LIFE ENVIRONMENT STRYMON

Ecosystem Based Water Resources Management to Minimize Environmental Impacts from Agriculture Using State of the Art Modeling Tools in Strymonas Basin

LIFE03 ENV/GR/000217

Task 1. Strymonas Basin Integrated Surface Water – Ground Water Model

Technical Report "Strymonas Basin Integrated Surface Water & Groundwater Model – Phase II. Impact Assessment on Water Resources and Ecosystems from Agriculture Activities"

THE GOULANDRIS NATURAL HISTORY MUSEUM
GREEK BIOTOPE / WETLAND CENTRE

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1. INTRODUCTION

1.1. Description of the study area

Strymonas constitutes a transboundary river and its catchment is shared among Bulgaria (50.0 %), Serbia (4.0 %), FYROM (9.5 %) and Greece (36.5 %). The Greek part of the catchment covers an area of 6400 km^2. The elevation of the catchment ranges from 2200 m to sea level. The plain elevations vary from 45 m to sea level, and exhibit a small slope in the direction from Northwest to Southeast.

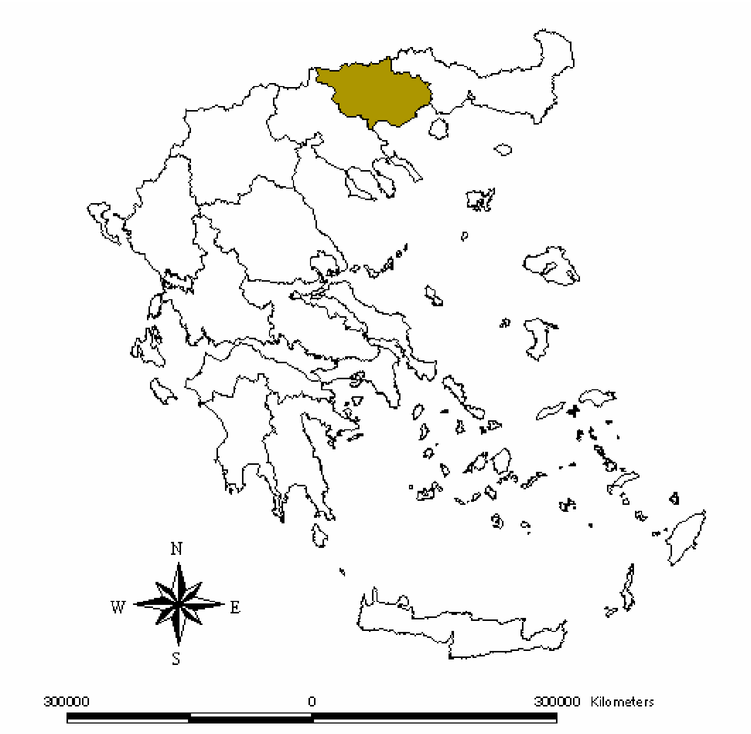


Figure 1. The 11th water district of Greece

River Strymonas and Lake Kerkini (artificial lake fed by Strymonas) are the main surface water bodies in the catchment, which in turn support its natural enrichment with groundwater. The length of the river in Greece is 121 km and the mean annual inflow discharge from Bulgaria is 75 m^3s^{-1}. Strymonas outflows to Strymonikos Gulf whose coastal ecosystems are very important for fisheries, biodiversity and tourism. Lake Kerkini was constructed during 1933-36 mainly for protection against floods caused by Strymonas River. Soon after it was used as a reservoir for irrigation water. During recent decades a unique wetland ecosystem has been developed in its shores, which is protected by the Ramsar Convention and EU legislation.

Agricultural activities, which constitute the main water user in the catchment, take place in its lower part (elevation less than +100 m). From the 100.000 ha of arable land, 84.500 ha are irrigated either directly from Strymonas River and Lake Kerkini (54.500 ha) or from streams and pumping wells (30.000 ha).

1.2 Surface water management in Strymonas basin

Strymonas River and Lake Kerkini are the main water sources for irrigation in the basin. The irrigation and drainage of the plain areas are elaborated through a dense network of irrigation canals and drainage ditches.

Land Reclamation Service of Serres – Greece (DEB-S) is the competent authority for the management of water for irrigation through its administrative and technical supervision of the General Land Reclamation Agency (G.L.R.A.) and of the 10 Local Land Reclamation Agencies (L.L.R.A.). These agencies are organizations of an agro-cooperative nature aiming at the management of land reclamation works and the distribution of irrigation water. The irrigation networks supervised by the above agencies are shown in Fig. 2.

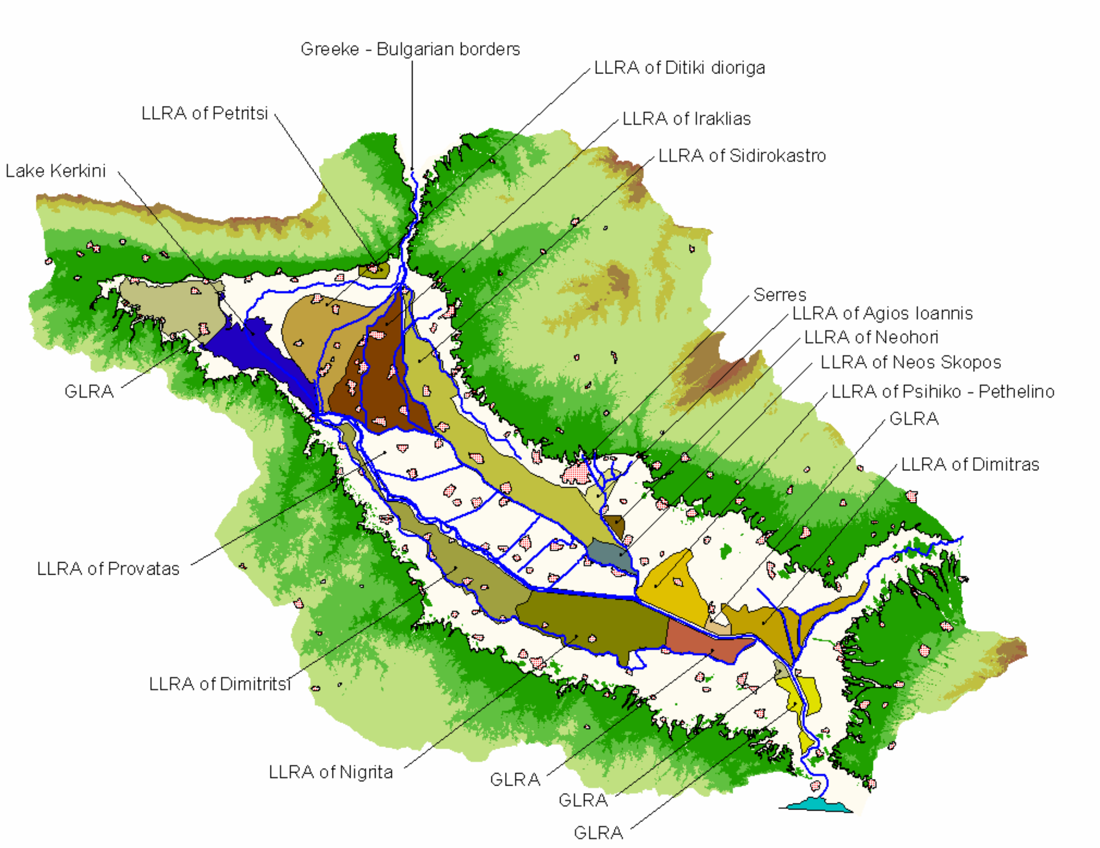


Figure 2. Irrigation networks in Strymonas River basin

During the irrigation period (from mid April to mid September) part of Strymonas discharge diverts through the "Y1" flow control structure into three irrigation networks (Ditiki Dioriga, Iraklia, Sidirokastro), while the remaining discharge outflows into the Lake Kerkini. Three more irrigation networks receive water directly from the lake through the "Y2" and "Y3" flow control structures (Provatas, Dimitritsi, Nigrita). Downstream the lake only a few amount of water is released in Strymonas River up to its joint with Belitsa drainage ditch. Meanwhile the latter receives the drainage water from all the networks located eastern of Strymonas River and supplies with water three more irrigation networks (Neohori, Neos Skopos, GLRA). The excess water of Belitsa outflows again into Strymonas River which in turn is used from the remaining irrigation networks (Figure 2).

During the period between autumn and spring the whole amount of Strymonas discharge flows into Lake Kerkini. The water level in the lake is controlled by four gates that also control the downstream discharge to avoid floods at the lowest area of the catchment, since the maximum conveyance of the river nowadays has been reduced to 200 m^3s^{-1} [9]. Downstream the lake, Strymonas River crosses the plain for 77 km and outflows into Strimonikos Gulf. The Gulf is also remaining the final receiver of all surface runoff of the basin.

The surrounding mountainous area of the plain (elevation higher than +100 m) drains through a number of torrents either in Kerkini Lake or in Strymonas River (Fig. 3). More precisely, the west part downstream of Lake Kerkini, drains through a number of torrents directly into Strimonas River. At the east, the main drainage canal Belitsa receives almost all surface runoff from both the plain and mountainous areas and finally outflows into Strymonas River (Fig. 3). The rest of the east mountainous area drains through the torrent Ag. Ioannis and small drainage ditches directly to Strymonas River. The north and west mountainous area drains through a number of torrents either to Strymonas River or Lake Kerkini.

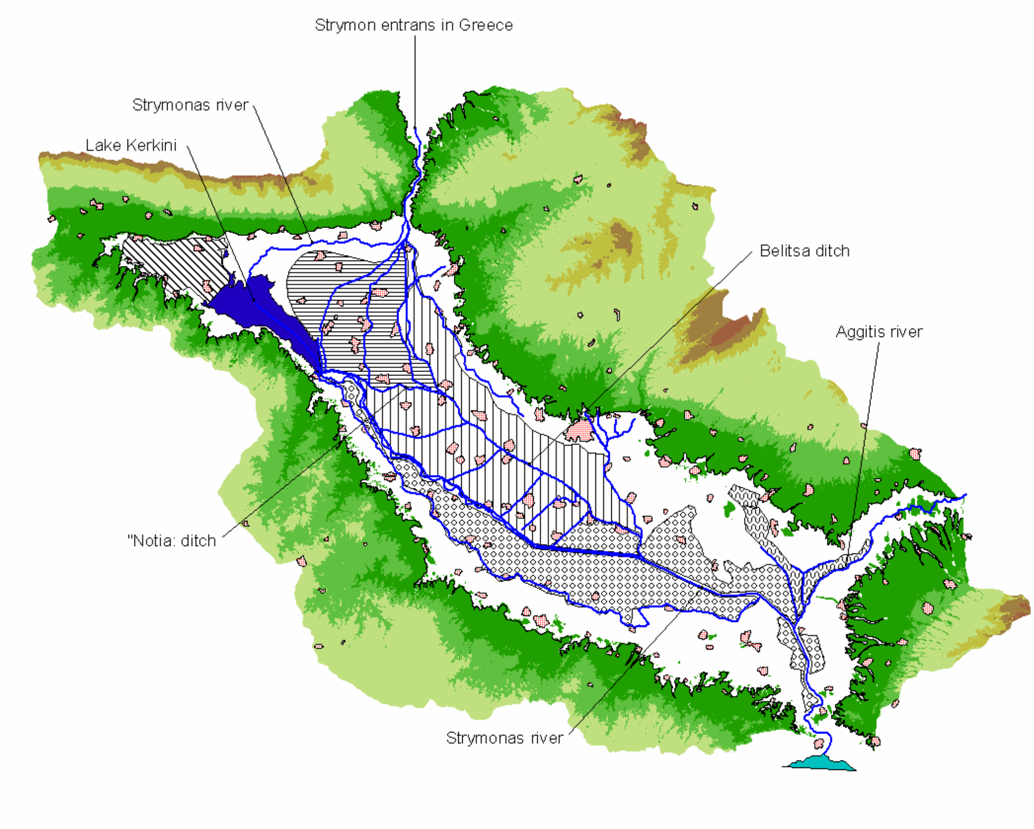


Figure 3. Drainage areas and final receivers in Strymonas basin.

1.3 Groundwater management in Strymonas basin

The plain of Serres is probably one of the richest ones in Greece in terms of surface water availability. In many cases soil studies in the area has shown that the crops could meet their irrigation needs directly from the capillary zone.

Due to the above, together with the early constructions of the Lake Kerkini and the accompanied land reclamation works, the use of ground water constitutes only a small percentage compared to surface water use in Strymonas basin.

For the same reason, data related to the ground water are very limited. Presently the agricultural area that meets its irrigation needs using ground water is located in places where surface water irrigation schemes have not yet been constructed. It is estimated that 25% of the agricultural land is irrigated by pumping wells (21,250 ha) and springs (8,750 ha).

2. METHODS AND TOOLS

For the purposes of this study the terminology that is used by the relevant guidance document "*Guidance for the analysis of Pressures and Impacts in accordance with the Water Framework Directive*" of WFD has been adopted (Table 1).

Table 1. The DPSIR framework as used in the pressures and impacts analysis.

Driver	an anthropogenic activity that may have an environmental effect (e.g. agriculture, industry)
Pressure	the direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry
State	the condition of the water body resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics)
Impact	the environmental effect of the pressure (e.g. fish killed, ecosystem modified)
Response	the measures taken to improve the state of the water body (e.g. restricting abstraction, limiting point source discharges, developing best practice guidance for agriculture)

Guidance for the analysis of Pressures and Impacts in accordance with the Water Framework Directive.

Since agriculture is the only "driver" that is considered in this study, the following "pressures" are investigated and quantified:

- Water abstraction from surface waters
- Water abstraction from groundwater
- Fertilizer applications

In the above mentioned guidance document there is a clear distinction between "state" and "impact". The main reason for this is that many of the impacts are not easily measurable and state is often used as an indicator of, or surrogate for, impact.

In this study the "state" of both surface waters and groundwater are assessed and quantified as it is described by the following parameters:
Rivers: discharge, nutrient concentration
Lake: water level, hydroperiod, nutrient concentration
Groundwater: Water level

A clear assessment and quantification of the "impacts" that certain pressures exert on an ecosystem requires time series of coinstantaneous data of both environmental factors (e.g. fauna and flora species population, habitat extent etc.) and pressures (e.g. abstracted discharge, pollutant loads). The conductance of such a research was not among the objectives of this study. However a detailed description in time and space has been elaborated regarding: a) the pressures that agriculture puts in the catchment and b) the state of both surface waters and groundwater as a result of the current management of irrigation water and agro-ecosystems.

2.1 Use of MIKE SHE/ MIKE 11

MIKE SHE is a fully distributed, physical based, finite difference hydrological modeling system dynamically coupled with MIKE 11 that contains an implicit, finite difference computation of unsteady flows in rivers and estuaries (Fig.4).

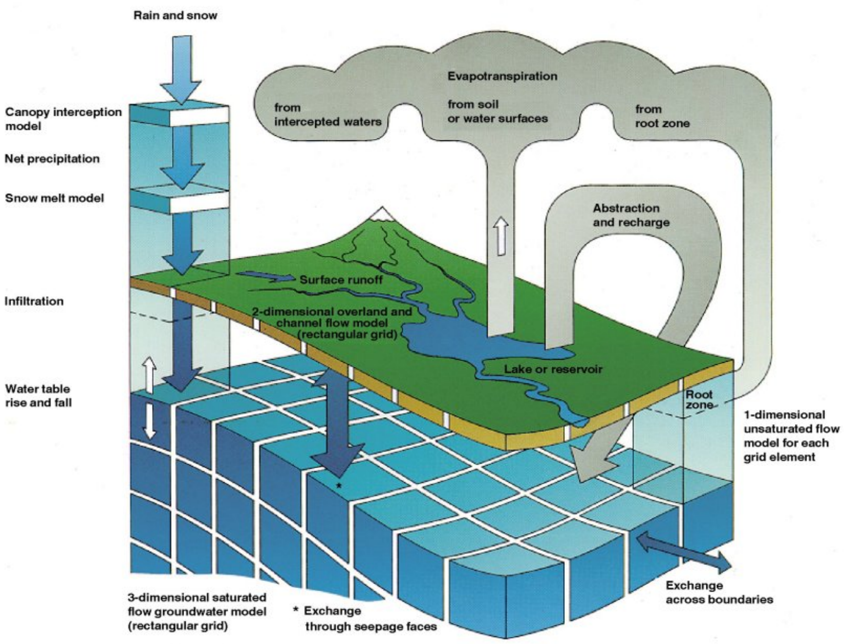


Figure 4. Conceptual representation of the model

In the plain (elevation less than +100 m) of Strymonas basin, were the pressures and impact analysis take place, the model area has been discretisized into a number of computational cells for the numerical solution of the governing equations. The spatial scale of MIKE SHE (grid size), has been chosen to be 400m x 400m allowing for a detailed representation of crop pattern, irrigation methods, irrigation conveyance system, water management structures and drainage system. The simulation covers the period from 1/1/2004 to 31/12/2006 while the time step was 24 hrs for MIKE SHE and 3min for MIKE 11.

Using the modelling system, the following major water flow processes have been simulated simultaneously in the basin:

- Runoff from the surrounding subcatchments
- Overland sheet flow and depression storage
- Infiltration and storage in the unsaturated zone
- Dynamic exchange between unsaturated zone-groundwater (recharge)
- Dynamic exchange between aquifers – rivers (seepage)

- Groundwater flow, storage and potential heads
- River/canal flow and water levels
- Evapotranspiration losses
- Effects of drainage
- Irrigation

2.2. Satellite image analysis

The composition of crops and their spatial distribution in a certain area (crop pattern), are directly related to the degree of pressures that agriculture puts on water resources and their ecosystems, both in terms of water extraction for irrigation and nutrients inputs. In this work, the yearly crop pattern in Strymonas plain was assessed using satellite image analysis techniques.

Five sets of images (SPOT5 pixel size 10mx10m), were obtained for the years 2004 to 2006 between April and August. All the images were georeferenced to the Greek Geodetic Reference System EGSA΄87 using ERDAS IMAGINE version 8.4.

In addition to the satellite images, which were the primary source of spatial data, topographic maps in 1:50.000 scale, the Digital Elevation Model (DEM) of the catchment and the Corine Landcover data base, were used for the acquisition of spatial information.

Field visits during spring and summer were performed to the study area for the collection of vegetation signatures. A total of about 120 - 150 signatures were collected from different crop samples. The position of all these signatures was recorded using the GPS and ArcPad system.

The classification procedure was including firstly the extraction of inhabited areas, clouds, water bodies, and rice beds since they could easily be delineated through direct digitization on the satellite image. The identification of the remaining crops was accomplished through a supervised classification method.

The resulted raster maps (10m x 10m) of the yearly crop patterns were upscaled to 400m x 400m in order to be readily available for the MIKE SHE hydrological model of the catchment. The error that was introduced regarding the extent of each crop by resizing the cells in the raster maps was corrected by comparing the total area of each crop with statistical data derived from the Local Land Reclamation Agencies. Hence, new raster maps (400m x 400m) of the yearly crop pattern were resulted which used in MIKE SHE model for the spatial estimation of the irrigation water needs in the catchment.

Crop pattern raster maps combined with information on agricultural practices (e.g. amounts of fertilizers applied per crop) can be proven very useful in estimating the pressures that agriculture exerts in a specific area.

2.3. Farm management survey

Since no any record is kept by the competent authorities regarding agricultural practices in the basin, data related to fertilizers were acquired through an extended farm management survey. The survey was conducted over a three year period (2004-2006), with in-person interviews, using a questionnaire designed to account for all aspects of farming practices in local farms.

Taking into account the size of the area as well as the structure of agriculture in the basin a sample of 295 farms uniformly distributed in the basin was examined. The type of fertilizers (Nitrogen, Phosphorous), the amount and the time they are applied were among the information retrieved from the farmers through individual interviews.

3. RESULTS AND DISCUSSION

3.1. Analysis of pressures in Strymonas basin water resources

The magnitude of pressures in terms of water abstraction that agriculture exerts on surface waters (River Strymonas and Lake Kerkini) in the catchment is shown in Figures 5 to 9. A total amount of about 580 x 10^6 m^3 per year is abstracted from these main water bodies and delivered to the irrigation networks. However only the half (280 x 10^6 m^3) is finally used to cover the irrigation needs. The rest is diverted downward through the drainage networks. The efficiency in the irrigation networks as it can be seen from the above figures varies from 45 to 55 % or even less (25 % for the networks of Dytiki Dyoriga).

The above small efficiencies imply that a there is a grate ability in the catchment for further reductions regarding the water delivered to agriculture and hence for lowering the pressures that water abstractions exert on surface water resources.

The pressures that agriculture exerts on groundwater within the area that is covered by irrigation networks in terms of water abstraction is shown in Figures 10 to 15 while the total amount of groundwater that is abstracted from the whole catchment is given in Figure 16. An amount of about 135 x 10^6 m^3 of groundwater is abstracted per year from the catchment for irrigation purposes. In this case where the irrigated crops meet their needs with water pumped from groundwater the efficiency is much higher and varies from 70 to 90 % following to the irrigation methods that are used by the farmers. Drip irrigation is related with higher efficiencies than sprinkles and one could suggest the promotion of the former for further reduction of water losses. However drip irrigation is rather inefficient -economically and technically - for these areas where cotton, corn and sugar beets are the prevailing crops.

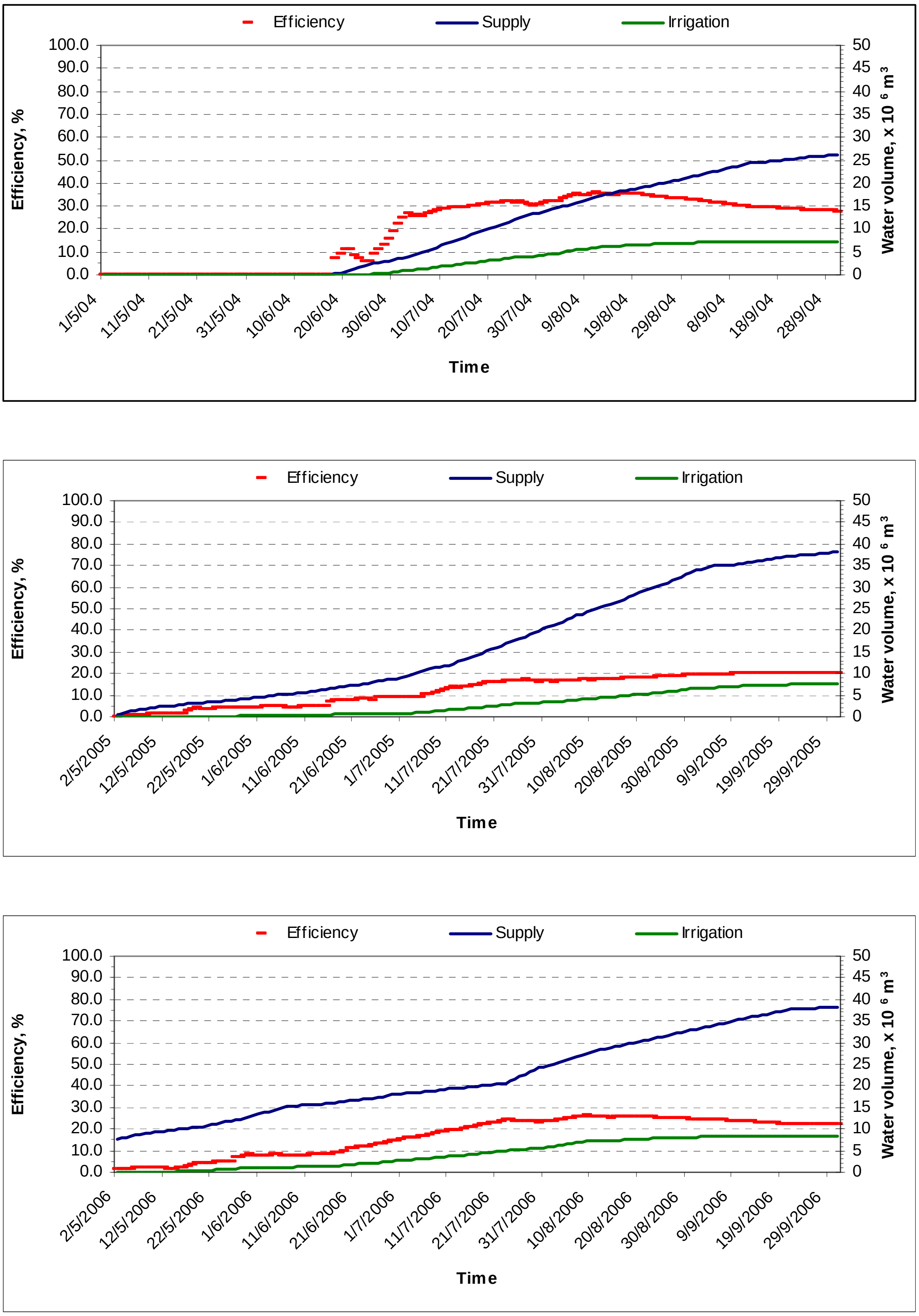


Fig. 5. Total volume of supplied and irrigated water and estimated efficiency in the irrigation networks of TOEB Dytiki Dyoriga during 2004 - 2006.

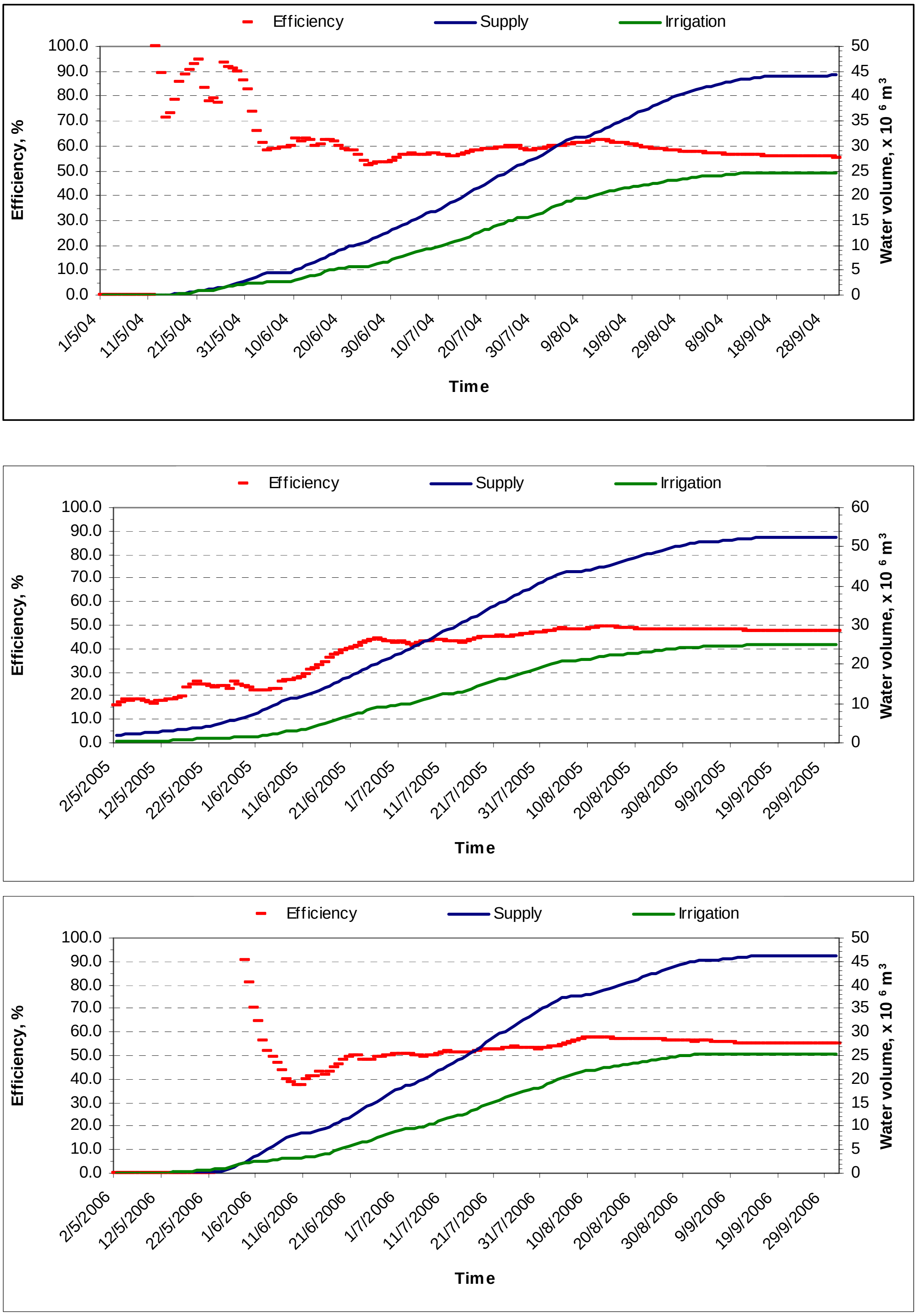


Fig. 6. Total volume of supplied and irrigated water and estimated efficiency in the irrigation networks of TOEB Iraklia during 2004 - 2006.

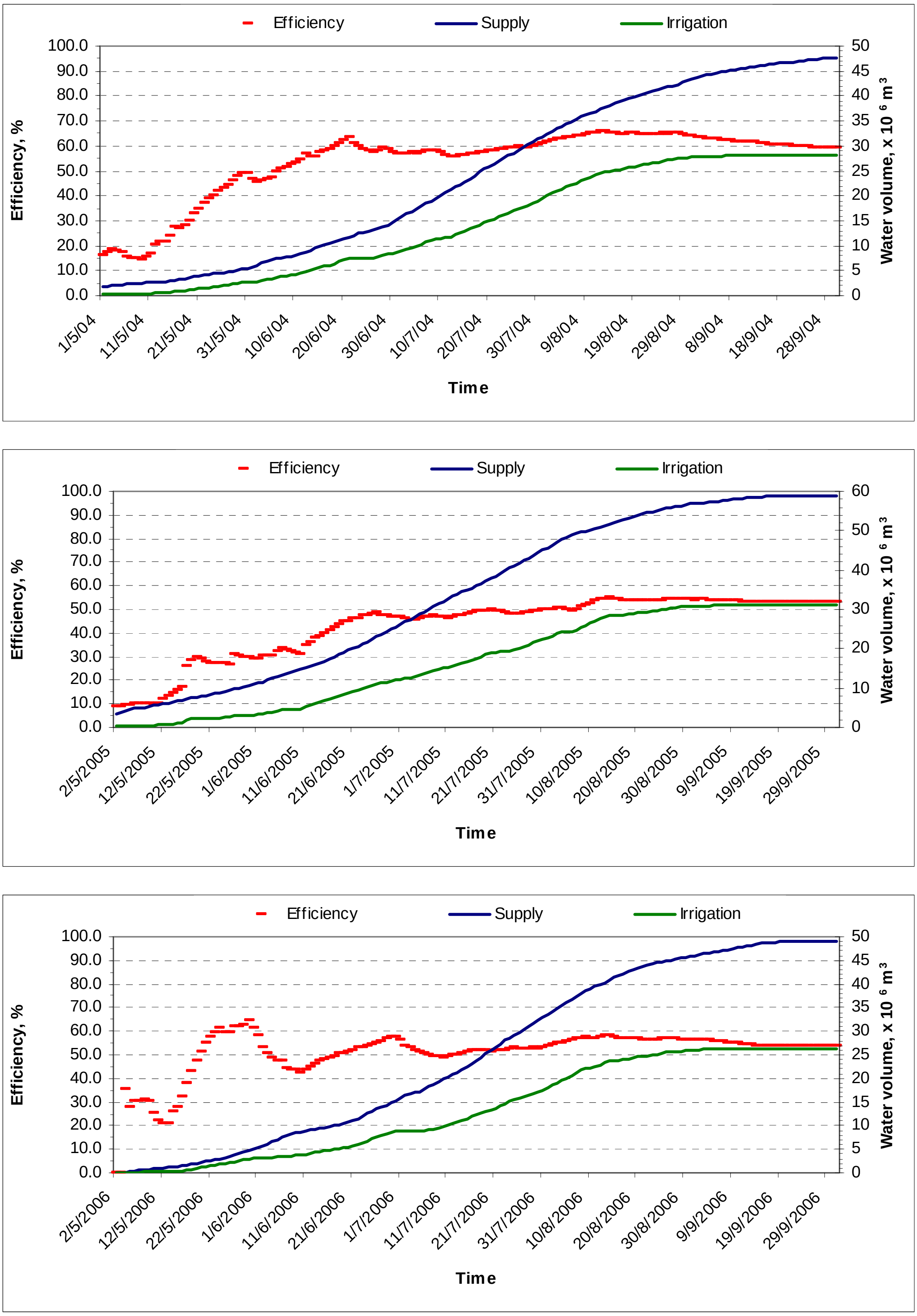


Fig. 7. Total volume of supplied and irrigated water and estimated efficiency in the irrigation networks of TOEB Sidirokastro during 2004 - 2006.

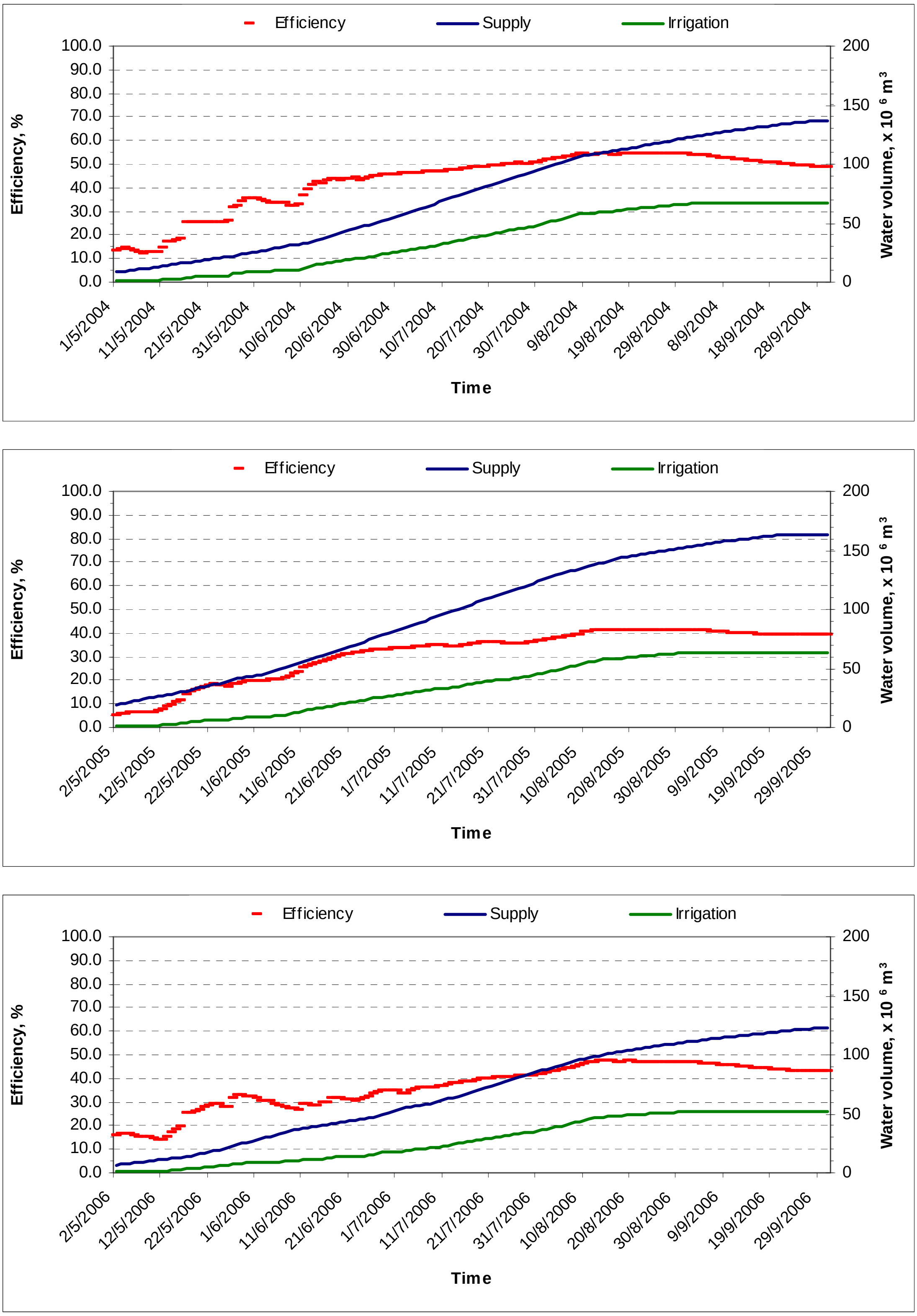


Fig. 8. Total volume of supplied and irrigated water and estimated efficiency in the irrigation networks of TOEB Dimitritsi, Nigrita and GOEB during 2004 - 2006.

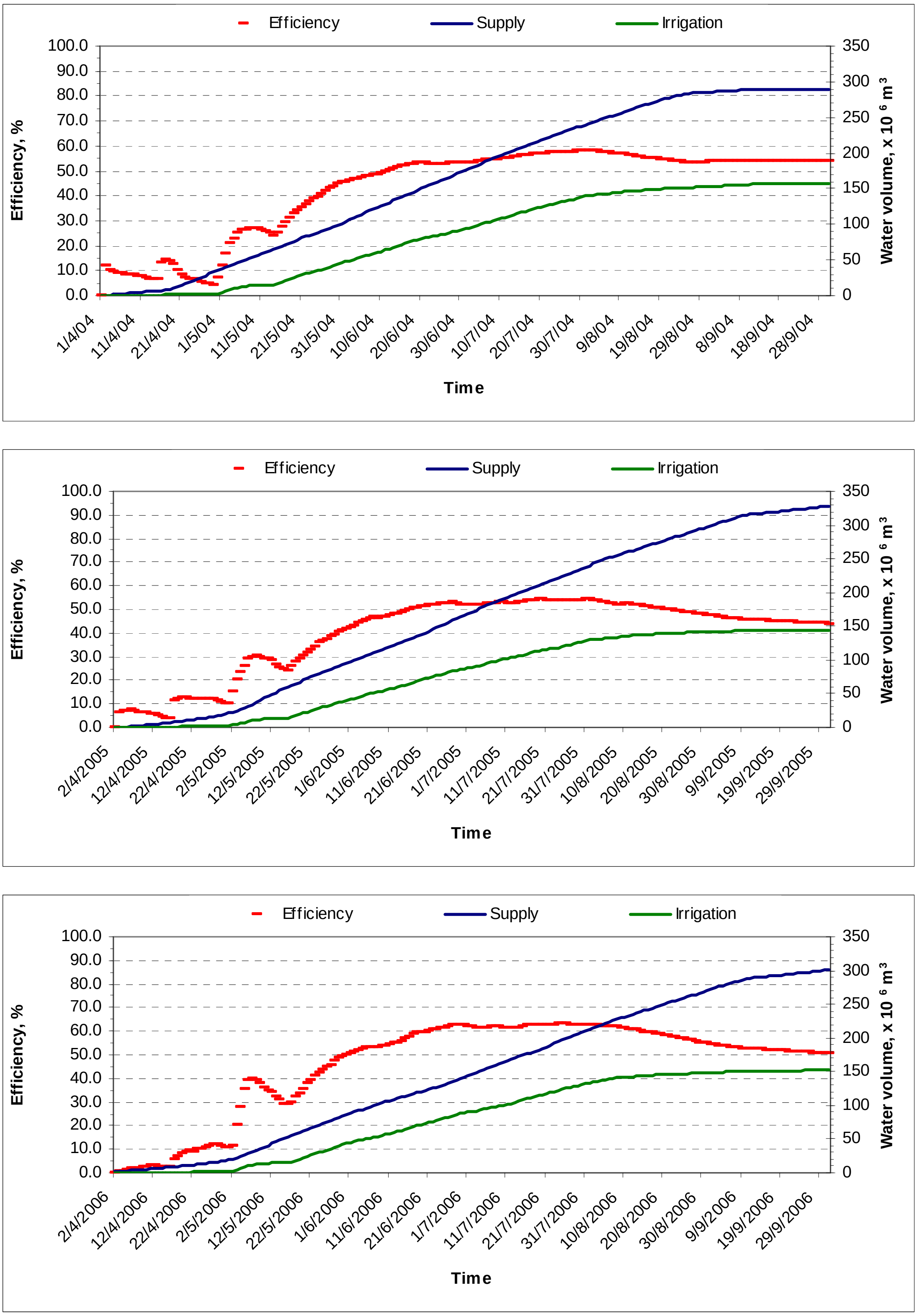


Fig. 9. Total volume of supplied and irrigated water and estimated efficiency in the irrigation networks of TOEB Provatas during 2004 - 2006.

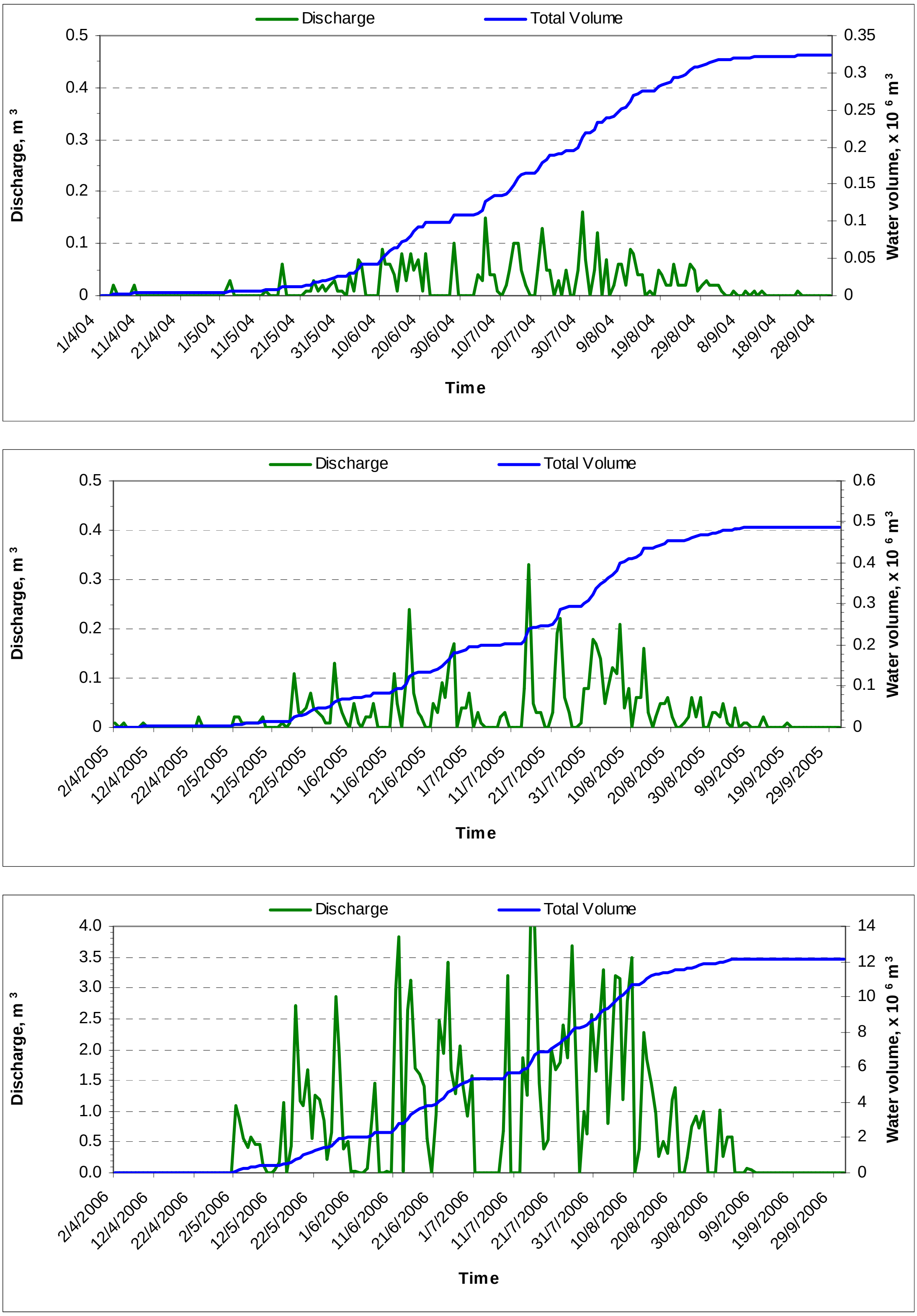


Fig. 10. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of Capetan Mitrousi irrigation network.

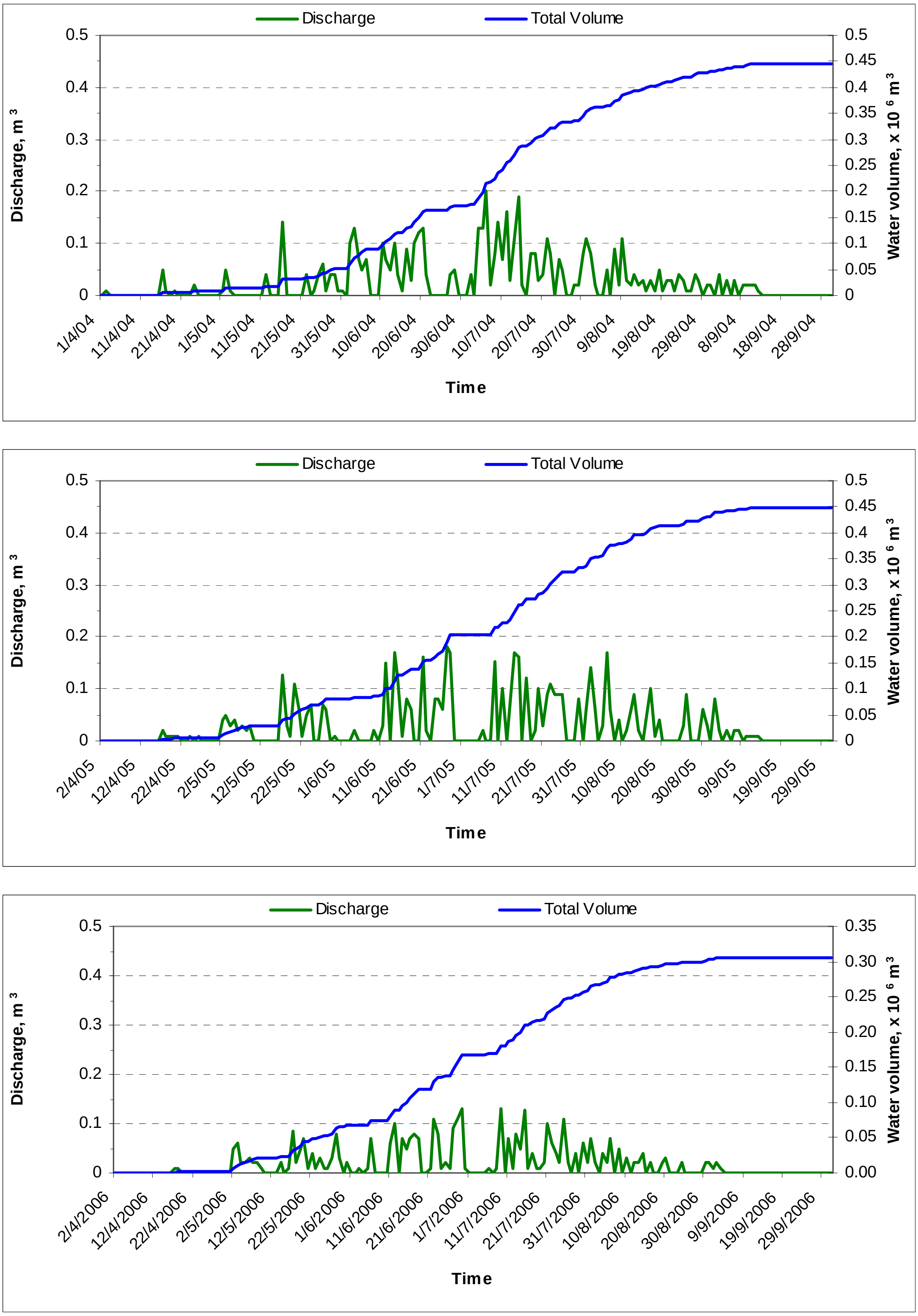


Fig. 11. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of Neohoriou irrigation network.

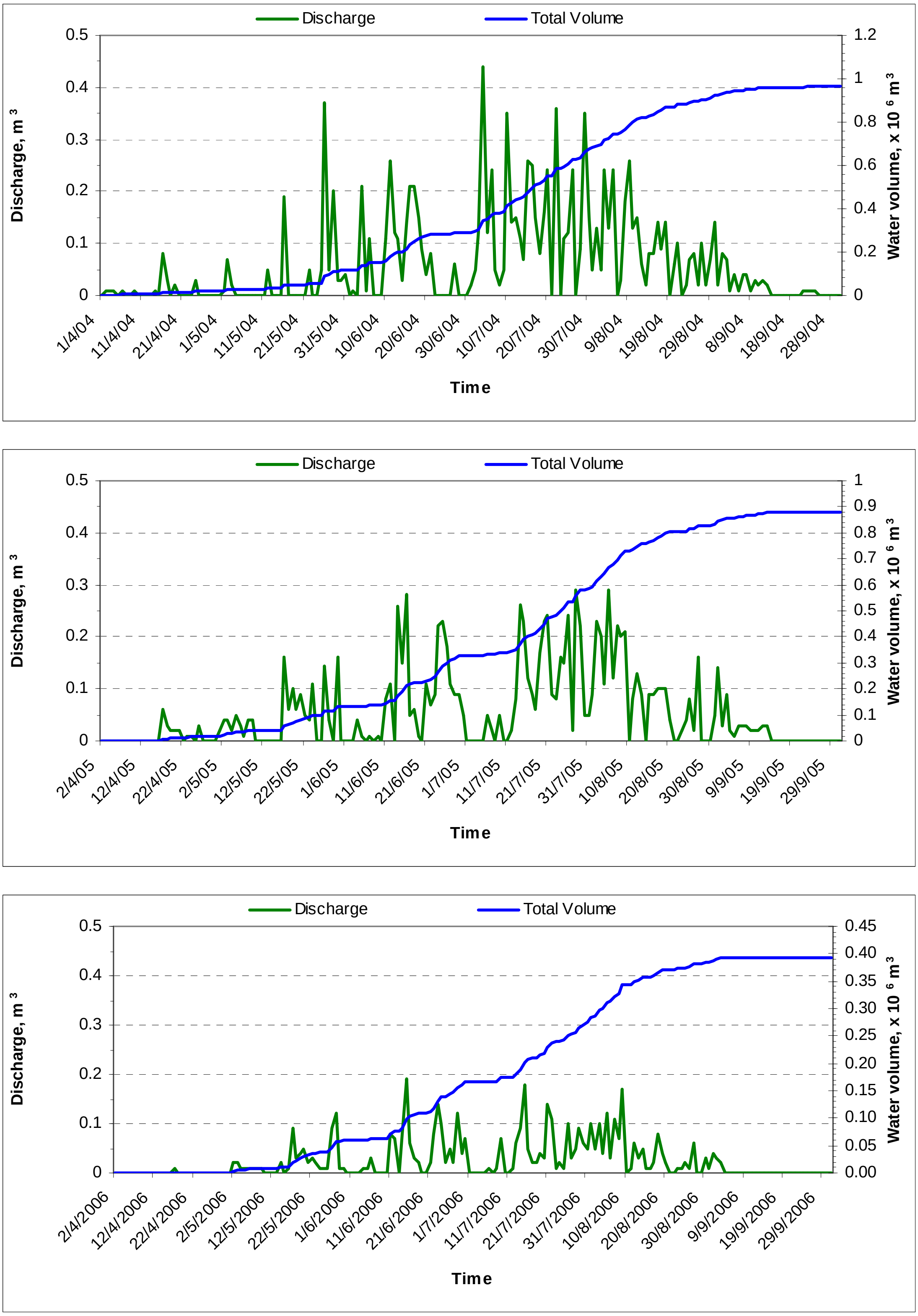


Fig. 12. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of Neos Skopos irrigation network.

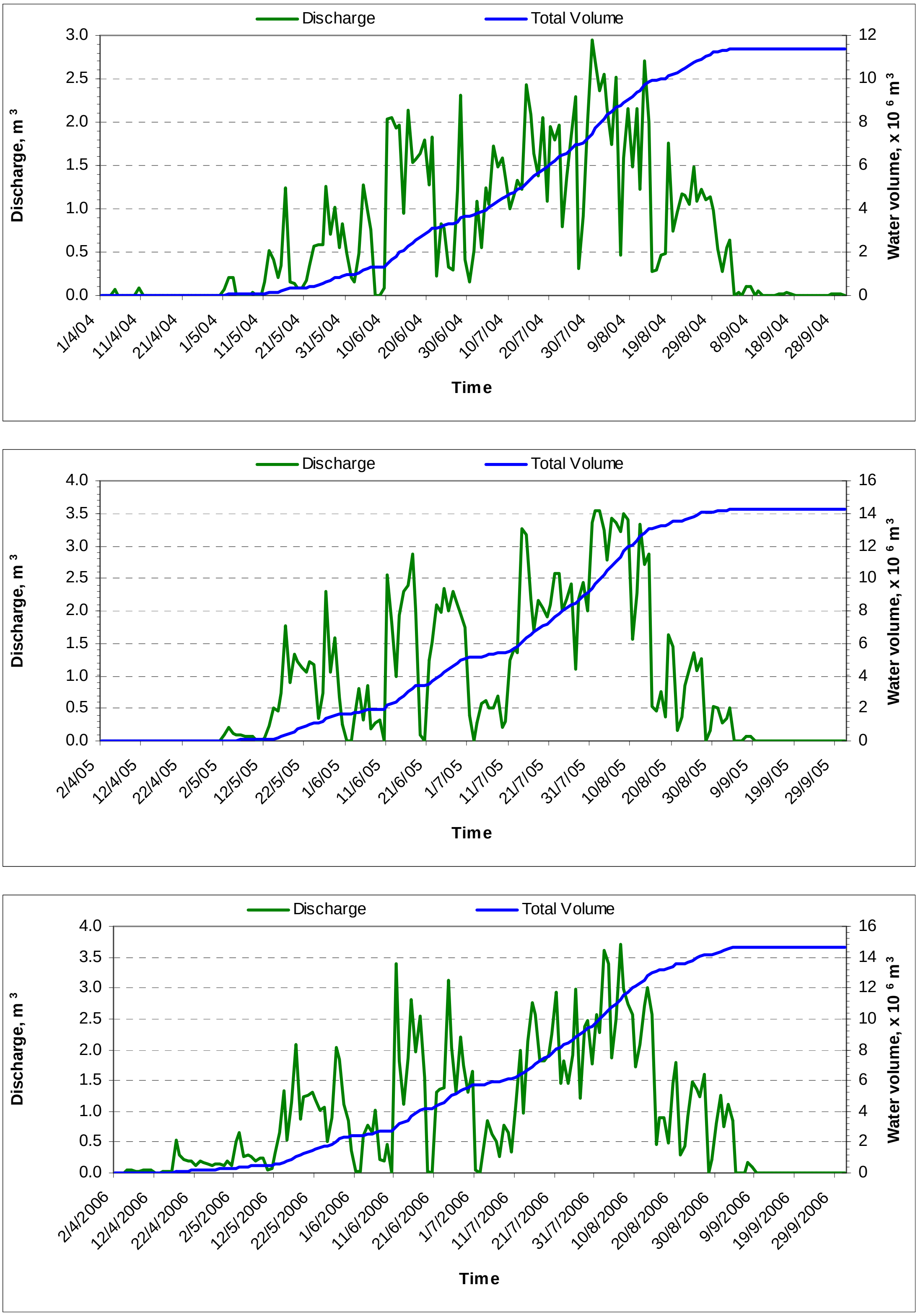


Fig. 13. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of Pethelino irrigation network.

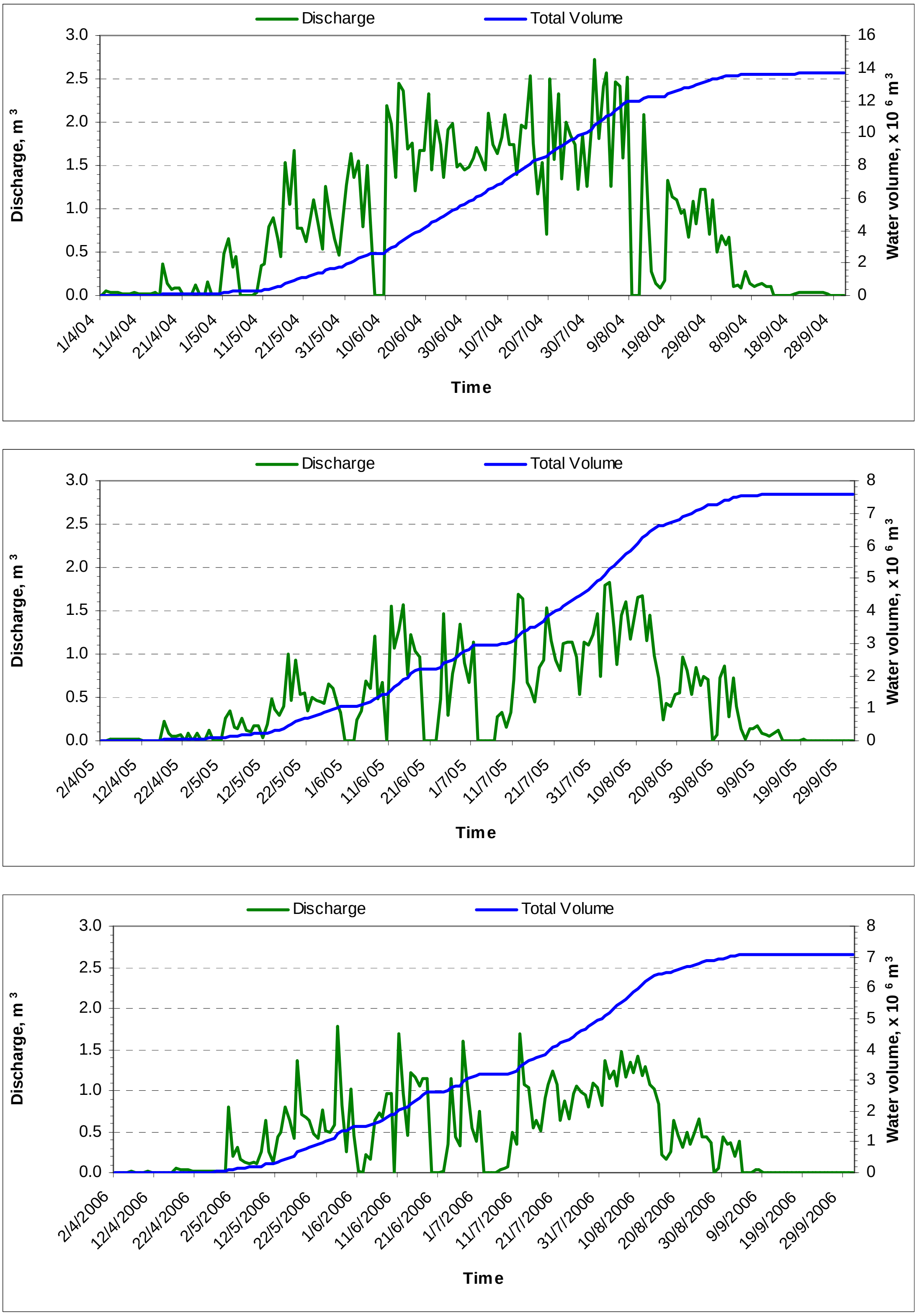


Fig. 14. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of GOEB irrigation network of Serres.

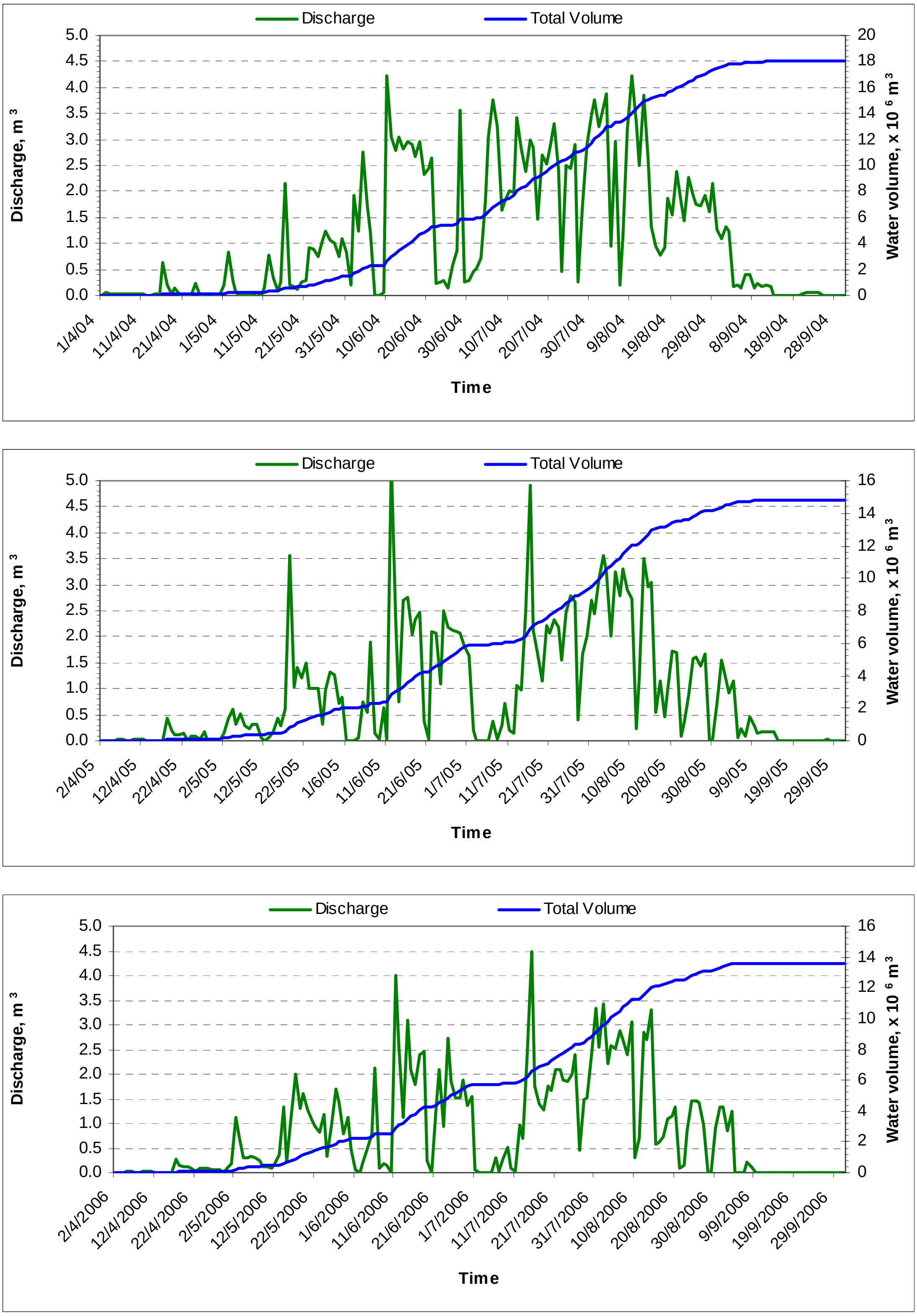


Fig. 15. Groundwater discharge and total volume that was abstracted during the period 2004 – 2005 to cover the irrigation needs of the 5th irrigation network of Serres.

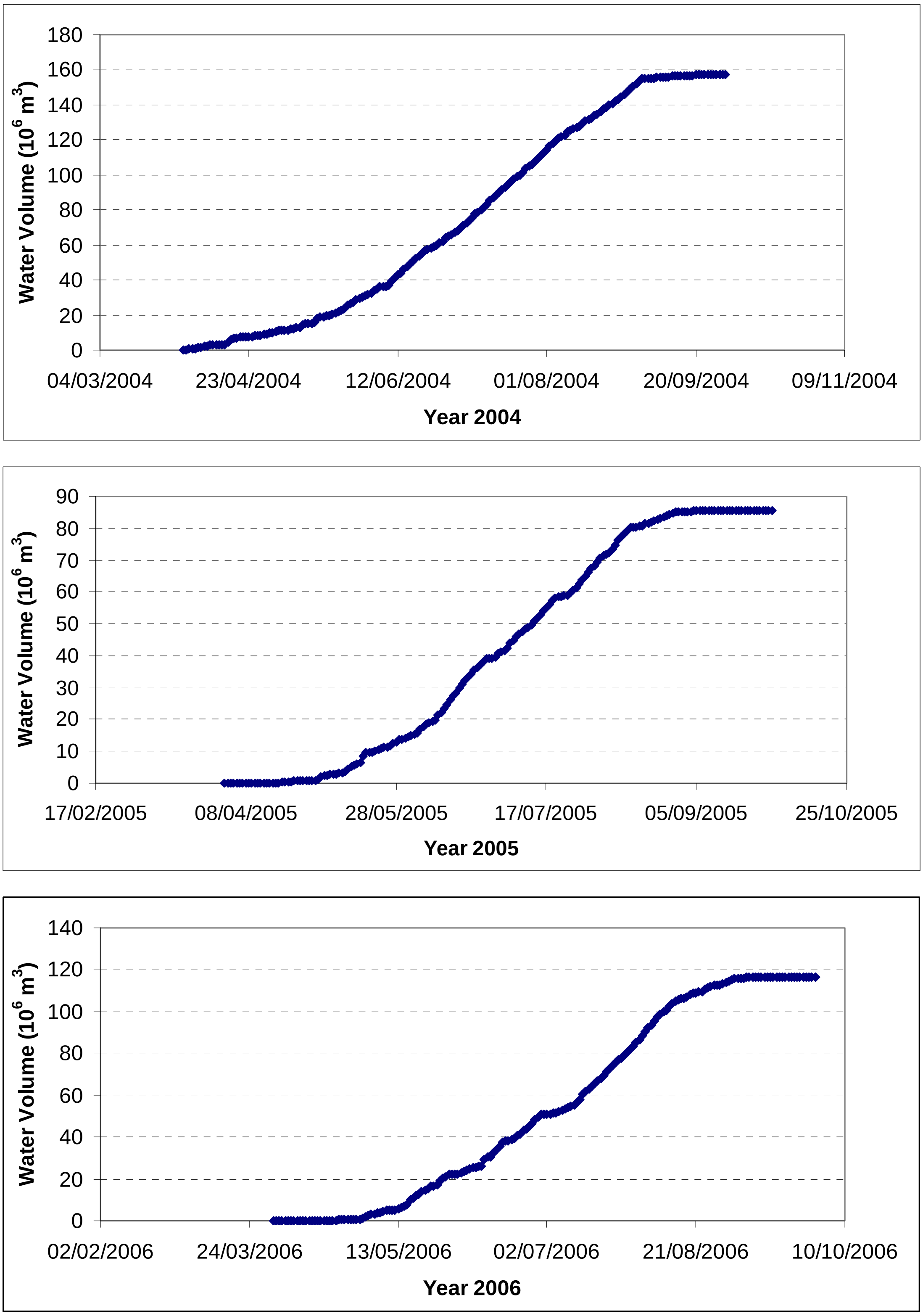
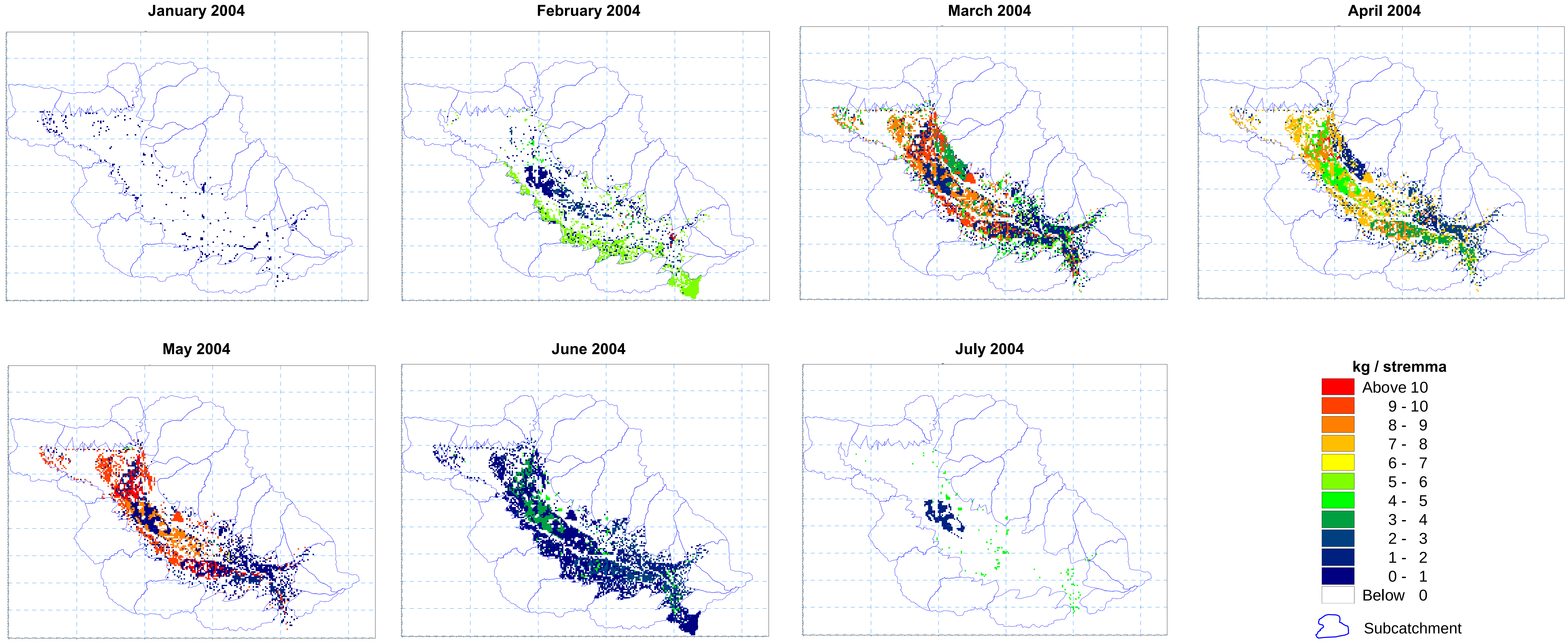
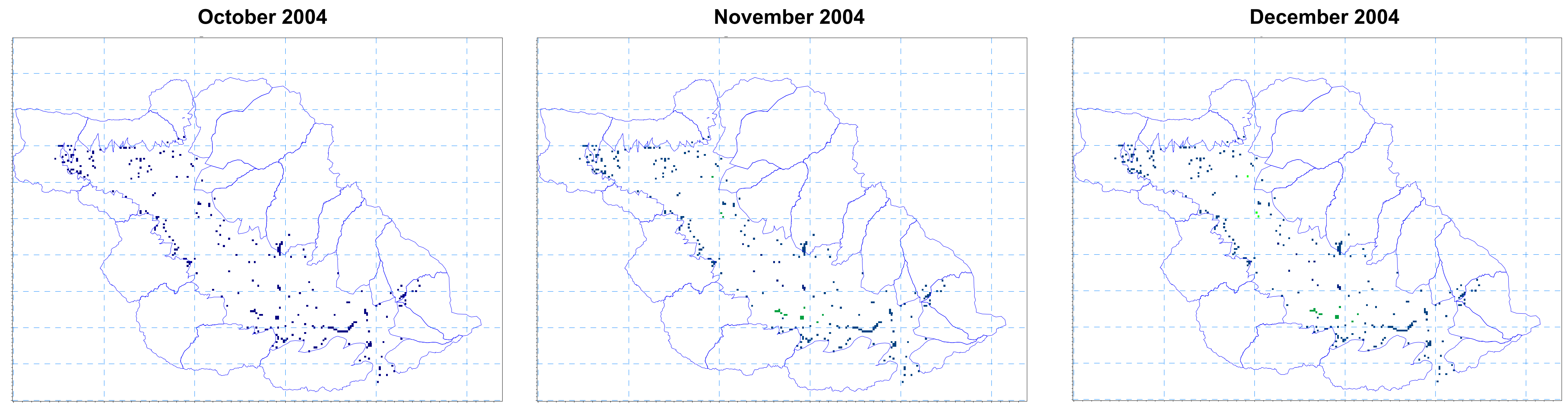


Fig. 16. Total volume of groundwater that is abstracted from Strymonas catchment for irrigation purposes during the period 2004 - 2006.

The spatial and temporal distribution of the pressures that agriculture exerts in the catchment in terms of fertilizer applications (N and P in kg/stream) are shown in Figures 17 and 18. A total amount of 14400 tn of Nitrogen and 5900 tn of Phosphorous is applied per year in the catchment. Regarding phosphorous the main pressure is observed during February (640 tn), March (2350 tn) and April (2160 tn), while regarding Nitrogen during February (1590 tn), March (4060 tn), April (3780 tn), May (2900 tn) and June (1300, tn).

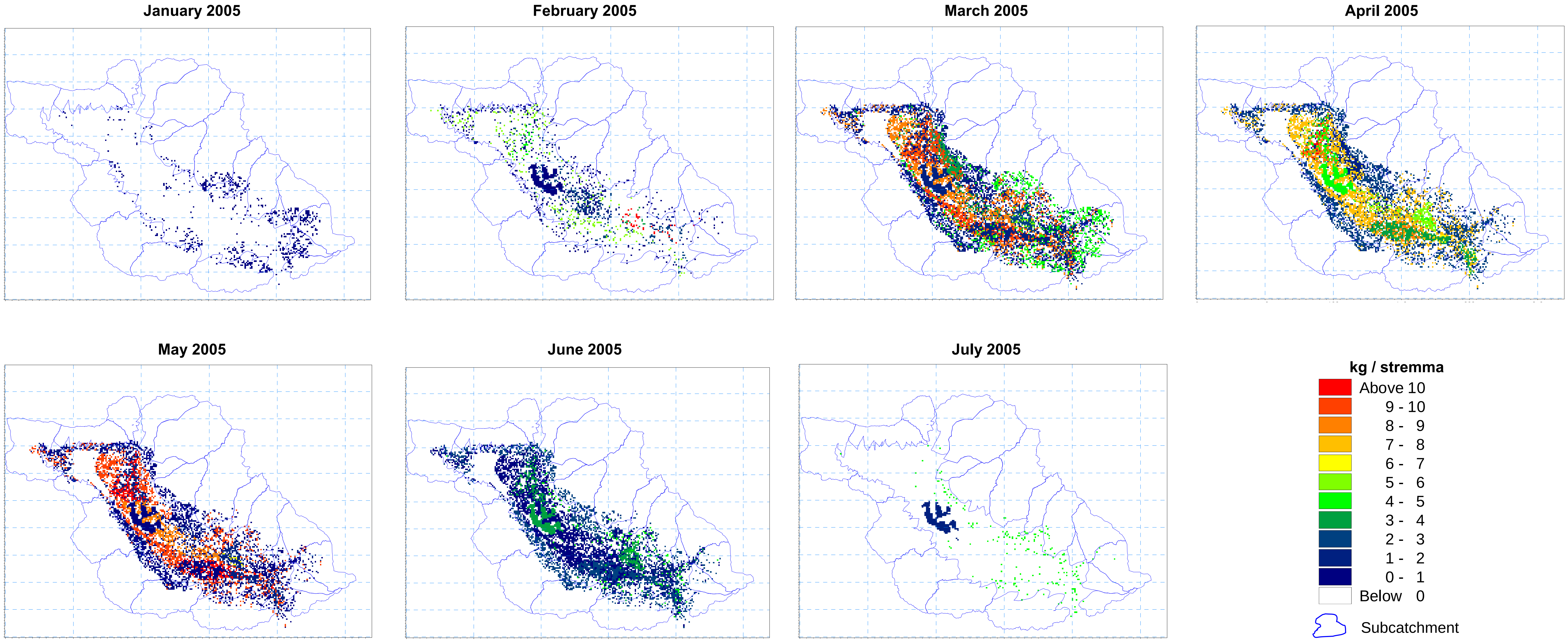


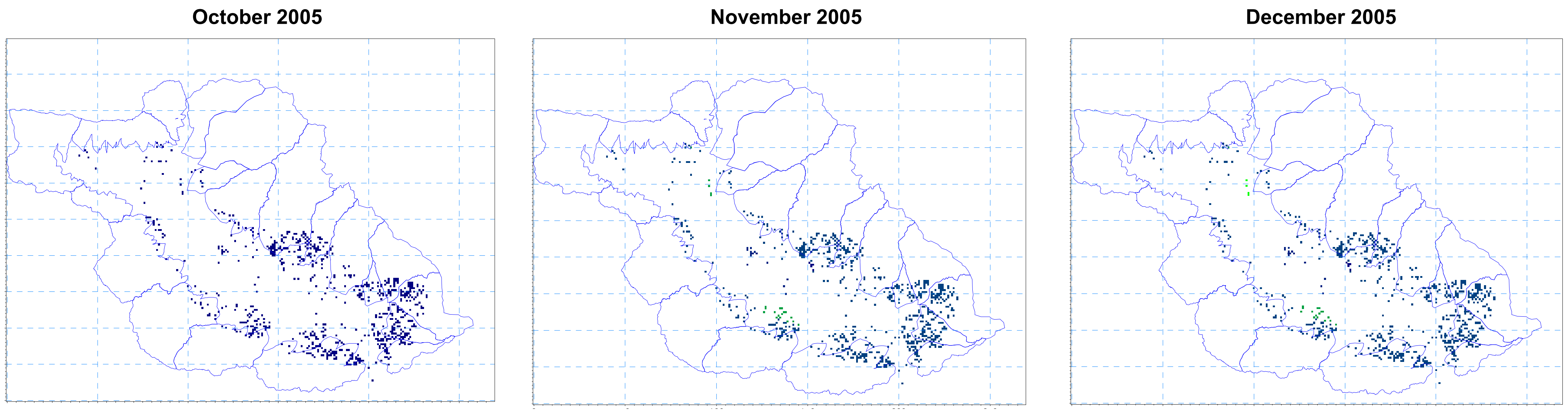


Period of application	N, tn
January	23.2
February	1,284.9
March	3,263.0
April	3,152.4
May	2,445.9
June	1,017.0
July	136.3
August *	0.0
September *	0.0
October	20.6
November	117.4
December	121.1
TOTAL	**11,581.8**

* During August and September there is no fertilizer application

Fig. 17a. Spatial and temporal distribution of applied N (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)

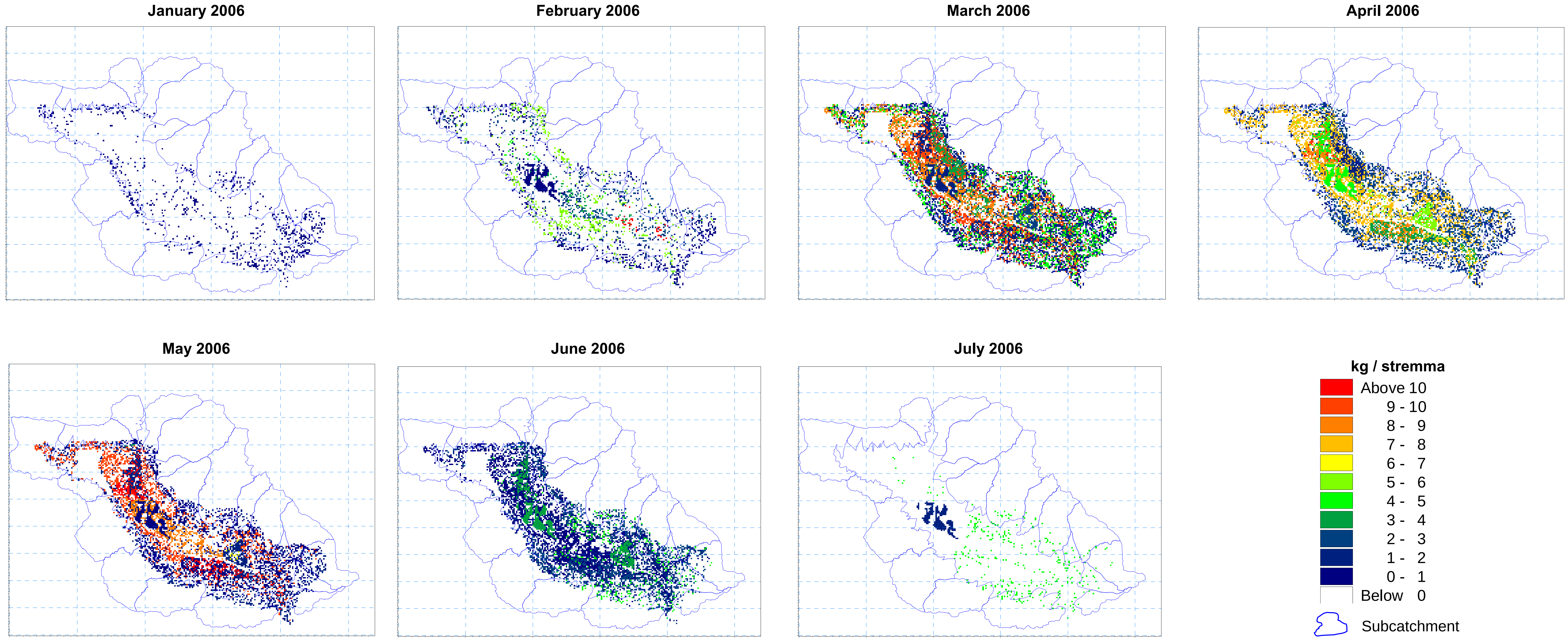


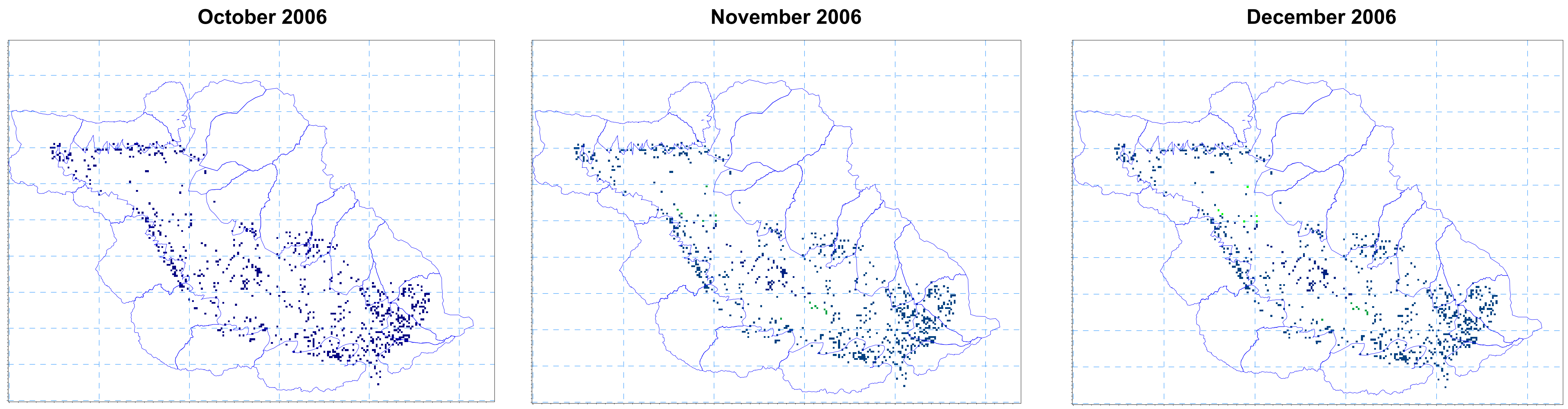


Period of application	N, tn
January	55.5
February	544.0
March	4,253.4
April	4,023.3
May	3,153.6
June	1,440.7
July	170.3
August *	0.0
September *	0.0
October	48.9
November	279.8
December	288.6
TOTAL	**14,258.1**

* During August and September there is no fertilizer application

Fig. 17b. Spatial and temporal distribution of applied N (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)

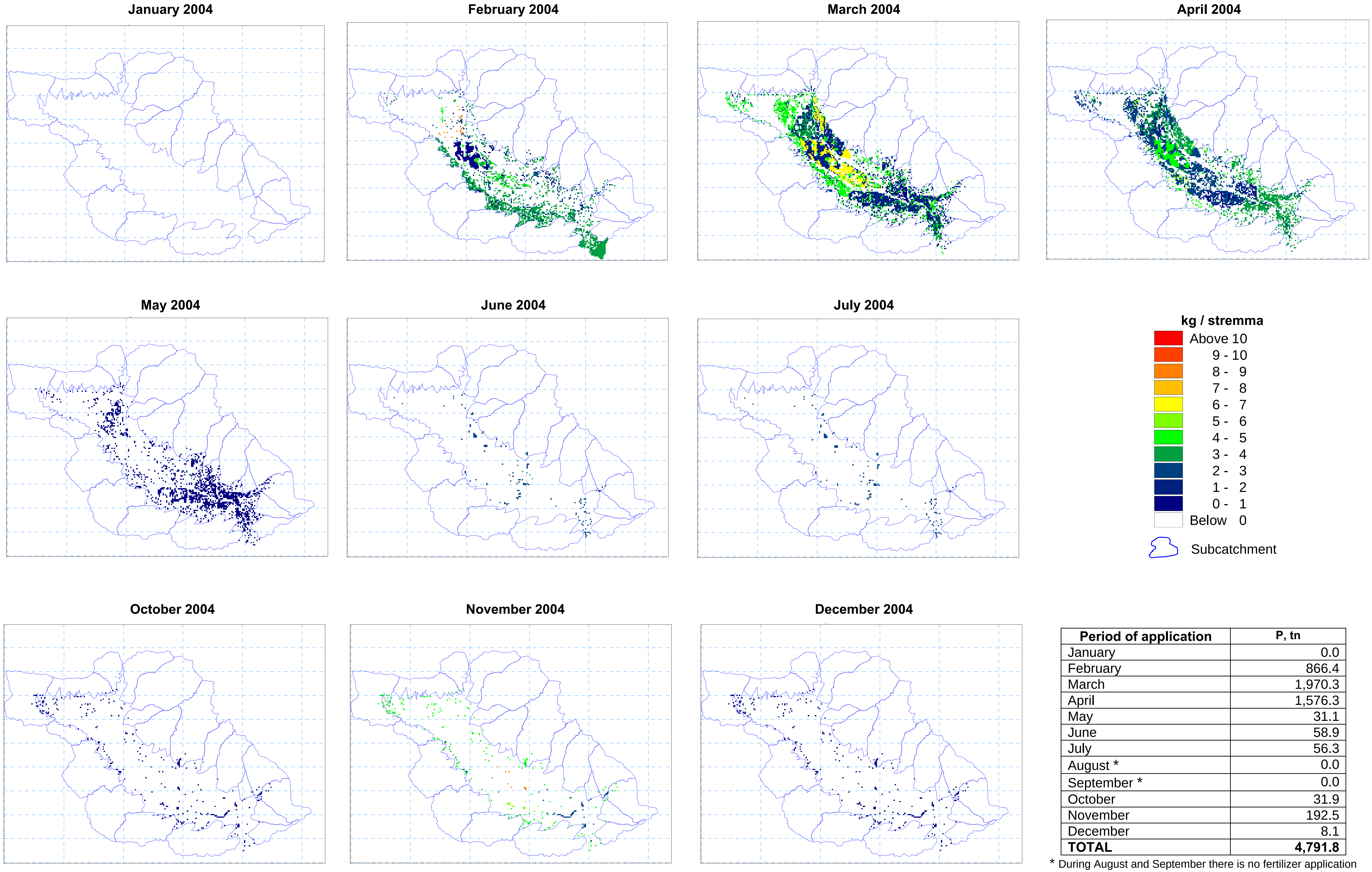




Period of application	N, tn
January	60.4
February	2,952.1
March	4,664.0
April	4,173.0
May	3,171.8
June	1,455.3
July	266.1
August *	0.0
September *	0.0
October	53.3
November	304.7
December	314.4
TOTAL	**17.415.1**

* During August and September there is no fertilizer application

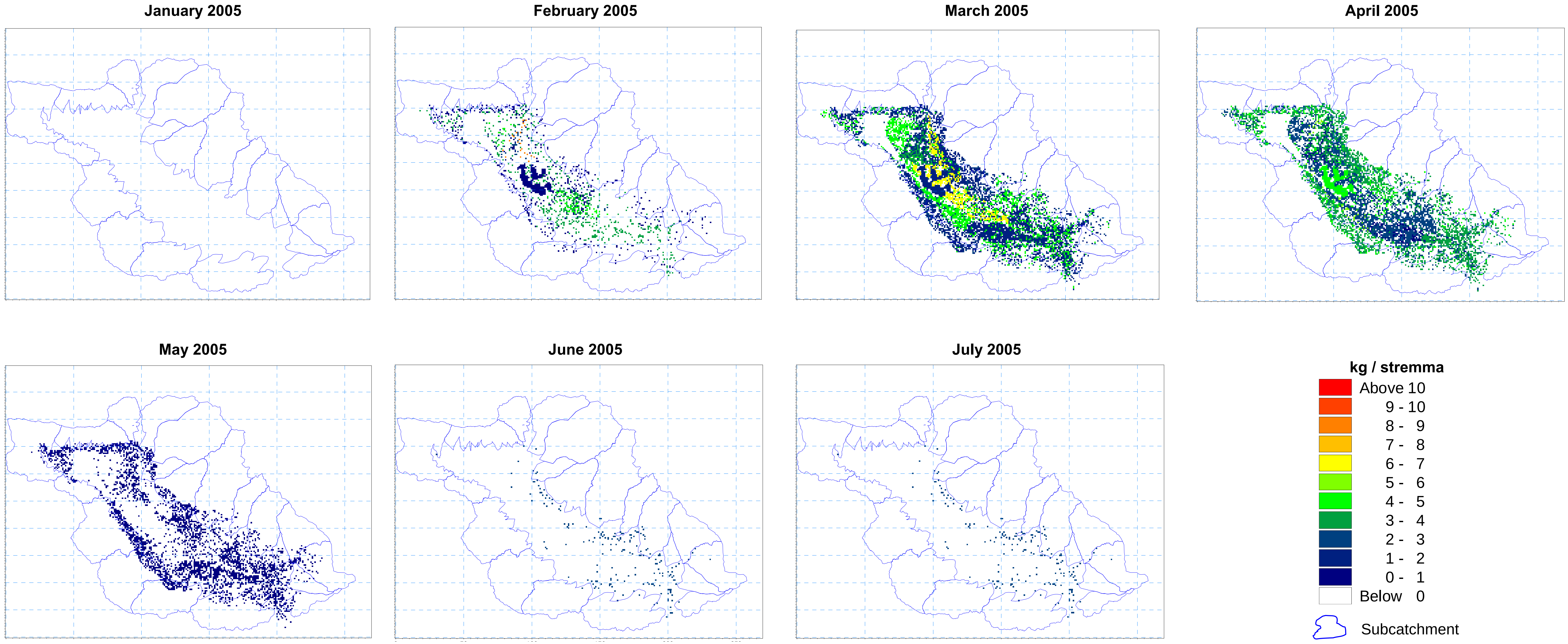
Fig. 17c. Spatial and temporal distribution of applied N (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)

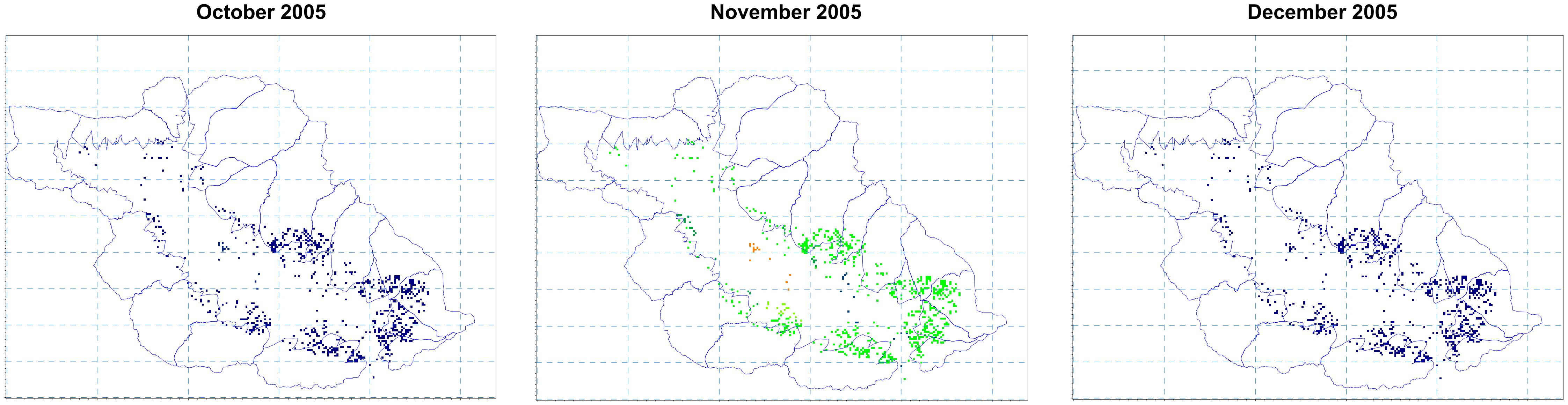


Period of application	P, tn
January	0.0
February	866.4
March	1,970.3
April	1,576.3
May	31.1
June	58.9
July	56.3
August *	0.0
September *	0.0
October	31.9
November	192.5
December	8.1
TOTAL	**4,791.8**

* During August and September there is no fertilizer application

Fig. 18a. Spatial and temporal distribution of applied P (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)

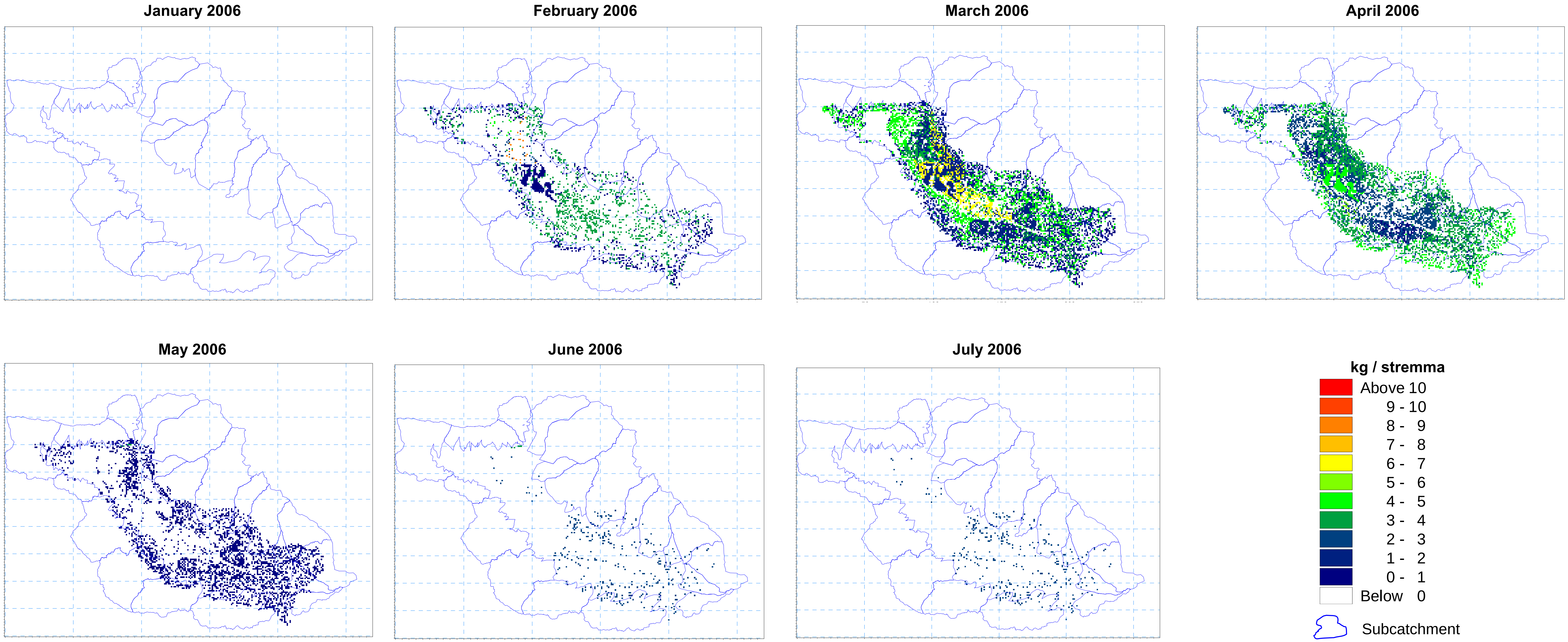


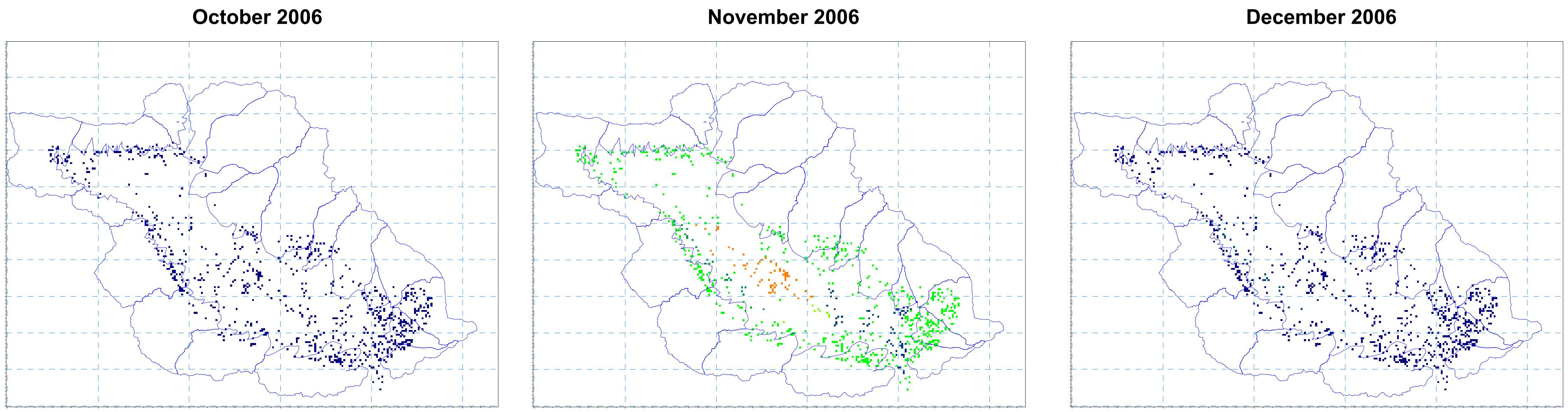


Period of application	P, tn
January	0.0
February	431.2
March	2,491.8
April	2,470.0
May	85.1
June	77.3
July	77.3
August *	0.0
September *	0.0
October	84.3
November	478.5
December	20.2
TOTAL	**6,215.7**

* During August and September there is no fertilizer application

Fig.18b. Spatial and temporal distribution of applied P (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)





Period of application	P, tn
January	0.0
February	625.7
March	2,601.3
April	2,424.8
May	102.0
June	138.7
July	136.1
August *	0.0
September *	0.0
October	89.7
November	546.5
December	32.7
TOTAL	**6,697.5**

* During August and September there is no fertilizer application

Fig.18c. Spatial and temporal distribution of applied P (kg/stremma) in Strymon basin (1 stremma = 0.1 ha)

3.2 Analysis of surface water and groundwater "state" in Strymonas basin

The Greek part of Strymonas River can be distinguished in four sections on the base of the flow pattern within its banks under the current management of water resources in its catchment: a) the section which starts at the Greek – Bulgarian borders up to the upper end of lake Kerkini, b) Lake Kerkini, c) the section downstream the dam of the lake up to the joint with Belitsa ditch and d) the section up to the end of the river into the sea (Fig 19).

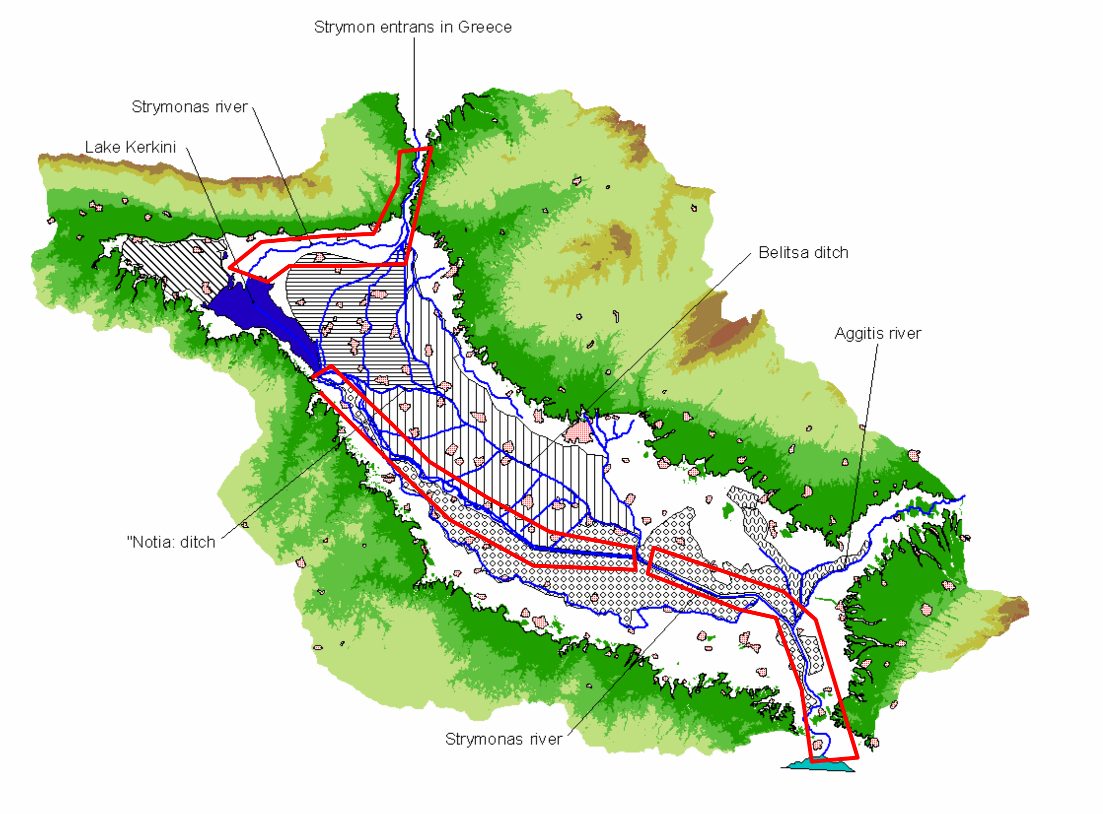


Fig. 19. Delineation of Strymonas River in sections following the flow pattern

In the first section the discharge and hence the presence of water into the river is determined by the releases from the Bulgarian part as well as the abstractions that take place in Greece during summer for irrigation purposes. The discharge that inflows and outflows from this section for the period 2004 – 2006 is shown in Figure 20.

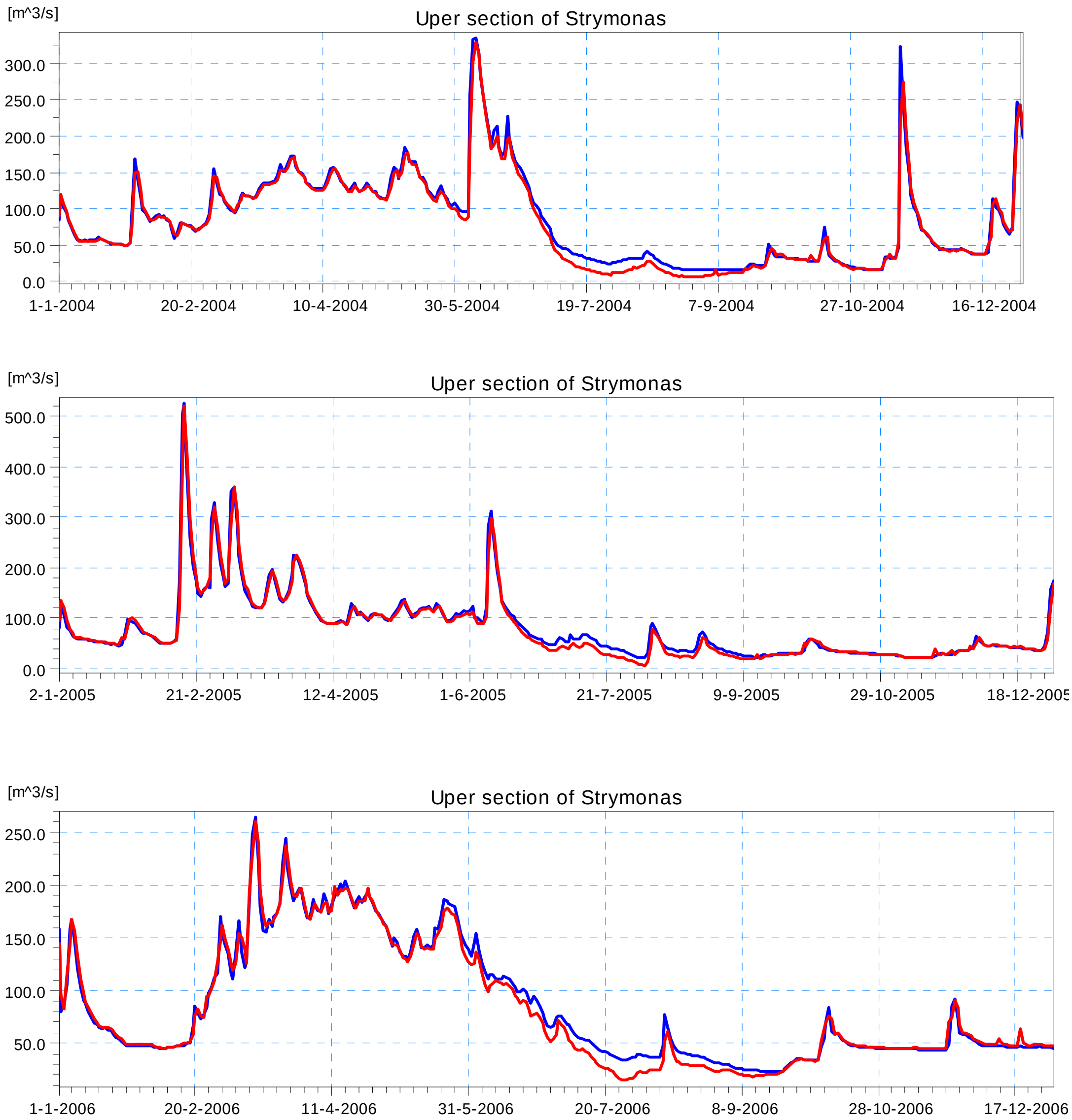


Fig. 20. Inflow and outflow discharge in the upper section of Strymonas River during 2004 – 2006.

In Lake Kerkini, the flow pattern is fully controlled for flood protection and water storage for irrigation. The state of Lake Kerkini regarding its water level fluctuation during period 2004 – 2006 is shown in Figures 21 and 22. As it can be observed, the water level in the lake was not only above the proposed environmental water level but also above the currently regulated for irrigation purposes maximum water level in two of the three years. The influence of the lake's water level in the distribution of water depths is shown in figure 23. It can be observed that the minimum water depth in the lake at its maximum water level is grater than three meters causing significant pressures to its ecosystems.

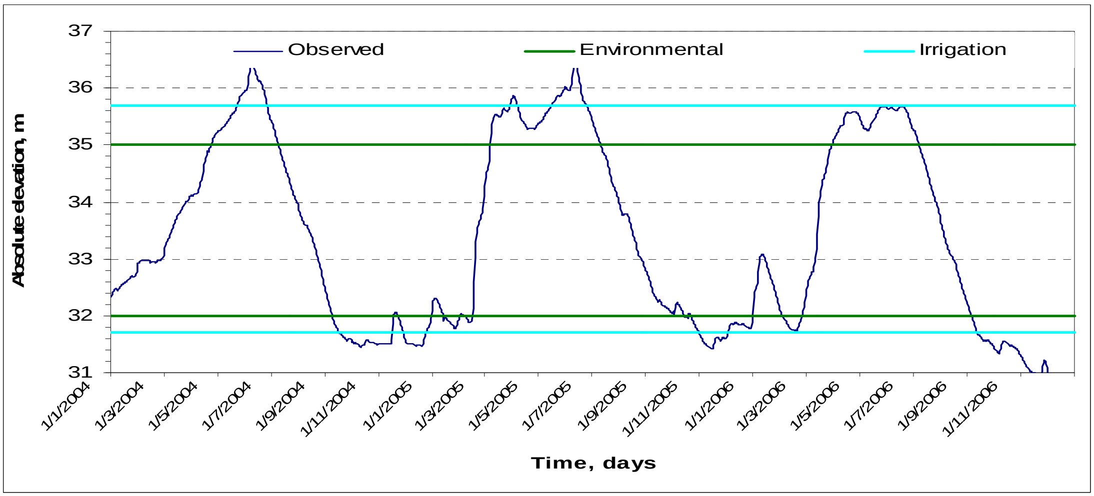


Fig. 21. Observed, proposed environmental and currently regulated for irrigation purposes water level in Lake Kerkini.

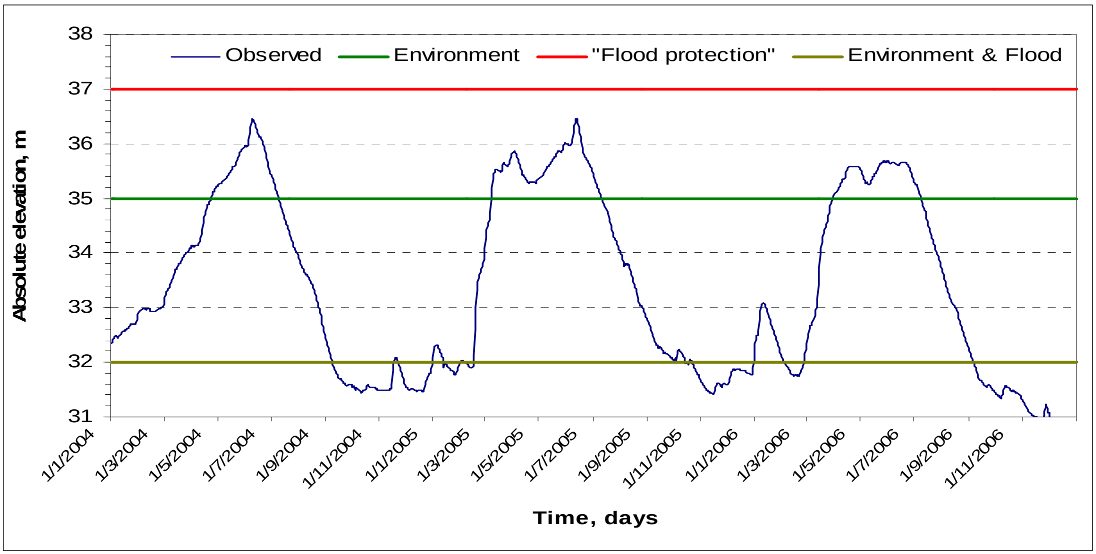


Fig. 22. Observed, proposed environmental and currently regulated for flood protection purposes water level in Lake Kerkini.

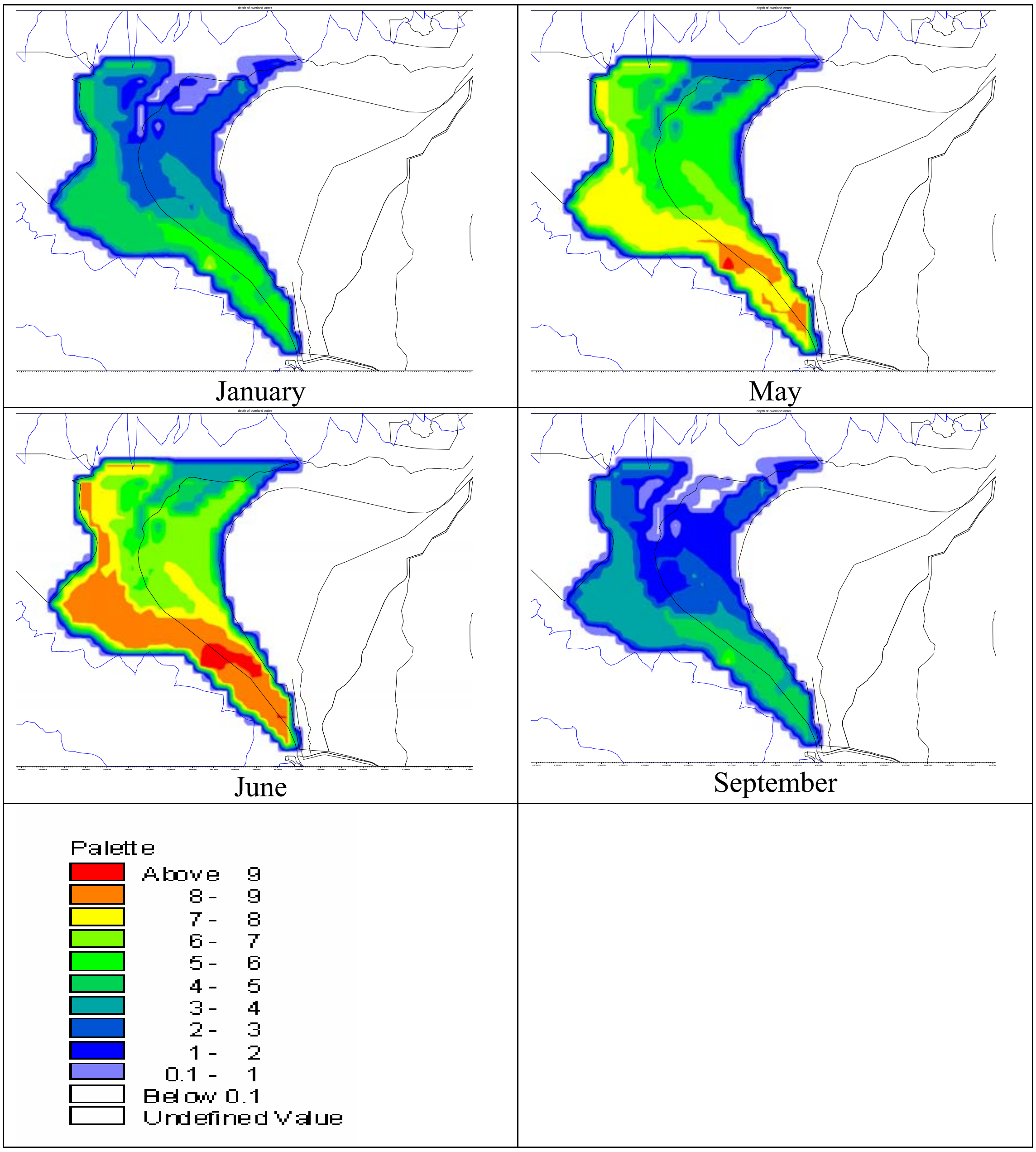


Fig. 23. Spatial distribution of water depth in Lake Kerkini.

In the third section of Strymonas River, the discharge is controlled by the releases from the lake's dam which are determined following to the degree of the lake's fullness. However during summer only a minimum discharge is released downstream the dam in order to secure the availability of water for irrigation purposes. The inflow and outflow discharge in this section for the period 2004 -2006 is shown in Figure 24.

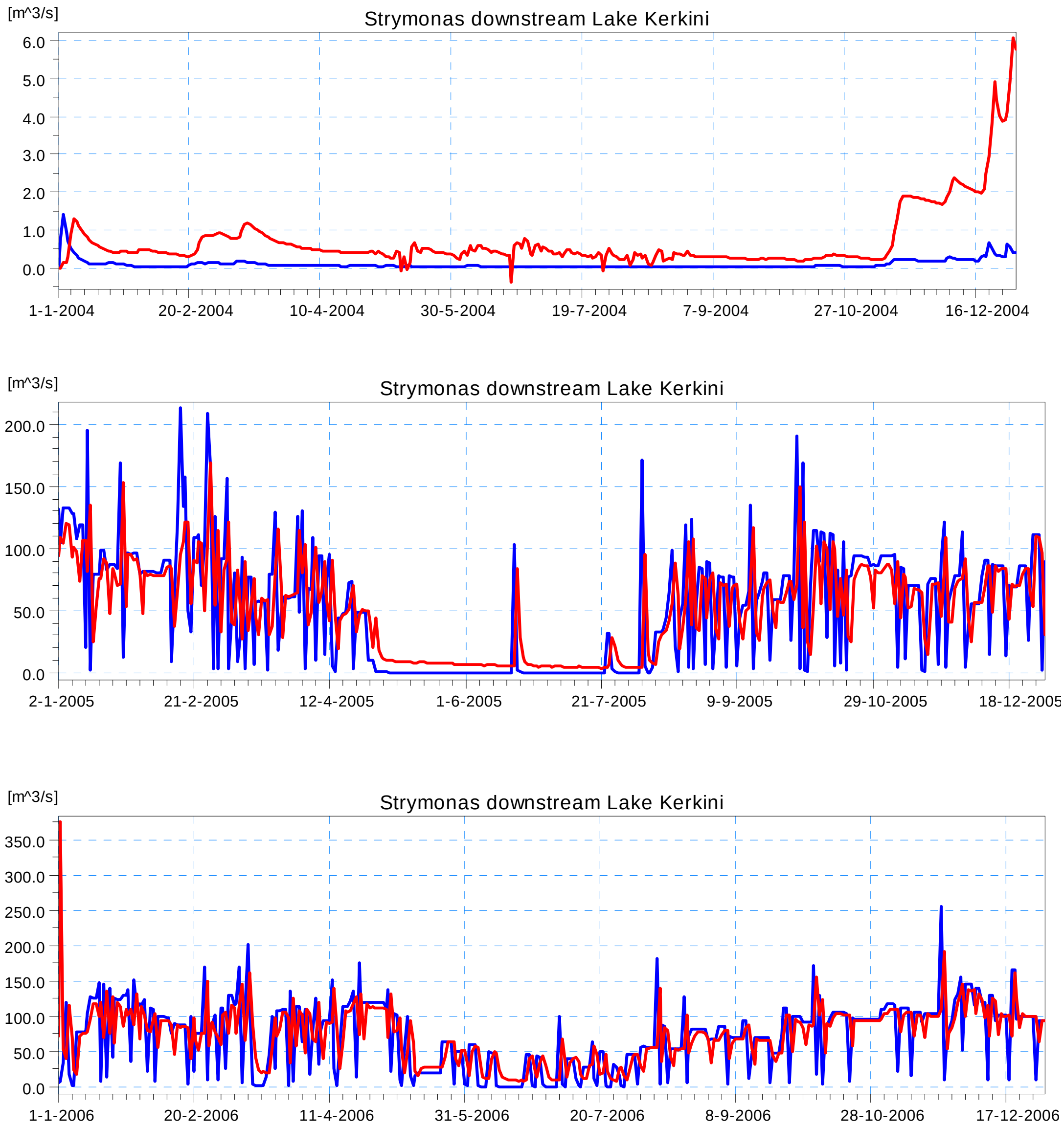


Fig. 24. Inflow and outflow discharge in the section Strymonas River downstream Lake Kerkini during 2004 – 2006.

The forth section of the river is the only one which is characterized by a permanent flow even during summer. It receives the total discharge of Belitsa ditch and Aggitis River. Belitsa is the final receiver of the drainage of four irrigation networks. The inflow and outflow discharge in this section for the period 2004 -2006 is shown in Figure 25.

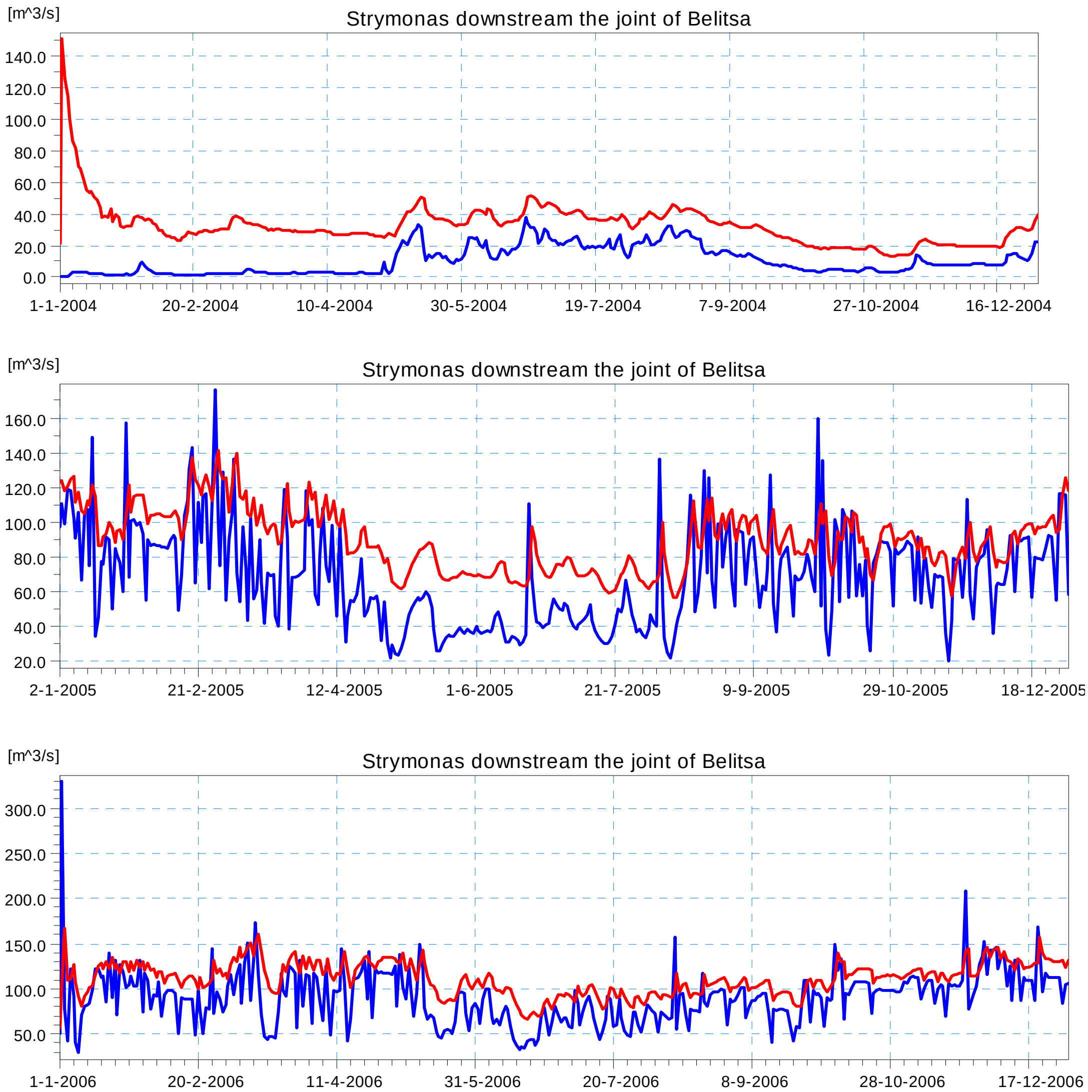


Fig. 25. Inflow and outflow discharge in the section Strymonas River downstream the joint with Belitsa during 2004 – 2006.

The state of the main surface water systems in Strymonas catchment in terms of nutrients concentration (NO_3 and PO_4) is shown in Figures 26 to 28.

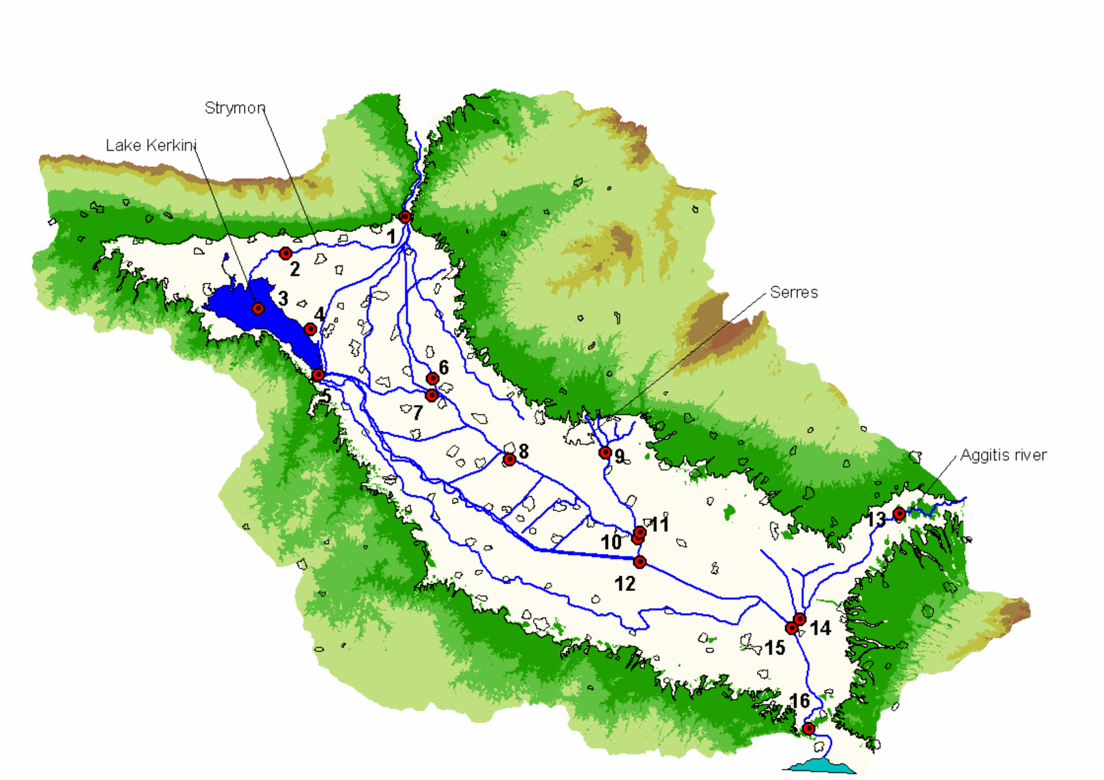


Fig . 26. Spatial distribution of water quality sampling stations in Strymonas catchment.

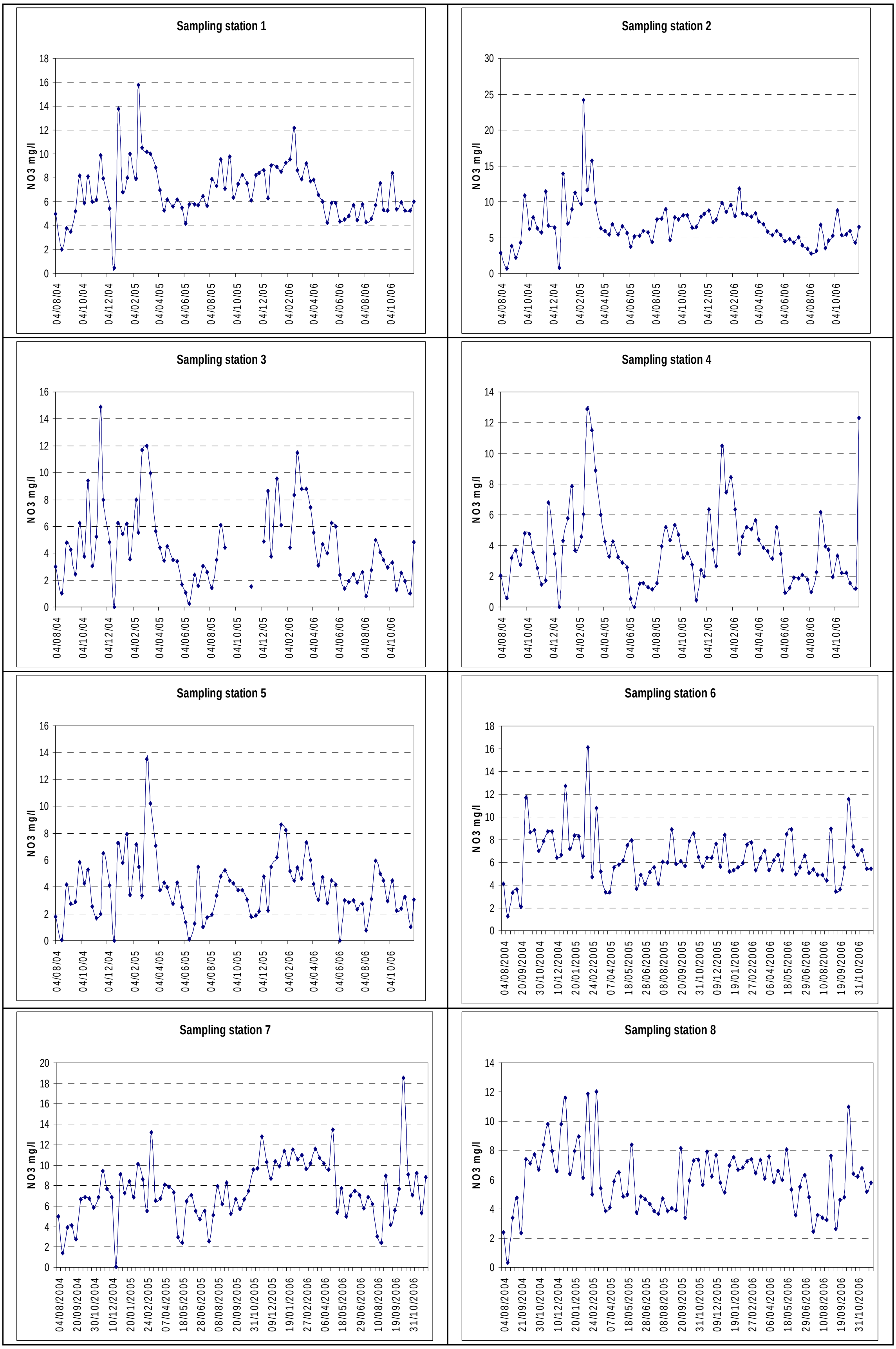


Fig. 27a. Temporal and spatial distribution of NO_3 (mg/l), in Strymonas catchment surface water systems

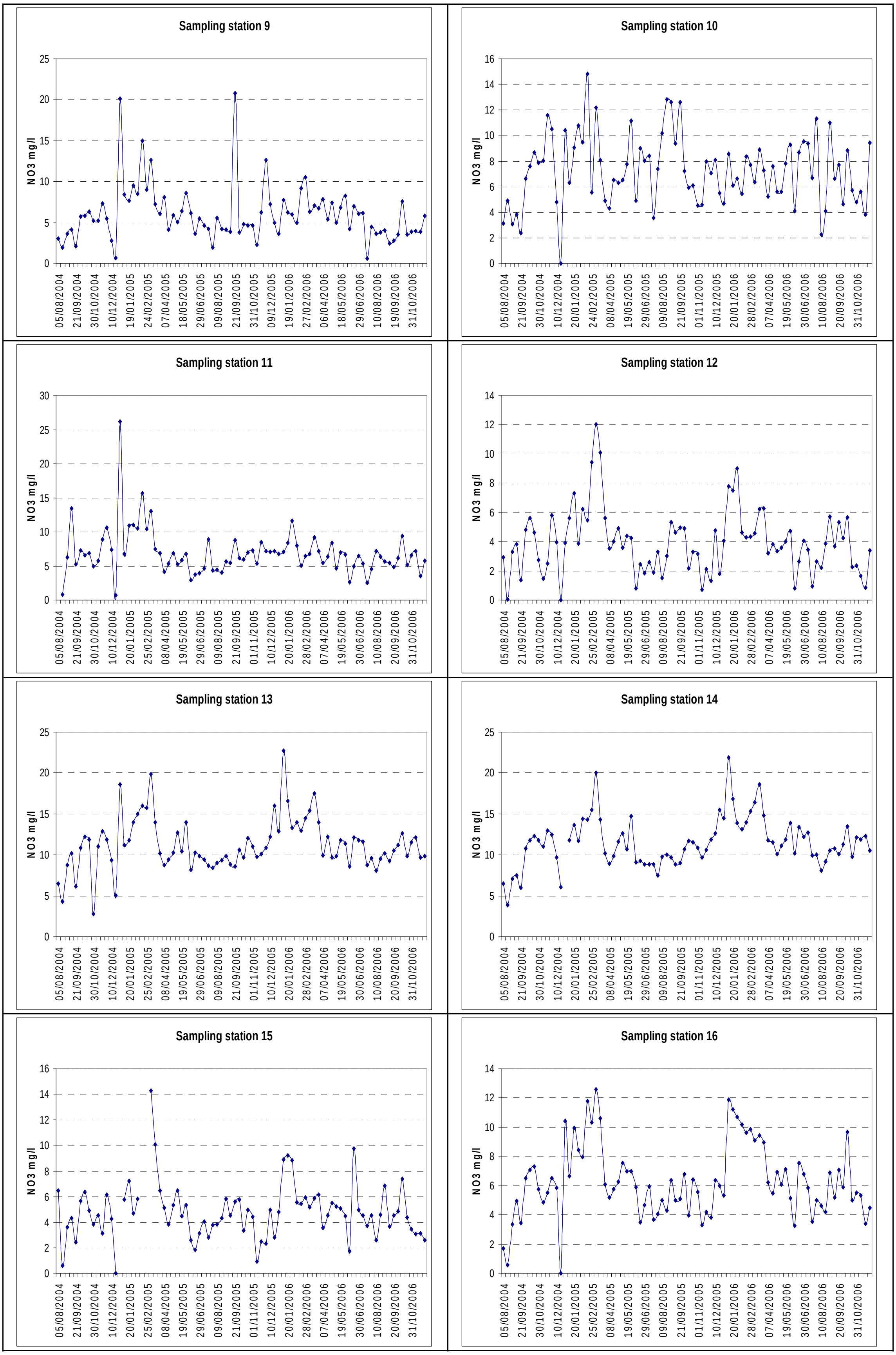


Fig. 27b. Temporal and spatial distribution of NO_3 (mg/l), in Strymonas catchment surface water systems

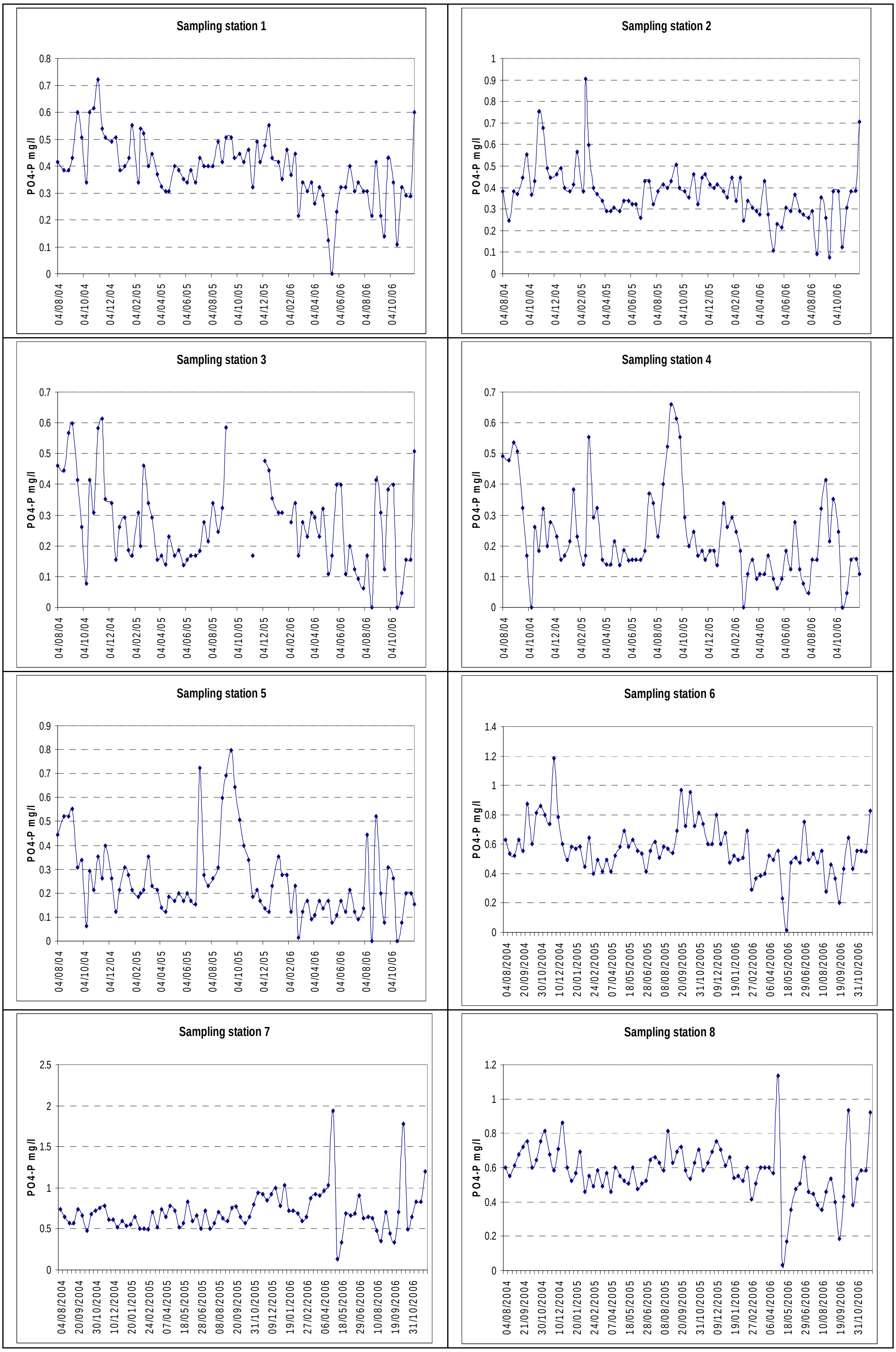


Fig. 28a. Temporal and spatial distribution of PO_3 (mg/l), in Strymonas catchment surface water systems

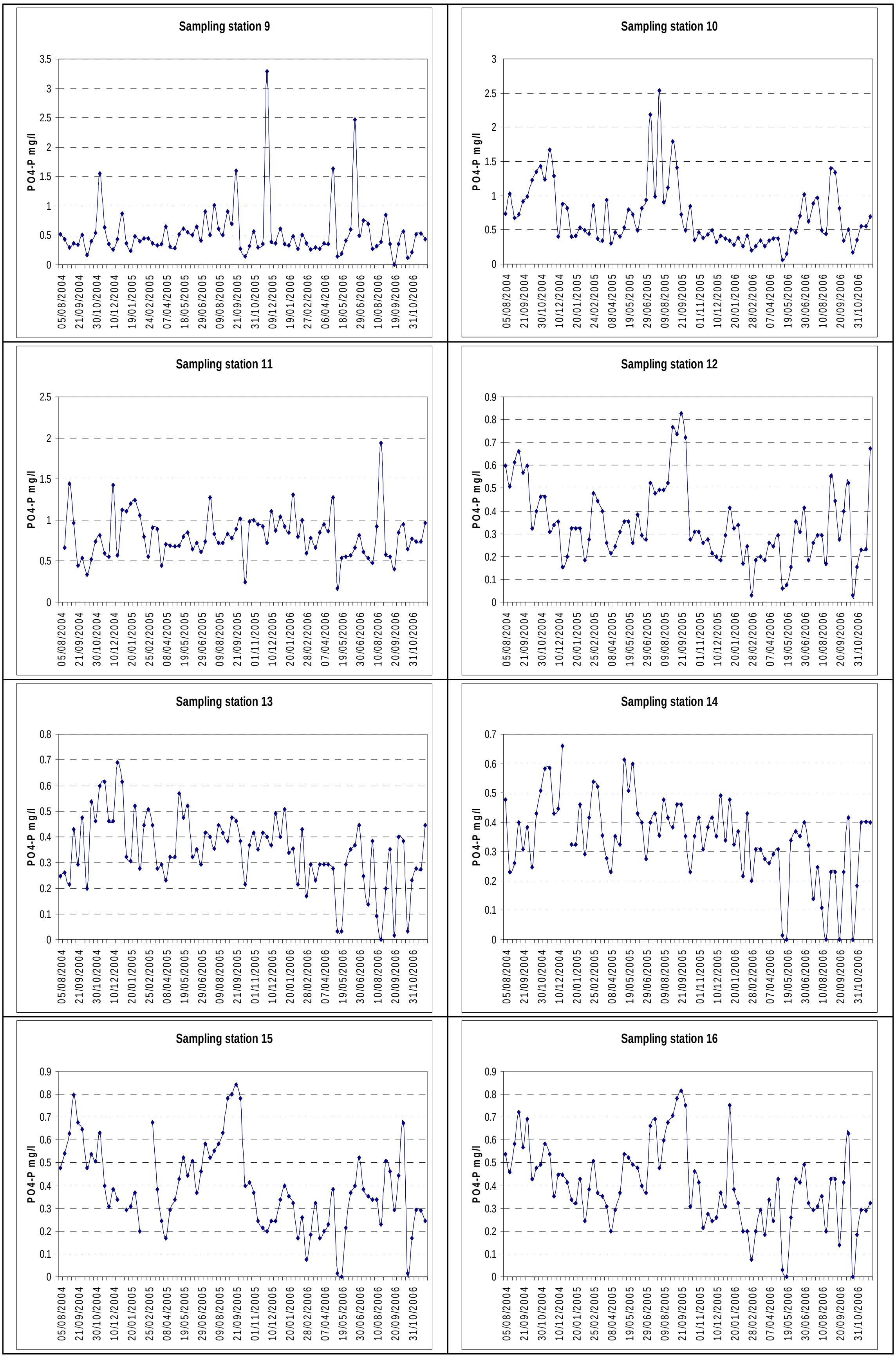


Fig. 28b. Temporal and spatial distribution of PO_3 (mg/l), in Strymonas catchment surface water systems

Regarding groundwater in the catchment only in a few cases as it can be observed in Figures 29 and 30 is observed a substantial drop of water table. In most of the cases the water table drops a few meters during summer and then is fully recovered next winder.

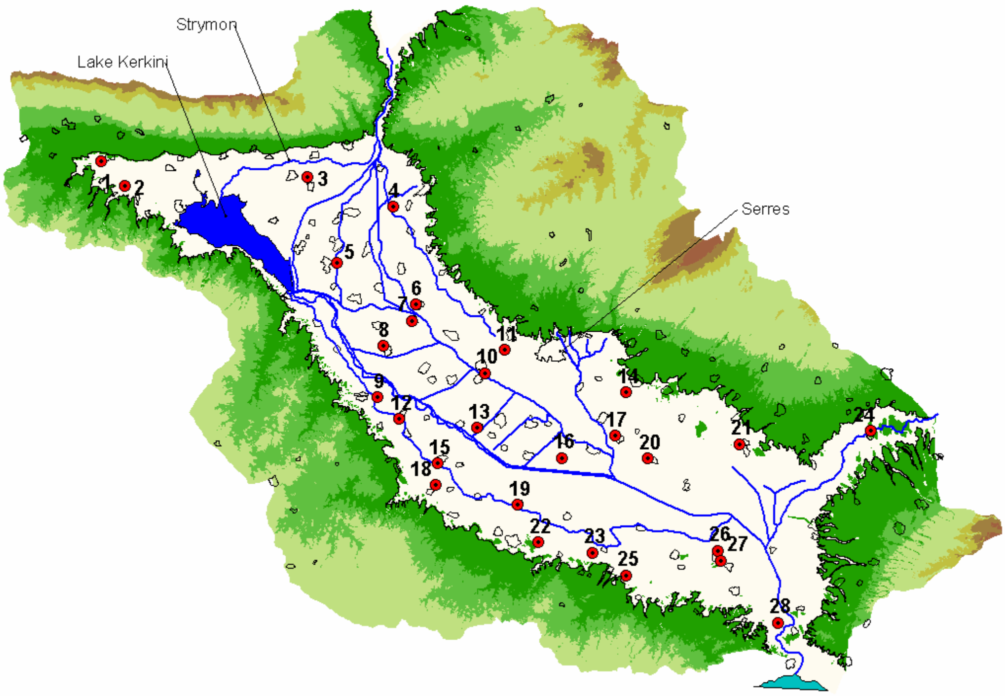


Fig . 29. Spatial distribution of groundwater sampling stations in Strymonas catchment.

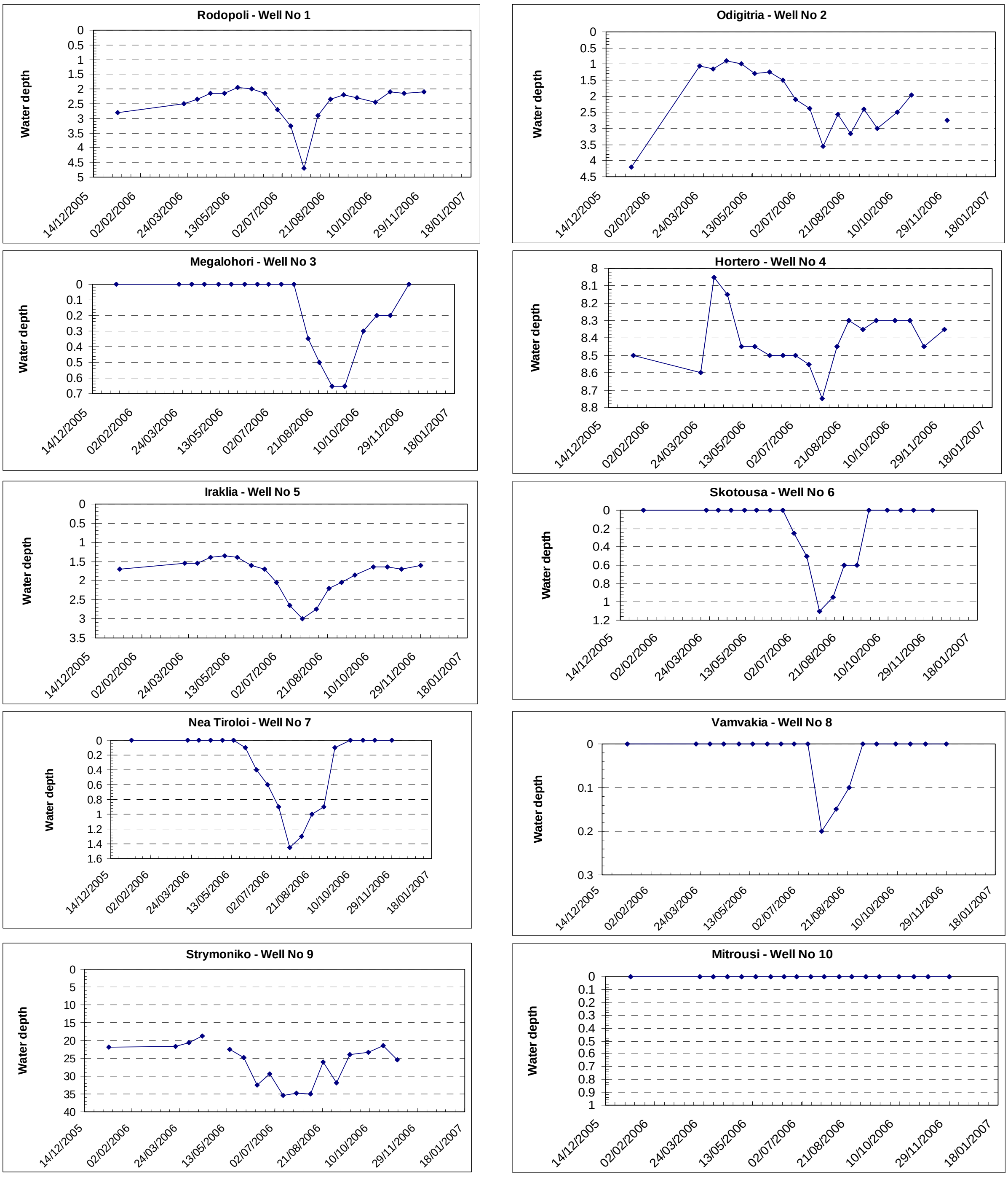


Fig . 30 a. Underground Water table fluctuation

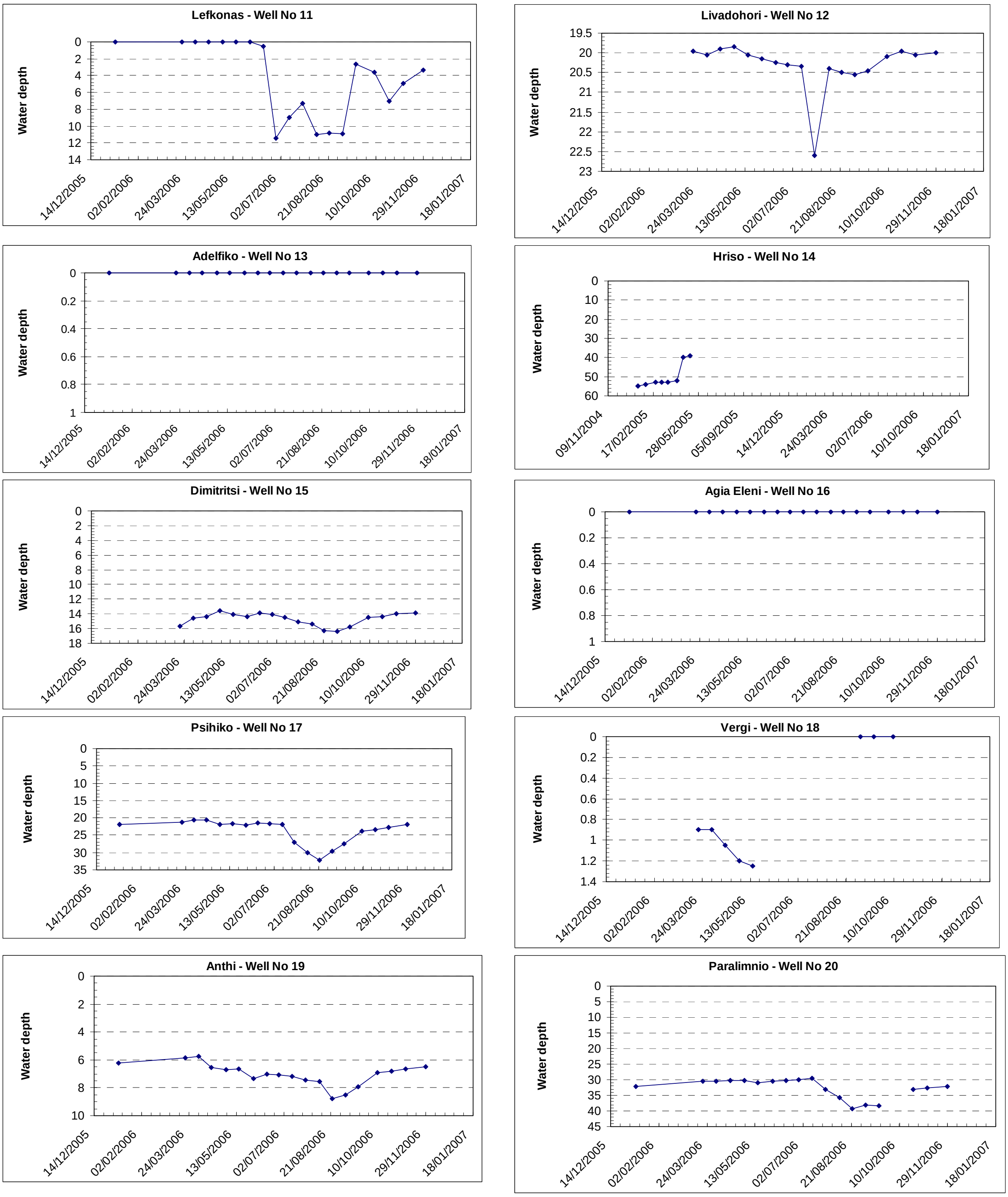


Fig . 30 b. Underground Water table fluctuation

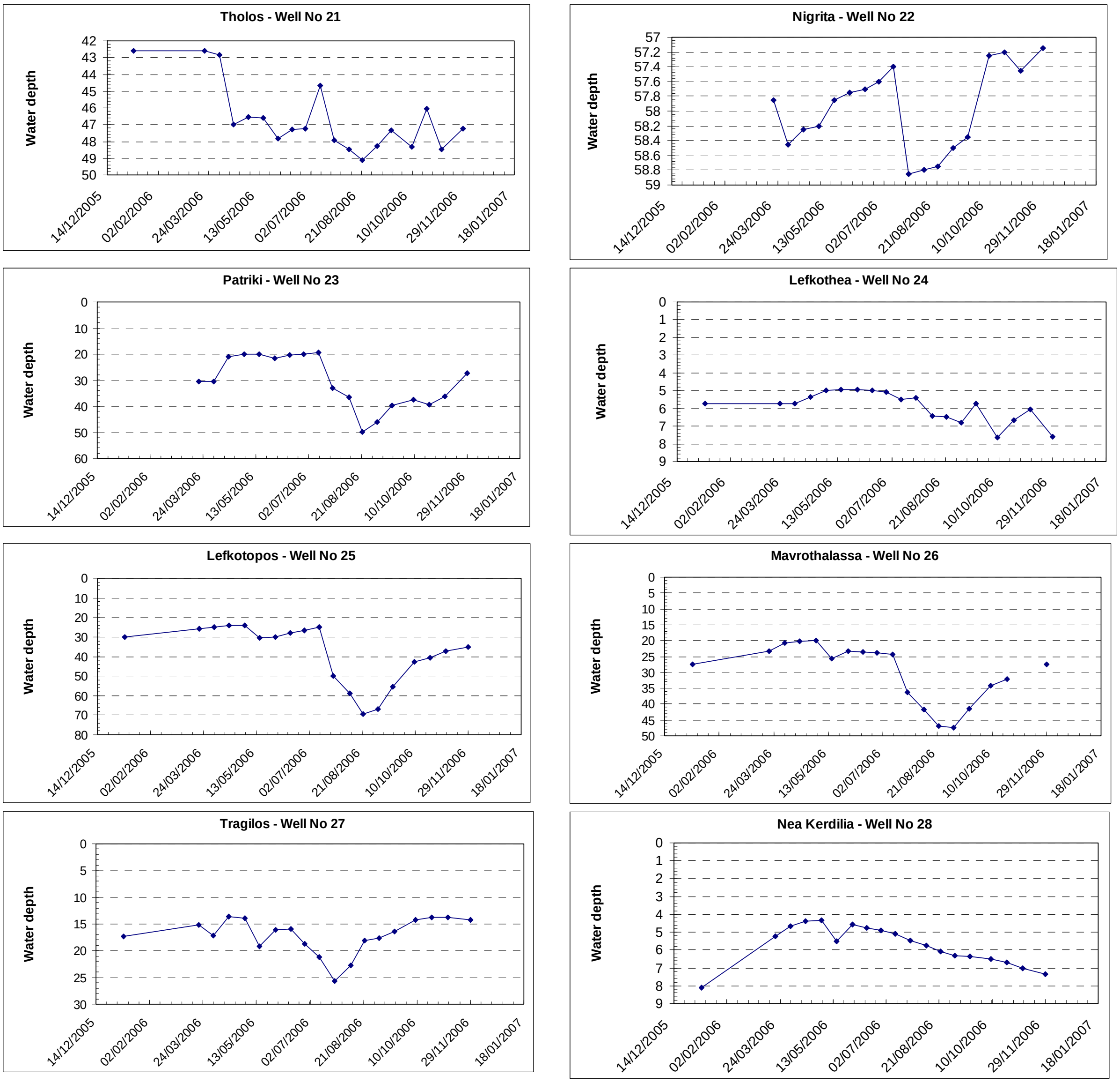


Fig . 30 c. Underground Water table fluctuation