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AGRICULTURAL LAND USE, WATER QUALITY CONTROL AND RELATED BEST MANAGEMENT PRACTICES: LAKE VICO (CENTRAL ITALY) CASE STUDY[1]

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ABSTRACT

For some years now, the growing rate of point sources depuration and the diffuse sources of agrochemicals have become an issue of high relevance for environment safety. Lake Vico basin (Central Italy, about 60 km northern to Rome, fig.1) is an optimal site to investigate this problem, the increasing of lake trophic state, due to diffuse agricultural nutrient sources, above all phosphorus, being clear.

Phosphorus is mobilized from agricultural land bounded to sediment (Sharpley *et al.*, 1994) and, in fact, one of the more severe environmental problems for this area is the large quantity of sediment that heavy rainfalls produce running on agricultural land. This problem was stressed in the 1970s, when the agricultural systems became intensive and almost all the old extensive arable land (above all wheat) were substituted with specialized, intensive orchards (hazelnut: Leone and Ripa, 1998).

Thus, this territory needs a plan for Best Management Practices (BMPs) and model approach is fundamental to assess them. In particular, it is necessary to evaluate phosphorus export zones that contribute most to environmental concerns, to plan related BMPs and to evaluate their effectiveness.

This was done by simulating the response of the agricultural system (in terms of water quality threat, in this case soil erosion and phosphorus loss to water) to the first adopted BMP, which consisted in leaving weeds under intensively tilled hazelnut trees, to protect the soil from erosion. It is a BMP, which has been adopted for ten years, by 92/2078/CEE arrangement support.

The simulation was based on GLEAMS (*Groundwater Leaching Effects of Agricultural Management Systems*; Knisel, 1993), a management field scale model, whose results have been basin scale extended, by a simple regression model which allowed, with the aid of a GIS, to extend results to the wide area.

This approach allowed critical areas to be highlighted and to evaluate, spatially, the efficiency of the adopted BMP, which means, in other words, to have an efficiency evaluation of support funds to sustainable agriculture and, above all, their most suitable spatial allocation. This last result seems fundamental in terms of land planning evolution, because, at the present, funds to support EU policy have a homogeneous distribution (i.e. without a geographic evaluation of their efficiency) and this often means that in critical areas they are insufficient and in non-critical areas they are wasted.

1. INTRODUCTION

For some years the growing rate of point sources depuration and the deterioration of water quality have generally been attributed to increased non point pollution source loads, which are notoriously consequences of land use (Haycock and Muscutt, 1995; Mattikalli and Richards, 1996). For example, in Italy, NO_3 groundwater concentration very often exceeds attention limit for drinkable water (25 mgL^{-1}) when recharge comes from intensive agriculture land. But nitrate in water is a European-wide problem: in fact, a specific directive was issued, in 1991 (91/676/CEE directive).

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Fig. 1. The Lake Vico

Agrochemicals (nitrogen, phosphorus and pesticides) move from agricultural land into water bodies in two essential ways (Novotny & Olem, 1994): nitrogen, in the very soluble nitrate chemical form, prevalently reaches groundwater by leaching (transported by percolating water); phosphorus prevalently reaches surface waters, bounded to eroded sediment (Sharpley *et al.*, 1994). The behaviour of pesticides is intermediate, depending on the particular substance solubility and soil-water partition characteristics. In any case, the engine is water movement, while the carburant is agricultural land use and, then, non-point pollution is the consequence of the complex interaction between hydrological situation, land management and the environmental system (meteorological setting, soil kind, topography etc.).

Consequences depend upon the nature of sources: diffuse in space, intermittent in time and closely related to land use, not only from loads point of view (nutrients and pests export from agricultural land), but also from the system vulnerability point of view: climate, soils, topography or presence of buffer systems (riparian vegetation, hedges and wetlands that intercept sediments and runoff and favourite water denitrification, for example) can completely change the real impact of the same load. This means high complexity and surely not linear (and often very chaotic) behaviour in sources production and a context characterized by high uncertainty, where only few points can be considered sure:

1. Key point of the problem is land use management.
2. Experimental responses are limited by chaotic behaviour of the system monitored and, then, only very long time knowledge and monitoring could be sufficient to assess processes and concerns experimentally (perhaps, and, in any case, how long is not known).
3. The model approach is consequently fundamental, but it needs focus for land use and special attention in managing its uncertainty, which does not consist only in limits of ability of models to interpret reality, because the same reality has an erratic behaviour. Consequently, land managers will not always have the possibility to directly verify models (and, perhaps, in many cases, it could be a time consuming chimer). Then, verification of the models cannot come from the classical approach of deterministic sciences, based on some experimental data related to single phenomena (for example: rainfall-runoff events and consequent soil yield and chemical loss), but would aim to interpret the anthropogenic-environmental system and the long term response to land use (for example: a freshwater eutrophication in consequence of basin land use). In fact, long term mean values generally attenuate the variability typical of single events and, hence, simulations of models will be less affected by noise and uncertainty.

The study area (Lake Vico basin, Central Italy, about 60 km north of Rome, fig. 1) is an optimal site to investigate these kinds of problems and it has already been a subject for other studies, mostly aimed at defining planning criteria to control lake trophy evolution. They mostly underlined the environmental peculiarities of the place, first of all the lake itself, whose trophic state is increasing (Franzoi, 1997), mostly due to heavy soil erosion and related non-point sources of phosphorus from agricultural land (Leone and Marini, 1993). Phosphorus is mobilised from agricultural land bounded to sediment and, in fact, one of most serious environmental problems for this area is the large amount of sediment that heavy rainfalls produce running on agricultural land (Leone, Preti and Ripa, 1997). This problem was stressed in the seventies, when agricultural systems passed from the traditional extensive ones to the present intensive and almost all the old extensive arable land (above all wheat) was substituted with specialized hazelnut trees.

The Lake Vico basin has also typical problems of agricultural non-point pollution. In these cases, the first managing topic consists in the necessity of an integration of landscape characteristics (climate, topography, land use etc.) to establish critical zones where an agricultural land use change with an optimal management will be necessary (Garnier *et al.*, 1997). In other words, this means adopting a plan of Best Management Practices (BMPs), a series of integrated practices at field scale and basin scale. In the first case, BMPs can consist in reducing fertilizer inputs, ameliorating soil structure (i.e. reducing soil erodibility and increasing soil water retention capacity), crop rotations with soil covering during the rainy season etc. (Stewart *et al.*, 1975; US-NRC, 1993 ; Ongley, 1996). At basin scale it is necessary to impede soil and nutrient runoff towards water bodies, by the so-called landscape structures, such as vegetated hedges around cultivated fields, or buffer strips along the waterways, bogs and wetlands at the interface between freshwaters and land. These structures intercept sediment and agrochemicals, but can also take up nutrient or allow denitrification (transforming nitrogen in the soil in gaseous form), favouring denitrifying bacteria growth (Correll, 1996).

This is the key for land planning: pursue the best land order, integrating more BMPs and taking care of land owners' acceptability, which means spatial allocation of critical areas ("hot spots". see Schoumans *et al.*, 2001) whose last, but not least, result is the most rationale fund allocation, aimed at agricultural sustainability. Models have to be used to aid this objective, aiming to assess environmental efficiency of the planned order, evaluating land processes by complex anthropogenic-environmental system simulation.

In the specific case of Lake Vico, it is necessary to evaluate phosphorus export zones that contribute most to environmental concerns, to plan related BMPs and to evaluate their effectiveness.

The final aim of the research is then to improve the understanding of nutrient export related to land use, proposing simple ways to manage the typical complexity of this topic. In this work, a compromise way between detailed simulations and simple approach (at basin scale) is proposed, to evaluate the effectiveness of the proposed BMP.

2. MATERIALS AND METHODS

The study area is a igneous rocks basin (40,8 km²), dominated by the lake (12,1 km²) which has a particular sensitivity to eutrophic and pollution problems, due to the following factors (Istituto Italiano Idrobiologia, 1971; Franzoi *et al.*, 1997; Leone, Preti and Ripa, 1998):

Geology: the area is young from this point of view, volcanic activity was exhausted only about nine hundred thousands years ago. It is then normal to expect an erosive phase in the landscape evolution of the whole basin. This means a less hierarchised hydrographic net and consequent higher peak runoff; more frequent recurrence of diffuse runoff and erosion and consequent more destructive water action (Leone *et al.*, 2002).

Morphology: the lake has no tributary, the mean water renovation time is high (17 years) and the slope is very steep in most places.

Ecological water body conditions: seasonal stratification of water temperatures and the trend to anoxic conditions of lake epilimnion, which favour particulate phosphorus release from bottom sediment.

Land use: a large amount of agriculture is practised in erosive risk zones. Furthermore, the principal crop (hazelnut) needs bare soils to optimise mechanical harvesting.

These general considerations are confirmed by monitoring, which stated the relevant increase of total phosphorus water concentration (fig. 2, Franzoi, 1997).

It is then necessary to manage agricultural systems with the aim to transform them in to sustainable ones from the point of view of lake tolerable trophic state. Consequently, the first step in the study was assessment of land use risk, translated in a map of erosive risk (Leone, Preti and Ripa, 1997), which may be the basis of an informative system for best land management.

Provided that land use has a fundamental role in environmental lake status, land use evolution is fundamental as well to highlight the reasons that led to water trophy growth. In consequence, land use evolution has been evaluated by interpretation of 1940, 1954, 1971, 1983 and 1994 aerial photos, whose results (for 1954, 1971 and 1994) are reported in table 1, while the maps for 1954, 1971 and 1994 are reported in fig. 3.

1994 is practically the same as the present land use, because there were no substantial changes.

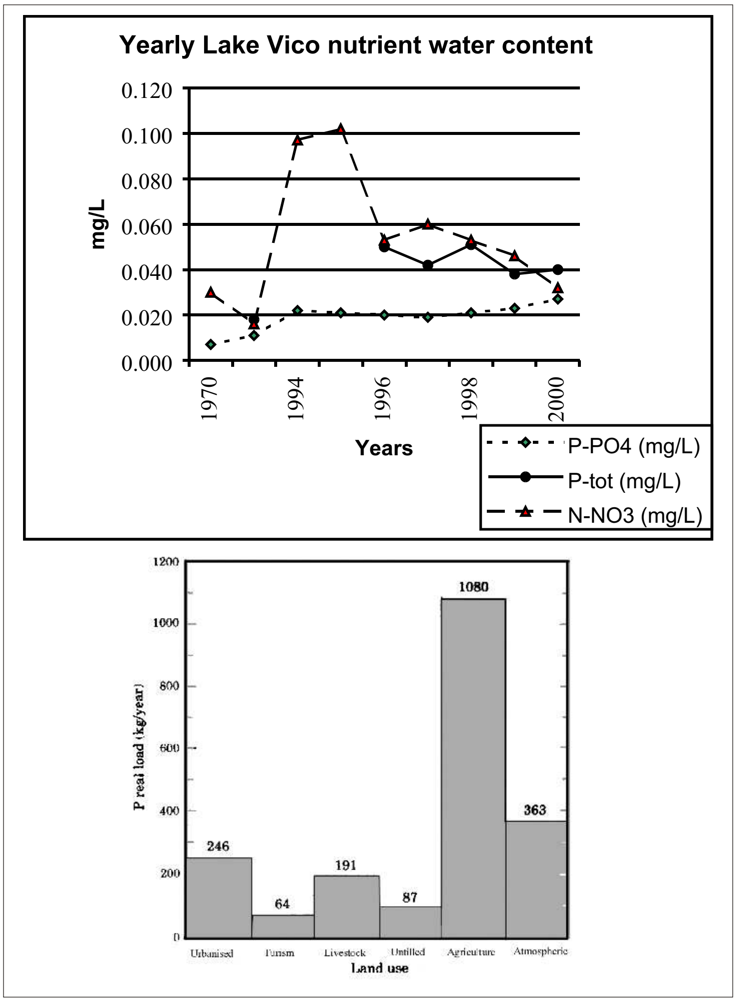

Fig. 2. Nutrient water content and phosphorus loads into the Lake Vico basin.

Table 1. Land use time evolution for Lake Vico basin.

Year	Arable [ha]	Hazelnut [ha]	Chestnut [ha]	Urban [ha]	Coppice [ha]	Bush [ha]	Wood [ha]	Wetland [ha]
1954	1027	411	115	10	85	11	1179	92
1971	469	891	94	58	123	50	1147	72
1994	151	1225	120	79	63	60	1171	151

Table 2. Cross tabulation of 1954 land use (columns) vs. 1971 land use (rows).

	Arable	Wetland	Hazelnut	Coppice	Bush	Chestnut	Wood	Urban
Arable	442	20	9	0	0	5	0	0
Wetland	0	72	0	0	0	0	0	0
Hazelnut	482	0	353	14	0	42	0	0
Coppice	0	0	0	13	65	0	0	46
Bush	39	0	0	0	0	11	0	0
Chestnut	17	0	19	6	0	53	0	0
Wood	0	0	0	0	0	16	1124	7
Vineyard	19	0	0	0	0	0	0	0
Urban	28	0	18	0	0	0	10	3
Cane	0	6	0	0	0	0	0	0

Table 3. Cross tabulation of 1971 land use (columns) vs. 1994 land use (rows).

	Arable	Wetland	Hazelnut	Coppice	Bush	Chestnut	Wood	Urban
Arable	120	27	0	0	0	0	0	0
Wetland	12	50	0	0	0	0	0	0
Hazelnut	236	0	881	51	0	49	0	0
Coppice	0	0	0	1	65	0	62	0
Bush	17	0	0	0	27	0	16	0
Chestnut	24	0	0	0	19	50	27	0
Wood	0	0	0	71	0	16	1100	7
Vineyard	0	0	0	0	0	0	0	0
Urban	13	0	0	0	0	0	7	59
Cane	0	6	0	0	0	0	0	0

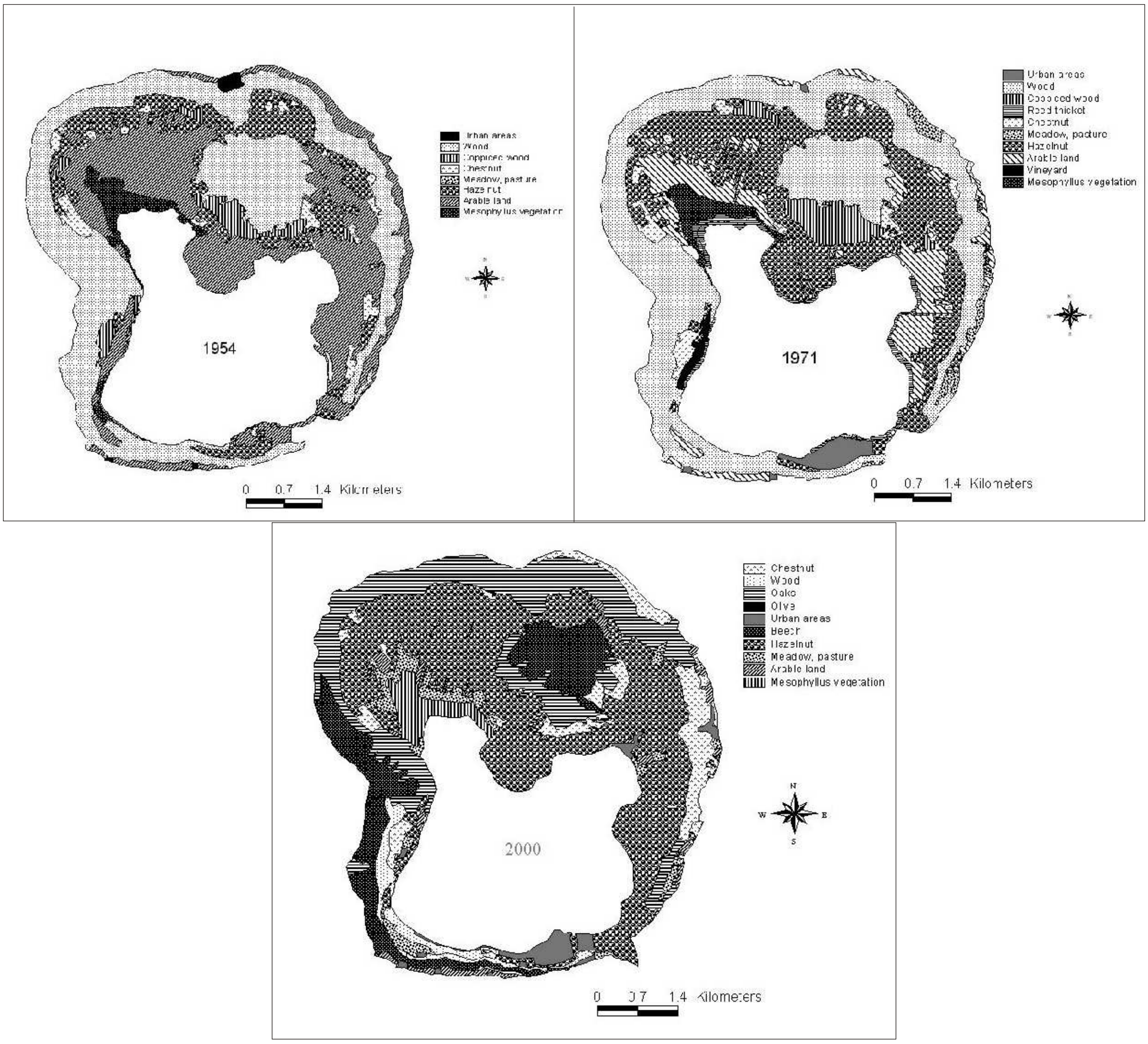

Fig. 3. Lake Vico Basin land use in 1954, 1971 and 2000, respectively.

These land cover time series maps assessed three focus points in the recent history of Vico basin (but, also, in the wider north Lazio area):

<u>1954</u>: conventional (practically since medieval age) extensive agriculture, economically very poor.
<u>1971</u>: transitional phase of shifting from extensive to intensive systems (economically rich), i.e. the "green revolution" of the Sixties and Seventies of the last century.
<u>1994</u>: the agricultural landscape transformation is completed and, practically, identical to the present.

Since 1994 there has been no substantial land cover evolution, but relevant change in the management of agricultural cover (hazelnut fields), thanks to 92/2078/CEE support, which has led to the BMP (weeds cover) adoption, in practically every farm. Doubtless this is a soil conservative practice, whose usefulness has been evaluated in terms of soil erosion by the USLE (Wishmeier & Smith, 1978) classical approach, applied to the wide area, thanks to GIS technology, and repeated for the three main scenarios: extensive and intensive, conventional agriculture; present intensive, but also conservative management, CEE supported (Leone and Ripa, 1998).

This work assessed the role of land use and land cover in basin sediment production, but also the necessity to manage the very high erosion risk areas better, whose sediment production remains non sustainable. In other words, the 92/2078/CEE supports are useless in not erosive risk zones, and, in zones of very high risk, they are insufficient for effectively conservative and sustainable agriculture and land order.

From the point of view of the use of models, USLE revealed a satisfactory approach to evaluate the general impacts of land use evolution (since 1954 to the present day), but more refined management (less rigid) basin scale models are necessary to plan effective BMPs. Then, SWAT (*Soil and Water Assessment Tool*, Arnold *et al.*, 1996) was tested. But this application was unsatisfactory from the point of view of sediment yield and, consequently, of phosphorus export, the main environmental concerns of the Vico basin. While hydrological results of SWAT simulations are congruent with the real situation, sediment yield is clearly underestimated, because the estimation of the topographic factor is too low. This is probably due to the very steep slope in the higher parts of the basin, which abruptly stops at the bottom of the hill, becoming suddenly flat. This means that the sub-basin approach of semi-distributed models such as SWAT can be inadequate, because it would require a very refined DTM and a division in an enormous and unpractical number of sub-basins. The 25 m raster of the present DTM revealed to be insufficient, but very rarely, in practical applications, more refined information will be available.

Thus, a new approach for critical areas was developed. It is based on field scale runs of GLEAMS, whose results permitted evaluation of sediment (A) and phosphorus (P) yield for different slopes, the main parameter influencing the processes.A simple regression model was built, correlating land processes to slope (Leone *et al.*, 2001).

For conventional agricultural management, for example, equations are:

$$A_{conv} \quad 7,7\,x^{1,07} \qquad P_{conv} \quad 13,42\,x^{0,23} \qquad [1]$$

where A is the sediment yield (Mg/ha/year), P is phosphorus export (kg/ha/year), x is the slope (dimensionless). These simple formulas can be considered meta-models (a meta-model is a simple approximation to a complex simulation model: Schoumans *et al.*, 2002), which allow GLEAMS results to be extended to the basin, using a GIS and a DTM and which allow a simple landscape zoning. In fig. 4 the related maps are shown. Advantages of this approach are the possibility to have:

- details from a field scale model such as GLEAMS, and, contemporarily, from the basin scale, thanks to GIS and eq. 1;
- territorial zoning by critical areas, which, comparing different landscape zones, does not need a very refined model calibration and validation, also in the very frequent cases of lack of experimental data and long series monitoring;
- critical area zoning in a completely distributed approach (cell by cell), which, in cases, like this, where management and BMPs plan is the focus, is more effective than the semi-distributed or lumped approach.

Furthermore, BMPs' effectiveness evaluation is possible, comparing scenarios with and without planned BMPs. For example, in the Vico case, considering herbs under hazelnut trees, economically supported by 92/2078/CEE arrangement, an environmental efficiency measure can be associated to funds' employment, defined by the following formulas:

$$E^{A}_{BMP} \quad \frac{A_0 \quad A_{BMP}}{A_0} \qquad\qquad E^{P}_{BMP} \quad \frac{P_0 \quad P_{BMP}}{P_0} \qquad [2]$$

where:

E^{A}_{BMP} effectiveness of the BMP from the soil erosion (*A*) point of view, ratio between soil erosion reduction, having adopted the BMP ($A_0 A_{BMP}$), with traditional tillage soil erosion (A_0).

E^{P}_{BMP} effectiveness of BMP from the phosphorus export (*P*) point of view, ratio between P export reduction, having adopted the BMP ($P_0 P_{BMP}$), with traditional tillage (P_0).

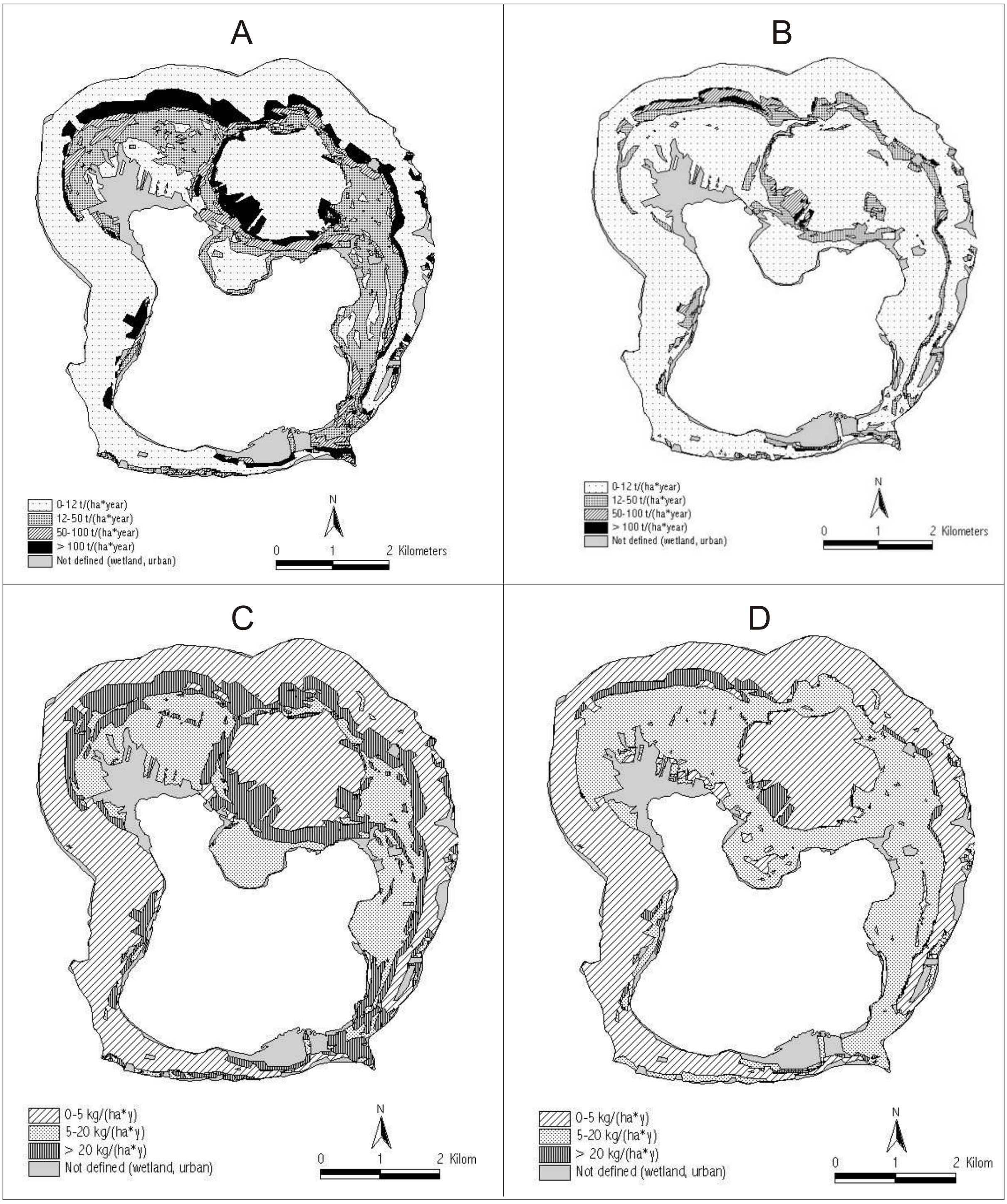

Fig. 4. GLEAMS simulated soil and phosphorus yield: conventional (A, C) and with BMP (B, D).

A basin scale extension of this information, using the same GIS-GLEAMS coupling approach, is also possible. Results for phosphorus are reported in fig. 5.

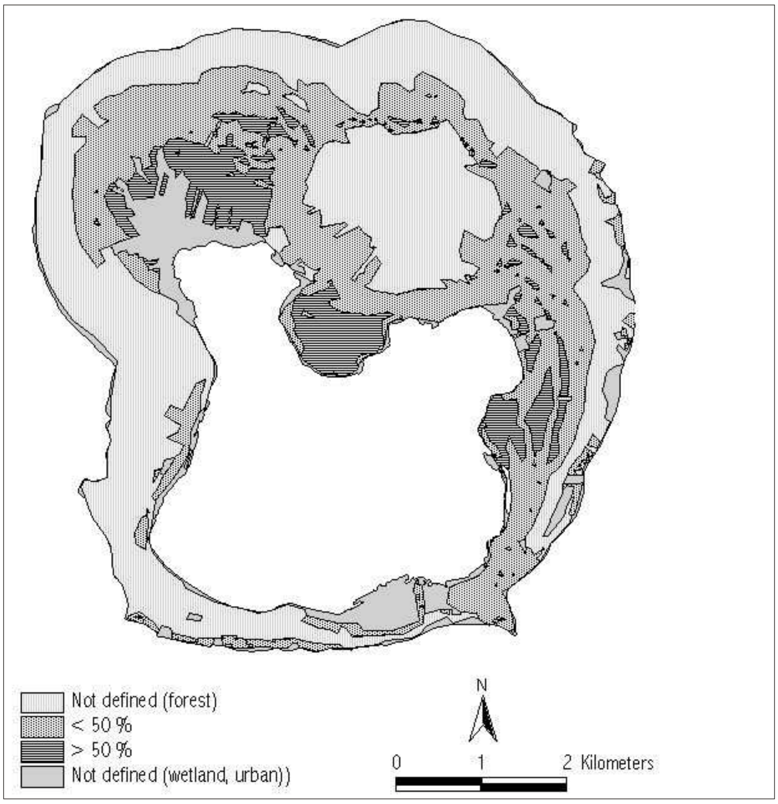

Fig. 5. BMP effectiveness for soil and phosphorus yield.

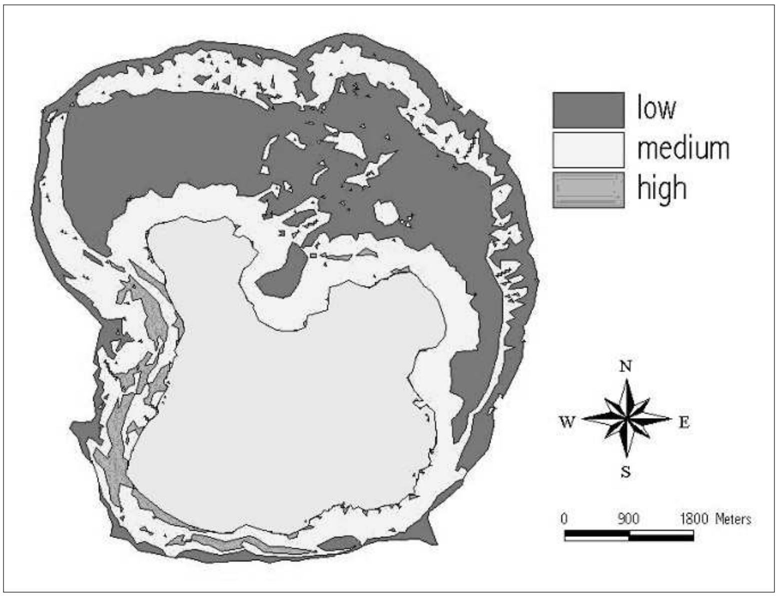

Fig. 6. Translocation capability of sediment (and phosphorus).

But GIS technology also gives the possibility to refine the approach better. In fact, results in fig. 4 regard A and P yield for each cell and not the export into the lake, the real impact of land use, that can be plus or minus reduced for effects of factors such as distance from waterways and change of slope (slope length). Thus, the concept of translocation capability of sediment (which also means phosphorus) has been introduced and evaluated, considering the following aspects:

distance from waterways;
distance from the lake perimeter;
the topographic, LS factor of USLE.

Fig. 6 shows the results.

The combination of this last map and the critical areas of fig. 4 gives the real impact of land use on the lake and a measure of effectiveness of control measures on the landscape (fig. 7).

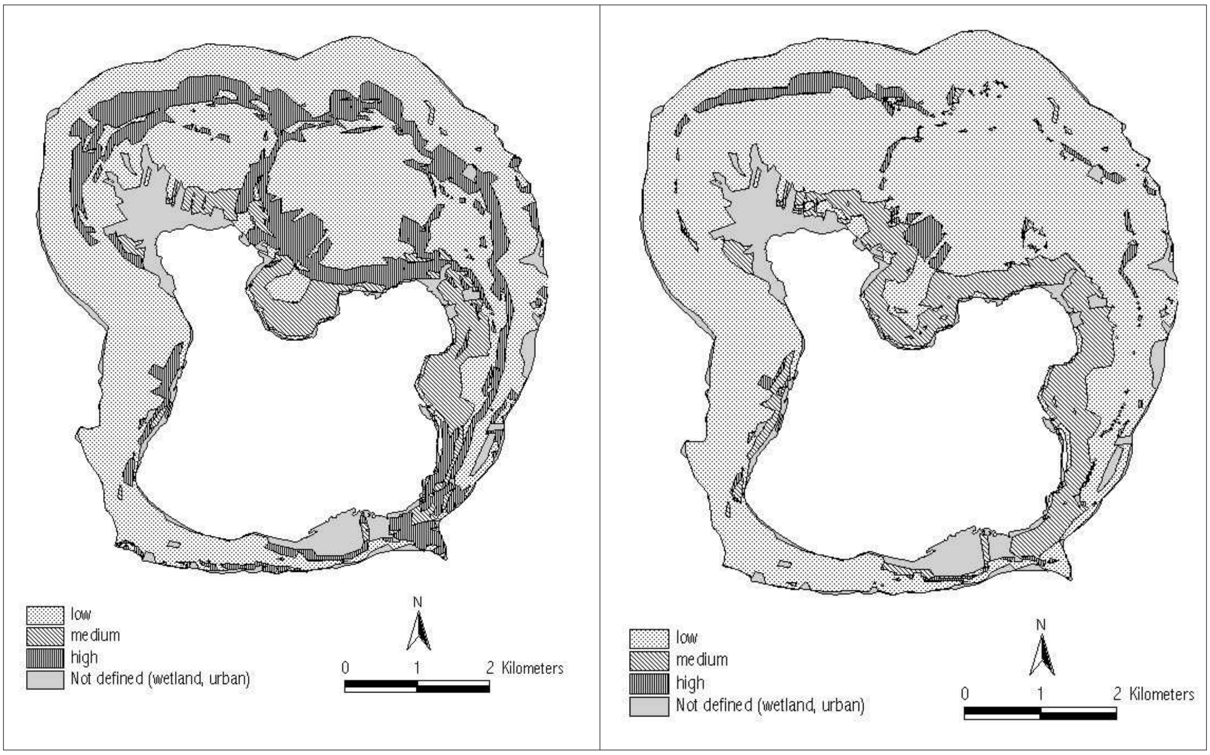

Fig. 7. Critical areas by matching soil and phosphorus yield and translocation capability.

3. CONCLUSIONS

The start of this work was the necessity to run dynamic management models to basin scale and the consequent critical areas definition. GLEAMS being an effective tool to manage non-point pollution from agriculture practices, but it being a field scale model, a method to extend its results to basin scale has been experimented, using a simple meta-model.

It allows highlighting of critical areas not only from the point of view of cell by cell simulations, but also considering translocation capability of sediment and phosphorus yield at field scale. Obviously this is a fundamental step, because factors such as slope changes, distance from waterways and from the lake influence the real value of impacts.

This kind of work is the base to better manage land planning aimed at non-point pollution control, related BMPs and economic support for their implementation.

In the present case, fundamental results in this sense have been reached: maps in fig.4 and 5 show the effectiveness of the proposed BMP (herbs under hazelnut trees) in terms of soil erosion and, above all, phosphorus: it is clear that these maps also give a quantitative measure of effectiveness of funds used to support environmentally compatible agriculture.

This approach (completely distributed) seems more satisfactory than the basin scale application, such as SWAT, which will necessarily be lumped or semi-distributed and, then, not satisfactory to interpret management necessities and to consider complexity of the system: above all topography, but also the lake surroundings, which, logically and clearly from fig.4 and 5, are fundamental for controlling phosphorus export into the lake. To divide the basin into sub-basin, although small, does not allow a satisfactory management of the strategic lake surroundings.

Hence the method seems good for comparisons between scenarios and related planned BMPs. But it also seems encouraging for more quantitative predictions, the results being well suited to expectations and to the hydrology of the basin (well known). Further work is in any case aimed at greater checking of quantitative results and consequent refinement of meta-model.

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