DRIPS – A DSS estimating the input quantity of pesticides for German river basins

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Abstract: The development of the GIS Decision Support System (DSS) – **D**rainage **R**unoff **I**nput of **P**esticides in **S**urface Water - based on model algorithms describing the major pathways of pesticide entry into surface waters has been initiated by the German Federal Environmental Agency (Umweltbundesamt, UBA) in 2000. The tool estimates the quantity of pesticide input from non-point sources via surface runoff, tile drainage and spraydrift. Furthermore, the resulting predicted environmental concentration of pesticides in surface waters (PEC_{sw}) can be retrieved considering the mean daily inputs of substances into various types of river-basins characterized by their daily discharge. A Graphical User Interface (GUI) was created provide users of the DSS with easy access to the model algorithms. Model parameters like dose rate, DT50, Koc and date of pesticides application et cetera can be modified by the user in order to generate customized scenarios for a choice of field crops, orchards and vineyards. Results are available as grid cell maps for the territory of Germany with high temporal and spatial resolution featuring distinct values PEC_{sw} for various types of streams and landscapes.

Keywords: diffuse pollution; pesticides; runoff; spraydrift; leaching; GIS; DSS

1. INTRODUCTION

In the context of authorizing pesticides by stakeholders within the European Union, modeling their environmental fate grew to be an integral part of a three-tiered approach for assessing the chemical's impact on aquatic-ecosystems [FOCUS, 2001]. GIS-based models offer a time and cost effective evaluation of various hazard scenarios on a regional- and national scale considering the spatial variability of model parameters. User-friendly Decision Support Systems (DSS) offer authorities and producers easy access to these models generally providing powerful tools for regionalized risk-assessment.

A reasonable share of pesticides sprayed for crop protection in agriculture accidentally pollutes non-target areas such as ditches, rivers and lakes. As a prerequisite of pesticide registration, manufacturers have to prove compliance of their products with threshold values set by the registration authorities believed to cause no severe damage to affected non-target ecosystems. One of these thresholds is the Predicted Environmental Concentration for Surface Waters (PEC_{sw}). The European Directive, 91/414/EC on Plant Protection Products requires manufacturers of pesticides to raise PEC_{sw} for their products up for registration. Stakeholders use these data to evaluate the potential hazard of the chemical on aquatic organisms prior to registration. Spatially distinguished PEC_{sw} scenarios are needed to adequately account for the heterogeneity of the agricultural areas the substance will be applied in. A DSS, such as DRIPS, containing a set of models calculating PEC_{sw} permitting the modification of model parameters in a user-friendly GIS shell, could be a helpful tool to producer and registration authorities alike.

2. DSS STRUCTURE

The core of DRIPS contains a set of models quantifying diffuse pollution from pesticides according to the methodology of Huber *et al.* [1998] and Bach *et al.* [2001]. The model components for runoff, tile drainage and spraydrift estimation are organized in independent modules which can be modified and executed separately. The model components are fully integrated into a GIS-shell as an ArcView v.3.2 extension. Model parameters can be modified in interactive dialogues. Basic data are stored in maps and database files. The user-friendly architecture of this DSS offers easy calculation of spatially distributed scenarios for risk-assessment of non-point pesticide pollution of surface waters. Results can be either produced numerically for further statistical analysis or as grid-maps covering the territory of Germany. The maps can be queried with full GIS-functionality to evaluate the results.

2.1 Data

A set of grid and vector maps are implemented in DRIPS containing spatially distributed information for most of the input parameters required for model runs (Table 1). All of these basic maps as well as the result maps conform to the map: "administrative boundaries of Germany 1:1 Mio" [IFAG/BKG, 1996]. The grid maps feature a spatial resolution of 1 km^2/pixel.

Type	Implemented Data	Source
grid map	annual precipitation	German weather service (DWD)
	frequency of rainstrorm occurenc	German weather service (DWD)
	soil	BUECK 1000 (BGR, 2000)
	landcover	CORINE-landcover project
	drainage density	Hydrological Atlas (HAD)
	tile drain density	BAFG
vector map	administrative units	BGR/BKG
	river network	UBA, iimaps
	catchments	UBA, iimaps
data base	daily discharge 1960-199x values	fed. watermanagement agencies
	pesticide Koc, DT50 values	UBA
	agro-statistics 1995	fed. statistical service
	soil-cover of field crops at date of application	Feldwisch und Hecker 1997
	saisonal variaton factor (runoff)	Auerswald, 1996
	saisonal index/week numbers (runoff)	Lutz, 1984
	maximum drainage coefficient	Auerswald und Haider, 1996

Table 1. Data available in DRIPS

Pesticide application parameters (Table 2), such as dosage and substance data, have to be specified by the user, before executing a model run.

Input Data	status
crop	**r**equried
date of substance application	r
dosage of substance	r
substance name or Koc, DT50	r
ammount + duration of rainstorm	**o**ptional
spraying-distance to stream (drift)	o

Table 2. Data requirements

2.2 Graphical User Interface

With activating the DRIPS extension within ArcView a set menu items are amended to the program's usual GUI. Pop-up dialogues query for necessary model parameters to be set for the required task. The main menu offers a choice of routes (runoff, tile drainage, spraydrift) for diffuse pollution entry to be considered for PEC_{sw} estimation. Furthermore, the area of interest (AOI) can be specified, within the territory of Germany.

Substance parameters of the pesticide applied have to be specified in a separate dialogue. The sorption coefficient (Koc) and half-life (DT50) characterize the substance's persistency and sorption in soil after application. Both values are relevant to quantify the amount of substance translocation by a runoff event or drainage water and can be set for the substance subject to simulation. Alternatively, substances already on the market can be chosen from a list. Mean Koc, DT50 values [UBA/BBA, 1998] for the chosen substance are then retrieved automatically from a database. Furthermore, an average dose of application is associated with the substance. The crop subject to treatment and the date of pesticide application has to be chosen. The default value of 10mm/24hrs for a rainstorm event assumed to trigger surface runoff can also be modified.

3. MODELS

3.1 Runoff

The amount of a substance to be translocated by surface runoff water essentially depends on the period of time elapsed between pesticide application and actual occurrence of a runoff-producing rainfall event [Mills and Leonard, 1984]. To quantify the fraction of the applied chemical in the runoff water (1) the threshold level of the rainstorm causing surface runoff, (2) the probability of its occurrence, (3) the volume of surface runoff as well as (4) the concentration of the active substance in the runoff water has to be determined.

1. It is assumed that rainfall events of 10 mm in 24 h or larger are sufficient to trigger surface runoff [Huber *et al*., 1998].

2. The mean probability of runoff-producing rainfall occurrence with a given volume and duration in a certain period is determined by the Gumbel-Distribution [Gumbel, 1958]. Gumbel distribution functions of 60 min and 24hrs, the latter with separate datasets for summer and winter, are available in DRIPS to predict the probability of a runoff occurrence. The time interval between pesticide application and the occurrence of a rainstorm – which is important to determine the substance's degradation – can be derived from the Gumbel data by a probability density function according to Mills and Leonard [1984]. Furthermore, a seasonal variation factor was

implemented, to account for the more variable frequency of rainstorm occurrences in the summer season [Auerswald, 1996].

3. The calculation of the runoff volume caused by a runoff-producing rainfall is based on the USSCS's curve-number-method [SCS, 1990]. The curve numbers were modified according to Lutz [1984] in order to adapt the SCS-CN-method to Central European conditions. Required data to obtain the curve numbers are land use and hydrological soil properties considering the current soil cover at the time of an event are required.

4. The pesticide concentration in runoff water at the beginning of a rainstorm highly depends on the substance's decay as well as the retention capacity of the crop and soil it was applied on. Degradation can be calculated with a first-order decay function returning the fraction of the pesticide's initial load, considering the time interval between application and a rainstorm [Mills and Leonard, 1984]. Decay is controlled by a breakdown coefficient depending on the chemical's half-life *DT50*. A probability density function returns the fraction of the initial load of the pesticide available on the soil surface for translocation with runoff water by considering the time interval between application and a rainstorm with a certain probability of occurrence mentioned earlier on [Mills and Leonard, 1984].

Furthermore, the fraction of the substance available for runoff translocation is reduced by absorption in the plant cover present at the time of application. A factor representing the degree of plant cover of crops in specific climatic zones at a certain stages of maturity was considered in the model approach [Bach *et al.*. 2000].

Only a portion of the remaining runoff-available pesticide load is expected to be found in the runoff-suspension during a rainstorm event. That is the fraction of the substance subject to desorption processes within the first centimeters of the topsoil. Consequently, the model only calculates pesticide displacement for the liquid phase. Erosion is not taken into account. A semi-empirical approach was adopted from GLEAMS [Leonard *et al.*, 1987] where the soluble amount of the runoff-available pesticide load can be extracted with a desorption-coefficient. An instant balance of a substance between the liquid and solid phase is pre-supposed. The desorption coefficient can be derived empirically from the distribution coefficient *Kd*, which in turn can be obtained from the linear organic carbon partition coefficient and the content of organic carbon in soil [CREAMS/GLEAMS: Leonard *et al.*, 1987].

The fraction of the initial pesticide load remaining after desorption has to be expected as surface water input as a result of a runoff-producing rainstorm event.

3.2 Leaching

Germany's registration authorities make use of the model PELMO by Klein *et al.* [1997] for assessing the risk of pesticide displacement via leaching. To conform to registration standards, PELMO was adopted in DRIPS as the model of choice to estimate the quantity of pesticides transported by leaching water. PELMO is used to simulate the displacement of a substance to 0.8 m depth. At that depth, the leachate is expected to enter a tile drainage system - if installed on the land – or be subject to further vertical translocation. In the latter case, the pesticide ultimately reaches the ground water body, if it does not fully degrade along the way. The input of pesticides into surface waters from the ground water body is considered to be negligible in Germany [Bach *et al.*, 2000]. Hence, pesticide input via leaching is only calculated for drained areas. A grid cell map of Germany's drained areas is provided by Behrendt *et al* [1999].

In the same manner as for the runoff, it is presupposed that only the share of a pesticide, which is not subject to foliage-interception is transported in the leachate. Since PELMO does not consider interception, a factor representing the degree of plant cover in specific climatic zones at a certain stages of maturity is used for adjustment. The remaining PELMO result is the actual fraction of the initial dose found in the leachate at 0.8 m depth. The solution is expected to enter a tile drain at that depth leading towards a surface water body nearby.

3.3 Drift

Surface water input of a sprayed pesticide via direct drift, is expected for the fraction of the substance, which is not reaching the target area but is directly blown into an adjacent stream. Generally, pesticide loss by drift is significantly higher for fruit- or grapevine plantations than for field crops. This is mainly due to different spraying-techniques, like the use of boom sprayers in field crops and air blast sprayers in grapevine plantations [Ganzelmeier *et al.*, 1995]. DRIPS uses the drift tables published by Germany's Federal Biological Research Center for Agriculture and Forestry (BBA) as a basis for estimating the fraction of a substance displaced by spray drift. The tables are also used by registration authorities to set up spraying-distance requirements for pesticides. Different tables are available for 90th, 70th and 50th percentiles providing separate spray drift values for fruit, grapevine and field crops - each for two phenological zones and for specific proximities of surface water and site of application [BBA, 2000].

The degree of expected pesticide input via drift highly depends on the proximity of the next surface water body to the sprayer. No sufficient set of data providing information about the exact location of smaller ditches – being the most common type of surface water body in agriculturally used land – is available for Germany. The mean drainage density of the river network is used alternatively to judge the probability of a substance reaching a surface water body via drift. A grid map available in DRIPS was derived from the Hydrological Atlas of Germany (HAD) by Huber *et al.* [1998]. The amount of pesticide input also depends on the width of the river. Larger water bodies are susceptible to higher amounts of deposition. However, most larger streams have adequate buffer zones shielding pesticide input to some extent. Unshielded small ditches are frequently found in agriculturally used areas prone to receive frequent deposition. A factor accounting for stream-width with different values for 1^{st} and 2^{nd} order (and higher) streams (definition of Strahler, [1957]) was implemented in DRIPS.

3.4 PEC_{sw}

The Predicted Environmental Concentration (PEC_{sw}) of a pesticide in a surface water body, reflects the cumulated diffuse pollution of the surrounding area treated with the substance. It is an indicator for the hazard potential of that substance to aquatic life. PEC_{sw} are expected to show significant variation, if the same substance is applied in different agroecological regions with heterogenic environmental parameters such as soil, precipitation, land use etc. Therefore, spatially distinguished estimations of PEC_{sw} are required to adequately judge the environmental impact of a substance in nature. DRIPS will provide PEC_{sw} estimation for more than 400 catchments distributed all over Germany for any pesticide with known chemical properties. The basis for PEC_{sw} calculation are the expected mean daily inputs (E) of a pesticide estimated by the previously discussed pathways of runoff, tile drainage and spray drift. The ratio of the mean daily input into various types of surface water bodies characterized by their daily discharge (Q) yields the predicted environmental concentration (PEC_{sw}) of the respective surface water body.

$$PEC_{sw} = E/Q \qquad [1]$$

Time series of continuous daily discharge data were gathered for more than 200 gauging stations from 1963 up to the mid 1990s. Representative mean daily discharge values are derived from this time series for every catchment, which can be associated with a gauging station. Flow duration curves are being set up for the catchments where data are available. Flow duration curves can be used to calculate the discharge of ungauged catchments from gauged catchments with similar site specific parameters such as size, rivermorphology and drainage density. To produce the missing parameters, the Germany river-network is classified into approximately six regions *(r)* of similar drainage density and rivernet-morphology. Also, all surface water bodies will be classified *(g)* according to their volume of discharge. Significant combinations of both classes *(r)* and *(g)* such as drainage density of 2^{nd} order streams in a certain region will be used as model variables for discharge calculation. The basic river network to be used is provided by Behrendt *et al.* [1999].

Up to date, the data set to derive flow duration curves for all of the catchments in question is not yet complete. Nevertheless, DRIPS can already be used to calculate PEC_{sw} (Figure 1) on the basis of mean annual discharge values for selected catchments.

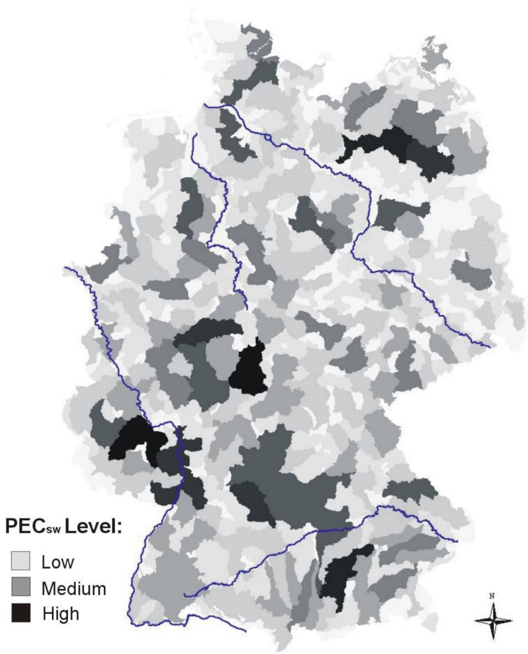

Figure 1 PEC_{sw} of a pesticide resulting from runoff

4. RESULTS AND DISCUSSION

To satisfy the requirements of the European Directive 91/414/EC, PEC_{sw} have to be determined for every plant protection product on the market. Producers as well as stakeholders are in need of methods/tools to judge the environmental impact of new products for aquatic life by producing PEC_{sw}. It is obligatory for pesticide manufacturers to determine PEC_{sw} values for product registration. Stakeholders on the other hand are requested to judge the environmental impact of new substances on aquatic life on the basis of PEC_{sw}. Harmonized sets of models, such as the FOCUS Step 3 approach [FOCUS, 2001] featuring ten scenarios representative for EU agriculture, are helpful to both producers and authorities to estimate the environmental impact – and with the chances for registration – on a common basis.

The DSS DRIPS aims to provide producers and stakeholders with regionally differentiated scenarios of PEC_{sw} for the territory of Germany. Models implemented in the DSS already comply with Germany's registration requirements for the pathways of tile drainage (PELMO) and spray drift (BBA drift tables). The graphical user interface offers easy modification of the essential model parameters to run different scenarios. Full GIS integration of the model approaches provides a spatially discriminated visualization of the model results on maps with 1 km^2 resolution for the diverse agroecosystems of Germany. DRIPS is a time- and cost-effective DSS to assess the probability of pesticide contamination of surface waters and the resulting initial concentration of the pesticide in surface water bodies.

It has to be kept in mind, that results of a model approach on a regional scale do not accurately predict concentrations of pesticides found in on-site measurements. This DSS is rather aimed to produce scenarios for a first-screening of the hazard potential of plant protection products. The probability based model approach enables the user to vary environmental- and substance parameters in order to produce scenarios ranging from the conservative "worst case" assumption up to more or less "realistic" conditions. The scenarios can be used by chemical companies to confirm compliance with existing threshold values or for stakeholders to set up new thresholds. Model results such as frequency distributions of PEC_{sw} can serve as a basis for discussion in-between manufacturers and stakeholders to identify areas prone to high contamination. Field campaigns could be initiated at these areas, if simulated products are already in use. Pesticides up for registration could be permitted with regional restrictions for locations of low risk. DRIPS could be used as a qualitative risk assessment tool for plant protection products by producers and stakeholders alike estimating PEC_{sw} in German surface waters.

5. ACKNOWLEDGEMENTS

This project is funded by the Federal Environmental Agency (UBA), Berlin: UBA-FE-Project 299 24 272

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