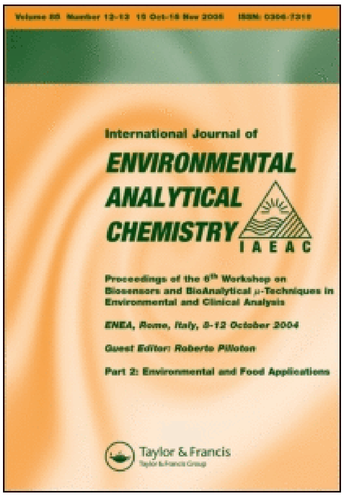

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Evaluation of crop-protection-product losses into surface waters with the SEPTWA system

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SEPTWA (System for the Evaluation of Pesticide Transport to WAters) is a system that has been developed in Belgium since 1995 for the evaluation, at the macro-scale, of surface-water pollution by crop protection products. It considers the actual application rates in the agricultural and non-agricultural sectors, and takes into account the diffuse (runoff, drainage, drift) and non-diffuse (point losses) emission sources. SEPTWA version 2.2 has been validated on the basis of a monitoring dataset of a large hydrographic catchment in Belgium, the Dyle. This validation process confirmed the model's potential, but it also showed that a more appropriate dataset is needed for a more reliable validation of the model.

Keywords: Pesticides; Emission; Losses; Prediction; Surface water; SEPTWA

1. Introduction

The SEPTWA (System for the Evaluation of Pesticide Transport to WAters) model has been developed since 1995 at VAR to assist the Belgian legal authorities for decision-making in the field of environmental impact of pesticides and, more particularly, for the presence of pesticides in the aquatic systems. It has also been used by the regional authorities to improve their monitoring programmes of surface waters.

Most of the models used in registration are very complex one-dimensional (or nearly two-dimensional) models. A large quantity of input data is needed, and evaluations are made at the field scale (edge-of-field). Several of these one-dimensional models have to be used to feed a surface water fate model to obtain a Predicted Environmental Concentration (PEC) of an active substance in waters.

SEPTWA on the other hand is a simple, pragmatic, analytical and macro-scale model whose aim is to evaluate the most likely pesticide losses to surface waters, taking into

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account relevant transport processes: runoff, drainage, spraydrift and most of all, point losses, which, as shown by several recent studies, play a major role in the pollution of surface waters by crop-protection products [1–4]. A study on a small catchment in Belgium (Nil catchment, 32 km^2) shows that the contribution of the point losses to the total load of the river is 50–80% [5–6].

For the application of crop protection products SEPTWA works with effective amounts applied and not with standard application rate. Therefore, an application database created on basis of surveys in the agricultural and non-agricultural sectors is integrated in SEPTWA.

2. Short description of the SEPTWA model

The working principles of the model can be summarized as follows [7]:

2.1. *First step: Evaluation of pesticide applications in the different parts of the country and in the different sectors of uses*

This is done by using specific databases on land use (acreage for the different crops, density of the railway network, housing, etc.) and applications. SEPTWA works with a time-span of fourteen days: the repartition of the application with time and, hence, of the amounts applied are calculated and introduced in the database considering this time-span.

2.2. *Second step: Calculation of the losses to surface waters*

Four different entry routes are considered and a specific emission factor [5–7] (see Table 1):

(1) *Direct losses*: Becuase of rinsing and cleaning of the spraying equipment, spillages at the farm site are generally estimated at 0.5% of the total amount applied.

Table 1. Emission factors (in percentage of the amount applied) considered by SEPTWA for the evaluation of losses into surface waters.

Entry route	Agriculture uses		Other uses (railway, home and garden, turf and amenities, etc.)
	Application	Emission factor (%)	
Point losses	All	0.50	–
Drift	Seed/granules	0.00	–
	Field spraying	0.01	
	Orchard	0.03	
Runoff and erosion	Seed/granules	0.08	0.40% for applications on permeable surfaces
	Field spraying/orchard	0.40	2.00% for applications on impermeable surfaces
Drainage and hypodermic flow	If GUS* <3	0.005	–
	If $3<$ GUS <4	0.050	
	If $4<$ GUS <4.5	0.500	
	If GUS >4.5	5.000	

(2) *Drift* is estimated at 0.01% of pesticide applied in field spraying, which corresponds to the combination of a drift factor of 1% and a water:land ratio of 1%. The drift factor is greater for application in orchard and is considered as zero for applications as seeds treatments or granules.
(3) *Runoff and erosion* are supposed to be independent of the nature of the chemical and are taken into account whatever the region of interest. A higher load factor is considered for herbicides applied on impermeable surfaces.
(4) *Drainage and interflow* (i.e., lateral flow in the unsaturated subsurface soil layers) are also taken into account, and their importance is linked to the Ground water Ubiquity Score (GUS) index of the chemical of interest. ($\mathrm{GUS} = \log \mathrm{DT}_{50} \times (4 - \log K_{\mathrm{oc}})$ where DT_{50} is the half-life in days and K_{oc} the soil organic carbon/water partition coefficient [8].).

On the basis of the emission factors shown in table 1, the estimated percentage of the total amount applied that reaches surface waters will be in the range of 0.6–5.9%.

2.3. *Third step: Distribution of losses with time, degradation and crop interception*

The model calculates the losses (= amounts transported to waters) for every fortnight. These losses will be maximal (i.e. as estimated using the above-mentioned emission factors) only if the rainfall was sufficient during the considered fortnight. If not, the model considers that transport to surface water was not complete, and part of the losses will be moved to the next fortnight. Thus, some of the losses will appear at the moment of application, while others will occur later depending on the weather conditions. In this last case, the degradation of the product in the soil is taken into account. In addition, losses can be reduced if the pesticide is applied on a developed crop (interception and reduction in the amount reaching the soil). It is important to note that the model does not consider dissipation processes such as degradation in water or adsorption on sediments.

At the end of this step, the outputs of the system are (1) the total loads and (2) the distribution of the loads with time (with a time span of a fortnight) for each of the 36 river basins of Belgium.

2.4. *Fourth step: Calculation of the concentration in surface water*

For the calculation of the average fortnight concentration (output of SEPTWA), a relation has been developed to determine an average annual flow as a function of the total annual rainfall. This has been done on basis of 5 years measurements of the flow (1996–2000) at the outlet of each catchment.

3. Experimental

The dataset used for the validation was composed of concentrations measured once week between March and June in 2000 and 2001 at the outlet of the Dyle watershed (ca. 4580 km^2). The Dyle (or Dijle) catchment is located in central Belgium (figure 1) and composed of both rural and urbanized areas. The active substances followed in this monitoring are atrazine (maize), chloridazon (sugar beet), diuron (non-agricultural use and orchard), isoproturon (wheat and barley), lenacil (sugar beet),

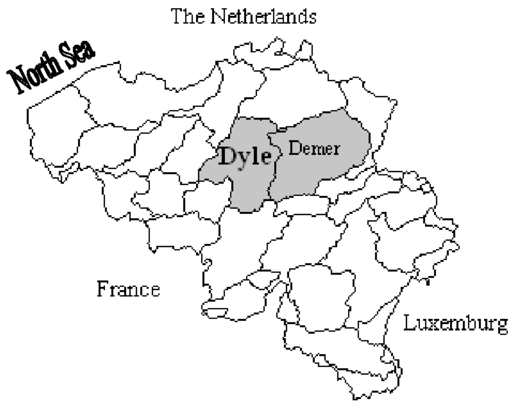

Figure 1. Location of the Dyle catchment in Belgium (the Demer is a sub-basin of the Dyle).

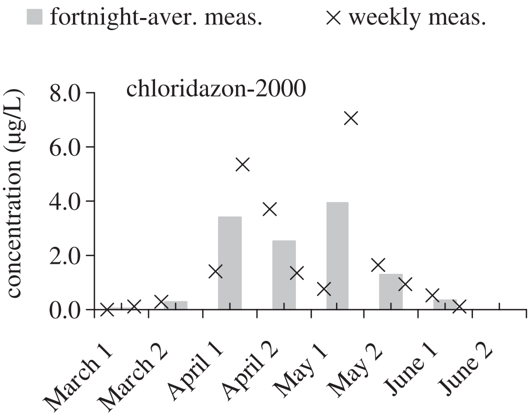

Figure 2. Concentrations measured in the weekly point samples and resulting fortnight-averaged concentrations for chloridazon between March and June 2000 in the Dyle catchment (May 1 = first fortnight of May and May 2 = second fortnight of May).

metolachlor (maize and sugar beet) and simazine (non-agricultural uses, orchard and peas). These compounds are widely used on the Dyle catchment (approximately 2900–60 500 kg per year depending on the substance).

Since the time-span of SEPTWA is a fortnight, we will work with fortnight-averaged concentrations (average of two weekly concentrations). However, the measurements were made on point samples, which means that the samples were taken at a specific moment in the week and are not necessarily representative of the week average concentration. Figure 2 presents the concentrations measured each week for chloridazon (crosses). It appears that the variation of the concentrations can be important from one week to another. In the first fortnight of the month of May (May 1), the two weekly concentrations measured are 0.79 and 7.08 µg/L (ratio:9). To compare them with the estimations from SEPTWA, these two values will be converted in a single fortnight-averaged concentration of 3.93 µg/L. So, in this assessment of the SEPTWA model, it is necessary to keep in mind that an uncertainty also exists on monitoring data.

The flow-rate measurements were provided by the Hydrologische Informatiecentrum (HIC), Waterbouwkundig Laboratorium en Hydrologisch Onderzoek, Administratie Waterwegen en Zeewezen, Vlaamse Gemeenschap. The analyses of the pesticides concentrations in water were carried out following the analytical method described by Gerard [9]. The validation process was realized on the version 2.2 of SEPTWA using the two years dataset 2000 and 2001.

4. Results and discussion

The 'measured' loads were calculated by multiplying the fortnightly averaged concentration by the total water flux during the fortnight.

4.1. *Total loads*

Figure 3 and table 2 show the generally good agreement between the loads evaluated by SEPTWA, for the period March–June 2000 and 2001, and those calculated from the monitoring data. Simazine is strongly overestimed by SEPTWA (166% in 2000 and 650% in 2001), probably due to the poor quality of the input data (amount applied according to surveys carried out in 1996, whereas it is known this compound is used less nowadays). For the other six compounds, the evaluations are mostly higher than the results from monitoring: six cases out of 12 range from –16% to +49%, the other 6 from +74% to +234%.

However, the loads calculated from monitoring data are very different from one year to the other, whereas the evaluations change very little. For example, the measured

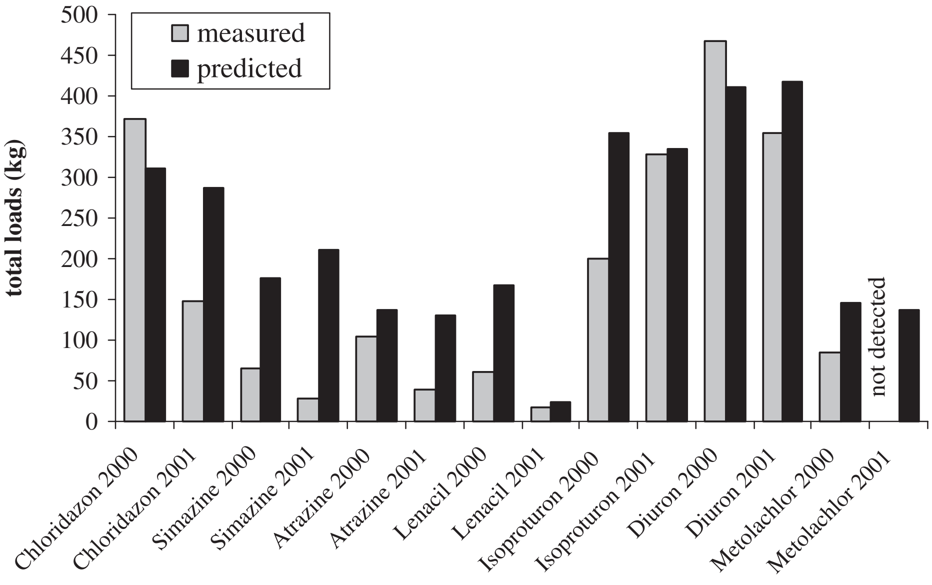

Figure 3. Comparison between the measured loads and the evaluations by SEPTWA for the period March–June 2000 and 2001.

Table 2. Difference between predicted loads (SEPTWA) and monitoring data.

	(Predicted–measured)/measured (%)	
	2000	2001
Atrazine	31	234
Chloridazon	–16	93
Diuron	–12	17
Isoproturon	77	2
Lenacil	179	49
Metolachlor	74	Not detected
Simazine	166	650

loads of chloridazon are 371 kg in 2000 and 148 kg in 2001, whereas the corresponding evaluations by SEPTWA are 311 and 286 kg. Another example is isoproturon: 201 and 328 kg from monitoring, vs. 355 and 336 kg from SEPTWA. This variation in the measured loads is surprising for two reasons:

(1) The substances considered here are systematically used in the crop protection programme, and the crops treated with these products are major Belgian crops whose cultivated areas do not vary from year to year, especially on a large basin scale.
(2) The weather conditions of the two years were not very different, and in any case SEPTWA takes climatic data in consideration.

It is well known that pesticide losses due to runoff and drainage can be highly variable because they are linked to high peak concentrations that are difficult to monitor without intense sampling programmes [10]. Previous studies performed in Belgium on small watersheds have shown that runoff and drainage from the field are minor routes of water pollution [6]. However, the variation from year to year can be due to variability of the point losses. These losses can be variable because they depend on the way the pesticides are handled by the farmers. However, it has been shown in the study on the Nil catchment in Belgium that, in the absence of specific information on good agricultural practices, the handling behaviour of the farmers tends to be fairly constant [6]. This seems to be true also as far as disposal of spray rests and cleaning water is concerned. Hence, the question can be raised if the variation of the measured loads is real or the result of an artifact due to infrequent sampling. A thorough analysis carried out by our research team on the Demer River (sub-basin of the Dyle River; see figure 1) has shown that the 'day to day' variation in pesticide concentrations can be has high as 1:3 (results not shown), which seems to indicate that the estimation of loads can be wrong when a 'once a week' sampling rate is applied.

4.2. *Cumulated loads*

SEPTWA also gives the evolution of the loads with time (time-span of 14 days): examples of cumulated loads are given in figure 4 for diuron, isoproturon and chloridazon. The match is very good for diuron. For isoproturon in 2001, the match is good for the total load (see also figure 2), but there is a shift in time. In contrast, the evolution with time is more or less correctly given for isoproturon during the year 2000 but SEPTWA strongly overestimated the loads, as mentioned above

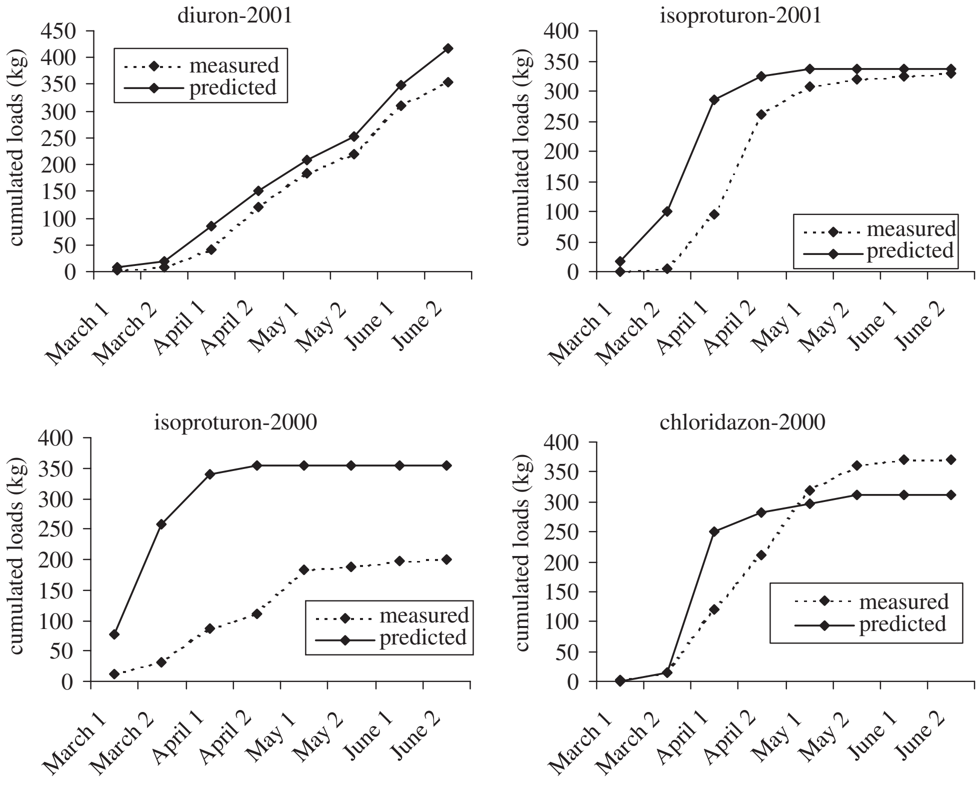

Figure 4. Evolution with time of the measured loads and the evaluations by SEPTWA for diuron (2001), isoproturon (2000 and 2001) and chloridazon (2000) for the period from March until June (March 1 = first fortnight of March and March 2 = last fortnight days of March).

(figure 2). As to the case of chloridazon in 2000, SEPTWA overestimates the losses in March, while there is an underestimation during the months May and June.

4.3. *Concentrations (fortnight average)*

A third output of SEPTWA is the average fortnightly concentration. Predicting concentrations imply that an additional source of error is added because the water flows must also be predicted.

The predicted concentrations are compared with measured concentrations in figure 5. On this figure are presented for each fortnight: the predicted concentration (solid line) and the fortnight-averaged concentrations (dashed line). The predictions are very good for diuron. For isoproturon in 2001, the shift in time is still present. For lenacil, a substance with a higher GUS index, the concentration is also well predicted. As to chloridazon in 2000, the peak concentration measured in May 1 is not predicted by SEPTWA, but it is important to note that this discrepancy is mostly imputable to only one measured value (i.e. 7.08 μg/L for the sample taken during the second week of May).

An overly high uncertainty on the dataset does not allow a clear-cut conclusion on the real evaluation capabilities of the system. A good dataset for the validation of

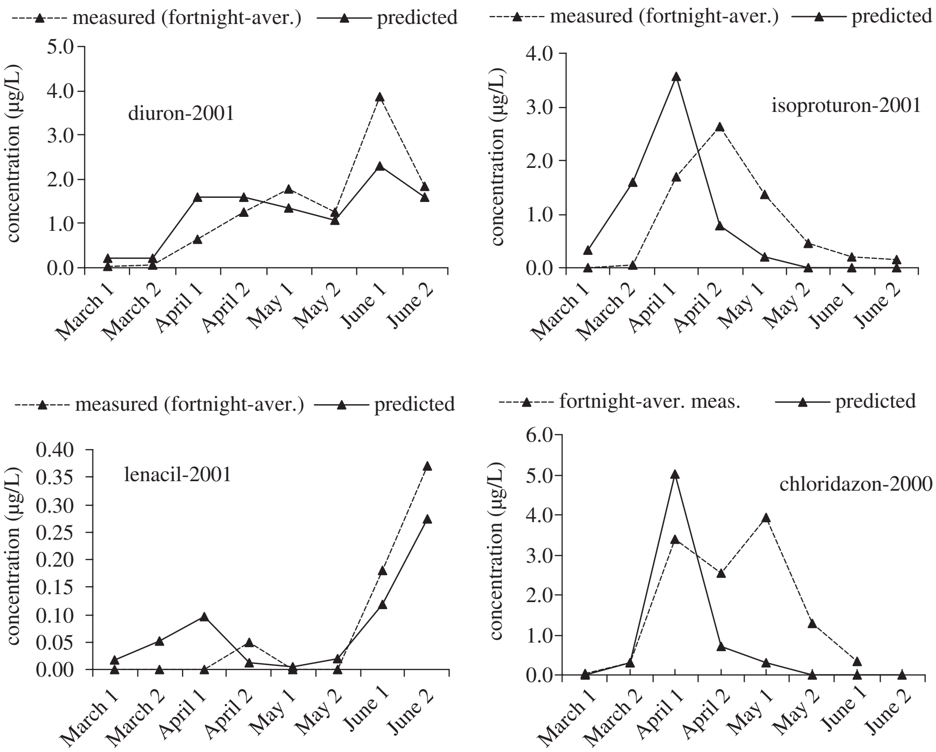

Figure 5. Comparison between the measured and predicted concentrations at the outlet of the Dyle catchment for diuron (2001), isoproturon (2000 and 2001) and lenacil (2001) for the period from March until June (March 1 = first fortnight of March and March 2 = last fortnight days of March).

SEPTWA must contain average concentrations, measured in samples prepared by mixing several sub-samples (more than one per day) to obtain a sample representative of the week or the fortnight.

4.4. *Mitigation solutions*

The evaluations by SEPTWA can be used to test which mitigation measures will be most adapted to achieve a real reduction in the pesticide loads in the rivers. Figure 6 shows the reduction of isoproturon loads obtained if each transport route is on turn considered as zero. Actions on point losses (promotion of the good agricultural practices) will reduce considerably the river loads (63%) in comparison with reducing the drainage (0.2%) or runoff (36%) losses. Note that for substances with a higher GUS index, the drainage will be a more important entry route to surface waters because the emissions factor for this process increases with the GUS; however, for the most common range of GUS values, the point losses will be the most dominant source of losses according to the evaluations of SEPTWA. Of course, the predictions carried out with SEPTWA cannot be extrapolated to other regions for which it is known that drift, runoff and drainage can play a more important role.

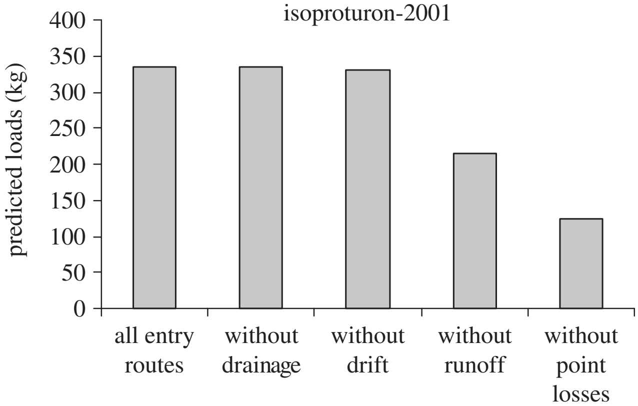

Figure 6. Difference in the total isoproturon loads predicted by SEPTWA according to various mitigation scenarios.

5. Conclusions

Compared with other models for estimating the transport of pesticides to surface water such as EXAMS, TOXSWA and ABIWAS (see, for example, the report of the FOCUS group, DG Agriculture, European Commission) [11], it can be said that SEPTWA is simple and user friendly. But SEPTWA is above all, a pragmatic model because it considers all types of applications and all relevant sources of pollution including some point-source emission at the farm level (the so-called direct losses) while the above-mentioned models deal only with drift and/or runoff and/or drainage (i.e. the diffuse sources). On the other hand, the model is functional (the different entry routes to water are described in a scientific way) and analytical (equilibrium is assumed to be reached for each time-span considered, i.e. 15 days, and the losses are calculated accordingly). In addition, SEPTWA needs data on pesticide use for a whole country or for a large hydrographic basin. In this respect, SEPTWA differs considerably from other existing models that are generally used according to well-defined pesticide application scenarios (for instance, to make assessments in the framework of the pesticide directive 91/414/EC) and not according to real pesticide applications in a large area. Finally, the model is deterministic and not probabilistic, because it works with a finite value of the input parameters (DT50, Koc, rainfall, application rate, etc.). All these features taken together make the system unique and adequate for a first screening at the scale of a country or hydrographic basin.

To obtain good evaluations, it is crucial to have accurate data on the total amounts applied and, if the evolution in time is important, on the timing of applications. The present integrated database including pesticide use, timing of application, crop acreage and rainfall is valid for Belgium only (national surveys) and such a database needs to be regularly updated.

The evaluation capabilities of SEPTWA seem to be good when compared to the monitoring data gathered on the Dyle River during 2001 and 2002, but a further validation process must be conducted with a more adapted monitoring dataset. More frequent sampling and monitoring data, for instance, seem to be of prime importance in order to increase the quality of the dataset. It is important, also, to be able to cope with the uncertainties of the input data and, as a matter of fact, with the uncertainties of the predictions that can be made using these data. Thus, taking into account these restrictions, the SEPTWA model should be improved in the future to be able to make more accurate estimations.

As already shown in some pilot experiments [6–7], this study, based on SEPTWA estimations, tends to confirm that the implementation of actions aiming to fight point losses (good agricultural practices) will have the most beneficial impact on the reduction in crop protection products loads in surface waters, at least under the conditions prevailing in Belgium.

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