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Cooperation between USDA and Bulgaria in Agro-environmental Water Quality Programs

Dimitar Stoichev, Marvin Shaffer, James Starr, Jerrell Lemunyon, Dimitranka Stoicheva, Milena Kercheva and Venelina Kolev*

ABSTRACT

A joint program between the USDA and Bulgaria was established to address needs for surface and groundwater protection. Objectives of the program were to obtain information on water contamination in the Yantra River basin of Northern Bulgaria; to provide technical assistance; and to transfer economically sustainable technologies to improve the environmental management of agricultural farming practices. The monitoring scheme from 1994-1997 was designed to obtain information for the different components of the agroecosystem along a transect across a selected watershed. Groundwater monitoring was one of the most important ecological and social parts of the project. Agricultural activities were studied at four locations and crop conditions: 1) field crop rotation, 2) pasture, 3) peach orchard, and 4) four household gardens. Cultural practices at these locations included intensive vegetable rotation, irrigation, manuring, and frequent soil cultivation. The balance and dynamics of the main nutrients in the plant-soil-groundwater system were assessed from meteorological data, chemical composition of the precipitation, soil and soil solution characteristics under different land use, nitrate content of the plants, and groundwater quality.

The risk for nitrate leaching in the monitored variants of land use was estimated with the aid of the NLEAP (Nitrate Leaching and Economic Analysis Package) model. The main results of the joint project were the assessment of agricultural related sources of groundwater nitrate contamination and the realization of the educational program.

INTRODUCTION

Concern about the environment increases with educational and economical development. Groundwater contamination with nitrates is drawing the attention of people and scientists in many countries. More than 75% of the drinking waters in the centralized water supply system in Bulgaria are from groundwater sources (Stoeva and Raikova, 1981). Home wells in rural areas, most of which are not included in the monitoring system of the Health Authorities, are especially susceptible to nitrate contamination. Groundwater protection is a high priority problem for the country.

The aim of this paper is to present some of the achievements of the international agro-environmental water quality program. The objectives of a joint program between the USDA and Bulgaria were to obtain information on water contamination in the Yantra River basin (Northern Bulgaria); to provide technical assistance; and to transfer low cost, economically sustainable technologies to improve the environmental management of agricultural farming practices.

MATERIALS AND METHODS

Studies were carried out during the period 1994-1997 on a small watershed in the region of Parvomaitsi village, situated in the central part of the Yantra River basin (Figure 1). The main ecological problems in the village are nitrate contamination of the groundwater and water pollution of the Yantra River by nutrients and various home solid wastes. During the last few years, some of the wells supplying drinking water were closed because their nitrate content had exceeded the maximum permissible contaminant level (11.3 mg L^{-1} NO_3-N).

The monitoring scheme of the project during the study period was designed to obtain information for the different components of the agroecosystem along a transect across the selected watershed (perpendicular to the river across

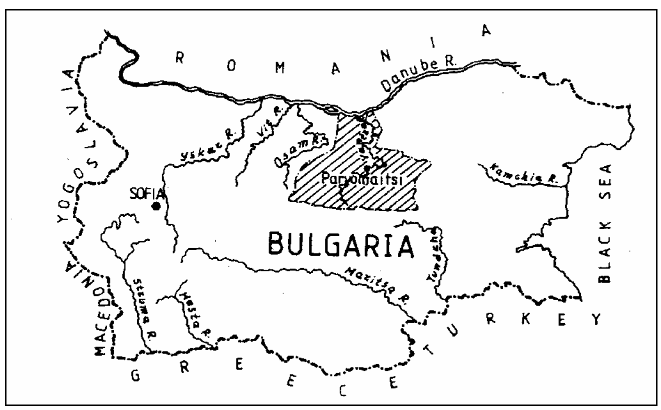

Figure 1. Location of study area.

*Dimitar Stoichev, Dimitranka Stoicheva, and Milena Kercheva, N. Poushkarov Institute of Soil Science and Agroecology, P.O. Box 1369, Sofia, Bulgaria; James Starr, USDA-ARS, BARC, Beltsville, MD 20705; Jerrell Lemunyon, USDA-NRCS, P.O. Box 6567, Fort Worth, TX 76115; Marvin Shaffer, USDA-ARS, P.O. Box E, Fort Collins, CO 80522; and Venelina Koleva, University of Veliko Tarnovo, Bulgaria. *Corresponding author: shaffer@gpsr.colostate.edu

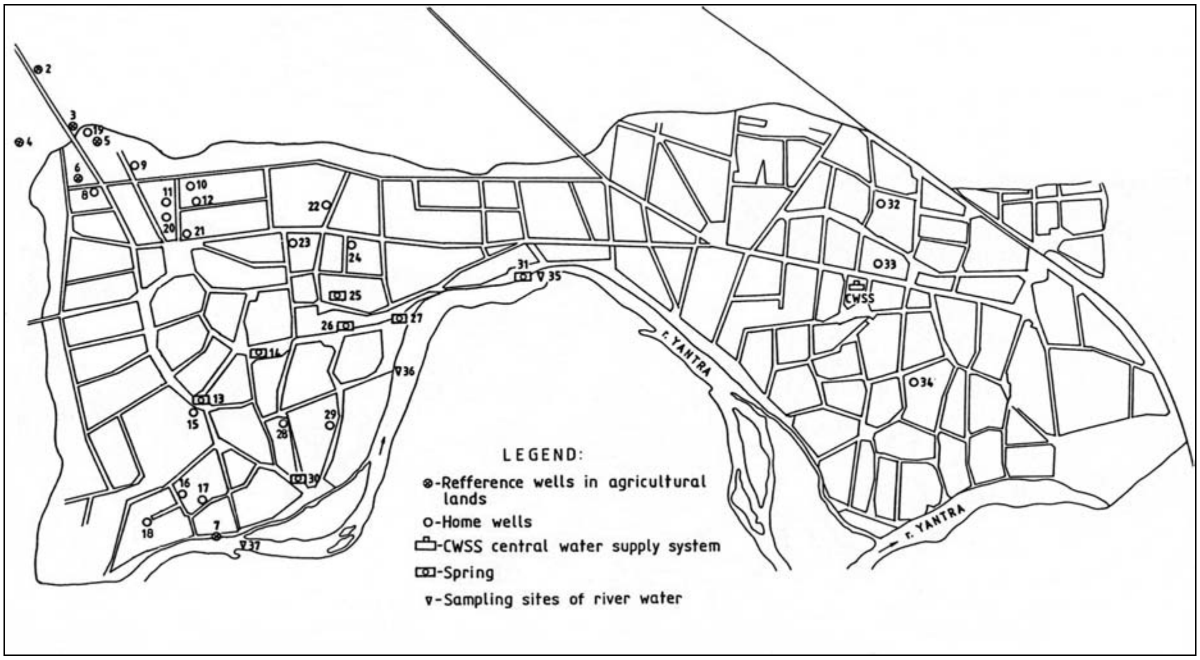

Figure 2. Map of monitored reference wells and home wells in the village of Parvomaitsi.

the cross-hatched area of Fig. 1). Groundwater monitoring of 24 home wells and seven specially built reference wells (Fig. 2) was one of the most important ecological and social parts of the project (Stoichev et al., 1998b). The balance and dynamics of the main nutrients in the plant-soil-groundwater system were assessed from data on the meteorological conditions, chemical composition of the precipitation, soil and soil solution characteristics under different land use, nitrate content of the plants, and groundwater quality (Final report, 1997). The distribution of nitrogen in the underlying vadose zone of the studied Leached Chernozem (Typic Haplostolls) and Alluvial-Meadow soils (Fluvaquentic Haplustolls) was determined in disturbed soil samples taken when the reference wells were drilled (Stoichev et al., 1998d). Agricultural activities were studied on four different types of land use: 1) field crop rotation, 2) pasture, 3) peach orchard, and 4) four household gardens. Cultural practices at these locations included intensive vegetable rotation, irrigation, manuring, and frequent soil cultivation.

The USDA provided equipment to increase the technical level of the whole research process. New equipment was used for additional climate data collection (Campbell weather station, atmometers), deep soil and geological sampling (Gidding Machine), soil solution chemistry under field conditions (suction cup lysimeters), express nitrate measuring (Nitracheck), and water table monitoring. The modeling approach used to estimate the risk for nitrate leaching from the monitored variants of land use was realized using NLEAP - Nitrate Leaching and Economic Analysis Package (Shaffer et al., 1991). The model calculates several indices on the basis of detailed nitrogen and water budgets in two layers - the top 30 cm of the soil and the layer from 30 cm to the depth of the active root zone. Using the event-based time step, it predicts the nitrate-nitrogen available to leach (NAL), NO_3-N leached (NL), Annual Leaching Risk Potential (ALRP), Aquifer Risk Index (ARI), and other indicators of water and solute movement.

RESULTS AND DISCUSSION

Climate characteristics and meteorological conditions of the study period produced low risk for leaching under rainfed conditions. Maximum precipitation typically occurs in May to June (Fig. 3), with mean monthly precipitation exceeding mean monthly evapotranspiration from November through February. Climate conditions for leaching in this region occur mainly in late winter and spring. The risk of leaching in summer months increases in vegetable gardens under irrigation.

The soils in this study are classified as moderately well drained, Leached Chernozem and very well drained Alluvial-Meadow soils. Soil cracks can develop in the Leached Chernozem soil, facilitating downward movement of soil solution in some cases. The physical properties in the top layer of both soils have changed significantly in household gardens as a result of manuring, which is a common practice in the village.

Chemical composition of precipitation during the study period is characterized with neutral reaction, with only a few acid rainfall events recorded. Mean annual nitrogen input with precipitation was about 32 kg ha^{-1}.

Nitrate leaching below the soil root zone and subsequent downward movement through the intermediate vadose zone occurs naturally in the observed pilot area. However, the amount of nitrates leached under both pasture and long-term cultivated crop fields was small and probably would not cause groundwater contamination (reference wells No 2-6, Fig. 4). The large dairy farm located on the Leached Chernozem is a point source of contamination, due to the long-term storage of the farmyard manure before 1990. This

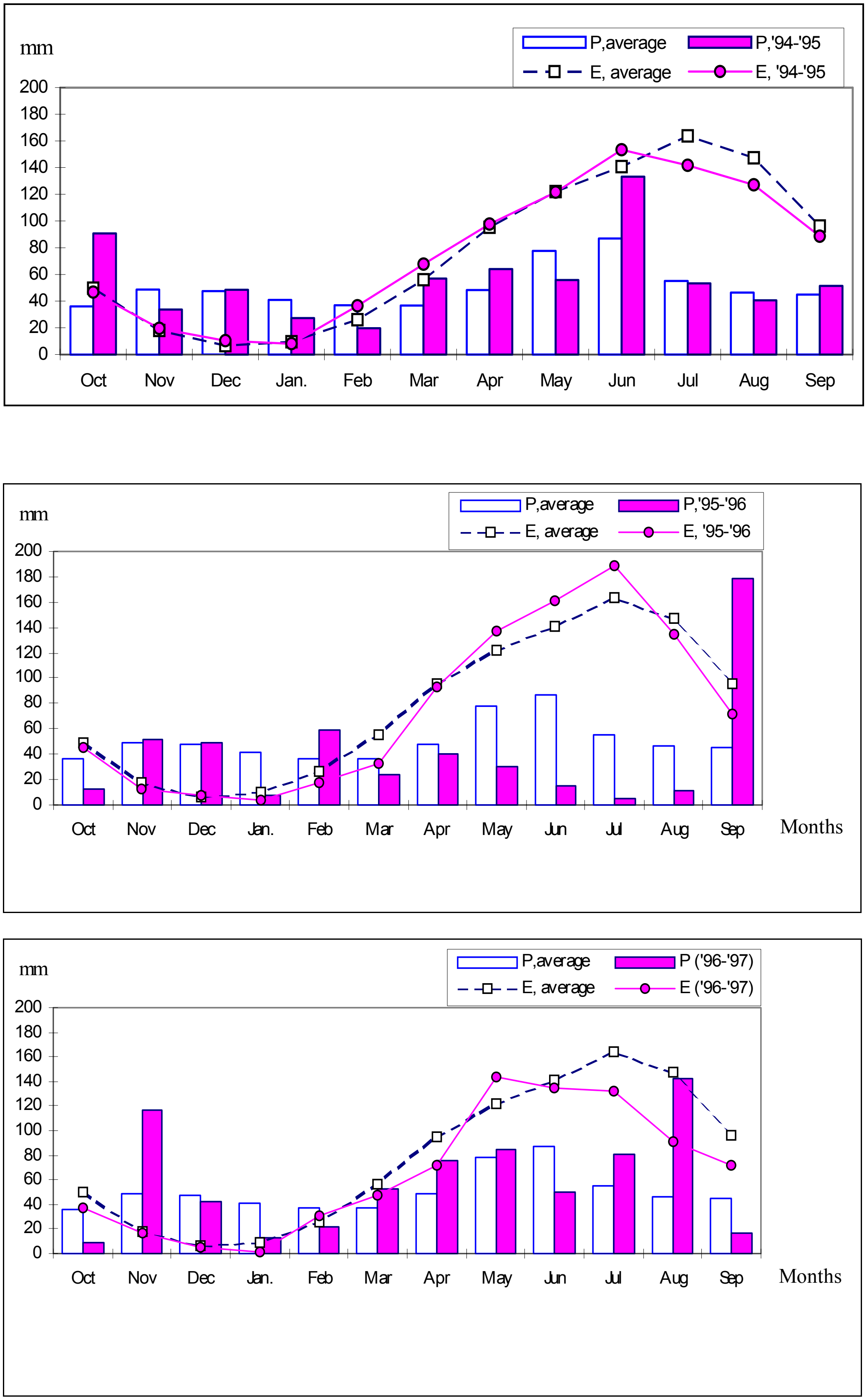

Figure 3. Monthly sums of precipitation (P) and reference potential evapotranspiration (ETr) in Gorna Oryahovitsa during the study period and average for 1951-1970.

Table 1. Mean values of the soil chemical parameters for the period of observation at different land use.

Parameter	Depth	Leached Chernozem				Alluvial-Meadow Soil	
	cm	Pasture	Orchard	Field No1	Garden No2	Pasture	Garden No3
Humus, %	0-30	3.24	1.89	2.17	5.97	1.50	3.24
	30-60	1.76	1.69	1.79	2.57	0.88	1.09
	60-90	0.85	1.36	1.17	1.46	0.29	0.94
pH	0-30	6.0	5.3	4.5	6.6	7.5	6.9
	30-60	5.9	5.3	4.7	6.5	7.5	7.0
	60-90	5.9	5.4	4.8	6.3	7.9	7.2
K_2O, mg 100 g^{-1}	0-30	50	33	25	132	17	41
	30-60	36	29	27	104	19	25
	60-90	29	33	28	85	15	17
Nmin, mg kg^{-1}	0-30	8	9	11	89	3	29
	30-60	6	6	10	63	5	17
	60-90	4	4	10	41	4	12
P_2O_5, g 100 g^{-1}	0-30	7.9	11.5	13.1	150.6	11.1	97.1
	30-60	1.7	6.4	6.0	82.5	8.2	54.1
	60-90	0.4	0.8	3.1	35.0	4.0	25.6

Table 2. Predicted annual NO_3-N available to leach (NAL), NO_3-N leached (NL), leachate volume (LP) and leaching depth below the root zone (D).

Crop	Year	NAL, kg ha^{-1}	NL, kg ha^{-1}	LP, mm	D, m
winter wheat	1994-1995	102	-	-	-
winter wheat	1996-1997	91	13	76	0.46
maize	1994-1995	52	7	51	0.30
maize	1995-1996	41	21	76	0.55
maize	1996-1997	133	49	152	0.94
tomato (garden 1)	1996-1997	287	144	229	1.40
tomato (garden 2)	1996-1997	1262	655	280	1.80

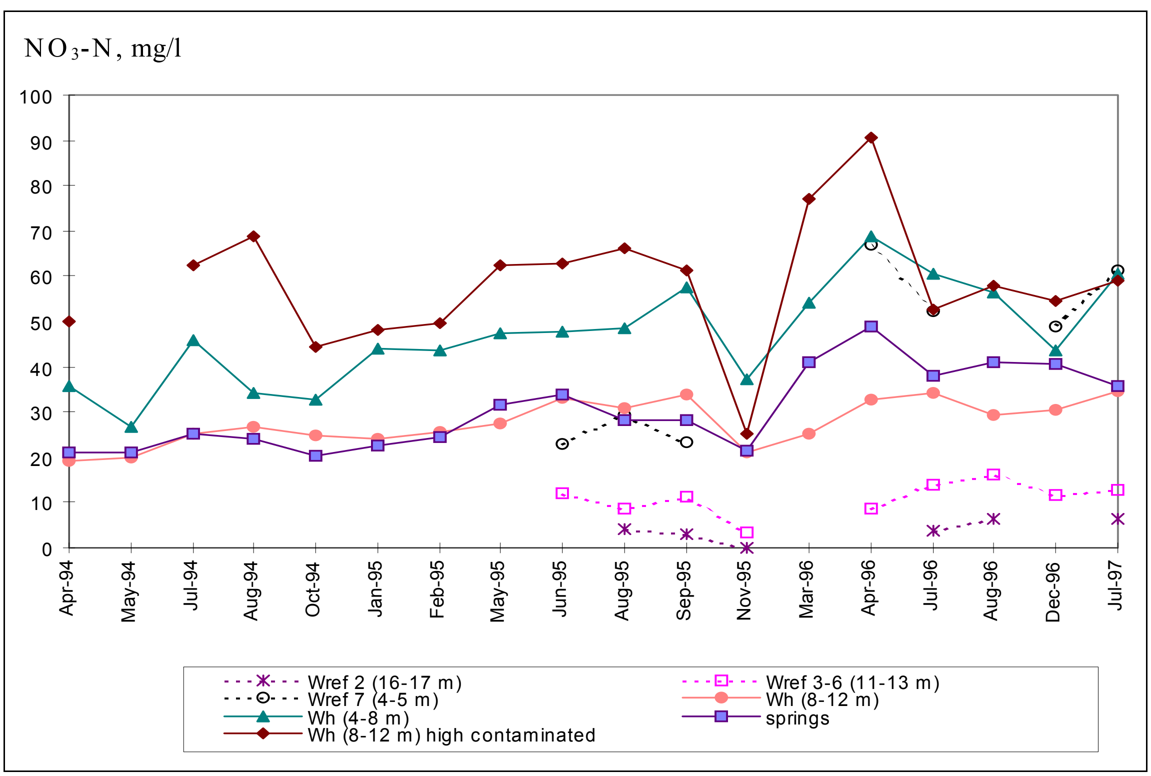

Figure 4. Dynamics of nitrate-nitrogen of groundwater in home wells (Wh), reference pipe wells (Wref), and springs.

hot spot, containing about 1200 kg ha^{-1} residual nitrogen in the geological profile, has not spread over a large area due to low rates of water exchange between geological layers.

During the study period, the rate of fertilizer application on the field crops (20-60 kg N ha^{-1}) did not present a substantial source for high residual nitrogen accumulation or groundwater nitrate contamination. However, the household gardens are a subject of high nitrogen loading, creating potential point sources for nitrogen pollution of shallow groundwater (Table 1). The residual mineral nitrogen content in the gardens is about 2-5 times higher than the field crop rotation area. The high annual rate of manure application (184 kg N ha^{-1}) in some household gardens is the main reason for soil profile enrichment with nitrogen. A significant source of residual nitrate-nitrogen accumulation is the frequent irrigation with groundwater from home wells. The nitrogen input by irrigation in the first Yantra River terrace of the Alluvial-Meadow soils amounts to 90 kg ha^{-1}, which is enough to supply nitrogen uptake by the main vegetable crops.

Groundwater monitoring provided the basis to group these wells into six groups according to the depths of the groundwater table, types of the wells and the groundwater quality data (Stoichev et al., 1998b, 1998c). Mean nitrate-nitrogen in the groundwater of the home wells was 2 to 7 times the Bulgarian maximum permissible contaminant level of 11.3 ppm (Fig. 4). The groundwater of the first Yantra River terrace is most vulnerable to nitrate pollution because of the higher water permeability of the coarse textured Alluvial-Meadow soil, shallow groundwater, and high intensity of agricultural practices.

Application of the NLEAP model using basic data from the pilot area showed that the correspondence between predicted and observed values was sufficient (Stoichev et al., 1998a) for evaluating the fate of nitrate-nitrogen in the monitored watershed. Some of the annual indexes calculated by the model are presented in Table 2. The results show that the highest risk factors for nitrate-nitrogen leaching are the fallow state of fields, and high rates of manuring and intensive irrigation in the gardens. The leaching in the non-irrigated fields occurs mainly during the fallow period from December till April (Fig. 5 and 6), while the intensively irrigated gardens are commonly maintained near "field capacity" resulting leaching in summer months too. Vegetable crops such as irrigated tomato showed higher rates of nitrate leaching. Field crops such as winter wheat grown under non-irrigated conditions showed relatively little nitrate leaching.

To avoid the high residual nitrogen accumulation in the soil profile as a potential source for groundwater contamination, farmers have to maintain a proper nitrogen balance. They should take into account nitrogen input by precipitation, irrigation, plant residues, and home organic waste, which in many cases are enough to fully supply nitrogen uptake by the yield production.

Poor home solid waste management is the main reason for the river-bank pollution and direct river-water contamination by different solid waste components.

The lack of a centralized sewage system and the use of uncontrolled septic tanks for home liquid waste collection

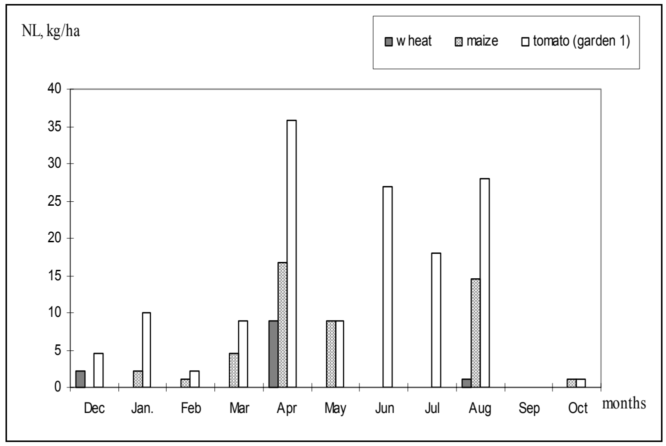

Figure 5. NLEAP NL predicted values for 1997 at different land use.

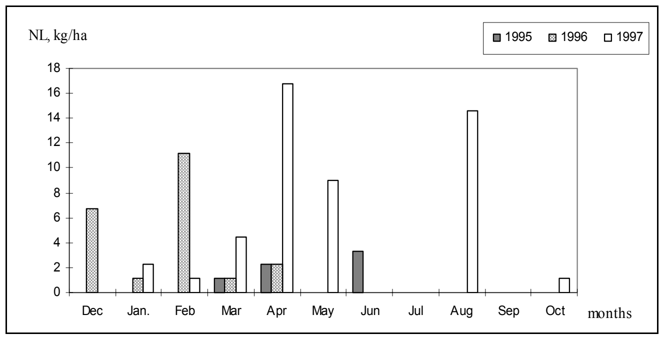

Figure 6. NLEAP NL predicted values for 1995, 1996 and 1997 under maize.

are the reasons for direct microbiological contamination of many home wells and may also contribute to nitrate contamination.

The goal of the educational program of the project was to help the villagers to minimize groundwater contamination by improved management of their organic and home solid wastes. (Table 3). For this purpose, specialists were engaged from different state and local authorities. On the basis of the scientific literature provided by the US team, villagers were issued brochures concerning collection, storage and use of manure, organic residues composting, and protection of drinking water. The American colleagues demonstrated the movement of the water with a special groundwater model, which showed that all wells in a village are connected in a continuous system.

The organized social inquiry was found to be a promising method for receiving needed information and a good way for personal education. The questions included in the inquiry encouraged the people to think about these problems. With the help of this inquiry, we established that most of the people considered their knowledge of drinking water quality as insufficient. A very small number of them clearly understood the connection between the amount of the fertilizer and manure applications and the excess nitrate content in their vegetables and drinking water.

The restoration of a part of the riparian zone was realized as a way of involving villagers in the river water protection

Table 3. Educational program of the Agro-environmental water quality program in the Yantra River basin.

Educational aspects	Means
1. On site demonstration and education of the villagers	Lectures, discussions Demonstration (groundwater model, plant, soil and groundwater sampling in the home vegetable gardens) Social inquiry Brochures Providing solid waste containers Restoration a part of the riparian zone
2. Graduate student	Participation in field study trips Preparing material for brochures Conduct social inquiry Defend thesis
3. Training courses for specialists	Scientific exchange Model simulations

from direct pollution by solid waste, and as a biological filter for the nutrients in the surface runoff and groundwater.

The specialization of Bulgarian scientists and a graduate student in agroecological monitoring on a watershed level were accomplished during the short-term training courses in the USA and during the visits of US scientists in Bulgaria.

CONCLUSIONS

The cooperation between USDA and Bulgaria was very helpful and fruitful in the organization of this ecological project, which contributed to the large Danube River program. The main results of the joint project were the assessment of agricultural related sources of groundwater nitrate contamination and the realization of the educational program.

As a social benefit of the joint work, some households started to reduce the nitrogen input in their gardens and they began to produce vegetables with acceptable nitrate content. The received information and obtained experience will be used as a methodological approach in further environmental impact assessments on a watershed level.

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