

# DRIPS – a decision support system estimating the quantity of diffuse pesticide pollution in German river basins

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**Abstract** The GIS based decision support system DRIPS – **D**rainage **S**praydrift and **R**unoff **I**ntput of **P**esticides in **S**urface **W**aters – has been developed to estimate the predicted environmental concentration ( $PEC_{sw}$ ) of pesticides in surface waters resulting from diffuse sources.  $PEC_{sw}$  can be calculated on a catchment scale by quantifying the expected mean daily inputs of pesticides via surface runoff, tile drainage and spraydrift for various types of river basins characterized by their daily discharges. DRIPS is fitted with a Graphical User Interface (GUI) to provide easy access to the model algorithms. Model parameters like dose rate, DT50, Koc and date of pesticides application, etc. can be modified by the user in order to generate customized scenarios predicting  $PEC_{sw}$  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  $PEC_{sw}$  values for approximately 400 catchments.

**Keywords** Diffuse pollution; DSS; GIS; PEC; pesticides; runoff

## Introduction

Pollution of surface water-bodies by non-point sources, such as agriculturally used plant protection products can cause severe impacts on non-target organisms in aquatic ecosystems and for human health, if threshold levels of specific active ingredients (a.i.) are exceeded. To maintain high surface water quality standards the contribution of various diffuse sources of input – here surface runoff, tile drainage and spraydrift – have to be assessed for a.i. in order to reduce their impact on the ecosystem.

Modeling the environmental fate of pesticides grew to be the focus of research activity within the European Union in the context of pesticide registration, being a rather inexpensive and effective alternative to monitoring campaigns. User-friendly Decision Support Systems (DSS), like DRIPS, offer authorities and producers easy access to models generally providing powerful tools for regional risk-assessment.

The predicted environmental concentration in surface waters  $PEC_{sw}$  is commonly used by stakeholders to judge the hazard potential of a pesticide. The European Directive 91/414/EC on plant protection products requires manufactures of a.i. to supply  $PEC_{sw}$  for products to pass registration. In the current registration procedure a substance needs to pass a single “worst case” scenario based on laboratory experiments to be considered non-toxic. This practice generally does not adequately account for the heterogeneity of the agricultural areas the a.i. is applied in. Spatially distinguished  $PEC_{sw}$  scenarios provide a more realistic basis for risk assessing a substance’s behavior in various landscapes. The probability based risk assessment tool DRIPS supplies regionally distributed  $PEC_{sw}$  on a catchment scale with a spatial resolution of 1 km<sup>2</sup>.

## DSS–GIS interface

The core of DRIPS contains a set of models quantifying diffuse pollution from pesticides according to the methodology of Huber *et al.* (2000) 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.

### Data

The basic aim of the DSS DRIPS is to serve as a risk assessment tool providing spatially distributed information on diffuse pesticide pollution and resulting  $PEC_{sw}$ . Hence, the majority of the parameters required for model simulations (Table 1) are implemented as a set of grid and vector maps conforming to the map “administrative boundaries of Germany 1:1 Mio” (IFAG/BKG, 1996). Non-spatially distributed data such as the a.i. parameters DT50 and Koc are stored in dBASE database format. Pesticide application parameters, such as dosage and substance date, have to be specified by the user, before executing a model run.

### Models

#### Runoff

The amount of a substance to be dislocated 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 have 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.*, 2000).
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 24 hrs, the latter with separate datasets for summer and winter, are available in DRIPS to predict the probability of a runoff

**Table 1** DRIPS's basic data

| Type       | Implemented data                                 | Source                         |
|------------|--|--------------------------------|
| Grid map   | Annual precipitation                             | German weather service (DWD)   |
|            | Frequency of rainstorm occurrence                | 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. water management agencies |
|            | Pesticide Koc, DT50 values                       | UBA                            |
|            | Agro-statistics 1995                             | Fed. statistical service       |
|            | Soil-cover of field crops at date of application | Feldwisch and Hecker 1997      |
|            | Seasonal variation factor (runoff)               | Auerswald, 1996                |
|            | Seasonal index/week numbers (runoff)             | Lutz, 1984                     |
|            | Maximum drainage coefficient                     | Auerswald and Haider, 1996     |

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 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 centimetres 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  $K_d$ , 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.

### 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 stage 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.

#### **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.* (2000). 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 1st and 2nd order (and higher) streams (definition of Strahler (1957)) was implemented in DRIPS.

#### **PEC**

In order for stakeholders to judge the hazard potential of new substances on aquatic-ecosystems  $PEC_{sw}$  are required as part of a three tiered approach for pesticide registration within the European Union (FOCUS, 2001).  $PEC_{sw}$  generally reflect the cumulative inputs of a substance from the area of application in a river-stretch by diffuse sources. For instance  $PEC_{sw}$  values at the outlet of a river-catchment represent the sum of all non-point source inputs estimated in the catchment. Due to the heterogeneity of different catchments in terms of their environmental parameters (soil, precipitation, land use, etc.) controlling pesticide dislocation,  $PEC_{sw}$  are expected to show significant variation, if applied nationwide. 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 bases for  $PEC_{sw}$  calculation are the expected mean daily inputs (E) of an a.i. within these catchments estimated by the previously discussed pathways of entry. 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:

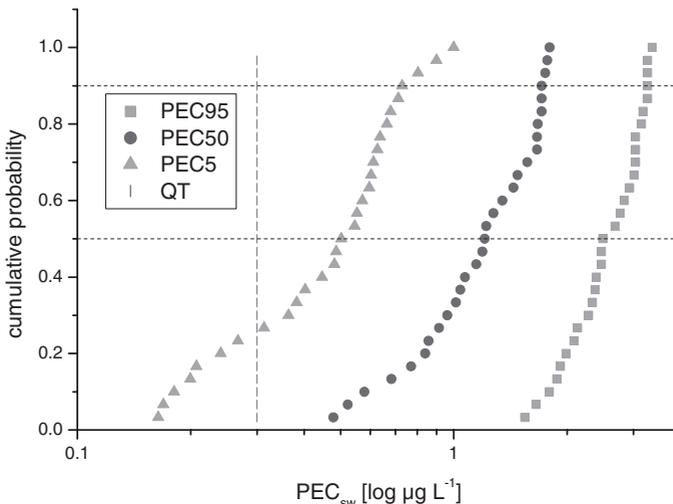
$$PEC_{sw} = E/Q \quad (1)$$

To provide  $PEC_{sw}$  estimates on a catchment scale, discharge data of the gauging stations of each catchment outlet were needed. Time series of continuous daily discharge data were gathered for more than 200 gauging stations with a 30 year record from 1971 to 2000. Representative mean daily/monthly discharge values were derived from this time series for each catchment. However, in order to also supply  $PEC_{sw}$  for the remaining ungauged catchments, discharge data had to be estimated. For this purpose, flow duration curves (FDC) were set up from the available time series for gauged stations. FDCs are cumulative frequency curves of daily discharges during a year representing the proportion of time that a particular discharge is equaled or exceeded during the period of observation (LeBoutillier and Waylen, 1993).

Statistical analysis of long time series of daily discharge data allows us to correlate annual flow frequency characteristics with physical parameters of the respective catchment, such as size, topography, morphology, geology, precipitation, drainage density (Searcy, 1959). Hence, FDCs can be used to calculate the discharge of ungauged catchments from gauged catchments with similar site-specific characteristics. Physical parameters are raised and attributed to all catchments available in the DSS. FDCs can be assigned to ungauged catchments belonging to the same discharge-class as gauged ones.

Two options are available in DRIPS to estimate  $PEC_{sw}$  resulting from pesticide dislocation by either surface runoff, tile drainage or spraydrift: (i) monthly  $PEC_{sw}$  average, (ii) probability of  $PEC_{sw}$  distribution for selected catchment and month. Option (i) produces an output map with average  $PEC_{sw}$  values attributed to each of the 400 catchments. The simulation is based on median monthly discharge values ( $Q$ ) of each catchment. Option (ii) produces a line graph (Figure 1) of the probability distribution of  $PEC_{sw}$  for a selected month. Various percentiles (5th, 25th, 50th, 75th, 95th) of discharge data are available for  $PEC_{sw}$  estimation.

This option provides a basis for probabilistic risk assessment of any a.i.'s behaviour within a catchment with defined physical features. The simulation of the probability of a substance to pass set thresholds under realistic conditions can help stakeholders to establish



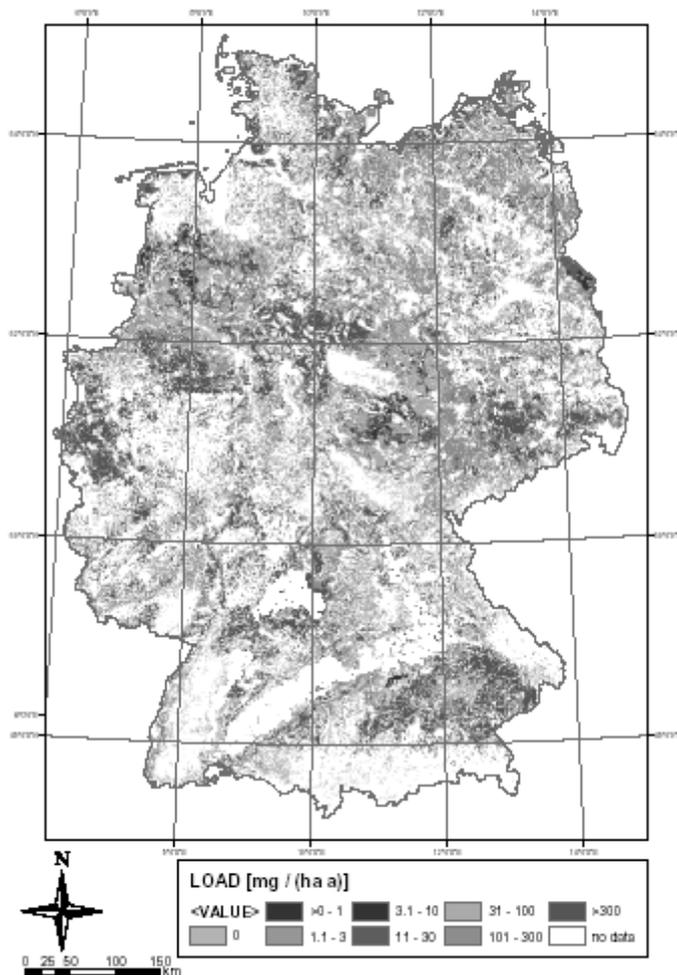
**Figure 1** Estimated DRIPS probability distributions (5th–95th percentile) for  $PEC_{sw}$  of isoproturon resulting from surface runoff inputs at Frankfurt Nied (Nidda) in April 2000 (QT = QualityTarget)

new regulations and producers to check the compliance of newly developed substances with existing laws.

## Results and discussion

$PEC_{sw}$  values are commonly used in environmental risk assessment for estimating the effects of the cumulative diffuse pollution of an a.i. on aquatic life. Producers of pesticides have to obligatorily determine  $PEC_{sw}$  for new substances to pass the European registration requirements, as specified in the EU Directive 91/414/EC. The current registration procedure only determines whether or not an a.i.'s  $PEC_{sw}$  exceeds a set "worst case" value. Regionally differentiated  $PEC_{sw}$  scenarios would provide a somewhat more realistic basis to judge a substance's environmental impact within the various agroecological regions it is applied in. The FOCUS 3rd tier approach (FOCUS, 2001) featuring ten standard scenarios representative for the EU's main agroecological regions, is a step towards regionalized risk assessment of diffuse pollution on a EU scale.

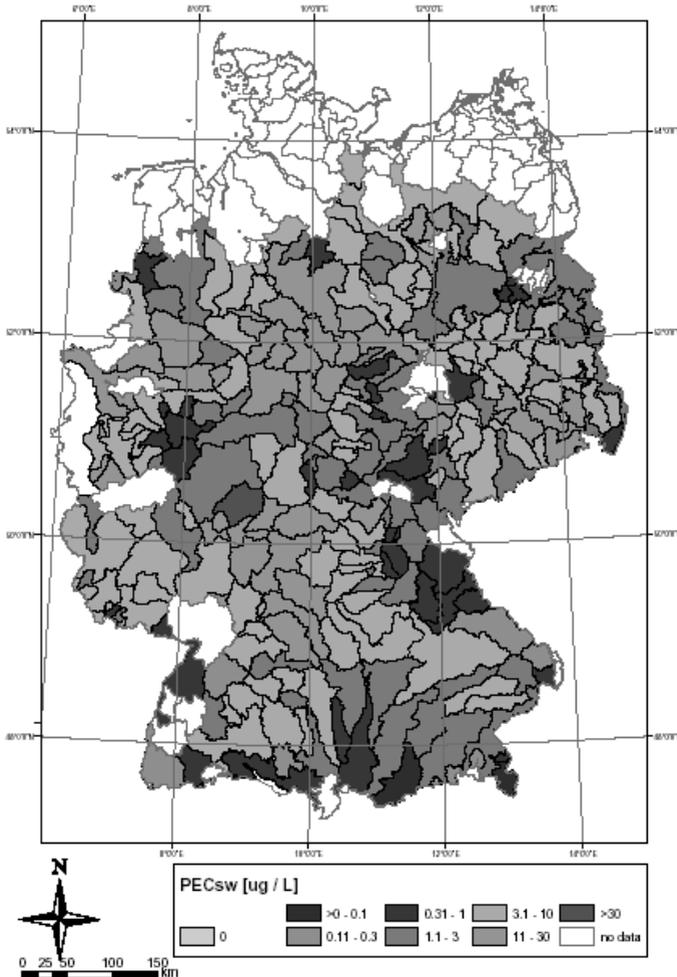
On a national scale, the DSS DRIPS is available providing producers and stakeholders with regionally differentiated  $PEC_{sw}$  scenarios for the territory of Germany. Models implemented in the DSS already comply with Germany's registration requirements for the pathways of tile drainage (PELMO) and spray drift (BBA drift tables). The graphical user



**Figure 2** Estimated annual surface runoff load of isoproturon, year 2000 [ $mg\ ha^{-1}\ a^{-1}$ ]

interface offers easy modification of the essential model parameters to run different scenarios. Full GIS integration of the model approaches offers a spatially discriminated visualization of the model results of loads and  $PEC_{sw}$  on maps with  $1 \text{ km}^2$  resolution (Figure 2, Figure 3) for the manifold 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.

Due to the regional scale of the model approach, results 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 to identify areas prone to high contamination by diffuse pollution. Field campaigns could be initiated at these areas, if simulated products are already in use. Results maps could be employed by stakeholders to establish regional instead of national threshold values for pesticide registration. DRIPS was developed to serve as a qualitative risk assess-



**Figure 3**  $PEC_{sw}$  of isotoproturon from surface runoff, drainage and spraydrift inputs as the 90th percentile over all year 2000 concentrations based on mean (50th percentile) discharge conditions

ment tool for estimating the regionalized hazard potential of pesticides in surface waters for the territory of Germany.

### Acknowledgements

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

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