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Abstract. The impact of implementing different best management practices (BMPs) at the small watershed scale were examined for the Petzenkirchen catchment in Austria and Lake Vico in Italy, in terms of data needs, hydrological processes, tools and models involved. Identification of critical source areas for targeting soil and phosphorus losses turned out to be crucial for correct allocation of BMPs. Comparison of environmental effectiveness and costs, both calculated using various modelling approaches, enabled us to compare different levels of introducing BMPs ecologically and economically. Within each catchment, small areas of land tended to be the source of disproportionately large amounts of pollution . Therefore, confining mitigation to these areas costs less than targeting wider areas. This suggests that a policy for environmental programmes should be focussed on hydrological units and critical source areas within these units instead of introducing universal controls - the ‘watering can’ principle - as practised today.

Introduction

There is general agreement that agricultural activities are a major nonpoint source of nutrients reaching water (Novotny & Chesters, 1989; Sharpley et al., 1999; Rekolainen et al., 1999). This problem mainly occurs in watersheds with a high percentage of intensively managed land and associated high rates of fertilizer application. In particular, eutrophication, which is caused mainly by excessive input of nutrients (especially P) from farming activities, has been identified as the most critical problem impairing the quality of surface waters (Sharpley et al., 1999). The special features of nonpoint source pollution makes the design of mitigation policies difficult (Shortle et al., 1998): the environmental agencies are faced by a wide range of potential polluters, whose individual emissions cannot be measured with accuracy at reasonable cost, and thus the allocation of the mitigation effort among the potential polluters is particularly difficult.

Agri-environment schemes are bundles of best management practices (BMPs) which are proposed by legal authorities to help farmers manage their activity in an environmentally-friendly way. The programmes are recommended to farmers on a voluntary basis, offering incentives to compensate the costs of implementation. For a particular environmental concern, there may be many BMPs that could be recommended (NERC, 2002). Regulators need to select those practices they want to support and they need to select the terms under which they are supported. As national agri-environmental schemes are currently offered on a voluntary basis in Italy, Austria and various other European countries (Italian Regional Administrations, 2000; ÖPUL-2000, 2005; MAF, 1999), farmers have to compare the advantages and disadvantages of participation and decide if the scheme would benefit them. Farmers reach their decisions by personal judgement and regulators currently use the farm level for decision making. However, the relevant scale to reach environmental goals for water quality is not the farm but the watershed scale. Here the problem arises that for different environmental pollutants, different areas within the watershed might be better suited to target each hazard. Moreover, for a single pollutant different areas within a watershed will pose a different degree of risk of causing pollution. In order to obtain environmental effectiveness, the concept of critical source areas within watersheds has been used in various approaches (e.g. Gburek et al., 2000; Heathwaite et al., 2003; Bontems et al., 2005a).

Costs of implementing BMPs have consequences for their actual environmental effectiveness. Farmers are less likely to adopt high cost BMPs even though they may be the most effective. Implementation costs for particular BMPs are equally important for regulators, as they usually want to mitigate pollution at least cost. Therefore, comparison of candidate BMPs on cost-effectiveness criteria should be an important step in the development of any agri-environmental scheme so that a trade off between economic optimization and groundwater loadings can be arrived at (Lee, 1999). Heilman et al. (1997) suggested that voluntary programmes to improve the quality of water affected by agriculture should target the farms that have an economic incentive to adopt management systems with water quality benefits. Kraft & Toohill (1984), who used the concept of a ‘representative farm’ to explore the impacts of conservation practices, indicated that these practices could increase returns to management and real property while meeting erosion standards. Lacroix et al. (2005) calculated the economic impacts of various anti pollution scenarios as the difference of incomes in relation to a baseline scenario. Wossink & Osmond (2002) focussed on the economic elements driving farmer and landowner decisions in their efforts to design cost-effective programmes to improve water quality. Despite the fact that the financial support given for a specific BMP is often a strong driver for adoption, other restrictions for adoption of proposed BMPs exist in terms of ‘social acceptance’ (Wu & Babcock, 1999; Bontems et al., 2005b). An integrated view of critical source areas, along with a cost-effectiveness comparison of BMPs has been worked out for nitrogen by Turpin et al. (2006) for a mesoscale watershed in France.

The aim of this paper is to conduct an integrated study of environmental effectiveness and implementation costs of selected BMPs at the small watershed scale. Based on the comparison of cost-effectiveness at this scale, the aim is to discuss how the BMPs for agri-environmental scheme designs affects water quality and implementation costs, especially in relation to the critical source area concept. In order to demonstrate this, two watersheds with contrasting agronomic and environmental conditions were used.

Methods

Hydrological effectiveness

Lake Vico - general characteristics and selection of BMPs

The first study area chosen was the Lake Vico catchment, an igneous rock basin (40.8 km^2), located in central Italy. The lake, which has a surface area of 12.1 km^2, is located in the centre of the basin and is particularly vulnerable to eutrophication. The reasons for this vulnerability (Leone & Ripa, 1998), are that the area is young in geological terms. In fact, volcanic activity ceased in the basin only approximately nine hundred thousand years ago and the landscape is still in an erosive phase of evolution.. Furthermore, vulnerability to eutrophication factors (intrinsic) are the very long hydraulic residence time (17 years), and the trend to anoxic conditions of the hypolimnion which, allows the release of phosphorus from the bottom sediment of the lake. Besides the natural vulnerability of the lake, agricultural activities, especially hazelnut production, further enhance the risk of increasing phosphorus concentration of the lake water. The drainage network in the catchment is not organized hierarchically and as a result, there are high runoff peaks, frequent occurrence of surface runoff and erosion and destructive water action (Leone et al., 2002). Settlements are few and small and therefore the eutrophication problems originate from non point source pollution. Today, the main phosphorus transport is caused by erosion in hazelnut plantations, which are kept free of ground cover. Therefore the proposed BMP to reduce phosphorus movement into the lake is the establishment of meadows under hazelnut trees to provide crop cover to control erosion. Regulation 92/2078/CE, which was introduced in 1992, aimed at reducing the amount of fertilizer and pesticides employed but not directly at establishing meadow under hazelnut trees. Therefore the proposed BMP can be seen as a consequence of the agricultural practices.

Monitoring system

In order to gain more confidence in model results, measured data were used to calibrate the hydrological models employed. The Lake Vico catchment was equipped with a meteorological station for continuous measurement of rainfall, temperature and solar radiation. Runoff was measured in a sub-basin of the catchment, the Scardenato creek (2.66 km^2) using a continuous flow meter and an automatic water sampler. In addition, a hazelnut tree field ($1730m^2$) was equipped with a sampling unit to get information on P losses.

Delineation of critical source areas

Source factors determine the areas within catchments with a high potential to contribute P, whereas transport factors determine whether this potential is translated into P loss. We defined the areas where source factors and transport factors coexist, as being critical areas for P loss. The approach used to designate critical areas was based on the use of the field scale simulation model GLEAMS and an additional meta model, which was derived from the application of GLEAMS. A meta model is a simple approximation to complex simulation models (Schoumans et al., 2002). GLEAMS (Knisel, 1993) is a field scale, management oriented model. The model allows evaluation of the effects of agricultural management, by providing the quantities of nitrogen, phosphorus, sediments and pesticides that reach the edge of a field and the bottom of the root zone and are, therefore, potentially able to pollute water bodies. The model was used to evaluate sediment yield (A) and particulate phosphorus (PP), with reference both to the two scenarios with and without BMP application and to slope angle, the latter being the parameter that influences A and PP mobilization most. For each of the scenarios, we considered the mean annual values of A and PP outputs for fifty simulation years and for all the simulated slopes. In this way, a simple regression model (Leone et al. 2001) was built, which is the meta model derived from the GLEAMS runs:

$$Y = aX^{b} \qquad (1)$$

where:

Y is the land use impact in terms of sediment yield or PP release, with or without the application of the BMP, in t $ha^{-1}yr^{-1}$ and kg $ha^{-1}yr^{-1}$, respectively; X is the slope; a and b are two empirically derived parameters of the regression between GLEAMS results (Y) and slope (X).

Using the meta model the GLEAMS results were extended to all areas of the basin on the basis of their potential contribution in terms of A and PP with and without implementation of the BMP crop cover (Ripa et al., 2006).

Petzenkirchen catchment

General characteristics and selection of BMPs

Petzenkirchen is a small watershed feeding into the River Erlauf, located in the pre-alpine areas of Lower Austria. The area is mainly formed of tertiary sediments. Due to the soft parent material, the area is undulating and prone to erosion when fields are intensively cultivated. Due to the high risk of mud floods at the outlet of the Petzenkirchen catchment, retention ponds have recently been constructed. Agricultural land covers more than 90% of the catchment. The watershed drains an area of about 0.7 km^2. Elevations range from 260 to 300 m asl with mean slopes of about 8%. Average annual rainfall is 700 mm distributed more or less evenly throughout the year. Mean annual temperature is 9.0°C. A typical crop rotation is winter cereal - winter cereal - maize - spring cereal. Typical farm size is 30 ha for full time farmers (50%) and 15 ha for part time farmers. Three BMPs were tested: conservation tillage (BMP 1), changing arable land into grassland without fertilisation and only two annual cuts (BMP 2), and growing winter cereals instead of spring cereals (BMP 3). For BMP 2 two different options were considered for the economic evaluation. BMP 2a describes implementation costs that are targeted only at one farm, BMP 2b was calculated using the assumption that implementation costs were applied uniformly to all farms in the catchment. These measures have been chosen because they are able to reduce erosion and associated phosphorus transport effectively (Strauss et al., 2003). The advantage of BMP 3 is the dense crop cover in May when erosive rainfalls first start (Strauss et al., 1995). BMPs 1 and 3 are part of the Austrian ÖPUL programme (ÖPUL-2000, 2005), which offers contracts to farmers on a voluntary basis. Within that programme, no direct options to reduce phosphorus movement into waters exist. However, the chosen BMPs are the most effective to protect soil against soil erosion. BMP 2 was part of a former ÖPUL programme.

Monitoring system

Petzenkirchen catchment was equipped with an automatic flow recording system, a flow triggered water sampling unit and high resolution climatic data. All necessary spatial information (soil, land use) was available at least at field scale. A Digital Elevation Model with resolution of 5 m was used to derive information about slopes and hydrological pathways.

Delineation of critical source areas

Hydrological pathways were derived by automatic delineation using the steepest descent algorithm of Jensen & Domingue (1988), implemented in a GIS. Because many hydrological active features within catchments may not be detected using flow path generation, we conducted an additional field survey to estimate actual runoff flow paths and correct the automatically derived data where necessary. We then applied the soil erosion model EUROSEM (Morgan et al., 1998) to identify critical source areas of soil erosion. The model was applied under assuming the “worst case”, i.e. all arable land was assumed to be in freshly prepared seedbed conditions. This assumption allowed routing of the water flowing between critical source areas and the water body, and identification of those areas that are most likely to deliver sediment to the water body. The identified areas were ranked according to their contribution to sediment delivery and simulations of the BMPs effectiveness were performed by increasing the area of BMP implementation according to this ranking, i.e. the areas delivering the largest amounts of sediment were the first to be treated.

Model calibration

In order to improve confidence in the predictive capabilities of the hydrological models employed it was necessary to calibrate them with data that had been obtained from the catchments. EUROSEM was applied to the Petzenkirchen catchment for an extreme event in spring 2002 (Strauss & Peinsitt, 2002). In order to use EUROSEM in a grid-based catchment area it was necessary to use the SPIES-application, a software linkage between ArcView GIS and EUROSEM (Magagna et al., 2000). BMPs were then simulated by changing the values for those input parameters of the model that were affected by a particular BMP. The main changes for each BMP were to the parameters affecting soil cover.

Effectiveness assessment

The comparison of the hydrological effectiveness for the different simulated scenarios in the case study areas was carried out as:

$$E = \frac{P_0 - P_{BMP}}{P_0} \quad (2$$

Where:

E is the effectiveness of the BMP considered in terms of the reduction of a particular pollutant and P_0 and P_{BMP} are the quantities of a particular pollutant produced without and with the BMP implementation, respectively.

Cost assessment

Costs were assessed with a whole farm modelling approach that simulates the agricultural land use at farm level, calculating the economic returns and the costs that would result if particular BMPs were applied. Whole farm modelling for cost calculation is suited for the case of critical areas within the watershed if the data describing farm production activities exist. As these data are usually not available at the required scale, an alternative approach is to model representative farms (Skop and Schou, 1999). Optimization runs for the representative farm show the trade offs and abatement cost curves illustrating the relationship between economic returns of the farm and implementation of each BMP. The design of the representative farms has to be built realistically, as the cost assessment at the watershed level is an aggregation of costs obtained for these representative farms.

The representative farm is devised from regional data and local expertise, represented by only one farm type: dairy for the Petzenkirchen catchment and hazelnut growing farm for the Lake Vico catchment) within the catchment. For construction of the coefficients matrix, technical data that consist of input and output flows were provided from expertise on the farming systems in the area. Ratios between outputs and inputs have been assumed constant (deterministic farm model) as well as their prices using their mean value for the current year. The bio-economic model was developed in mixed integer linear programming using GAMS software (Brooke et al., 1998). Cost calculation is based on the assumption that the levels of incentive linked with a BMP in the optimal modelled solution represents the direct costs of its implementation (Lescot, 2004). To calculate the costs for the whole catchment individual costs were summed assuming that all farms implemented the same share of their acreage with the BMP. This assumption could be changed in the case of more targeted measures covering implementation only on farms located on critical areas. Jansen et al.(1999) used a linear programming model to indicate the optimal spatial allocation of variants of farm management such that desired regional and sub-regional nitrate concentrations are obtained at minimum regional cost.

Results

Hydrological effectiveness

Lake Vico catchment

The monitoring period (1999-2004) was characterised by prolonged drought and very few relevant rainfall events occurred. In summer 2001, two runoff events occurred, generated by two short, but intense, showers with return times of about 5 and 30 years. These rains exported 5 and 18 kg ha^{-1} of total phosphorus from the monitored hazelnut field. These events did not produce any flood in the Scardenato creek, probably due to the extreme dryness of soils in the basin and the short duration of the events.

Figure 1 show maps of soil erosion (t ha^{-1} yr^{-1}), without (Fig. 1a) and with (Fig. 1b) application of the chosen BMP as well as particulate phosphorus load (kg ha^{-1} yr^{-1}), without

BMP (Fig. 1c) and with BMP (Fig. 1d) application. Numerical values come from the application of the metamodel (Eq. 1) using parameter values of Table 1.

Table 1: Coefficients *a* and *b* in Eq.1

Figure 1. GLEAMS simulated soil and phosphorus yield in Lake Vico: conventional agriculture (a, c) and with BMP (b, d), adapted from Ripa et al. (2006)

The soil erosion methodology was tested against the USLE, (Wischmeier & Smith,1978). Results obtained were similar (Leone et al., 2006), mean annual soil loss amounted to 17.5 t ha^{-1} yr^{-1} (USLE) and 14.5 t ha^{-1} yr^{-1} (meta model).

However, it was more difficult to apply the USLE at basin scale because of the impact of single input factors which were difficult to obtain. However, both approaches, were congruent in their order of magnitude, they were able to explain the areas of higher risk, that are located in the Northern and Eastern part of the basin and compared well with experimental data (Leone et al., 2006).

These results can be considered encouraging for comparative studies of application of BMPs to critical source areas, but absolute values cannot be validated at present, as knowledge of the basin hydrology in conditions of extreme rainfall is not available. The absolute values of P loss seem to be too high (Fig. 1c, 1d), but become more reasonable given the naturally high P content of the soils around Lake Vico. Measured data of P export from the hazelnut fields support this view. Extension of the chosen BMP to the whole critical area would result in a reduction of 80% of soil loss and 40% of P loss as compared to conventional management.

Petzenkirchen catchment

During the monitoring period (2001-2004) several severe events occurred in 2002. We used one of these events (March 2002) for calibration of EUROSEM. Table 2 gives an overview on flow conditions, sediment load and particulate P export during the calibration event compared to mean values for the whole monitoring period.

Table 2: Rainfall characteristics, total flow, sediment and phosphorus load for the event of March 2002, and mean annual sediment and phosphorus loads for the monitoring period 2001-2004

Results presented in Table 2 reveal the strong influence of single events on sediment and P export in this catchment. It has been shown elsewhere, that transport of particulate bound phosphorus, rather than soluble phosphorus forms, dominates phosphorus transport during erosion events (Quinton et al., 2003). Therefore erosion could be taken as a surrogate for phosphorus transport in this work under the assumption that a uniform distribution of soil P status is assumed over the entire watershed. Although this was not the case, measurements of soil P contents at various sites within the catchment did not allow discrimination of phosphorus values for individual fields. Figure 2a enables identification of the main flow paths within the Petzenkirchen catchment. This was used as a basis for the ranking of critical source areas within the catchment (Fig. 2b). Ranking was performed for the three most critical areas only.

Figure 2a: Identification of critical source areas for soil erosion and PP transport in the Petzenkirchen catchment

Figure 2b: Rank order for critical source areas of soil erosion and particulate P transport in the Petzenkirchen catchment

After calibration, EUROSEM was applied to the Petzenkirchen catchment and for each successive simulation additional areas were assigned BMP's according to their ranking. Finally, effectiveness of BMP implementation was calculated for each simulation. Figure 3 gives the change in effectiveness with increasing area of implementation for the different BMPs.

Figure 3: Effectiveness of BMPs implementation for the catchment Petzenkirchen

Figures 2 and 3 depict erosion as being a very localised process. Identifying risk areas and implementation of BMPs on them led to large reductions in soil loss. Only a few fields in the catchment were contributing substantially to the sediment load and targeting only 6% of the catchment produced a 31-61% reduction in the total catchment sediment and hence in P load. This is in contrast to findings for other pollutants such as nitrate, where a reduction in pollution corresponds more linearly with implementation area of BMPs (Feichtinger et al., 2005). Concerning the differences between the implemented BMPs, BMP2 (permanent grassland) proved to be more effective than BMP3 (winter crops) which in turn was calculated to be more effective than BMP1 (conservation tillage).

Costs

Lake Vico catchment

In the first period after implementation of regulation 2078/92, the differences between the conventional agricultural practices and the practices complying with the regulation were very noticeable. A larger amount of fertilizers was applied in the conventional management and also there was a change in tillage system. In 1999, the regulation was replaced by the Rural Development Plan 2000-2006. This Plan also contains the proposed BMP of establishing meadows under hazelnut trees and estimates the costs for implementation at 520 €$\cdot$ha^{-1}. This is in contrast to our calculations which suggest, that the BMP could be implemented without any additional costs because farm incomes were estimated to be 1774 €$\cdot$ha^{-1} with standard practices and 2012 €$\cdot$ha^{-1} after BMP application. Our view is supported by a recent evaluation of the management activities, which shows that already during the period of the regulation 2078/92 - with no direct subsidy for establishment of a grass cover - a slow but noticeable change in agricultural techniques has taken place (CEC DG VI, 1998). The tillage has been reduced and it is now common practice to allow hazel nut orchards to develop a weed cover. In addition the use of fertilizers has been reduced to the amount suggested in the 2078/92 regulation. However, hazelnut yield was not affected by these changes according to the information provided by the farmers.

Petzenkirchen catchment

When changes in practice affect only a small percentage of the total arable area of the catchment, calculations show that implementation costs are similar when BMPs are either targeted only at one farm or applied uniformly to all farms (Table 3). Nevertheless with BMPs targeted only at one farm or a few farms, implementation costs would have been higher if the BMPs had been applied to a larger part of the catchment, because marginal costs of implementation at the farm level are not constant (Table 4). However, evaluation of critical source areas has demonstrated, that effectiveness is much higher when BMPs are targeted at those areas. Because costs are calculated from a representative farm, costs values are indicative. Uncertainty in the costs should be further analysed given the population of farms within the watershed. This population may not be as homogenous as assumed in our case studies. When the costs per unit of reduction in loss of P are compared, BMP 3 (conservation tillage) was the most effective and BMP 2 (permanent grassland) the least effective BMP (Table 3).

Table 3: Effectiveness and associated costs of the different BMPs at various levels of implementation

Table 4: Cost of implementation of BMP 2 for the representative farm

The costs calculated by modelling turned out to be close to the compensations proposed by the Austrian agri-environmental programme ÖPUL 2000 (BMLFUW, 2000) for these BMPs. Nevertheless analysis of results shows that when the BMP involve a change of crop (like BMP2 grassland), the amount of compensation per hectare needed to make the changes profitable varies from farm to farm (Feichtinger et al., 2005; Lescot 2004). Thus, a mechanism with a set incentive per hectare may result in limited uptake. Unfortunately most agri-environmental programmes offer a fixed compensation per hectare irrespective of the total area covered by the BMP.

Discussion

Results of the environmental effectiveness calculations demonstrate that for the conditions prevailing in both catchments, erosion and phosphorus loss may be decreased effectively by addressing critical source areas, which cover only a relatively small area of those catchments. Making these results acceptable in practice would however need tools that could provide satisfactory outcomes for both policy makers and farmers at a scale larger than the tested catchments. Models with different degrees of detail could be one possibility due to the given constraints in data availability (Heathwaite et al., 2005). In fact, the approaches tested here can also be seen as nested in the sense that identification of critical source areas was performed using a simple procedure of routing water through a catchment, whereas detailed analysis of cost-effectiveness for the identified critical source areas was based on more detailed techniques. In the case of the Petzenkirchen catchment the chosen approach claimed to be "process based". Theoretically, it would therefore be easier to apply it at least to neighbouring catchments or for similar environmental conditions. Due to temporal and spatial constraints, the chosen approach is clearly suited only for small watersheds. However, these are the catchments where hydrological connectivity between pollution source and water channel is usually high. Because of its simplicity, the approach chosen for Lake Vico seems at first sight better suited for application at larger scales. However, as the meta-model has been derived empirically only for Lake Vico catchment, it would need re-parameterization for application to other sites. This is especially the case in situations where factors other than slope are dominating transport into the aquatic system.

When choosing between BMPs at the Petzenkirchen catchment, there is a trade off between costs and environmental effect, exemplified with BMP 3 and BMP 2: the environmental benefit of BMP 2 is the greatest, but it costs more. The question is which of these BMPs should be chosen? Although BMP 3 has the best cost-effectiveness ratio, BMP 2 may be still a suitable candidate if BMP 3 falls short of the environmental objective or if the receptor water body is particularly valuable in terms of recreation benefits. Therefore there are several different options to reach a desired environmental goal and the advantage of applying the described methodology is that farmers may be offered a set of options rather than a single solution. This flexibility may increase uptake of BMPs and benefit the overall environmental benefit. In practical terms, this suggests that the concept of critical source area should be an integral part of contract menus dealing with phosphorus and soil loss measures (see Bontems et al., 2005a for an example of such a contract menu).

The main results of the GLEAMS and meta model application to the Lake Vico basin suggest that:

1) it is feasible to spread to the catchment scale the detail of the field scale which is fundamental to BMP evaluation;

2) to zone landscape by critical areas, related to the main environmental processes of interest, soil erosion and phosphorus mobilization in this case is the fundamental tool to understand where the real impacts are located, and how much they could be reduced by BMP application.

As a consequence of 2), zoning landscape by BMP effectiveness results in improved management information. Untargeted implementation of a particular BMP provides the same financial support to all farmers irrespective of whether they are generating real impacts, while the proposed targeted support allows better use of resources, increasing or reducing them on the basis of environmental impact. Although the meta-model is a simple equation it performs well by summarizing all the factors of the complex environmental and anthropogenic system that is an integral part of the GLEAMS model.

It must be recognised that even the most sophisticated of models remains only a simplified and idealized abstraction of the real system, necessarily including only a selection of the relevant elements and processes, while neglecting others. The adopted modelling approach, inevitably introduces a lot of uncertainty resulting from the type of model, input parameter errors, but also from intrinsic, chaotic behaviour of the actual system. However it is not clear that large, over parameterised, deterministic models can do a satisfactory job, because it is almost impossible to validate them (Heathwaite, 2003).

For these reasons, we did not implement simulation models as tools to reach the unattainable goal of absolute predictions, but rather as tools that help to assess the relative environmental effectiveness of "alternative" agricultural practices and to evaluate land processes, while taking into account the complex man-environment interactions. It is in these terms that we can expect simulation models to improve the process of land management oriented to water protection.

Conclusions

The aim of this study was to compare environmental and economical effectiveness of particular best management practices in two small catchments subject to erosion and P loss. Results achieved suggest that for the considered pollutants a two step procedure of first evaluation of critical source areas followed by the application of simulation models, would enable policy makers to allocate monetary resources in an efficient way. However, environmental effectiveness is only one of several priorities of agricultural policy.

In addition, whereas the levels of best management practice implementation for policy is the administrative unit, this study has shown, that hydrological units would be better suited - at least for the pollutants investigated. Finally, the comparison between environmental effectiveness and economic evaluation introduces the possibility of comparing the cost effectiveness of different management practices.

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List of Tables

Table 1: Table 1: Coefficients *a* and *b* in Eq.1 for the meta model at Lake Vico

Y	**Management Option**	***a***	***b***
Soil erosion [t ha^{-1} yr^{-1}]	Conventional	287.73	1.216
	BMP	84.85	1.340
Particulate phosphorus [kg $ha^{-1}yr^{-1}$]	Conventional	26.21	0.100
	BMP	13.89	0.041

BMP = Best Management Practice

Table 2: Rainfall characteristics, total flow, sediment and phosphorus load for the event of March 2002, and mean annual sediment and phosphorus loads for the monitoring period 2001-2004 at Petzenkirchen catchment

Rainfall (mm)		Total flow (mm)		Sediment load (t)		Phosphorus load (kg)	
Event	Annual	Event	Annual	Event	Annual	Event	Annual
126	793	29.4	140	30.7	23.8	15	19.7

Table 3: Effectiveness and associated costs of the different Best Management Practices (BMP) at various levels of implementation in the Petzenkirchen catchment

Area implemented (%)		Effectiveness (%)			Costs (€)			
Total area	Total arable area	BMP 1	BMP 2	BMP 3	BMP 1	BMP 2a	BMP 2b	BMP 3
5.2	6.1	31	61	44	377	1111	1111	374
6.5	7.7	38	74	52	467	1374	1374	462
14	16.5	46	84	62	1008	2969	2989	999

BMP 1: conservation tillage

BMP 2: grassland instead of arable land; 2a: grassland on every farm, BMP 2b: grassland on one farm

BMP 3: winter cereals instead of spring cereals

Table 4: Cost of implementation of Best Management Practice 2 (unfertilised grassland) for the representative farm in the Petzenkirchen catchment

Area implemented (% of arable land)	Costs (€·ha^{-1})
from 5% to 42%	321
from 43% to 50%	334
from 51% to 54 %	354
from 55% to 87%	442
from 88% to 90%	912
from 91% to 97 %	941
from 97% to 98%	1030
From 99% to 100%	1188

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