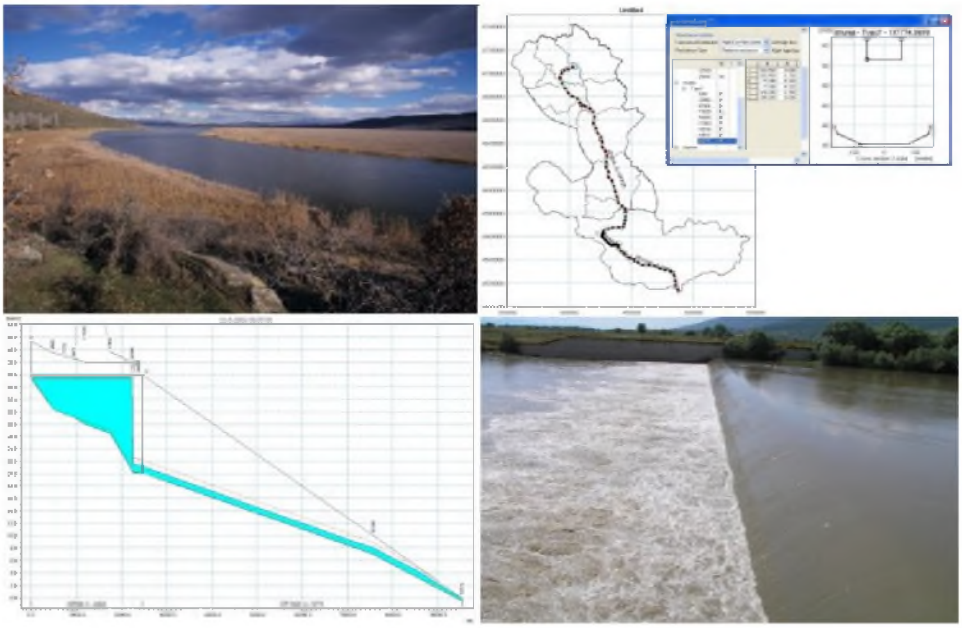
Hellenic Republic
Ministry of Foreign Affairs
Hellenic International Development Cooperation Department

Hellenic-Bulgarian cooperation for the protection and management of natural resources



Use of modern technology for the protection and management of water resources in Strymonas/Struma River basin

THE GOULANDRIS NATURAL HISTORY MUSEUM
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ΕΡΓΟ ΧΡΗΜΑΤΟΔΟΤΟΥΜΕΝΟ ΑΠΟ ΤΗΝ ΥΠΗΡΕΣΙΑ ΔΙΕΘΝΟΥΣ ΑΝΑΠΤΥΞΙΑΚΗΣ ΣΥΝΕΡΓΑΣΙΑΣ ΥΠΟΥΡΓΕΙΟ ΕΞΩΤΕΡΙΚΩΝ ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ	**PROJECT FINANCED BY THE HELLENIC AID MINISTRY OF FOREIGN AFFAIRS HELLENIC REPUBLIC**	**ПРОЕКТЪТ Е ФИНАНСИРАН С ПОМОЩТА НА МИНИСТЕРСТВОТО НА ВЪНШННТЕ РАБОТИ НА РЕПУБЛИКА ГЪРЦИЯ**

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ANNEX IV

Simulated and observed solute concentration of substances for measurement stations located in Greece

(measurement stations are shown in PART I)

INTRODUCTION

EKBY, in collaboration with "Nikola Pushkarov" Institute of Soil Science, implemented in the transboundary basin of Strymonas/Struma River a project entitled: "Hellenic-Bulgarian cooperation for the protection and management of natural resources: application in Strymonas/Struma River basin"

The aims of the project are: a) to promote the Hellenic – Bulgarian cooperation in the field of sustainable natural resources protection and management, b) the use of modern technology (state of the art software tools) for the protection and management of water resources in the Strymonas/Struma basin.

The project is founded by the Hellenic Ministry of Foreign Affairs-Hellenic International Development Cooperation Department (Hellenic Aid) and its duration was from December 2004 till April 2008

The present technical report aims to describe the development of the hydrological-hydraulic model of the transboundary basin of Strymonas/Struma River using MIKE 11 modelling tool. The report consists of two parts. In Part I the construction of Digital Elevation Model and the monitoring network of meteorological and hydrological parameters are described in detail.

In Part II the input data, results and calibration of the modelling processes are analyzed. Furthermore, the results are compared with the standards of Directive 2000/60/EC and used for the assessment of surface water status in Strymonas/Struma River basin. Finally, proposed measures are discussed for the protection and sustainable management of surface water in the basin.

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1. Description of study area

The Strymonas/Struma River basin (Figures 1 and 2), has a total area of 16,747 km^2. It is a trans-boundary basin shared by, Bulgaria (50.6%, 8,473 km^2), Greece (35.8%, 5,990 km^2), FYROM (9.8%, 1,641 km^2) and Serbia (3.8%, 643 km^2). It fed by 58 tributaries of first and second order, 42 of which belong to Bulgarian territory and the remaining 16 to Hellenic territory.

The total length of of the river is about 390 km and springs from the Southern slopes of the Vitosha Mountain, in Bulgaria, (2180 m a.m.s.l.), nearly 0.6 km South from Cherni vrah village. After a south-southeast route of 290 km, Strymonas/Struma River leaves Bulgarian territory near Kulata village (85 m a.m.s.l.). At the Bulgarian territory there are 50 artificial lakes covering an area about 17 Km^2. The largest one is Studena witch covers an area of about 1.2 km^2 and has a storage capacity of 25.2 $x10^6$ m^3.

In Greek territory, after a route of 25 km, Strymonas/Struma River outflows into Lake Kerkini, which is an artificial lake, mainly used for irrigation purposes and flood protection. Maximum water volume in Lake Kerkini is 359.7$x10^6$ m^3 at water level altitude of 36 m. Downstream to Lake Kerkini, Strymonas/Struma River goes on for 77 km and keeps a direction from northwest to southeast before it outflows into Strymonikos Gulf.

In the Bulgarian part of the river basin, main water users of both surface water and ground water are domestic supply, industry and energy production and to a less degree irrigation.

In Greece, irrigation constitutes the main pressure to surface waters and groundwater in the basin. Agricultural activities take place in its lower part (elevation less than +100 m), covering an area of 100,000 ha. The irrigation and drainage of this area is been elaborated through a dense network of canals and ditches.

Fig. 1. Trans-boundary basin of Strymonas/Struma River

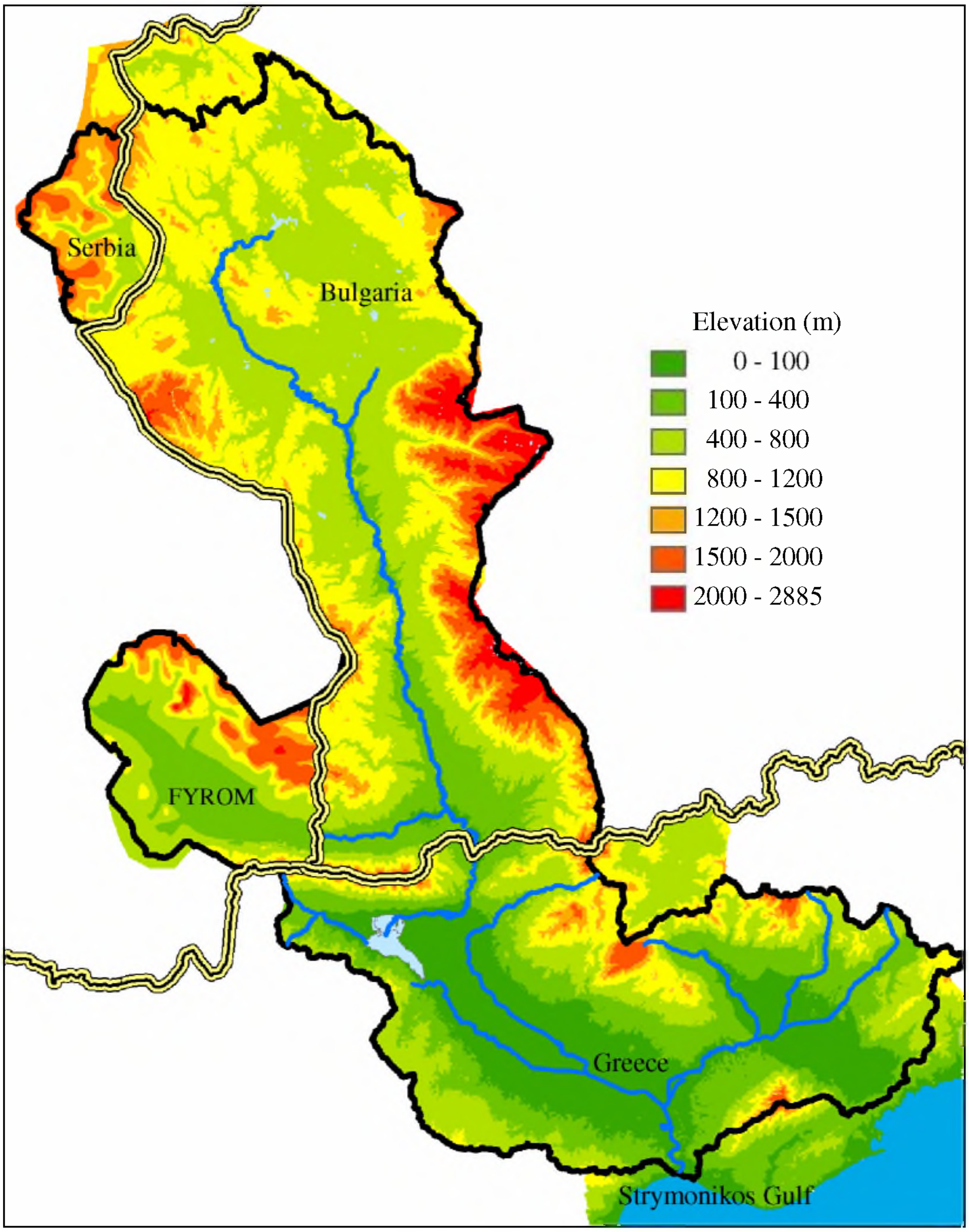

Fig. 2. Topography of Strymonas/Struma River basin

2. The Digital Elevation Model

2.1. Introduction

The most common digital data of the shape of the Earth's surface is cell-based DEMs (Digital Elevation Models). A DEM is a raster representation of a continuous surface (Fig. 3), usually referring to the surface of the Earth. The accuracy of this data is determined primarily by the resolution (distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Elevation

Fig. 3. DEM is a grid with values representing altitudes

A high quality DEM can be used as a basic data set to perform surface water hydrologic analysis and to extract hydrographic characteristics of the area like watershed delineation, flow direction, flow accumulation and stream ordering.

The scope of this technical report is to describe how we used spatial data to create a high quality *depresionless* DEM and how we use it to perform watershed delineation of the Strymonas/Struma basin.

2.2. Materials and methods

2.2.1. Study area

Before collecting any spatial data we had to make a rough estimation of our study area which is Strymonas/Struma's River basin. We used a 1:1.000.000 scale topographic map from the Hellenic Army Geographic Survey covering all the area of the river and it's branches and a draft watershed was designed by hand on the map (Fig. 4).

2.2.2. Spatial data collection

The spatial data required for DEM construction is:

- Contour lines
- Hypsographic points
- Stream network with stream orientation
- Lakes and reservoirs of the area.

So the next step was to collect this kind of data from the available sources. The projection system that we used for all this data is the Hellenic Geodetic Reference System 1987 (EGSA87). Any spatial data collected that was not on this projection system, was reprojected in EGSA87 using ArcGIS PROJECT command.

Fig. 4. Draft delineation of the Strymonas/Struma basin on a 1:1.000.000 scale map (red line)

Contour lines

Contour lines were provided by Nikola Pushkarov Institute of Soil Science for the part of the catchment area in Bulgaria and EKBY for the Greek part. These data sets contained contours with a 100 meters interval for the mountainous areas and with 20 meter interval for plain areas.

Strymonas/Struma River basin extends mainly in three countries Bulgaria, Greece and FYROM. However contour lines from FYROM's area were not available. These contours were digitized by EKBY, using Hellenic's Army Geographic Survey topographic maps in 1:1.000.000 and 1:250.000 scale (Fig. 5).

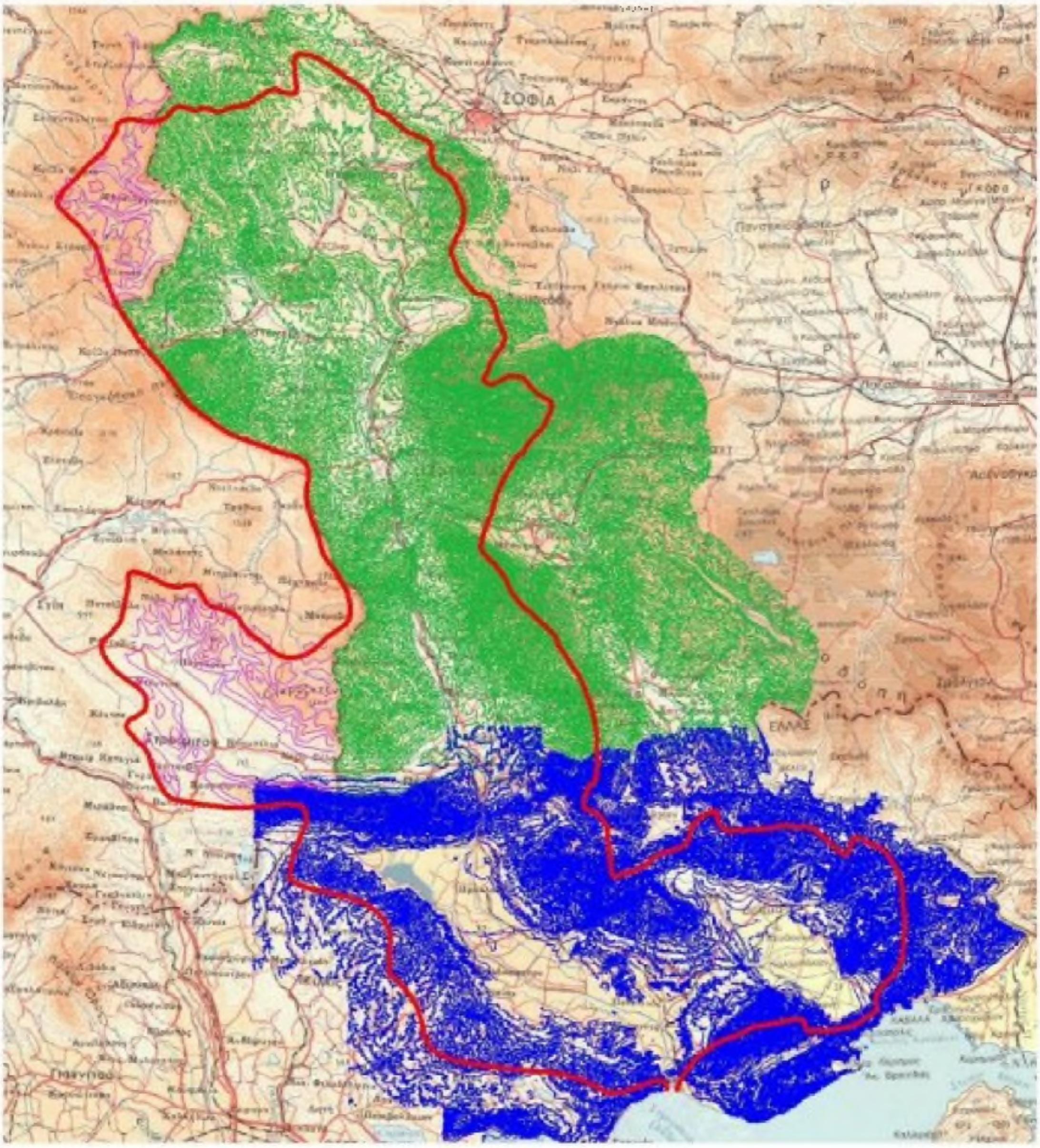

Fig. 5. Contour lines provided by Nikola Pushkarov Institute of Soil Science (green lines) and EKBY (blue lines).

Hypsographic points

This data set was collected with the same procedure as described in the previous paragraph for contour lines. A total of 2461 points were collected where 1775 of them are from the Greek part of the catchment area and the rest 686 are from the Bulgarian and FYROM part (Fig. 6).

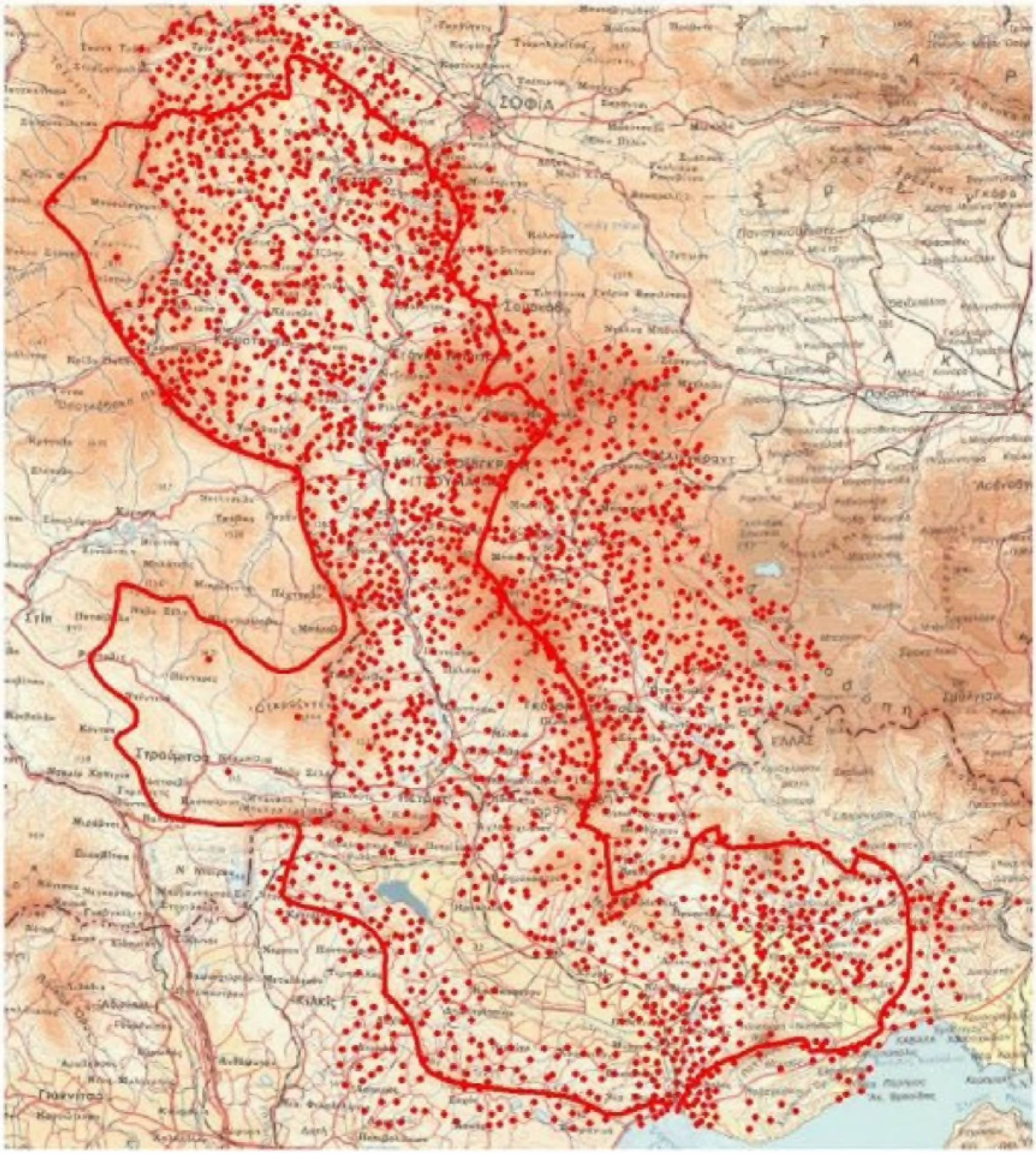

Fig. 6. Hypsographic points for the Strymonas/Struma River basin

Stream network with stream orientation

The stream network of the catchment area was composed using data from Nikola Pushkarov Institute of Soil Science for the Bulgarian part and EKBY for the Greek part (Fig. 7). After composing this layer, an extensive and careful check was performed for every branch of the network to have the correct orientation. This means that streams should have orientation from higher areas to lower ones (Fig. 8).

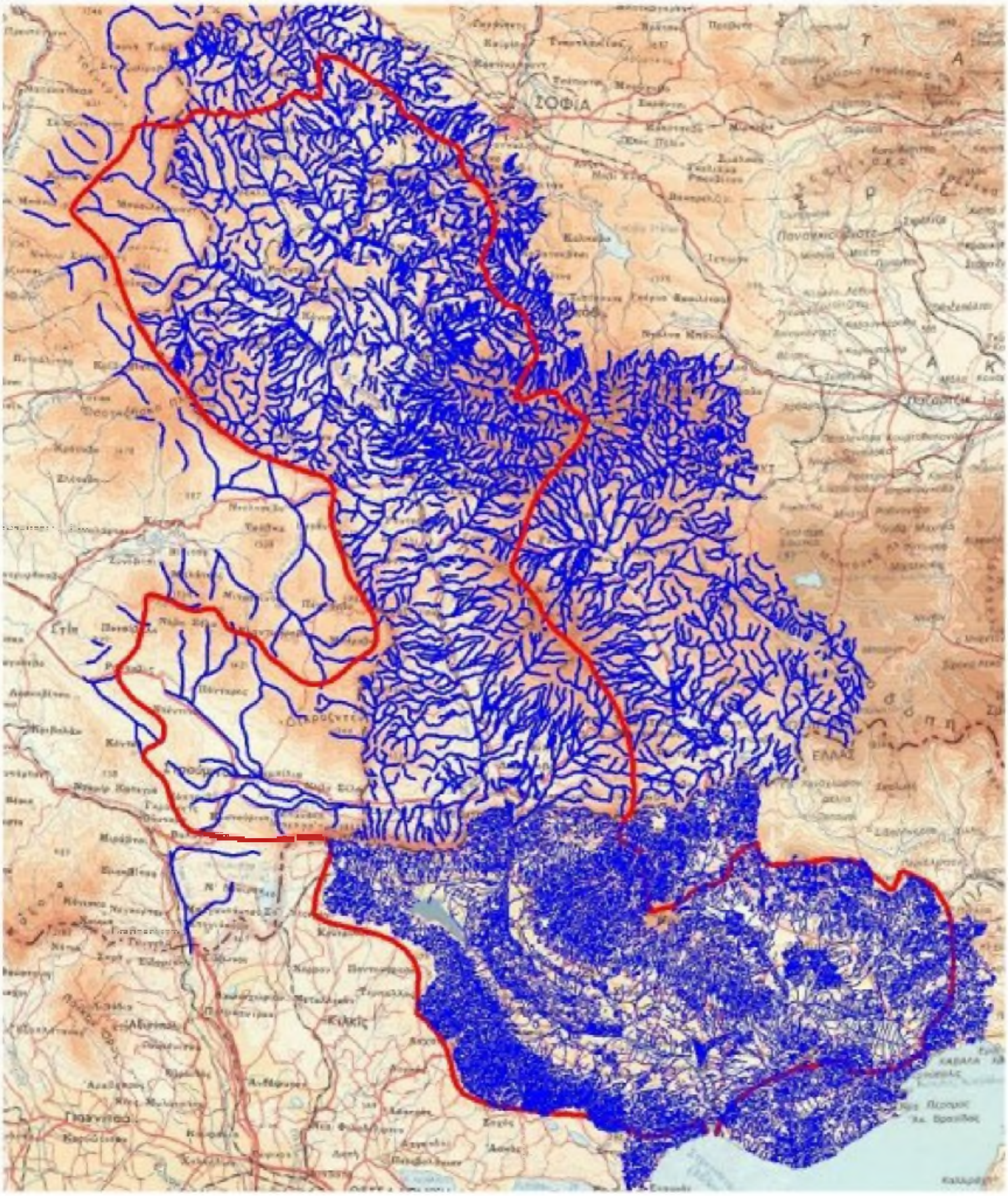

Fig. 7. Hydrographic network for the Strymonas/Struma River basin

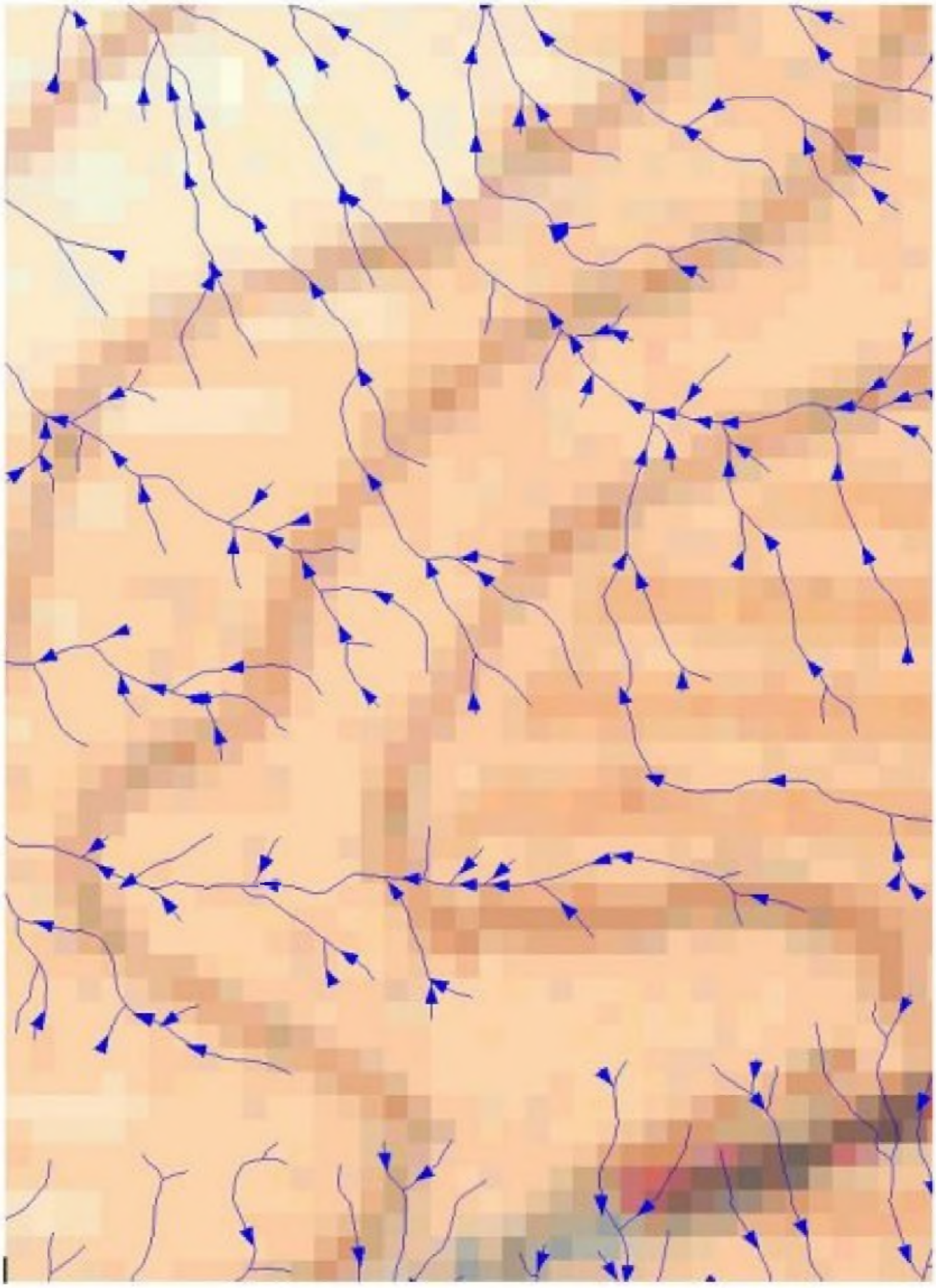

Fig. 8. Detail of the hydrographic network showing the direction of each branch (blue arrows)

Lakes and reservoirs of the area

A polygon shapefile containing the area's lakes and reservoirs was also composed to be used as an input to the interpolation software for the creation of the DEM.

2.2.3. Interpolation of spatial data

We used ArcGIS TOPOGRID command to create a first approach for the area's DEM. The TOPOGRID command is an interpolation method specifically designed for the creation of hydrological correct digital elevation models from comparatively small, but well selected elevation and stream coverages. It is based upon the ANUDEM program developed by Michael Hutchinson (1988, 1989). A resolution of 30 by 30 meters per pixel was chosen for the resulting DEM. This first approach of the area's Digital Elevation Model always have some interpolation errors depending on the quality of the data used and on the area's morphology. These errors are pixels representing sinks and peaks. When a pixel is much lower or higher from the surrounding pixels, then we have a sink or peak error respectively. In order to have a hydrological correct DEM or a depressionless DEM we have to eliminate these errors (Fig 9). These errors were identified and removed using suitable tools from ArcGIS GRID extention.

The corrected DEM was checked using the FLOWDIRECTION and FLOWACCUMULATION layers to verify that it can successfully simulate area's water flow.

The final, hydrological correct DEM of the area (Fig 10) will be used for catchment and subcatchment areas delineation.

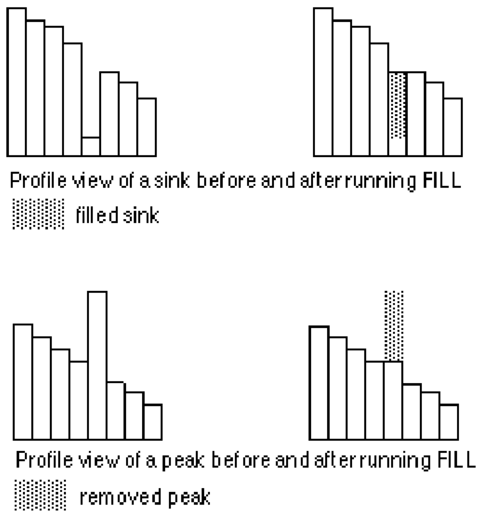

Fig. 9. Interpolation errors like peaks and sinks have to be removed in order to produce a depressionless DEM

2.2.4. Catchment and subcatchment areas delineation

The procedure to delineate the catchment and subcatchment areas using a depressionless DEM is well documented in ArcGIS *Spatial modeling, Cell based modeling with GRID* manual and can be described by the flowchart on Fig 11.

This procedure was followed to delineate:

- Strymonas/Struma River basin polygon
- The major subcatchments of the Strymonas/Struma using a mean value for flow accumulation.

Using the river's basin polygon we finally clipped the depressionless DEM to the catchment's boundary.

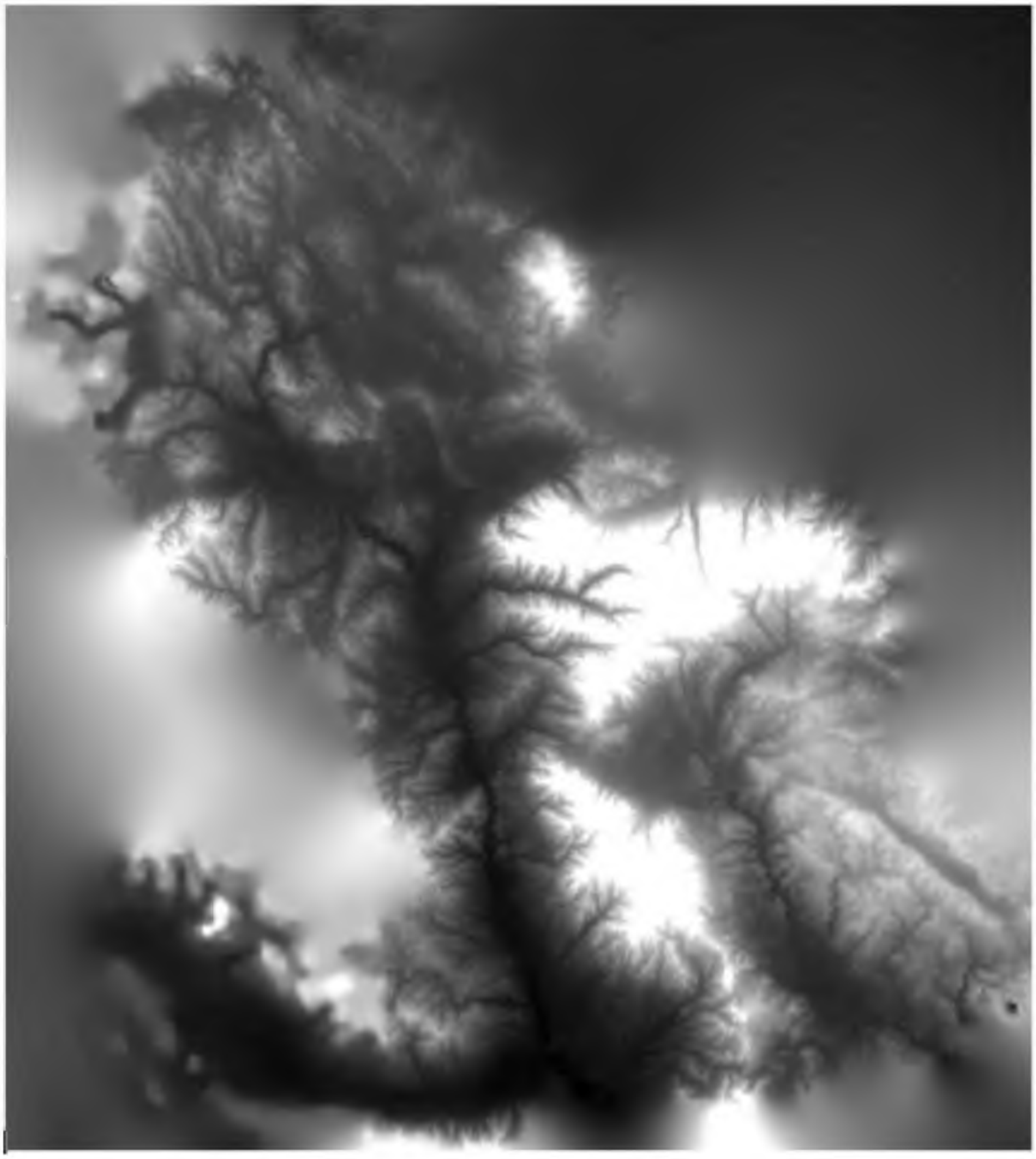

Fig. 10. The final depressionless DEM of Strymonas/Struma basin

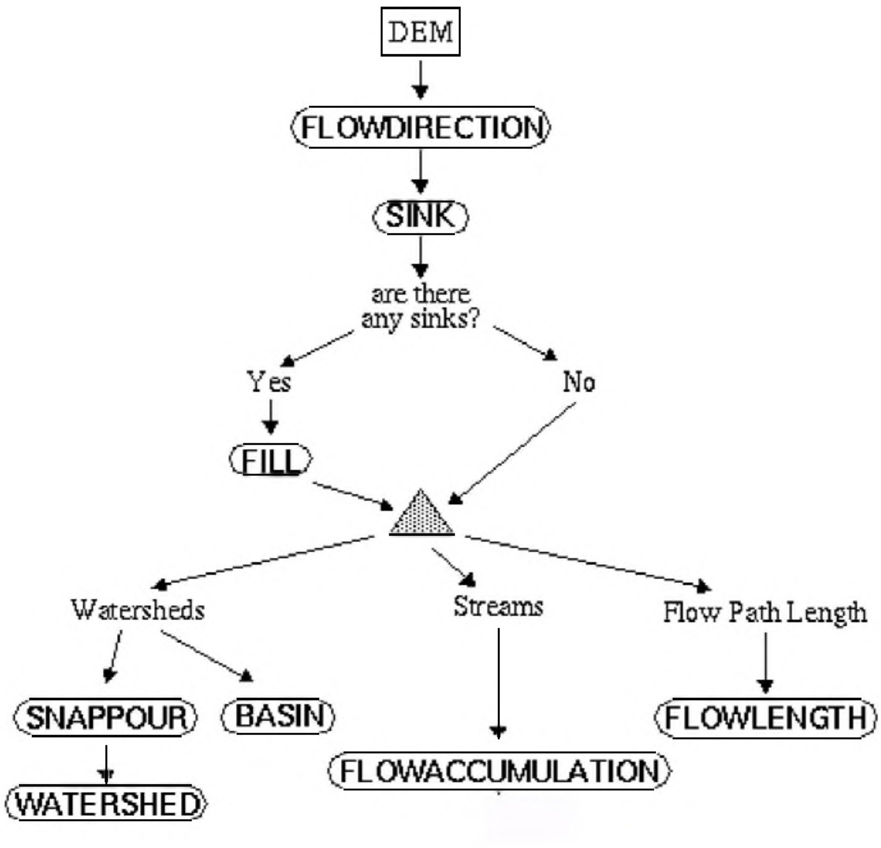

Fig. 11. Flowchart showing the procedure to delineate watersheds using ArcGIS commands

2.3. Results and discussion

2.3.1. Depressionless DEM

The characteristics of the created depressionless DEM created are:

Cell size: 30 X 30 meters
Number of rows : 9233
Number of columns : 7407
Data type : Floating Point
Xmin boundary : 341962 meters
Xmax boundary : 564172 meters
Ymin boundary : 4482862 meters
Ymax boundary : 4759852 meters
Minimum value : 0 meters
Maximum value : 2885.826 meters
Mean value : 717.176 meters
Standard deviation of values : 502.871

2.3.2. Basin and subcatchment areas

The basin and subcatchment polygons are shown in Fig. 12. The subcatchment area delineation in the Greek part of river's basin was performed using only one pour point: the junction of Strymonas/Struma River with Aggitis River. Thus only two subcatchments were delineated in this area. For the rest of the rivers basin (the Bulgarian and FYROM part) the subcatchment delineation was performed by choosing pour points with a mean value of flow accumulation.

As the depressionless DEM, the flowdirection and flowaccumulation layers of the area are available (flowaccumulation and flowdirection layers can easily calculated from the DEM) we can delineate *any* subcatchment in the basin just by defining its outlet and running the WATERSHED command in ArcGIS. We can also merge two or more adjoining subcatchments to the one larger subcatchment using the DISSOLVE command.

Fig 12. Subcatchments of Strymonas/Struma River basin

3. Monitoring network of meteorological and hydrological parameters

3.1. Meteorological station network

Among the most important elements for a hydrological study are the meteorological data. In Strymonas/Struma basin there is a dense network of meteorological stations which are shown in Fig. 13. Within the framework of this project precipitation data of eight (8) stations in Bulgaria and 11 ones stations in Greece were used. The period they cover is from 2000 to 2006. The position and the name of the meteorological stations are given in Table 1. Also data related to temperature were used from the above stations (Kyustendil, Sadanski, Rilski Manastir and Serres).

Table 1. Meteorological stations in Strymonas/Struma River basin used during the project

Territory		Data	Location	Latitude (X,m)	Longitude (Y,m)	Altitude m
Bulgarian	1	Precipitation	Boboshevo	417287.1608	4667238.8595	
	2	Precipitation	Dolene	419096.6079	4588608.5968	
	3	Precipitation	Dren	430943.8826	4695559.728	
	4	Precipitation	Kalishte	404070.6357	4704772.8389	
	5	Precipitation	Krupnik	426952.0160	4633278.7484	
	6	Precipitation	Melnik	449476.3200	4597032.4146	
	7	Precipitation	Rakovo	394028.3240	4660039.0679	
	8	Precipitation, Temperature	Rilski manastir	445352.8891	4664690.3766	
	9	Temperature	Kyustendil	394601.7571	4684875.0553	
	10	Temperature	Sadanski	439833.5481	4601757.7949	
Hellenic	1	Precipitation, Temperature	Serres	460479.8143	4547770.8075	34
	2	Precipitation	Kato Orini	466258.3265	4561105.8342	745
	3	Precipitation	Ano Vrontou	473021.0900	4571900.8558	1040
	4	Precipitation	Nea Zihni	485403.6148	4541897.0457	280
	5	Precipitation	Alistrati	496833.6577	4545230.8024	300
	6	Precipitation	Aidonohori	477624.8492	4519830.7516	212
	7	Precipitation	Nigrita	457463.5589	4529197.0203	111
	8	Precipitation	Lithotopos	434127.2623	4553644.5692	50
	9	Precipitation	Ano Poroia	418728.4815	4572218.3564	395
	10	Precipitation	Sidirokastro	449684.7934	4561122.0902	78
	11	Precipitation	Ahladohori	462067.3181	4575552.1131	500

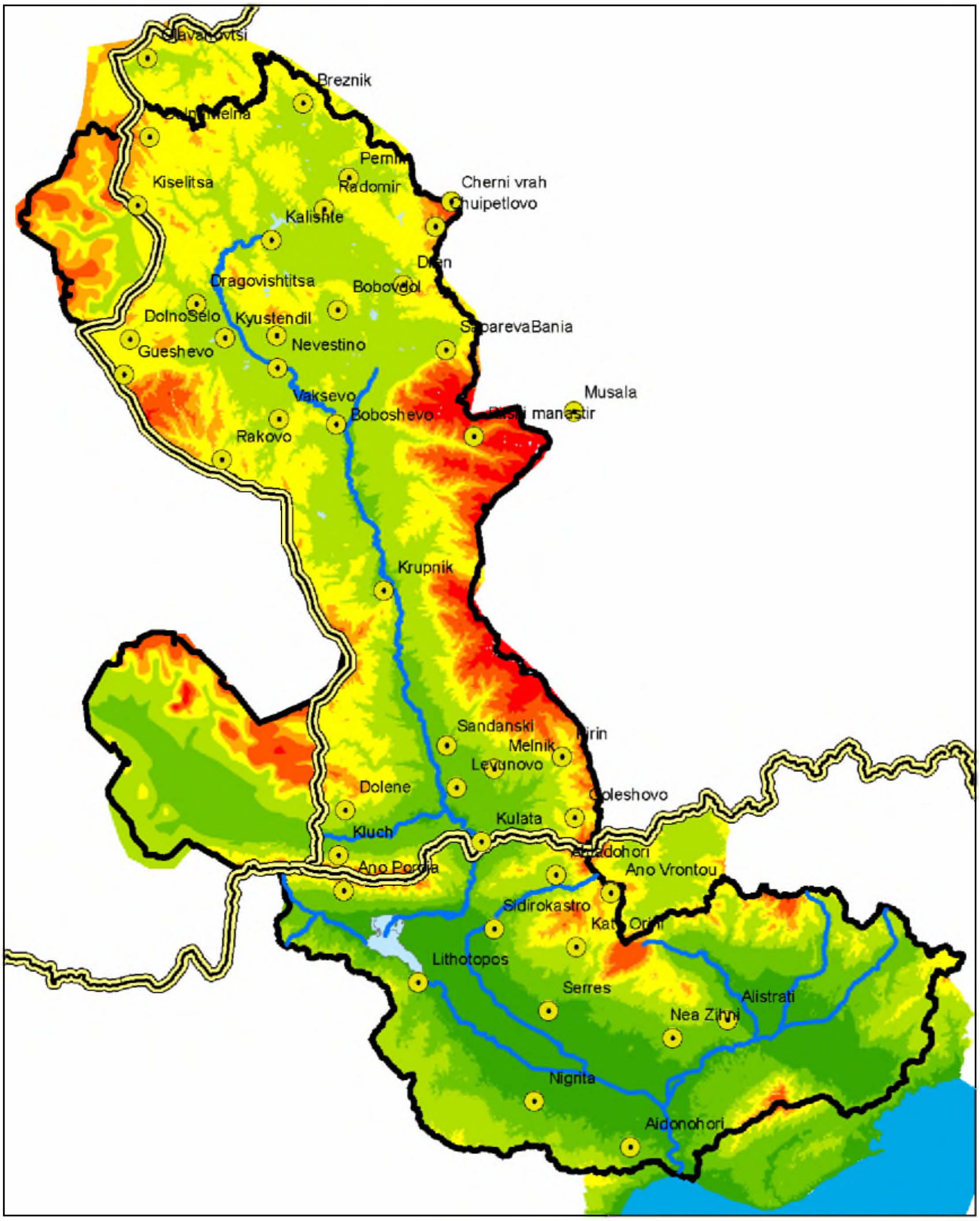

Fig. 13. Precipitation and meteorological stations in Strymonas/Struma basin

Missing values of precipitation data for the period 2004 – 2006 of Krupnik and Dolene were calculated using monthly data from Melnic station due to their adequate correlation (Fig. 14 to 17). The following equations were used:

Krupnik station: $y=0.7488x+6.5755$ ($R^2=0.7446$)

Dolene station: $y=1.2256x + 11.887$ ($R^2=0.832$)

where x is monthly precipitation height (mm)of Melnik station.

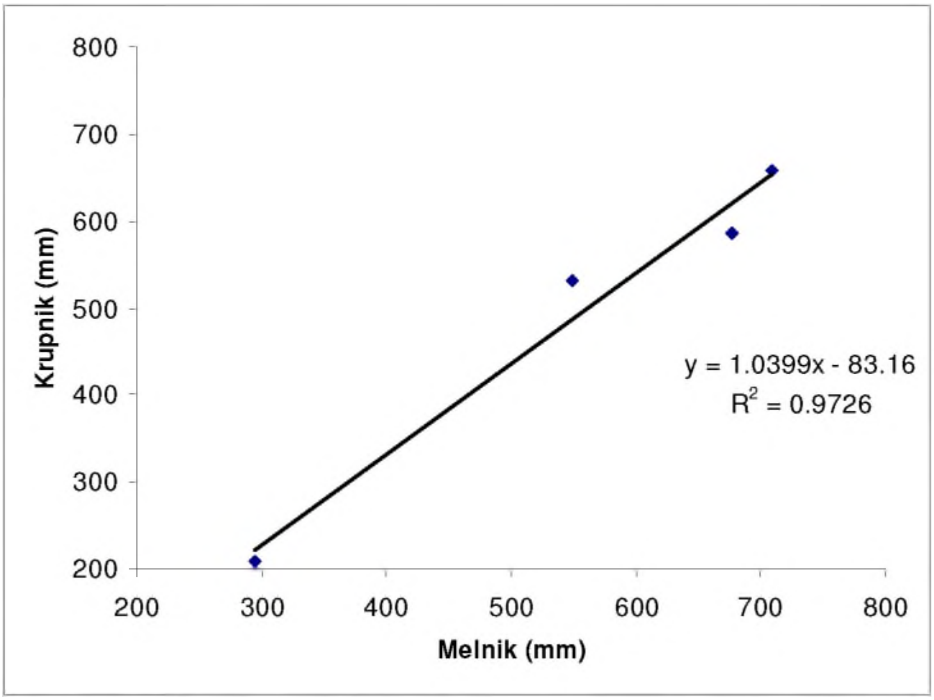

Fig. 14. Correlation of yearly precipitation data between Melnik and Krupnik meteorological stations

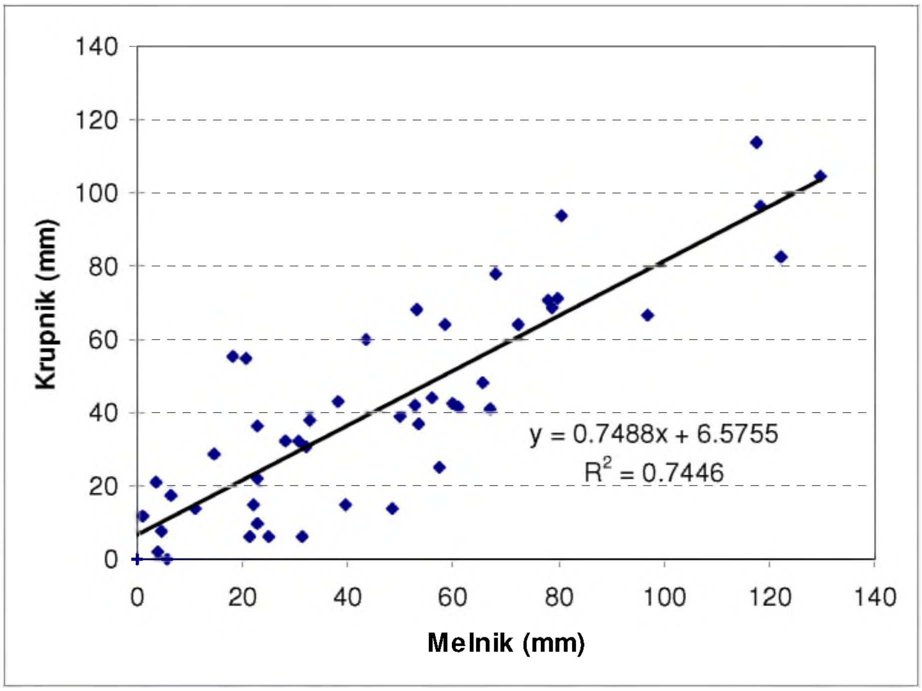

Fig. 15. Correlation of monthly precipitation data between Melnik and Krupnik meteorological stations

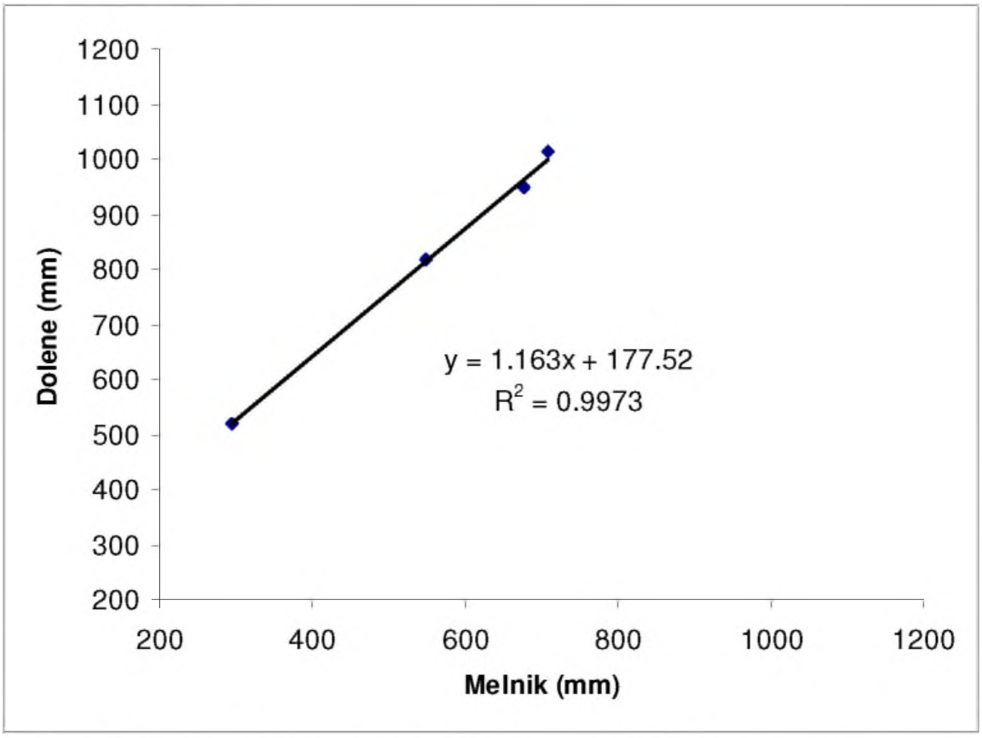

Fig. 16. Correlation of yearly precipitation data between Melnik and Dolene meteorological stations

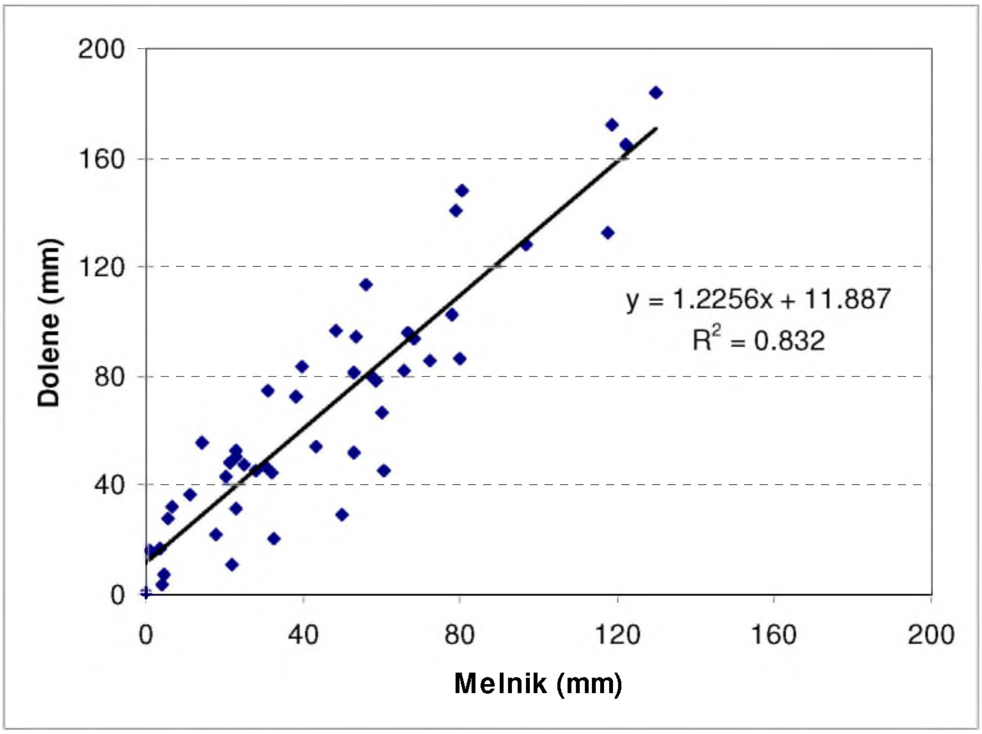

Fig. 17. Correlation of monthly precipitation data between Melnik and Dolene meteorological stations

3.2. Monitoring stations of surface water quantity

The surface water quantity monitoring network includes 29 hydrometric stations which are part of the Bulgarian National Hydrometric System (Fig. 18 and Table 2). Also in Hellenic territory there are 12 water level auto-recorders which have been established within the framework of LIFE Environment project "STRYMON"[1]" (Fig. 18).

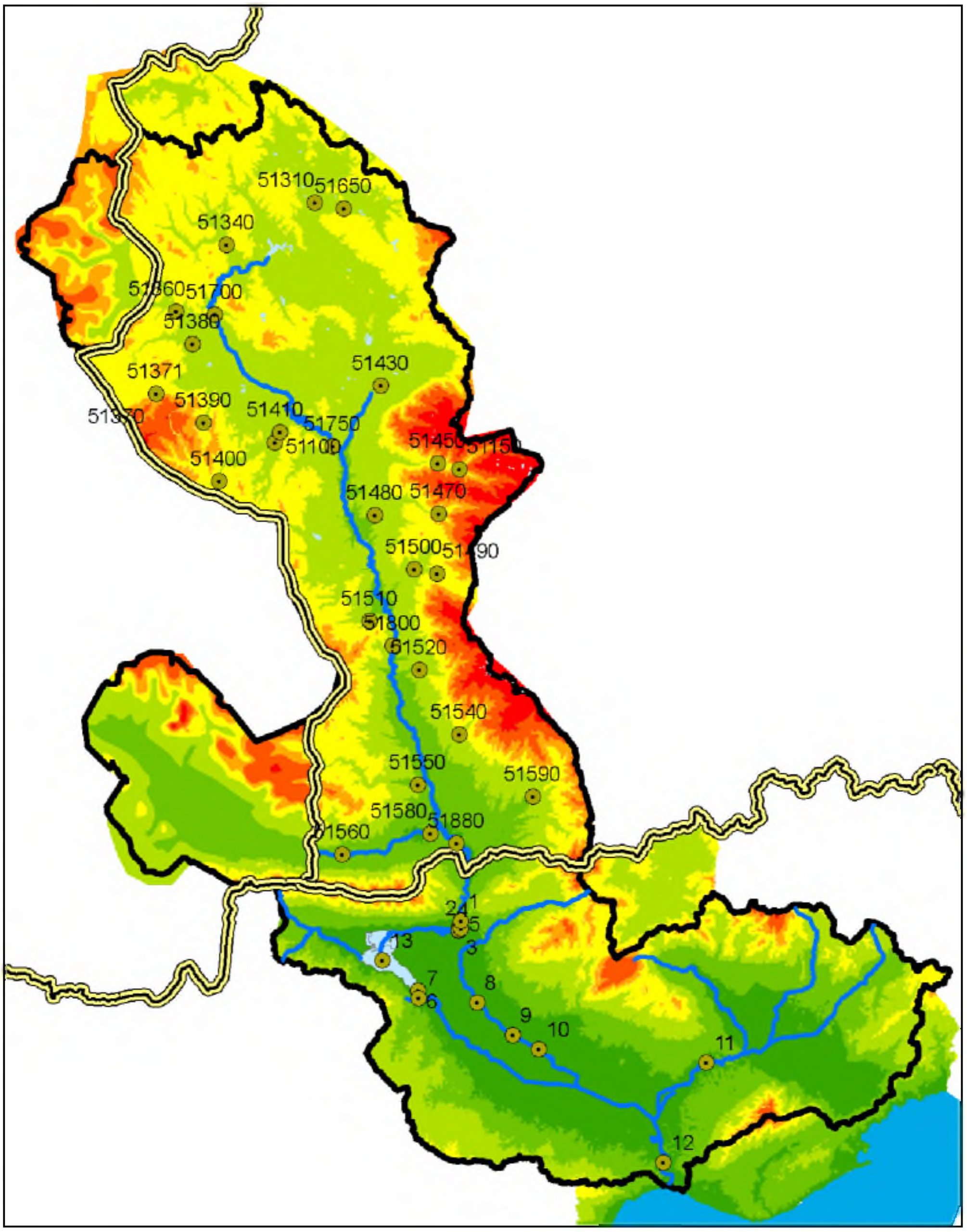

Fig. 18. Surface water quantity monitoring network in Strymonas/Struma basin

[1] The Life Environment project with sort name "Strymon" is a 4-year project (2003-2007) entitle: "*Ecosystem Based Water Resources Management to Minimize Environmental Impacts from Agriculture Using State of the Art Modeling Tools in Strymonas Basin*" (contract number LIFE03 ENV/GR/000217). The project is co-funded by the Goulandris Natural History Museum - Greek Biotope/Wetland Centre (EKBY), the Prefecture of Serres – Directorate of Land Reclamation of Serres (DEB-S), the Development Agency of Serres S.A. (ANESER S.A.) and the Local Association for the Protection of Lake Kerkini (SPALK).

Table 2. Surface water quantity monitoring network in the Bulgarian territory.

n	Station code	Station Name	Lat X (m)	Lon Y (m)	Elev H (m)	Elev HGPS
1	51100	Rechitsa - village Vaksevo	405449	4668061	549.90	557
2	51150	Iliyna river - Brichi bor area	443711	4662618	1004.84	1025
3	51310	Konska river - Batanovtsi town	413835	4717808	653.37	663
4	51340	Treklyanska reka - Vranya stena vIll	395488	4709091	611.24	623
5	51360	Dragovshtitsa - Goranovtsi village	385102	4695306	570.10	547
6	51370	Bistritsa (Sov.) - Gurlyano village	381019	4678270	990.89	1004
7	51371	Bistritsa (Sov.) - Gurlyano (LKS)	380976	4678267	991.96	1004
8	51380	Bistritsa (Sov) - Sovolyano village	388574	4688500	553.35	559
9	51390	Novoselska river - Novo selo village	390844	4672273	814.97	862
10	51400	Eleshnitsa - Rakovo village	393987	4660157	775.11	785
11	51410	Eleshnitsa - Vaksevo village	406564	4670279	528.23	534
12	51430	Djerman - Dupnitsa town	427449	4679883	497.17	514
13	51450	Rilska - Pastra village	439227	4663836	858.46	896
14	51470	Bistritsa (bl) - GD Slavovo	439439	4653437	856.46	864
15	51480	Bistritsa (Bl) - Blagoevgrad	426219	4653127	395.14	405
16	51490	Gradevska (Elovs.) - Marevo village	439049	4641029	691.97	436
17	51500	Gradevska river - Gradevo river	434285	4641984	492.34	502
18	51510	Soushitska river - Polena village	425103	4631221	445.88	458
19	51520	Vlahinska river - Vlahi village	435439	4621117	437.01	466
20	51540	Bistritsa (Sand) - lilianovo village	443623	4607768	514.88	526
21	51560	Strumeshnitsa river - Strumeshnitsa v	419436	4582929	171.62	194
22	51580	Strumeshnitsa river - Mitino village	437720	4587267	84.04	97
23	51590	Bistritsa (Pir) - G. Spanchevo villag	458800	4594863	316.72	329
24	51650	Struma - Pernik town	419732	4716556	681.71	694
25	51700	Struma - Rajdavitsa village	393163	4694632	501.12	533
26	51750	Struma - Boboshevo town	417442	4667377	371.16	384
27	51800	Struma - Kresnensko hanche	429824	4626161	203.08	277
28	51880	Struma - Marino pole village	443112	4585246	72.94	92
29	51550	Lebnitsa - Lebnitsa vilage	435045	4597375	100	144

The distribution of the 12 water level recorders in the Greek part of Strymonas/Struma river basin was determined taking into account the current management of surface water network. Hence the recorders were established at the inlets and outlets of either the natural water bodies or the irrigation and drainage networks.

The 1st water level recorder has been established in Strymonas/Struma River just upstream the flow control structure "Ypsilon 1 (Y1)" (Fig. 18 and 19) aiming at the monitoring of Strymonas/Struma inflows into the catchment.

The flow control structure "Ypsilon 1 (Y1)" diverts water from Strymonas/Struma River to the main canal called "2K", and to the "Trimeristis" canal which in turn diverts water to the canals of "Ditiki dioriga", "Kentriki dioriga" and "Anatoliki dioriga" (Fig. 19). The canals of "Kentriki dioriga" and "Anatoliki dioriga" supplies with water 6.230 ha and the canal "Ditiki dioriga" irrigates a region of 4.930 ha. Three water level recorders have been established in the upper end of each one of the above canals aiming to monitor the discharges that are supplied to the above irrigated regions.

The canal of “2K” has a discharge capacity of 7 m^3/s and supplies an irrigation networks of 7.360 ha (Fig. 19). A water level auto-recorder (No 5) has been established about 3 km downstream its upper end and before water distribution occurs to secondary canals.

The sixth water level recorder has been established just downstream the flow control structure “Ypsilon 2 (Y2)” under the bridge of “Enotiki Dioriga” (Fig. 19). “Enotiki Dioriga” supplies with water an irrigation network of Serres that covers an area of 14.120 ha.

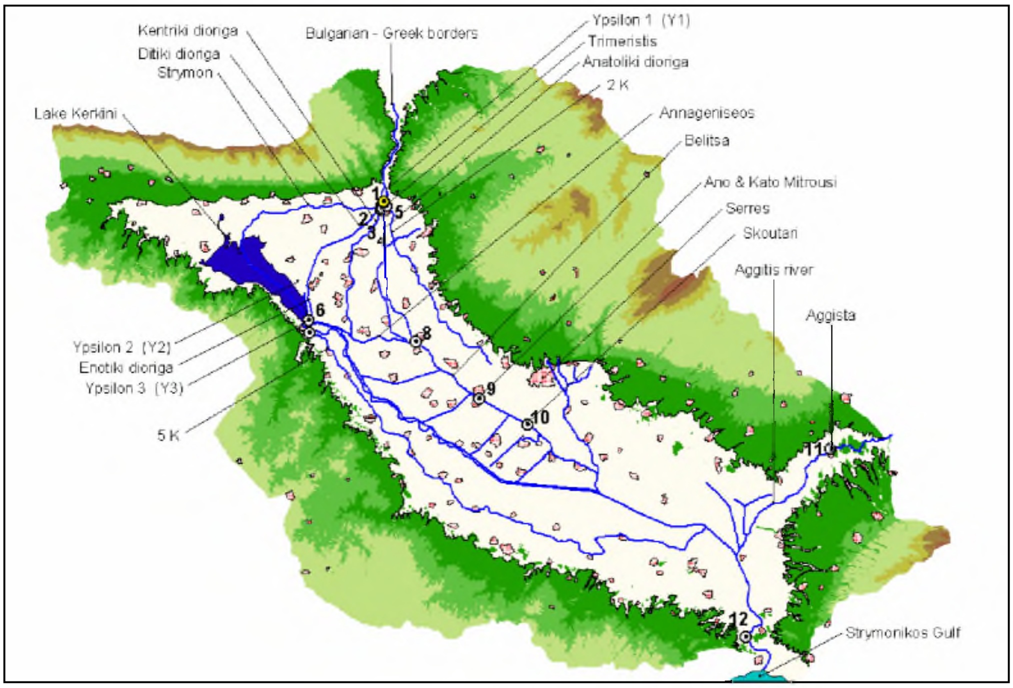

Fig. 19. Distribution of water level reorders in Greek part of Strymonas/Struma basin

The 7th water level auto-recorder has been established downstream the “Ypsilon 3 (Y3)” flow control structure through which water diverts to the “5K” canal. The canal “5K” supplies with water the two irrigation networks of 6.430 ha and 4.760 ha respectively.

The 8th, 9th and 10th water level auto-recorders are located in “Belitsa” drainage ditch. The No 8 instrument has been established in “Belitsa” ditch just before the outlet of “Annageniseos” ditch (Fig. 19), aiming at monitoring the water flow at its upper end. The instrument No 9 has been established under the bridge near the villages “Ano Mitrousi” and “Kato Mitrousi” (Fig. 19). The water flow at this point comes from drainage water from the up stream cultivated areas during the summer while during the rest period, comes mainly from the upstream torrents.

The 10th water level auto-recorder is located under the bridge of village “Skoutari”. At this position the flow regime in “Belitsa” ditch can be calculated taking into account the measurements of the 9th and 10th water level auto-recorders.

The 11th water level auto-recorder has been established at “Aggitis” River near the “Aggistas” Railway Station (Fig. 19). At this point the net inflow of “Aggitis” into the catchment can be estimated.

The last water level auto-recorder (12th) has been established 2 km upstream of Strymonas/Struma basin outlet into Strymonikos Gulf (Fig. 19) aiming to monitor the total runoff of Strymonas/Struma basin into the sea. This water level auto-recorder has been replaced in 2007 by a prototype discharge station.

3.3. Monitoring stations of surface water quality

Data of 31 water quality monitoring stations was used for the purpose of this project (Fig. 20). There were 15 stations in Bulgarian territory and the covered period was from 2000 to 2004. The frequency of data was not the same for all the stations. In the Greek territory there were 16 stations (station no 9 excluded due to lack of data) and the covered period was from 8/2004 to 11/2006. The frequency of data was every 10 days. Information regarding the stations and the frequency of data are given at the Table 3. The water quality parameters that were used for the project, were temperature (T), pH, dissolved oxygen (DO), electrical conductivity (ECw), NO_3, NH_4^+, PO_4^{3-} and BOD_5. At the Greek territory BOD_5 was measured only at sample stations 1, 3, 13 and 16 (Fig. 20).

For the spatial distribution of the 16 stations in Greece, the functioning and the management of surface water network in the catchment was taken into account. Hence the stations were established at the inlets and outlets of either the natural water bodies (e.g. Strymonas/Struma River, Lake Kerkini, Ag. Ioannis springs etc) or the main irrigation and drainage networks in the catchment (Fig. 21). Also care was taken the position of the stations to be identical to that ones where water level auto-recorders have been established.

The 1st sampling station (No 1) has been established in Strymonas/Struma River, just upstream the flow control structure "Ypsilon 1 (Y1)" (Fig. 21), aiming to monitor the quality of water close to border between Bulgaria and Greece. The distance from the borders is about 10 Km, and there is no any human activity in the area that could affect the quality and quantity of the water that inflows from the neighbor country. Also, since this position is too close (less than 500 m) to the flow control structure "Ypsilon 1 (Y1)", it can give the quality of the water that diverts into the irrigation networks of Local Land Reclamation Agencies (L.L.R.A.) Iraklias and Sidirokastro (Fig. 22).

The irrigation and drainage of the plain area at the Greek part of Strymonas/Struma basin is been elaborated through a dense network of irrigation canals and drainage ditches. The Land Reclamation Service of Serres – Greece (DEB-S) is responsible for the water resources management in the agricultural area through its administrative and technical supervision of the General Land Reclamation Agency (G.L.R.A.) and of the 10 Local Land Reclamation Agencies (Fig. 22). These agencies are organizations of an agro-cooperative nature aiming to the management of land reclamation works and the distribution of irrigation water.

A sampling station (No 9) has been established downstream of Agios Ioannis' springs, aiming to monitor the quality of water that inflows into the irrigation network of Ag. Ioannis (Fig. 22).

The sampling station No 13, has been established at Aggitis River, aiming to monitor the quality of water that comes from its catchment. Also this station gives information with regard to the quality of the water that fed a part of Dimitra's irrigation network (Fig. 22).

A number of sampling stations were established inside Lake Kerkini due to its importance both for its ecosystem and its role as a provider of water for irrigation. Hence the sampling station No 2 has been established at its upper end, sampling station No 3 in the middle of the lake and sampling stations No 4 and No 5 close to the flow control structures "Ypsilon 2 (Y2)" and "Ypsilon 3 (Y3)" (Fig. 21). The later fed with water Strymonas/Struma River downstream the dam of the lake and the irrigation networks of Provatas (No 4), Nigritas and Dimitritsi networks (No 5) (Fig. 22).

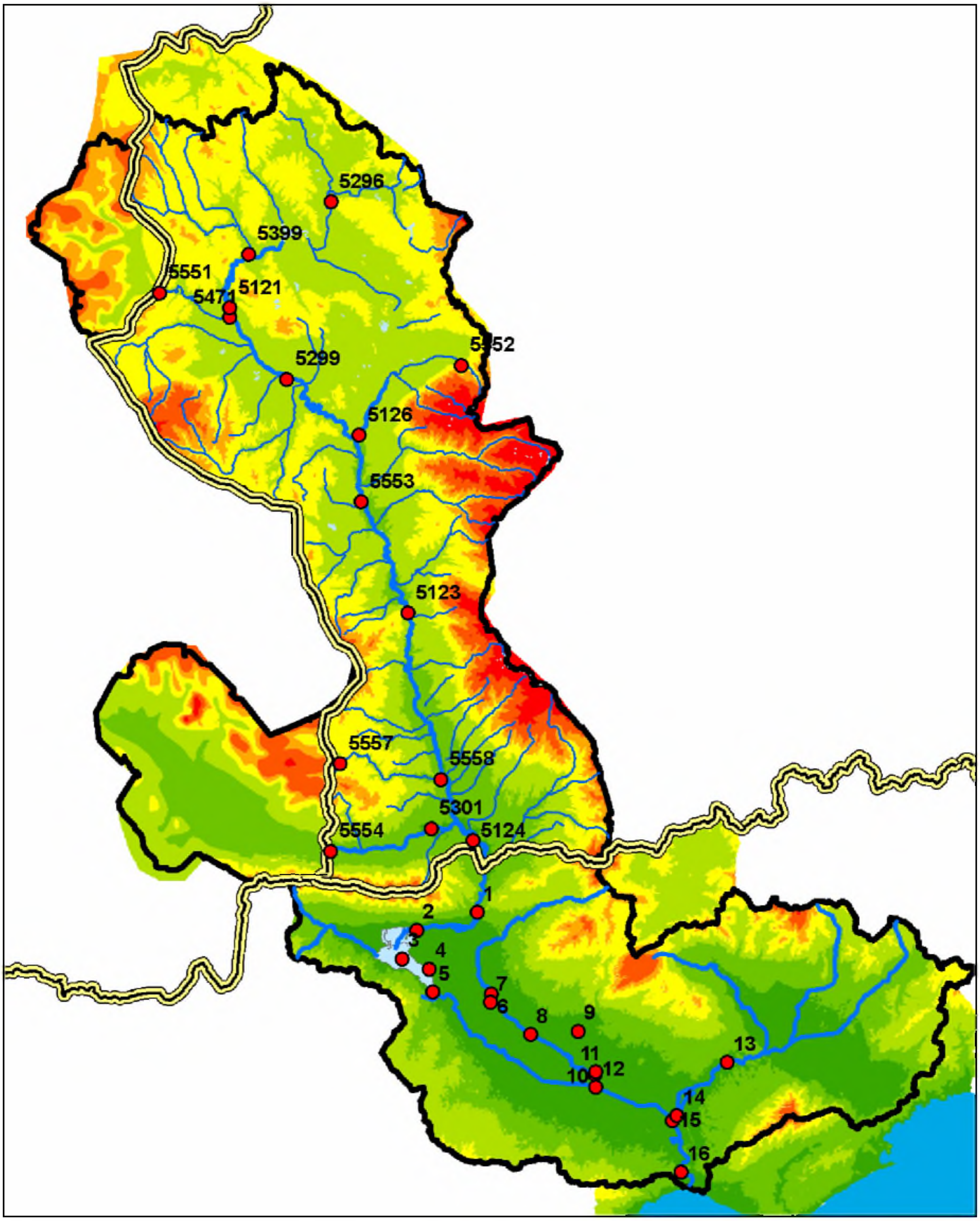

Fig. 20. Water quality monitoring stations in Strymonas/Struma basin

Table 3. Water quality monitoring stations in Strymonas/Struma basin used during the project

Territory	Station Code	Frequency (Samples/ year)	Location	Latitude (X,m)	Longitude (Y,m)
Bulgarian	5557	12	Lebnitsa river	165825	4608098
	5554	12	Strumeshnitsa	163240	4590355
	5124	12	Struma	192330	4591559
	5551	2	Dragovshtitsa river	132400	4705168
	5301	12	Strumeshnitsa	183899	4594266
	5296	12	Struma	167978	4722476
	5399	12	Treklyanska	150837	4712431
	5471	12	Dragovshtitsa	146494	4699721
	5299	12	Struma	157702	4686719
	5126	12	Djerman	172039	4674812
	5552	2	Djerman	193335	4688313
	5553	12	Struma	172009	4661216
	5123	12	Struma	180635	4638300
	5121	12	Struma	146599	4701612
	5558	12	Lebntsa	186235	4604124
Hellenic	1	36	Strymonas-Sidirokastro	443739	4570370
	2	36	Strymonas - Kerkini	431385	4566660
	3	36	Lake Kerkini	428483	4560890
	4	36	Lake Kerkini	433915	455878
	5	36	Lake Kerkini	434713	4554090
	6	36	Belitsa	446560	4553730
	7	36	Notia tafros	446435	4552050
	8	36	Belitsa- Mitrousi	454590	4545440
	9	36	Agios Ioannis	464360	4546130
	10	36	Belitsa - Agios Ioannis	467720	4537290
	11	36	Agios Ioannis - Belitsa	467934	4537900
	12	36	Strymonas -Belitsa	467963	4534800
	13	36	Aggitis river	494763	4539780
	14	36	Aggitis - Strymonas	484468	4528930
	15	36	Strymonas - Aggitis	483598	4527950
	16	36	Strymonas Amfipolis	485378	4517500

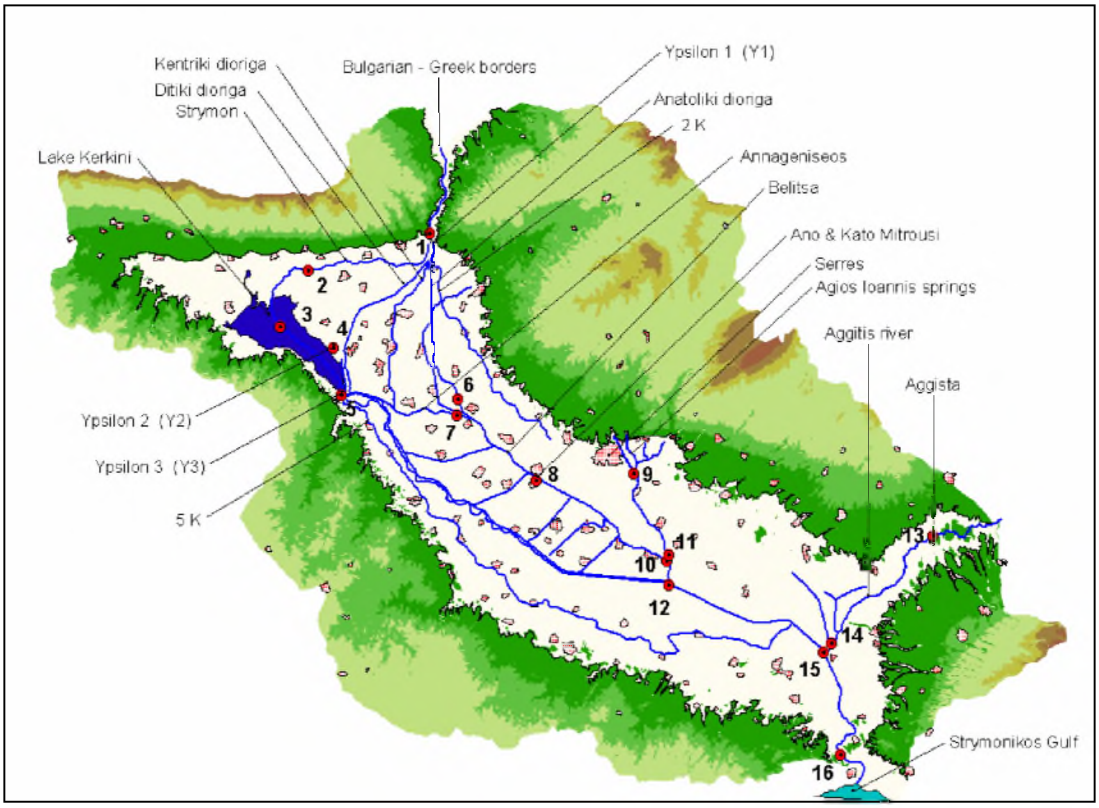

Fig. 21. Distribution of sample stations in the Greek part of Strymonas/Struma basin

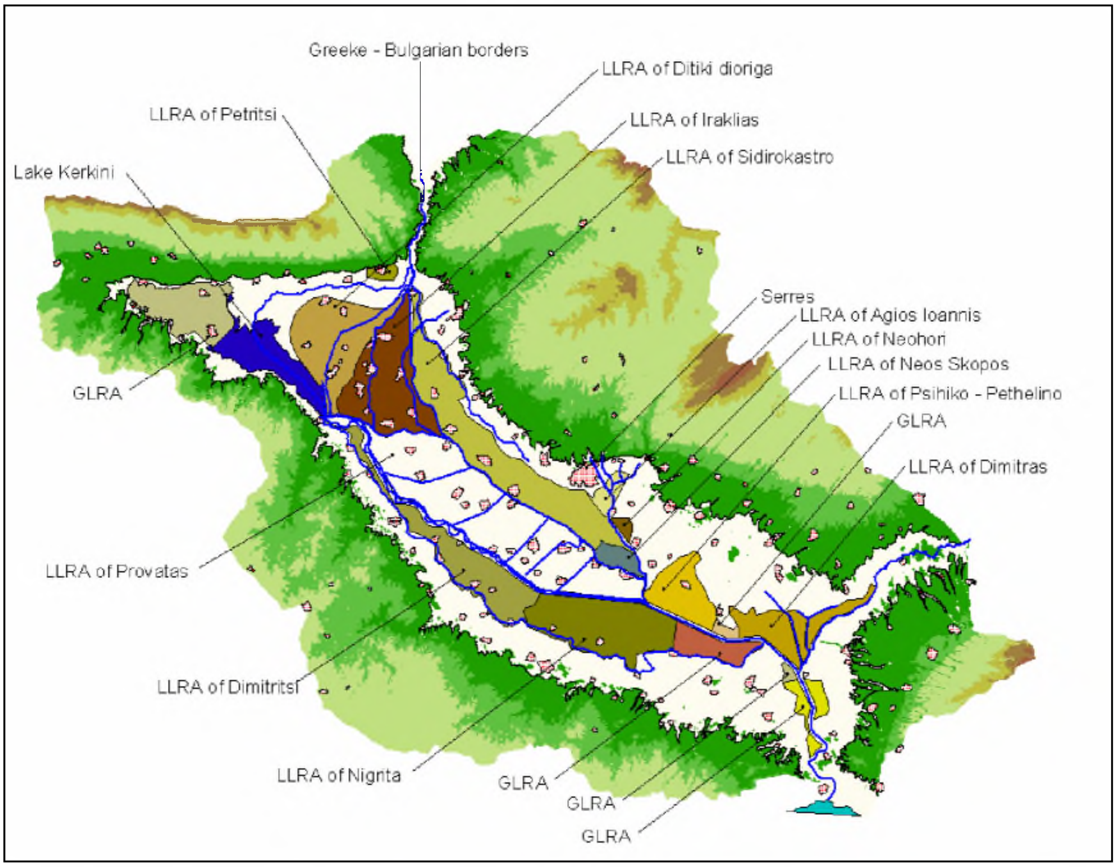

Fig. 22. Irrigation networks of the plain area in the Greek part of Strymonas/Struma basin

A water body of major importance in the catchment is the drainage ditch of Belitsa (Fig. 21). It receives almost all of the drain water that comes from the agricultural area located east of Strymonas/Struma River, and following fed with water the irrigation networks of the Land Reclamation Agency and Neos Skopos (Fig. 22). Four sampling stations have been established in Belitsa ditch No 6, No 7, No 8 and No 10 (Fig. 21 and 22).

The sampling station No 6, is aiming at monitoring the quality of water that drains from the upper part of Sidirokastro network and a very small part of Iraklias irrigation network (Fig. 22). Also station No 6 gives information for the quality of water at the upper end of Belitsa ditch.

The sampling station No 7, is aiming to monitor the quality of water that drains from the agricultural area of Iraklias irrigation network (Fig. 21 and 22) and outflows into Belitsa ditch.

The sampling station No 8, has been established in the Belitsa ditch just downstream the outlet of the drain water that comes from the upper part of Provatas irrigation network. It is important to be mentioned here that the drain water of this area gives the main discharge of Belitsa ditch, due to the high quantities of irrigation water for the rise crops.

The sampling station No 10, has been established in Belitsa ditch just before Ag. Ioannis and Belitsa brunch connection.

Sampling station No 11 has been established in Ag. Ioannis springs and aims to monitor the quality of water before the brunch connection of Ag. Ioannis and Belitsa.

Sampling station No 12 is located in Strymonas/Struma River before its junction with the Belitsa ditch. It aims to monitor the water quality of Strymonas/Struma River after it has been influenced by the drainage water of Dimitritsi, north part of Nigritas and the south part of Provatas irrigation networks (Fig. 21 and 22).

Sampling station No 15 is located in Strymonas/Struma River, just before Agitis River outflows in it. It aims to monitor the water quality of Strymonas/Struma River after it has been influenced by the drainage water (Fig. 21 and 22) of the following areas:

- The south part of Nigritas irrigation network
- The west part of Dimitras network and
- The right and left Strymonas/Struma banks irrigation networks commanded by the General Land Reclamation Agency.

The sampling station No 14 is located in Agitis River just before it outflows into Strymonas/Struma River and after it has been influenced by the drainage water of the east part of Dimitras irrigation network.

Finally a sampling station, No 16, has been established at the outlet of Strymonas/Struma River 2 km before Strymonikos Gulf (Fig. 21). It is near by the position where the innovated construction of discharge recorder has been established.

4. Quantitative and qualitative data of surface water

4.1. Meteorological data

The north part and the mountain area of the Bulgarian territory can be characterized as Mountain climatic region and the south and plain area of the Bulgarian territory with the Hellenic part of Strymonas/Struma basin can be characterized as Mediterranean climatic region. In the north part of the catchment the precipitation during summer is a little higher than that during spring, while near Petrich, for example, winter has the heaviest precipitation (Breznik 172 mm in summer and 146 mm in spring, Dupnitsa – summer rainfall 171mm, spring rainfall 176mm, Petrich – average winter snowfall 210mm, summer rainfall 124 mm). In the mountain regions spring rainfall is the most abundant.

The total annual precipitation at meteorological stations in Strymonas/Struma River basin is given in Table 4 and the total annual amount of precipitation at the Bulgarian and Hellenic parts of Strymonas/Struma basin shown at the Fig 23. The monthly values of precipitation data at meteorological stations in Strymonas/Struma River basin are given in Annex I (Table 1 and 2). The temperature variation that has been recorded at the meteorological stations is shown at the Fig. 24.

Table 4. Total annual precipitation at meteorological stations in Strymonas/Struma River basin

Territory		Location	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Bulgarian	1	Boboshevo	265	383	637	597	537	700	523
	2	Dolene	519	820	1013	949	945	1037	898
	3	Dren	323	585	726	672	627	856	520
	4	Kalishte	278	511	661	488	689	813	587
	5	Krupnik	208	531	658	586	569	625	541
	6	Melnik	294	549	708	676	655	729	617
	7	Rakovo	306	571	897	821	797	767	635
	8	Rilski manastir	471	778	1028	914	908	1176	810
Hellenic	1	Serres	279	338	803	448	527	623	711
	2	Kato Orini	512	648	630	676	732	617	512
	3	Ano Vrontou	385	593	910	752	726	741	710
	4	Nea Zihni	243	362	747	615	527	623	711
	5	Alistrati	380	503	979	694	576	798	776
	6	Aidonohori		340	1145	646	392	355	614
	7	Nigrita	397	255	0	474	410	392	574
	8	Lithotopos	135	359	27	965	587	690	629
	9	Ano Poroia	372	635	893	696	748	632	702
	10	Sidirokastro	205	380	826	412	471	523	540
	11	Ahladohori	270	460	730	545	535	702	595

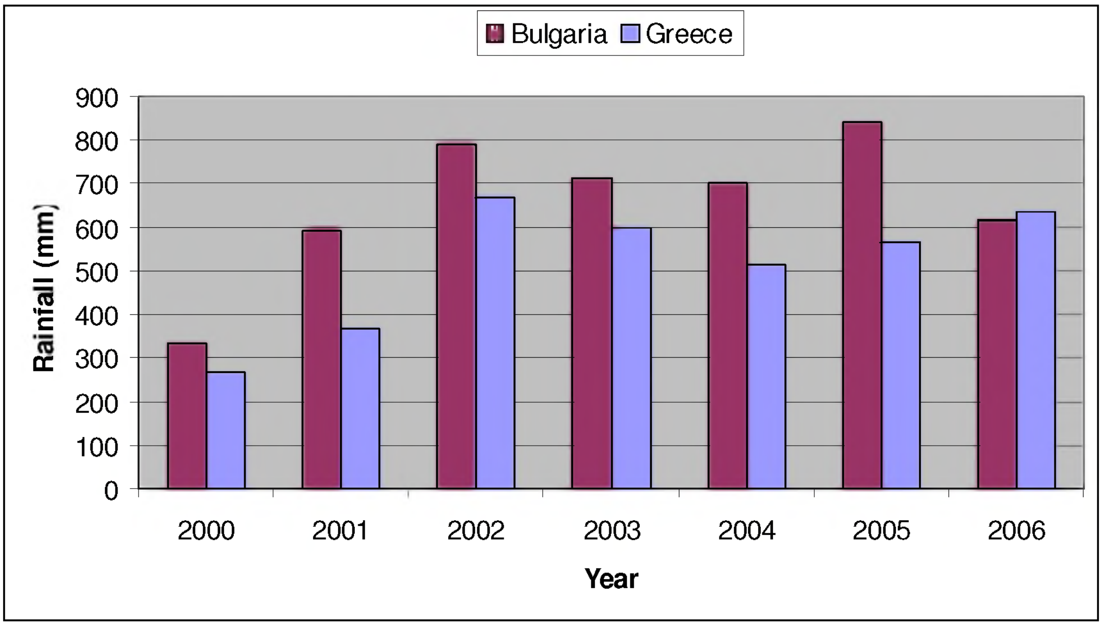

Fig. 23. Total annual precipitation at Bulgarian and Hellenic territory of Strymonas/Struma River basin

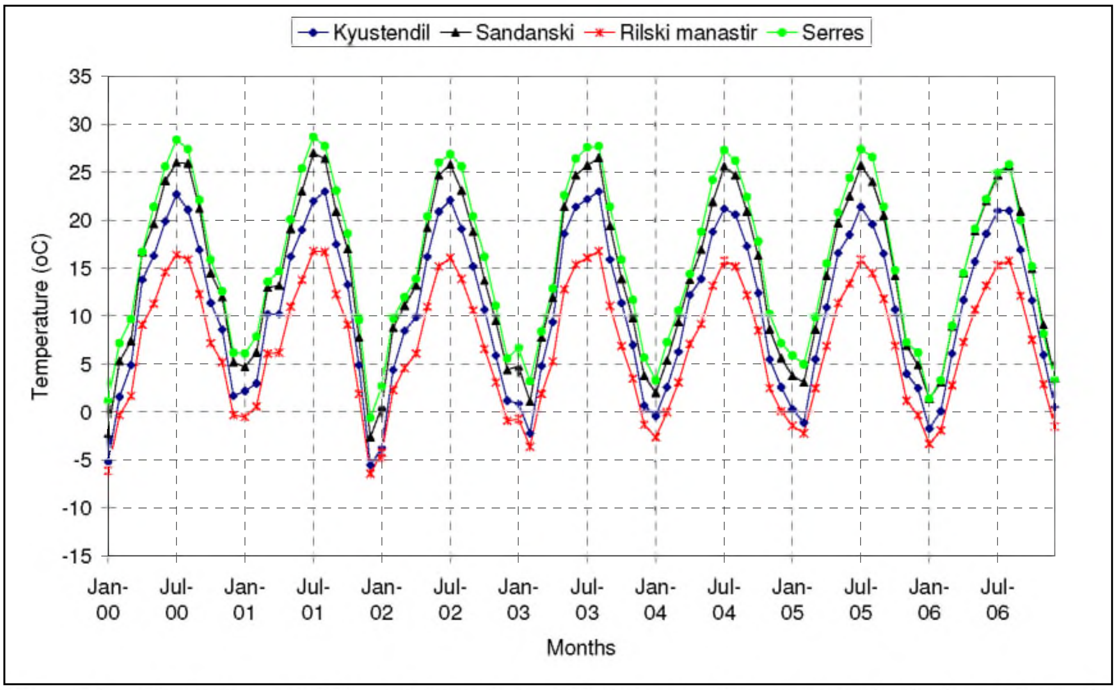

Fig. 24. Average monthly temperature variation at the meteorological stations in Strymonas/Struma basin

4.2. Discharge data

Discharge data from the main hydrometrical stations at the Bulgarian territory, regarding minimum, maximum and average values, are presented in Table 5. Station codes of Table 5 referred at Fig 18 and the period covered is from 2000 to 2006. The values of the average monthly flow and its characteristics in the hydrometric stations along the river are given in Annex I (Table 3).

In the Greek territory the discharge that enters from Bulgaria flows into Lake Kerkini (Fig 25). During the irrigation period (May-September) a maximum discharge of 40 m^3/s is released downstream the Lake while of the rest of the year a maximum amount of 200 m^3/s is allowed in Strymonas/Struma River downstream the Lake.

Table 5. Discharge in hydrometrical station of Struma/Strymonas River basin at Bulgarian territory

n	Station code	Location	Min, m^3/s	Max, m^3/s	Average, m^3/s
1	51100	Rechitsa - village Vaksevo	0.001	3.9	0.27
2	51150	Iliyna river - Brichi bor area	0.395	10.0	1.49
3	51310	Konska river - Batanovtsi town	0.010	12.6	0.70
4	51340	Treklyanska reka - Vranya stena vIllage	0.096	23.4	1.76
5	51360	Dragovshtitsa - Goranovtsi village	0.400	35.1	2.68
6	51370	Bistritsa (Sov.) - Gurlyano village	0.003	6.7	0.35
7	51371	Bistritsa (Sov.) - Gurlyano (LKS)	0.011	0.8	0.27
8	51380	Bistritsa (Sov) - Sovolyano village	0.040	14.3	1.40
9	51390	Novoselska river - Novo selo village	0.002	3.4	0.33
10	51400	Eleshnitsa - Rakovo village	0.145	15.0	1.41
11	51410	Eleshnitsa - Vaksevo village	0.175	14.3	1.98
12	51430	Djerman - Dupnitsa town	0.528	16.2	1.94
13	51450	Rilska - Pastra village	0.800	27.1	4.50
14	51470	Bistritsa (bl) - GD Slavovo	0.004	15.1	1.42
15	51480	Bistritsa (Bl) - Blagoevgrad	0.007	15.8	2.62
16	51490	Gradevska (Elovs.) - Marevo village	0.065	4.8	0.59
17	51500	Gradevska river - Gradevo river	0.040	8.4	1.10
18	51510	Soushitska river - Polena village	0.032	7.4	0.52
19	51520	Vlahinska river - Vlahi village	0.220	8.2	1.02
20	51540	Bistritsa (Sand) - lilianovo village	0.090	10.5	0.62
21	51560	Strumeshnitsa river - Strumeshnitsa village	0.120	31.2	3.48
22	51580	Strumeshnitsa river - Mitino village	0.580	47.7	5.25
23	51590	Bistritsa (Pir) - G. Spanchevo village	0.037	5.1	0.36
24	51650	Struma - Pernik town	0.200	21.6	1.28
25	51700	Struma - Rajdavitsa village	0.250	63.5	6.10
26	51750	Struma - Boboshevo town	1.800	135.0	18.67
27	51800	Struma - Kresnensko hanche	4.191	228.0	32.63
28	51880	Struma - Marino pole village	5.000	336.9	59.27

In Belitsa ditch which is the main drainage canal in the plain area of Strymonas/Struma basin at the Greek territory, the maximum discharge that occurs during irrigation period (20 m^3/s) outflows finally into Strymonas/Struma River. About 10 Km upstream from Strymonikos Gulf, the Aggitis River outflows to Strymonas/Struma River (from 6 to 76 m^3/s). Finally Strymonas/Struma River outflows to Strymonikos Gulf.

The minimum, maximum and average discharge of Strymonas/Struma River, Belitsa and Aggitis are given in Table 6. Station codes of Table 6 referred at Fig 18 and the data period is from 2004 to 2006. The monthly minimum, maximum and average discharge of Strymonas/Struma River inflow at Hellenic territory shown in Fig. 26.

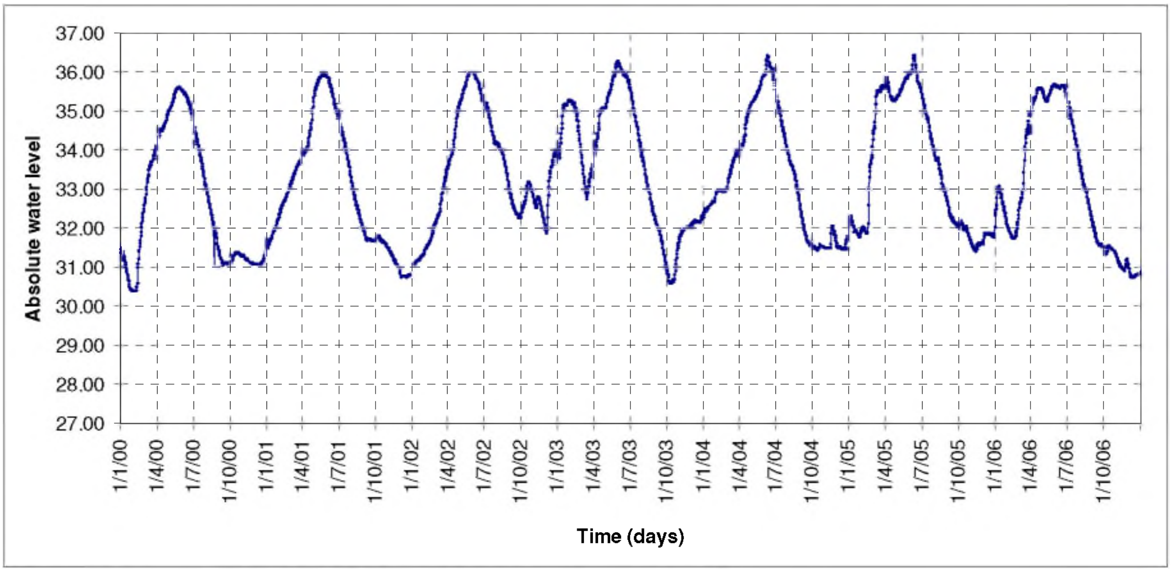

Fig. 25. Daily water level of Lake Kerkini from 2000 to 2006

Table 6. Discharge in hydrometrical station of Struma/Strymonas River basin at Hellenic territory

Station code	Location	Min, m^3/s	Max, m^3/s	Average, m^3/s
1	Strymonas	6.7	202.8	70.8
10	Belitsa	0.9	33.9	9.9
11	Aggitis	6.4	75.7	16.7
12	Strymonas	69.8	133.5	93.8

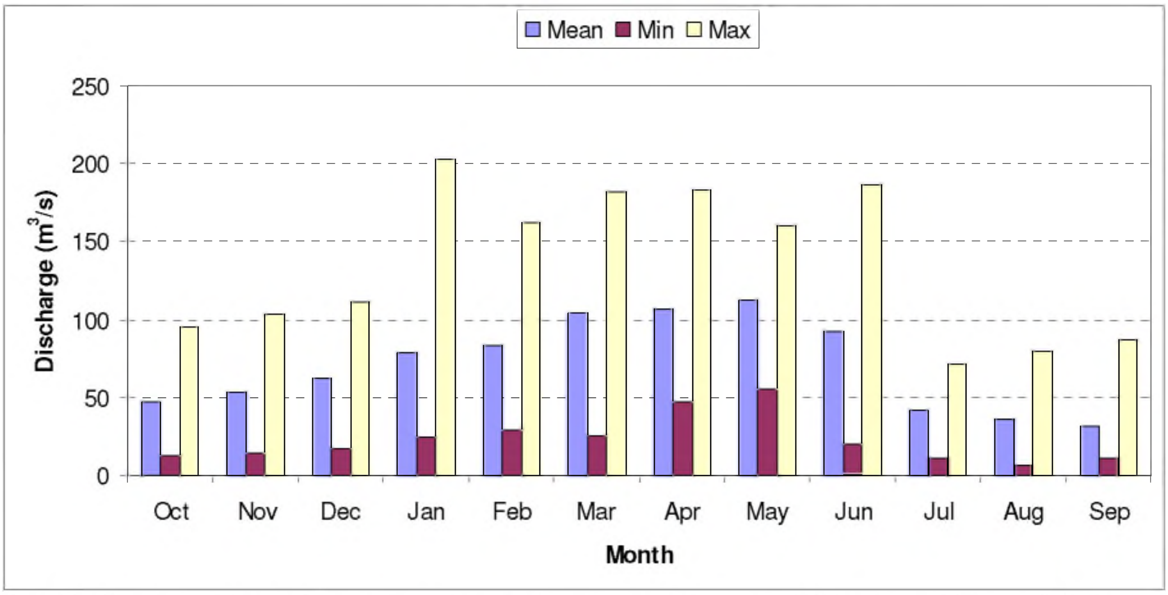

Fig. 26. The monthly minimum, maximum and average discharge of Strymonas/Struma River inflow at Hellenic territory

4.3. Water quality data

Data of water quality monitoring stations acquired by 15 stations in the Bulgarian territory (covered period 2000-2004) and 16 stations in the Greek territory (covered period 8/2004-11/2006). The location of the stations and their codes are shown in Fig 20. the quality parameters monitored are:

- temperature (T)
- pH
- dissolved oxygen (DO)
- electrical conductivity (ECw)
- NO_3
- NH_4^+
- PO_4^{3-}
- BOD_5 (In the Greek territory BOD_5 was measured at sample stations 1, 3, 13 and 16)

Minimum, maximum and mean values of the above parameters are given in Table 7.

Table 7. Statistical analysis of Strymonas/Struma water quality monitoring parameters

Bulgarian territory

code 5121			
Elements	min	max	Mean
T water, ^{o}C	0.7	25	12.45
pH	7.8	9.1	8.47
DO, mg/l	6	14.2	8.58
ECw µS/cm	240	700	527
BOD_5, mg/l	0.65	27	3.34
NH4, mg/l	0	0.81	0.090
NO_3, mg/l	0.05	2.69	1.371
PO_4, mg/l	0	1.26	0.360

code 5123			
Elements	min	max	Mean
T water, ^{o}C	0.4	26	12.86
pH	7.06	8.8	8.06
DO, mg/l	3.49	13.3	9.15
ECw µS/cm	213	2463	428
BOD_5, mg/l	0.88	11.5	3.12
NH4, mg/l	0	1.9	0.405
NO_3, mg/l	0.01	4	1.029
PO_4, mg/l	0.04	2.2	0.612

code 5124			
Elements	min	max	Mean
T water, ^{o}C	0.7	27.8	13.26
pH	7.02	8.7	8.04
DO, mg/l	6.2	13.3	8.97
ECw µS/cm	207	533	393
BOD_5, mg/l	0	8.1	2.31
NH4, mg/l	0	3.13	0.344
NO_3, mg/l	0	5	1.057
PO_4, mg/l	0.04	1.8	0.569

code 5126			
Elements	min	max	Mean
T water, ^{o}C	1.9	28.4	14.12
pH	6.9	9.3	8.44
DO, mg/l	3.8	17.4	7.71
ECw µS/cm	127	728	430
BOD_5, mg/l	1	26	5.25
NH4, mg/l	0	2.7	0.359
NO_3, mg/l	0.001	4.1	1.951
PO_4, mg/l	0.04	1.99	0.464

code 5296			
Elements	min	max	Mean
T water, ^{o}C	1.8	23.4	12.39
pH	7.2	8.9	8.22
DO, mg/l	3.5	10.5	7.40
ECw µS/cm	238	10031	1079
BOD_5, mg/l	1.2	14.1	4.32
NH4, mg/l	0.01	1.42	0.360
NO_3, mg/l	0	21.65	6.774
PO_4, mg/l	0.03	1.26	0.462

code 5299			
Elements	min	max	Mean
T water, ^{o}C	10.6	27	16.42
pH	7.7	8.8	8.20
DO, mg/l	5.7	8.8	7.29
ECw µS/cm	331	573	478
BOD_5, mg/l	1.7	5	2.84
NH4, mg/l	0.008	0.15	0.062
NO_3, mg/l	0.61	1.3	1.036
PO_4, mg/l	0.04	0.53	0.309

code 5301			
Elements	min	max	Mean
T water, ^{o}C	0.9	22.5	12.95
pH	6.5	8.7	7.77
DO, mg/l	2.5	12.8	8.10
ECw µS/cm	210	630	421
BOD_5, mg/l	0	15	4.41
NH4, mg/l	0.03	5	1.305
NO_3, mg/l	0	6	1.410
PO_4, mg/l	0.1	3.6	1.100

code 5399			
Elements	min	max	Mean
T water, ^{o}C	1.5	24	10.92
pH	7.3	9	8.28
DO, mg/l	4.2	16.5	8.26
ECw µS/cm	141	440	280
BOD_5, mg/l	0	52	2.83
NH4, mg/l	0	2.21	0.044
NO_3, mg/l	0	2.92	0.295
PO_4, mg/l	0	1.59	0.070

code 5471			
Elements	min	max	Mean
T water, ^{o}C	0.5	24	11.61
pH	7.2	9.1	8.36
DO, mg/l	5.9	15.2	8.83
ECw µS/cm	130	413	271
BOD_5, mg/l	0	39	2.77
NH4, mg/l	0	0.17	0.033
NO_3, mg/l	0.05	1.56	0.457
PO_4, mg/l	0	0.74	0.065

code 5550			
Elements	min	max	Mean
T water, ^{o}C	2.8	24	12.73
pH	8	9.1	8.40
DO, mg/l	3.8	11.5	8.03
ECw µS/cm	48	582	132
BOD_5, mg/l	0	3	0.96
NH4, mg/l	0	0.49	0.068
NO_3, mg/l	0	7.38	0.975
PO_4, mg/l	0	1.19	0.276

code 5551			
Elements	min	max	Mean
T water, °C	4.5	23	12.27
pH	8	8.7	8.47
DO, mg/l	6.7	14.5	8.81
ECw μS/cm	204	340	235
BOD_5, mg/l	0	3.1	1.66
NH4, mg/l	0	0.34	0.051
NO_3, mg/l	0.2	0.63	0.357
PO_4, mg/l	0	0.16	0.045

code 5552			
Elements	min	max	Mean
T water, °C	3.8	21.1	12.75
pH	7.2	8.8	8.29
DO, mg/l	4.9	12	8.06
ECw μS/cm	45	468	179
BOD_5, mg/l	0	1.8	0.93
NH4, mg/l	0	0.08	0.020
NO_3, mg/l	0	0.48	0.207
PO_4, mg/l	0	0.08	0.027

code 5553			
Elements	min	max	Mean
T water, °C	0.2	30.4	12.85
pH	6.8	9.1	8.21
DO, mg/l	5.6	14.8	9.82
ECw μS/cm	215	534	393
BOD_5, mg/l	0.29	6.5	2.23
NH4, mg/l	0	1.6	0.236
NO_3, mg/l	0.03	5	0.989
PO_4, mg/l	0.07	1.8	0.427

code 5554			
Elements	min	max	Mean
T water, °C	0.3	24.2	12.68
pH	7.15	8.4	7.96
DO, mg/l	6.2	13.3	8.63
ECw μS/cm	205	520	390
BOD_5, mg/l	0.4	6.9	1.83
NH4, mg/l	0	2.2	0.298
NO_3, mg/l	0	3.2	1.483
PO_4, mg/l	0.2	4.2	1.219

code 5557			
Elements	min	max	Mean
T water, °C	1.5	26	10.82
pH	7.3	8.9	8.10
DO, mg/l	5.8	13.6	9.09
ECw μS/cm	94	233	146
BOD_5, mg/l	0	3	1.04
NH4, mg/l	0	0.87	0.093
NO_3, mg/l	0	0.8	0.220
PO_4, mg/l	0	1.3	0.181

code 5558			
Elements	min	max	Mean
T water, °C	0.2	25.5	12.38
pH	6.98	8.8	8.07
DO, mg/l	6.5	14	9.33
ECw μS/cm	101	236	168
BOD_5, mg/l	0.2	4	1.00
NH4, mg/l	0	2	0.143
NO_3, mg/l	0	1.2	0.210
PO_4, mg/l	0	1.4	0.249

Hellenic territory

code 1			
Elements	min	max	Mean
T water, °C	3.1	27	14.81
pH	3	10	8.10
DO, mg/l	1.5	15.2	10.10
ECw μS/cm	133	808	297
BOD_5, mg/l	0	8	1.33
NH4, mg/l	0	4.64	0.203
NO_3, mg/l	0.46	15.8	6.950
PO_4, mg/l	0	0.722	0.389

code 2			
Elements	min	max	Mean
T water, °C	3.30	32.70	15.89
pH	5	10	8.34
DO, mg/l	2.35	18.40	10.36
ECw μS/cm	34	455	293
BOD_5, mg/l			
NH4, mg/l	0.000	3.990	0.150
NO_3, mg/l	0.63	24.20	6.887
PO_4, mg/l	0.077	0.906	0.376

code 3			
Elements	min	max	Mean
T water, °C	5.50	32.70	19.11
pH	6	11	8.81
DO, mg/l	1.35	18.65	11.28
ECw μS/cm	178	413	266
BOD_5, mg/l	0.00	16.00	4.50
NH4, mg/l	0.000	1.112	0.103
NO_3, mg/l	0.00	14.90	4.633
PO_4, mg/l	0.000	0.614	0.273

code 4			
Elements	min	max	Mean
T water, °C	4.30	28.30	18.29
pH	6	12	9.03
DO, mg/l	3.10	864.00	23.80
ECw μS/cm	8	395	254
BOD_5, mg/l			
NH4, mg/l	0.000	1.800	0.091
NO_3, mg/l	0.00	12.90	3.856
PO_4, mg/l	0.000	0.661	0.229

code 5			
Elements	min	max	Mean
T water, °C	3.10	283.00	22.46
pH	7	12	8.93
DO, mg/l	1.60	23.20	10.63
ECw μS/cm	194	337	253
BOD_5, mg/l			
NH4, mg/l	0.000	1.027	0.088
NO_3, mg/l	0.00	13.50	3.959
PO_4, mg/l	0.000	0.798	0.252

code 6			
Elements	min	max	Mean
T water, °C	4.30	25.30	15.80
pH	6	9	7.79
DO, mg/l	2.55	13.40	8.51
ECw μS/cm	97	646	388
BOD_5, mg/l			
NH4, mg/l	0.000	4.580	0.133
NO_3, mg/l	1.25	16.10	6.458
PO_4, mg/l	0.015	1.182	0.570

code 7			
Elements	min	max	Mean
T water, °C	4.40	27.10	16.91
pH	6	10	7.80
DO, mg/l	0.70	17.50	6.89
ECw μS/cm	140	899	565
BOD_5, mg/l			
NH4, mg/l	0.000	1.282	0.082
NO_3, mg/l	0.08	18.50	7.455
PO_4, mg/l	0.138	1.934	0.705

code 8			
Elements	min	max	Mean
T water, °C	5.00	28.30	17.27
pH	6	9	7.87
DO, mg/l	0.90	14.40	8.27
ECw μS/cm	181	677	450
BOD_5, mg/l			
NH4, mg/l	0.000	2.810	0.160
NO_3, mg/l	0.35	12.00	6.036
PO_4, mg/l	0.031	1.136	0.580

code 9			
Elements	min	max	Mean
T water, °C	6.50	25.40	16.67
pH	6	10	8.09
DO, mg/l	1.65	18.60	8.93
ECw μS/cm	140	408	299
BOD_5, mg/l			
NH4, mg/l	0.000	11.117	0.718
NO_3, mg/l	0.55	20.80	6.001
PO_4, mg/l	0.000	3.285	0.536

code 10			
Elements	min	max	Mean
T water, °C	3.70	28.60	15.96
pH	4	12	7.99
DO, mg/l	0.48	13.40	8.10
ECw μS/cm	142	760	376
BOD_5, mg/l			
NH4, mg/l	0.000	4.949	0.687
NO_3, mg/l	0.00	14.80	7.240
PO_4, mg/l	0.061	2.533	0.699

code 11			
Elements	min	max	Mean
T water, °C	3.40	30.00	16.99
pH	6	761	19.68
DO, mg/l	0.95	14.35	7.58
ECw μS/cm	174	946	434
BOD_5, mg/l			
NH4, mg/l	0.000	4.416	0.594
NO_3, mg/l	0.70	26.20	6.881
PO_4, mg/l	0.169	1.934	0.804

code 12			
Elements	min	max	Mean
T water, °C	2.70	32.00	17.90
pH	6	10	8.16
DO, mg/l	2.05	14.25	8.82
ECw μS/cm	127	524	286
BOD_5, mg/l			
NH4, mg/l	0.000	0.386	0.071
NO_3, mg/l	0.00	12.00	3.933
PO_4, mg/l	0.031	0.829	0.346

code 13			
Elements	min	max	Mean
T water, °C	7.80	28.80	16.50
pH	6	10	8.07
DO, mg/l	1.85	18.30	9.70
ECw μS/cm	293	521	394
BOD_5, mg/l	0.00	9.00	1.26
NH4, mg/l	0.000	2.590	0.147
NO_3, mg/l	2.75	22.70	11.235
PO_4, mg/l	0.000	0.691	0.348

code 14			
Elements	min	max	Mean
T water, °C	7.50	30.90	17.07
pH	6	10	8.21
DO, mg/l	2.30	17.10	9.57
ECw μS/cm	5	511	394
BOD_5, mg/l			
NH4, mg/l	0.000	1.690	0.072
NO_3, mg/l	3.85	21.90	11.528
PO_4, mg/l	0.000	0.661	0.346

code 15				code 16			
Elements	min	max	Mean	Elements	min	max	Mean
T water, ^{o}C	3.60	33.20	18.15	T water, ^{o}C	4.80	32.90	18.54
pH	6	11	8.11	pH	6	10	8.13
DO, mg/l	1.05	14.05	8.35	DO, mg/l	0.70	12.80	8.47
ECw μS/cm	224	443	318	ECw μS/cm	213	6910	479
BOD_5, mg/l				BOD_5, mg/l	0.00	10.00	2.91
NH4, mg/l	0.000	0.332	0.056	NH4, mg/l	0.000	1.490	0.102
NO_3, mg/l	0.00	14.30	4.808	NO_3, mg/l	0.00	12.60	6.300
PO_4, mg/l	0.000	0.844	0.392	PO_4, mg/l	0.000	0.814	0.399

5. Land use

Land use in Strymonas/Struma basin acquired from CORINE Land Cover database (Co-ordination of Information on the Environment) and is shown at the Fig. 27.

There are six main categories of the land user in Strymonas/Struma basin which include the 18 sub-categories that shown in Fig 27. The six main categories include:

- *Urban*
- *Agriculture*, which includes the sub-categories, Non-irrigated arable land, Permanently irrigated land, Rice fields, Vineyards, Fruit trees and berry plantations, Olive groves, Complex cultivation patterns and Land principally occupied by agriculture, with significant areas of natural vegetation
- *Forest*, with sub-categories, Agro-forestry areas, Broad-leaved forest, Coniferous forest, Mixed forest
- *Grassland*
- *Scrubby* with the sub-categories, Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub and Sparsely vegetated areas
- *Other* which includes all the other categories of land cover.

The land use categories and their percentage at the Bulgarian and Hellenic territory of Strymonas/Struma basin are given in Table 8.

Table 8. Land use in the Bulgarian and Hellenic territory of Strymonas/Struma basin

	Area Km^2			Area (%)		
Categories	**Bulgaria**	**Greece**	**Total**	**Bulgaria**	**Greece**	**Total**
Urban	290	100	390	3.42	1.67	2.70
Agriculture	2598	2643	5241	30.66	44.12	36.23
Forest	3517	1211	4729	41.51	20.22	32.69
Grassland	943	489	1432	11.12	8.17	9.90
Scrubby	1070	1439	2509	12.63	24.02	17.35
Other	55	108	163	0.65	1.80	1.13
Totals	8473	5990	14463	100	100	100

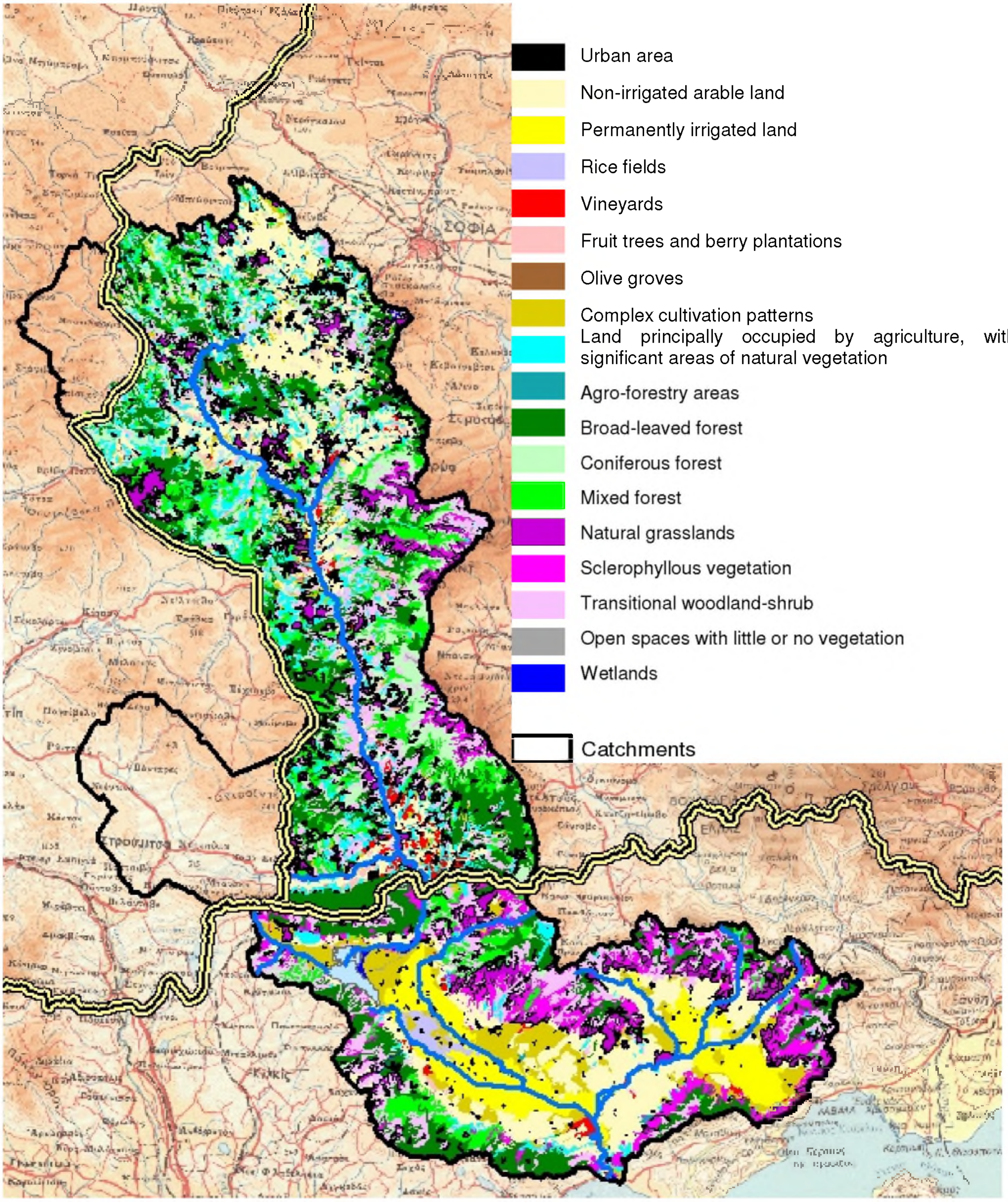

Fig. 27. Land use in Strymonas/Struma River basin

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1. Modelling framework

The simulation of surface water in Strymonas/Struma River basin has been performed with the use of specialized software, called MIKE 11. MIKE 11 is a modelling system for rivers and channels developed by Danish Hydraulic Institute (DHI). It is used for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. It is a dynamic, user-friendly, one-dimensional modelling tool for the detailed design, management and operation of both simple and complex river and channel systems.

MIKE 11 can be used for different purposes, depend on the availability of data and the desirable analysis of water resources system in the river basin. As far as concerned Strymonas/Struma River basin, the modelling framework includes the following three processes (see also Figure 1.1):

- Rainfall-Runoff simulation in sub catchments of Strymonas/Struma River basin (Rainfall-Runoff model)
- Simulation of water flow in Strymonas/Struma River (Hydrodynamic model)
- Simulation of water quality in Strymonas/Struma River (Advection-Dispersion model)

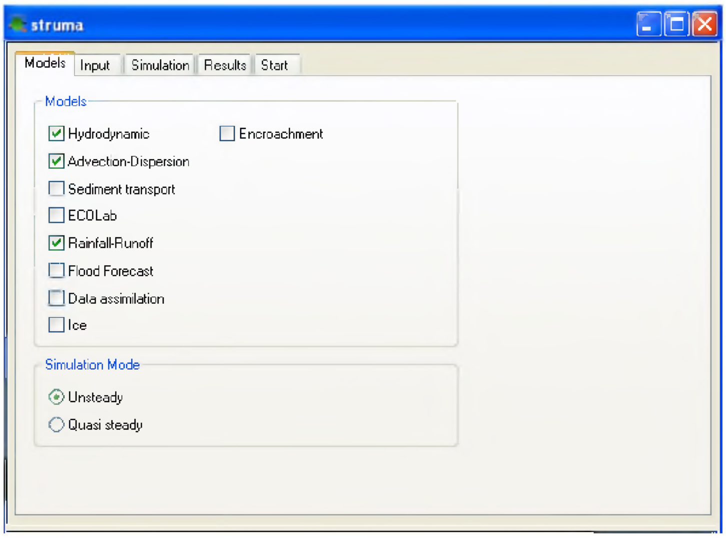


Fig. 1.1. Definition of modelling framework in Strymonas/Struma River using MIKE 11

Input data, results and calibration of the different modelling processes are analyzed in the next paragraphs. Initially, the Rainfall-Runoff model was applied in all sub-catchments of Strymonas/Struma River. Secondly, the Hydrodynamic model was applied in order to estimate water depth and discharge along the Strymonas/Struma River, taking as input data the results (runoff) from Rainfall-Runoff models. Finally, the Advection-Dispersion model was also applied in Strymonas/Struma River for the simulation of water quality, using the results both from Rainfall-Runoff models and the Hydrodynamic model.

The results of the simulation produced by the models are compared with the standards of Directive 2000/60/EC and also used for the assessment of the status of surface water bodies in Strymonas/Struma River basin. Furthermore, based on the results of the simulation, proposed measures are discussed for the protection and sustainable management of surface water bodies.

2. Rainfall – runoff modelling

2.1. Description of NAM module

Rainfall – Runoff (RR) modelling is the process of transforming rainfall into catchment (sub-catchment) runoff. Almost all RR models take as input data, at least, precipitation and potential evapotranspiration and calculate as result catchment runoff. Rainfall-Runoff modelling is used to estimate how much runoff/discharge a catchment produces and to make an initial/rough investigation of the hydrologic cycle in the catchment.

From the available RR models in MIKE 11, NAM was chosen due to its capability to simulate rainfall-runoff events at a daily time step as well as to simulate snow effects. NAM represents various components of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages. Each storage represent different physical elements of the catchment and NAM can be prepared in a number of different modes depending on the requirement.

From a technical point of view, NAM model can be characterized as a deterministic, lumped, conceptual model with moderate input data requirements. As default, NAM is prepared with 9 parameters representing the Surface zone, Root zone and the Ground water storages as shown in Table 2.1. The structure of the NAM model is showed in Fig. 2.1.

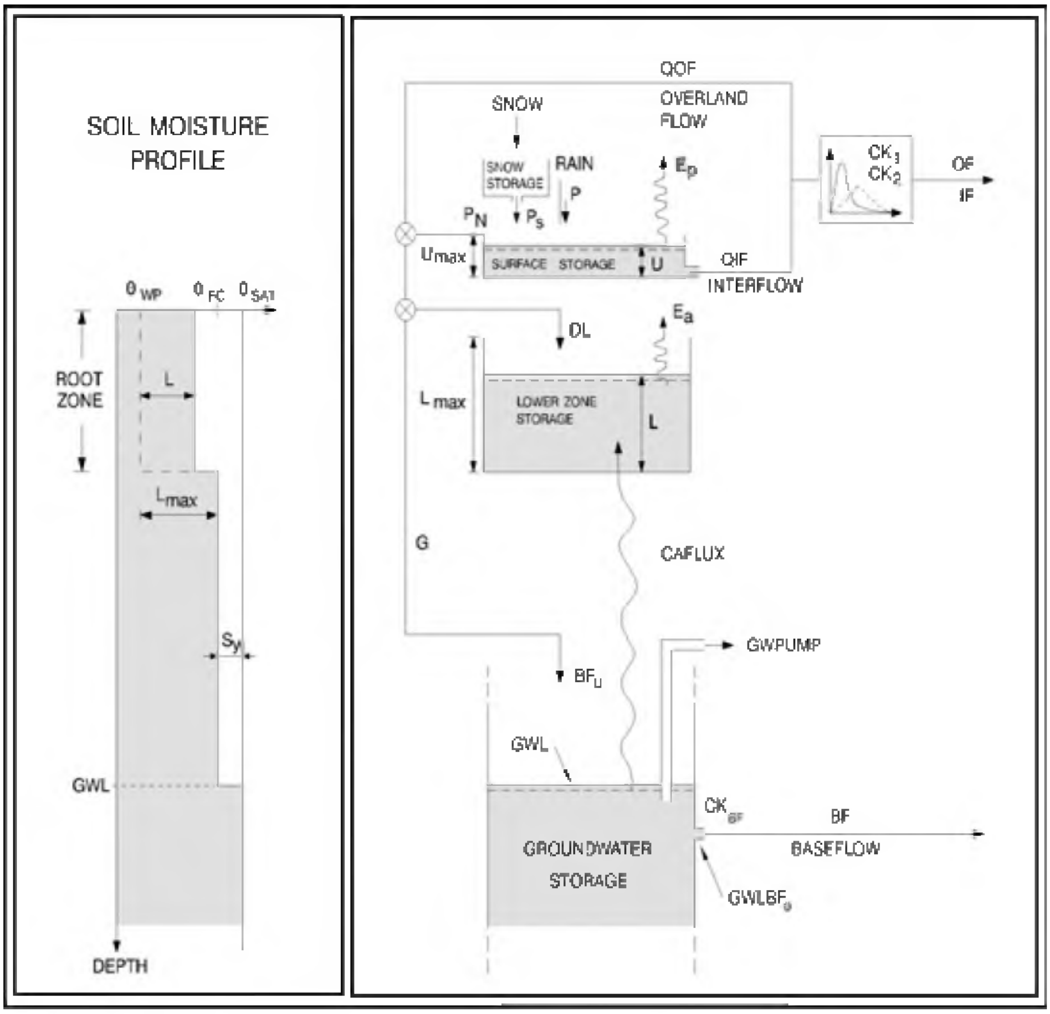


Fig. 2.1. The structure of NAM model

Table 2.1. The main parameters of NAM

Parameters	Units	Description	Bandwidth
Surface-Rootzone			
Max. water content in surface storage – Umax	mm	Represents the cumulative total water content of the interception storage (on vegetation), surface depression storage and storage in the uppermost layers (a few cm) of the soil	10-20
Max. water content in root zone storage – Lmax	mm	Represents the maximum soil moisture content in the root zone, which is available for transpiration by vegetation	50-300
Oveland flow runoff coefficient – CQOF		Determines the division of excess rainfall between overland flow and infiltration	0.1-1.0
Time constant for routing interflow – CKIF	hour	Determines the amount of interflow, which decreases with larger time constants	500-1000
Time constant for routing overland flow – CK1,2	hour	Determines the shape of hydrograph peaks. High, sharp peaks are simulated with small time constants, whereas low peaks, at a later time, are simulated with large values of these parameters	3-48
Root zone threshold value for overland flow – TOF		Determines the relative value of the moisture content in the root zone (L/Lmax) above which overland flow is generated.	0.0-0.7
Root zone threshold value for interflow – TIF		Determines the relative value of the moisture content in the root zone (L/Lmax) above which interflow is generated	0.0-0.7
Groundwater			
Root zone threshold value for groundwater recharge – TG		Determines the relative value of the moisture content in the root zone (L/Lmax) above which ground water recharge is generated.	0.0-0.7
Time constant for routing baseflow – CKBF	hour	Can be determined from the hydrograph recession in dry periods	1000-4000

2.2. Input data

2.2.1. Sub-catchment delineation

The different physiographic characteristics (altitude, slope, land use, geology etc.), which are described direct or indirect via model parameters, vary significantly to the extent of a river basin. Furthermore, results (runoff/discharge) from a RR model are only available at the outlet of the catchment. In addition to that, data from discharge stations is used from the calibration of a RR model. Therefore, a Rainfall-Runoff model is usually applied in sub-catchments of a river basin.

The sub-catchment delineation of Strymonas/Struma River basin was based on the physiographic characteristics of the area, the monitoring network system of hydrological parameters, significant lakes/reservoirs as well as the water uses. In Fig. 2.2 is shown the sub-catchments of Strymonas/Struma river basin, which have been included in MIKE11 and applied the NAM model, while the surface area of the sub-catchment is given in Table 2.2. Notice that the sub-catchments in Fig. 2.2 concern only the Greek and Bulgarian territory, but the areas given in Table 2.2, which are used in the model, concern the total area for catchment Dragovishtitsa and Strumeshnitsa, which are shared between Bulgaria-Serbia and Bulgaria-FYROM, respectively.

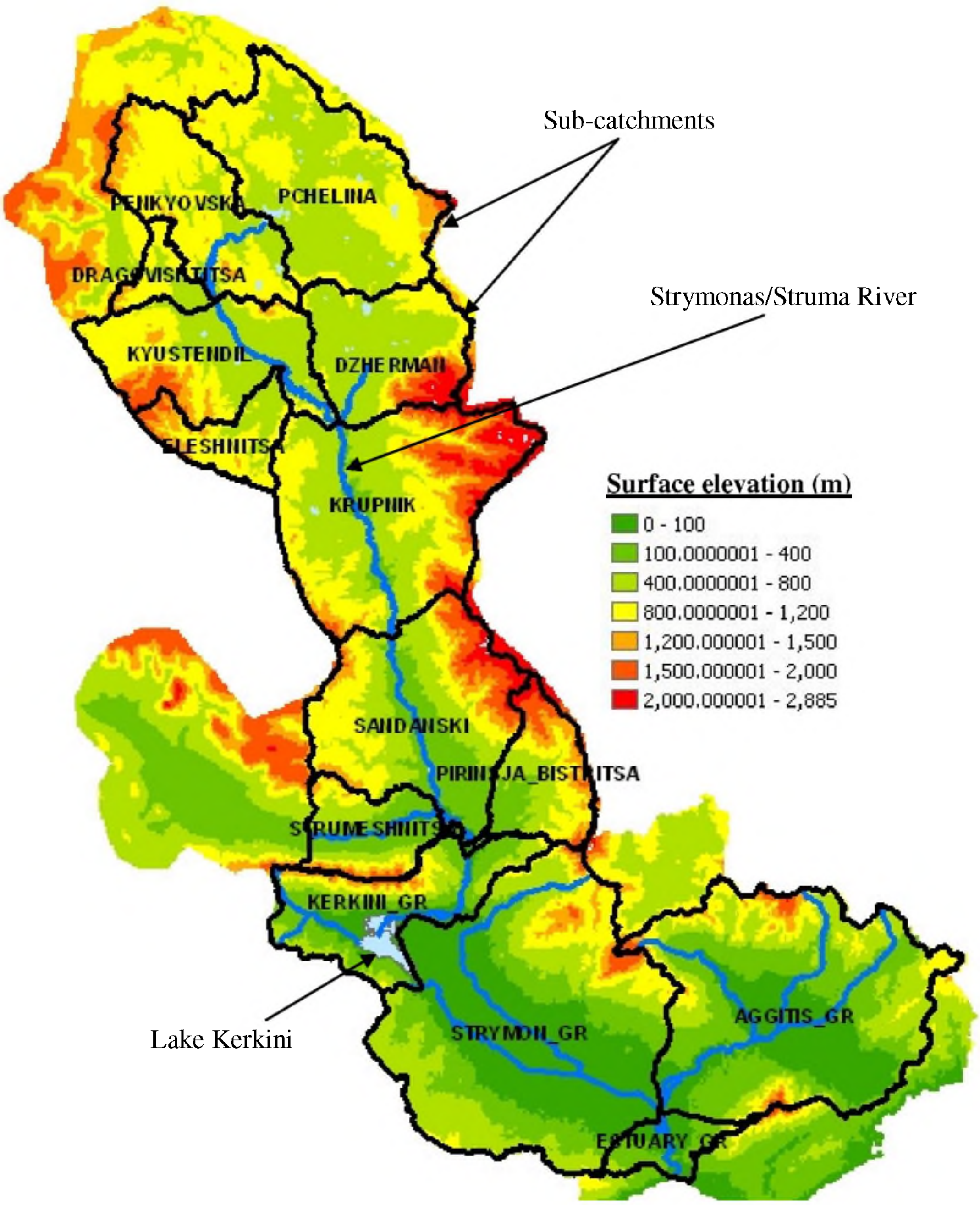


Fig. 2.2. Sub-catchments of Strymonas/Struma River basin

Table 2.2. Surface area of sub-catchments in Strymonas/Struma River

CATCHMENTS	km^2	CATCHMENTS	km^2
PCHELINA	1379	KRUPNIK	1742
SANDANSKI	1435	STRUMESHNITSA	2077
ELESHNITSA	345	PIRINSJA_BISTRITSA	485
PENKYOVSKA	810	KERKINI_GR	753
DRAGOVISHTITSA	819	STRYMON_GR	2728
KYUSTENDIL	908	ESTUARY_GR	219
DZHERMAN	757	AGGITIS_GR	2234

2.2.2. Rainfall and temperature distribution

The relevant meteorological data used in the model concern daily rainfall data from 19 stations and monthly temperature data from 4 stations. The distribution of these data in the sub-catchments has been performed with the polygon Thiessen method. In Fig. 2.3 is shown the Thiessen polygons for the rainfall stations while in Tables 2.3 and 2.4 are shown the contribution of each station in sub catchments for precipitation and temperature, respectively, as have been incorporated in the model.

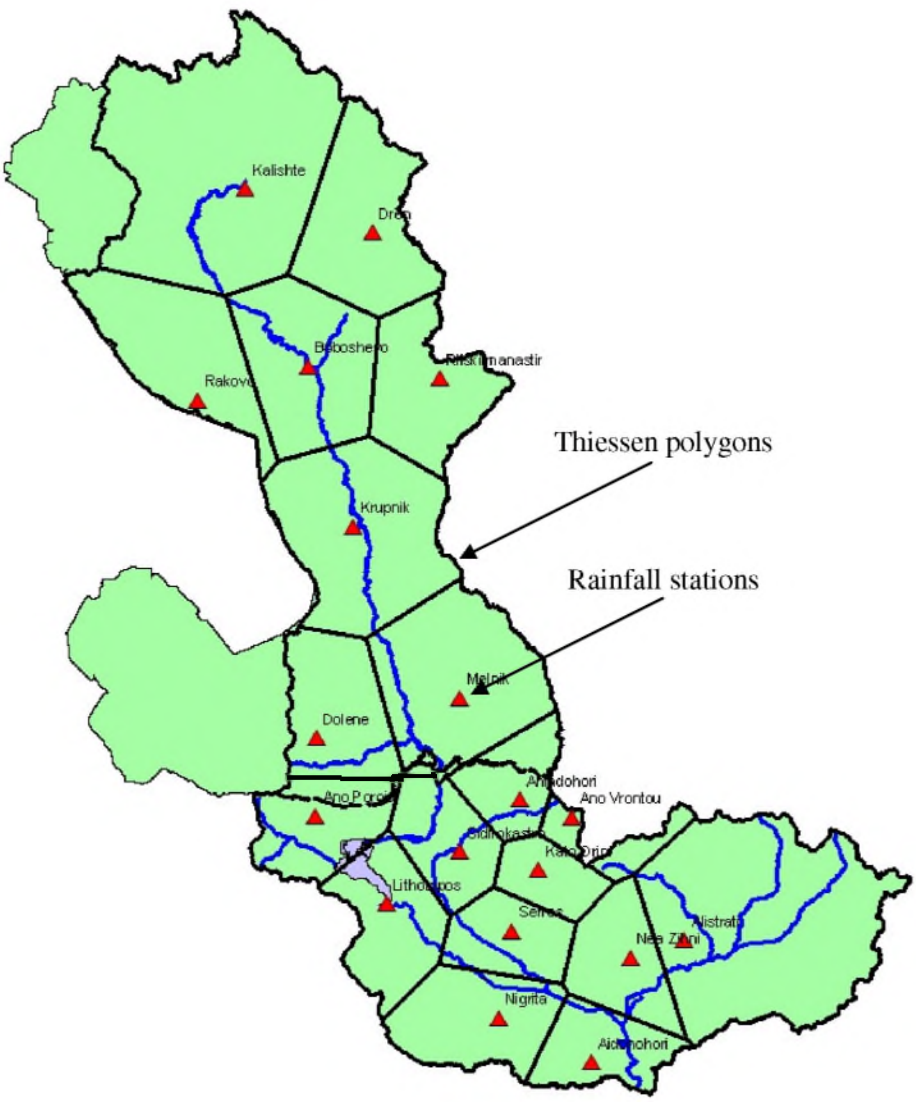


Fig. 2.3. Thiessen polygons in Strymonas/Struma River basin for rainfall stations

Table 2.3. Spatial distribution, %, of rainfall stations in sub-catchments

Rainfall stations	Sub-catchments													
	SANDANSKI	ELESHNITSA	PENKYOVSKA	DRAGOVISHTITSA	KYUSTENDIL	DZHERMAN	KRUPNIK	STRUMESHNITSA	PIRINSJA_BISTRITSA	KERKINI_GR	STRYMON_GR	ESTUARY_GR	AGGITIS_GR	PCHELINA
Kalishta			100	82	24	3								65
Dren				18		49								35
Rilski manastir						16	30							
Boboshevo		16			21	32	23							
Rakovo		84			55		2							
Melnik	47								100					
Ano Poroia										50				
Sidirokastro										30	10			
Ahladoxori										20	6			
Lithotopos											15			
Nigrita											20			
Serres											15			
Orini											10			
Ano Vrontou											4			
Zihni											8		10	
Alistrati													90	
Krupnic	29						45							
Dolene	24							100						
Aidonoxori											12	100		
Sum per sub-catchment	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 2.4. Spatial distribution, %, of temperature stations in sub-catchments

Temperature stations	Sub-catchments													
	SANDANSKI	ELESHNITSA	PENKYOVSKA	DRAGOVISHTITSA	KYUSTENDIL	DZHERMAN	KRUPNIK	STRUMESHNITSA	PIRINSJA_BISTRITSA	KERKINI_GR	STRYMON_GR	ESTUARY_GR	AGGITIS_GR	PCHELINA
Sandanski	100							100	100					
Kyustendil		100	100	100	100	50								100
Rilski manastir						50	100							
Serres										100	100	100	100	

2.2.3. Potential evapotranspiration

In NAM model, the actual evapotranspiration is calculated by the model based on potential evapotranspiration (maximum rate of actual evapotranspiration) and model parameters. The potential evapotranspiration is not calculated by the model and usually is estimated by the available data in meteorological stations. The spatial distribution of potential evapotranspiration in the sub-catchments follows the spatial distribution of temperature (see Table 2.4).

In Strymonas/Struma River basin, the potential evapotranspiration has been estimated from the available temperature data using the Thornthwaite method. The Thornthwaite method uses the following formula:

$$E_p = 16 \cdot L_d \cdot \left(\frac{10 \cdot T}{I} \right)^{\alpha} \qquad (2.1)$$

where

E_p : potential evapotranspiration (mm/month)

T : mean monthly air temperature (°C)

I : annual index of temperature

α : exponent dependent by I

L_d : the ratio of average day duration of every month to day duration of 12 hours

The annual index of temperature, I, and the exponent, α, are calculated from the relationships:

$$I = \sum_{n=1}^{12} \left(\frac{T_n}{5} \right)^{1.514} \qquad (2.2)$$

$$\alpha = 0.675\ 10^{-6}\ I^3 - 0.771\ 10^{-4}\ I^2 + 1.792\ 10^{-2}\ I + 0.49239 \qquad (2.3)$$

while L_d is a coefficient depended on latitude and the month of the year and can be derived from tables (Chow, 1964).

In Diagram 2.1 is shown the potential evapotranspiration at the four stations used in NAM model of Strymonas/Struma River basin.

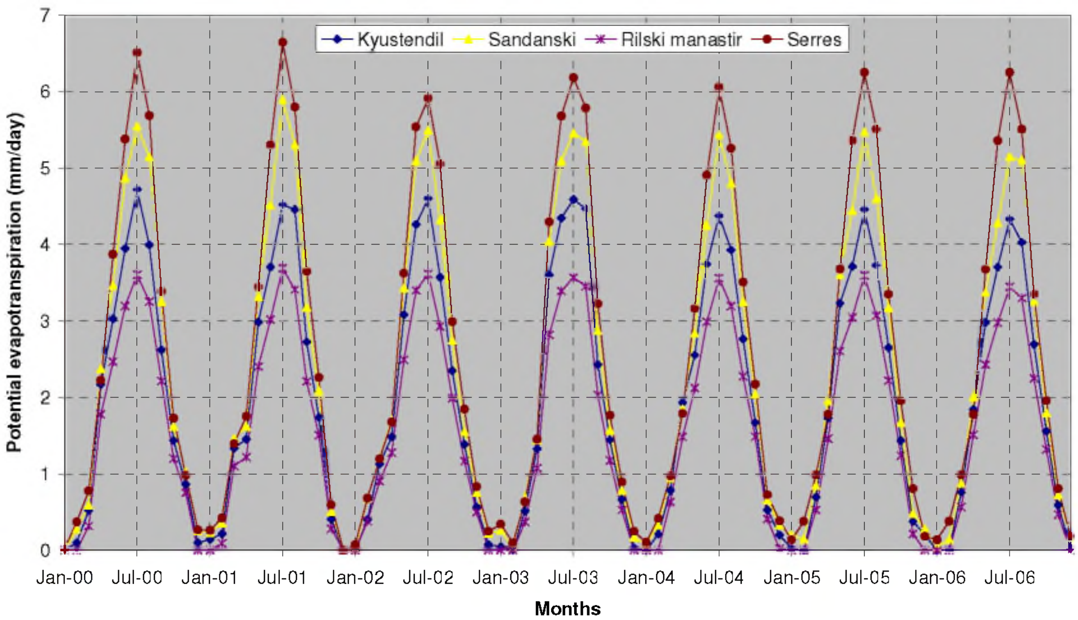


Diagram 2.1. Potential evapotranspiration in Strymonas/Struma River basin

2.3. Results and model calibration

2.3.1. Criteria for model calibration

As has been mentioned above, Rainfall-Runoff modelling is used to estimate how much runoff/discharge a catchment produces. The calculated discharge depends on meteorological data, model parameters and model setup.

In the NAM model the parameters represent average values for the entire catchment. While in some cases a range of likely parameter values can be estimated, it is not possible, in general, to determine the values of the NAM parameters on the basis of the physiographic, climatic and soil physical characteristics of the catchment, since most of the parameters are of an empirical and conceptual nature (MIKE 11 reference manual, 2007). Thus, the final parameter estimation must be performed by calibration against time series of hydrological observations, usually discharge observations.

Both graphical and numerical evaluation criteria should be applied in the calibration process. The graphical evaluation includes comparison of the simulated and observed hydrograph, and comparison of the simulated and observed accumulated runoff. Among the most significant numerical criteria are the overall water balance error and the Nash-Sutcliffe coefficient.

The overall water balance error, WB_{er}, expresses the difference between the mean simulated and mean observed runoff/discharge and is given by the formula:

$$WB_{er} = |1 - Q_s / Q_o| \tag{2.4}$$

where
Q_s : mean calculated discharge (m^3/s)
Q_o : mean observed discharge (m^3/s)

The Nash-Sutcliffe coefficient, R_{NS}, is given by the formula:

$$R_{NS} = 1 - \frac{\sum_i (Q_{s,i} - Q_{o,i})^2}{\sum_i (Q_{o,i} - Q_o)^2} \tag{2.5}$$

where
$Q_{s,i}$: calculated discharge at time i (m^3/s)
$Q_{o,i}$: observed discharge at time i (m^3/s)

Henriksen et al. (2003) presented an evaluation of model performance/results according to the above criteria, as shown in Table 2.5.

Table 2.5. Evaluation of model results

Evaluation criteria	**Performance indicators**				
	Perfect	*Very good*	*Good*	*Poor*	*Very poor*
WB_{er} %	<5	5-10	10-20	20-40	>40
R_{NS}	>0.85	0.65-0.85	0.5-0.65	0.20-0.50	<0.20

2.3.2. Calibration strategy

The simulation period was from 1/1/2001 until 31/12/2006 and the time step was equal to 1 day. The calibration period was from 1/1/2003 until 31/12/2004 and the validation period from 1/1/2005 until 31/12/2006. Year 2001 was not used in the evaluation process and used as the "warm up" period of the model, while discharge data were not available at a daily time step for year 2002.

Not all of the stations in Strymonas/Struma River used in the detailed calibration process of NAM model that will be presented hereunder. Some stations are located in tributaries of Strymonas/Struma River, mainly in the Bulgarian territory of the basin, and are used only for a rough estimation of water balance. Also, some stations are located in irrigation and drainage channels, in the Greek territory, which cannot be simulated by the NAM model and therefore there are not used.

From the available discharge data, it was chosen 4 stations in Strymonas/Struma River and 3 stations in main tributaries. Relevant information about discharge stations is given in Table 2.6 and the location of these stations is shown in Fig. 2.4.

Fig. 2.4. Location of discharge stations used for calibration of Rainfall-Runoff model

Table 2.6. Discharge stations used in calibration of Rainfall-Runoff model

River/tributary	Code	Location	Time period	Time step
Struma/Strymonas	51700	Rajdavitsa village	1/1/2000-31/12/2001, 1/1/2003-31/12/2006	daily
	51750	Boboshevo town		
	51800	Kresnensko hanche		
	51880	Marino pole village		
Dragovshtitsa	51880	Goranovtsi village	1/1/2000-31/12/2001, 1/1/2003-31/12/2004	
Eleshnitsa	51880	Vaksevo village		
Strumeshnitsa	51880	Mitino village		

Initial model setup

Initially, the NAM model was setup with the 9 basic parameters (Table 2.1). An auto-calibration procedure (MIKE 11 reference manual, 2007) in combination with a manual calibration was followed in order to make an initial estimation of model parameters.

Specifically, the auto-calibration procedure used to estimate the parameters of Pchelina and Penckyovska catchments based on station 51700, the parameters of Dragovitsa based on 51360, the parameters of Eleshnitsa based on 51410, the parameters of Strumenitsa based on 51580 and the parameters of Sandanski catchment based on station 51880.

The estimated parameters from the auto-calibration were transferred to neighborhood catchments and the model results were compared against all stations in Strymonas/Struma River. The evaluation of model results shown that a manual calibration, which was based on a trial-error procedure, improved significantly the numerical evaluation criteria. Also, the auto-calibrated parameters of Eleshnitsa catchment were not used at all, since they worsen model results. Finally, the most appropriate parameters from the above procedure are given in Table 2.7.

Table 2.7. NAM parameters at the initial model setup

Catchments	Model parameters								
	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF
SANDANSKI	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
ELESHNITSA	11.2	219	0.294	447	32.8	0.08	0.11	0.26	3992
PENKYOVSKA	11.1	288	0.356	320	31.0	0.67	0.13	0.36	3932
DRAGOVISHTITSA	11.2	219	0.294	447	32.8	0.08	0.11	0.26	3992
KYUSTENDIL	11.1	288	0.356	320	31.0	0.66	0.13	0.36	3932
DZHERMAN	11.2	219	0.294	447	32.8	0.08	0.11	0.26	3992
KRUPNIK	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
STRUMESHNITSA	19.4	298	0.416	321	27.0	0.89	0.87	0.50	3941
PIRINSJA_BISTRITSA	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
KERKINI_GR	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
STRYMON_GR	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
ESTUARY_GR	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
AGGITIS_GR	10.3	100	0.341	279	16.1	0.84	0	0.01	1597
PCHELINA	11.1	288	0.356	320	31.0	0.66	0.13	0.36	3932

A graphical evaluation of model results is presented in Diagram 2.2(a-d) for the calibration period and in Diagram 2.3(a-d) for the validation period. Numerical criteria are shown in Tables 2.8a and 2.8b for the calibration and validation period, respectively. The average value for all stations of WB_{er} is 8.3% (*very good*) and of R_{NS} is 0.54 (*good*) for the calibration period. Year 2003 is simulated better than 2004 almost in all cases.

As far as concern the validation period, the average value of WB_{er} is 14.9% and of R_{NS} is 0.59, which means that model results are evaluated as *good*. The performance indicators for the validation period are worsened, for the most of the discharge stations, compared to the calibration period.

Concluding, it can be said that changing the values of model parameters no further significant improvement can be achieved. Therefore, the errors produced by the model are owed to model setup or to error in meteorological and hydrological data.

Table 2.8a. Evaluation of model results for calibration period at the initial model setup

Evaluation criteria	**Station codes**							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2003	2004	2003	2004	2003	2004	2003	2004
WB_{er} %	2.8	23.8	0.7	5.6	2.1	0.7	1.8	28.6
R_{NS}	0.58	-0.46	0.86	0.60	0.73	0.58	0.84	0.62
Performance indicators	*Good*	*Very poor*	*Perfect*	*Good*	*Very good*	*Good*	*Very good*	*Poor*

Table 2.8b. Evaluation of model results for validation period at the initial model setup

Evaluation criteria	**Station codes**							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2005	2006	2005	2006	2005	2006	2005	2006
WB_{er} %	19.1	9.1	3.0	2.9	15.2	46.7	9.9	11.6
R_{NS}	0.36	0.58	0.73	0.64	0.65	0.57	0.83	0.38
Performance indicators	*Poor*	*Good*	*Very good*	*Good*	*Good*	*Very poor*	*Very good*	*Poor*

Incorporation of extended groundwater parameters

Since the efforts to improve the graphical and numerical evaluation criteria were in vain, it was chosen to incorporate 2 extended groundwater parameters (see Table 2.9). According to these parameters, a lower groundwater reservoir is activated and included into the model setup in order to simulate a slower baseflow in catchments.

For the estimation of these 2 new parameters it was chosen a manual procedure but the evaluation criteria were not improved significantly. Therefore, the auto-calibration procedure was activated again and the estimated parameters were furthermore changed with manual calibration. The final model parameters are presented in Table 2.10.

It has to be mentioned, that the model parameters for the STRYMON_GR and AGGITIS_GR, which are shown in Table 2.10, were chosen based on the physiographic characteristics of these catchments. More specifically, it was anticipated that these catchments will produce a small amount of water as overland flow and/or interflow, since they have a very dense drainage network, a large area covered by agriculture and a mild surface slope. Therefore, the TOF, TIF and Lmax parameters were modified appropriately based on the graphical evaluation presented in Annex II.

Table 2.9. Extended groundwater parameters of NAM that activated in modelling Strymonas/Struma River catchment

Parameters	Units	Description	Bandwidth
Lower base flow/Recharge to lower reservoir – Cqlow		Recharge to the lower ground water reservoir as a percentage of the total recharge	0-100
Time constant for routing lower baseflow – Cklow	hour	Baseflow time constant, which is usually larger than the CKBF	1000-30000

Table 2.10. NAM parameters after the incorporation of the extended groundwater parameters

Catchments	Model parameters										
	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF	Cqlow	Cklow
SANDANSKI	10.0	50	0.104	200	17.1	0	0	0	2780	46	2794
ELESHNITSA	14.8	145	0.104	1000	23.5	0.33	0.19	0.50	2141	3	2137
PENKYOVSKA	17.8	149	0.200	792	24.2	0.47	0.70	0.17	2360	50	$3\ 10^4$
DRAGOVI-SHTITSA	14.8	145	0.104	1000	23.5	0.33	0.19	0.50	2141	3	2137
KYUSTENDIL	17.8	149	0.200	792	24.2	0.47	0.70	0.17	2360	50	$3\ 10^4$
DZHERMAN	14.8	145	0.104	1000	23.5	0.33	0.19	0.50	2141	3	2137
KRUPNIK	10.0	50	0.104	200	17.1	0	0	0	2780	46	2794
STRUME-SHNITSA	20.0	300	0.101	1000	39.4	0.40	0.70	0.25	1597	100	$3\ 10^4$
PIRINSJA_ BISTRITSA	10.0	50	0.104	200	17.1	0	0	0	2780	46	2794
KERKINI_GR	10.0	50	0.104	200	17.1	0	0	0	2780	46	2794
STRYMON_GR	10.0	200	0.104	200	17.1	0.5	0.5	0	2780	46	2794
ESTUARY_GR	10.0	200	0.104	200	17.1	0.5	0.5	0	2780	46	2794
AGGITIS_GR	10.0	200	0.104	200	17.1	0.5	0.5	0	2780	46	2794
PCHELINA	17.8	149	0.200	792	24.2	0.47	0.70	0.17	2360	50	$3\ 10^4$

A graphical evaluation of model results is presented in Diagram 2.4(a-d) for the calibration period and in Diagram 2.5(a-d) for the validation period. Numerical criteria are shown in Tables 2.11a and 2.11b for the calibration and validation period, respectively.

For the calibration period, the average value of WB_{er} is 11.8% (*good*) and of R_{NS} is 0.64 (*very good*). Compared to initial model setup, WB_{er} is increased 3.5 % but R_{NS} is improved significantly. For the validation period, the average value of WB_{er} is 13.3% (*good*) and of R_{NS} is 0.67 (*very good*). For the most of the discharge stations, the performance indicators for the validation period are improved as compared to the calibration period.

Table 2.11a. Evaluation of model results for calibration period after incorporating the extended groundwater parameters

Evaluation criteria	Station codes							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2003	2004	2003	2004	2003	2004	2003	2004
WB_{er} %	6.5	11.9	5.9	20.0	1.2	2.5	12.8	33.5
R_{NS}	0.67	0.25	0.87	0.59	0.73	0.58	0.83	0.60
Performance indicators	*Very Good*	*Poor*	*Very Good*	*Poor*	*Very good*	*Good*	*Very good*	*Poor*

Table 2.11b. Evaluation of model results for validation period after incorporating the extended groundwater parameters

Evaluation criteria	Station codes							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2005	2006	2005	2006	2005	2006	2005	2006
WB_{er} %	5.2	15.9	2.3	9.7	13.2	43.6	8.1	8.5
R_{NS}	0.68	0.55	0.83	0.71	0.66	0.58	0.80	0.56
Performance indicators	*Very good*	*Good*	*Very good*	*Very good*	*Good*	*Very poor*	*Very good*	*Good*

Incorporation of snow effects (final model setup)

From a meticulous observation in Diagram 2.5, especially at January-February and for stations 51700-51750, it can be noticed that even significant events of precipitation/rainfall exist; the observation discharge is not affected. From this fact, in combination with the low temperatures that are observed in the Bulgarian territory of Strymonas/Struma catchment, it can be inferred that the discharge is affected by snowfall. Therefore, the snow-melt module was also included in the NAM model and 2 new parameters were also used for model calibration (Table 2.12). Except for the model parameters the activation of snow module requires temperature data for the catchments that will be applied.

The calibration of snow-melt module parameters was done manually according to temperature data and a trial and error procedure. The snow module was applied only in specific catchments and the final parameters are shown in Table 2.13. With the new model setup, an auto calibration procedure was applied but model parameters, and consequently evaluation criteria, were not changed significantly. As a result, except for parameters of snow-melt module, the values of the rest model parameters are those shown in Table 2.10.

A graphical evaluation of model results is presented in Diagram 2.6(a-d) for the calibration period and in Diagram 2.7(a-d) for the validation period. Numerical criteria are shown in Tables 2.14a and 2.14b for the calibration and validation period, respectively.

Table 2.12. Snow-melt module parameters of NAM that activated in modelling Strymonas/Struma River catchment

Parameters	Units	Description	Bandwidth
Constant Degree-day coefficient – Csnow	mm/day/^{O}C	The content of the snow storage melts at a rate defined by the degree-day coefficient multiplied with the temperature deficit above the Base Temperature	2-4
Base Temperature snow/rain – T_0	hour	Precipitation is retained in the snow storage only if the temperature is below the Base Temperature, whereas it is by-passed to the surface storage (U) in situations with higher temperatures	usually at or near zero degree ^{O}C

Table 2.13. NAM parameters values of snow-melt module in Strymonas/Struma River catchment

Catchments	Model parameters	
	Csnow	T_0
ELESHNITSA	2	0
PENKYOVSKA		
DRAGOVISHTITSA		
KYUSTENDIL		
DZHERMAN		
KRUPNIK		
PCHELINA		

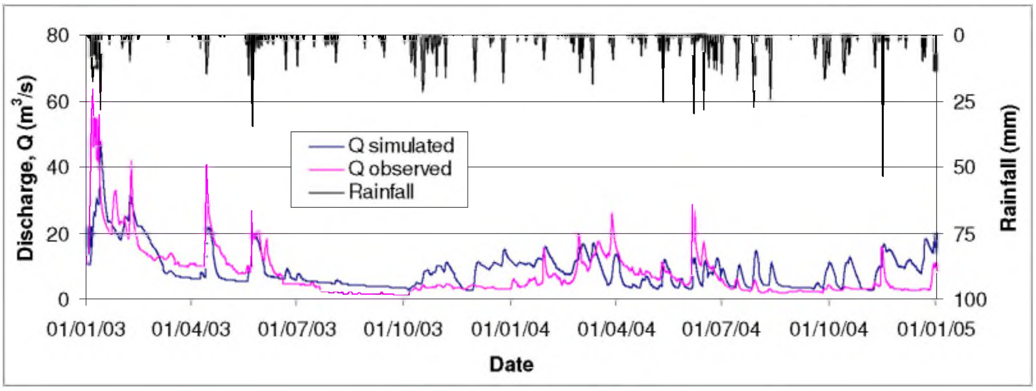
Table 2.14a. Evaluation of model results for calibration period after incorporating the snow-melt module

Evaluation criteria	**Station codes**							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2003	2004	2003	2004	2003	2004	2003	2004
WB_{er} %	5.0	14.9	4.2	13.1	2.7	7.2	12.8	33.5
R_{NS}	0.67	0.22	0.88	0.61	0.78	0.60	0.83	0.60
Performance indicators	*Very Good*	*Poor*	*Perfect*	*Good*	*Very good*	*Good*	*Very good*	*Poor*

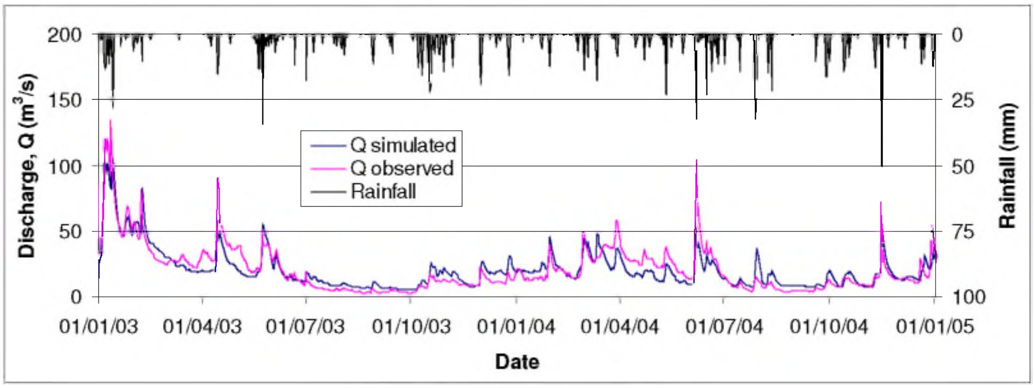
Table 2.14b. Evaluation of model results for validation period after incorporating the snow-melt module

Evaluation criteria	**Station codes**							
	51700		51750		51800		51880	
	Years		Years		Years		Years	
	2005	2006	2005	2006	2005	2006	2005	2006
WB_{er} %	7.0	13.2	0.2	7.4	12.3	37.1	8.1	8.5
R_{NS}	0.70	0.54	0.86	0.71	0.62	0.56	0.80	0.56
Performance indicators	*Very good*	*Good*	*Perfect*	*Very good*	*Good*	*Poor*	*Very good*	*Good*

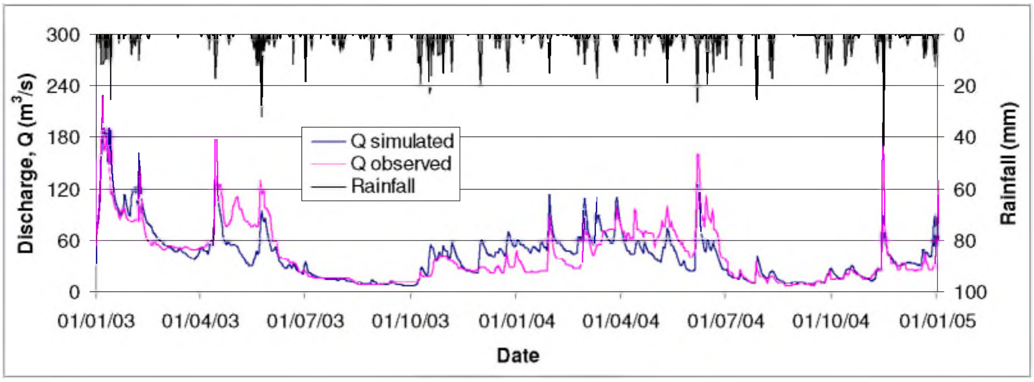
For the calibration period, the average value of WB_{er} is 11.7% (*good*) and of R_{NS} is 0.65(*very good*), which means that evaluation criteria are not improved significant. For the validation period, the average value of WB_{er} is 11.7% (*good*) and of R_{NS} is 0.67 (*very good*). Again, numerical evaluation criteria are not improved significant, compared to the previous model setup. However, from a graphical evaluation between Diagram 2.5 and 2.7, it is observed that, especially for winter months, the simulated discharge estimate better the observations of discharge.



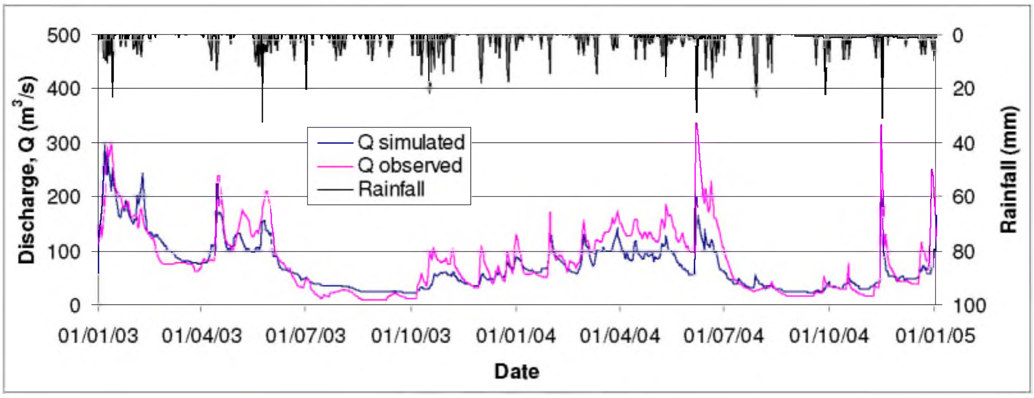
(a) station 51700



(b) station 51750

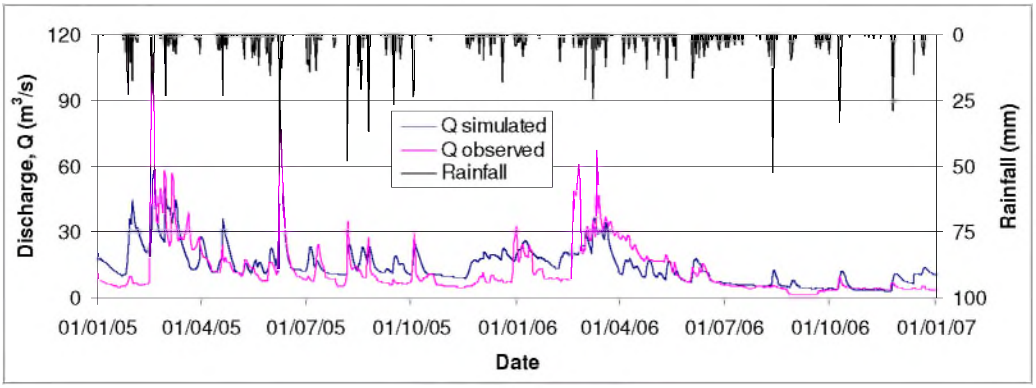


(c) station 51800

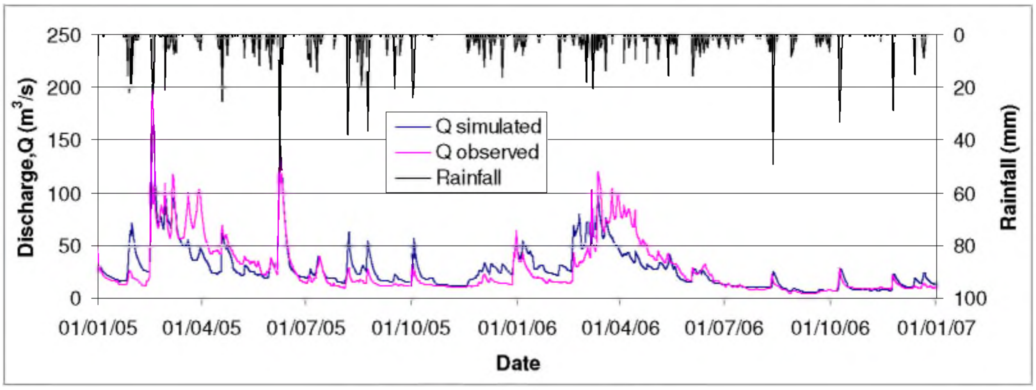


(d) station 51880

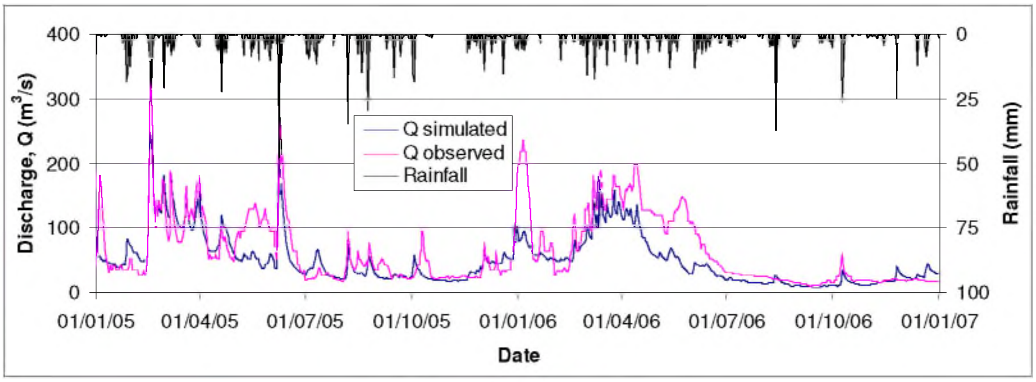
Diagram 2.2. Discharge in Strymonas/Struma River for the calibration period (initial model setup)



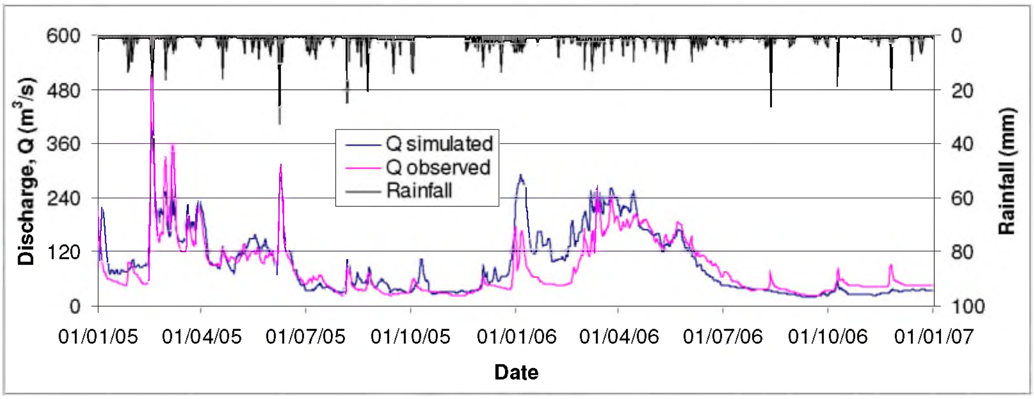
(a) station 51700



(b) station 51750

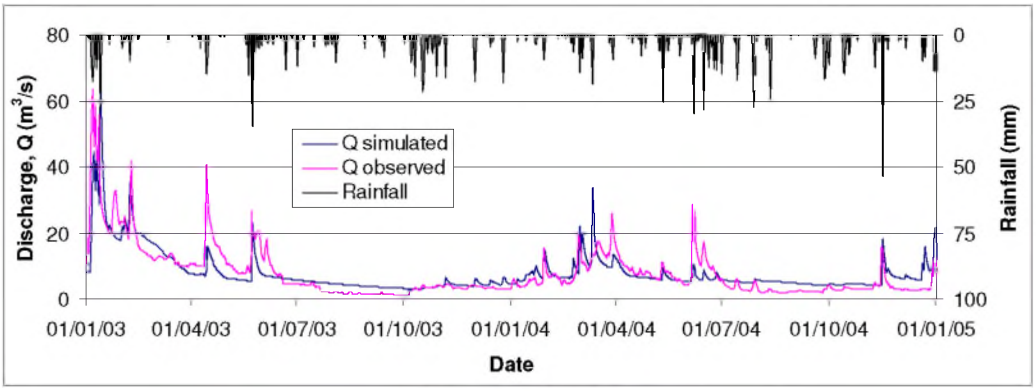


(c) station 51800

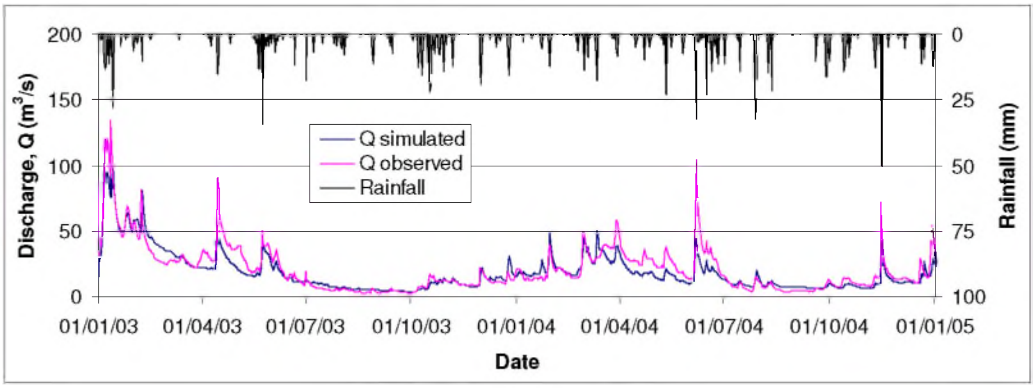


(d) station 51880

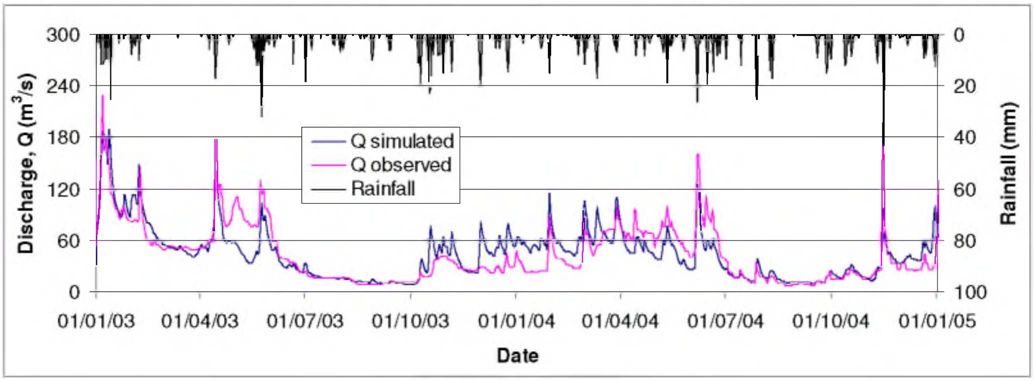
Diagram 2.3. Discharge in Strymonas/Struma River for the validation period (initial model setup)



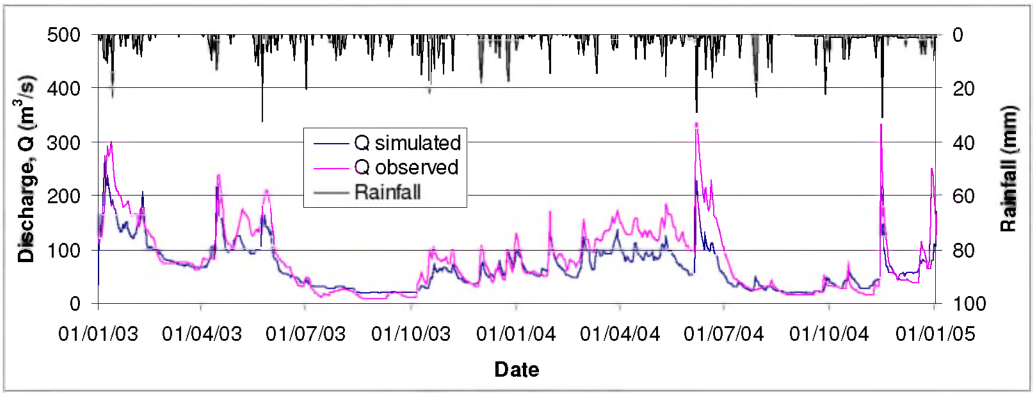
(a) station 51700



(b) station 51750

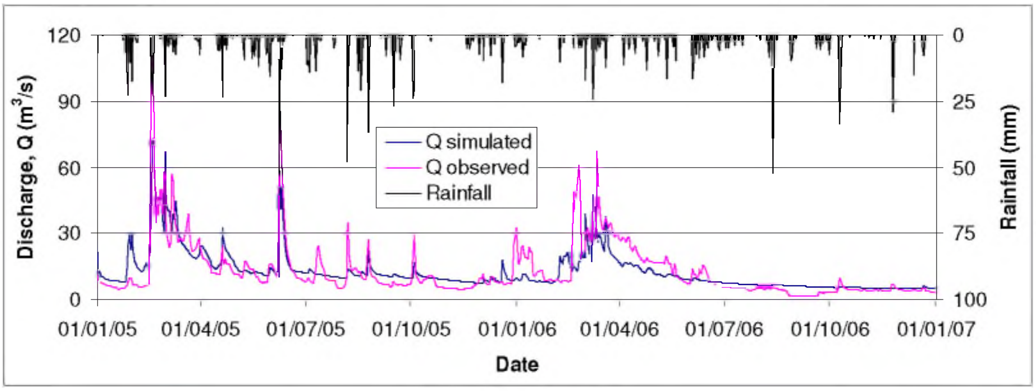


(c) station 51800

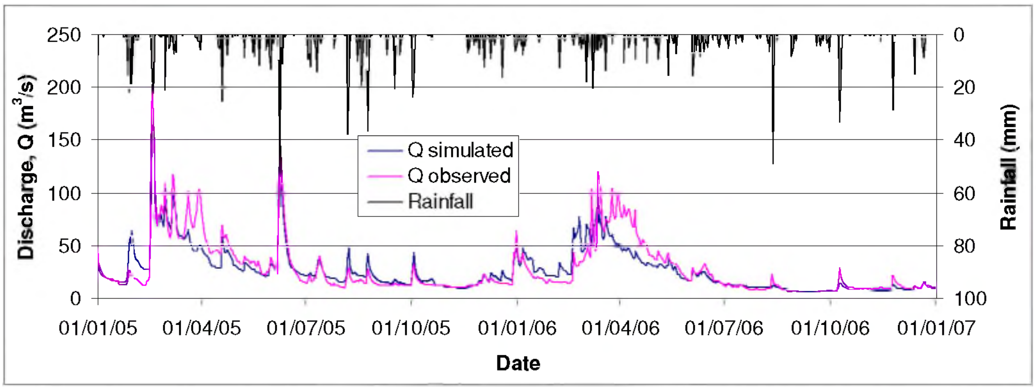


(d) station 51880

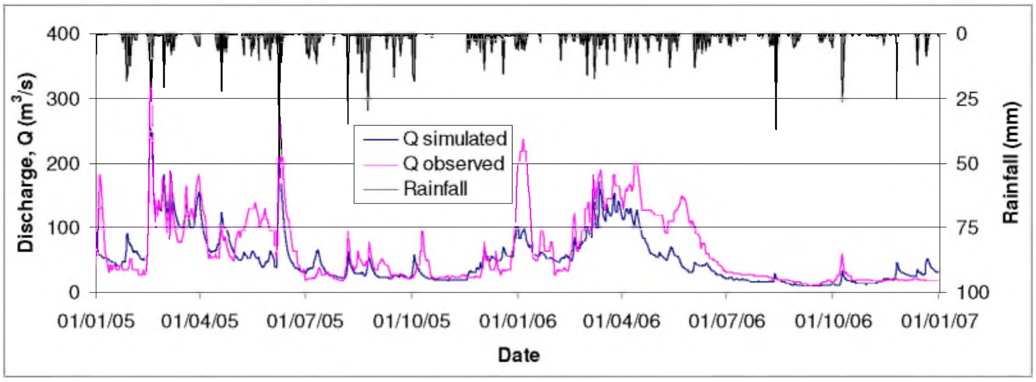
Diagram 2.4. Discharge in Strymonas/Struma River for the calibration period (extended groundwater parameters)



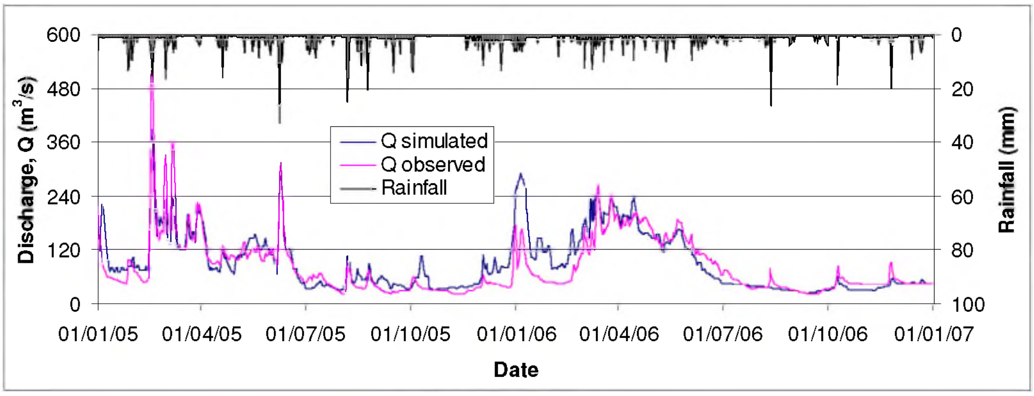
(a) station 51700



(b) station 51750

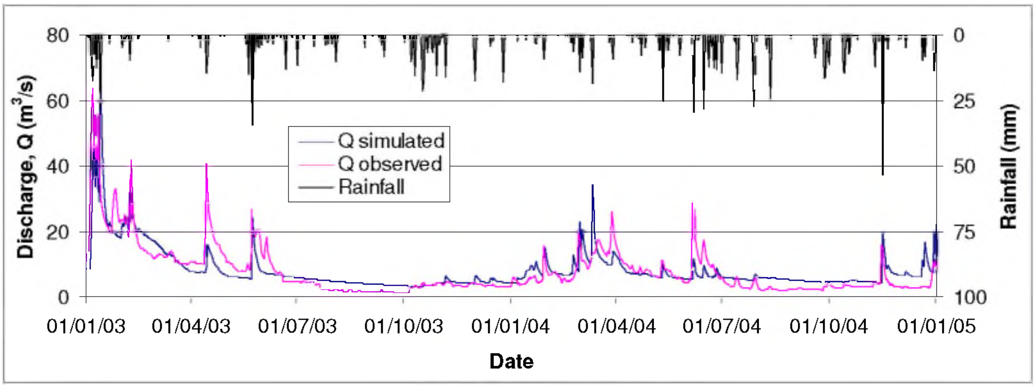


(c) station 51800

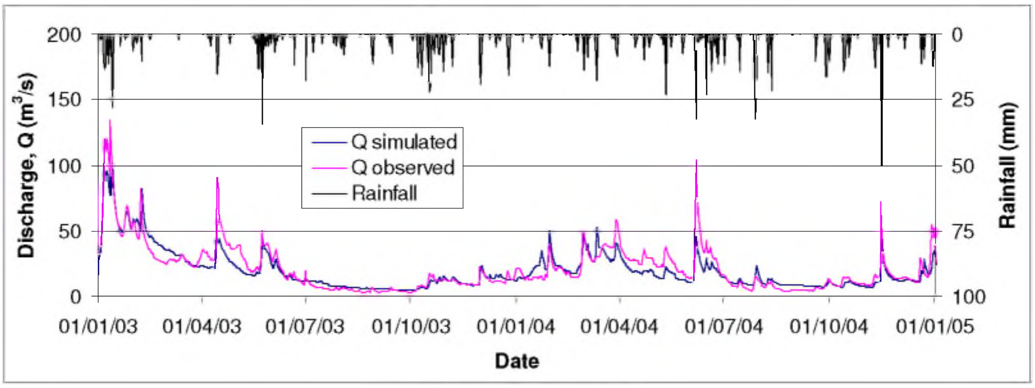


(d) station 51880

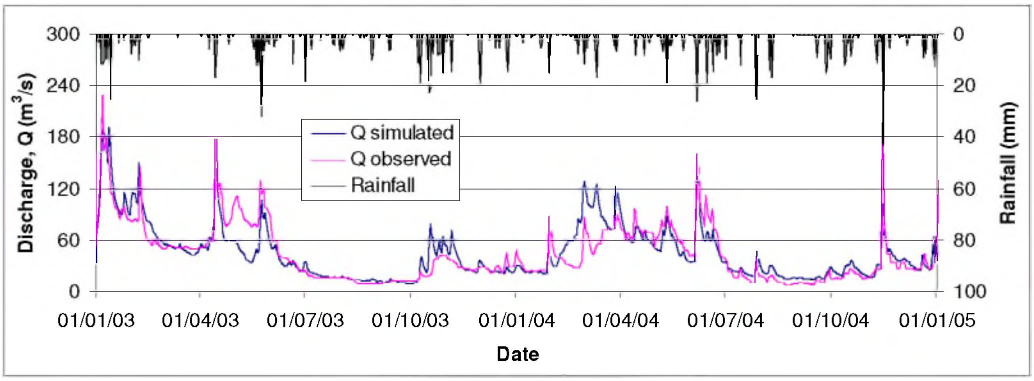
Diagram 2.5. Discharge in Strymonas/Struma River for the validation period (extended groundwater parameters)



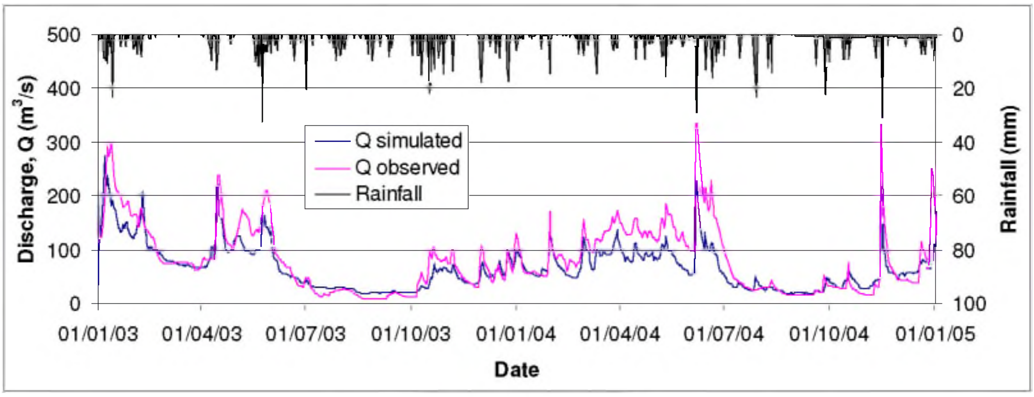
(a) station 51700



(b) station 51750

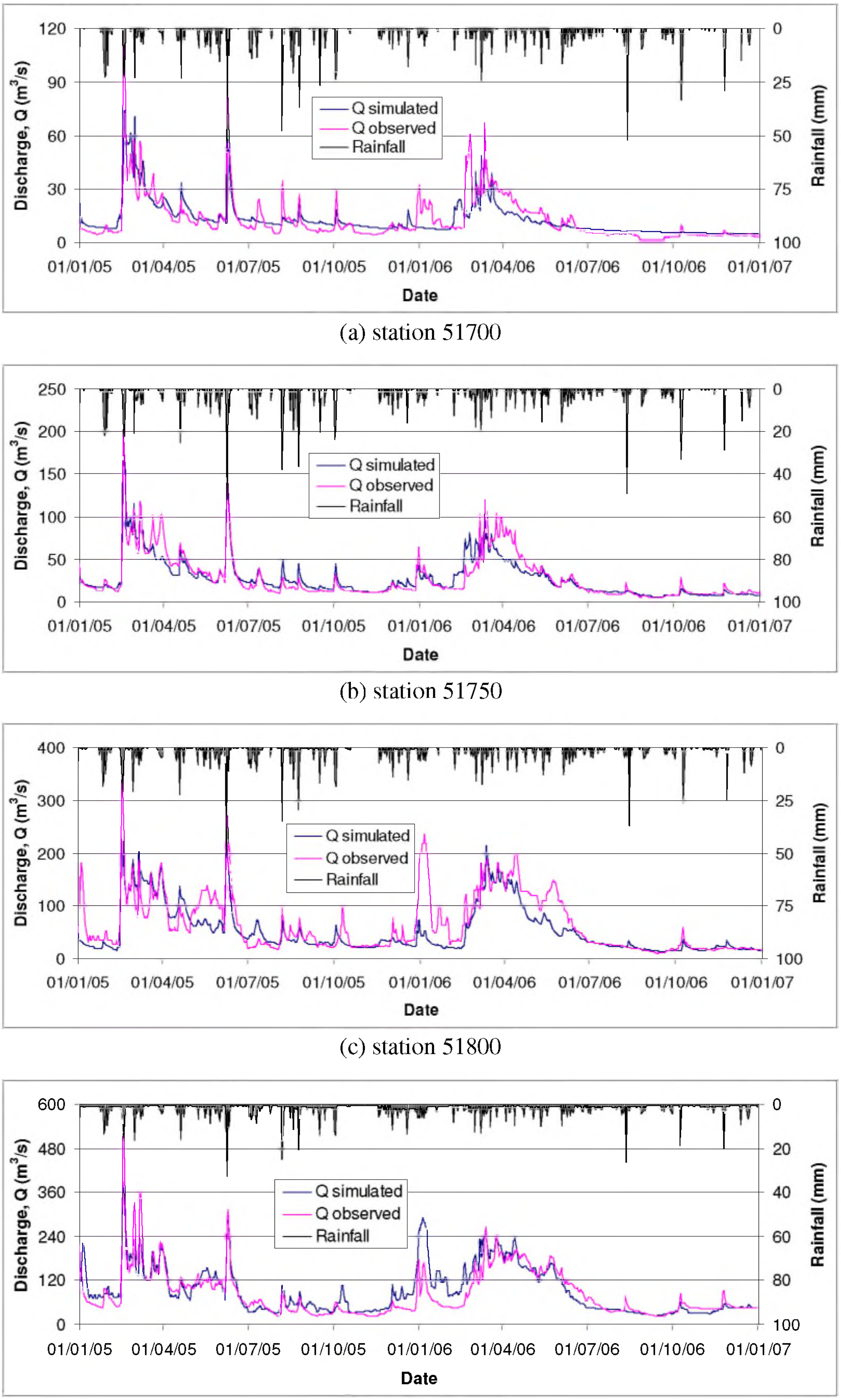


(c) station 51800



(d) station 51880

Diagram 2.6. Discharge in Strymonas/Struma River for the calibration period (snow-melt module)



(a) station 51700

(b) station 51750

(c) station 51800

(d) station 51880

Diagram 2.7. Discharge in Strymonas/Struma River for the validation period (snow-melt module)

2.3.3. Final model evaluation

In the previous paragraph it was described analytical the steps that was followed during the model calibration. The final model setup includes the incorporation of the extended groundwater parameters (NAM parameters given in Table 2.10) with the addition of the snow-melt module (NAM parameters given in Table 2.13).

In Table 2.15 are shown synoptically the evaluation of model results for the final setup. The model simulates satisfactory in most cases the discharge in Strymonas/Struma River basin. Stations 51700 and 51750 are simulated satisfactory both for calibration and validation period. In stations 51800 and 51880, the errors in water balance are significant for the validation and the calibration period, respectively, and probably these errors are due to the procedure of gap filling data in rainfall stations of Dolene and Krupnic, where data was missing for years 2004, 2005 and 2006 (see also in Part I). Especially for station 51880, errors also occur from the unsuccessful simulation of STRUMENITSA catchment due to lack of meteorological stations in the mountain area of the catchment as well as for the partly known water volume used for fulfilling water demands.

The annual water balance (average values of 2001-2006) in catchments that simulated with NAM model is shown in Table 2.16. Annual precipitation is varying from 558 mm to 931 mm, with an average value of 686 mm, while the average value of runoff coefficient is 0.27.

Table 2.15. Evaluation of model results for calibration-validation period

Discharge stations	**Calibration period**				**Validation period**			
	WB_{er}		R_{NS}		WB_{er}		R_{NS}	
51700	3.9	*Perfect*	0.59	*Good*	1.0	*Perfect*	0.64	*Good*
51750	8.1	*Very good*	0.80	*Very good*	3.0	*Perfect*	0.80	*Very good*
51800	2.1	*Perfect*	0.72	*Very good*	23.5	*Poor*	0.59	*Good*
51880	22.5	*Poor*	0.72	*Very good*	8.3	*Very good*	0.71	*Very good*

Table 2.16. Water balance in catchments of Strymonas/Struma River basin

	Surface area	**Precipi-tation**[1]	**Evapotran-spiration**[2]	**Runoff**[3]		**Storage** (=1-2-3)	**Runoff coefficient**
Catchments	km^2	mm	mm	m^3/s	mm	mm	
SANDANSKI	1435	703	448	11.2	246	9	0.35
ELESHNITSA	345	718	492	2.4	219	7	0.30
PENKYOVSKA	810	625	465	3.0	117	43	0.19
DRAGOVISHTITSA	819	625	471	3.8	148	7	0.24
KYUSTENDIL	908	680	486	4.4	154	40	0.23
DZHERMAN	757	674	460	4.8	202	12	0.30
KRUPNIK	1742	691	375	16.6	301	15	0.44
STRUMESHNITSA	2077	931	664	9.5	145	122	0.16
PIRINSJA_ BISTRITSA	485	656	389	3.9	255	12	0.39
KERKINI_GR	753	639	393	5.6	233	13	0.36
STRYMON_GR	2728	558	438	8.8	102	18	0.21
ESTUARY_GR	219	582	352	1.5	210	20	0.40
AGGITIS_GR	2234	709	495	13.6	192	21	0.30
PCHELINA	1379	639	478	5.2	120	40	0.19

Simulated and observed accumulated water volumes are presented in Diagrams 2.8, 2.9, 2.10 and 2.11 for the discharge stations 51700, 51750, 51800 and 51880, respectively. Station 51700 is simulated pretty well. Water volume in station 51750 is slightly underestimated from the model in most of the years, usually at late spring and early summer. Station 51800 is simulated very well except for year 2006, where water volume is underestimated significantly.

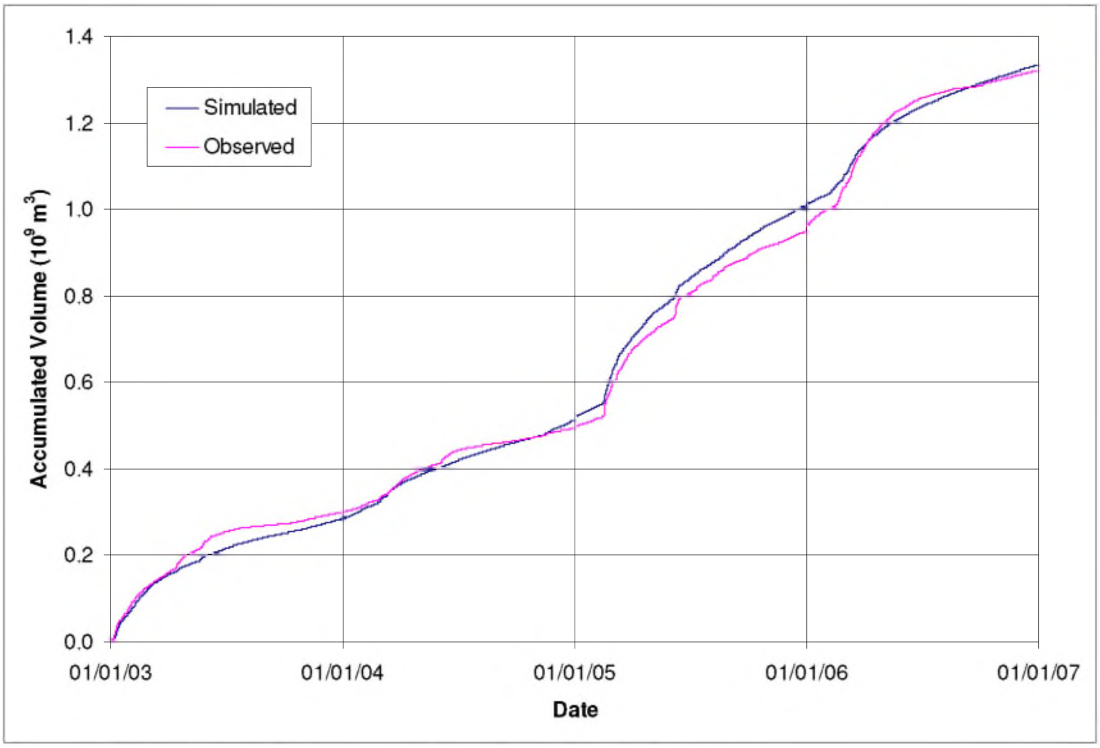


Diagram 2.8. Accumulated water volume in station 51700

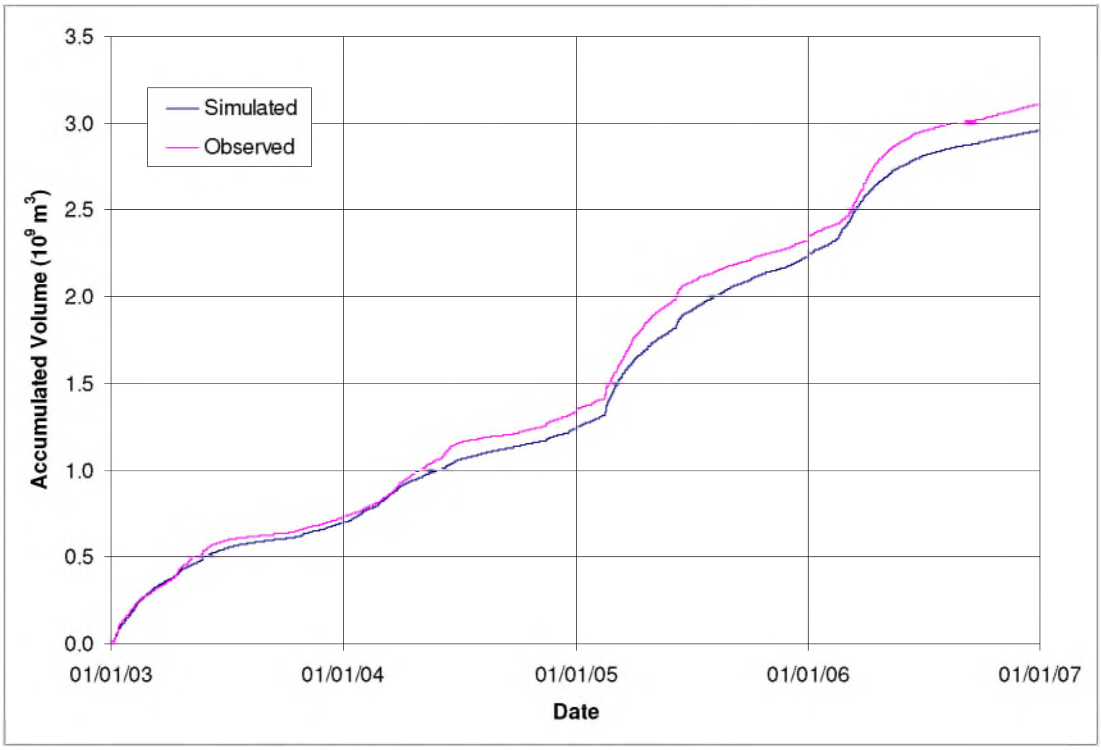


Diagram 2.9. Accumulated water volume in station 51750

Finally, water volume in station 51880 is underestimated for the whole time period shown in Diagram 2.11, and especially at year 2004. Water volume at year 2005 is simulated pretty well, since the two lines follow a parallel direction, while is overestimated during year 2006, especially at winter and spring months.

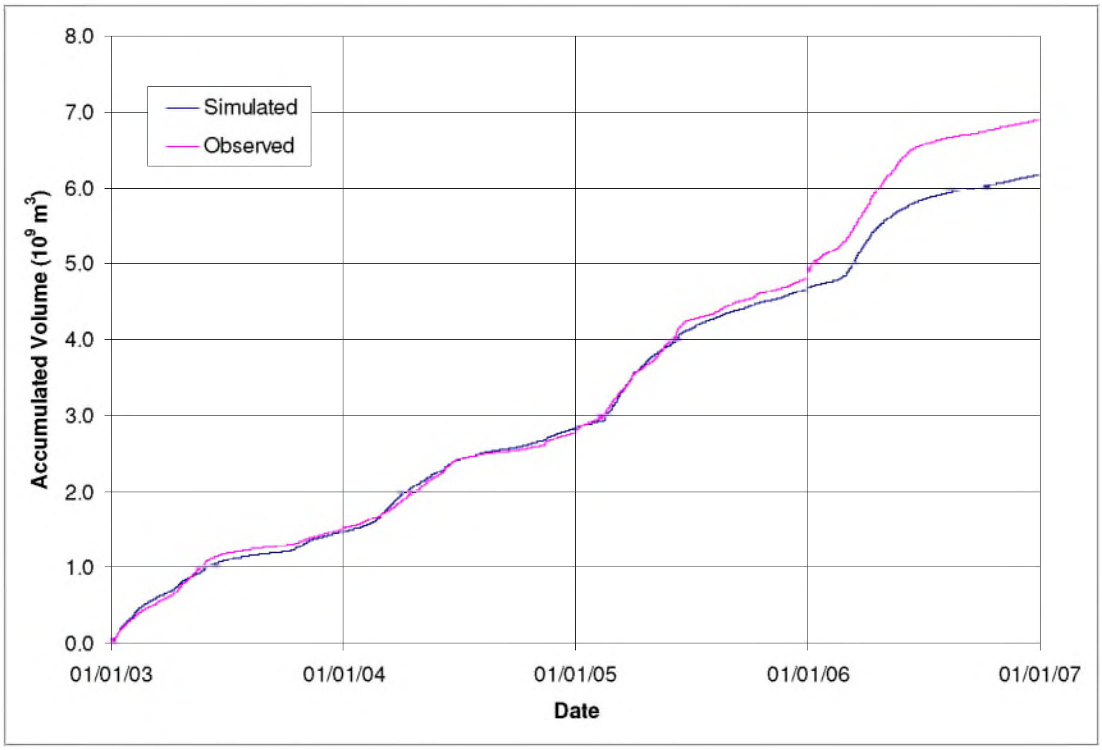


Diagram 2.10. Accumulated water volume in station 51800

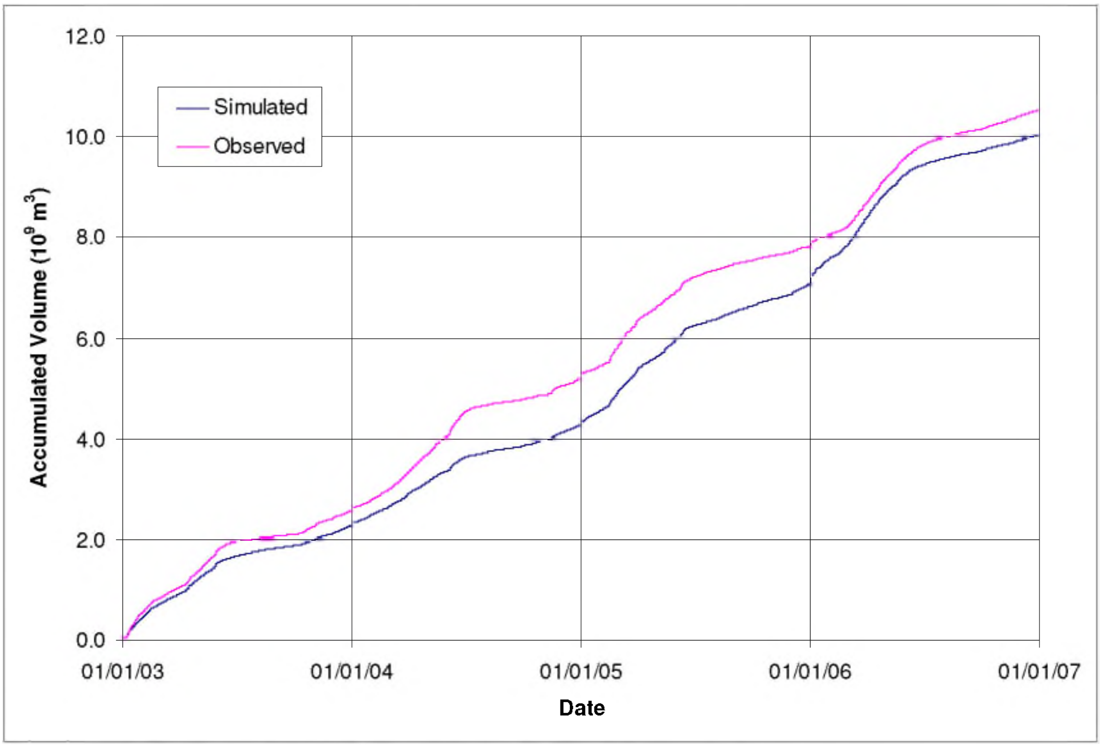


Diagram 2.11. Accumulated water volume in station 51880

3. Hydrodynamic and qualitative simulation

3.1. Description of methodology

The hydraulic modeling system MIKE 11 and its modules Hydrodynamic (HD) and Advection – Dispersion (AD), have been used for the simulation of water quantity and quality in Strymonas/Struma River.

The MIKE 11 hydrodynamic module (HD) is used for the computation of unsteady flow (discharge and water level) in rivers. It uses a one-dimensional, implicit, finite difference scheme for the numerical solution of equations regarding the conservation of volume and momentum (the well known Saint-Venant equations).

The HD module can describe sub-critical as well as supercritical flow conditions through a numerical scheme, which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation.

The advection-dispersion (AD) module is used for the simulation of water quality in rivers, based on the one-dimensional equation of conservation of mass of dissolved or suspended material (the advection-dispersion equation). The module requires output from the hydrodynamic module, in time and space, in terms of discharge and water level. In Table 3.1 is shown the substances that simulated by the model.

Table 3.1. Simulated dissolved substances in Strymonas/Struma River basin

Substances	Units
BOD_5	mg/l
NH_4	mg/l
NO_3	mg/l
PO_4	mg/l

3.2. Input data

3.2.1. River network schematization

The schematization of a river network in MIKE 11 is conducted by digitizing a sufficient number of points alongside the river network branches using as a background a georeferenced map. In this way both the shape and length of the river network branches are automatically calculated by the system taking into account the distance between the adjacent points. The denser the digitized points are the more accurate the river's representation is.

In the case of Strymonas/Struma model, only the main root of the river, at both territories the Bulgarian and the Greek one, has been included taking also into account Lake Kerkini. Since the later is expected to have a different hydraulic-computational behavior compared to the rest of the river, the final schematization included three individual branches (Fig 3.1):

- Strymonas/Struma River before Lake Kerkini
- Lake Kerkini
- Strymonas/Struma River after Lake Kerkini

The computational grid in MIKE 11 (i.e. points where the discharge, Q, and water level, h, respectively, are computed at each time step), consists of alternating Q-points and h-points alongside the braches of the river. It is generated automatically by the model, on the base of the maximum distance between the adjacent Q and h-points, dx, which has been set equal to 250 m for Lake Kerkini and 5000 m for the 2 branches of Strymonas/Struma River.

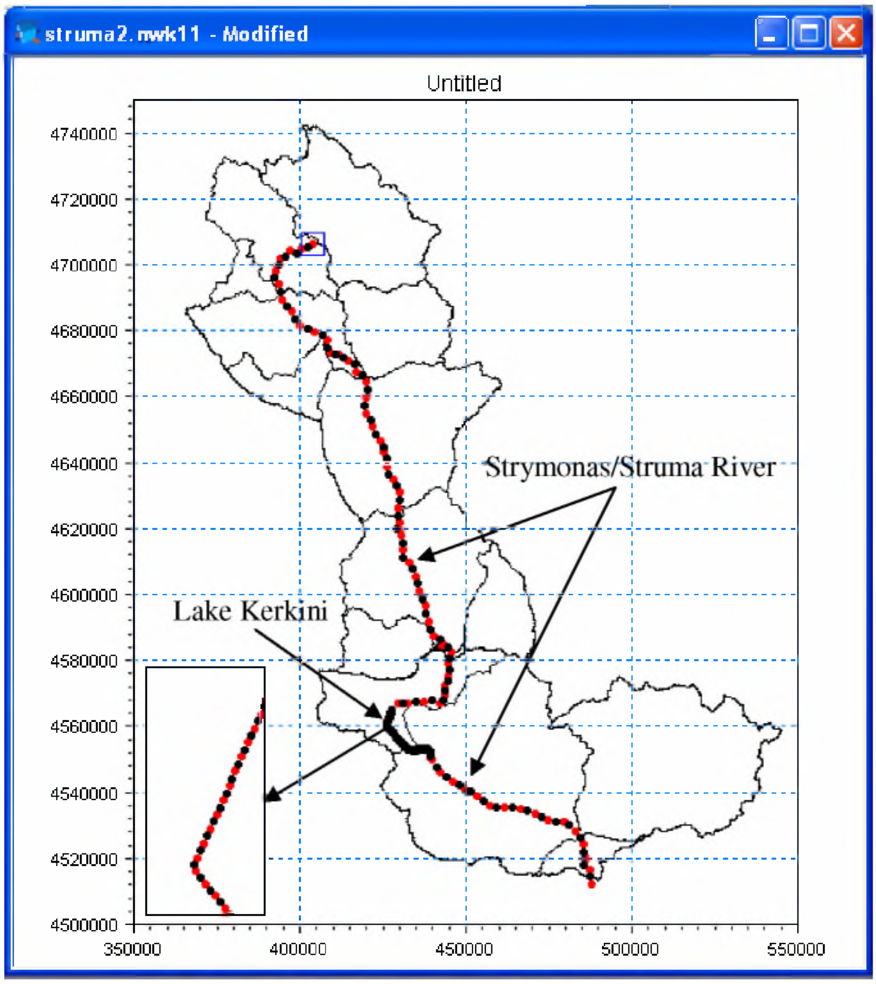


Fig. 3.1. River network schematization and computational grid of Strymonas/Struma River basin in MIKE 11 (discharge Q-points: black points, water level h-points: red points)

3.2.2. River geometry and cross sections

The geometry of each river branch is specified in MIKE 11 through a number of representative cross sections. Cross sections and their elevation (datum) are important to both discharge capacity and storage capacity of the river system.

There are two types of cross section data; the raw survey data and the derived processed data. The raw data are the input data for the model (Fig. 3.2); describe the shape of the cross section and typically come from a section survey of the river. The processed data are derived from the raw data and contain all information used by the computer model (e.g. cross section area, flow width, hydraulic radius).

Data regarding cross sections in Strymonas/Struma River and Lake Kerkini were obtained from fieldwork as well as previous studies [Psilovikos et al. (1992), Mertzianis (1994)]. Information regarding the elevation (datum) of each cross section has been extracted from the Digital Elevation Model (DEM) of the basin. Upstream to Lake Kerkini, the bottom slope of

Strymonas/Struma River varies from 1.2 to 4.8‰, with an average value of 2.9‰ and downstream to Lake Kerkini the bottom slope is close to 0.5‰.

In Fig. 3.3 is shown the location of cross sections that used in the model. The total number of cross sections is sixteen (16); 6 of them concern Lake Kerkini, 7 the river branch upstream the lake and 3 of them the river branch downstream of the lake.

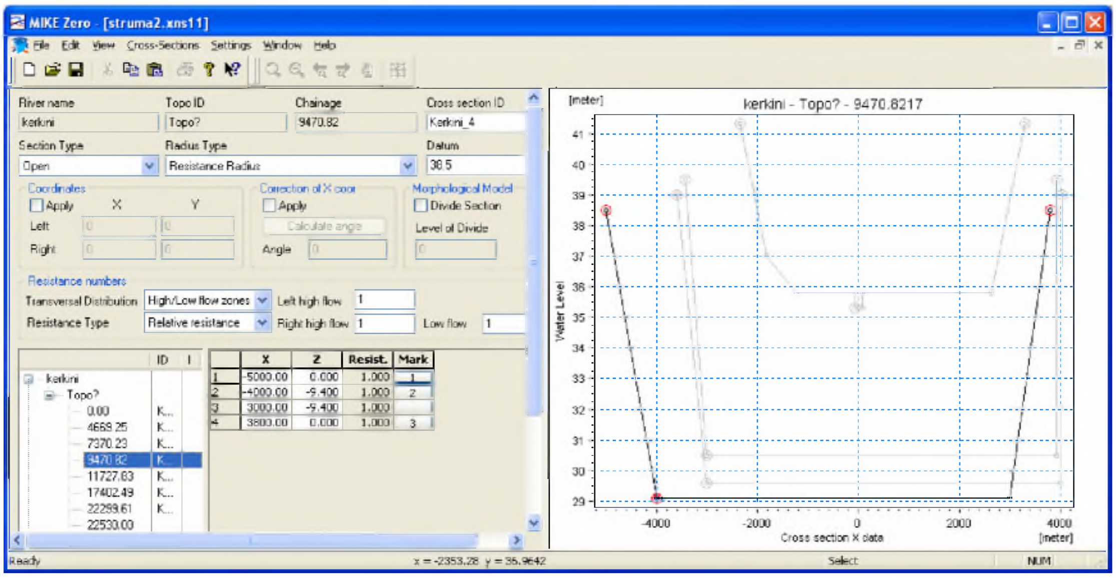


Fig. 3.2. Input data of cross section in MIKE 11

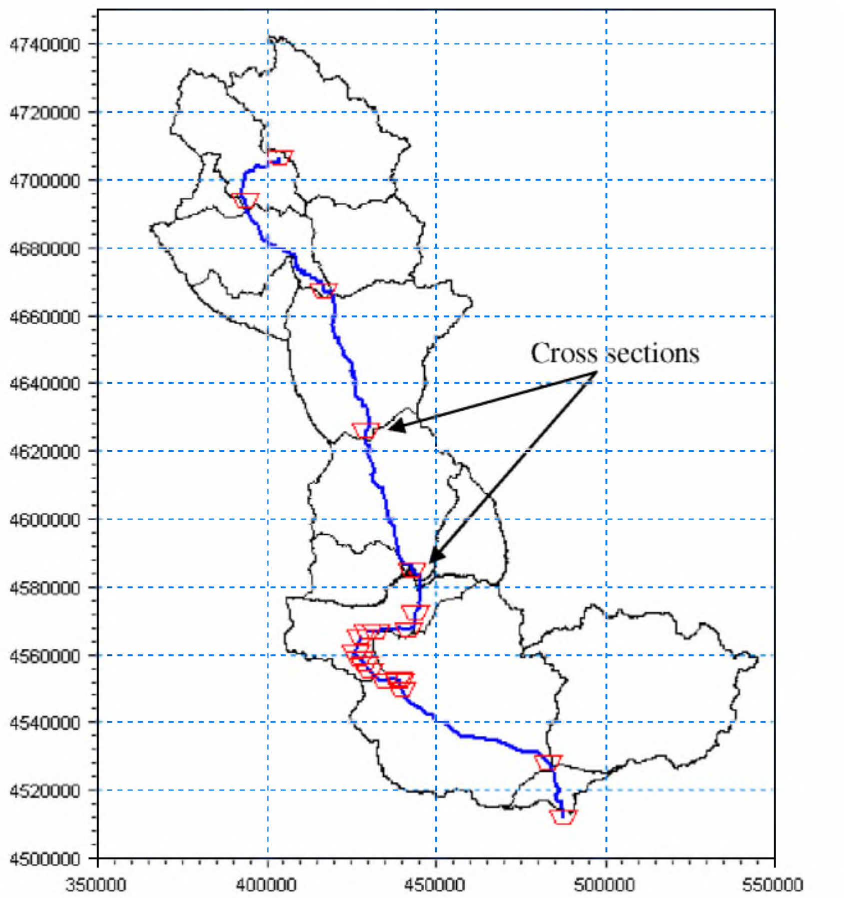


Fig. 3.3. Location of cross sections in Strymonas/Struma River model

3.2.3. Boundary conditions

Boundary conditions are required for all model boundaries, i.e. all upstream and downstream ends of model branches which are not connected at a junction. The relationships applied at these boundaries may consist of:

- constant values of h (water level) or Q (discharge)
- time varying values of h or Q
- a relationship between h and Q

At the upstream boundary of Strymonas/Struma River, a time varying boundary condition of discharge, Q, is applied which comes from the calculated total runoff of catchments PCHELINA and PENKYOVSKA as it has resulted from the Rainfall-Runoff model. At the downstream boundary of the river a constant value of water level, h, is applied equal to the elevation of sea level, h=0 m.

Further to the boundary conditions described above, a number of lateral inflows and outflows of water, pollutants, precipitation and evaporation have been applied in the model.

Lateral water inflows in Strymonas/Struma River come from its tributaries' catchments runoff, as they have been calculated by the Rainfall-Runoff model. In some cases, the runoff is added at a specific point of Strymonas/Struma River while in other cases is distributed alongside a specific segment of the river.

Lateral water outflows in Strymonas/Struma River are related to abstractions either for agriculture or urban water supply. The total abstracted water volume has been estimated to 697×10^6 m^3/year (or 22 m^3/s). In Table 3.2 are given the annual water volumes that have been included in the model.

Table 3.2. Annual water demands ($\times10^6$ m^3) in Strymonas/Struma River basin

Water use	Bulgaria	Greece		Total
		sub-catchment Strymonas	sub-catchment Aggitis	
Urban	98	19	17	134
Irrigation*	16	495	52	563

* Water volume demands that met by surface water

Water losses from Strymonas/Struma River bed are also taken into account. More specifically, it was estimated that 10% of total discharge in Strymonas/Struma River percolates to deep groundwater of STRYNON_GR catchment (see paragraph 2.2.1). Furthermore this amount of percolation is denoted by the reduced conveyance of the river at the lowest areas (Ahinos area – 15 to 20 km upstream to estuaries) in the catchment where it is estimated to maximum value 200 m^3/s (Halkidis I. and Papadimos D., 2007). The percolated water volume is assumed not to reappear in Strymonas/Struma River bed. Such an approach has been also adopted in similar studies in the catchment (Doulgeris et al. 2007).

From a technical point of view, the water losses have been implemented in MIKE 11 (MIKE 11 reference manual, 2007) with a *Global* boundary condition of type *Groundwater Head*, which has been set up equal to -2 m. The calculation of losses is mainly based on a specified *leakage coefficient*, equal to 3×10^{-6}, and the difference between the simulated water level in river and the predefined *Groundwater Head.*

Inflows of dissolved substances (BOD_5, NH_4, NO_3 and PO4) in Strymonas/Struma River applied as time varying boundary conditions, assuming that the calculated runoff from the Rainfall-Runoff model has a specific, also time varying, concentration of substances. The concentration of substances at catchment runoff assumed to be equal with the observed concentration in tributaries of Strymonas/Struma River.

Precipitation and evaporation have been taking also into account at Lake Kerkini, as varying boundary inflow and outflow, respectively. Evaporation at Lake Kerkini assumed to be equal to the potential evapotranspiration of Serres meteorological station.

3.2.4. Parameters of hydrodynamic and advection-dispersion module

The bed resistance parameter is one of the most important in HD module. In MIKE 11, two approaches can be applied for the specification of bed resistance, either a uniform or a triple zone approach. In Strymonas/Struma River it was chosen the uniform approach with a constant value of Manning number, M=15 $m^{1/3}/s$.

As far as concern the AD module, the dispersion coefficient, D, can be described as a function of the mean flow velocity, V, according to the relationship $D = a V^b$, where a, is the dispersion factor and b is the dispersion exponent. Typical value ranges for D is 1-5 m^2/s for small streams, 5-20 m^2/s for rivers. In Strymonas/Struma River it was chosen a constant value of dispersion coefficient, D=10 m^2/s.

The simulation time step for HD and AD modules was chosen to be 1 min. Simulation with a larger time step caused systematical violations of Courant Number, i.e. CN>1, while smaller time step increased significantly the computational time.

3.3. Results and model calibration

3.3.1. Estimation of outflow at Lake Kerkini

The calibration of the hydrodynamic model based on the fluctuation of water level at Lake Kerkini. Lake Kerkini collects water from the upstream catchment of Strymonas/Struma River and supplies the irrigation networks during summer.

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 basin. The operation of the gates is not exactly known while is difficult to be incorporated in detail in the model. Furthermore, the downstream discharge from Lake Kerkini is also not known.

Therefore, an automatic procedure of MIKE 11 was used, throughout of which the fluctuation of water level is known a-priori and the operation of gates is controlled in such a way that the simulated water level at every time step is equal, or at least very close, to the observed water level. As a result, the downstream discharge from Lake Kerkini is calculated by the model. In Fig. 3.4 is shown the control definitions used in MIKE 11 for the operation of gates and in Diagrams 3.1 and 3.2 the fluctuation of water level and the inflow/outflow discharge at Lake Kerkini, respectively.

Following the automatic procedure for the operation of gates in MIKE 11, one of the model parameters that have to be specified, is the *Max. Speed* (m/s), which defines the maximum allowable change in gate level per time, or rephrasing, defines the maximum allowable movement of the gates. This parameter has to be specified carefully in order to avoid very rapid changes in gate level, which is probably not realistic and can produce an unacceptable rapid variation in released outflow. Furthermore, it can create numerical instabilities during the simulation and a significant increase in computational time. For Lake Kerkini, five values were checked up on *Max. Speed*; 0.5, 0.05, 0.005, 0.0005 and 0.0001 m/s. The simulated water level was close to the observations for all the values, but for *Max. Speed* = 0.0005 m/s, it was closer to observations and with the minimum "ups and downs". For the same value it was also noticed the smallest variation in released outflow from Lake Kerkini, either for high or low flows, while for the other values of *Max. Speed* it was noticed rapid changes of released outflow. Therefore, it was chosen for Lake Kerkini to be *Max. Speed* = 0.0005 m/s.

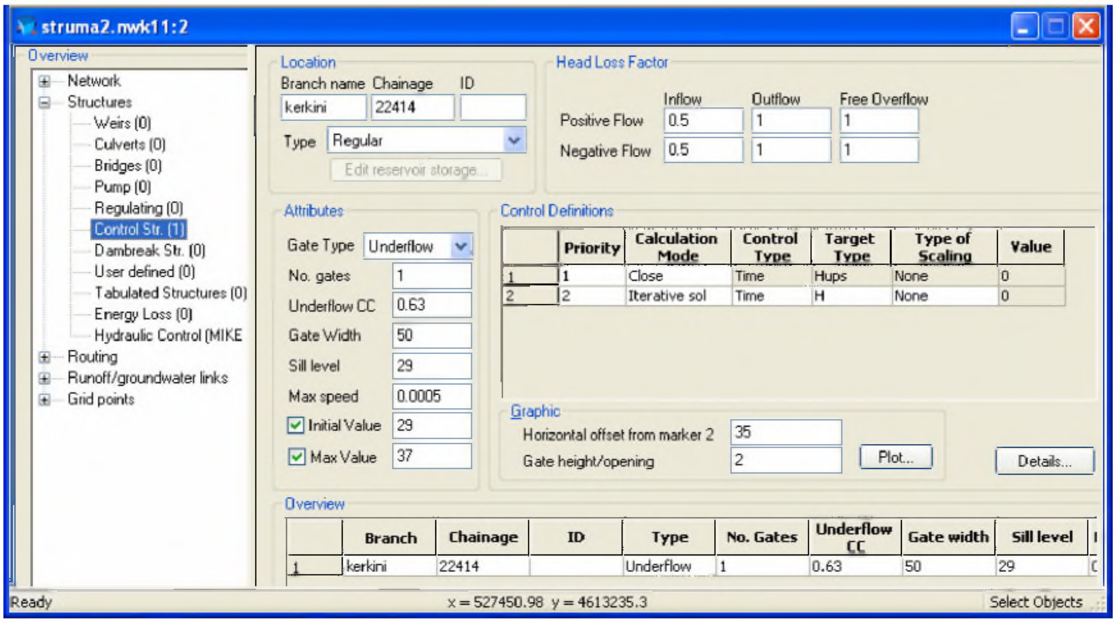


Fig. 3.4. Control definitions for the operation of gates at Lake Kerkini in MIKE 11

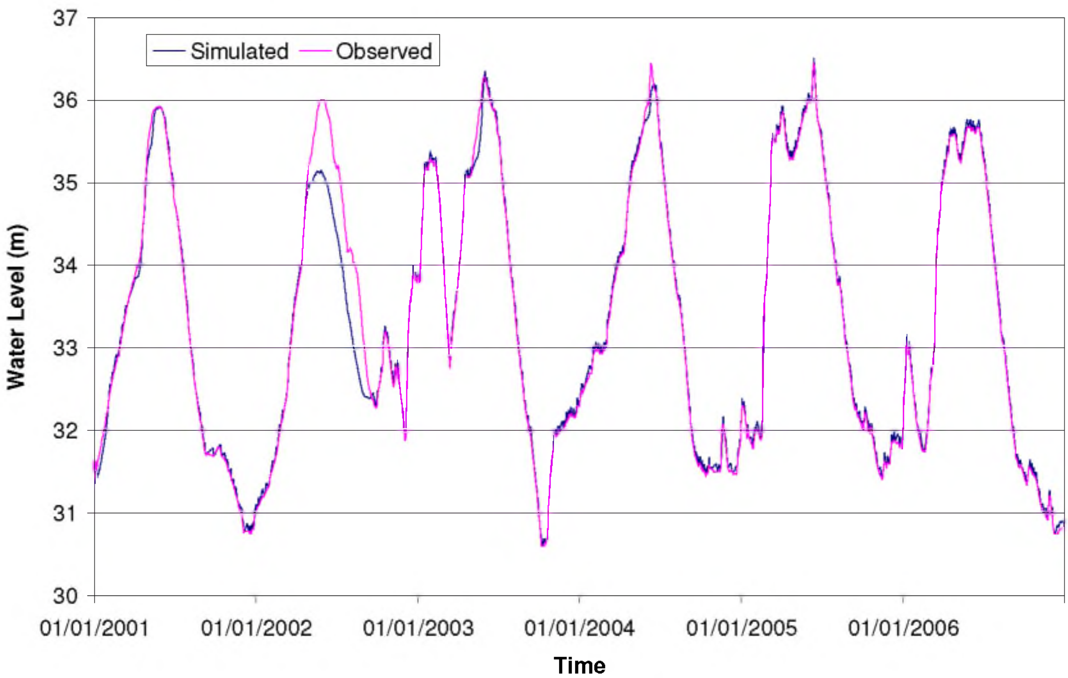


Diagram 3.1. Simulated and observed water level fluctuation at Lake Kerkini

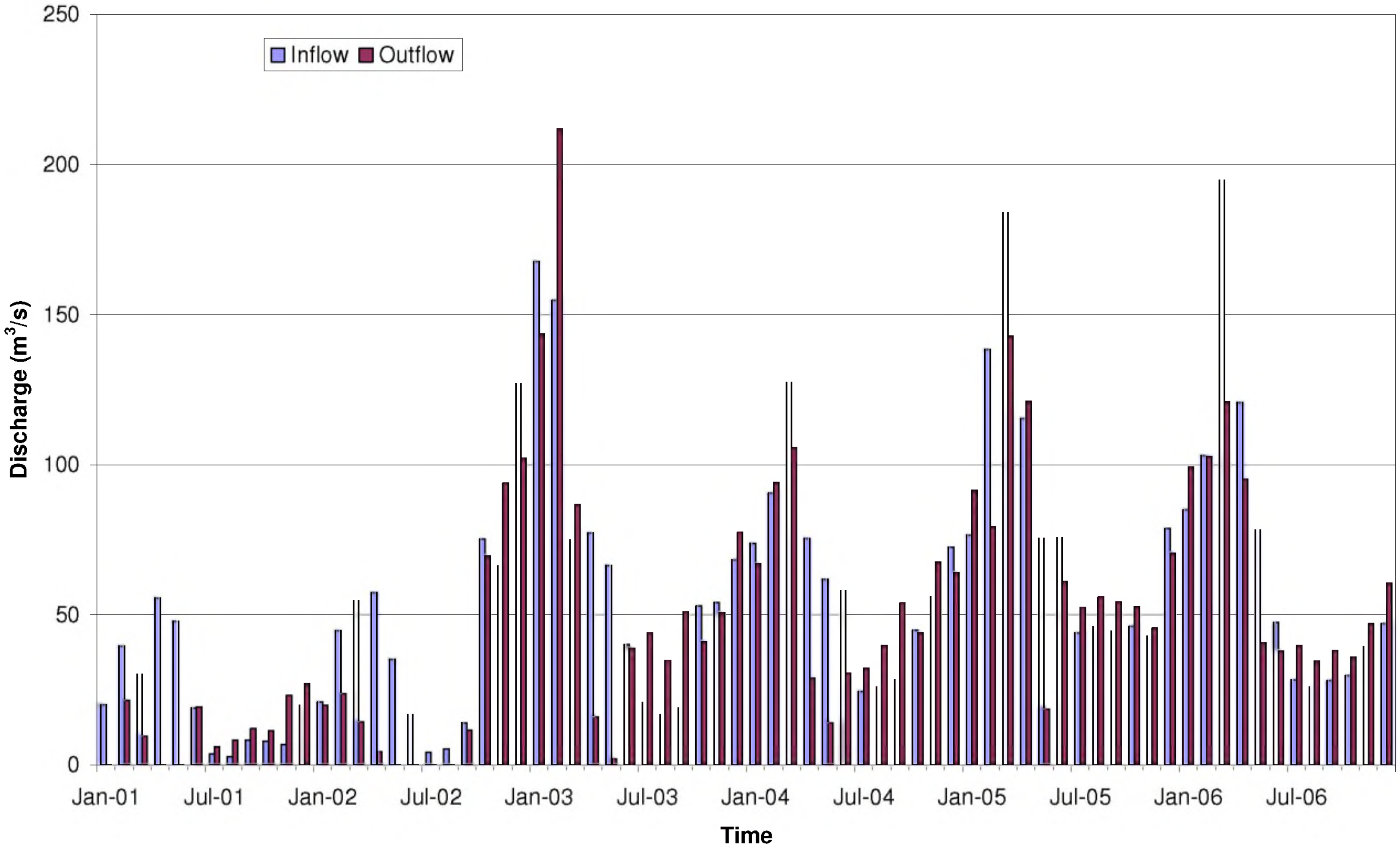


Diagram 3.2. Simulated inflow-outflow discharge at Lake Kerkini

3.3.2. Estimation of pollution loads in sub-catchments

As have been mentioned in section 3.2.3, the concentration of runoff in nutrients (BOD_5, NH_4, NO_3 and PO4), from Rainfall-Runoff model, assumed to be equal with the observed in the corresponded tributaries of Strymonas/Struma River. Since, there were not available observations for all the tributaries/catchments, a scale factor applied as a calibration parameter. The initial estimation of this factor was based on the gauged catchment area and the area of catchments in the vicinity without observations. The final (calibrated) values of scale factor were determined from the graphical evaluation of model results in comparison with observations of solute concentration in Strymonas/Struma River. In Table 3.3 are given the catchments that used as inflow of nutrients concentration and the final values of the scale factor. The simulated concentration of nutrients compared to the observed is shown in Annexes III and IV for monitoring stations located in Bulgaria and Greece, respectively.

Table 3.3. Inflow of nutrients concentration from catchments

Catchments	**Surface area (km^2)**	**Surface area used at water quality model (km^2)**	**Scale factor** (calibration parameter)
DRAGOVISHTITSA	819	2072	2.5
DZHERMAN	757	2499	3.3
STRUMESHNITSA	2077	3319	1.6
AGGITIS_GR	2234	2234	1.0
STRYMON_GR	2728	3538	1.3

3.3.3. Presentation of results in MIKE VIEW

Available results from model regarding Strymonas/Struma River simulation concern the following parameters:

- Discharge
- Water level (or depth)
- Water quality parameters' concentration (BOD_5, NH_4, NO_3, PO_4)

These parameters are available at the computational points along river and for every time step of simulation. The manipulation of these parameters/results can be achieved with MIKE VIEW software. In Fig. 3.5 is shown a sample of available results for Strymonas/Struma River.

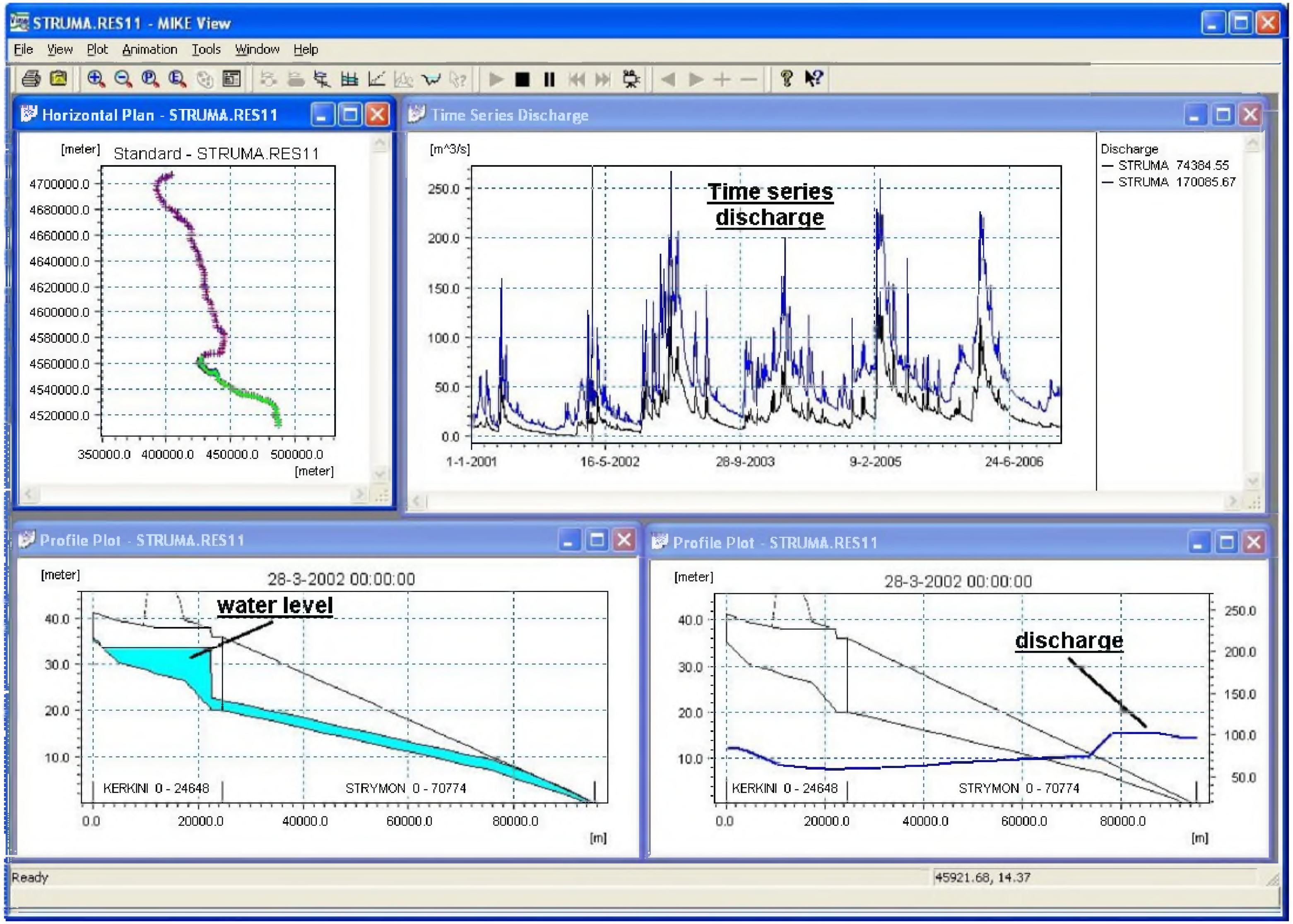


Figure 3.5. Results at Struma/Strymonas River in MIKE VIEW

4. Assessment of the status of surface water and correlation of the simulation results with Directive EU/2000/60

4.1. Water quantity evaluation

Strymonas/Struma River has enough water to cover the water demands of the current activities in its basin. To this direction Lake Kerkini plays a fundamental role by supplying with water the irrigation networks at the plain area of the basin during summer, where discharge in the River is low. Furthermore, the lake offers protection against floods to the downstream areas where high peaks of discharge are quite often in Strymonas/Struma River.

However, both Strymonas/Struma River and Lake Kerkini are subject to pressures under the current water management in the catchment. Downstream to Lake Kerkini, the water regime of Strymonas/Struma River is affected by the released water quantities from the lake, which are closely related to the irrigation networks' demands. As a result, the water quantity that ends up to the estuaries of Strymonas/Struma River is not the appropriate to support its "ecological demands". Furthermore, the seasonal fluctuation of water in the lake has resulted to the severe degradation of its ecosystem (Gerakis et al., 2007).

With the previous thoughts in mind and using the numerical model that has been developed for Strymonas/Struma River basin, it will be tried to examine the importance of pressures, from a water quantity point of view, in Strymonas/Struma River estuary and in Lake Kerkini.

Water flow regime at the estuary of Strymonas/Struma River

The estimation of Environmental Flow Requirements or more simply, Minimum Ecological Discharge, in a river is not a trivial work. Several tries have been done to give general directions and instructions for a feasible and scientific way in order to estimate the minimum ecological discharge (Tennant 1976, Dunbar et al. 1998, Dyson et al. 2003), either along the river or at the estuary of it. Methods that used to estimate the minimum discharge fall into five basic categories; hydrological, hydraulic, habitat simulation, holistic and methods focused to specific features of the ecosystems. However, different climatic and morphological characteristics prevent to apply a general rule for the quantification of minimum discharge for every river.

Gerakis et al. (2007) study the significant rivers in Macedonia and Thrace regions of Greece and conclude to estimate the minimum ecological discharge at their estuaries. Specifically for Strymonas/Struma River, after the processing of discharge data for years 1982-1989, both simulated and observed data, they propose that the minimum ecological discharge at the estuary of the River should be variable from month to month and around the order of 40 to 60 m^3/s for the months of February through June, being reduced to a discharge around the order of 30 m^3/s for the remaining period.

In Diagram 4.1 is shown the simulated discharge at the estuary of Strymonas/Struma River, based on the numerical model that has been presented in previous paragraphs where the water demands in the catchment are completely met. Additionally, is also shown the simulated discharge at the hypothetical case where the water demands are not met and furthermore the Lake Kerkini is not included in the simulation. At the same diagram is also shown the minimum ecological discharge, as has been estimated by Gerakis et al. (2007). During the dry years 2001 and 2002, the simulated discharge (water demands are met) is significant below the ecological discharge and furthermore is close to zero ("dry river") at summer 2002. On the other hand, the simulated discharge in the case where the water demands are not met is very close to the ecological discharge. During the normal and wet years 2003-2006, the values of simulated discharge (water demands are met) are higher than ecological discharge for almost all months and "ecological deficit" is mainly appeared only during April and May, as it is depicted also in Diagram 4.2.

Water level at Lake Kerkini

Lake Kerkini was initially constructed to control floodwater of Strymonas/Struma River, and later to serve as reservoir for irrigation purposes. According to Gerakis et al. (2007), after the creation of the new dam in 1982, have been recorded changes in the primary habitat and impacts on the fauna of the region. Principal measures that need to be taken are to control the minimum water level of the lake at 32 m (a.m.s.l.) and the maximum to no more than 35 m (a.m.s.l.). In Diagram 4.3 is shown the simulated water level fluctuation compared with minimum and maximum ecological values. As it can be seen water level in the lake fluctuates beyond the ecological limits and varies mainly from 31 m to 31.5 m during autumn-winter to usually more than 36 m during spring.

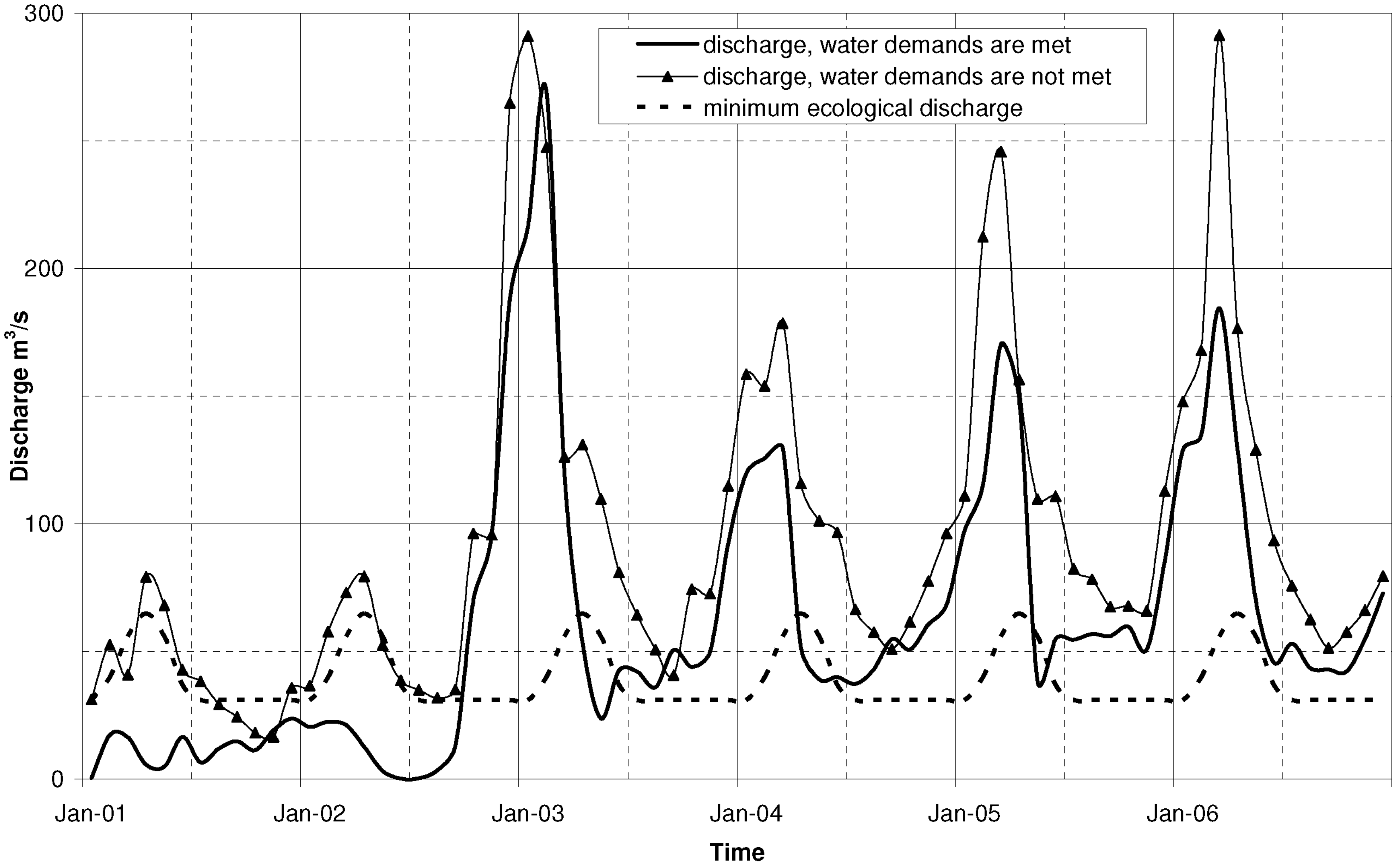


Diagram 4.1. Simulated discharge at Strymonas/Struma River estuary compared with minimum ecological discharge from Gerakis et al. (2007)

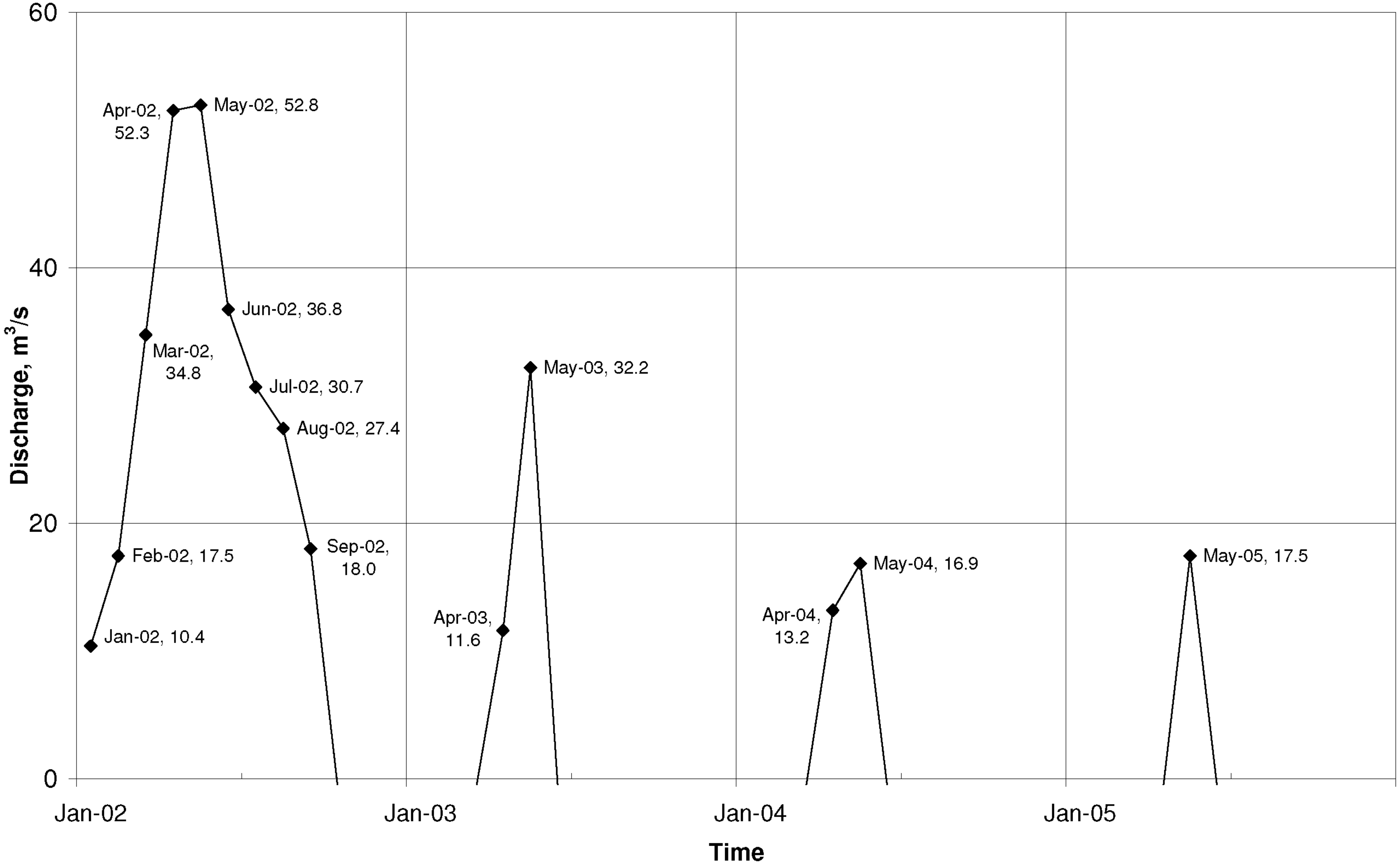


Diagram 4.2. "Ecological deficit" of discharge at Strymonas/Struma River estuary

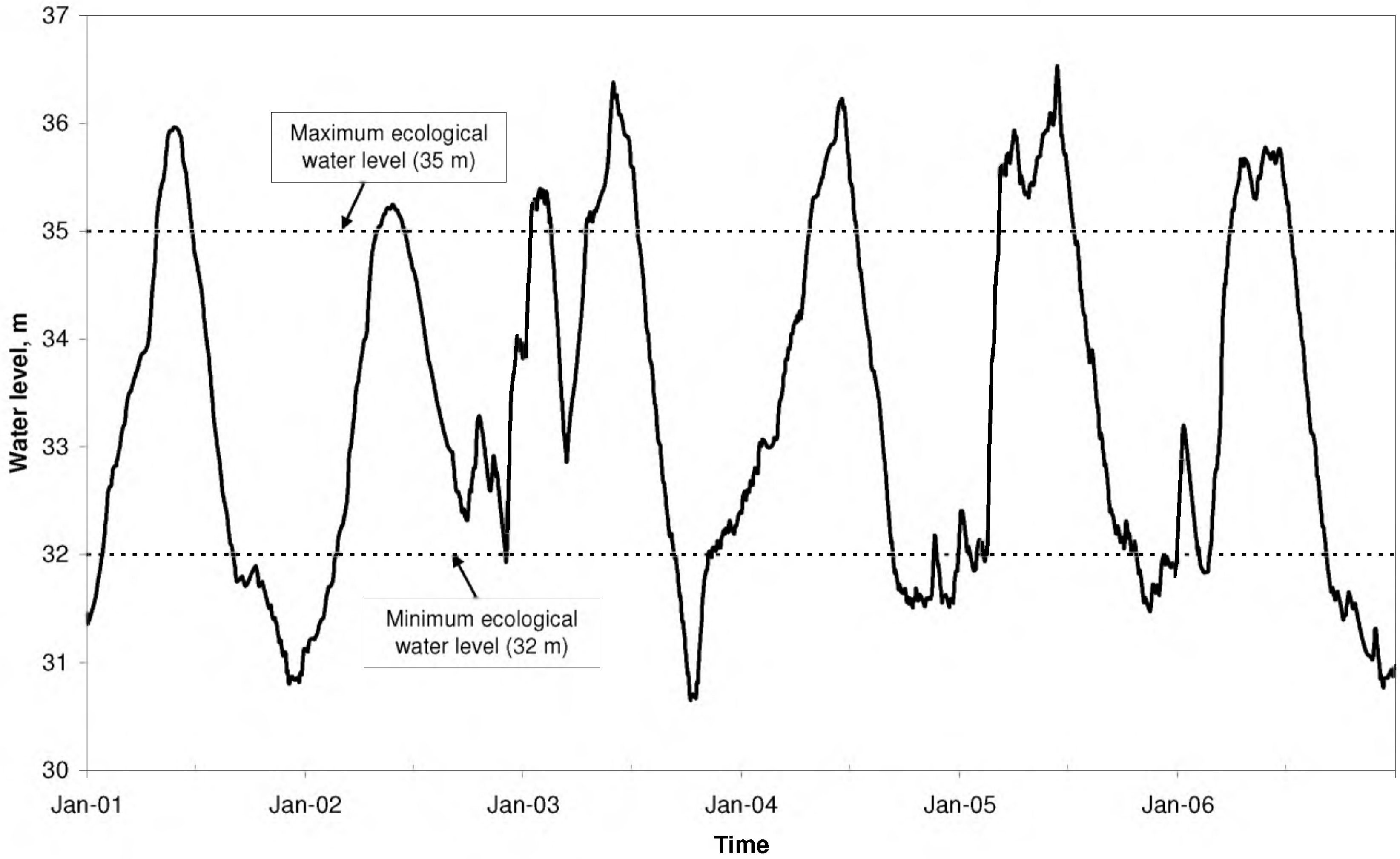


Diagram 4.3. Simulated water level at Lake Kerkini compared with minimum and maximum ecological water levels from Gerakis et al. (2007)

4.2. Water quality evaluation

Quality of water is sometimes an underestimated factor in followed practices of water resources management. This happens due to a lot of reasons, such as difficulties to monitor concentration of chemical or biological substances, the large number of substances that have to be studied and, in some cases, the partial knowledge of the exact mechanisms that drives the transformation, absorption, adsorption and movement of a specific substance. However, it is essential to monitor the quality of water and in cases where the concentration of substances is above specific levels, it has to be tried, even usually not easy, to infer the reasons for that.

At Directive 2000/60/EC, which establishes a framework for Community action in the field of water policy, is mentioned relevant legislation, which gives the Highest Desirable Level (HDL) and the Maximum Permissible Level (MPL) for a number of specific substances. These levels are different depending on the purpose water is used, such as for domestic water supply or to be the habitat for different species of fishes. In Table 4.1 are given the HDL and MPL for a number of water quality parameters.

Table 4.1. Highest Desirable Level (HDL) and the Maximum Permissible Level (MPL) of water quality parameters according to 2000/60/EU

Water quality parameters	**Water Supply, 75/440**		**Fishes, 2006/44/EK, 78/659**			
			Salmonid		**Cyprinid**	
	HDL	MPL	HDL	MPL	HDL	MPL
BOD_5, mg/l	3	7	3		6	
DO, %	>70	>30				
DO, mg/l			>9	>7	>7	>5
NO_3, mg/l	25	50				
NH_4, mg/l	0.05	4	0.04	1	0.2	1
NO_2, mg/l			0.01		0.03	
P_2O_5, mg/l	0.4	0.7				
PO_4, mg/l			0.2		0.4	
T water, ^oC	22	25	10.0-21.5		10.0-28.0	
Conductivity μS/cm	1000					
pH	6.5-8.5	5.5-9.0	6.0-9.0		6.0-9.0	

In Diagrams 4.4-4.7 are shown the simulated water quality parameters at three monitoring stations and in Table 4.2 are given the average and the maximum values of the parameters. Station 5124 is located to Strymonas/Struma River close to border between Bulgaria and Greece, station 3 is located in the middle of Lake Kerkini and station 16 is located a couple of kilometres before Strymonas/Struma River estuary (see also relevant map in Part I).

Table 4.2. Concentration of water quality parameters in Strymonas/Struma River basin

Simulated water quality parameters	**Station codes**					
	5124		**3**		**16**	
	average	maximum	average	maximum	average	maximum
BOD_5, mg/l	3.2	10.3	2.6	4.5	1.4	3.8
NH_4, mg/l	0.5	1.5	0.3	1.1	0.3	1.5
NO_3, mg/l	1.1	1.9	0.9	1.4	6.4	18.1
PO_4, mg/l	0.5	1.1	0.4	0.8	0.5	0.9

Concentration of BOD_5 (Diagram 4.4) is decreasing along the river from upstream to downstream and in station 5124 is usually higher than Highest Desirable Level (HDL), while sometimes is also higher than Maximum Permissible Level (MPL) for water supply. This is probably happen due to domestic and industrial activities in Bulgaria.

NH_4 (Diagram 4.5) is always higher than HDL, for water supply and salmonid, and enough times is higher that MPL for fishes, but not for water supply.

NO_3 (Diagram 4.6) is always lower than HDL and MPL, but is significant higher in station 16 compared to the other two stations. This has to be related with the intensive agricultural activities at the plain of catchment in Greece.

PO_4 (Diagram 4.7) is always higher than HDL and often is also higher than MPL. This is happen to all stations but values are higher in station 5124 compared to the other two stations. This is probably related to a combination of all manmade activities.

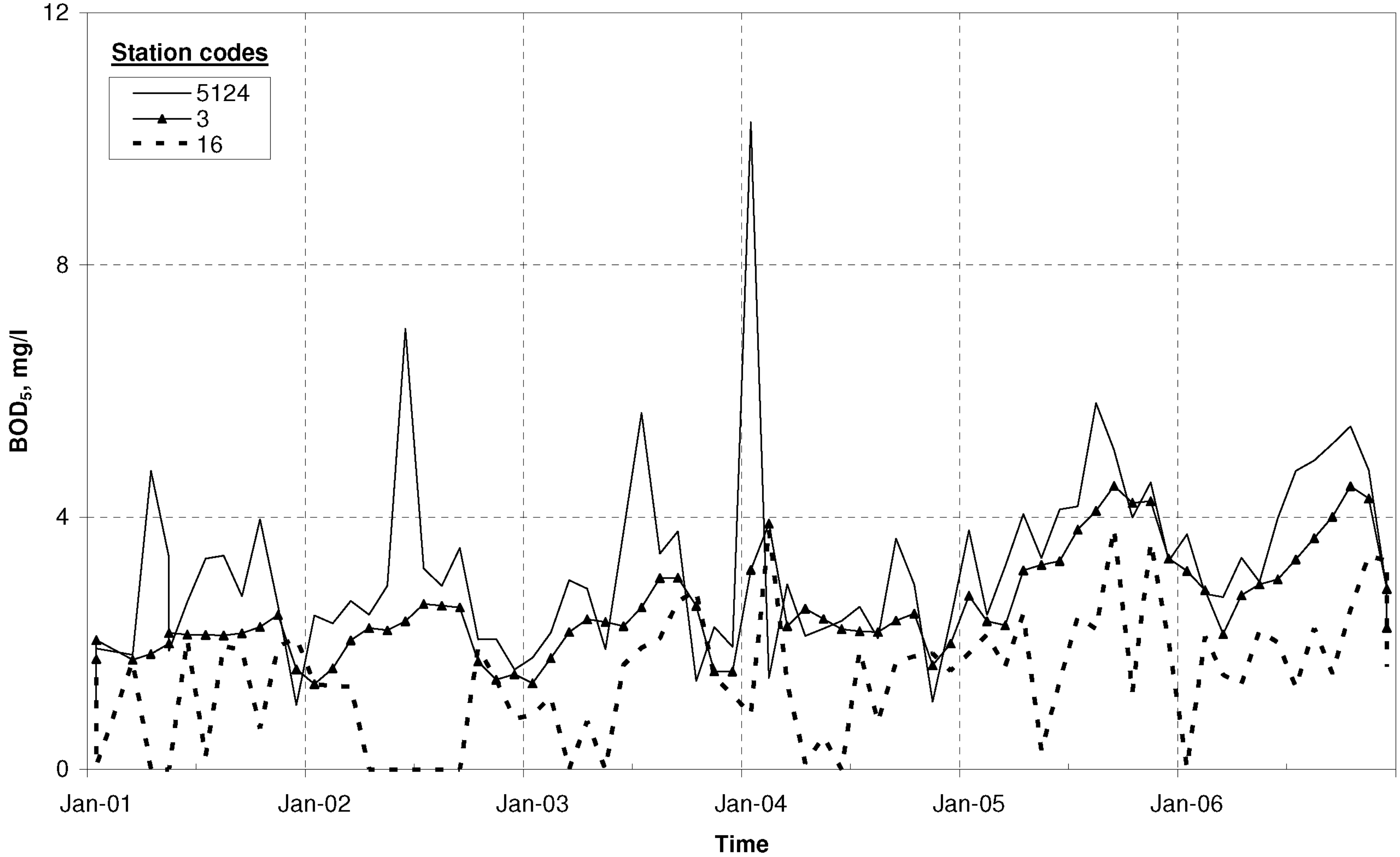


Diagram 4.4. Simulated concentration of BOD_5 along Strymonas/Struma River

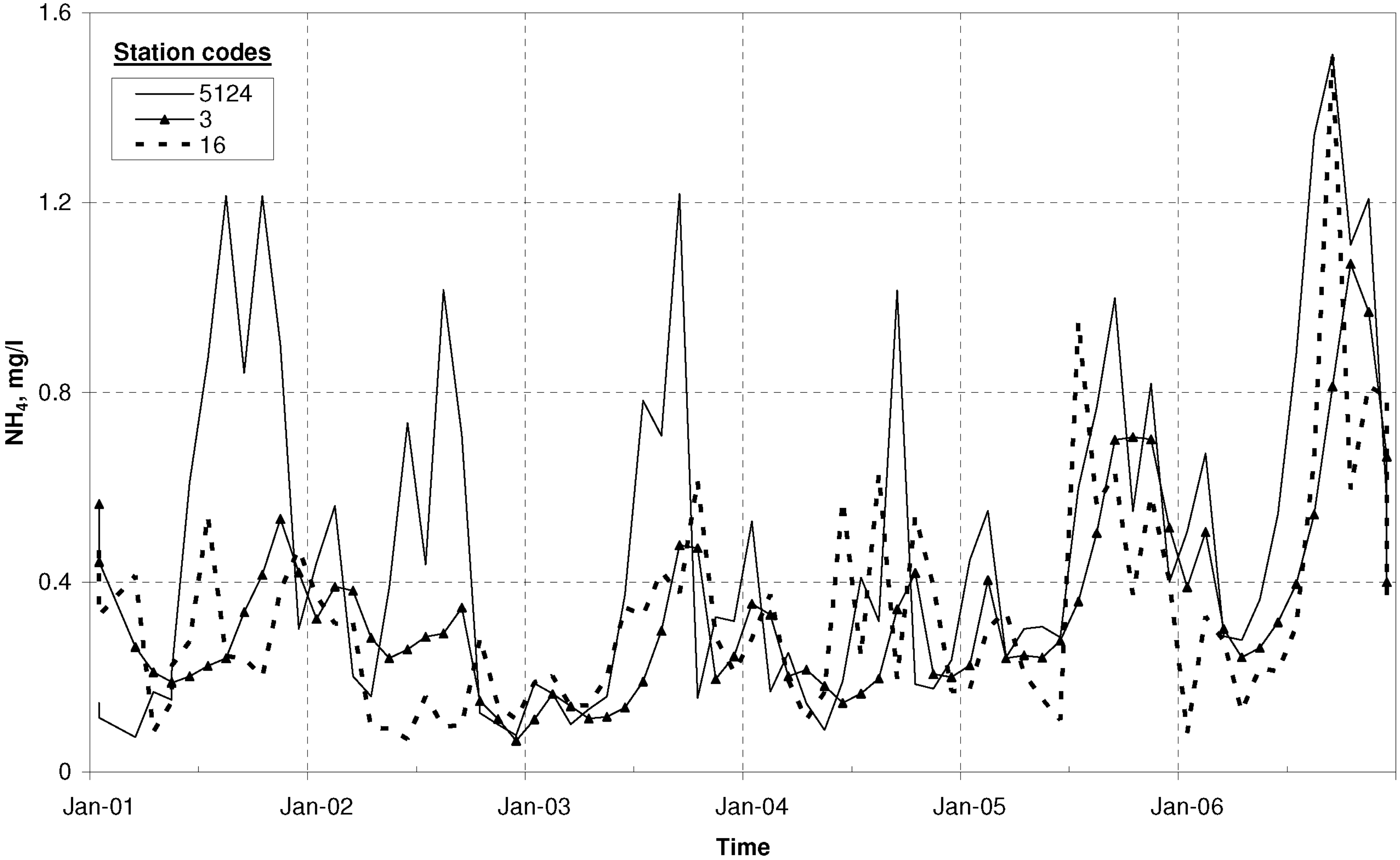


Diagram 4.5. Simulated concentration of NH_4 along Strymonas/Struma River

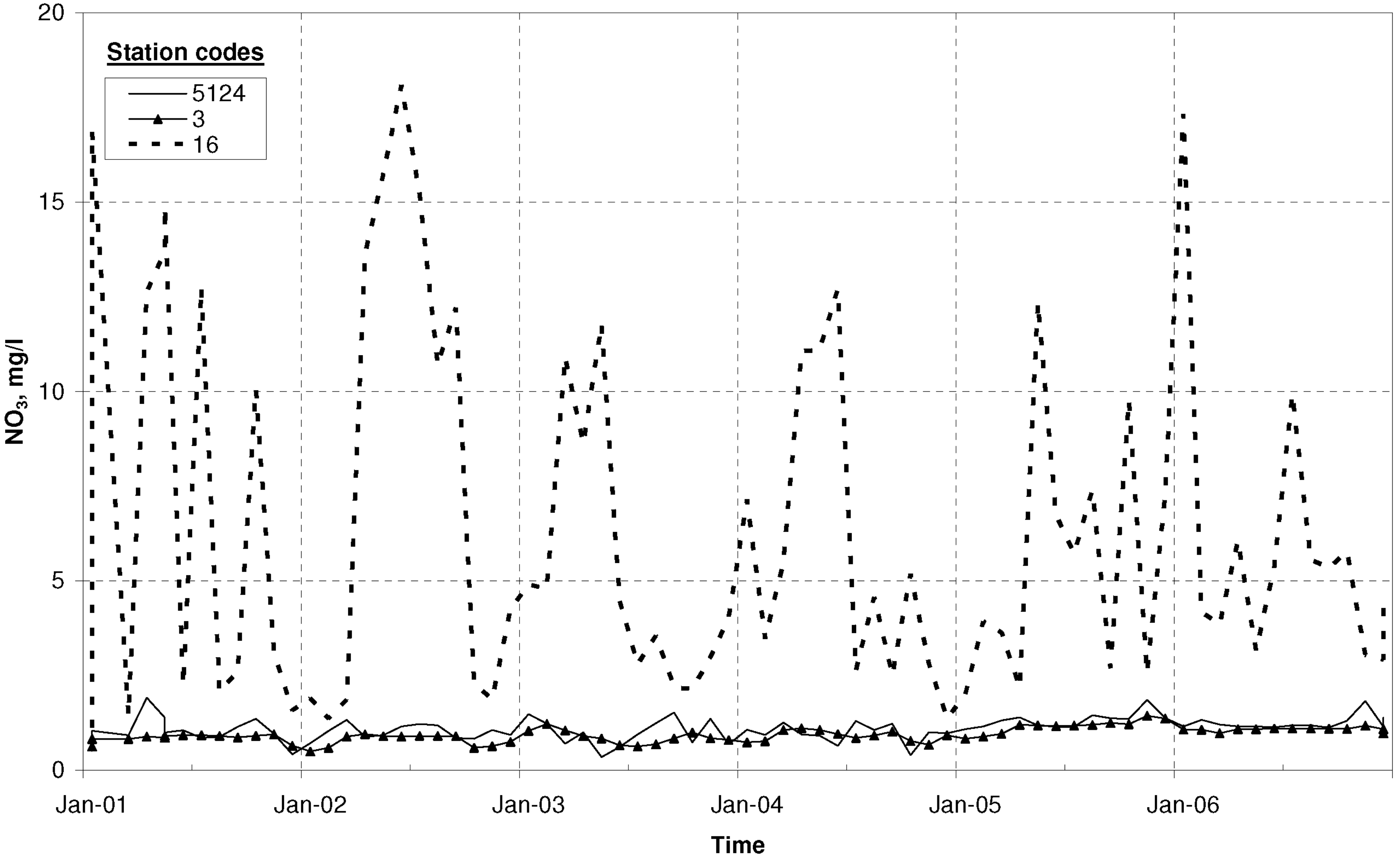


Diagram 4.6. Simulated concentration of NO_3 along Strymonas/Struma River

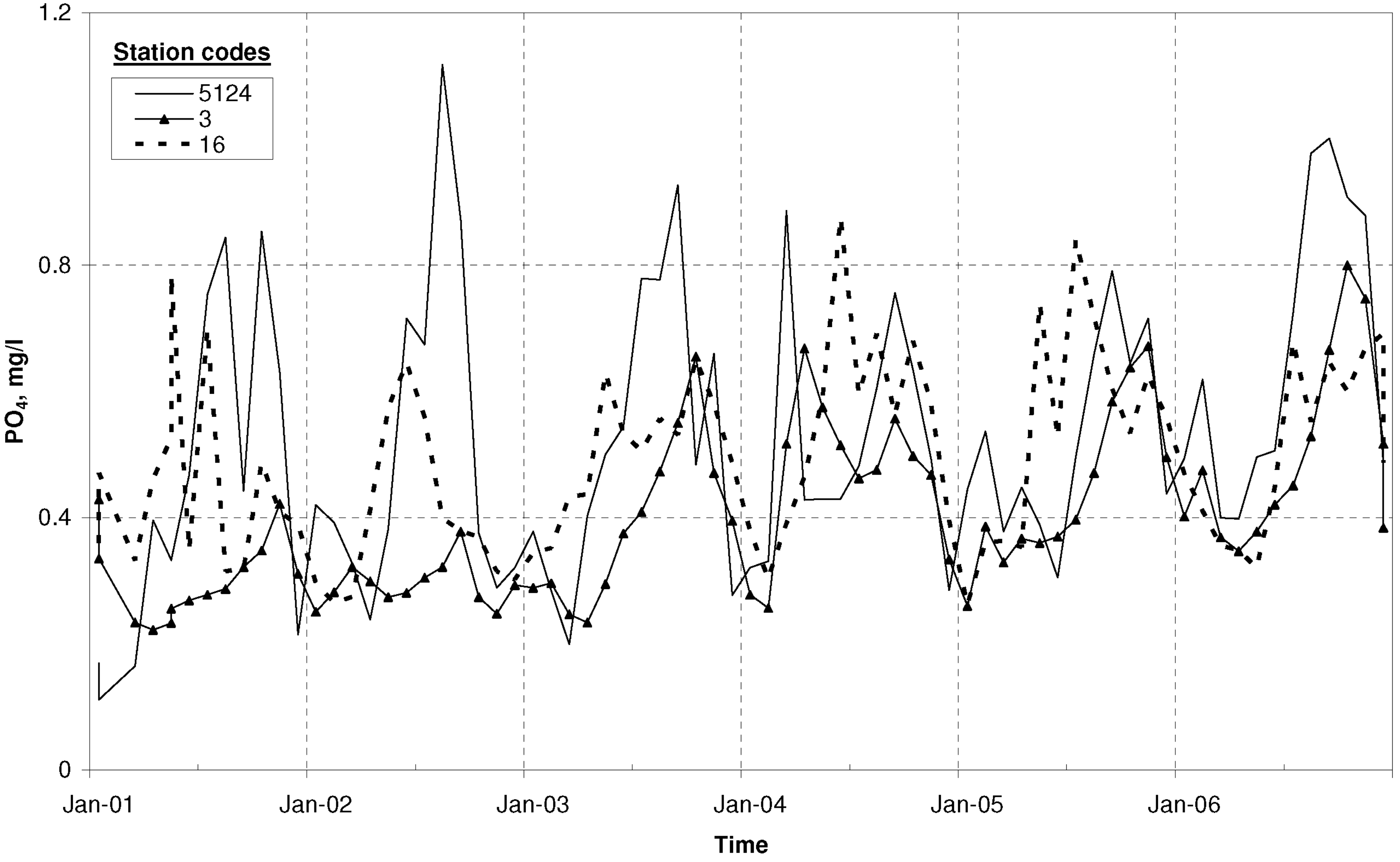


Diagram 4.7. Simulated concentration of PO_4 along Strymonas/Struma River

4.3. Discussion - proposed measures

Water demands in Strymonas/Struma River basin are generally met in most of the hydrological years. Lake Kerkini in Greece and a large number of small reservoirs in Bulgaria are playing an important role to this direction. However, the environmental objectives are not fully achieved, especially in dry hydrological years. The discharge that ends up in Strymonas/Struma River estuary and the fluctuation in Lake Kerkini are not always the desirable ones.

These two environmental aspects, regarding Lake Kerkini and the river estuary, have to be addressed in combination, taking also simultaneously into account the irrigation demands in the plain area of the catchment in Greece. To this direction, more numerical experiments, which are out of the scope of this project, can be performed to inquire efficiently the different alternative solutions, both for normal and dry hydrological years.

As far as the quality of water in Strymonas/Struma River concerns, it should be pointed out that there is a high concentration of BOD_5 and PO_4. BOD_5 is above all standard levels, especially in the Bulgarian part of the catchment. Concentration of PO_4 also appears in high values, both in the Bulgarian and the Greek part of the catchment. A partial alleviation of these problems should be a reconsideration of the system for sewage treatment in the Bulgarian part of the catchment, probably both for domestic and industrial wastes. Furthermore, runoff from agricultural wastes in the Greek part of the catchment probably should be controlled more efficiently.

Another thing that has to be mentioned is the increase of NO_3 along the Strymonas/Struma River. Concentration of NO_3 is always lower than all standard levels, but there is a worrying increase in the Greek part of the catchment, mainly due to intensive agricultural activities. One measure to control this would be to decrease the amount of fertilizers by cultivating crops which are less demanding in fertilizers. Also, the occasionally low water flow downstream to Lake Kerkini is additionally responsible for the higher values of NO_3.

Concluding, it has to be said that the proposed measures presented previously are closely related to the results of the simulation that has been performed during the current project. Other references to specific problems (e.g. illuviation of Lake Kerkini, high concentrations of other substances) and related measures can be found from relevant studies.

5. Bibliography

Chow, V.T, 1964. Handbook of applied hydrology. Mc Graw-Hill New York, N.Y. USA.

Doulgeris, Ch., Papadimos D. and Katsavouni S., 2007. Development of water resources management model. Application to current situation – Water district of East Macedonia (Vol. 4) in the framework of the project "Development of hydroinformatic systems and tools for water resources management in water districts of West Macedonia, Central Macedonia, East Macedonia and Thrace". Greek Ministry of Development, ENM – EKBY – DHI. 96 p (in Greek).

Dunbar, M.J., A. Gustaritd, M.C. Acreman and C.R.N. Elliot. 1998. Overseas approaches to setting River Flow Objectives. Bristol Environmental Agency W6-161.

Dyson, M., G. Bergkamp and J. Scanion. 2003. Flow: essentials of environmental flows. IUCN, Gland, Switzerland and Cambridge, UK. 118 p.

Gerakis, P.A., S. Tsiouris and Vassiliki Tsiaousi (Editors), 2007. Water regime and biota: proposed minimum values of lakes water level and of rivers discharge in Macedonia and Thrace, Greece. The Goulandris Natural History Museum/Greek Biotope-Wetland Centre (EKBY). Thermi, Greece. 256 p. (in Greek, summary in English).

Halkidis, I. and D. Papadimos (Editors), 2007. Technical report of LIFE Environment project: Ecosystem Based Water Resources management to Minimize Environmental Impacts from Agriculture using State-of-the-Art Modeling Tools in Strymonas Basin. Greek Biotope/Wetland Centre (EKBY). Thermi, Greece. 117 p. (in Greek, summary in English).

Henriksen H.J., Troldborg L., Nyegaard P., Sonnenborg T. O., Refsgaard J. C. and Madsen B., 2003. Methodology for construction, calibration and validation of a national hydrological model for Denmark. J. Hydrology, 280:52-71.

Mertzianis, Ch. 1994. Study Case of Flood Waves at Strymonas River. M.Sc. thesis. School of Agriculture, Aristotle University of Thessaloniki. 133 p. (in Greek).

MIKE 11, 2007. A Modelling System for Rivers and Channels. Reference manual. Danish Hydraulic Institute, Denmark, pp. 516.

Psilovikos, A., A. Almpanakis and E. Papafilipou-Penou. 1992. Research of Lake Kerkini's and Strymonas River bands illuviation problem and deal with proposals. Research committee of Aristotle University Thessaloniki. 205 p. (in Greek).

Tenant, D.L. 1976. Instream flow regimes for fish, wildlife, recreation and related environmental resources. Fisheries 1: 6-10.

Table 1. Monthly precipitation data in the Bulgarian territory of Strymonas/Struma River basin

TSID 100 - Boboshevo-62500 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	33	30	50	18	31	30	15	7	37	3	7	6	22	3	50	266
2001	40	21	16	110	22	26	13	18	28	2	32	55	32	2	110	383
2002	16	12	66	56	54	49	70	40	110	73	40	53	53	12	110	637
2003	79	22	2	53	89	56	36	23	20	125	51	42	50	2	125	597
2004	25	30	53	14	39	102	42	17	56	36	69	54	45	14	102	537
2005	57	83	33	60	50	91	68	102	32	30	39	55	58	30	102	700
2006	36	31	96	41	56	41	12	54	15	45	59	37	44	12	96	523
Mean	41	33	45	50	49	56	37	37	42	45	42	43	43			
Min	16	12	2	14	22	26	12	7	15	2	7	6		2		
Max	79	83	96	110	89	102	70	102	110	125	69	55			125	
													Mean yearly precipitation value:			**520**

TSID 98 - Dolene-61690 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	29	81	47	48	75	84	37	28	11	48	16	17	43	11	84	519
2001	95	53	51	172	114	52	22	73	80	4	21	86	69	4	172	820
2002	32	8	94	67	79	45	148	46	128	103	82	184	85	8	184	1013
2003	87	44	1	45	165	96	97	56	32	133	55	141	79	1	165	949
2004	62	16	34	64	66	205	55	16	79	0	0	0	50	0	205	595
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	61	40	45	79	100	96	72	44	66	72	44	107	69			
Min	29	8	1	45	66	45	22	16	11	4	16	17		0		
Max	95	81	94	172	165	205	148	73	128	133	82	184			205	
													Mean yearly precipitation value:			**825**

TSID 103 - Dren-63490 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	44	45	43	34	26	32	14	5	57	0	18	7	27	0	57	323
2001	28	41	39	118	53	54	31	26	72	12	45	66	49	12	118	585
2002	20	14	93	57	67	101	64	114	89	67	20	20	60	14	114	726
2003	112	22	2	52	108	79	10	36	15	153	54	31	56	2	153	672
2004	22	17	60	28	63	92	55	36	66	55	83	49	52	17	92	627
2005	67	74	45	41	91	83	57	199	59	42	22	76	71	22	199	856
2006	33	22	76	49	45	84	42	51	21	31	45	21	43	21	84	520
Mean	47	34	51	54	65	75	39	67	54	52	41	38	51			
Min	20	14	2	28	26	32	10	5	15	0	18	7		0		
Max	112	74	93	118	108	101	64	199	89	153	83	76			199	
													Mean yearly precipitation value:			**616**

TSID 102 - Kalishta-63460 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	45	32	33	14	22	24	22	2	58	4	11	12	23	2	58	278
2001	37	27	20	144	33	32	32	42	65	6	35	39	43	6	144	511
2002	17	5	62	65	50	44	76	83	93	87	37	42	55	5	93	661
2003	94	17	3	25	87	27	21	15	13	118	37	33	41	3	118	488
2004	27	30	49	26	47	141	90	37	69	47	77	49	57	26	141	689
2005	90	75	45	43	82	89	70	148	47	50	23	49	68	23	148	813
2006	23	36	80	50	48	80	18	99	26	58	37	33	49	18	99	587
Mean	47	32	42	52	53	62	47	61	53	53	37	36	48			
Min	17	5	3	14	22	24	18	2	13	4	11	12		2		
Max	94	75	80	144	87	141	90	148	93	118	77	49			148	
													Mean yearly precipitation value:			**575**

TSID 96 - Krupnic-61360 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	39	42	32	6	6	15	14	0	15	6	12	21	17	0	42	208
2001	37	37	22	96	44	68	55	43	25	2	38	64	44	2	96	531
2002	18	8	78	43	64	31	94	32	67	71	48	105	55	8	105	658
2003	71	55	0	41	83	41	14	29	10	114	60	69	49	0	114	586
2004	47	17	60	24	39	0	57	24	0	0	0	0		0	60	268
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	42	32	38	42	47	39	47	26	29	48	40	65	41			
Min	0	0	0	0	0	0	0	0	0	0	0	0		0		
Max	71	55	78	96	83	68	94	43	67	114	60	105			114	
													Mean yearly precipitation value:			**496**

TSID 97 - Melnik-61670 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	50	53	31	21	31	40	11	6	22	25	1	3	24	1	53	294
2001	54	23	23	118	56	53	18	38	58	4	33	72	46	4	118	549
2002	7	5	68	60	58	32	81	28	97	78	66	130	59	5	130	708
2003	80	21	0	61	122	67	48	15	23	118	44	79	56	0	122	676
2004	51	17	59	35	49	86	16	23	125	68	39	90	55	16	125	655
2005	58	64	42	24	56	50	47	80	92	39	38	142	61	24	142	729
2006	57	32	75	49	57	45	57	58	32	48	74	32	51	32	75	617
Mean	51	31	42	53	61	53	40	35	64	54	42	78	50			
Min	7	5	0	21	31	32	11	6	22	4	1	3		0		
Max	80	64	75	118	122	86	81	80	125	118	74	142			142	
													Mean yearly precipitation value:			**604**

TSID 99 - Rakovo-62480 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	34	29	35	26	38	33	20	9	29	17	25	11	26	9	38	306
2001	55	35	17	79	22	56	59	100	40	0	38	71	48	0	100	571
2002	23	9	60	85	69	47	91	98	171	108	42	95	75	9	171	897
2003	121	32	0	49	80	83	62	86	16	181	46	65	68	0	181	821
2004	59	27	56	55	35	138	94	65	63	45	95	66	66	27	138	798
2005	60	88	49	53	42	64	62	130	19	41	49	112	64	19	130	767
2006	38	55	89	59	67	54	23	75	27	57	45	45	53	23	89	635
Mean	56	39	43	58	50	68	59	81	52	64	48	66	57			
Min	23	9	0	26	22	33	20	9	16	0	25	11		0		
Max	121	88	89	85	80	138	94	130	171	181	95	112			181	
													Mean yearly precipitation value:			**685**

TSID 101 - Rilski manastir-62540 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	83	61	59	107	26	59	4	15	17	2	22	14	39	2	107	471
2001	60	60	47	159	60	63	28	89	62	12	62	75	65	12	159	778
2002	17	18	97	122	96	57	97	130	157	100	71	66	86	17	157	1028
2003	119	32	5	72	116	44	50	68	37	260	49	63	76	5	260	914
2004	104	81	58	52	131	119	65	33	55	60	80	71	76	33	131	909
2005	85	120	109	63	141	89	149	123	62	30	72	132	98	30	149	1176
2006	45	63	117	111	58	86	36	65	44	37	68	82	68	36	117	810
Mean	73	62	70	98	90	74	61	75	62	72	61	72	72			
Min	17	18	5	52	26	44	4	15	17	2	22	14		2		
Max	119	120	117	159	141	119	149	130	157	260	80	132			260	
													Mean yearly precipitation value:			**869**

Table 2. Monthly precipitation data in the Hellenic territory of Strymonas/Struma River basin

TSID 85 - Aidonoxori [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000																
2001	48	30	58	68	37	24	37	12	3	0	8	15	28	0	68	340
2002	25	10	89	37	4	63	61	9	114	70	207	457	95	4	457	1145
2003	68	17	5	70	54	5	12	37	39	77	25	237	54	5	237	646
2004	70	18	26	17	21	20	0	55	26	16	70	52	33	0	70	392
2005	14	43	21	1	35	19	16	36	88	32	2	49	30	1	88	355
2006	53	79	89	14	19	41	50	10	95	113	20	32	51	10	113	614
Mean	46	33	48	34	28	29	29	27	61	51	55	140	48			
Min	14	10	5	1	4	5	0	9	3	0	2	15		0		
Max	70	79	89	70	54	63	61	55	114	113	207	457			457	
													Mean yearly precipitation value:			**582**

TSID 86 - ALISTRATI2001 [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000																
2001	62	37	48	69	55	34	108	35	0	0	29	25	42	0	108	503
2002	26	13	125	59	27	72	155	39	99	60	111	193	82	13	193	979
2003	39	7	7	36	89	35	84	15	48	101	72	161	58	7	161	694
2004	45	8	46	51	57	77	19	39	34	30	47	122	48	8	122	576
2005	87	72	77	18	71	48	56	84	132	4	75	72	67	4	132	798
2006	68	83	80	23	97	80	79	23	85	69	36	52	65	23	97	776
Mean	55	37	64	43	66	58	84	39	66	44	61	104	60			
Min	26	7	7	18	27	34	19	15	0	0	29	25		0		
Max	87	83	125	69	97	80	155	84	132	101	111	193			193	
													Mean yearly precipitation value:			**721**

TSID 88 - Nigrita [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	6	32	3	25	25	13	15	0	12	106	143	17	33	0	143	397
2001	56	15	22	58	46	32	4	14	0	0	8	0	21	0	58	255
2002	4	9	46	36	7	51	74	15	71	84	58	244	49	15	241	699
2003	51	6	7	22	49	55	21	36	25	68	49	87	39	6	87	474
2004	51	12	16	31	78	39	3	40	16	10	47	69	34	3	78	410
2005	38	46	52	13	38	7	40	14	64	0	48	34	33	0	64	392
2006	84	31	40	10	44	92	14	15	31	171	43		52	10	171	574
Mean	41	21	27	28	41	41	14	13	31	62	57	75	38			
Min	4	6	3	10	7	7	2	-26	0	0	8	0		-26		
Max	84	46	52	58	78	92	40	40	72	171	143	241			241	
													Mean yearly precipitation value:			**457**

TSID 89 - Orini [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000																
2001	37	28	32	74	66	83	6	100	44	0	15	28	43	0	100	512
2002	29	29	183	0	0	0	0	6	150	53	78	122	54	0	183	648
2003	70	10	1	27	82	70	85	22	28	77	45	115	53	1	115	630
2004	54	9	38	34	76	128	18	29	125	32	44	92	56	9	128	676
2005	54	77	72	33	83	32	48	65	130	0	87	52	61	0	130	732
2006	34	30	65	63	35	93	48	7	78	65	56	45	51	7	93	617
Mean	46	30	65	38	57	67	34	38	92	38	54	76	53			
Min	29	9	1	0	0	0	0	6	28	0	15	28		0		
Max	70	77	183	74	83	128	85	100	150	77	87	122			183	
													Mean yearly precipitation value:			**636**

TSID 90 - Poroia [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	55	76	35	19	42	41	32	0	5	42	11	15	31	0	76	372
2001	95	40	29	100	72	32	9	18	18	0	41	181	53	0	181	635
2002	33	11	62	67	25	53	96	26	148	70	96	204	74	11	204	893
2003	104	19	0	30	133	47	46	23	27	105	68	93	58	0	133	696
2004	39	12	43	46	49	165	17	7	108	83	92	88	62	7	165	748
2005	53	72	44	13	70	40	10	114	130	4	74	10	53	4	130	632
2006	19	70	103	40	38	98	41	53	48	117	75		64	19	117	702
Mean	57	43	45	45	61	68	36	34	69	60	65	99	57			
Min	19	11	0	13	25	32	9	0	5	0	11	10		0		
Max	104	76	103	100	133	165	96	114	148	117	96	204			204	
													Mean yearly precipitation value:			**668**

TSID 91 - Serres [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	7.2	27	9.3	54.7	32.8	59.2	11.1	1.2	12.1	56.8	6.8	1.1	23	1	59	279
2001	53	26	29	46	51	10	46	31	17	0	20	9	28	0	53	338
2002	20	14	70	75	28	90	61	35	94	47	70	199	67	14	199	803
2003	63	3	2	26	56	39	11	7	11	83	38	108	37	2	108	448
2004	53	14	38	58	94	90	16	21	42	19	30	52	44	14	94	527
2005	51	60	46	27	58	57	44	43	117	4	69	50	52	4	117	623
2006	53	67	76	24	51	93	35	51	72	47	93	51	59	24	93	711
Mean	49	31	43	43	56	63	35	31	59	33	53	78	48			
Min	20	3	2	24	28	10	11	7	11	0	20	9		0		
Max	63	67	76	75	94	93	61	51	117	83	93	199			199	
													Mean yearly precipitation value:			**533**

TSID 92 - Sidirokastro [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	6	36	17	37	16	13	15	3	14	44	5	0	17	0	44	205
2001	50	21	26	87	62	15	8	40	38	0	10	24	32	0	87	380
2002	17	13	41	52	21	83	108	24	138	73	60	198	69	13	198	826
2003	60	5	0	14	84	16	23	10	33	62	47	60	34	0	84	412
2004	54	1	23	40	52	59	32	1	71	34	51	54	39	1	71	471
2005	51	47	26	26	60	27	21	36	113	10	65	42	44	10	113	523
2006	55	43	71	65	54	48	25	18	45	68	48		49	18	71	540
Mean	42	24	29	46	50	37	33	19	64	41	41	63	41			
Min	6	1	0	14	16	13	8	1	14	0	5	0		0		
Max	60	47	71	87	84	83	108	40	138	73	65	198			198	
													Mean yearly precipitation value:			**480**

TSID 84 - AHLADOHORI [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	0	44	32	24	46	43	14	21	1	20	10	14	22	0	46	270
2001	47	22	37	94	54	31	10	51	88	0	25	0	38	0	94	460
2002	4	15	61	57	40	85	63	36	128	59	77	105	61	4	128	730
2003	48	12	0	34	105	59	51	7	26	85	46	72	45	0	105	545
2004	45	19	39	26	59	78	21	17	60	18	90	61	45	17	90	535
2005	45	99	29	47	77	28	20	99	116	3	72	66	58	3	116	702
2006	27	33	70	83	33	74	61	26	42	51	34	61	48	26	83	595
Mean	31	35	38	52	59	57	34	37	66	34	51	53	46			
Min	0	12	0	24	33	28	10	7	1	0	10	0		0		
Max	48	99	70	94	105	85	63	99	128	85	90	105			128	
													Mean yearly precipitation value:			**548**

TSID 93 - Vrontou [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000																
2001	70	40	46	88	56	59	36	86	76	0	17	20	49	0	88	593
2002	0	7	69	63	76	81	128	41	97	90	98	161	76	0	161	910
2003	48	0	0	54	146	65	55	46	37	135	89	78	63	0	146	752
2004	34	5	21	64	80	76	31	152	52	66	68	77	60	5	152	726
2005	36	48	50	32	119	20	56	67	178	3	81	51	62	3	178	741
2006	50	31	101	98	40	86	74	24	53	99	25	29	59	24	101	710
Mean	40	22	48	67	86	64	63	69	82	65	63	69	62			
Min	0	0	0	32	40	20	31	24	37	0	17	20		0		
Max	70	48	101	98	146	86	128	152	178	135	98	161			178	
													Mean yearly precipitation value:			**739**

TSID 94 - Zihni [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000																
2001	43	8	53	43	58	13	21	30	24	0	25	43	30	0	58	362
2002	24	13	100	55	6	65	28	50	64	60	106	178	62	6	178	747
2003	72	8	18	32	105	64	48	0	17	80	48	123	51	0	123	615
2004	53	14	38	58	94	90	16	21	42	19	30	52	44	14	94	527
2005	51	60	46	27	58	57	44	43	117	4	69	50	52	4	117	623
2006	53	67	76	24	51	93	35	51	72	47	93	51	59	24	93	711
Mean	49	28	55	40	62	63	32	32	56	35	62	83	50			
Min	24	8	18	24	6	13	16	0	17	0	25	43		0		
Max	72	67	100	58	105	93	48	51	117	80	106	178			178	
													Mean yearly precipitation value:			**598**

TSID 95 - Lithotopos [mm]

Year	Jan	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Mean	Min	Max	Sum
2000	0	33	3	0	11	10	5	13	0	50	8	2	11	0	50	135
2001	37	25	21	79	52	12	13	47	74	0	0	0	30	0	79	359
2002	0	3	6	18	0	0	0	0	0	0	0	0	2	0	18	27
2003	153	0	0	52	137	145	51	66	75	160	56	70	80	0	160	965
2004	18	45	29	46	71	97	21	19	50	34	73	84	49	18	97	587
2005	85	76	37	15	80	26	36	90	98	6	53	88	57	6	98	690
2006	49	73	82	98	33	71	29	48	45	37	64		57	29	98	629
Mean	49	36	26	44	55	52	22	40	49	41	36	41	41			
Min	0	0	0	0	0	0	0	0	0	0	0	0		0		
Max	153	76	82	98	137	145	51	90	98	160	73	88			160	
													Mean yearly precipitation value:			**485**

Table 3. Annual distribution of the Strymonas/Struma River flow for the period 1961 - 1998

HMS 51650 Struma river – Pernik [m^3/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
average	2.003	2.291	2.449	2.655	3.18	2.54	1.736	1.586	1.511	1.588	1.86	2.032
min	1.038	1.07	0.885	0.99	1.06	1.02	0.82	0.814	0.774	0.817	0.965	0.9
max	5.57	6	4.99	7.07	7.677	5.88	4.76	6.32	2.36	3.67	5.24	6.12

HMS 51700 Struma r. near Rajdavitsa [m^3/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
average	9.272	10.798	11.322	12.38	14.943	11.596	7.761	7	6.645	6.934	8.031	8.942
min	2.034	2.162	1.734	2.011	2.463	2.571	1.807	1.942	1.899	1.601	1.891	2.232
max	39.516	42.567	28.181	41.193	37.892	30.988	20.332	26.995	12.789	14.85	22.382	26.141

HMS 51750 Struma r. Boboshevo [m^3/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
average	25.632	29.527	30.927	33.427	40.139	31.546	21.354	19.288	18.483	19.439	22.419	24.685
min	9.524	10.121	8.121	8.644	11.534	11.492	8.46	8.325	7.916	7.497	8.855	10.451
max	99.486	107.166	66.117	93.488	93.828	76.733	47.981	63.706	30.792	41.35	52.819	61.69

HMS 51800 Struma r. Krupnik [m^3/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
average	43.594	50.263	53.031	57.314	69.99	54.744	37.149	33.586	32.148	33.972	39.193	43.074
min	15.911	16.907	13.566	15.727	19.268	19.313	14.133	13.148	12.502	12.523	14.792	17.459
max	167.398	180.321	108.072	171.199	177.274	137.48	94.139	124.99	52.545	93.704	103.632	121.036

HMS 51880 Sruma r. Marino pole [m^3/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
average	73.41	85.29	89.08	96.45	117.05	90.69	61.42	55.44	53.44	56.01	64.63	71.09
min	33.58	35.68	28.63	26.86	37.26	33.63	27.4	23.88	22.71	24.06	31.21	31.18
max	295.88	318.72	186.87	256.8	289.28	219.62	130.9	173.8	99.03	141.17	144.1	168.3

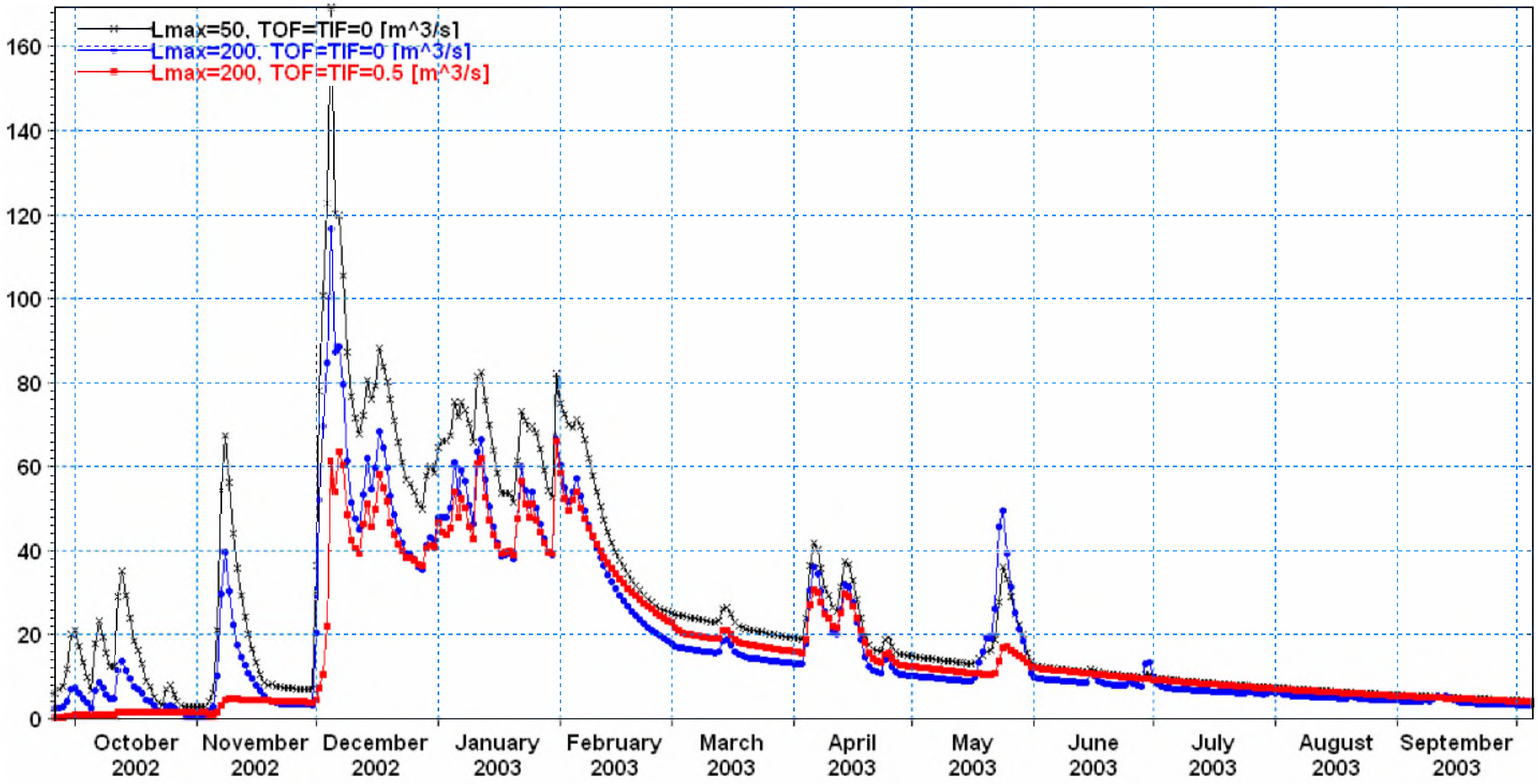


Diagram 1. Runoff in STRYMON_GR catchment for different values of model parameters (Lmax, TOF, TIF)

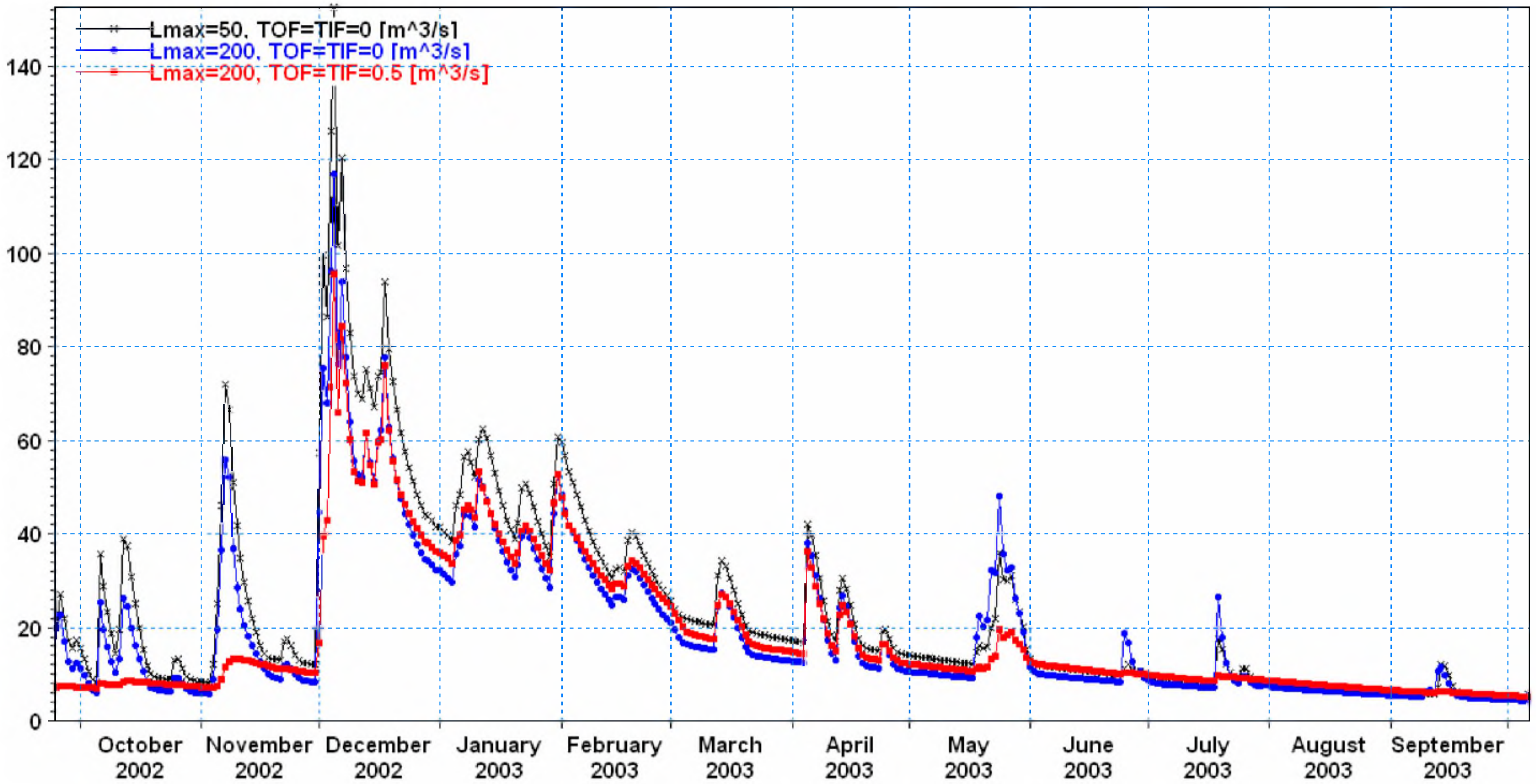
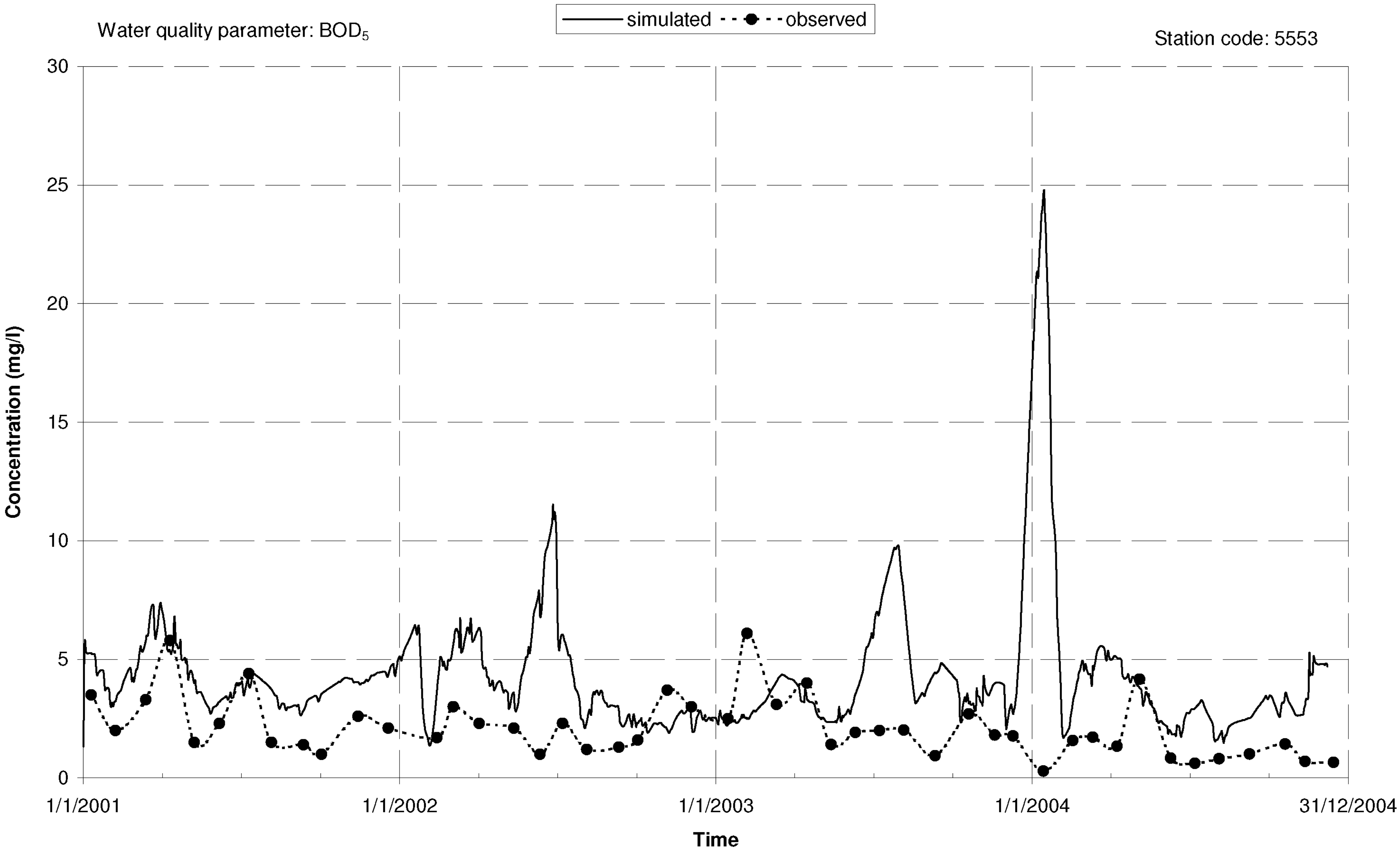
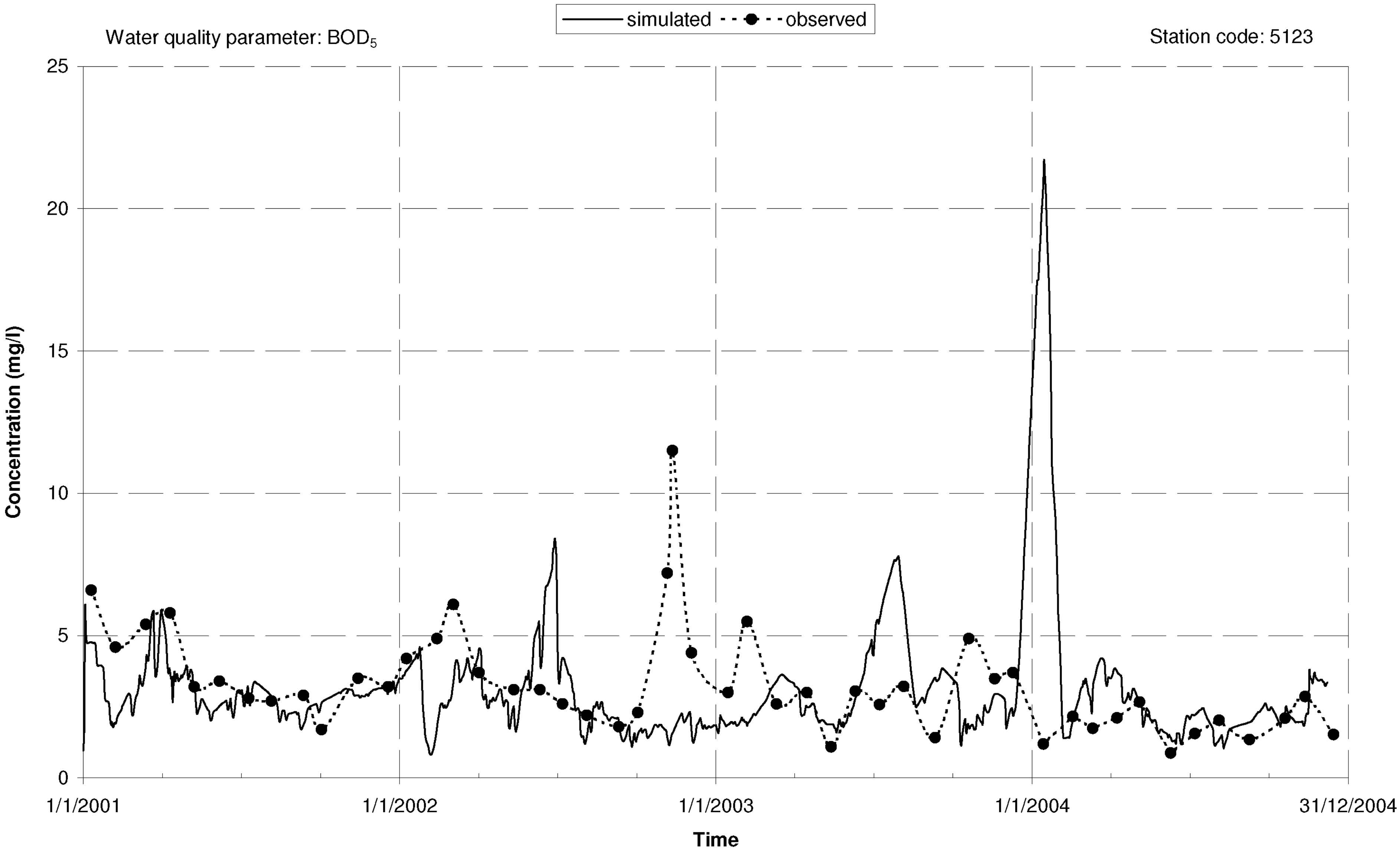
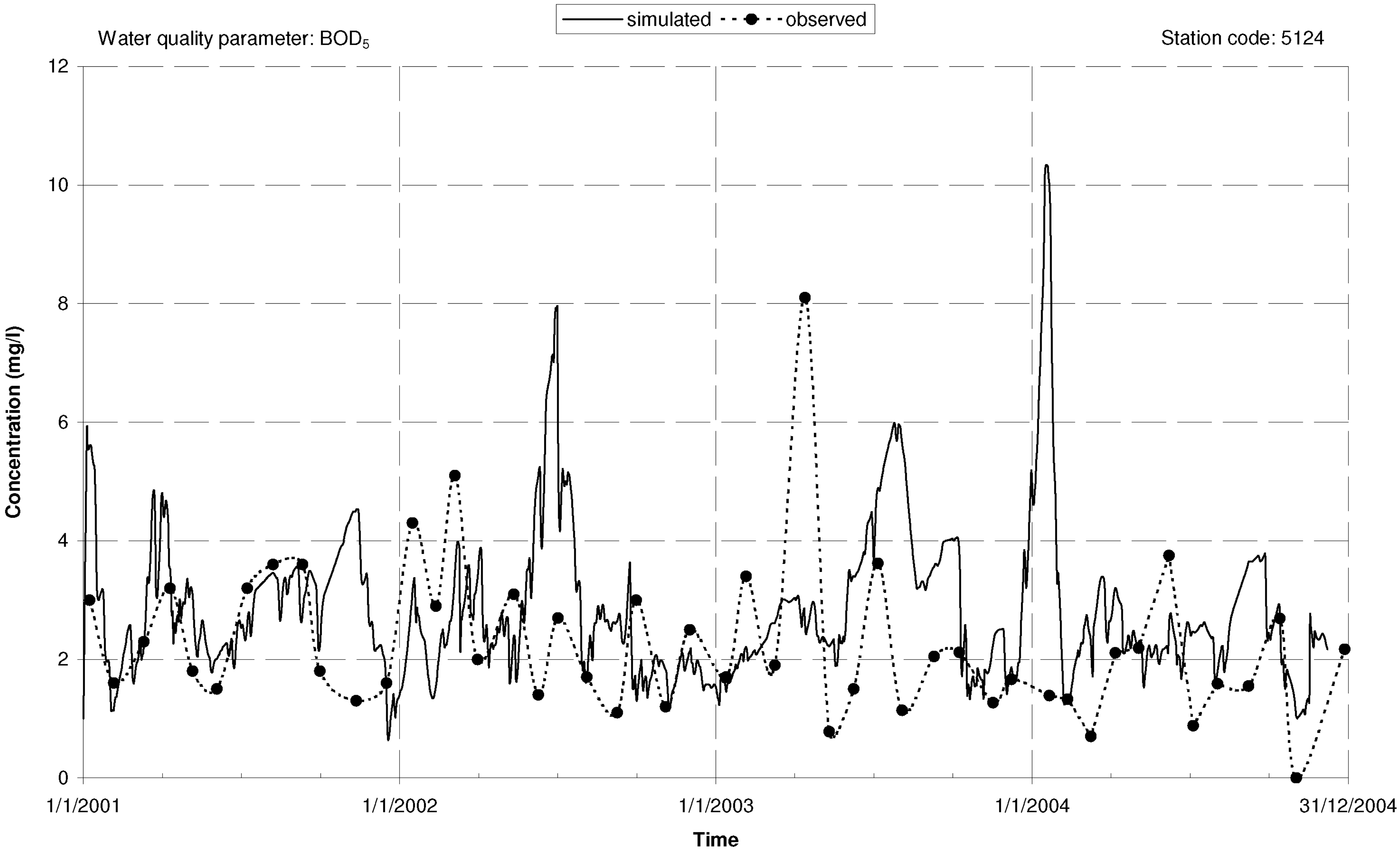


Diagram 2. Runoff in AGGITIS_GR catchment for different values of model parameters (Lmax, TOF, TIF)

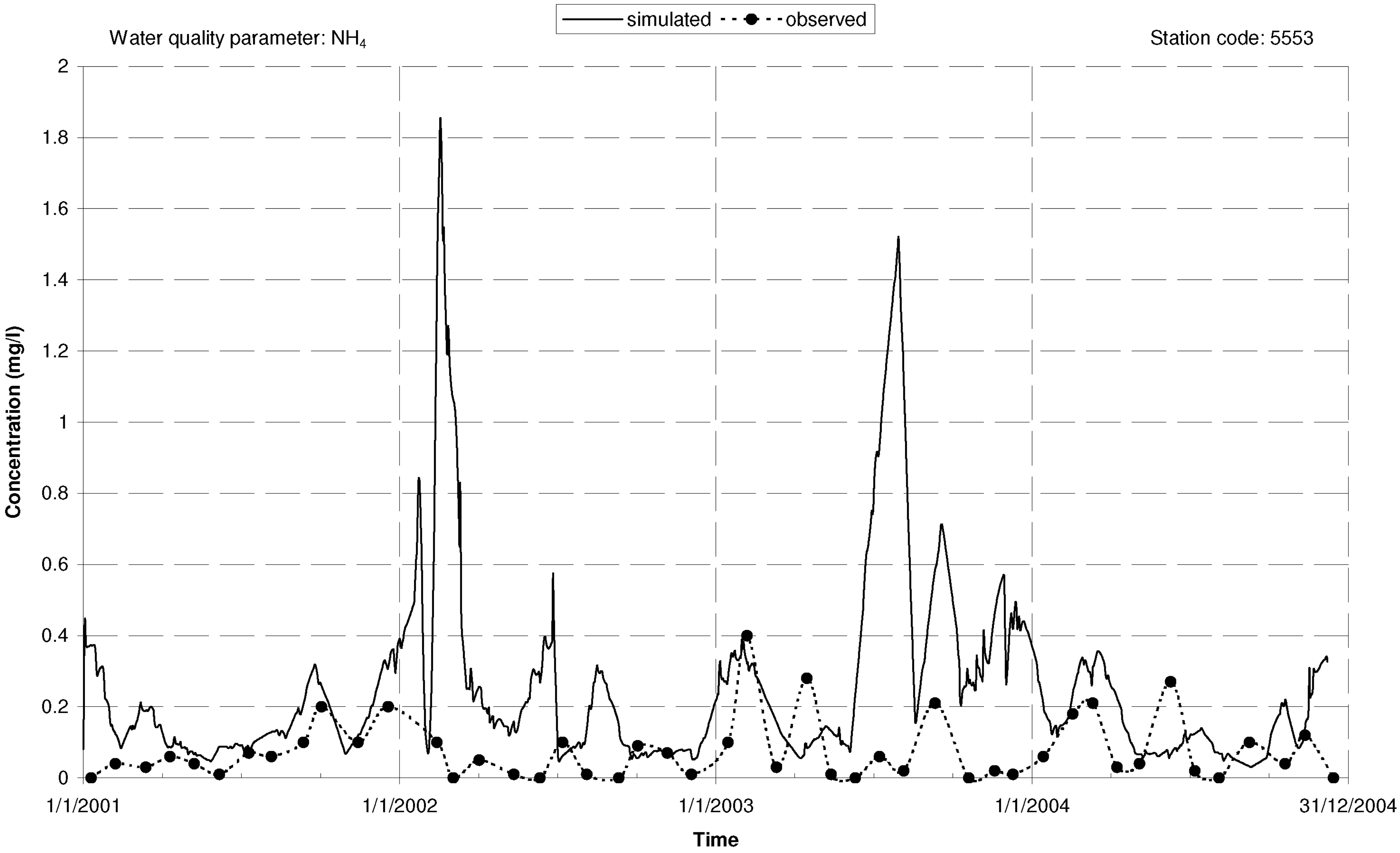


simulated
observed
Water quality parameter: BOD_5
Station code: 5553
30
25
20
15
10
5
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

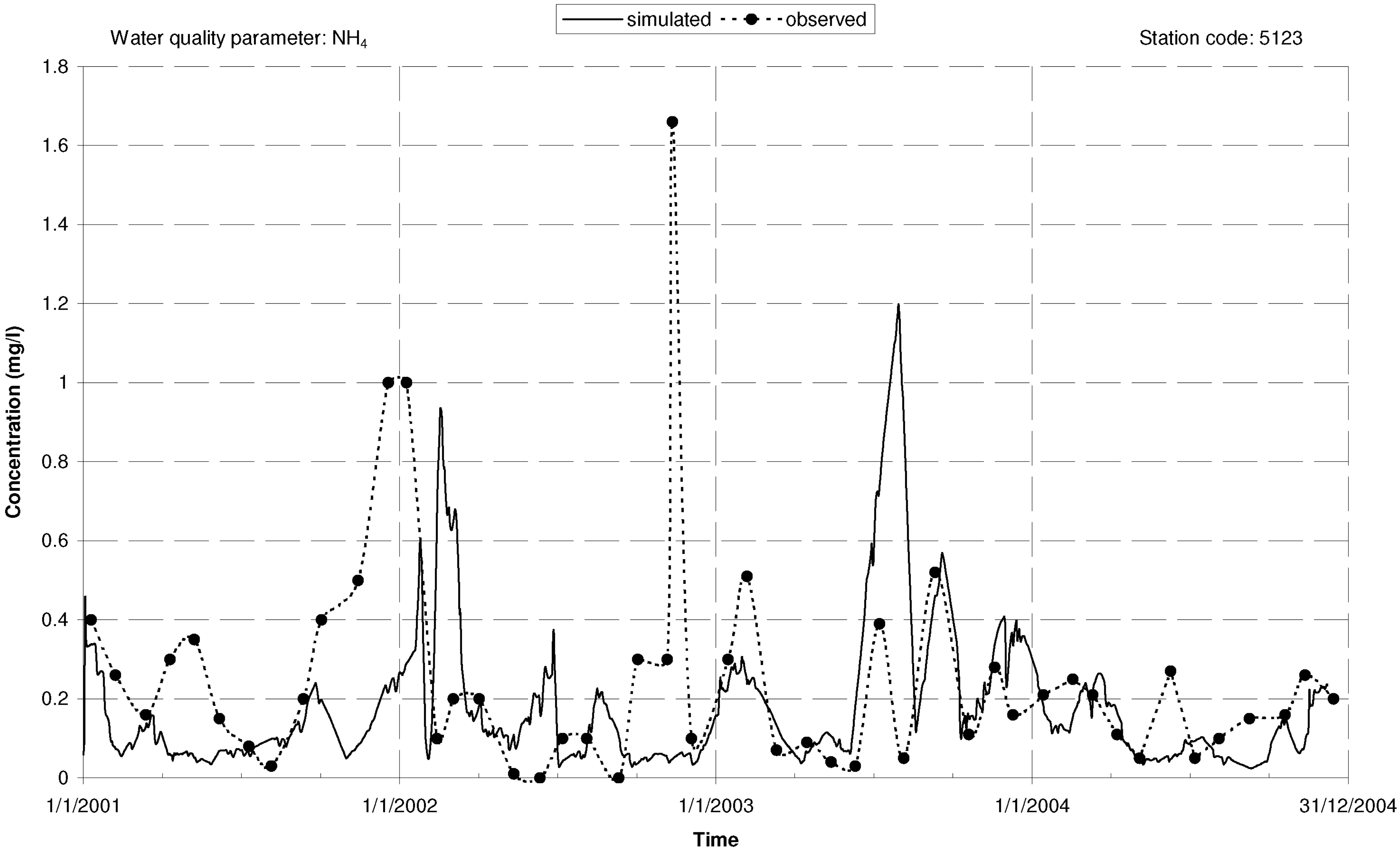

simulated
observed
Water quality parameter: BOD5
Station code: 5123
25
20
15
10
5
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

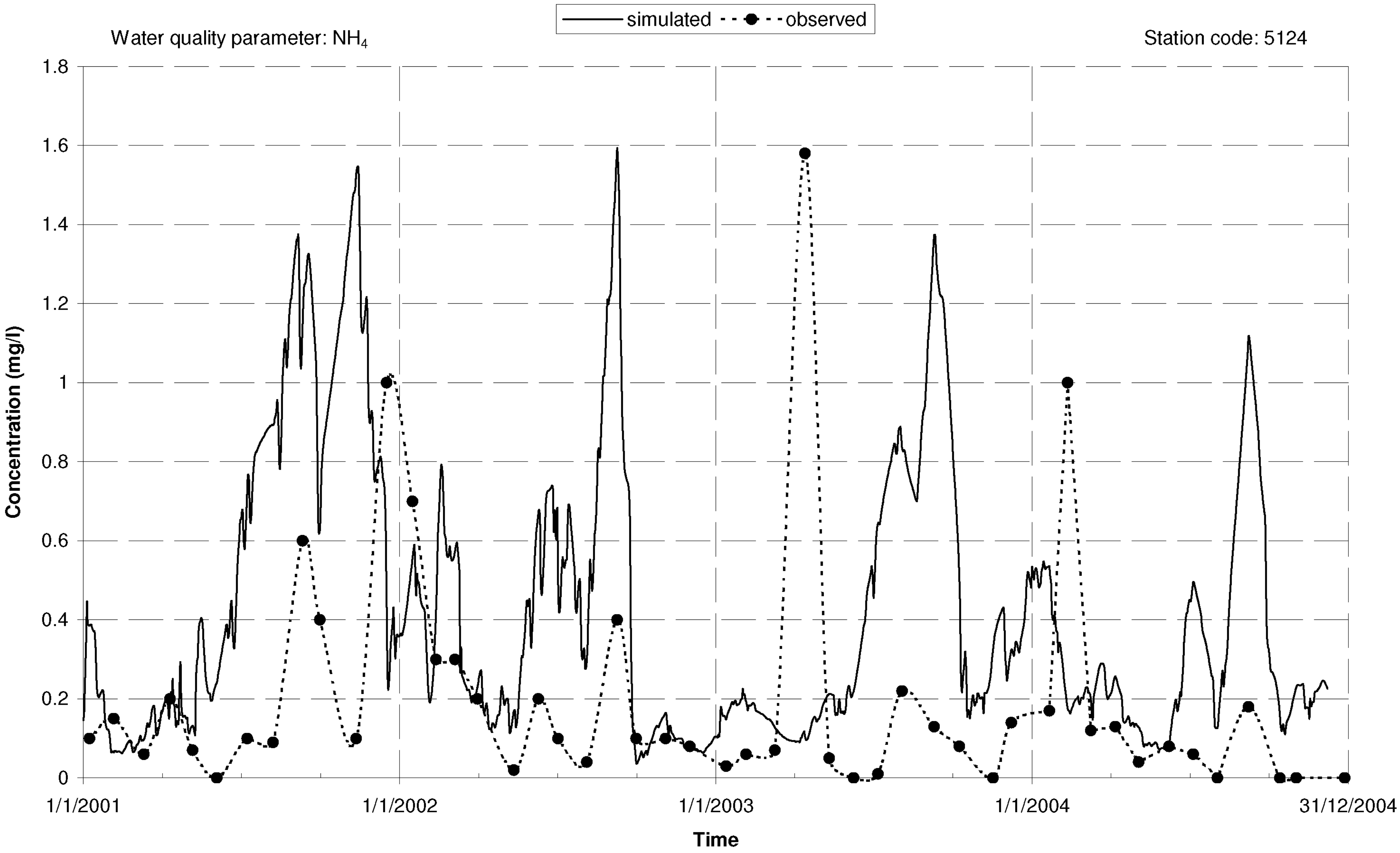


simulated
observed
Water quality parameter: BOD_5
Station code: 5124
Concentration (mg/l)
0
2
4
6
8
10
12
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

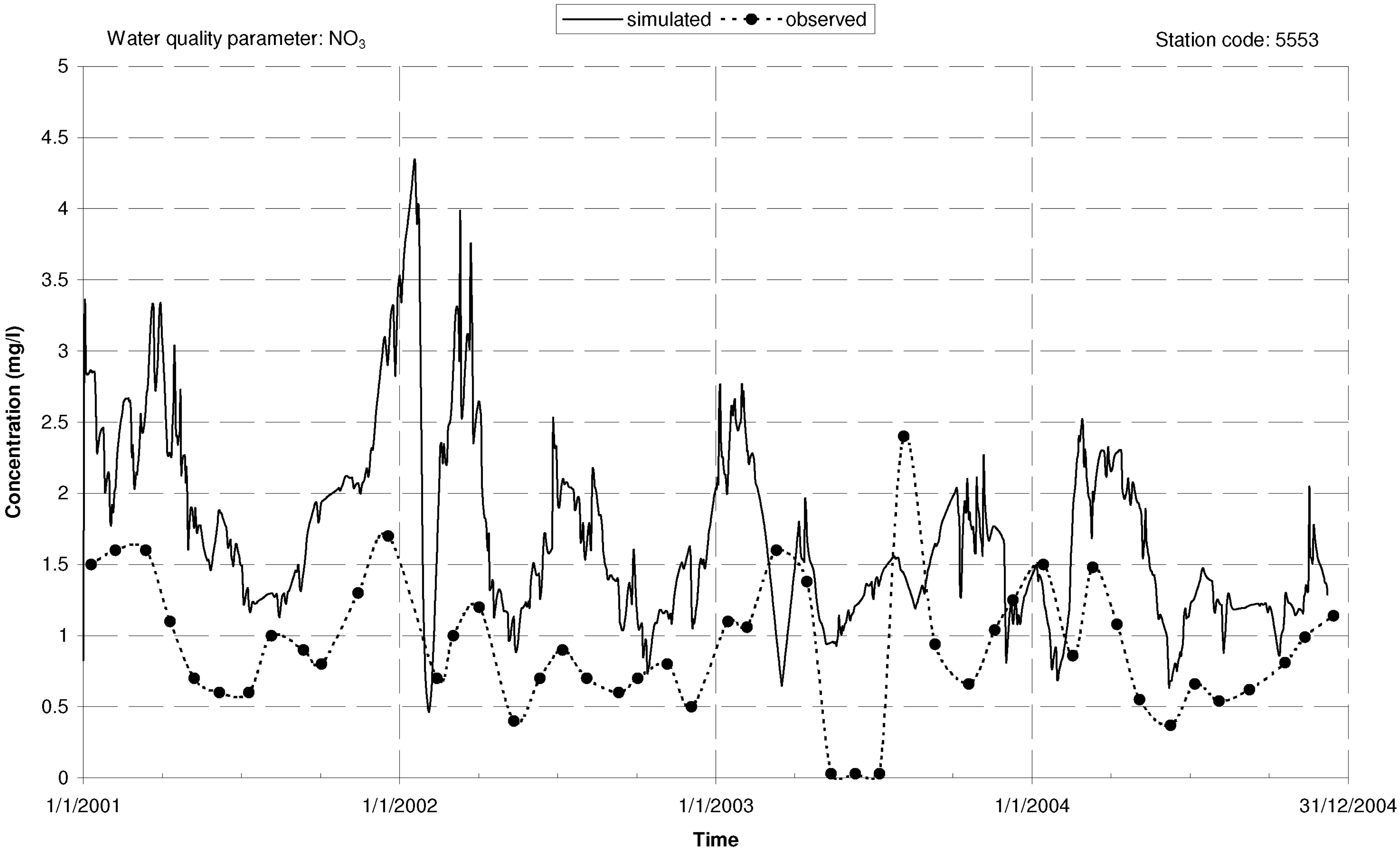


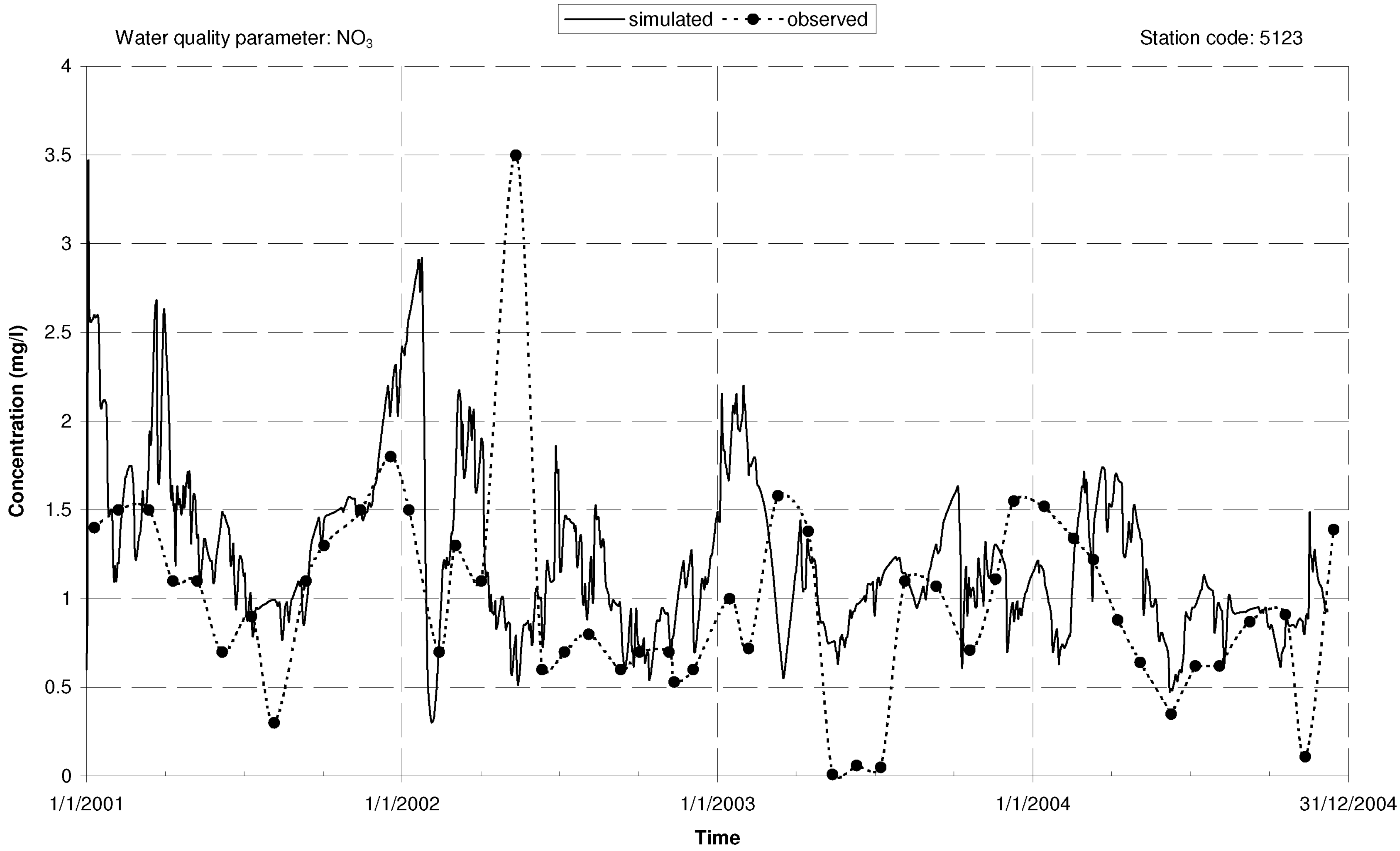
simulated
observed
Water quality parameter: NH4
Station code: 5553
Concentration (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

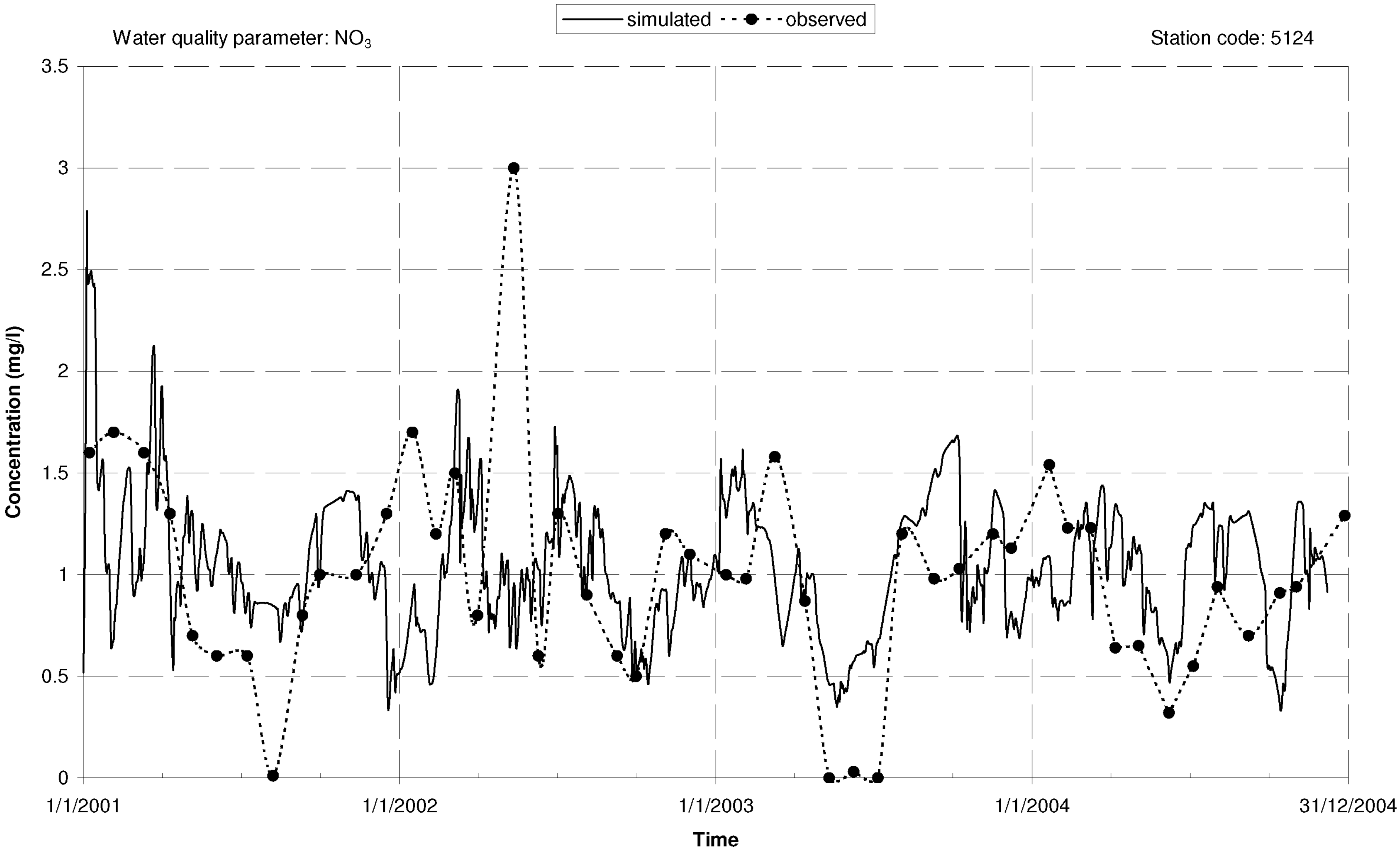

simulated
observed
Water quality parameter: NH_4
Station code: 5123
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time



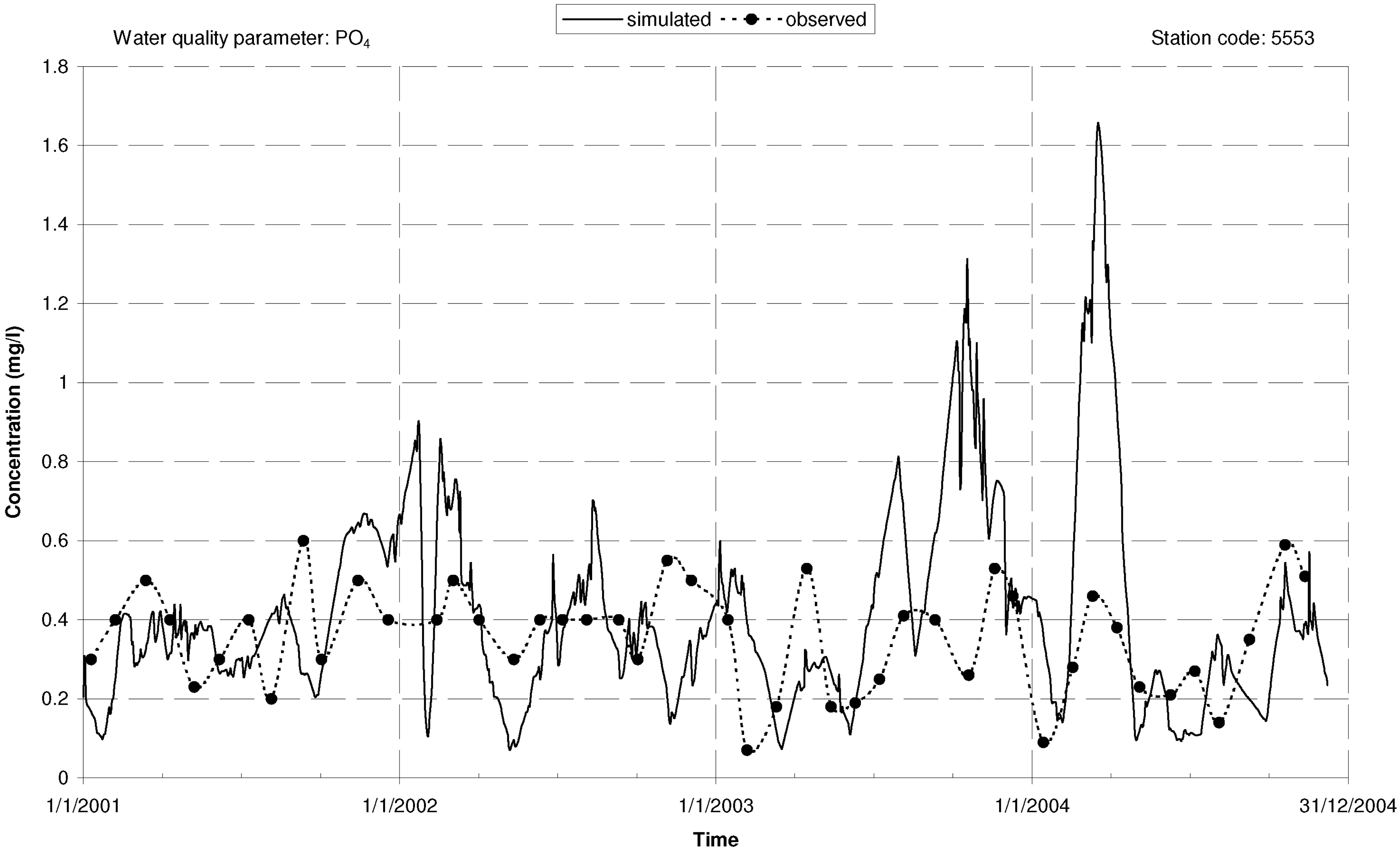
simulated
observed
Water quality parameter: NH4
Station code: 5124
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

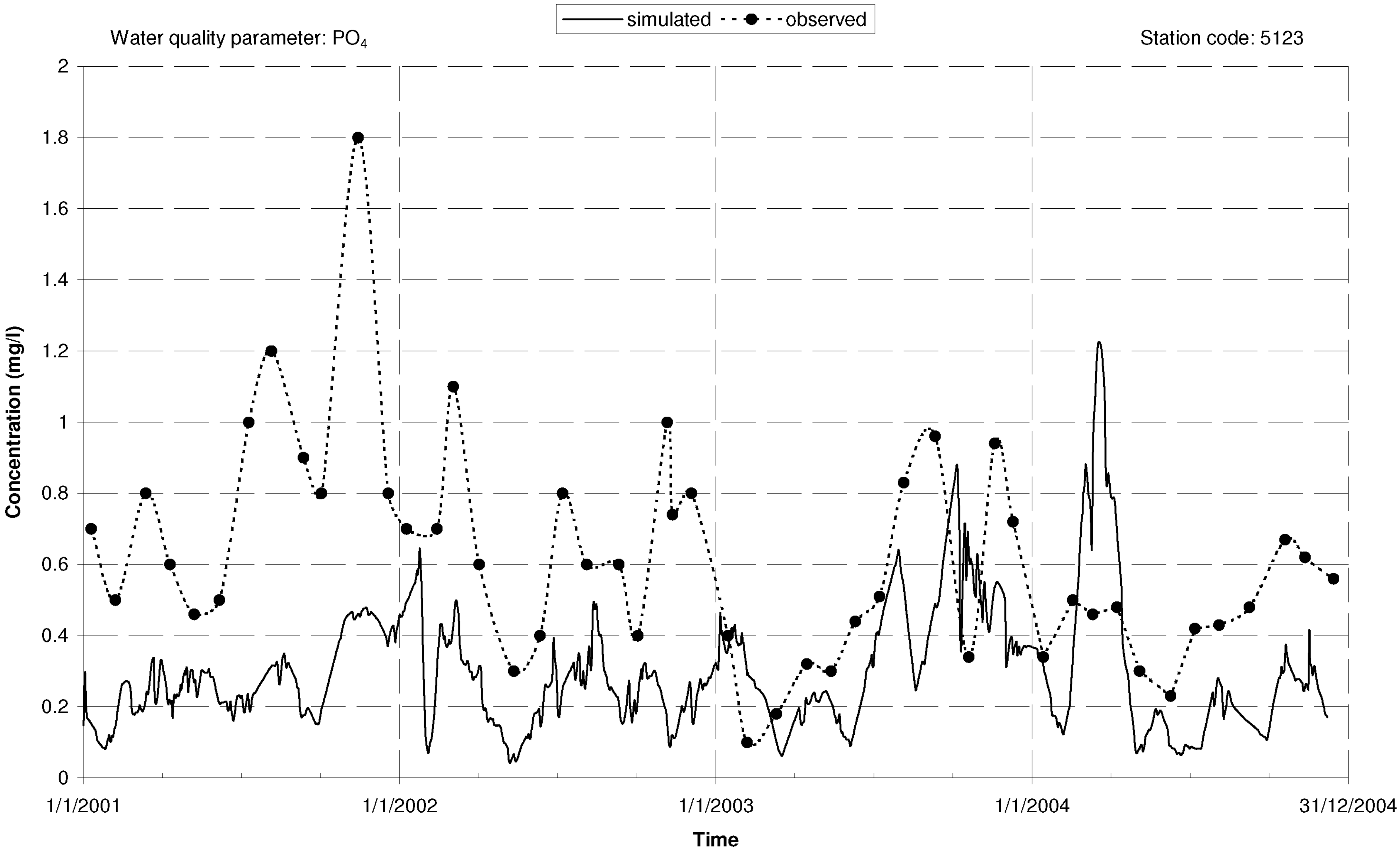

simulated
observed
Water quality parameter: NO_3
Station code: 5553
Concentration (mg/l)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

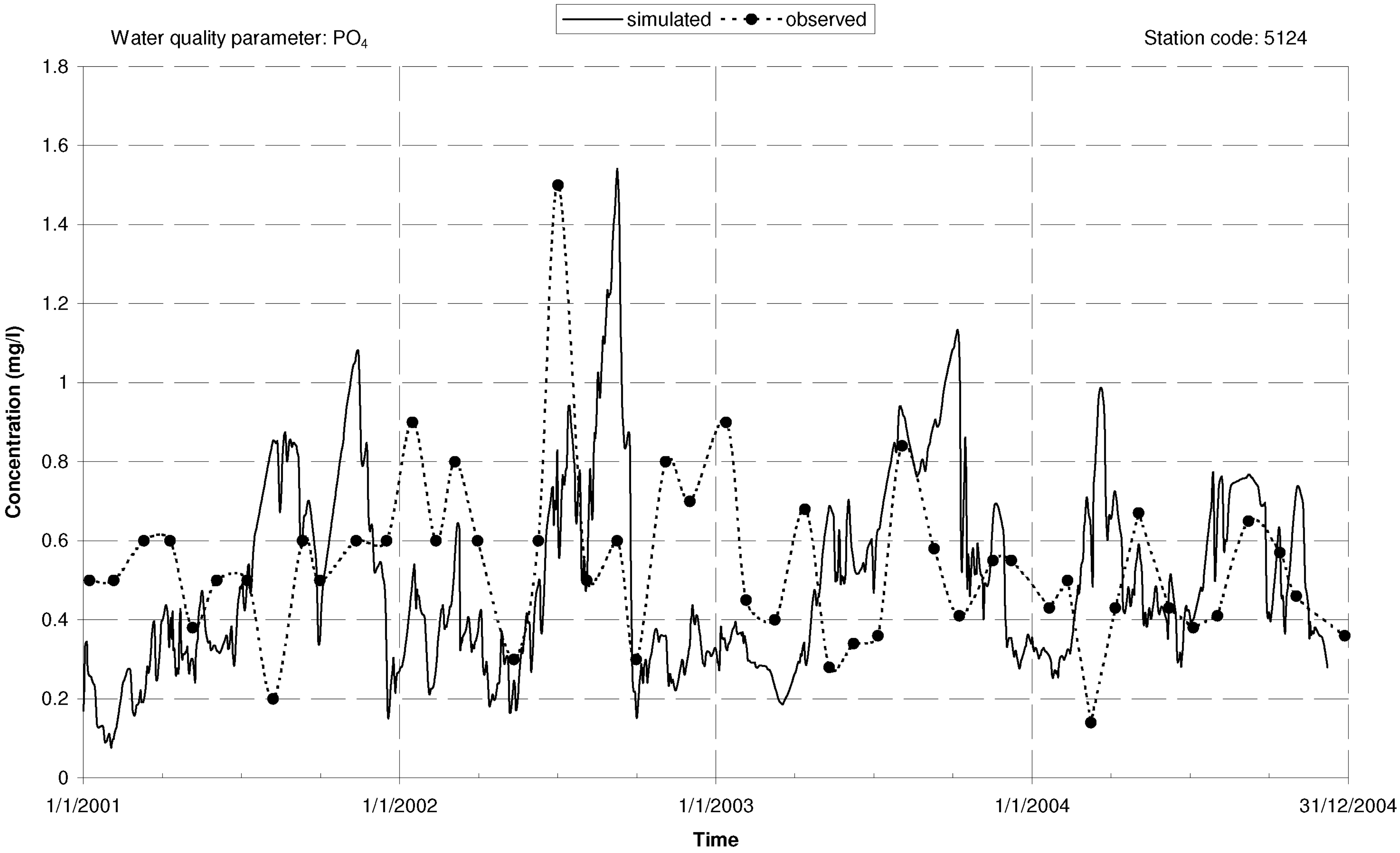

simulated
observed
Water quality parameter: NO_3
Station code: 5123
Concentration (mg/l)
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time



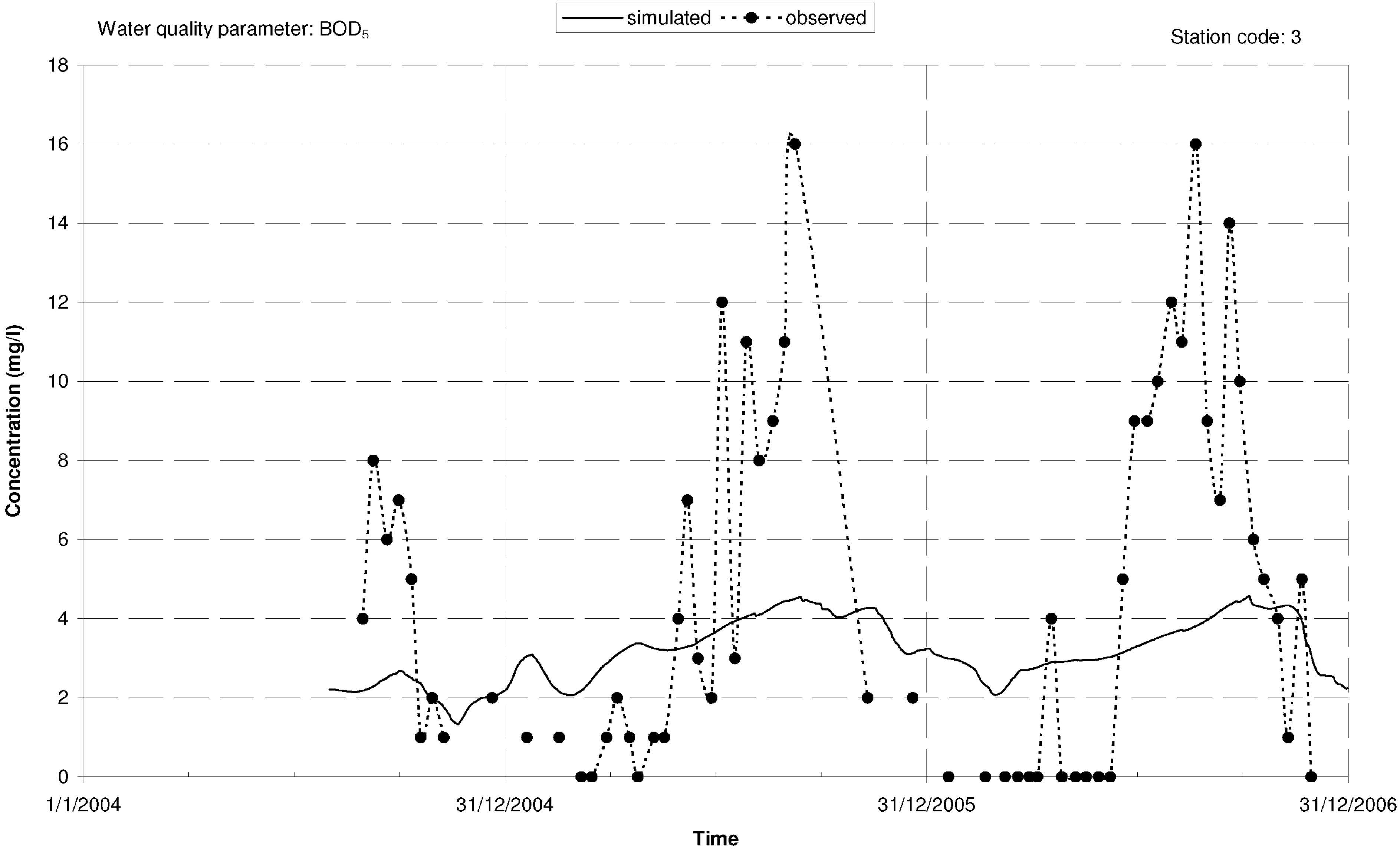
simulated
observed
Water quality parameter: NO_3
Station code: 5124
3.5
3
2.5
2
1.5
1
0.5
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time


simulated
observed
Water quality parameter: PO_4
Station code: 5553
Concentration (mg/l)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

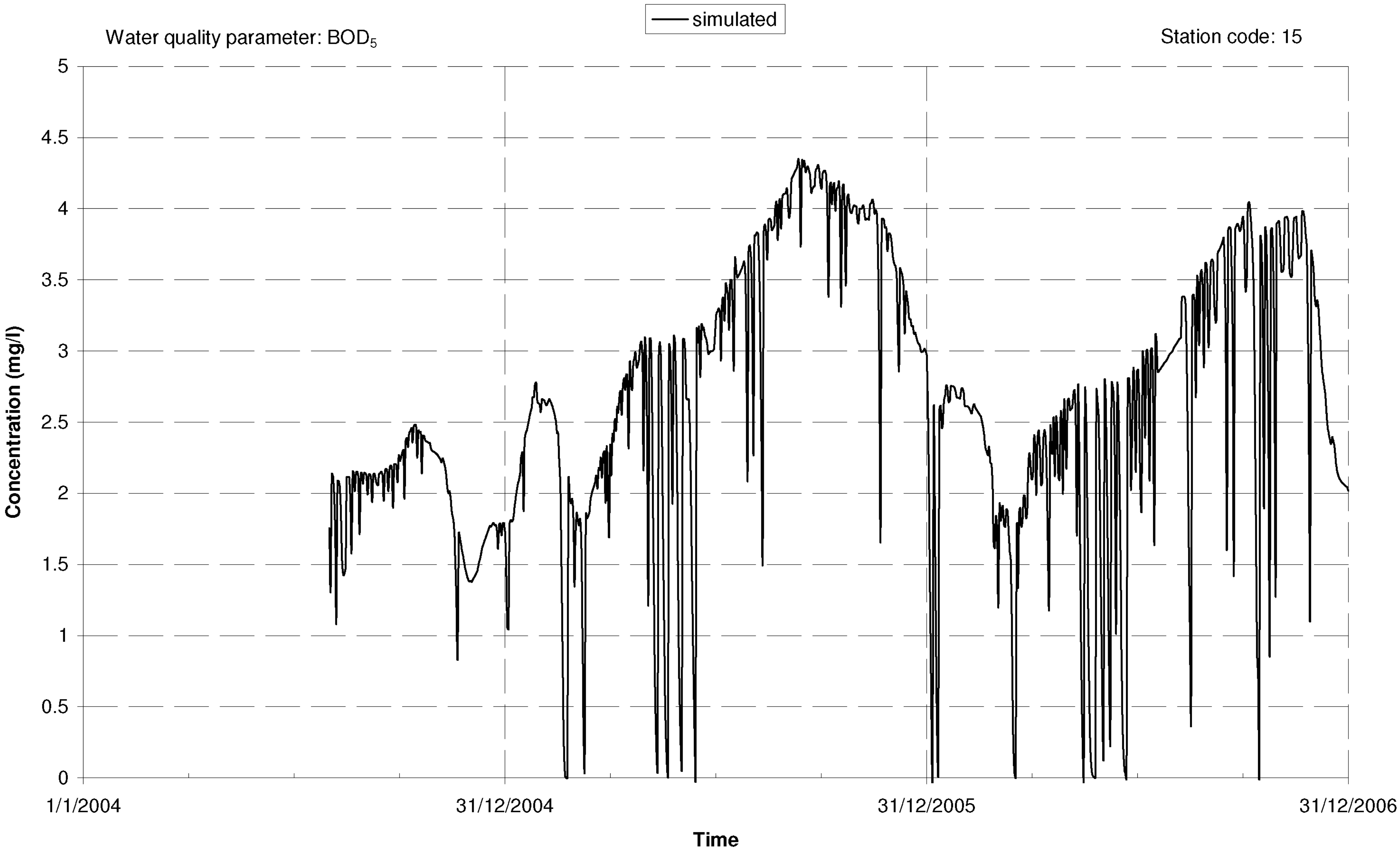

simulated
observed
Water quality parameter: PO4
Station code: 5123
Concentration (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time



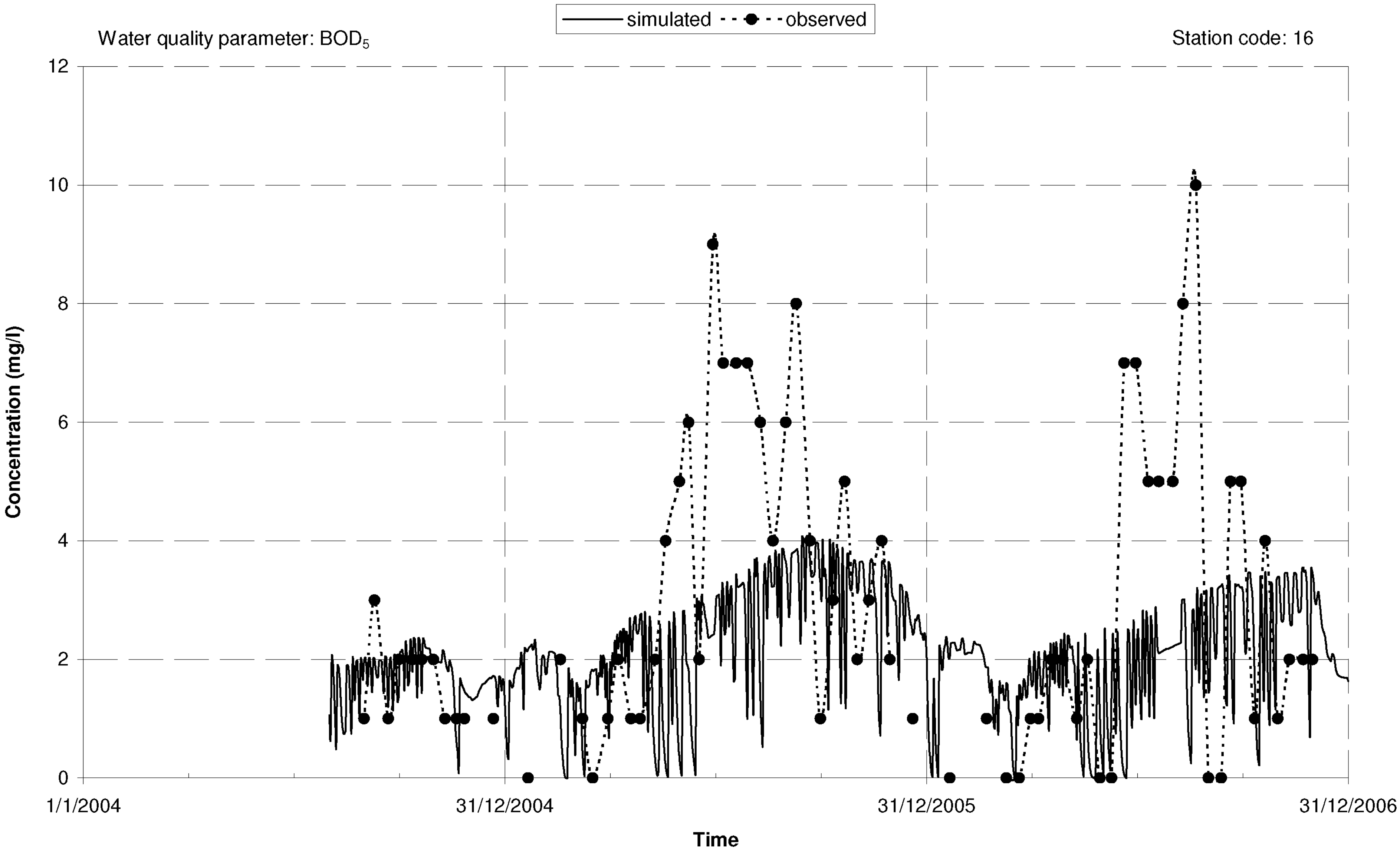
simulated
observed
Water quality parameter: PO4
Station code: 5124
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/l)
1/1/2001
1/1/2002
1/1/2003
1/1/2004
31/12/2004
Time

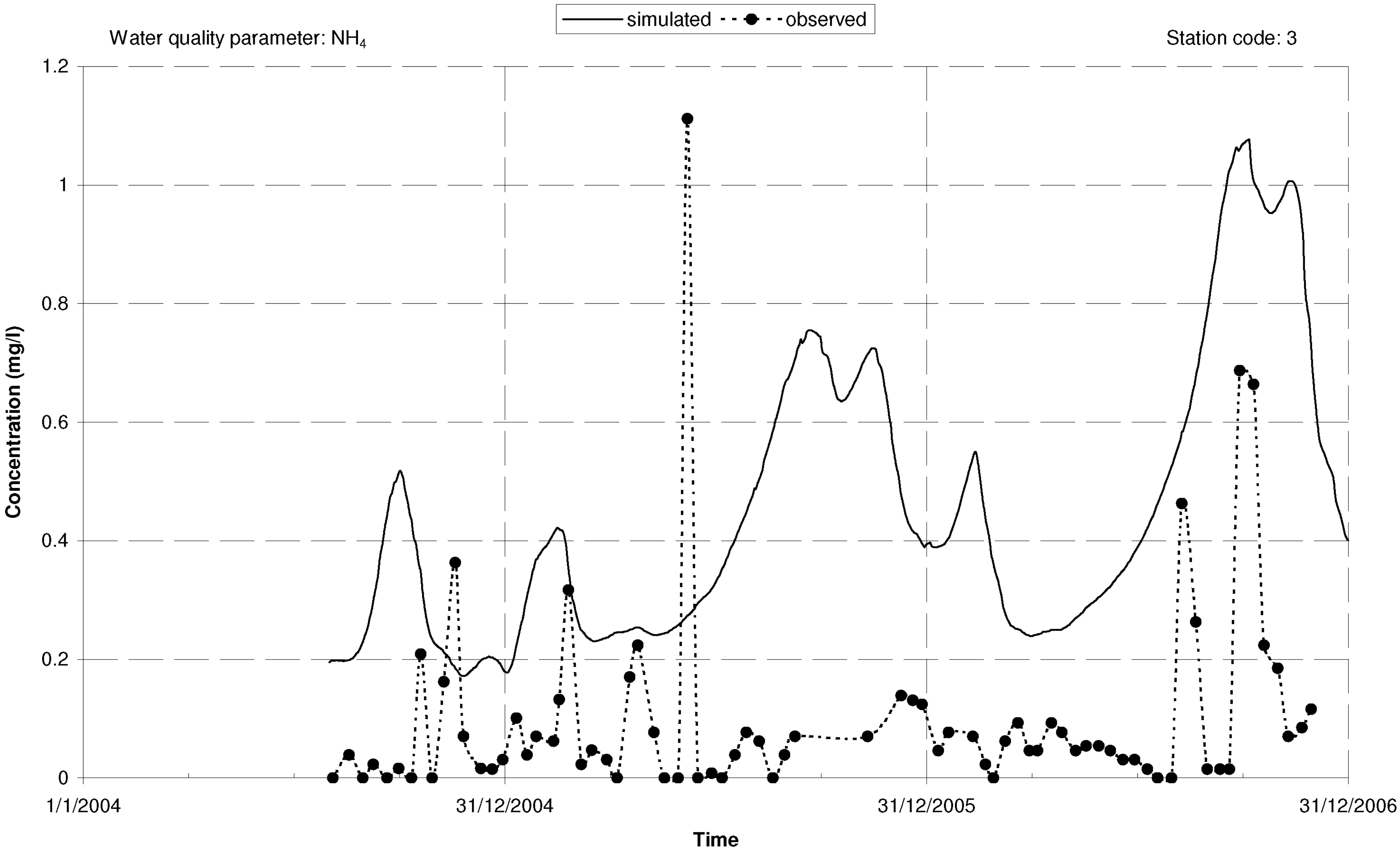


simulated
observed
Water quality parameter: BOD_5
Station code: 3
18
16
14
12
10
8
6
4
2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time

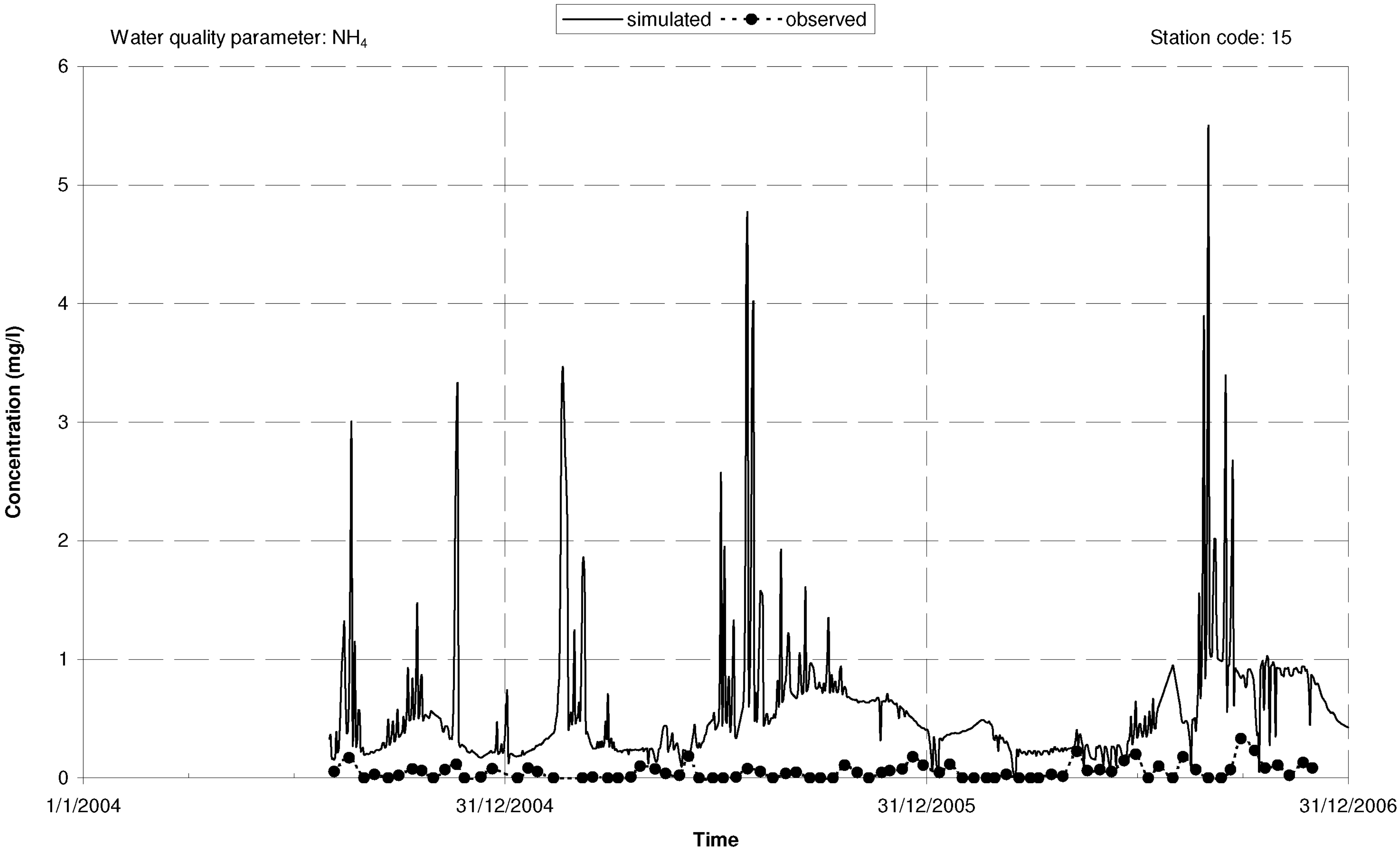


simulated
Water quality parameter: BOD_5
Station code: 15
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time

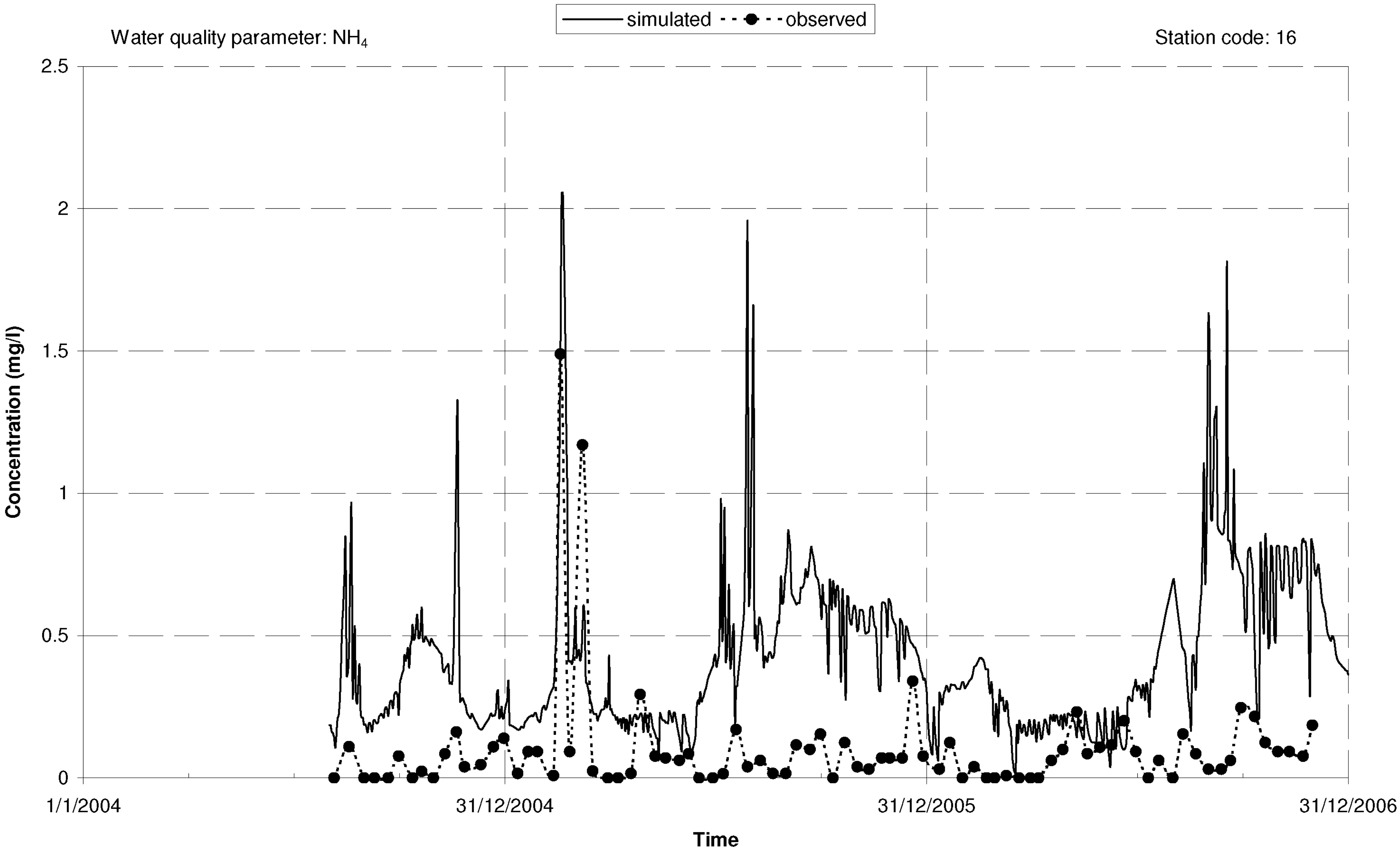

simulated
observed
Water quality parameter: BOD5
Station code: 16
12
10
8
6
4
2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time



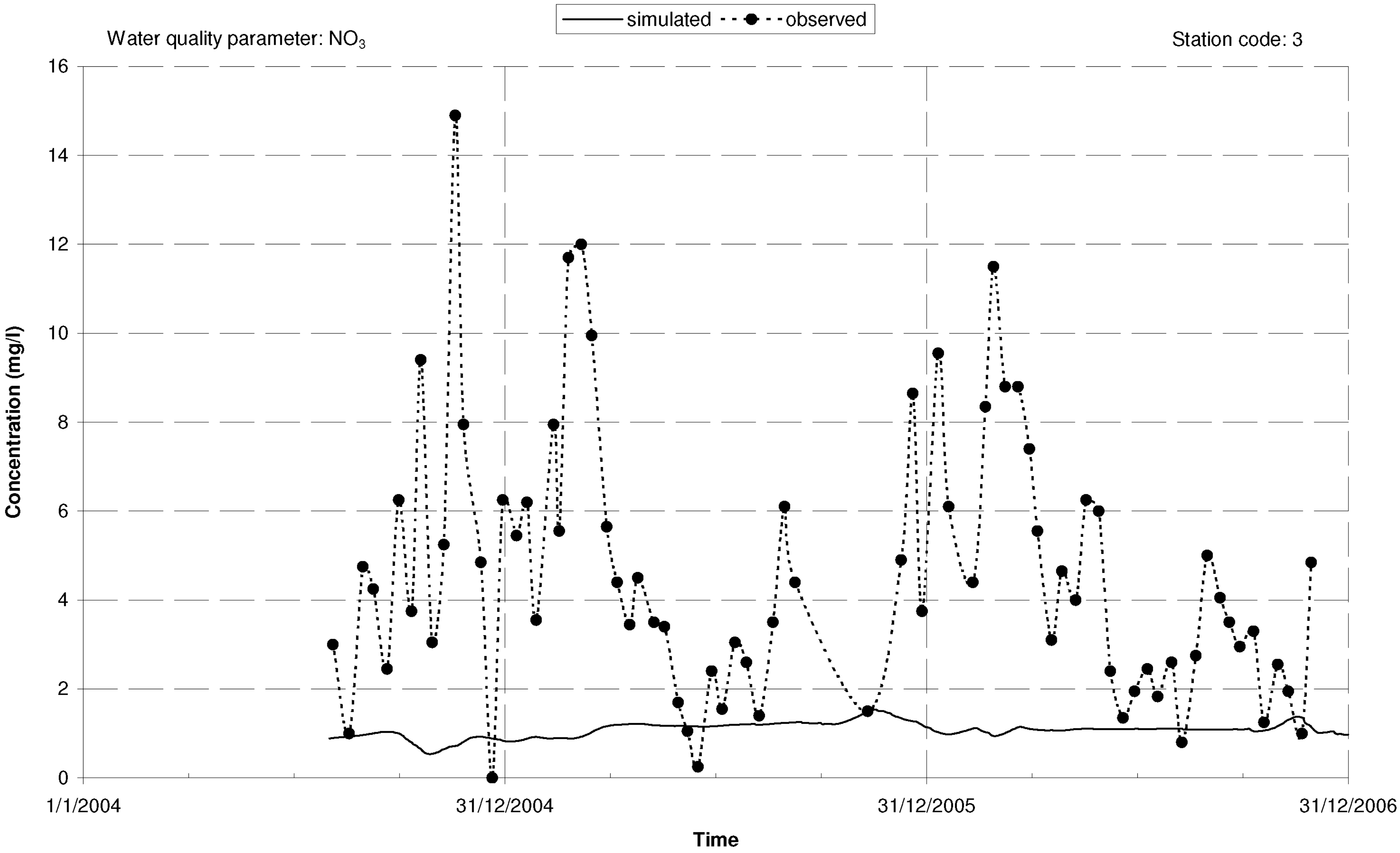
simulated
observed
Water quality parameter: NH4
Station code: 3
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time



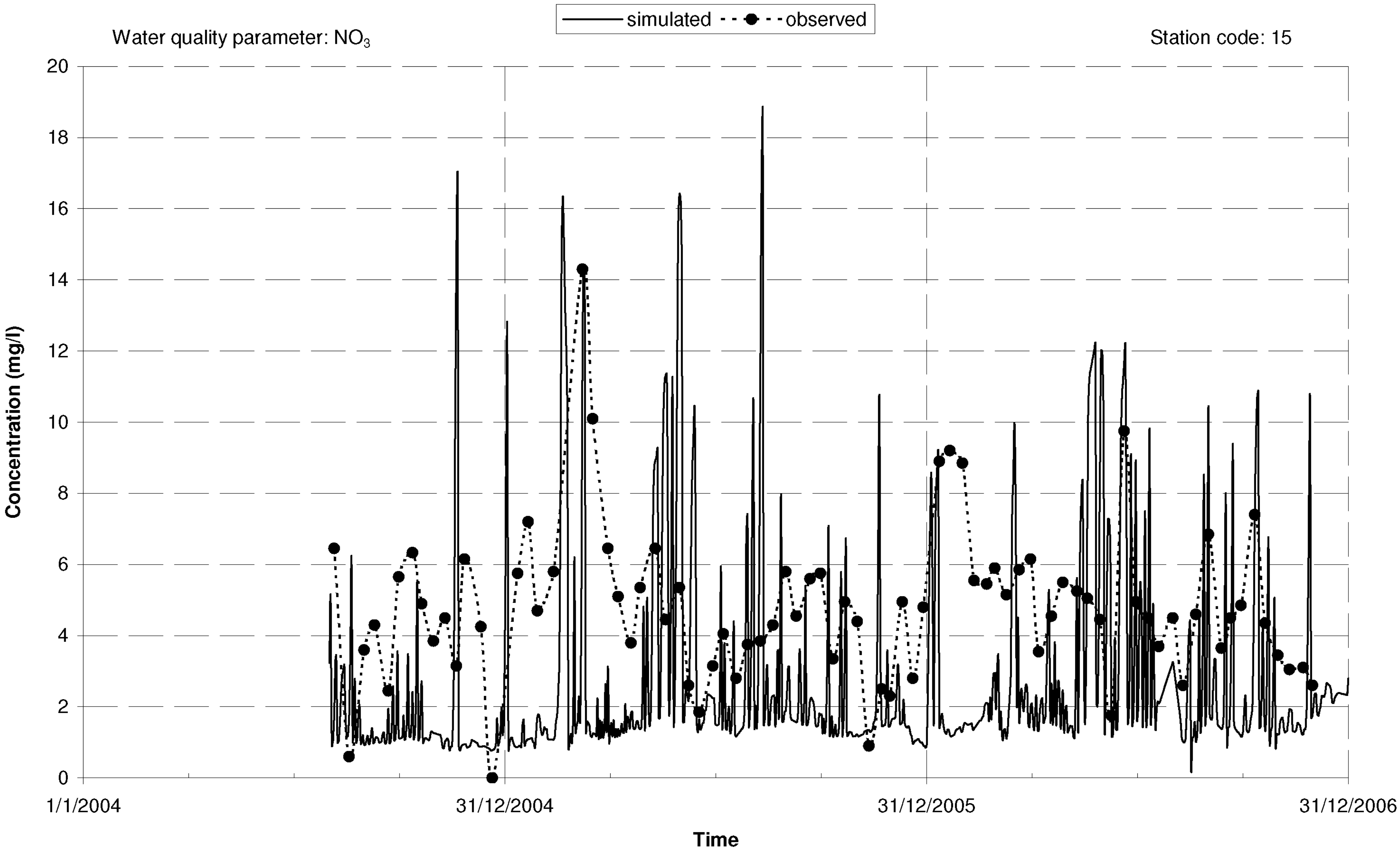
simulated
observed
Water quality parameter: NH4
Station code: 15
Concentration (mg/l)
6
5
4
3
2
1
0
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time



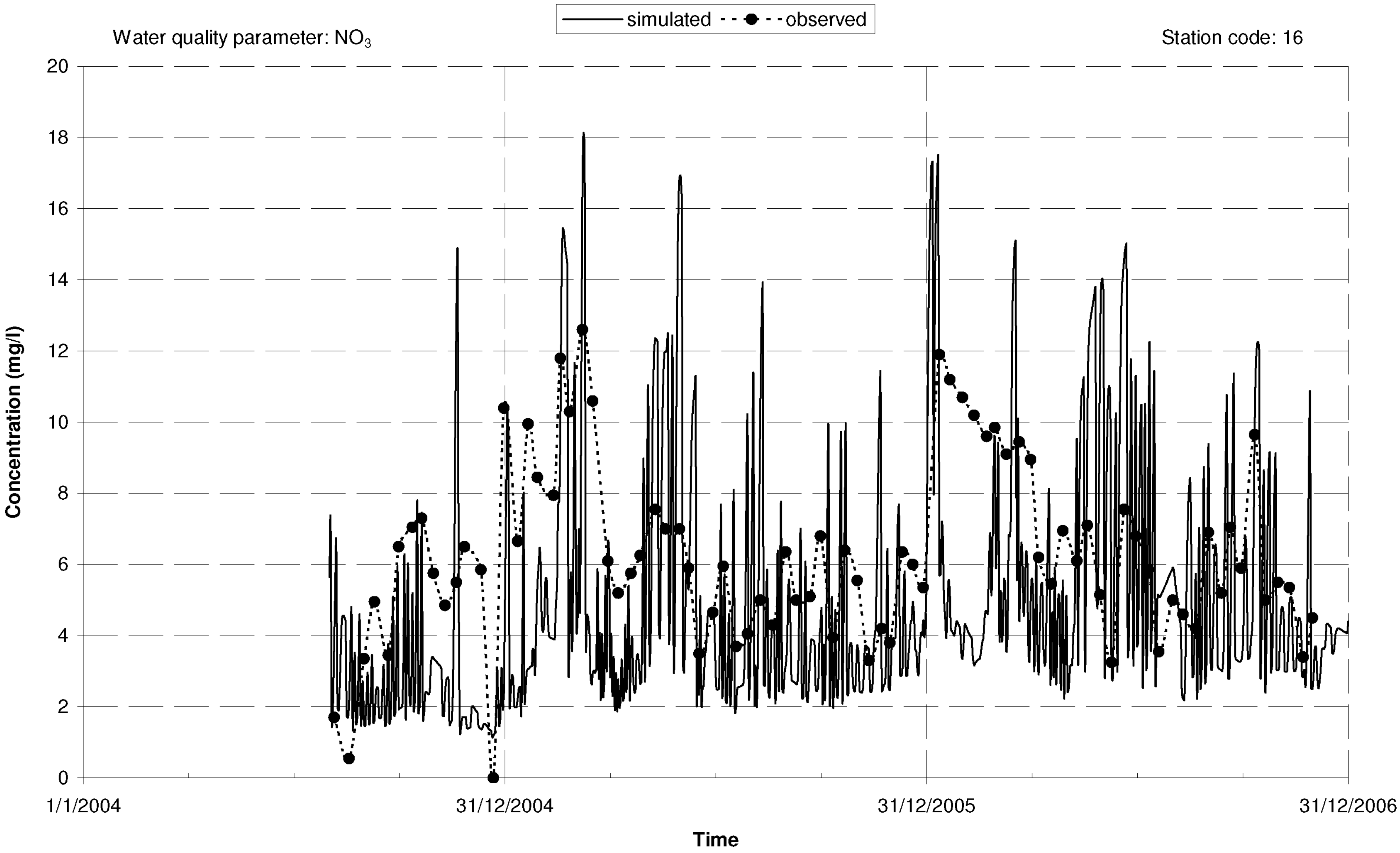
simulated
observed
Water quality parameter: NH_4
Station code: 16
2.5
2
1.5
1
0.5
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time



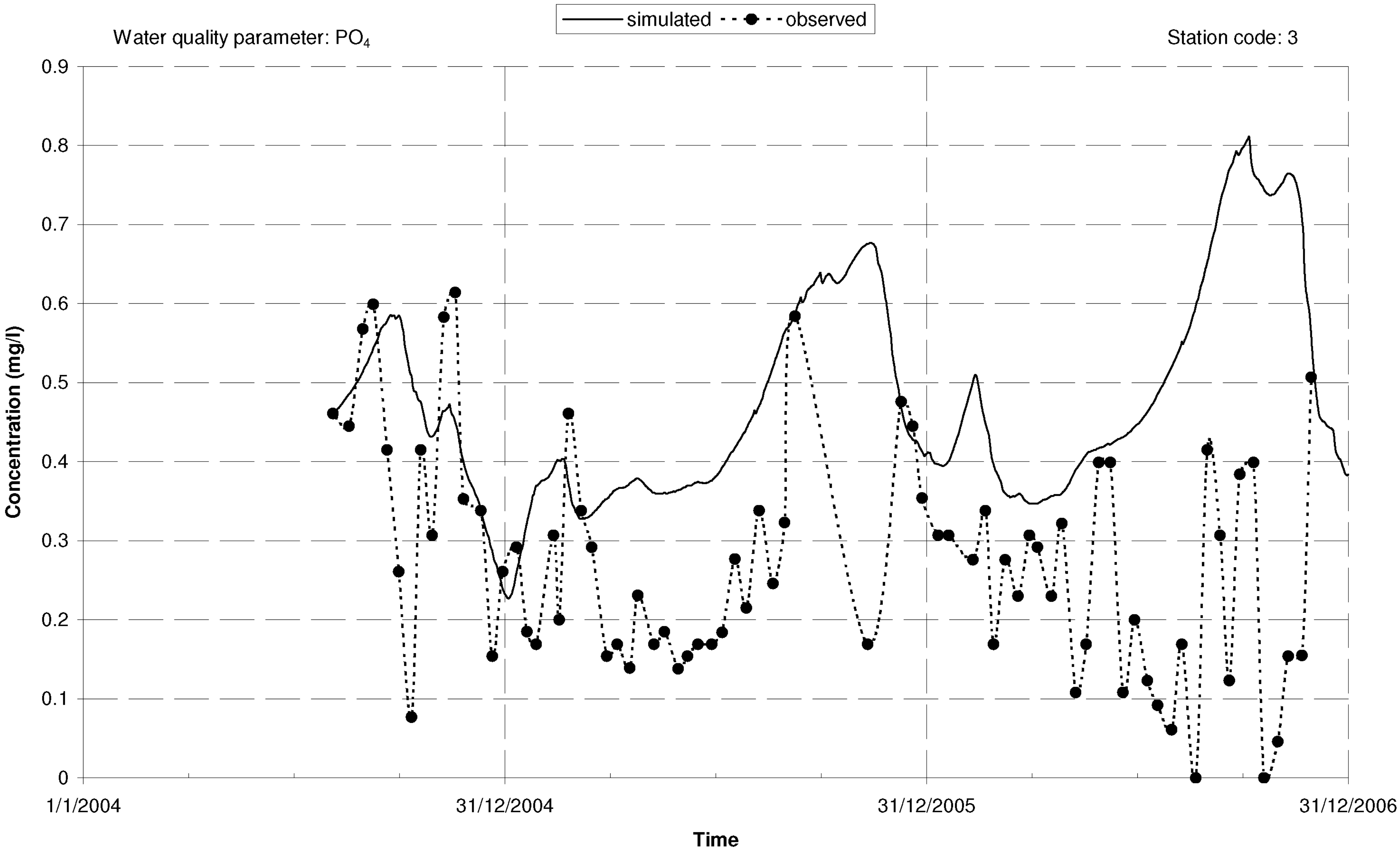
simulated
observed
Water quality parameter: NO3
Station code: 3
16
14
12
10
8
6
4
2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time

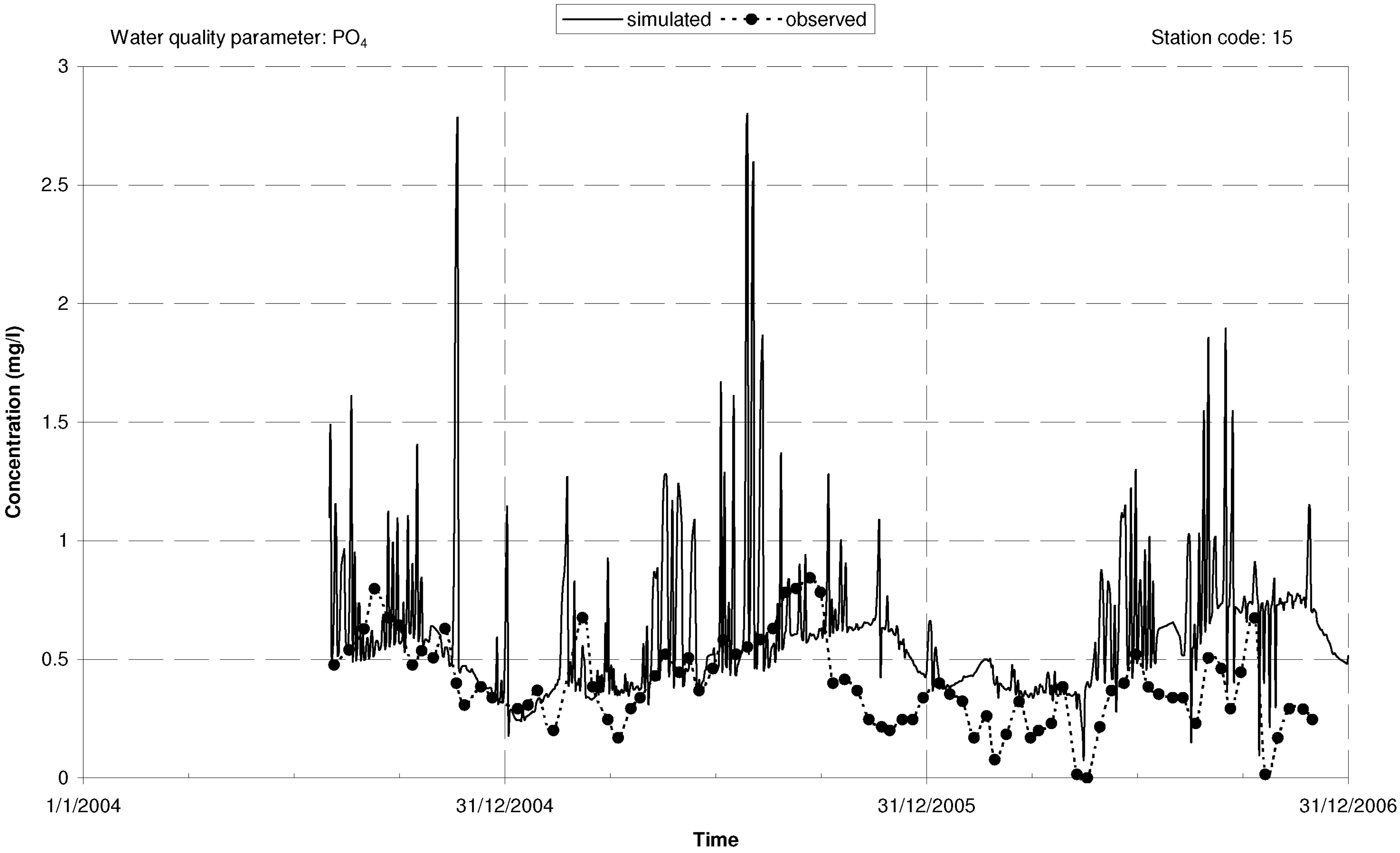


simulated
observed
Water quality parameter: NO3
Station code: 15
20
18
16
14
12
10
8
6
4
2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time

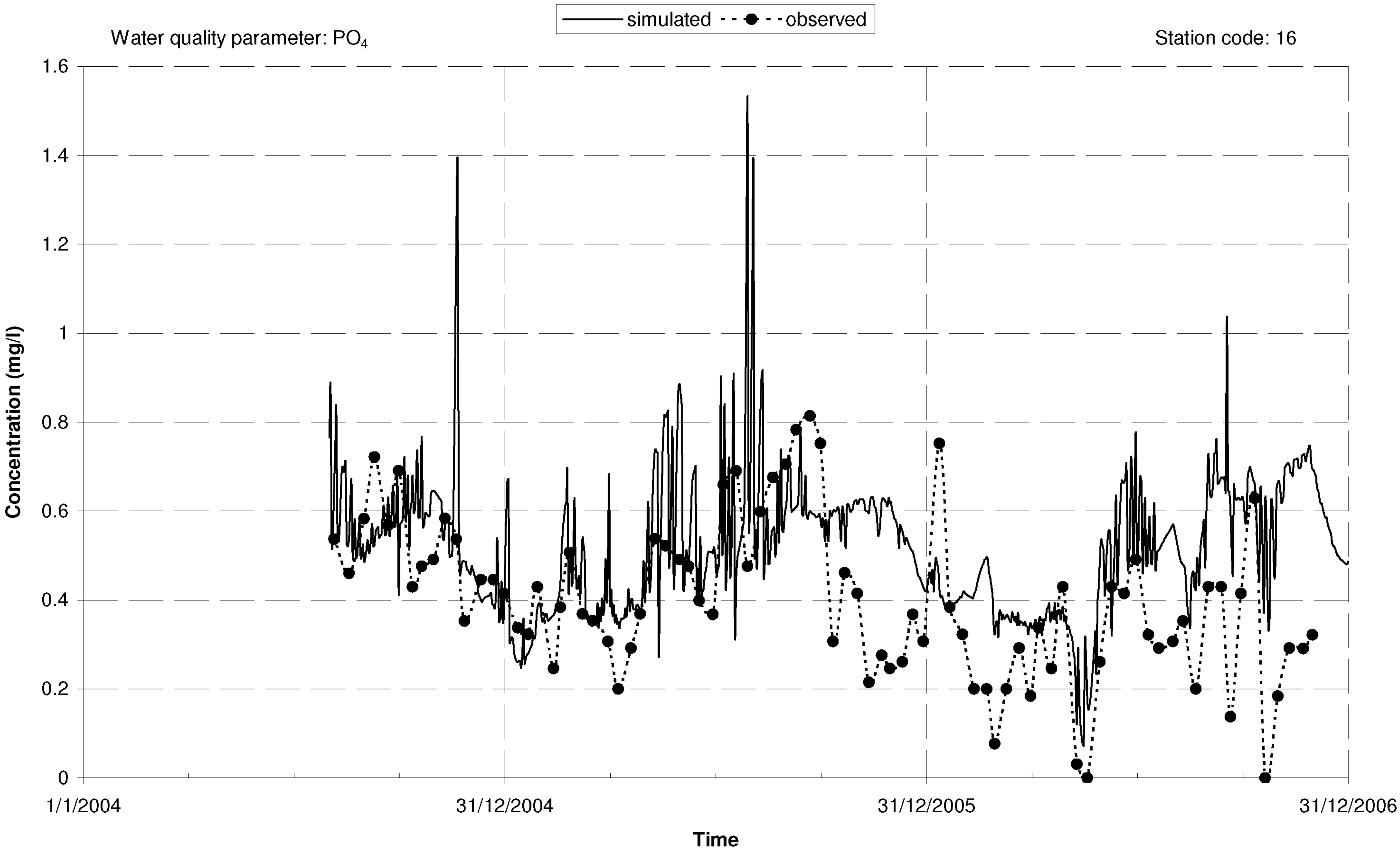


simulated
observed
Water quality parameter: NO_3
Station code: 16
20
18
16
14
12
10
8
6
4
2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time


simulated
observed
Water quality parameter: PO4
Station code: 3
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time



simulated
observed
Water quality parameter: PO_4
Station code: 15
Concentration (mg/l)
3
2.5
2
1.5
1
0.5
0
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time


simulated
observed
Water quality parameter: PO_4
Station code: 16
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/l)
1/1/2004
31/12/2004
31/12/2005
31/12/2006
Time