the ESDB internal code for surface texture could be used to define the HSG as presented in table 4.

Table 2. Data requirement and sources.

DATA TYPE		DESCRIPTION	MANDATORY/USED	SOURCE
SHAPEFILES	Weather stations	Weather station locations (points)	Y / Y	MARS STAT (2007)
	Point Sources	Point source discharge locations (points)	N / N	
	Water Extraction	Water withdrawal locations (points)	N / N	
	Tile Drain	Locations of tile-drained areas (polygons)	N / N	
	Basins	Basin boundary used for modeling (polygons)	Y / Y	CCM2 & WWF (2006, 2007)
	Streams	Map of stream network (lines)	Y / Y	CCM2 & WWF (2006, 2007)
	Unpaved Roads	Map of unpaved roads (lines)	N / N	
	Roads	Road map (lines)	N / N	
	Septic Systems	Septic system numbers and types (polygons)	N / Y	ELISA (2001)
	Animal Density	Animal density (in AEUs per acre) (polygons)	N / Y	FAO GeoNetwork (GLiPHA, 2005)
	Soils	Contains various soil-related data (polygons)	Y / Y	ESDB & ISRIC-WISE (2003, 2006)
	Physiographic Provinces	Contains hydrologic parameter data (polygons)	N / Y	
GRID FILES	Land Use/Cover	Map of land use/cover (16 classes)	Y / Y	Corine 2000 & Global Land Cover 2000
	Elevation	Elevation grid	Y / Y	SRTM (2006)
	Groundwater-N	Background estimate of N in mg/l	N / N	
	Soil-P	Estimate of soil P in mg/kg (total or soil test P)	N / N	

Table 3. Hydrologic soil group in relation to surface texture

HSG	Surface Texture
A	Sand, Loamy Sand or Sandy Loam
B	Silt Loam or Loam
C	Sandy Clay Loam
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay

Table 4. ESDB internal code for surface texture in relation to the HSG.

ESDB Internal Code for Surface Texture	HSG
0	D
9	A
1	A
2	B
3	C
4	D
5	D

Animal density: The animal density input layer to the AVGWLF model is based on an animal equivalent unit (AEU) which was prepared by using data on poultry, sheep, pigs, cattle, goats and buffaloes available from the GLiPHA maps data base of the FAO for the year 2005. An AEU is traditionally defined as 1000 pounds of animal weight (equals 453.6 kg of animal weight) (Kellogg et al., 2000). The layer was produced by assuming an average weight for each of the animal categories and giving it a fraction of an AEU, as illustrated in table 5.

Table 5. AEU for various animal category.

Animal Category	One Animal equal to:
Horse	1.0 AEU
Cattle	0.9 AEU
Pig	0.25 AEU
Goat	0.04 AEU
Sheep	0.06 AEU
Buffalo	1.4 AEU
Poultry	0.004 AEU

Septic systems: The AVGWLF septic system input layer was based on the ELISA population grid from 2001, separating the population connected to septic systems and public wastewater treatment plants according to United Nations Statistics Division - Environment Statistics (http://unstats.un.org/UNSD/ENVIRONMENT/wastewater.htm) and other internet sources (for countries not included in United Nations Statistics Division - Environment Statistics estimates).

Crops: For conformity reasons, all basins draining into the Mediterranean were assumed to have a principal crop growing period between April and October, as well as manure application periods between February and April and October and November.

4.2.2. Results

Mediterranean-discharging watersheds were agglomerated into 66 larger watersheds to reduce the total simulation time of this exercise (see figure 4). Using the data layers, as indicated in table 2, the AVGWLF model was used to generate estimates of streamflow and nutrients for each of the larger 65 watersheds (the Nile river watershed was not simulated). In a subsequent step, the average streamflow and TN and TP loads were aggregated for all 65 watersheds, using the meteorological years that were common to all (i.e., 1996 – 2005), in order to make a comparison to the estimations for TN and TP as reported in EEA/UNEP (1999) and UNEP/FAO/WHO (1996). The EEA/UNEP (1999) estimates were based on land-based inputs to the Sea, while the UNEP/FAO/WHO (1996) approximations were based on the 50 largest rivers discharging into the Mediterranean Sea.

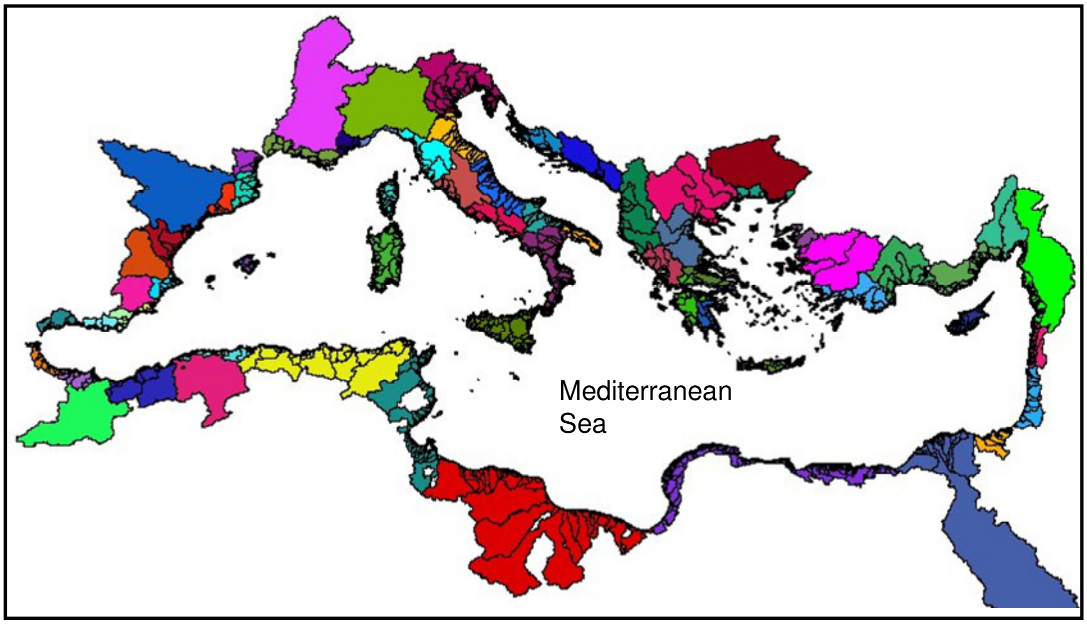

Figure 4. Basin aggregation used for simulation purposes (adjacent aggregated watersheds are indicated the same color).

Results obtained were thus calibrated using the only data found for this purpose (UNEP/MAP/MED POL, 2004, see table 1). These data are in form of annual averages; however, the reference period for these averages is not reported. Nevertheless, these data were utilized for calibration purposes, assuming that they are well representative of the period used in the AVGWLF simulations. Due to the limited amount of actual data available for calibration purposes, the only measure for calibration used was to first match the average annual values for streamflow and then for nutrients (when available). The calibration was undertaken using 15 of the individual basins. These were deemed to be sufficient to then, at a post-calibration stage, assign the calibrated values to the original aggregated basins geographically located close-by around the respective calibrated individual basin and having similar hydroenvironmental conditions and characteristics.

Figure 5 depicts the 15 individual watersheds selected for calibration purposes. There were no reliable basins available from the Asian part of the Mediterranean Sea to the northeastern African part. Boxplots along with the averages from the actual data and simulated, calibrated data for the 15 individual basins are depicted in figures 6 and 7. The final calibrated values were then applied to the respectively hydroenvironmentally similar and adjacent agglomerated basins. Figure 8 shows the association of the agglomerated basins with each respective individual basin. The agglomerated basins, for which the newly calibrated were applied, were re-run. The subsequent output for streamflow and TN and TP was aggregated and then added to the agglomerated basins for which no calibration could be undertaken. The results are reported in table 6.

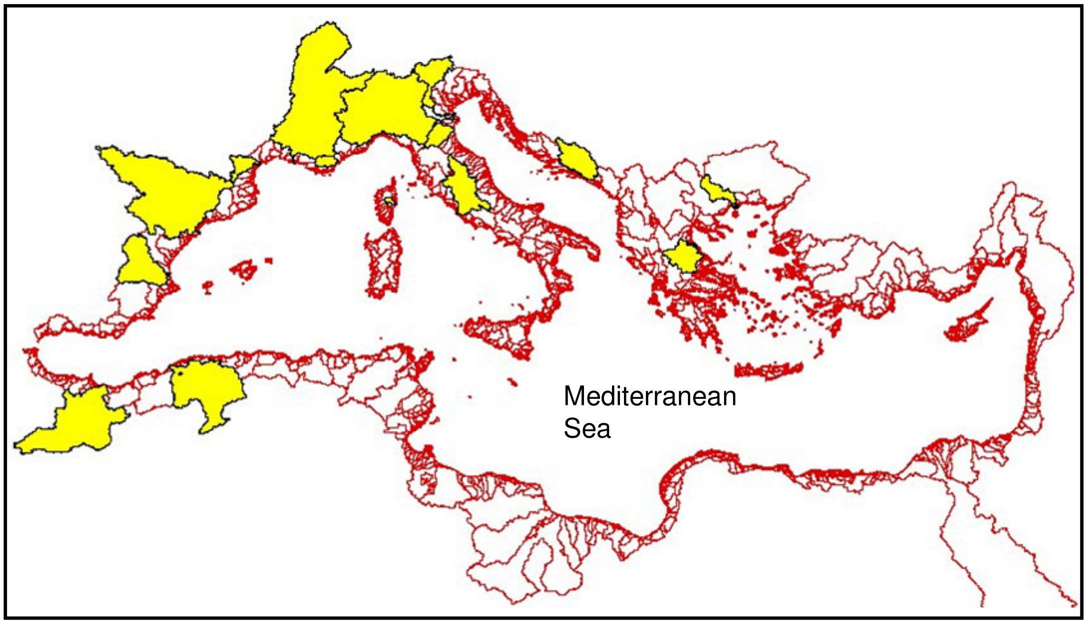

Figure 5. 15 individual basins used for calibration.

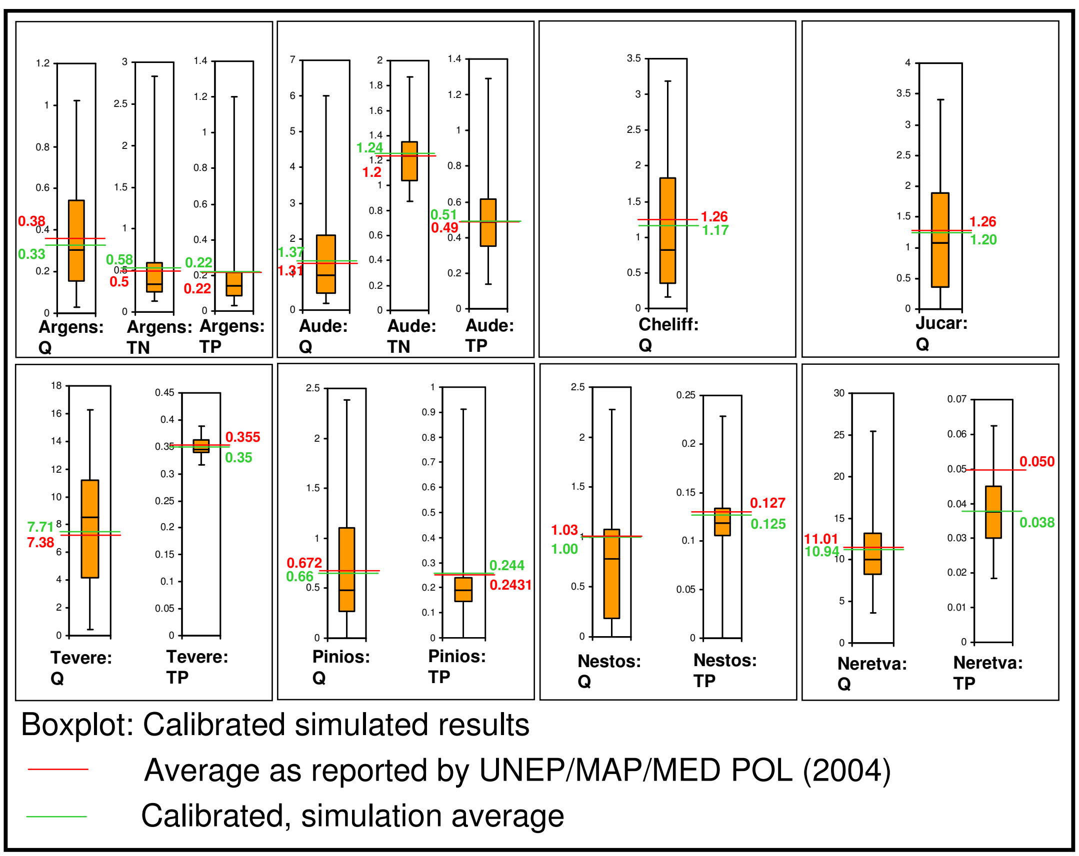

Figure 6. Boxplot and mean comparisons between calibrated simulations and actual data for the available individual basins.

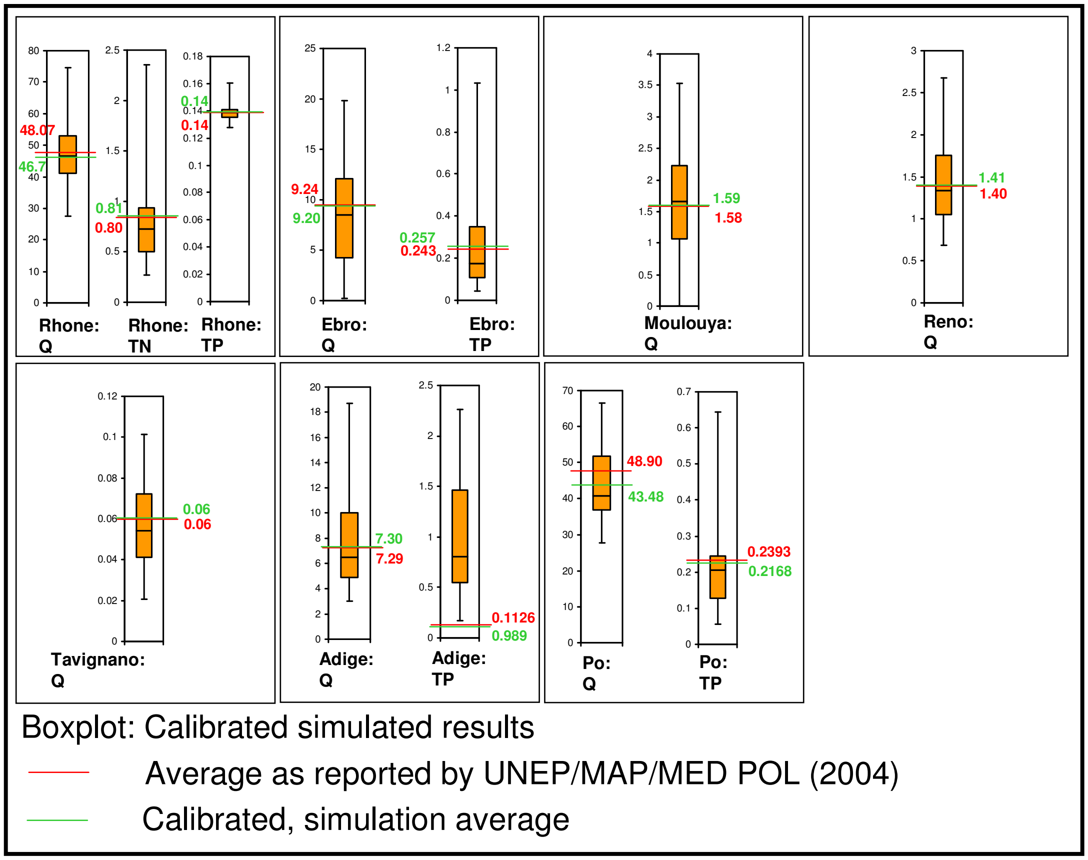

Figure 7. Boxplot and mean comparisons between calibrated simulations and actual data for the available individual basins (ctd).

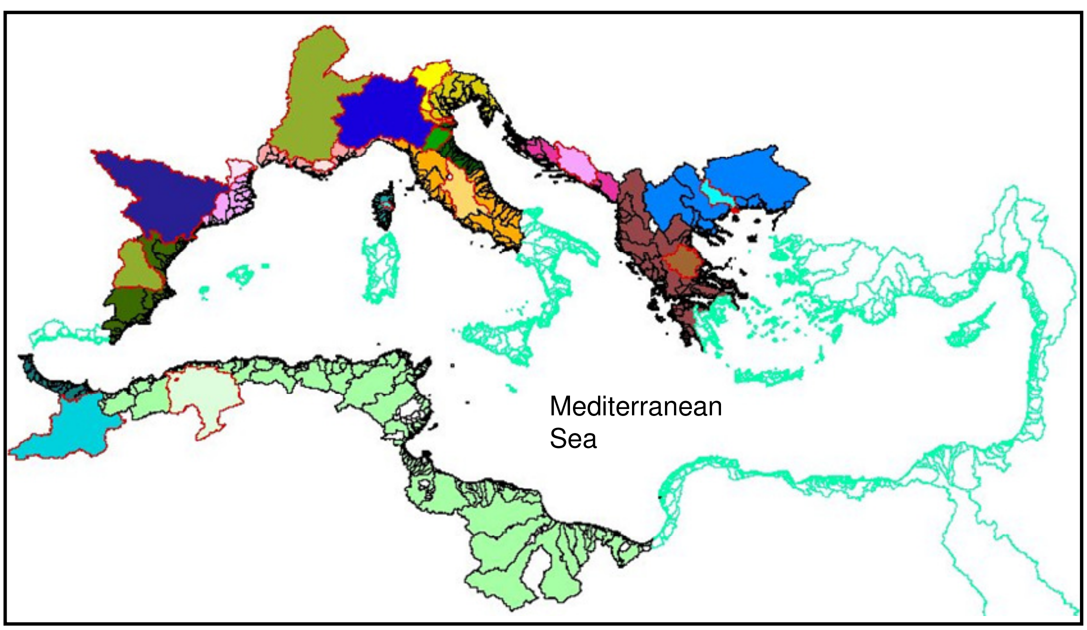

Figure 8. Association of the agglomerated basins with each respective individual basin.

Table 6. Calibrated AVGWLF simulation results in comparison to EEA/UNEP (1999) and UNEP/FAO/WHO (1996) estimates.

Calibrated Results from AVGWLF simulation
(average values ± standard deviation for 1996-2005):
Q: $3.64 \times 10^{11} \pm 0.53 \times 10^{11}$ m³/yr *(without Nile basin, Black Sea and Strait of Gibraltar inputs)*
TN: $1.67 \times 10^{6} \pm 0.55 \times 10^{6}$ ton/yr *(without Nile basin, Black Sea and Strait of Gibraltar inputs)*
TP: $0.10 \times 10^{6} \pm 0.02 \times 10^{6}$ ton/yr *(without Nile basin, Black Sea and Strait of Gibraltar inputs)*
IN COMPARISON:
EEA/UNEP (1999):
TN: 0.3×10^{6} ton/yr *(50 largest rivers discharging into the Mediterranean Sea)*
TP: 0.02×10^{6} ton/yr *(50 largest rivers discharging into the Mediterranean Sea)*
Q: 4.73×10^{11} m³/yr *(riverine input into the Mediterranean Sea)*
UNEP/FAO/WHO (1996):
TN: $1.5 – 2.5 \times 10^{6}$ ton/yr *(land-based range)*
TP: $0.15 – 0.25 \times 10^{6}$ ton/yr *(land-based range)*

Calibrated total streamflow does not include the Nile river, whose discharge to the Mediterranean Sea is estimated atl approximately 0.5×10^{10} m^3/yr (EEA/UNEP, 1999). After adding the Nile river estimate to the calibrated, simulated average, an estimate of 4.14×10^{11} m^3/yr is obtained for the Mediterranean Sea, excluding the Black Sea and Strait of Gibraltar inputs. This values compares relatively well with the streamflow from the EEA/UNEP (1999) estimate of 4.73×10^{11} m^3/yr. The TN and TP estimates from the calibrated simulation run, on the other hand, fall within the range or very close to the range given by the UNEP/FAO/WHO (1996) estimations. They are, however, a magnitude higher than the EEA/UNEP (1999) estimates. As previously mentioned, due to lack of the necessary calibration data the Middle Eastern part of the AVGWLF model could not be calibrated. In addition, the AVGWLF model did not incorporate any possible dams.

4.3. WATER EXCHANGE AT THE STRAITS OF GIBRALTAR AND DARDANELLES

Estimates of water and salinity exchange at the Straits of Gibraltar and Dardanelles can be found in the literature. In particular, for the Gibraltar Strait, estimates can be derived from the works of Bryden and Kinder (1991) and Bryden et al. (1994). For the Dardanelles Strait estimates can be derived, for example, from Stashchuka and Hutter (2001) and Beşiktepe (2003).

4.4. MULTIBOX APPROACH FOR INTERNAL COMPARTMENT EXCHANGE

Due to the high variability in nutrient conditions in the Mediterranean Sea, the LOICZ multi-box modelling approach seems the most sensible option to evaluate nutrient budgets. For this reason, a feasibility study has been carried out using the results of a multiannual run (1986 to 2005) of a 3D hydrodynamic model of the Mediterranean (Burchard and Bolding, 2002; Stips et al., 2004) to calculate water fluxes between several regions (figure 9). The average values (table 7), correspond to the analysis of monthly data simulation files from 1986 to 2005.

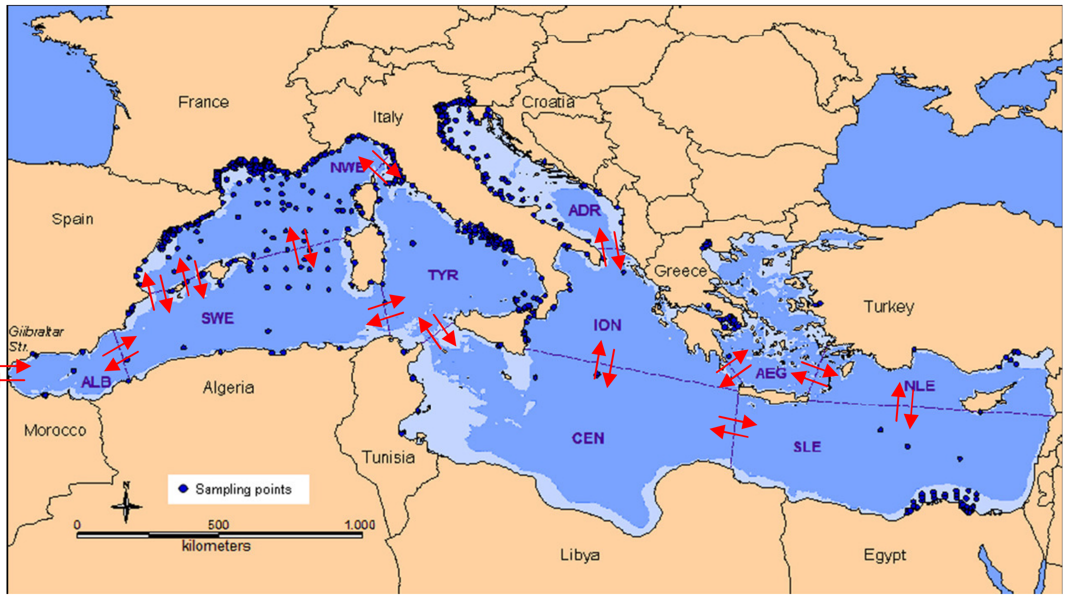

Figure 9. Mediterranean sub-basin definition (modified from Gómez-Gutiérrez et al., 2007).

5. Conclusions

The purpose of the present study was to determine the feasibility of applying the LOICZ budget to the Mediterranean Sea.
The activities carried out allow to conclude that all budget components can be reliably estimated and such budget correctly set up. In particular:

- estimates for precipitation and evaporation of the Mediterranean Sea can be obtained from ECMWF; other sources for estimates of such variables are available, and in a further implementation of this work a comparison between estimate sets will be carried out;
- estimates of annual flow and nutrient output to the Mediterranean Sea as required by the LOICZ budget can be obtained via the setting up of the AVGWLF model, with reasonable operating expense (time and effort) and with acceptable assumptions made for information/data not available for some or all of the regions, especially in the Asian and North African part of the Mediterranean;
- exchanges through the Gibraltar and Dardanelles Straits can also be reliably estimated, based on previous studies.

It is recognized that the estimates of all budget components, as illustrated in the paragraphs above, can be improved. It is foreseen that some of these improvements will be obtained already in the actual implementation of the LOICZ budget.

Table 7. Estimated fluxes between Mediterranean sub-regions.

Region	Flow (10^6 m^3 s^{-1})	Std (10^6 m^3 s^{-1})
Atlantic ALB	0.401	0.089
ALBtoAtlantic	-0.337	0.064
ALBtoSWE	1.768	0.426
SWEtoALB	-4.2545	0.709
Ibiza Channel		
SWEtoNWE	0.482	0.266
NWEtoSWE	-0.266	0.243
Ibiza-Mallorca		
SWEtoNWE	0.178	0.123
NWEtoSWE	-0.145	0.096
Mallorca-Menorca		
SWEtoNWE	0.024	0.019
NWEtoSWE	-0.046	0.032
Menorca-Sardinia		
SWEtoNEW	3.902	1.211
NWEtoSWE	-4.982	1.474
SWEtoTYR	0.418	0.255
TYRtoSWE	-0.696	0.191
NWEtoTYR	-0.001	0.004
TYRtoNWE	0.637	0.147
TYRtoCEN	-0.348	0.126
CENtoTYR	0.208	0.140
IONtoADR	0.465	0.189
ADRtoION	-0.319	0.117
CENtoION	9.361	1.859
IONtoCEN	-11.809	2.426
IONtoAEG	0.390	0.229
AEGtoION	-0.176	0.167
CENtoSLE	2.548	1.483
SLEtoCEN	-3.832	1.245
Creta-Cyprus		
SLEtoNLE	5.427	1.095
NLEtoSLE	-5.589	1.025
Cyprus-Continent		
SLEtoNLE	0.976	0.289
NLEtoSLE	-1.035	0.035
AEGtoNLE	0.648	0.198
NLEtoAEG	-0.282	0.137

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Abstract

The Mediterranean Sea is an important regional EU sea and often used to assess the impacts of global change on the environment, due to its practically enclosed character. As most of the northern part is bordered by the EU, it is also of interest in the evaluation of the environmental and economic impact of the implementation of the EU Water Framework Directive and related environmental legislation. For this purpose, the feasibility to carry out a budget approach, developed in LOICZ (Land Ocean Interactions in the Coastal Zone) project has been analyzed. The activities carried out allow to conclude that all budget components can be reliably estimated and such budget correctly set up. In particular:

- estimates for precipitation and evaporation of the Mediterranean Sea can be obtained from ECMWF; other sources for estimates of such variables are available, and in a further implementation of this work a comparison between estimate sets will be carried out;
- estimates of annual flow and nutrient output to the Mediterranean Sea as required by the LOICZ budget can be obtained via the setting up of the AVGWLF model, with reasonable operating expense (time and effort) and with acceptable assumptions made for information/data not available for some or all of the regions, especially in the Asian and North African part of the Mediterranean;
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