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ALTERRA
WAGENINGEN UR

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Abstract
Within the frame work of the Sino-Dutch Pesticide Environmental Risk Assessment Project (PERAP) and as part of the Chinese environmental risk assessment procedures models and scenarios were developed to estimate concentrations of Plant Protection Products (PPP) leaching to the groundwater and to estimate PPP concentrations in Chinese small surface waters. Protection goals considering groundwater and surface water were defined in detail. Realistic worst-case groundwater scenarios and surface water scenarios were defined to be used in respectively a Tier 1 leaching assessment of PPP a Tier 1 assessment of the risks of PPP to aquatic ecosystems in China. Data on soil, weather, crops, irrigation and agricultural practices were gathered for both scenario definitions. Existing models PEARL and TOXSWA were modified and parameterised for the scenarios defined.

Keywords: pesticides, scenarios, China, modelling, registration, PEARL, TOXSWA, leaching, exposure, groundwater, surface water, paddy rice.

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Preface

The work described in this report is done within the framework of the Sino-Dutch Pesticide Environmental Risk Assessment project (PERAP). PERAP is a cooperation platform between Chinese and Dutch governmental bodies and research institutes.

The Institute for the Control of Agrochemicals, Ministry of Agriculture of the MoA (ICAMA) is responsible for the pesticide registration procedures in China. The following themes are considered to be of importance in the registration procedure:

1. Physical / chemical properties;
2. Analytical methods;
3. Human toxicology;
4. Residues;
5. Environment (behaviour and fate of pesticides and ecotoxicology);
6. Efficacy.

The PERAP project is intended to assist China in the above mentioned theme "Environment" with the main goal to develop Chinese Environmental Risk Assessment (ERA) procedures for pesticide registration, including developing a series of relevant guidance documents. ICAMA and Alterra, Wageningen-UR, the Netherlands, the Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, (IARRP CAAS) and WILresearch, the Netherlands, have been working together towards this aim as the four major participants of the PERAP project. Some other institutions/organizations, such as Plant Research International, Wageningen UR, the Netherlands, Ctgb (Board for the Authorisation of Plant Protection Products and Biocides, the Netherlands), and others also made valuable contributions to this joint project.

The work was subdivided in 5 work packages and the main purposes of each work package is summarized below:

- 1: project inception and formalization, overall project management, formalizing the continuation of the activities of the consortium partners after 2009;
- 2: development of a risk assessment handbook, training of staff of four Contract Laboratories and ICAMA in the use of the handbook;
- 3: development of guidelines and SOPs for standardized laboratory tests and working towards GLP certification of the ICAMA laboratories;
- 4: development of capacity in working with environmental fate models and development of protective scenarios for China;
- 5: develop, discuss and formal approval of the criteria for ERA.

The project aimed at the development of sound environmental risk assessment procedures, applicable in the Chinese context and acceptable as legal framework for the Chinese registration procedure. This entails development of (i) capacity to perform eco-toxicological and behavioural tests under GLP, (ii) methods to estimate exposure under normal agricultural use of pesticides and (iii) a risk assessment handbook.

This report is the end result of activity (ii). The work for this activity is performed by Alterra, Wageningen UR, being the scientific partner from the Dutch side and the Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, (IARRP CAAS) and China Agricultural University (CAU) both located in Beijing, being the scientific partners from the Chinese side. The Chinese regulatory authority ICAMA (Institute for the Control of Agro-chemical of the Ministry of Agriculture) was intensively involved and took were needed risk management decisions. This report describes details of the models and the scenarios developed to estimate concentrations of pesticides leaching to the groundwater and pesticide concentrations in surface water as part of the Chinese environmental risk assessment procedures. It contains the results of the collaborative dedication of all work package 4 partners to construct a high quality and sustainable risk assessment framework that can be adopted now and extended and elaborated further on-demand.

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Summary

As part of the Chinese environmental risk assessment procedures models and scenarios were developed to estimate concentrations of plant protection products leaching to the groundwater and concentrations of plant protection products in Chinese small surface waters. This work was done within the frame work of the Sino-Dutch Pesticide Environmental Risk Assessment Project (PERAP). Together with the Chinese project partners protection goals considering groundwater and surface water were defined in detail. During the PERAP project scenarios and models were developed for only a part of the protection goals defined. Six realistic worst-case groundwater scenarios were defined for dry land agriculture north of the Yangtze River in China and two realistic worst-case groundwater scenarios were defined for paddy land south of the Yangtze River. These scenarios are intended to be used in a Tier 1 assessment of the leaching potential of plant protection products. For protection of the aquatic ecosystem in Chinese natural ponds south of the Yangtze River, two scenarios were defined to be used in the Tier 1 assessment of the risks of plant protection products to aquatic ecosystems in China. Data on soil, weather, crops, irrigation and agricultural practices were gathered for both scenario definitions for parameterisation of the scenarios. Existing models PEARL and TOXSWA were modified and parameterised for the scenarios defined.

1 Introduction

1.1 Background

The PERAP project aimed at the development of sound environmental risk assessment procedures, applicable in the Chinese context and acceptable as legal framework for the Chinese registration procedure. One of the activities in the project was to develop models and the scenarios to estimate concentrations of pesticides leaching to the groundwater and pesticide concentrations in surface water as part of the Chinese environmental risk assessment procedures. This work was performed by Alterra Wageningen UR, IARRP CAAS and CAU. The Chinese regulatory authority ICAMA joined the discussions and decided on all risk management issues.

The basis of the work described in this report is the roadmap that has been developed at the beginning of the project. This road map provides the main steps that are needed to develop exposure assessment scenarios, and guarantees their embedding within a consistent and well-structured risk assessment framework. It is based on the extended and long-time experience of the Dutch partner Alterra with risk assessment scenario development in the Netherlands and the European Union. The report contains detailed information on the scenario development steps, the parameterisation of the models and, furthermore, provides extended technical details to assure transparency and traceability of all the decisions that have been made during the development process. The developed scenarios have been implemented in two user friendly tools, i.e. ChinaPEARL and TOPrice. This report is part of a series of Alterra reports describing the work done within the PERAP project.

1.2 Structure of report

The report starts with a roadmap for the scenario development, followed by a description of the endpoints of the leaching and exposure assessments; discussing protection goals, decisions made and the place of the developed scenarios in the tiered approach (Section 2). After Section 2 the steps given on the roadmap are followed. Starting with a description of the data gathered for scenario development (Section 3) and followed by a description of the identification of the scenario zones (Section 4). Section 5 describes the conceptual models of the selected protection goals and Section 6 gives some backgrounds on the process of selecting simulation models for calculating leaching concentrations to groundwater and exposure concentrations in surface water. Section 7 describes for each selected protection goal the drivers and the chosen scenario selection procedure. Section 8 describes the implementation of the scenario selection procedures and its results (i.e. the scenario locations) and Section 9 describes the needed modifications to the PEARL model and TOXSWA model. Section 10 gives details about the parameterisation of the scenarios. Example calculations for the three selection goals are provided in Section 11. Finally Section 12 gives the main conclusions and recommendations for improvement and further investigation and implementation of the methodologies.

2 Outline of scenario development in the PERAP project

2.1 Roadmap for developing leaching and exposure scenarios

Eight consecutive steps were identified at the beginning of the project and used as a roadmap for the selection and parameterisation of leaching and exposure scenarios. These steps are depicted in Figure 1. Each step is explained below.

The first step consists of data gathering, and quantifying/geo-referencing the temporal and spatial variability of climate, soil types, land use, surface water systems, agricultural practices etc. This step is needed to underpin decision making. The next step (step 2) is an important step involving risk managers: decide whether the registration of pesticides in China should be based upon one scenario zone (i.e. the entire country) or multiple scenario zones. Reasons for considering more than one scenario zone could be: i) diversity in climate, soil, land use, ecological systems, etc., ii) spatial variability in pesticides use, iii) spatial variability in required efficacy trials for pesticide registration. In the third step scientists define options for the protection goal(s). These options are considered and selected by the risk managers resulting in clear definitions of the different protection goals (i.e. what to protect where and how strict; step 4) and the selection of the considered spatial scale (e.g. catchment size, size of the water body). In case more than one scenario zone is defined, the risk managers should attribute the different protection goals to the different scenario zones. The fifth step is defining a conceptual model for each protection goal. This includes identifying important processes and entry routes of pesticides. The sixth step is the choice of suitable simulation models. In this step also sensitivity drivers are identified while using the available simulation models. Step seven is the definition of vulnerability drivers and the choice of a scenario selection procedure. In addition to sensitivity drivers, vulnerability drivers are considered to represent the vulnerability related to a protection goal, and they show a strong spatial or temporal variability across a scenario zone. The most sophisticated type of a scenario selection procedure is vulnerability mapping using a spatial distributed model. In case vulnerability mapping is not possible due to lack of data or lack of suitable spatial distributed models the scenario selection procedure can be based upon a more simple vulnerability concept. The next step in the roadmap is to select a scenario location based upon the vulnerability drivers. This step is followed by the last step (step 8): parameterization of the scenario(s) in the model(s). This work involves a data gathering phase for the specific location and the parameterisation of the model with the scenario specific input files. Simulation results need to be evaluated on plausibility. Ideally this is followed by a validation step: testing the model and scenario against field data. The validation step is not shown in the roadmap, since it has not been part of the collaborative work within the PERAP project. We do however acknowledge that such a validation step is very important to increase confidence in the model(s) and the developed scenarios.

Figure 1 *Roadmap for developing scenarios for pesticide leaching and surface water exposure for China.*

2.2 Endpoints of the leaching and exposure assessments

2.2.1 Protection goals

Groundwater

The Chinese risk managers decided that groundwater needs to be protected from pollution with pesticides in such a way that it is suitable to be used as drinking water without purification. Unlike the EU, were 0.1 µg/L is used as a drinking water criterion, the Chinese risk managers decided that human toxicological criteria should be used. The drinking water criterion used in the Chinese groundwater risk assessment is calculated according to the *WHO guidelines for drinking water quality* (WHO, 2008). The Chinese risk managers furthermore decided that all groundwater bodies in China need to be protected and reasoned that when groundwater in agricultural areas is protected the groundwater outside agricultural areas is protected by definition.

Due to large hydrological differences between two major cropping systems in China, it is needed to distinguish between paddy land and dry land. Within PERAP paddy land is defined as: 'land on which irrigated rice crop is grown at least once within a year' and dry land is defined as: 'all cultivated land that is not paddy land'. Both agricultural land types are found all over China although paddy land is mainly found south of the Yangtze River and dry land is mainly found north of the Yangtze River.

PERAP aimed at developing scenarios for both dry land and paddy land. It was decided that separate scenarios for dry land and paddy land should not be developed for the scenarios located south of Yangtze River. Dry land crops and paddy rice are grown alternately in the same fields south of the Yangtze River. Crop rotation between paddy rice and dry land crops happens on a scale of months. On the other hand, pesticide leaching to groundwater is a process on a scale of years. This implies that the specific hydrology of cropping systems interfere. Cultivation of paddy rice results in high percolation rates (Janssen and Lennartz, 2006; Wopereis *et al*., 1992). The project group expected therefore high leaching concentrations and concluded that an additional dry land scenario was not necessary because the paddy land scenario would be protective. This hypothesis is evaluated in Section 11.

Chinese risk managers selected the following protection goals for groundwater in China:
a) Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River.
b) Groundwater in drinking water wells at 10 m deep in paddy land north of the Yangtze River
c) Groundwater at 2 m depth in paddy land south of the Yangtze River

Given the limitation in project time and budget it was decided to develop scenarios for groundwater protection goals (a) and (c) only, so the scenario development methodology and model parameterization of the scenarios for these protection goals are described in this report.

Note that the situation of protection goal (c) will become outdated in the future according Chinese authorities, because the Chinese government stimulates the building of deep groundwater wells (20-40 m deep).

Surface water

The Chinese risk managers decided to protect the ecosystems in small surface waters and (for the time being) they decided that it is not necessary to protect surface water as a source of drinking water.

The following protection goals were defined for the protection of aquatic ecosystems in small surface waters in China:
a) Aquatic ecosystems in natural ponds south of the Yangtze River.
b) Aquatic ecosystems in natural ponds north of the Yangtze River.
c) Aquatic ecosystems in level 3 drainage channels south of the Yangtze River.
d) Aquatic ecosystems in level 7 rivers north of the Yangtze River.
e) Aquatic ecosystems in rivers in the valley of hilly area south of the Yangtze River.

Note that in a) and b) only natural ponds are considered, i.e. ponds used for (commercial) fish culture are not part of these protection goals.

In the period 2008 – 2010 scenarios were developed for surface water protection goal (a) only, so the scenario development methodology and model parameterization of the scenarios for this protection goal are described in the report. A more detail description of protection goals (b), (c), (d) and (e) is given in Annex A.

2.2.2 Risk management decisions

Considering groundwater the Chinese risk managers decided that the endpoint of the groundwater assessment should be the overall 99th percentile of the leaching concentration (so a 99th percentile of the spatio-temporal population of leaching concentrations). This means that they decided to protect 99% of all possible situations in both space and time. The protection level is higher than the 90th percentile approach of the EU (FOCUS, 2000). This more conservative (i.e. on the safe side with respect to the risk assessment) leaching scenario is evaluated against the human toxicological criteria which are less strict than the European drinking water criterion of 0.1 µg/L.

Considering the protection of aquatic ecosystems in surface waters the Chinese risk managers decided that the endpoint of the exposure assessment of aquatic ecosystems should be the 90th percentile of the annual peak concentration the surface water (so a 90th percentile of the spatio-temporal population of peak concentrations in Chinese surface water bodies). This is in line with the European approach (FOCUS, 2000).

The population of water courses that should be protected should be permanent (always water-bearing) and should be natural or semi-natural (not man made).

The choice for first developing scenarios for aquatic ecosystems in natural ponds south of the Yangtze River was made by the Chinese risk managers. This does not mean that the natural pond scenarios result in the most conservative exposure concentrations in small surface waters in China. Preliminary calculations for the concentration of pesticides in level 3 drainage channels (protection goal (c)) indicated that the pesticide concentrations in these channels would be similar to the concentrations found in water overflowing the bunds around a paddy field. These concentrations may be 10 – 20 times higher than the concentrations calculated for the natural ponds south of the Yangtze River.

The Chinese risk managers decided to base the registration of pesticides in China upon multiple scenario zones (see Section 4). The area of agriculture indicated as Qinghai-Tibet in Figure 3 is that small that the Chinese risk managers decided that it was not necessary to develop scenarios located in this area. For the groundwater scenarios north of the Yangtze River the Chinese risk managers decided to select two or three scenario locations per scenario zone. This is a non-scientifically based decision as each scenario location in a scenario zone is regarded to be protective for 99% of all possible situations in the zone.

In China about 50% of the pesticides have a label specifying that it can be used on a series of crops (up to 10 crops). As mentioned in Section 2.2.1; it is common practice that crops are grown alternately on the same field especially south of the Yangtze River. A typical situation is two cycles of rice in a year. Instructions on the Chinese pesticide labels usually do not refer this situation; a label usually only specifies application in rice. The Chinese risk manager therefore decided that in case of such a label, the risk manager should apply the pesticide in both crop cycles when performing simulations with the scenarios developed.

For the short term the Chinese risk managers decided not to incorporate metabolites in to the risk assessment for aquatic ecosystems in the natural pond (note that it is however a long term goal to incorporate metabolites for this risk assessment as well). Reason for not incorporating metabolites in to the risk assessment for aquatic ecosystems in the natural pond is that deriving half-lives of metabolites in water and sediment is not straight forward. Chinese contract laboratories are at the moment not able to derive reliable half-lives of metabolites in water and sediment.

2.2.3 Operational decisions

All operational decision described in this section were communicated with the Chinese risk managers and they consented to these decisions. The first operational decision made was to assess groundwater leaching at 1 meter depth although the protection goals relate to deeper depths. The reason was that information on soil (e.g. texture, organic matter) was usually only available for soil profiles up to 1 meter. Extrapolating the available soil data to greater depth would introduce extra uncertainties. A scenario with extrapolated soil data might not be protective for situations in which fractured rocks or highly permeable substrates transport the pesticide quickly to the groundwater. The project group decided therefore in line with FOCUS (2000) to assess groundwater leaching at 1 meter depth.

The project group decided to assume that mole drainage is not a common practice in China at the moment (personal communication prof. Li Chongjiu , department of applied chemistry, China Agricultural University).

As already mentioned in Section 2.2.1. the project group expected that a paddy land scenario would be protective for both paddy land and dry land. For a paddy land scenario much higher leaching concentrations are expected than for a dry land scenario due to the higher percolation rates that occur in paddy land (Janssen and Lennartz, 2007; Wopereis *et al*., 1992). This hypothesis is evaluated in Section 11.

During establishing the most important drivers for groundwater in paddy land and surface water adjacent or surrounded by paddy land it became clear that it was possible to select the same scenario locations for both the groundwater and the natural pond scenario south of the Yangtze River. For the sake of simplicity and efficiency the models were parameterized for the same scenario locations south of the Yangtze River.

For both the groundwater in paddy land scenarios and the natural pond in paddy land scenarios, land use turned out to be an important driver. Often two or three harvests of different crops (e.g. paddy rice, vegetables, cereals etc.) take place from one field. For groundwater land use is therefore a driver for paddy rice much higher leaching concentrations are expected than for dry land crops such as vegetables or cereals. For the natural pond land use is a driver, because runoff from paddy rice fields is expected to be higher than runoff from field with dry land crops. For the exposure in the natural pond scenario it is also relevant how much area of the surrounded paddy land is cultivated with paddy rice and how much area is cropped with a dry land crop (for instance wheat or vegetables). The driver land use therefore complicates the scenario development considerably. Because of the limited time and budget available the project group decided to start with scenario development for the most simple and conservative case (i.e. 2 crop cycles of paddy rice). The scenario selection procedure of this first phase is described in Section 7.

It is common practice in China to plant crops on every inch of land. This means that crops are planted as close as possible to water bodies and sometimes even in the side slopes of the water bodies. For determination of the spray drift depositions on a water body the distance between the last row of the crop and the upper edge of the bank of the water body is assume to be zero.

Within PERAP spray drift curves for knapsac sprayers were developed (Franke *et al.,* 2010). The Chinese risk managers decided to use the curves for the humid and warm climate in the Chinese exposure assessment for the protection of aquatic ecosystems in the natural pond south of the Yangtze River.

The drift curves in Franke *et al.* (2010) are not worst case in case the wind speed is above 3 m s^{-1}. Chinese policy makers decided therefore that farmers should not spray if wind speeds are above 3 Baufort (3.4 – 5.4 m s^{-1}).

2.3 Position in the tiered assessment scheme

The tiered approach is the foundation of environmental risk assessment schemes used in the European pesticide registration procedures. EFSA (2010) defined a tier as a complete exposure or effect assessment resulting in an appropriate endpoint (in this case the PEC_{GW} or the PEC_{SW}). EFSA (2010) explains the concept of a tiered approach by starting with a simple conservative (i.e. on the safe side with respect to the risk assessment) assessment. Higher tiers add more detail and complexity to the scenarios and require more work to be done by the applicant and the regulator. These higher tiers are less conservative than the lower tiers.

The following general principles of tiered exposure approaches are given by EFSA (2010):

i. lower tiers are more conservative than higher tiers,
ii. higher tiers are more realistic than lower tiers,
iii. lower tiers usually require less effort than higher tiers
iv. in each tier all available relevant scientific information is used
v. all tiers aim to assess the same exposure goal.

Summarizing, the tiered exposure assessment needs to be internally consistent and cost-effective and to address the problem with higher accuracy and precision when going from lower to higher tiers (EFSA, 2010). These principles permit moving directly to higher tiers without performing the assessments for all lower tiers (EFSA, 2010). The Chinese risk managers embraced the idea of tiered approaches and decided that the developed models and scenarios for the Chinese pesticide risk assessment of leaching to groundwater and exposure in surface water described in this report are intended to be used in the first tier. With respect to leaching higher tiers within the Chinese risk assessment include monitoring studies or refinement of pesticide properties using field leaching studies. With respect to the exposure in surface water assessment higher tier options are not embedded in the risk assessment scheme developed during PERAP.

3 Data for scenario development

3.1 Soil data

The Office Of The Second National Soil Survey (1994) provided measured data of soil texture (according the Chinese classification system), organic matter content and occasionally dry bulk density.

Digital Soil Lab, Chinese Academy of Agriculture Sciences (2005) provided spatially distributed data of the organic matter content in the top 20 cm of the soil. Figure 2 shows the organic matter map for whole China.

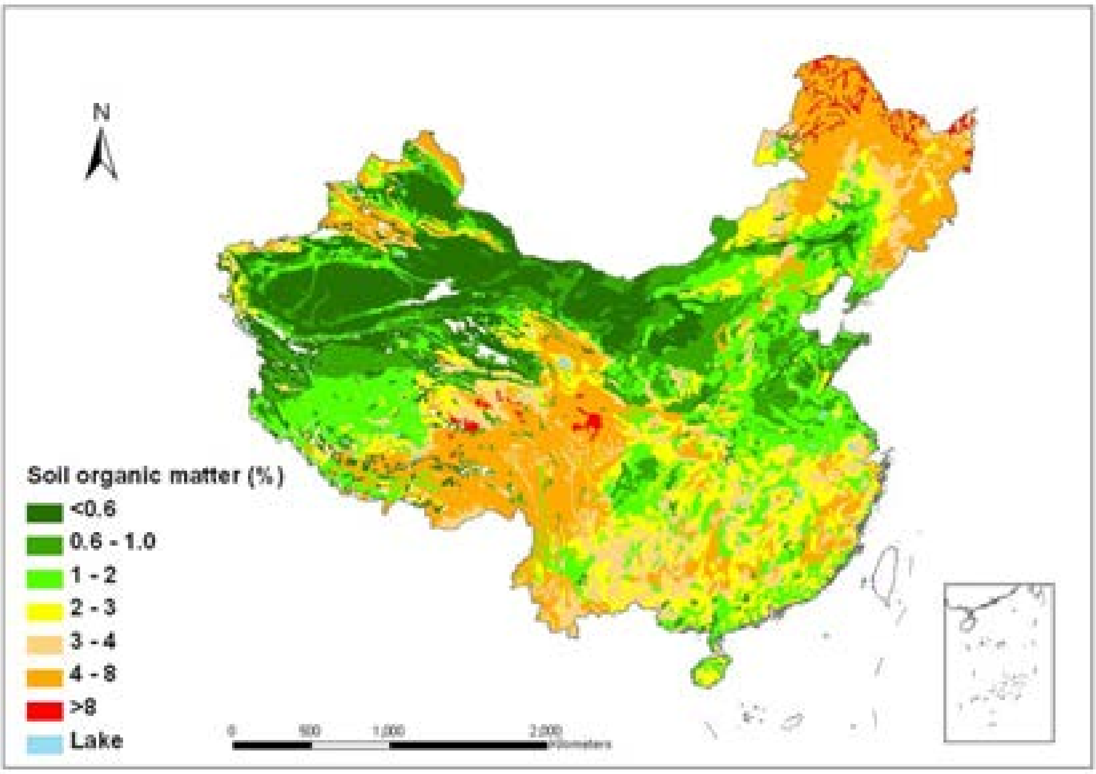

Figure 2 *Soil organic matter content map (in 0 – 20 cm) of Chinese (Digital Soil Lab, Chinese Academy of Agriculture Sciences, 2005).*

3.2 Meteorological data

Meteorological data from the China Meteorological Data Sharing Service System were available, of which only the data of meteorological stations categorized as international exchange stations were available for use and publication outside China. Therefore, precipitation data of all Chinese meteorological stations in the database could only be partly used for the selection of the scenario locations.

3.3 Agricultural systems and practices

3.3.1 Agricultural land types

The digitalized 1: 4 000 000 land use map (Digital Soil Lab, Chinese Academy of Agricultural Sciences, 2005) was used to identify the distribution of paddy land and dry land for the entire area used for agricultural purposes in China (Figure 3). Note that the area of dry land shown in Figure 3 does not include forest and grassland as these types of land use are considered to be irrelevant for pesticide risk assessment.

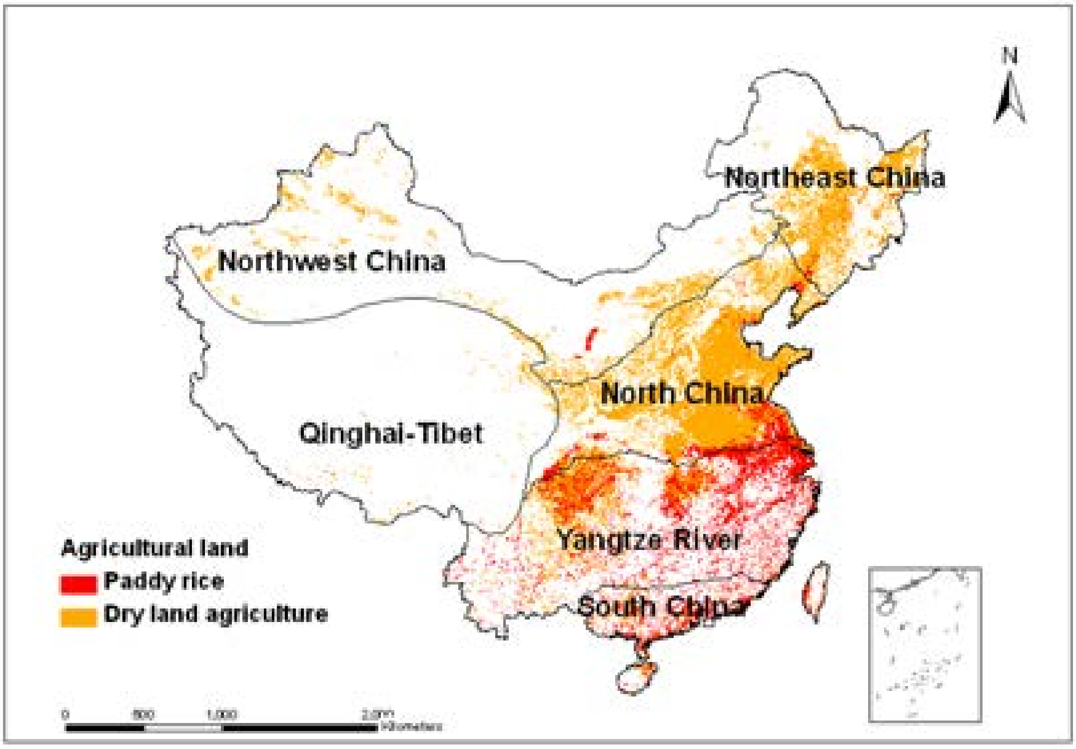

Figure 3 *Distribution of paddy land and dry land in China (Digital Soil Lab, Chinese Academy of Agricultural Sciences, 2005). Note that China is divided in to six parts: scenarios zones. This is one aspect of the method for defining scenario locations is the establishment of scenario zones (Section 4).*

3.3.2 Spatial and temporal variability of crop cultivation in China

The spatial and temporal variability considering crop cultivation in China is large. North of the Yangtze River one harvest a year is common in Northwest China, Northeast China and Qinghai-Tibet, while two harvest are year are common in North China (see Figure 3). South of the Yangtze River (areas Yangtze River and South China in Figure 3) two or three harvests a year are common. A popular system is the cultivation of paddy rice on a flooded fields (flooded paddy land) in roughly the period April – July, followed by growing vegetables on ridges on the same now drained field (drained paddy land) for the remaining period of the growing season. The more to the south the more likely that three harvests a year are common. Farmers located in the vicinity of urban areas tend to grow more cash crops (i.e. vegetables) than cereal crops (i.e. rice, wheat).

3.3.3 Agronomic practices of rice cultivation in China

Figure 4 shows the layout of a paddy rice field as drawn after discussion with Chinese paddy rice experts (among others Prof. Zhu Defeng, China National Rice Institute). A typical paddy rice field in China is surrounded by a bund (about 30 cm high). Each field has an outlet containing a bund of roughly 10 cm high. Farmers remove this bund to drain the paddy field. However water may overflow the bund in case of high precipitation amounts (in PERAP we defined this process as runoff overflow).

Chinese farmers use wet land preparation practices as ploughing (ca. 15 cm deep), rotating and harrowing. The aim is to make the soil level and to puddle the soil to prevent too much percolation.

Traditionally the fields are flooded while or immediately after transplanting the seedlings. Irrigation water is applied to ensure a minimal percolation flux of 1-2 mm/day (personal communication Prof. Zhu Defeng, China National Rice Institute) which is necessary to prevent the soil from becoming too anaerobic. According to Chinese experts, irrigation water (from surface water) is sufficiently available south of the Yangtze River and there is no economical reason (i.e. costs of water) for farmers to irrigate less than necessary. Farmers with neighbouring paddy rice fields usually irrigate simultaneously because the small irrigation systems are collectively owned. Irrigation is applied until the water depth on the paddy field is about 10 cm. In between irrigation events the water depth decreases due to evapotranspiration and percolation. Irrigation is applied again if the water depth on the field is a few centimetres. This system is depicted in Figure 5. Figure 5 also shows two major controlled drainage events (controlled drainage is defined in PERAP as the process in which the farmer deliberately destroys or lowers the barrier in the outlet of the paddy field to drain the water of the paddy field). One week before the tillering stage the farmer drains the field (so letting water out of the field by lowering the barrier in the outlet of the field) to enhance the tillering process by improving soil conditions (aerobic).

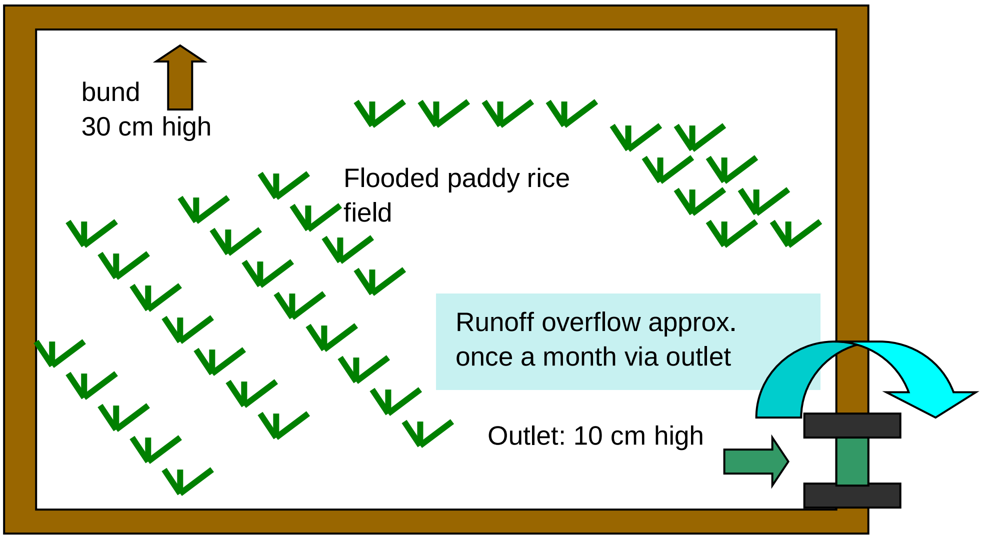

Figure 4 *The layout of a paddy rice field as drawn after discussion with the Chinese paddy rice experts (among others Prof. Zhu Defeng, China National Rice Institute.*

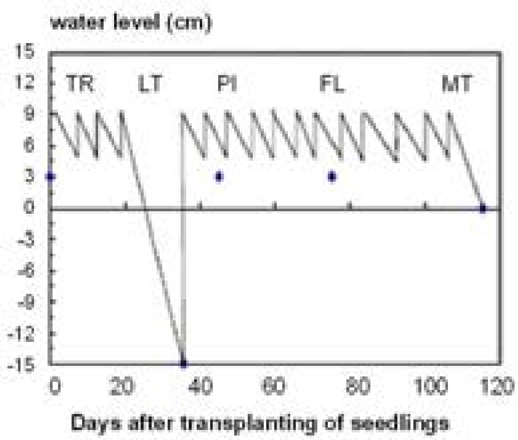

Figure 5 *Water level on a flooded paddy rice field as function of time according to traditional irrigation practices of paddy rice fields in China (from Prof. Zhu Defeng, China National Rice Institute). The abbreviations indicate the different crop stages: TR = transplanting, LT = Tillering stage, PI = Panicle development, FL = Flowering stage, MT = Maturation.*

3.4 Application of pesticides

3.4.1 Spray drift

Knapsack sprayers are the mostly used for applying pesticides in China. Franke *et al.* (2010) made in the framework of PERAP an estimation of spray drift from knapsack sprayers based on literature research and a modelling study. Figure 6 shows the spray drift curves calculated with the IDEFICS model using parameters that can be representative for the Chinese situation.

The following spray drift figures for the Chinese natural pond (20 m width, no buffer zone) are calculated from Figure 6: for 5 cm high crop and warm/humid climate: 3.73% (of the applied dosage) and for 50 cm high crop and warm/humid climate: 1.16% (of the applied dosage).

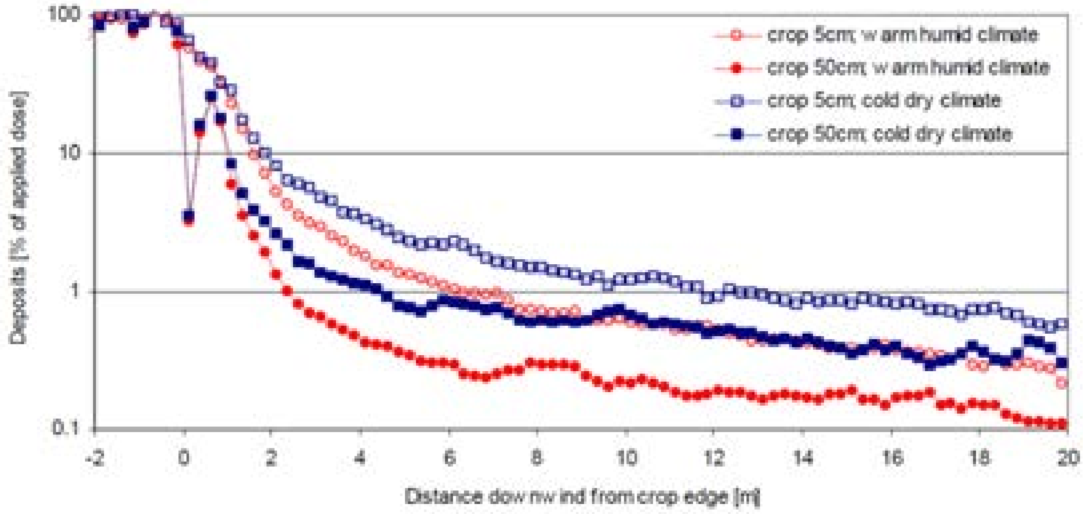

Figure 6 *Ground deposits as a function of distance from the crop edge, simulated by the IDEFICS model (from Franke et al., 2010).*

4 Identification of scenario zones

As explained in Section 2.1 there are several reasons for risk managers to consider whether registration should be done uniformly across the country or specific per area (scenario zone). Reasons for considering more than one scenario zone could be: i) diversity in climate, soil, land use, ecological systems, etc., ii) spatial variability in pesticides use, iii) spatial variability in required efficacy trials for pesticide registration.

China is a large country with significant differences in climate, soil and terrain for agriculture, which determine the unique cropping systems and agricultural structure in different regions.

To take these differences into account we divided the whole country into different zones (hereafter referred to as 'scenario zones' in the report). For each of the scenario zones, we established scenarios to represent the realistic worst-cases in environmental risk of pesticide use.

We divided China into six scenario zones by taking into account annual average precipitation and annual average temperatures (Figure 7). Meteorological data for a period of 36 years (1970-2005) from 580 meteorological stations in China (China Meteorology Bureau, 2007) and physical regionalization maps of Chinese agriculture (Yan et al., 2002) are basic data sources for establishing the scenario zones. ArcGIS Desktop version 9.2 was used to generate precipitation and air temperature maps. Details of the procedure are described in Annex B of this report. Climatic, soil and agricultural features of the scenario zones are listed in Tables 1, 2 and 3.

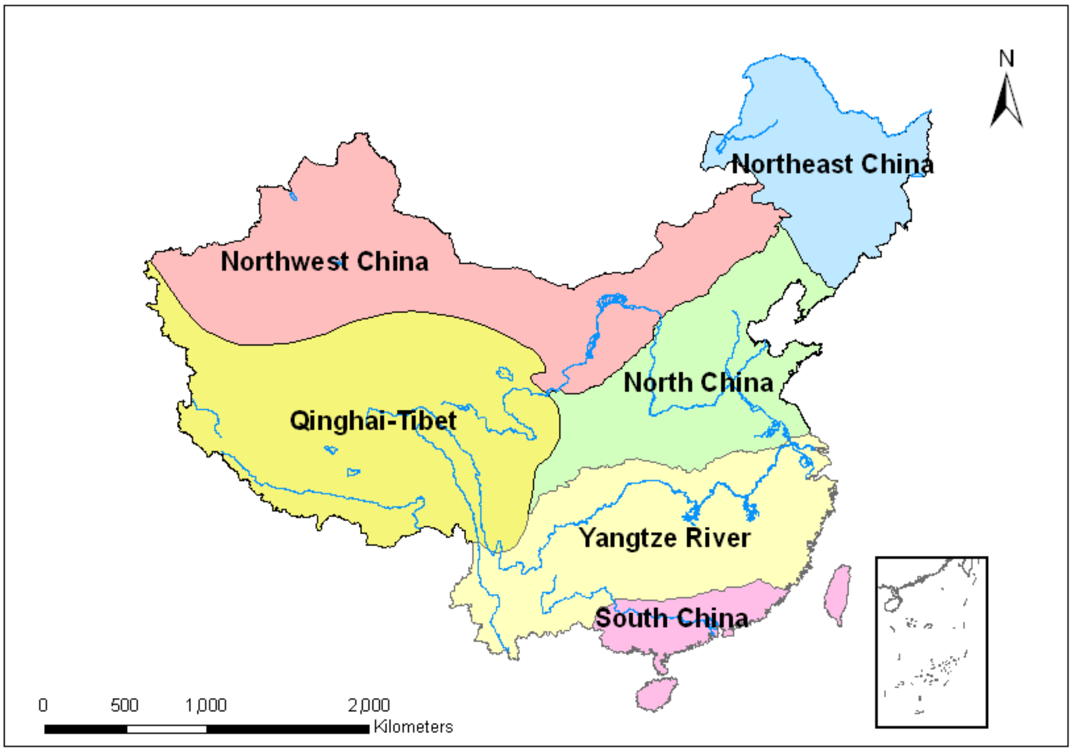

Figure 7 *Scenario zones in China.*

Table 1

Scenario zones and their main physical features

Scenario zones	Annual average precipitation (mm)	Annual average temperature (◦C)	Description of the landscape
Northeast China	400~800	<6	Plains, mountains
Northwest China	<400	<8	Plains, mountains, plateau and basins
North China	400~1000	6~12	Plains, loess plateau, mountains
Yangtze River Basin	>1000	12~20	Plains, mountains, basins
South China	>1000	>20	Hills, inter-valley plains, basins
Qinghai-Tibet plateau	<600	<8	Plateau, mountains, valleys

Table 2

Scenario zones and their main soil features

Scenario zones	Main soil type Chinese classification system (National Soil Survey Office, 1993a, 1993b, 1994, 1995a, 1995b, 1996)
Northeast China	Black soil, dark brown soil
Northwest China	Desert soil
North China	Fluvo-aquic soil, loess, cinnamon soil
Yangtze River Basin	Paddy soil, red earth, yellow earth, purplish soils
South China	Latosols
Qinghai-Tibet plateau	Felty soils, frigid pedocals

Table 3

Scenario zones and their main agricultural features. Main crops cultivated on dry land fields are given in order of size of cropped area.

Scenario zones	Main crops cultivated on dry land fields	Cropping system
Northeast China	maize, soya bean, potato, spring wheat, sorghum, millet, sugar beet, apple, pear, tobacco, water melon, sun flower, peanut, vegetable	One harvest per year
Northwest China	maize, potato, spring wheat, soya bean, millet, sorghum, cotton, spring rapeseed, sun flower, sugar beet, water melon, apple, pear, grape, vegetable	One harvest per year
North China	winter wheat, maize, soya bean, peanut, spring rapeseed, sesame, winter rapeseed, sweat potato, potato, cotton, apple, pear, grape, citrus fruit, vegetable	Three harvests every two-years
Yangtze River	maize, winter wheat, tobacco, winter rapeseed, peanut, sesame, soya bean, sweat potato, potato, sugar cane, linen, water melon, apple, pear, grape, citrus fruit, vegetable	Two or three harvests per year
South China	maize, soya bean, sweat potato, potato, winter wheat, spring wheat, peanut, rapeseed, sugar cane, citrus fruit, autumn maize, spring maize, banana, tobacco, vegetable	Two or three harvests per year
Qinghai-Tibet plateau	Agriculture area is too small to take in to account	One harvest per year

5 Conceptual model for the three selected protection goals

Within the PERAP project, scenarios have been developed for three protection goals, being i) groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River and ii) groundwater at 2 m depth in paddy land south of the Yangtze River and iii) Aquatic ecosystems in natural ponds south of the Yangtze River. In this Section the conceptual models for leaching or exposure scenarios are discussed.

5.1 Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River

The description of the protection goal itself explains the conceptual model. The scenario zones classified as north of the Yangtze River are: Northeast China, Northwest China and North China. As described in Section 2.2.1 the PERAP project group decided to assess groundwater leaching at 1 meter depth although the protection goal relates to 10 m depth. Processes relevant for leaching are: (i) convection and diffusion, (ii) sorption, (iii) transformation in soil, (iv) plant uptake, (v) volatilisation from the soil surface, (vi) dissipation at the crop canopy and (vii) wash-off from the crop canopy (Figure 8)

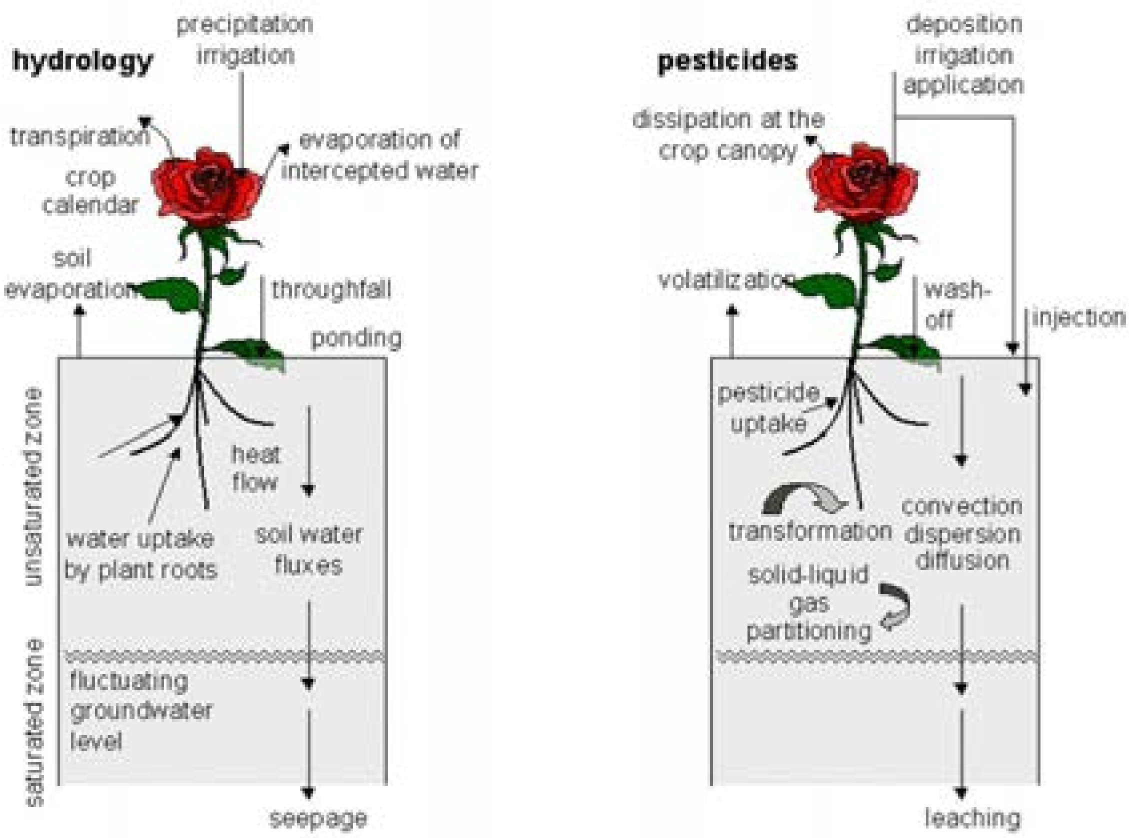

Figure 8 *Hydrological processes (left-hand site) and pesticide processes (right-hand site) relevant for leaching of pesticides to groundwater from dry land agriculture.*

5.2 Groundwater at 2 m depth in paddy land south of the Yangtze River

The description of the protection goal itself explains the conceptual model and a sketch of the situation is depicted in Figure 9. The scenario zones classified as south of the Yangtze River are: Yangtze River and South China. As described in Section 2.2.1 the PERAP project group decided to assess groundwater leaching at 1 meter depth although the protection goal relates to 2 m depth.

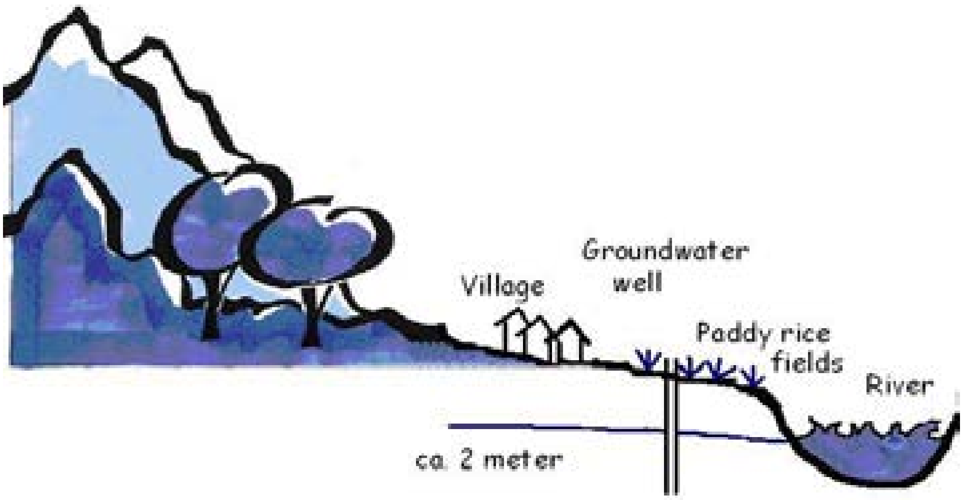

Figure 9 *Artistic impression of the groundwater system used as drinking water south of the Yangtze River in China.*

A rice paddy can be either flooded or drained. Pesticide processes relevant for flooded paddies are discussed below. Pesticides enter the paddy water layer via the processes: i) atmospheric depositions, ii) deposition from pesticide applications and iii) wash-off from the crop canopy. In the paddy water layer pesticides can be transformed, volatilized, disappear with water overflowing the bund (runoff overflow) or transported to the soil by infiltration of water in to the soil. In case the rice crop is small and does not fully cover the paddy water layer photolytic degradation might be an important process. In the soil relevant processes for leaching are: (i) convection and diffusion, (ii) sorption, (iii) transformation in soil and (iv) plant uptake (Figure 10).

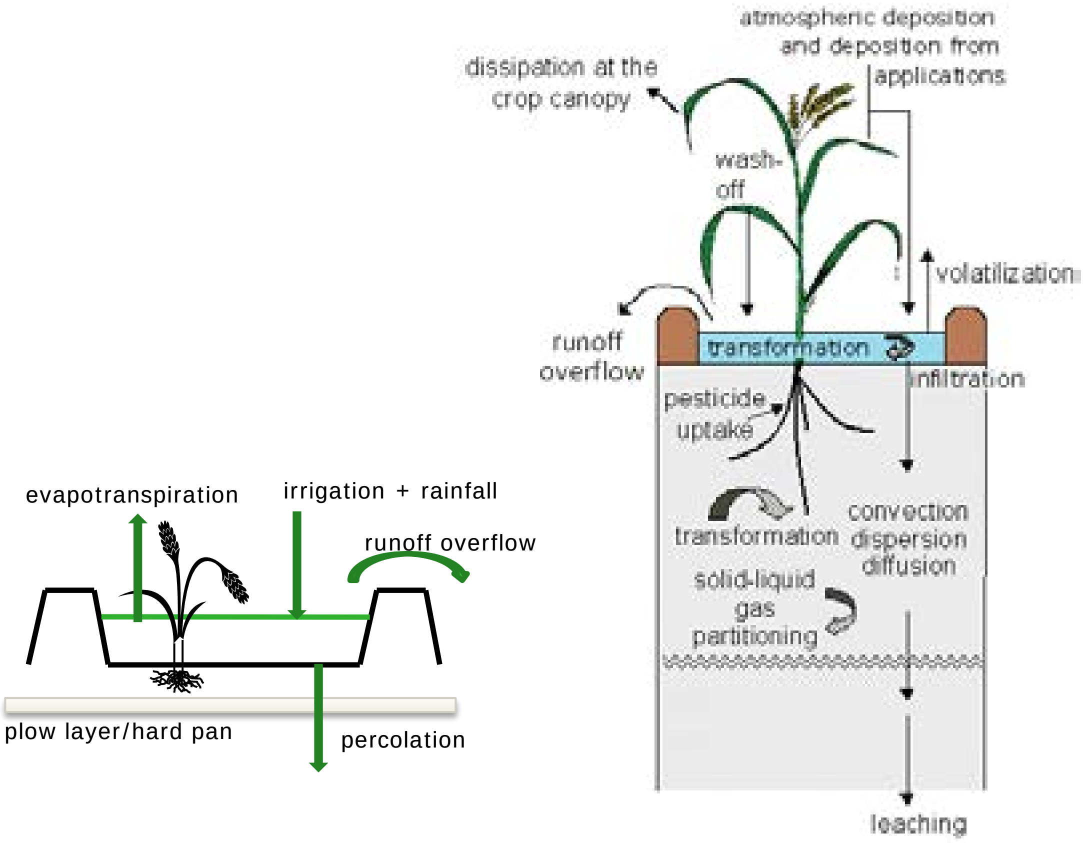

Figure 10 *Hydrological processes (left-hand site) and pesticide processes (right-hand site) relevant for leaching of pesticides to groundwater from flooded paddy rice fields.*

5.3 Aquatic ecosystems in natural ponds south of the Yangtze River

The conceptual model for the pond is established after discussions with the Chinese experts in the PERAP project group (Figure 11). Natural ponds are located in lower areas and have no inlet or outlet, i.e. no drainage channel. Ponds are assumed to be fed by precipitation and excess water originating from the surrounding area only. Both in the Yangtze River basin and in South China, ponds surrounded by paddy land are most common; however dry land fields surrounding a pond may be possible as well. Because the type of agricultural land surrounding the pond is important for defining a vulnerability concept, the PERAP project group formulated definitions for the different types of land use. These are given in Table 4.

Table 4
Vocabulary used in the PERAP project

Terminology	Description
Land use: paddy land	Land on which irrigated rice crop is grown at least once within the year
Flooded paddy	Paddy land that is flooded and cropped with rice (layer of water on the field)
Drained paddy	Paddy land that is drained to grow e.g. vegetables and other crops after the rice crop
Land use: dry land	All cultivated land that is not paddy land
Irrigated dry land	dry land with irrigation systems
Rain fed dry land	Dry land without irrigation systems
Bunds	Dikes around a paddy field about 30 cm high
Outlet of the paddy field	The outlet of the paddy field, usually a barrier of 10 cm high
Controlled drainage	Process in which farmer deliberately destroy the barrier in the outlet of the paddy field to let the water out of the paddy field.
Runoff overflow	Water from the (flooded) paddy field overflowing the barrier at the outlet or overflowing the bund
Surface runoff	Water flow on the soil surface of the dry land field or the drained paddy field. Surface runoff occurs when the precipitation rate exceeds the infiltration rate (Horton overland flow) or after the water storage volume of a soil has been exceed, which means that the groundwater table has reached the soil surface (Dunne overland flow) (Kroes et al., 2008).

For the natural ponds used in the scenarios for Yangtze River basin and South China, it is assumed that the ponds are rectangular, 20 x 33 m (~1 mu = 1/15 ha) in surface area, with water depth varying between 0.5 – 3 m. A pond is surrounded by a contributing area of 20 mu, containing various crops (water : land ratio is 20 : 1; this ratio was based on information gathered by Dr. Li Wenjuan from CAAS by means of personal communication with local Chinese experts).

The contributing area delivers water directly into the pond. Flooded paddies deliver controlled drainage water and runoff overflow to the pond, whereas drained paddies and dry land fields deliver surface runoff to the pond. The pond is supposed to have no outlet, and its water level dynamics are controlled entirely by water flows from the contributing area, precipitation, seepage and evaporation (Figure 12).

For the estimation of spray drift onto the pond, it is assumed that there is no buffer zone between the treated paddy and the pond. The distance between the last row of crop sprayed and the edge of water in the pond is generally small as crops are grown very close to the edge of the pond.

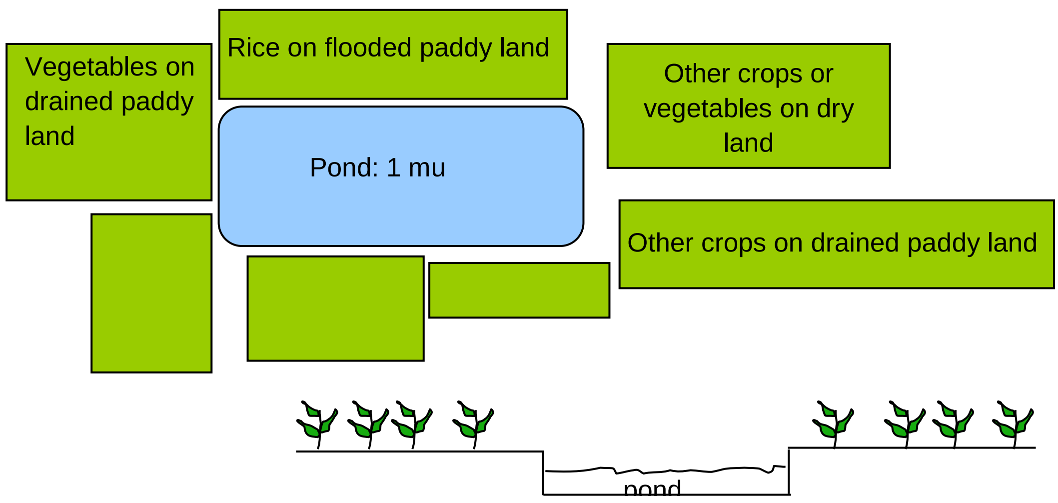

Figure 11 *Conceptual model of the natural pond where the aquatic ecosystem should be protected in the scenario zones Yangtze River basin and South China*

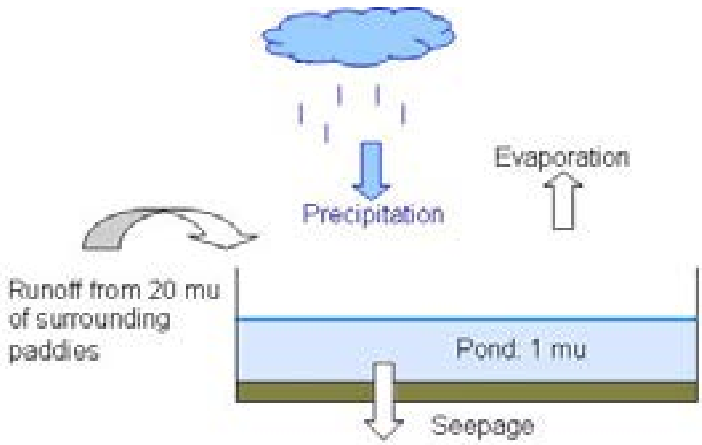

Figure 12 *Conceptual model of the water balance of the natural pond where the aquatic ecosystem should be protected in the scenario zones Yangtze River basin and South China.*

6 Models used

This section describes step 6 of the roadmap used in the PERAP project for developing scenarios (Figure 1). The Chinese risk managers decided to use numerical pesticide fate models to estimate leaching concentrations and exposure concentrations in the paddy water and surface water. These models are generally used in the lower tiers of pesticide risk assessment to calculate the environmental concentrations for a limited number of standard scenarios. The models considered a good alternative to measurements of the concentrations leaching to groundwater and concentrations in paddy water and surface water for the following reasons: models are compared to measurements i) cheap and fast, ii) models can cope with large variations in soils and climate, and iii) models can be used for the large number of pesticides (e.g.: > 100 in the EU).

Large numbers of pesticide leaching models (Siimes and Kämäri, 2003) and models for simulating pesticide exposure in paddy rice (MED-Rice, 2003) and pesticide exposure in surface water (FOCUS, 1997) are available. Several selection criteria were set by the PERAP project group. The most decisive aspect of model selection is the definition of the protection goal. A well-defined protection goal contains next to what should be protected (e.g. an ecosystem) a spatial component (e.g. in a natural pond) and a temporal component (e.g. use a time weighted average concentration or peak concentration in the assessment). The majority of available pesticide fate models are only applicable to one particular spatial scale. Next to the definition of the protection goal other considered criteria were:

1. Adequacy to the purpose and objectives; the model should include processes relevant for the simulated system and output needed for the objectives
2. Data requirements (model might be too complex for the available data input)
3. Computer system (does it work under windows, which window platform, does it work under a Chinese version of windows?)
4. Transparency: are the relevant parts of the source code (i.e. the part containing the mathematical descriptions of the pesticide processes and their analytical/numerical solutions) available for inspection?
5. Is a sensitivity analysis reported?
6. Documentation available?
7. User friendly?
8. Strict version control (reproducibility is crucial for registration authorities and notifiers)
9. Help desk service available?
10. Validation status (Is the model successfully tested against field data?)
11. Simulation time requirements (are e.g. simulations times > 30 minutes acceptable?)
12. Costs

Regarding item 2 it is important to mention that during the PERAP project it was not possible to select spatially distributed models due to the lack of adequate spatially distributed data on the scale of entire China.

Another very important and non-objective criteria for model selection was whether cooperation with other non-PERAP partners providing models (or modified versions of their models) was feasible within the budget and time frame of the PERAP project. Obviously, with an eye to project management, it was opted for the most efficient way of working.

For the protection goal groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River the existing PEARL model (Leistra *et al.,* 2001) was selected. Not being able to select a suitable existing model for simulation of pesticide fate in paddy rice and the pond next to the paddy rice field (see Annex D for details) that fulfilled the requirements the PERAP project group let to the decision to modify the existing PEARL and TOXSWA models. These modifications are described in Section 9 of this report.

7 Vulnerability drivers and selection procedures

7.1 Level of sophistication of the scenario selection procedures

The level of sophistication of the scenario selection procedures is determined by the availability of spatially distributed data and development time. Figure 13 provides an overview of recent EU scenario selection procedures and their level of sophistication. The procedures used for PERAP are also included in Figure 13. Roughly three levels of scenario selection procedures can be distinguished. The first level is definition of a simple vulnerability concept like applied for the FOCUS groundwater scenarios. For the FOCUS groundwater scenarios, the approach for scenario selection was to evenly split vulnerability between soil and weather. The second level op scenario selection is mapping the vulnerability for leaching or exposure using simple models like the metamodel of PEARL (Tiktak *et al.*, 2006) or the simple analytical model for exposure in soil used by the EFSA (EFSA, 2012). The most sophisticated procedure of scenario selection is the one applied for selecting the Dutch exposure of aquatic organisms scenario (Tiktak *et al.*, 2012). This method requires a parameterised spatially distributed model like GeoPEARL.

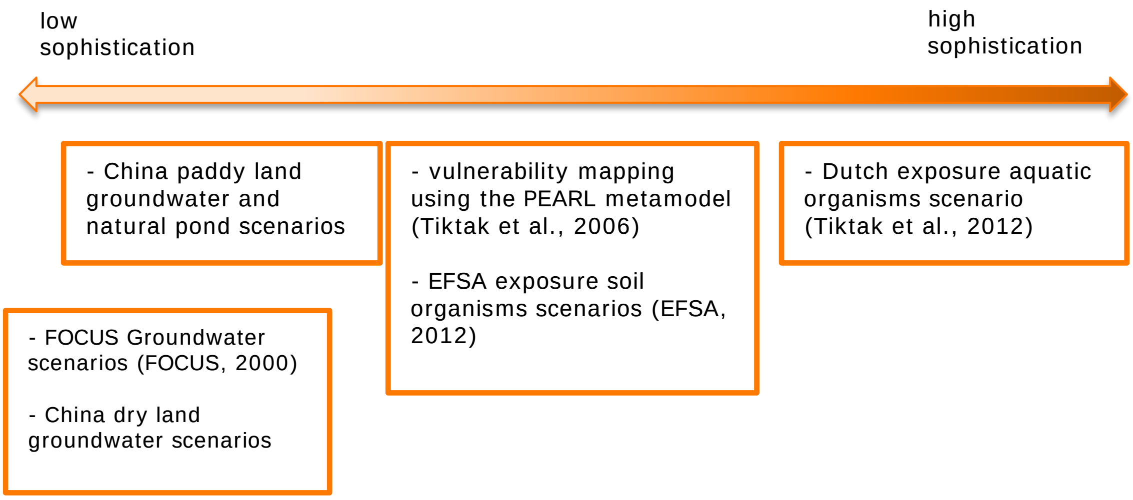

Figure 13 *Indication of the level of sophistication of the scenario selection procedures used for different existing scenarios in the EU and the developed scenarios for China.*

Similar to the FOCUS groundwater scenario locations representing annual average precipitation of the scenario zone are selected for the Chinese groundwater scenarios for dry land. For the Chinese groundwater and exposure in the natural pond scenarios for paddy land a more sophisticated approach is used regarding selection of the scenario with respect to weather (see Section 8.2 for more details). In the PERAP project spatially distributed data on soil and weather were not available for the Dutch partners. Also the time and budget available were not sufficient to use spatially distributed models.

7.2 Vulnerability, drivers for vulnerability and division between probability in time and space of the overall percentiles

7.2.1 Vulnerability and drivers for vulnerability

In general, vulnerability can be understood as the predisposition to be hurt. In the context of making scenarios for pesticide risk assessment vulnerability should be understood as the predisposition of a protection goal (groundwater for drinking water, aquatic ecosystem) to be at risk for exposure to pesticides. Some factors or processes (here called vulnerability drivers) will contribute more to the risk for exposure to pesticides than others.

FOCUS (2009) described the requirements for identification of drivers for leaching of pesticides in the European case. These requirements are also applicable for other cases if described in a more general way: a) the parameter (e.g. driver) should cause a pronounced sensitivity in leaching calculations with the selected model and b) the spatial data of this parameter should be available.
It is important to distinguish between sensitivity drivers and vulnerability drivers. Definitions of both are given below:

- sensitivity driver is a model input parameter from the scenario that has a large effect on the relevant model output (e.g. PEC);
- vulnerability driver is a model input parameter from the scenario that has been selected to represent the vulnerability

A sensitivity driver will only become a vulnerability driver if the sensitivity driver is strongly spatially or temporally variable; e.g. land use in the catchment will only become a vulnerability driver if it is strongly spatially variable across a scenario zone.

As noted in section 7.1 in PERAP a simplified scenario selection procedure (comparable to the procedure used for the FOCUS groundwater scenarios) was used. In this simplified procedure variability in time and space are considered separately. First it is assessed by which sensitivity drivers the leaching or exposure in the surface water is determined. Next, a very limited set of drivers that determines the vulnerability of the leaching or exposure scenario need to be selected out of the set of sensitivity drivers.

Once the vulnerability drivers have been selected, it is possible to determine their probability of occurrence in space and these probabilities in space need to be combined into one overall probability in space. Next, this overall probability in space is combined with the probability in time by simple calculation rules to obtain an overall probability in time and space for the target concentration, e.g. the pesticide concentration leaching to the groundwater. An example of such a calculation rule is: 90^{th} spatial percentile + 90^{th} temporal percentile = overall 99^{th} percentile.

The variability in time can be accounted for by including time series of the most important sensitivity and vulnerability drivers in the model calculations, e.g. for rainfall or temperature.

Main vulnerability drivers are not only defined by their physical features, such as climatic data, soil properties, slope, land use or pesticide entry routes (e.g. spray drift, runoff, or drainage into surface water), but are thus model-specific as well. Their impact on scenario vulnerability often depends on their interaction with compound properties. Therefore the selection of the main vulnerability drivers should be based on a combination of knowledge on main physical drivers for leaching or exposure in surface water, importance of pesticide physico-chemical processes, selected pesticide models and possible interaction with compound properties. This means that for applying a simplified scenario selection procedure expert judgement, next to data on spatial heterogeneity is just as relevant.

7.2.2 Division between probability in time and space of the overall percentiles

In case the aim of the scenario selection procedure is to obtain an overall 99th percentile leaching or exposure concentration considering both variability in space and time; the problem is then which combination of space and time percentiles will give an overall 99th percentile. Let us assume that the percentiles of the leaching or exposure concentration are a continuously increasing function of the percentiles in space and time (see Figure 14). Let us consider the leaching or exposure concentration for a combination of a 90th percentile in time and a 90th percentile in space. For this case it is certain that 81% of the leaching or exposure concentrations are lower than this value (0.9 × 0.9 × 100%, i.e. the green plane in Figure 14). It is also certain that 0.1 × 0.1 × 100% = 1% (i.e. the red plane in Figure 14) of the leaching or exposure concentrations are higher than this value. The areas of the question marks in Figure 14 sum up for this case to 2 × 0.1 × 0.9 × 100% = 18%. Without having more information on the relationship between the leaching or exposure percentile and the space and time percentile, the best guess is to assume that half of this 18% is above the value of the leaching or exposure concentration for the 90th percentiles in time and space and half is below this value. So the result is that the leaching or exposure concentration at the 90th percentiles in time and space corresponds to the 90th percentile (81% + 9%) of the population of leaching or exposure concentrations. The same reasoning can be set up for the 99th percentiles in time and space which then correspond to the 99th percentile of the leaching or exposure concentration.

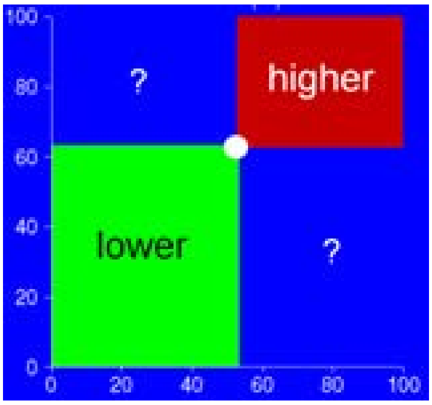

Figure 14 *Diagram of the percentile of a stochastic variable z which is a function of two variables x and y. The horizontal axis consists of percentiles of x and the vertical axis consists of percentiles of y. It is assumed that z increases continuously as a function of x and y. The point in the plane is an arbitrary combination of x and y percentiles.*

7.3 Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River

For the Chinese groundwater scenarios for dry land north of the Yangtze River the main drivers are organic matter (spatially variable) and precipitation (temporary variable). The vulnerability of the scenario was split evenly between these soil and weather properties. For the Chinese case we defined the overall 99th leaching concentration as the sum of the 90th percentile with respect to soil properties and the 90th percentile with respect to weather. Weather has also a spatial component (i.e. it might be variable across a scenario zone). For this case however we assumed that the spatial component of weather was less relevant.

Vulnerability concept for **groundwater** scenarios for **dry land north of the Yangtze River**:

Overall 99th percentile leaching concentration =

90th spatial percentile with respect to soil + 90th temporal percentile with respect to weather

The 90th percentile for soil is represented by the 10th percentile for organic matter content (sorted from smallest to largest value) as organic matter content is the main driver in the soil for leaching of pesticides (Boesten and van der Linden, 1991).

7.4 Groundwater at 2 m depth in paddy land south of the Yangtze River

The main vulnerability drivers for this protection goal are organic matter content of the soil and total annual percolation (this is valid for about more than 70% of the pesticides for pesticide use in paddy rice cultivation; see Section 11 for more information). The total annual percolation is the sum of precipitation, irrigation and evapotranspiration. For the remaining pesticides (30%) pH is usually a driver (i.e. a substance may show pH dependent sorption and/or degradation) (personal communication with Dr. Jos Boesten, Alterra). However within PERAP pH is not considered a driver for scenario development because pH dependency of substances was taken in to account via input of pesticide properties in to the model (see Section 12).

A third driver is land use. In Section 2.2.1 it was already mentioned that it is common practice to grow crops alternately on the same field especially south of the Yangtze River in China. A popular system is the cultivation of paddy rice on a flooded field (flooded paddy land) in roughly the period April – July, followed by growing vegetables on ridges on the same now drained field (drained paddy land) for the remaining period of the growing season. More to the south, three harvests a year has become common practice. Most typical is two harvests of rice (from flooded fields) in April-September, followed by growing vegetables on ridges on the same now drained field. Also other field crops like for instance maize or wheat might be grown. The sequence of crops in a year (i.e. two times rice followed by wheat or first crop is wheat, followed by rice, followed by vegetables) may differ. Hence, next to the spatial variability of land use there is also a temporal variability of land use in China, south of the Yangtze River. This complicates the scenario selection procedure considerably; different scenarios are needed for the different cropping sequences because the 90th percentile percolation differs per cropping sequence.

Within the PERAP project situation of pesticide applications in 2 crop cycles of paddy rice in flooded paddy fields while using the following vulnerability concept :

Vulnerability concept for **groundwater** scenarios for **paddy land south of the Yangtze River**:

Overall 99th percentile leaching concentration =

Spatial 90th percentile with respect to soil (organic matter) + spatial and temporal 90th percentile with respect to annual percolation

The scenarios developed are intended to be used to assess the risk of pesticide application by knapsack sprayers used in:
1. the crop **paddy rice** in the cropping system double harvests on paddy land
2. **other crops** (i.e. cereals, vegetables) in the cropping system double/triple harvests on paddy land

The project group decided to parameterise scenarios with:
1. two irrigated rice crops on a flooded paddy field
2. fallow land (no flooding) for remainder of the year
3. pesticide application in the irrigated rice crop (input to the model specified by the risk manager)

The scenarios are also protective for situation 2., i.e. pesticide application on other crops than paddy rice. For this situation the same conceptual model is used as for paddy rice application, hence, for the risk assessment the pesticide is supposed to be applied on the paddy rice. This (theoretical) application will lead for most pesticides (but not all; see Section 11.3) to higher concentrations in the groundwater than the intended application in other crops. This is because percolation amounts are in reality higher for the situation of a rice crop grown on a flooded paddy field than the percolation amounts for the situation of another crop (e.g. wheat, maize, vegetables) grown on drained paddy field.

Future steps will encompass the development of scenarios for pesticide application in other crops (i.e. cereals, vegetables) in the cropping system double/triple harvests on paddy land. The same vulnerability concept as used for the situation of pesticide applications in two crop cycles of paddy rice is applicable. The 90^{th} percentile location with respect to annual average percolation will however differ, because percolation amounts for this situation are different.

7.5 Aquatic ecosystems in natural ponds south of the Yangtze River

The main drivers for exposure in the Chinese natural pond are land use, runoff overflow from flooded paddies and surface runoff from drained paddies (dry land). Drift is not considered a driver because preliminary calculations demonstrated that the amounts of pesticide transferred into ponds via drift is small compared to amounts involved in runoff overflow and surface runoff.

The Chinese risk managers aim at protecting the aquatic ecosystem in 90% of all natural ponds in China. They decided to aim at a 90^{th} percentile overall exposure concentration in the pond, . This 90^{th} percentile exposure in the pond was defined as a combination of the 90^{th} percentile runoff (i.e. runoff overflow plus surface runoff) and the 50^{th} percentile of land use in the 20 mu surrounding the pond (see for conceptual model used Figure 11 and 12).

Like for the protection goal groundwater at 2 m depth in paddy land south of the Yangtze River the driver land use is a complicating factor. For the exposure assessment it matters whether there are 2 or 3 harvests a year and also the crop sequence in a year (e.g. rice-rice-vegetable or wheat-rice-vegetable) matters. After all, two (paddy) rice harvests a year lead to more runoff overflow events than one (paddy) rice harvest a year. For the exposure in the natural pond assessment it is also relevant to know how much area of the surrounded paddy land is cropped with paddy rice and how much area is cropped with a dry land crop (for instance wheat or vegetables). The driver land use therefore again complicates the scenario development considerably. Because of the limited time and budget available the project group decided to phase scenario development. The methodology was developed and land use information was collected. However, models were only parameterised for the first and most simple case (the first phase).

The project group differentiated three cases:
- Case 1: The pond is surrounded by 100% paddy rice
    a. the predicted environmental concentration (PEC) will be conservative for applications in rice,
    b. the PEC will be very conservative for applications in ‘other crops’ (other crops than paddy rice).
- Case 2: The pond is surrounded by a 50th percentile of land use (% of area paddy land)
    a. the PEC will be realistic worst case in rice,
    b. the PEC will be conservative for applications in ‘other crops’.
- Case 3: The pond is surrounded by a 50th percentile of land use (% of area of all agricultural land)
    a. The PEC is realistic worst case for applications in ‘other crops’.

The distinction between paddy land and agricultural land is important. Paddy land is land on which irrigated rice crop is grown at least once within a year. Agricultural land compromises both paddy land and dry land (all cultivated land that is not paddy land).

For each case the PERAP project group formulated a vulnerability concept.

1st case

Vulnerability concept for exposure scenarios **for the natural pond south of the Yangtze River:**

Overall 90th percentile exposure in the pond =

Spatial and temporal 90th percentile with respect to runoff overflow

2nd case and 3rd case

Vulnerability concept for **exposure** scenarios for **the natural pond south of the Yangtze River**:

Overall 90th percentile exposure in the pond =

Spatial and temporal 90th percentile with respect to the sum of runoff overflow and surface runoff + spatial 50th percentile with respect to land use

We determined for cases 2 and 3 average (50th percentile) situations of land use around ponds in the Yangtze River basin (double harvests) and in the South China region (double and triple harvests) based on China Agricultural Statistical reports (China Agricultural Press 2005, 2006, 2007) and a research project on winter fallow land in South China. The information is given in Annex E for future reference.

7.6 Same scenarios south of the Yangtze River, for groundwater at 2 m depth in paddy land and natural ponds

Because of the correspondence in the vulnerability concept for the scenarios for groundwater at 2 m depth in paddy land south of the Yangtze River and for the scenarios for aquatic ecosystems in natural ponds south of the Yangtze River the project group envisaged that the same scenario locations might be possible for both protections goals.

For leaching in paddy fields, percolation is considered to be one of the two main drivers. Percolation is driven by the sum of precipitation and irrigation. For exposure in the natural pond (1st phase) runoff overflow is the main driver. Runoff overflow is driven as well by precipitation and irrigation. Irrigation water is not limited south of the Yangtze River (plenty available, so farmers have no economical reason to irrigate less than necessary) and that farmers usually irrigate simultaneously (small irrigation systems are collectively owned)(personal communication prof. Zhu Defeng of the China National Rice Research Institute). Therefore, the PERAP project group did not consider irrigation as variable in time and space and therefore not a vulnerability driver in the scenario selection procedure.

The overlap in the two vulnerability concepts is thus found in the driver precipitation:

Leaching:	90th precipitation + 10th organic matter	= 99th leaching scenario
Pond:	90th precipitation	= 90th exposure natural pond

Reasoning of the project group for using the same scenario locations for both protection goals was as follows:

- Both the leaching and the pond scenario use the 90^{th} precipitation as a vulnerability driver (variable in space and time)
- Organic matter (variable in space) is not an important driver for vulnerability of the pond scenario, but a low organic matter content is probably also more worst case for a pond scenario because more pesticide might remain in the water layer:
    - it is likely that the sediment of a pond has a low organic matter content if the soil of the adjacent field has a low organic matter content.
    - it is likely that the pesticide concentration in the runoff water is higher when the organic matter content of the paddy soil is low

8 Implementation of the scenario selection procedures and results

8.1 Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River

The scenario selection procedure used for groundwater in drinking wells at 10 m deep in dry land north of the Yangtze River is depicted in Figure 15. First a 90th percentile location with respect to soil and a 50th percentile location with respect to climate is combined. As noticed in Section 7.3, we assumed that the spatial component of weather was less relevant. This is similar to what was done for the selection of the FOCUS groundwater scenarios. This method was copied for the PERAP project. However, we realized later on that this assumption is not scientifically sound. The spatial component of climate is just as relevant as the temporal component of climate. It is thus more defensible to calculate the 90th percentile of the annual average precipitation of all meteorological stations in a particular scenario zone (for instance 800 mm) and select from this pool of meteorological stations a station that has a similar 90th percentile of the annual average precipitation as the 90th percentile of the annual average precipitation of the scenario zone. This procedure was followed for scenario selection of the other two protection goals worked out in the PERAP project.

Method for the calculation of the overall 99th percentile vulnerability of the Chinese groundwater scenarios for dry land north of Yangtze River

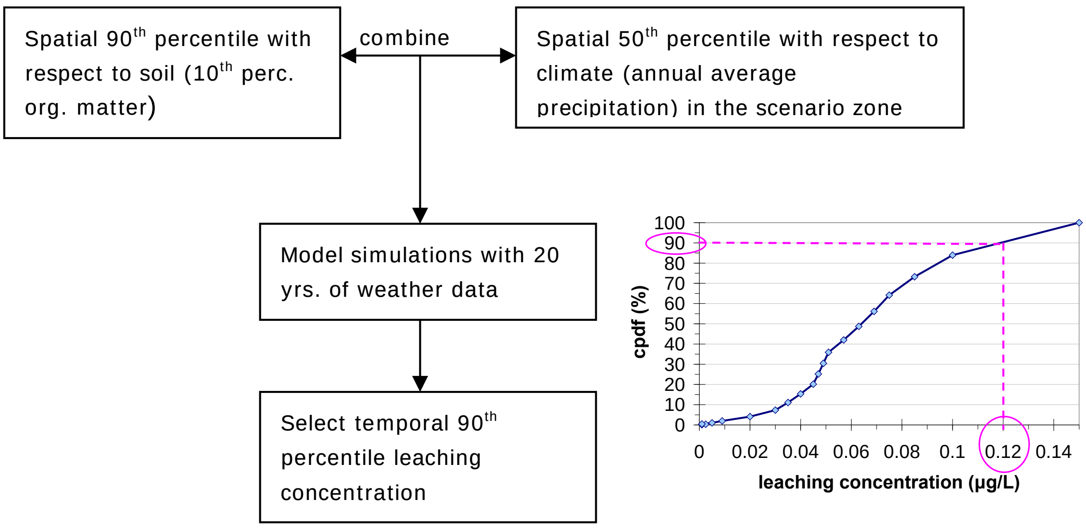

Figure 15 *Method for the calculation of the overall 99th percentile vulnerability of the Chinese groundwater scenarios for dry land north of Yangtze River*

As noted in Section 7.3, the 90th percentile for soil is represented by the 10th percentile for organic matter content (sorted from smallest to largest value). The 10th percentile for organic matter content was selected from the organic matter map (Figure C1 in Annex C). Table 5 shows per scenario zone the calculated 10th percentile of organic matter content and corresponding organic matter content class. Three scenario zones are considered for this protection goal, i.e. Northeast China, Northwest China and North China. Details of the procedure for calculating the 10th percentile of soil organic matter content for each scenario zone and the type dry land are described in Annex C of this report.

Table 5
The 10^{th} percentile organic matter content (%) and corresponding organic matter content class of each scenario zone

Land type	Scenario zone	Calculated 10^{th} percentile organic matter (%)	Corresponding organic matter content class (%)
Dry land	Northeast China	1.4	1 - 2
	Northwest China	0.61	0.6 - 1
	North China	0.66	0.6 - 1

Selected scenario locations using the scenario selection procedures described above are shown in Figure 16. Table 6 gives the main geographical, soil and climate properties of the selected scenario locations.

In the risk assessment procedure, for each of the selected locations, twenty years of model simulations will be performed using the PEARL model. The 90^{th} percentile of the annual average leaching concentration is calculated to represent (i) the 90^{th} percentile value in time associated with weather for the specific simulation conditions and (ii) the overall 99^{th} percentile leaching concentration considering the vulnerability associated with both soil and weather (Figure 16). The 90^{th} percentile of the annual average leaching concentration is calculated by ranking the 20 mean annual concentrations from lowest to highest and taking the average of the 18^{th} and 19^{th} ranked value. Note that when pesticide is applied every other or every third year, the 20 concentrations for each two or three year period are ranked and the average of the 18^{th} and 19^{th} value is calculated.

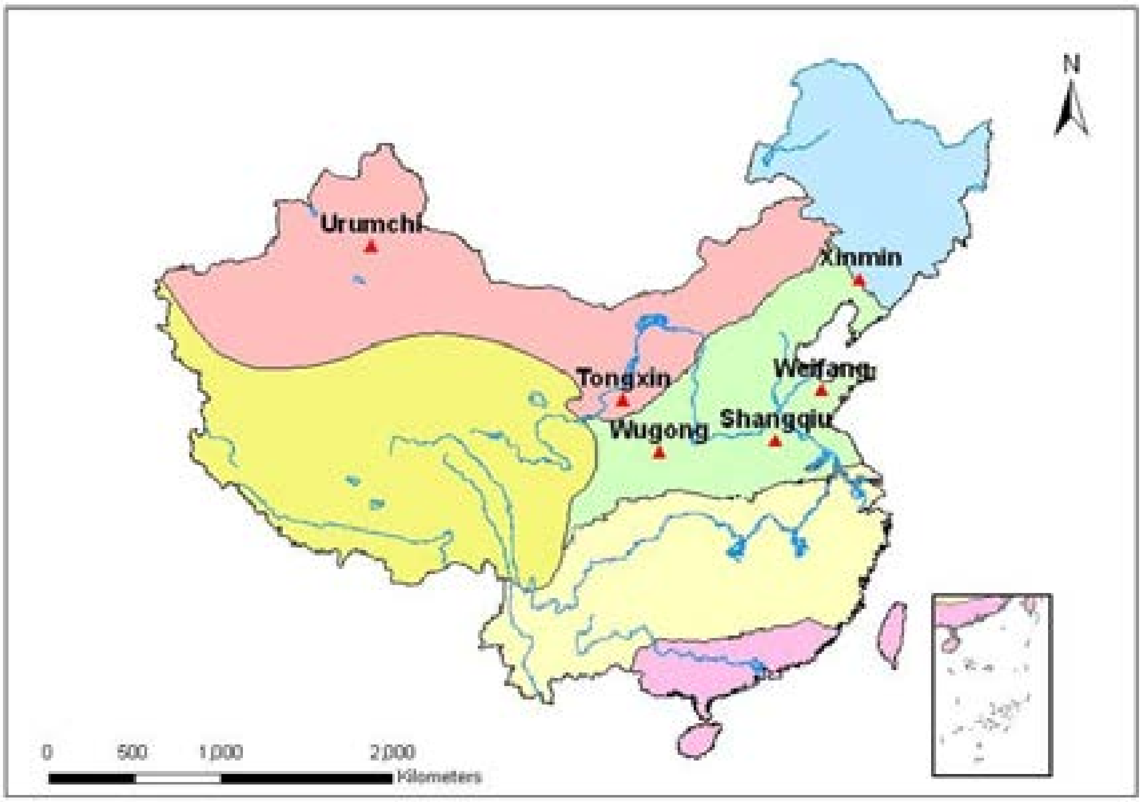

Figure 16 *Selected locations for groundwater scenarios for dry land north of the Yangtze River.*

Table 6.
Geographical, soil and climate properties of the selected locations for the groundwater scenarios for dry land north of the Yangtze River.

Scenario zone	Name	Province	Annual average precipitation (mm)	Annual average temperature (℃)	organic matter content class (%)
Northeast China	Xinmin	Liaoning	571.7	8.65	1 - 2
Northwest China	Urumchi	Xinjiang	252.4	6.73	0.6 - 1
	Tongxin	Ningxia	270.2	8.87	0.6 - 1
North China	Weifang	Shandong	599.1	12.40	0.6 - 1
	Shangqiu	Henan	654.7	14.09	0.6 - 1
	Wugong	Shaanxi	590.2	13.21	0.6 - 1

8.2 Same scenarios for groundwater at 2 m depth in paddy land south of the Yangtze River and aquatic ecosystems in natural ponds south of the Yangtze River

A schematic overview of the scenario selection procedure for the scenarios for groundwater at 2 m depth in paddy land south of the Yangtze River and aquatic ecosystems in natural ponds south of the Yangtze River is given in Figure 17. Execution of this scenario selection procedure is described step by step in Annex F.

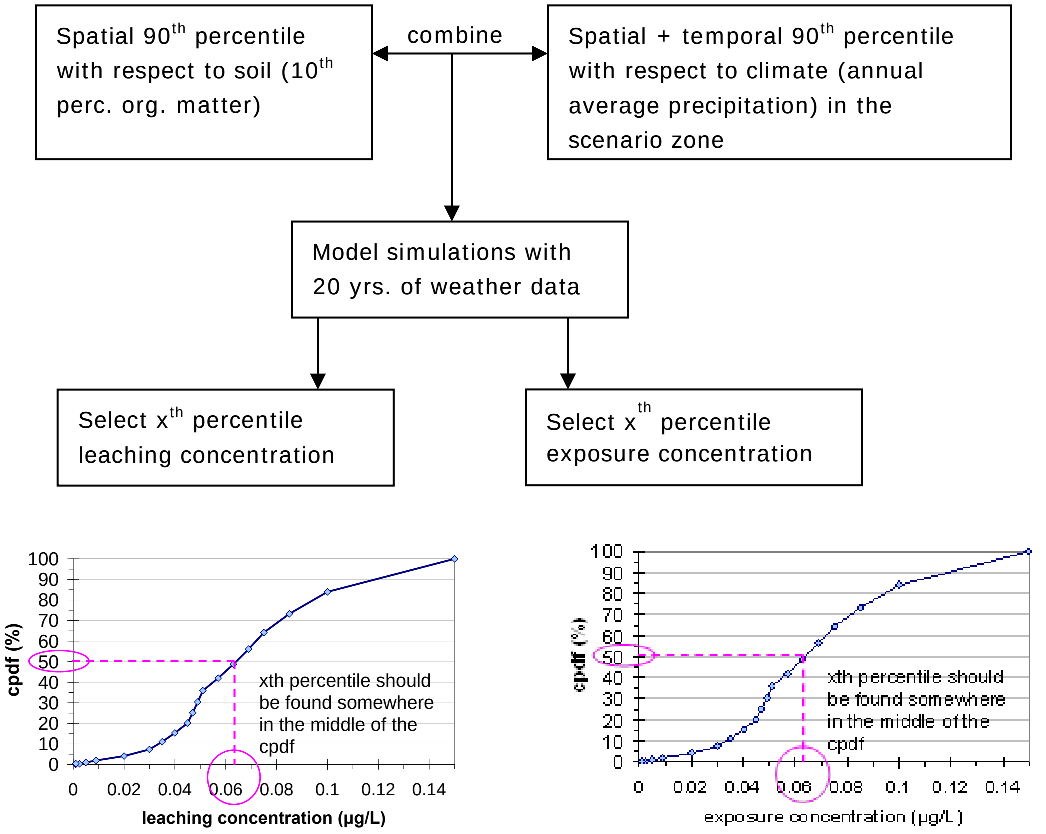

Figure 17 *Method for the calculation of the overall 99th percentile vulnerability of the Chinese groundwater scenarios for paddy land south of the Yangtze River and for the calculation of the overall 90th percentile vulnerability of the Chinese natural pond scenario south of the Yangtze River.*

The main driver for groundwater and the natural pond in paddy land south of Yangtze River scenarios is the annual average precipitation. Two scenario zones were distinguished for this protection goal, *i.e.* Yangtze river basin and South China. The 90th percentile of annual average precipitation was determined for each of the two scenario zones (2020 mm for Yangtze River basin and 2050 mm for South China; see Annex F for details). For each scenario zone, one meteorological station was selected which fulfilled the requirement that the (overall) 90th percentile weather of the specific scenario zone coincides with the 50th temporal percentile of the annual average precipitation of the selected meteorological station. The reason for aiming at a 50th percentile is that with only 20 years of meteorological data a high percentile (for instance 90th percentile) can easily result in the selection of a PEC of one extreme year. When the precipitation pattern of this year is known, the timing of application becomes decisive for selection of the 99th percentile PEC in surface water. This is undesirable.

As noted in Section 7.3, the 90th percentile for soil is represented by the 10th percentile for organic matter content (sorted from smallest to largest values). The 10th percentile for organic matter content was selected from the organic matter map (Figure F1 in Annex F). Table 7 shows per scenario zone the calculated 10th percentile of organic matter content and corresponding organic matter content class. Details of the procedure for calculating the 10th percentile of soil organic matter content for each scenario zone and land use paddy land at are described in Annex F of this report.

Table 7
The 10th percentile organic matter content (%) and corresponding organic matter content class of each scenario zone

Land type	Scenario zone	calculated 10th percentile organic matter (%)	corresponding organic matter content class (%)
Paddy land	Yangtze River	1.08	1 - 2
	South China	1.04	1 - 2

Weather stations were selected that are located in an area with an organic matter content corresponding to the 10th percentile of organic matter of the scenario zone. Cumulative frequency distributions of the annual precipitation were made for each selected weather station. Next, a weather station was selected per scenario zone, with the lowest temporal percentile corresponding to the overall 90th percentile of the annual precipitation of the particular scenario zone (2020 mm Yangtze River Basin and 2050 mm Lianping).

Table 8 gives per selected location the percentile that corresponded to the overall 90th percentile of the annual precipitation of the particular scenario zone. Because meteorological data of only a limited set of Chinese meteorological stations was available for the project, the percentiles in the table are higher than the 50th percentile aimed at. More details about the followed approach can be found in Annex F.

Table 8
Percentiles corresponding to the overall 90th percentile annual precipitation (see Annex F for the details) for the selected weather station location.

	Yangtze River Basin Meteostation and location Nanchang (2020mm) cpdf (%)	South China Location Lianping, meteostation Shaoguan (2050 mm) cpdf (%)
Corresponding temporal percentile of the selected meteo station	77.2	88.6

Selected scenario locations described above are shown in Figure 18.

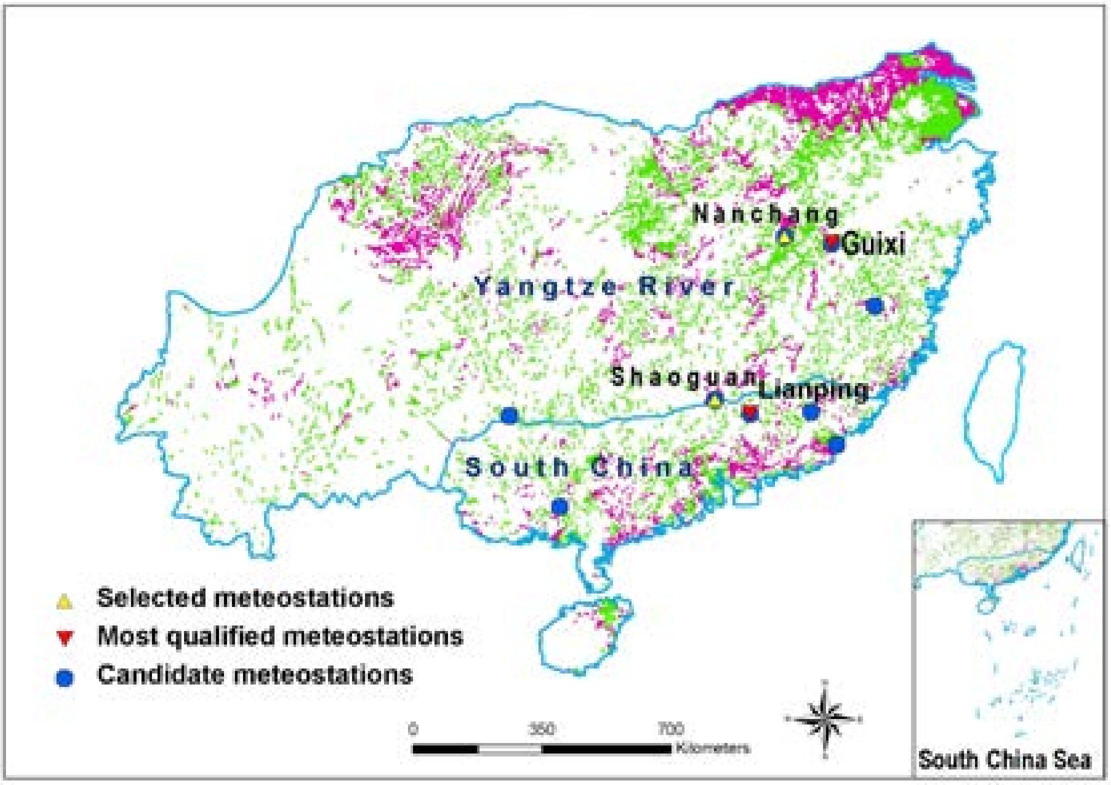

Figure 18 *Selected locations for the leaching and pond scenarios in paddy land south of the Yangtze River. See Annex F for the difference between Most qualified meteostations and Selected meteostations.*

9 Model modifications specific for Chinese environmental risk assessment

9.1 PEARL for paddy rice cultivation

The PEARL model is a 1-dimensional dynamic model that calculates leaching concentrations in groundwater. The model describes the fate of pesticide and relevant transformation products in soil and groundwater. Transformation is described using first order kinetics and sorption is described using a Freundlich type equation. The model is linked to the Soil-Water-Atmosphere Plant model (Van Dam *et al*., 1997), which solves the Richards equation for water movement in the (un-)saturated zone. The model used within the risk assessment procedures of the Netherlands and the EU. Model concepts of the PEARL model can be found in Leistra *et al*. (2001). For the PERAP project the PEARL model was extended to describe the fluctuating water level of a paddy water layer and pesticide behaviour in this layer, including pesticide degradation and runoff. The concepts are described below.

9.2 Model description of the paddy water layer

A paddy water layer is simulated with a water depth, Z. Z is assumed to vary in time between zero and Z_{max} due to precipitation, runoff overflow, surface runoff, leaching to the soil and evapotranspiration (see Figure 10). Pesticide enters this layer only via three routes: (i) pesticide application, (ii) wash-off from the rice crop, and (iii) atmospheric deposition. Diffusion to and from the soil layer and upwards seepage are excluded.
Only spray applications to the soil surface/water layer or the plant canopy is considered. The applied pesticide mass is applied to either the soil surface or the water layer dependent of the presence of the water layer.

Wash-off from the plant leaves is calculated according to:

- if Z = 0, then the wash-off flux goes to the top compartment of the soil
- if Z > 0, the wash-off flux goes to the water layer.

The pesticide balance of the water layer is described as follows:

$$\frac{dZc_{wl}}{dt} = +J_w - J_{\text{inf}} - J_{over} - J_{vol} - k_{t,wl} Z c_{wl} \qquad \text{(eq. 1)}$$

where
c_{wl} = concentration of substance in water layer (kg m^{-3})
J_w = areic mass rate of wash-off of substance (kg m^{-2} d^{-1})
J_{inf} = areic mass rate of infiltration of substance into soil (kg m^{-2} d^{-1})
J_{over} = areic mass rate of runoff overflow (kg m^{-2} d^{-1})
J_{vol} = areic mass rate of volatilisation at the water surface (kg m^{-2} d^{-1})
$k_{t,wl}$ = transformation rate coefficient of substance in the water layer of the paddy field (d^{-1})

The term on the left hand site of equation 1 is worked out as follows:

$$\frac{dZ \cdot c_{wl}}{dt} = \frac{\left(c_{wl}^{\ j+1} . z^{\ j+1}\right) - \left(c_{wl}^{\ j} . z^{\ j}\right)}{dt} \qquad \text{(eq. 2)}$$

where j is the index of grid points in time.
The infiltration rate of substance into the soil is assumed to be driven by convective flow only:

$$J_{\text{inf}} = q_{\text{inf}}\, c_{wl} \qquad \text{(eq. 3)}$$

where q_{inf} = volume flux of infiltration of water into the soil (m^3 m^{-2} d^{-1}).

The substance flux due to runoff overflow is described by:

$$J_{over} = q_{over}\, c_{wl} \qquad \text{(eq. 4)}$$

where q_{over} = volume flux of runoff overflow to the surface water system (m^3 m^{-2} d^{-1}).

The transformation rate coefficient of substance in the water layer is considered constant and is calculated from the half-life ($DegT50_{wl}$) in the water layer by]

$$k_{wl} = \frac{\ln\ 2}{DegT50_{wl}} \qquad \text{(eq. 5)}$$

The half-life in the water layer ($DegT50_{wl}$) is assumed to be constant, so independent of the temperature in the water layer. Only behaviour of the parent compound is simulated in the water layer. This is analogous to the simulation of behaviour on the plant surface.

The model delivers hourly values of the areic mass rate of runoff overflow J_{over}
for adequate coupling with the surface water model. Numerical aspects for the paddy water layer are described in Annex G.

9.3 Anaerobic degradation in paddy rice fields

Anaerobic conditions are assumed to occur in the top layer and the plough layer/hard pan of the paddy field, only in case a rice crop is present. To account for anaerobic degradation, the model considers a top soil layer with anaerobic conditions. This layer has a depth Z_{ana}, which is provided by the user. The degradation rate in case of anaerobic conditions has to be provided by the user as well.

The procedure for the description of the degradation rate is as follows:

1. the input file has to specify two DegT50 values for top soil: one for aerobic conditions, $DegT50_{ae}$ and one for anaerobic conditions, $DegT50_{re}$ ('re' from reduced);
2. the input file specifies the depth, z_{ana}, up to which anaerobic conditions are assumed to occur. The input file specifies the normal depth factors for transformation rate (1 for 0- z_{ana} cm, 0.5 for z_{ana} - 60 cm, 0.3 for 60-100 cm and zero for deeper layers;
3. if there is no rice crop on the field, then the rate is calculated as usual on the basis of $DegT50_{ae}$
4. if there is a rice crop, then anaerobic conditions are assumed to occur in the top layer, so the transformation rate is based on $DegT50_{re}$; however, aerobic conditions are assumed to occur below z_{ana} cm depth, so the DegT50 for layers below 30 cm depth remain the same. z_{ana} is an input parameter in the model.

This implies that the model has to recalculate the values of the depth factor (symbol $f_{d,t}$ in Eq. 7.5 at p. 61 of Leistra *et al.*, 2001) for the time periods when there is a rice crop on the field.

Considering this Eq. 7.5, it can be derived that this results in:

$$\frac{f_{d,t}}{DegT50_{ae}} = \frac{f_{d,t,re}}{DegT50_{re}} \qquad \text{(eq. 6)}$$

where $f_{d,t}$ is the depth factor for aerobic conditions and where $f_{d,t,re}$ is the depth factor for reduced conditions. This leads to the following expression for $f_{d,t,re}$:

$$f_{d,t,re} = f_{d,t} \frac{DegT50_{re}}{DegT50_{ae}} \qquad \text{(eq. 7)}$$

Please note that this calculation does not apply to the 0-30 cm layer: the factor $f_{d,t}$ for this layer should be 1 also under anaerobic conditions.

9.4 TOXSWA for the natural pond scenario

Model concepts of the TOXSWA model can be found in Adriaanse (1996). TOXSWA is a deterministic model that has been developed to calculate surface water concentrations in edge-of field water courses due to pesticide use. Specific concepts for simulating pesticide behaviour in the Chinese natural pond are described below.

9.4.1 Model description

Figure 19 shows for the cross sectional area of the Chinese natural pond the incoming and outgoing water fluxes.

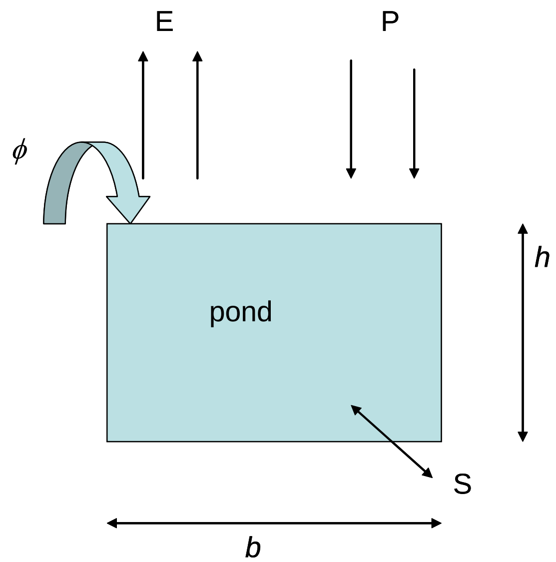

Figure 19 *Schematisation of the water balance of the Chinese natural pond. E is the evaporation, P is precipitation, S the exchange flux with groundwater and theta the runoff overflow plus controlled drainage. H and b represent the sizes water depth and the width of the pond.*

Incoming flows consist of precipitation, controlled drainage and runoff overflow from the paddy fields (output of the PEARL model) and exchange with the groundwater (upward seepage). Outgoing flows consist of evaporation and exchange with the groundwater (downward seepage).

The water conservation equation for the water layer of the Chinese natural pond reads:

$$b\frac{dh_{pond}}{dt} = \Phi + (P+E)b - SP_{pond}$$ (eq. 8)

where:

b	(m)	Width of the pond
h_{pond}	(m)	Water depth in the pond
Φ	($m^3\ m^{-1}d^{-1}$)	Water volume from the contributing area (i.e. controlled drainage and runoff overflow) divided by the length of the pond, l
P	($m\ d^{-1}$)	Precipitation
E	($m\ d^{-1}$)	Evaporation from the surface area of the pond (positive flux indicates upward transport)
S	($m\ d^{-1}$)	Exchange flux with the groundwater (upward and downward seepage) per sediment area ($=lP_{pond}$). The flux is defined positive in downward direction (so flux out of the pond is positive)
P_{pond}[1]	(m)	Wetted perimeter of the pond; area for exchange of water and substance mass between the water layer and the sediment
l	(m)	Length of the pond

The surface area of the water layer of the pond (A_{pond}) is ca. 1 mu (20x33 = 660 m^2). P_{pond} equals $b+2h_w$. where h_w is the water depth across which exchange with the groundwater occurs. h_w is assumed to be constant and set to 0.5 m for the Chinese natural pond scenarios.

The water volume from the contributing area, Φ, is calculated from the width of the contributing area (perpendicular to the pond), $B_{contr.area}$ (i.e. 20 mu divided by the length of the pond; 33 m) and the water flux from the contributing area (controlled drainage and runoff overflow), i.e. $q_{rodr,pond}$ (m/d)[2]. $q_{rodr,pond}$ is being calculated by the PEARL model on a daily basis. The contributing area is set to 20 mu and it is assumed that this is 100% cropped with paddy rice. The following applies:

$$\Phi = B_{contr.area} q_{rodr,pond}$$ (eq. 9)

The magnitude of the groundwater exchange flux S, which can be positive as well as negative, is unknown. Data on groundwater tables in surrounding fields and conductivities of sediment-soil interfaces are unknown. Therefore, a simple linear relation is assumed between the seepage flux and the water depth in the pond:

$$S = a(h_{pond} - h_{pond,\min})$$ (eq. 10)

Where, $h_{pond,min}$ (m) is the depth at which exchange with the groundwater is zero and a (d^{-1}) is an acceleration coefficient depicting the increase of S with h_{pond}. $h_{pond,min}$ and a are calibration parameter in the model. They need to be calibrated such that the variation of the water depth in time stays with the boundaries of 0.5 and 3 m.

S is defined in TOXSWA as follows:

$$S = \frac{B_{contr.area}}{P_{pond}} q_{sub,pond}$$ (eq. 11)

[1] Note: In Adriaanse (1996) is $P_{pond} = P_{hw}$ from the point of view from the balance of the water layer of the pond and $P_{pond} = P_{z=0}$ from the point of view of the balance of the sediment wanneer de balans van het sediment

[2] $q_{rodr,pond}$ (m/d) is the redundant water volume from the contributing area divided by the area of the contribution area, per time unit

where, $q_{sub,pond}$ (m d^{-1}) is the water volume that is exchanged with the groundwater across P_{pond} divided by the area of the contributing area. From eq. (10) and (11) follows:

$$q_{sub,pond} = \frac{a(h_{pond} - h_{pond,\min})P_{pond}}{B_{contr.area}} \quad \text{(eq. 12)}$$

An initial condition is required for solving the differential equation:

$$h_{pond}(t=0) = h_{pond,ini} \quad \text{(eq. 13)}$$

In the pond ideal mixing is assumed. The substance mass balance of the Chinese natural pond reads:

$$b\frac{d(c_{pond} \cdot h_{pond})}{dt} = -bk(c_{pond} \cdot h_{pond}) + bJ_{wa} - J_{wb,adv}P_{pond} \quad \text{(eq. 14)}$$

with:

c_{pond}	(kg m^{-3})	Concentration of the substance in the pond
k	(1/d)	Transformation rate coefficient for substance in the water layer of the pond
J_{wa}	(kg $m^{-2}d^{-1}$)	Areic mass flux of substance across the water-air interface
$J_{wb,adv}$	(kg $m^{-2}d^{-1}$)	Areic mass flux of substance across the water-sediment interface by advection

$J_{wb,adv}$ is defined as follows (see eq. (4.14) in Adriaanse (1996) :

$$J_{wb,adv} = \frac{B_{contr.area}}{P_{pond}} q_{sub,pond} c_s \quad \text{(eq. 15)}$$

c_s is defined as:

$$c_s = \begin{cases} c_{pond} & if \quad q_{sub,pond} > 0 \\ c_{sed} & if \quad q_{sub,pond} \leq 0 \end{cases} \quad \text{(eq. 16)}$$[3]

An initial condition is necessary in order to solve the differential equation:

$$c_{pond}(t=0) = 0 \quad \text{(eq. 17)}$$

The runoff component is treated as point source (see also Adriaanse (1996)).

De mass balance of the sediment is similar to Section 4.2 of Adriaanse (1996). However, in the scenario all diffusion fluxes are set to zero. By keeping the concept simple (no diffusion), interactions between the water layer and sediment do not occur. Concentrations in the water layer are not decreasing due to diffusion to the sediment and vice versa, increase of the concentration in the water layer due to back diffusion from the sediment to the water does not occur. This is also means that values for the half live in the sediment and the sorption coefficient for sorption in the sediment are not required.

[3] The chinese pond scenarios are parameterised such that $q_{sub,pond} < 0$ does not occur; so substane mass transfer from the sediment to the water layer by advection does not occur.

10 Parameterisation of the models for the scenarios

10.1 Introduction

In this section the parameterisation of the Chinese scenarios the PEARL model and TOXSWA model for the Chinese scenarios are described. The PEARL model is used for all three selected protection goals. For the groundwater protection goals ('Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River' and 'Groundwater at 2 m depth in paddy land south of the Yangtze River') the PEARL model delivers the necessary endpoint, being the 99th percentile leaching concentration. For the surface water protection goal ('Aquatic ecosystems in natural ponds south of the Yangtze River') PEARL is used to calculate the runoff overflow (water and substance fluxes) from the paddy field into the pond and the necessary endpoint for this protection goal is calculated with the TOXSWA model (Figure 20), being the 90th percentile of the annual peak concentration in surface water.

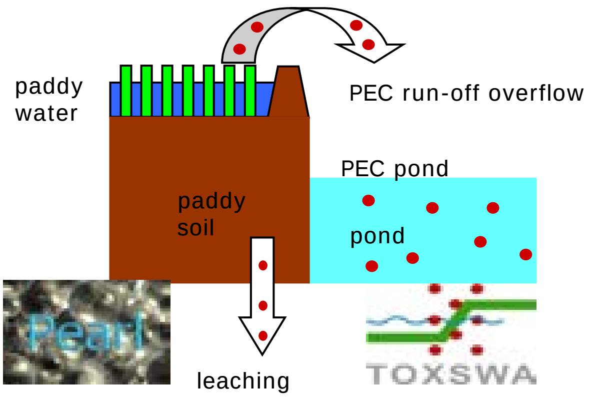

Figure 20 *Schematic overview of the use of the PEARL and TOXSWA model for calculation of the necessary endpoints for the three selected protection goals.*

The PEARL software in fact comprises two models: 1. the hydrological model SWAP (Soil Water Atmosphere Plant; Kroes *et al.*, 2008) for simulation of water flow and heat transport in the soil-plant systems and 2. The pesticide model PEARL (Leistra *et al.*, 2001) for simulation of pesticide behaviour in soil-plant systems and their emissions to the environment.

The parameterisation of the PEARL/SWAP model for all three protection goals is described in Section 10.2. Input data in to the model is discussed first, followed by a description of the calibration strategy used and a description of the implementation of this calibration strategy.

The parameterisation of the TOXSWA model for the surface water protection goal 'Aquatic ecosystems in natural ponds south of the Yangtze River' is described in Section 10.3. first model input data on sediment characteristics, weather and runoff are described, followed by a description of the calibration of the hydrology of the pond.

10.2 Parameterisation of the PEARL/SWAP model

10.2.1 Soil data

10.2.1.1 Introduction

Soil data of the selected locations for the groundwater scenarios were found in literature (The Office Of The Second National Soil Survey, 1994). Measured data of soil texture (according the Chinese classification system), organic matter content and occasionally dry bulk density were available for the soil profiles of the selected locations. Note that the depths at which the data was measured differs per soil profile.

10.2.1.2 Organic matter content

Per scenario soil information was gathered. Per soil layer information on soil texture and (measured) organic matter content was available. However, the 90th percentile organic matter content (0-20 cm) was calculated for each scenario zone and it was decided to use the 90th percentile organic matter content as scenario input for calculations of pesticide leaching. As the thickness of the soil layers differ per soil profile, the measured organic matter content per soil layer was scaled to the calculated 90th percentile organic matter content (0-20 cm).The scaling method is described in Annex H and calculations for two different soil profiles are written out to illustrate the scaling method.

Results of the scaling method for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China are shown in Table 9. The results for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China are shown in Table 10.

Table 9

Measured and scaled organic matter contents for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China

Locations	Soil profile Chinese name	depth (cm)	90% percentile organic matter (0-20 cm) (%)	Measured organic matter (%)	Scaled organic matter (%)
Xinmin	泥甸淤土	0-18	1.4	1.66	1.426
	草甸土亚类甸泥砂土土属	18-45		1.36	1.168
		45-94		1.11	0.953
		94-140		0.79	0.679
Urumchi	淡棕灰土	0-8	0.61	0.97	0.682
	淡棕钙土亚类淡棕钙泥砂土土属	8-30		0.8	0.562
		30-65		0.58	0.408
		65-90		0.58	0.408
Tongxin	老牙村淤绵土	0-20	0.61	0.75	0.610
	黄绵土亚类绵土土属	20-136		0.71	0.577
Weifang	临淄立黄土	0-22	0.66	1.07	0.660
	褐土亚类褐黄土土属	22-38		0.89	0.549
		38-74		0.3	0.185
		74-97		0.32	0.197
		97-120		0.26	0.160
Shangqiu	底砂两合土	0-20	0.66	0.94	0.660
	潮土亚类潮壤土土属	20-38		0.85	0.597
		38-68		0.51	0.358
		68-100		0.25	0.176
Wugong	斑斑黑油土	0-14	0.66	1.14	0.689
	塿土亚类塿粘土土属	14-23		0.98	0.592
		23-97		1.1	0.665
		97-180		1.19	0.719
		180-200		1.06	0.641

Table 10
Measured and scaled organic matter contents for the soil profiles of the locations selected for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

Locations	Soil profile Chinese name	depth (cm)	90% percentile organic matter (0-20 cm) (%)	Measured organic matter (%)	Scaled organic matter (%)
Nanchang 南昌	水稻土 潴育水稻土亚类黄泥田土属	0-15	1.33	2.39	2.034
		15-24		1.61	1.370
		24-36		0.59	0.502
		36-100		0.47	0.400
Lianping 连平	水稻土	0-14	1.07	2.67	2.272
	潴育水稻土亚类潮泥砂田土属	14-21		1.6	1.362
		21-42		0.94	0.800
		42-67		0.85	0.723

10.2.1.3 Dry bulk density

Measured data on dry bulk density was taken from literature (The Office Of The Second National Soil Survey, 1994). However, of many soil profiles the dry bulk density was not available. In those cases the dry bulk density was estimated using the pedotransfer function of Bollen *et al*. (1995) which was also implemented in the SWAP-PEARL model:

$$\rho_b = 1800 + 1236 m_{om} - 2910\sqrt{m_{om}} \qquad \text{(eq. 18)}$$

where:

ρ_b	dry bulk density	kg m^{-3}
m_{om}	mass content of organic matter	kg kg^{-1}

For consistency the scaled organic matter content was used to calculate the dry bulk density using eq. 18. Measured and calculated dry bulk densities of the selected locations are shown in Table 11 and 12.

Table 11

Measured (*) and calculated dry bulk densities for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China

Location	Soil profile Chinese name	Depth (cm)	Dry bulk density g/cm^3
Xinmin	泥甸淤土	0-18	1.37*
	草甸土亚类甸泥砂土土属	18-45	1.54*
		45-94	1.41*
		94-140	1.48*
Urumchi	淡棕灰土	0-8	1.57
	淡棕钙土亚类淡棕钙泥砂土土属	8-30	1.59
		30-65	1.62
		65-90	1.62
Tongxin	老牙村淤绵土	0-20	1.58
	黄绵土亚类绵土土属	20-136	1.59
Weifang	临淄立黄土	0-22	1.24*
	褐土亚类褐黄土土属	22-38	1.39*
		38-74	1.49*
		74-97	1.67
		97-120	1.69
Shangqiu	底砂两合土	0-20	1.57
	潮土亚类潮壤土土属	20-38	1.58
		38-68	1.63
		68-100	1.68
Wugong	斑斑黑油土	0-14	1.57
	塿土亚类塿粘土土属	14-23	1.58
		23-97	1.57
		97-180	1.56
		180-200	1.57

* measured dry bulk density

Table 12

Calculated dry bulk densities for the soil profiles of the locations selected for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

Location	Soil Chinese name profile	Depth (cm)	Dry bulk density g/cm^3
Nanchang	水稻土	0-15	1.41
	潴育水稻土亚类黄泥田土属	15-24	1.48
		24-36	1.60
		36-100	1.62
Lianping	水稻土	0-14	1.39
	潴育水稻土亚类潮泥砂田土属	14-21	1.48
		21-42	1.55
		42-67	1.56

10.2.1.4 Soil texture

The soil texture data was given in a Chinese classification system based on the ISSS system (National Soil Survey Office, 1992). This classification system does not correspond to the USDA classification system for soil texture. The ISSS textural classification system is provided in Table 13. The USDA classification system is given for reference in Table 14.

Table 13

Soil particle size limits (diameter in millimetres) of soil separates in the Chinese soil textural classification system

Name of soil separate	Diameter limits
coarse sand*	2 – 0.2
fine sand	0.2 – 0.02
silt	0.02 – 0.002
clay	less than 0.002

* Note that the sand separate is split into two sizes (coarse sand and fine sand.). The size range for sands, considered broadly, comprises the entire range from coarse sand to fine sand, i.e., 2-0.02 mm.

Table 14

Soil particle size limits (diameter in millimetres) of soil separates in the USDA soil textural classification system.

Name of soil separate	Diameter limits
very coarse sand*	2 - 1
coarse sand	1 - 0.5
medium sand	0.5 - 0.25
fine sand	0.25 - 0.1
very fine sand	0.1 - 0.05
clay	less than 0.002

* Note that the sand separate is split into five sizes (very coarse sand, coarse sand, etc.). The size range for sands, considered broadly, comprises the entire range from very coarse sand to very fine sand, i.e., 2.00-0.05 mm.

For estimating the van Genuchten parameters, a software package (Van Genuchten *et al.,* 1991) was used that contains data of soil texture using the USDA classification system. It was therefore considered necessary to convert the soil texture data to this classification system. The software uses only one class for sand: 2 – 0.05 mm. Therefore, the fraction of particles at 0.05 mm was estimated from the Chinese data for coarse sand and fine sand, by interpolating the cumulative particle-size distribution. Figure 21 shows an example of a cumulative particle-size distribution, commonly presented as a log normal distribution (Nemes *et al*., 1999). Although Nemes *et al*. (1999) concluded that other methods for interpolation of the cumulative particle-size distribution are better than the loglinear interpolation procedure, we did use this procedure for its simplicity and because it is frequently used (*e.g.,* Leij *et al*., 1994; Tietje and Hennings, 1996). The mathematical notation of the loglinear interpolation on the φ scale (see Figure 21) is given in Eq. 19:

$$CP_n = CP_{n-1} + \frac{(-\varphi_n)-(-\varphi_{n-1})}{(-\varphi_{n+1})-(-\varphi_{n-1})}(CP_{n+1} - CP_{n-1})$$

(eq. 19)

where

CP	the cumulative percentage on the particle-size distribution curve	-
-Φ	the $\log_2$ value of the particle-size limits	mm
n	missing particle-size limit	-
n-1	the preceding neighbouring limit	-
n+1	succeeding neighbouring limit	-

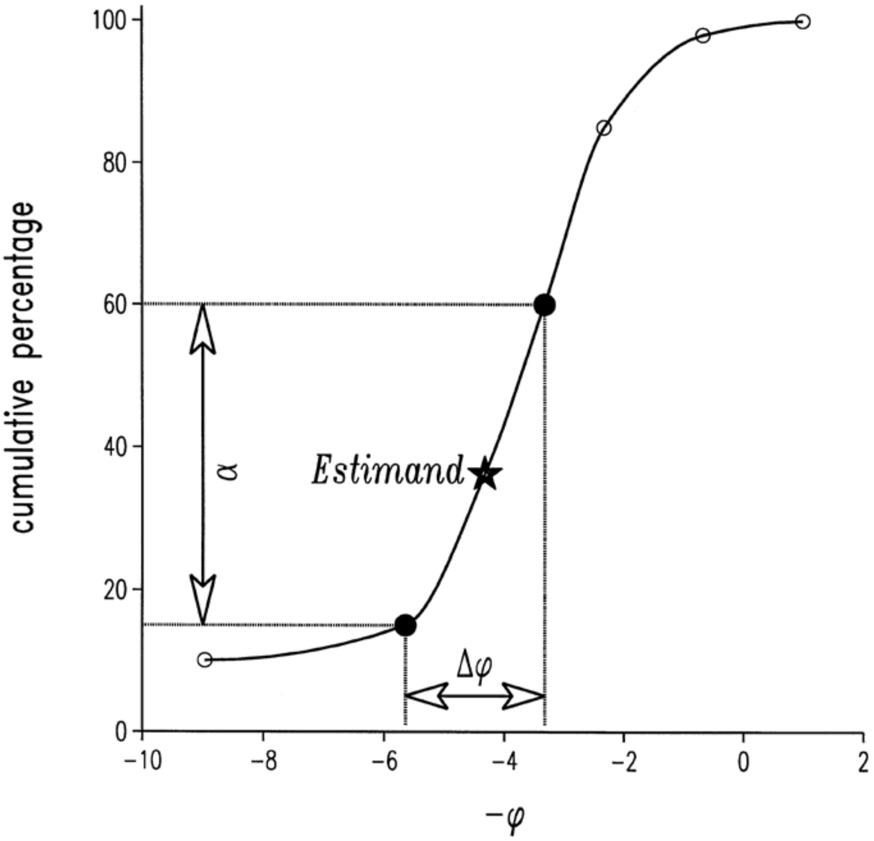

Figure 21 *Representation of distances between particle-size fractions (α) and between particle-size limits (Δφ). Dots represent measured values and the star represents an estimated value. (Taken from Nemes et al., 1999; with permission). Note that −φ is the log2 value of the particle-size limits in mm, so particle size limit 0.02 mm corresponds to −φ = log2 (0.02) = -3.9.*

Measured soil texture (Chinese classification system) and results of the log linear interpolation method to convert soil texture to the USDA soil texture classification system are given in Table 15 for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China. Table 16 lists the soil texture values for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

Table 15

Measured soil texture (Chinese classification system) and soil texture converted to the USDA soil texture classification system for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China

			Soil texture (mm); Chinese classification system				Soil texture (mm); USDA classification system		
Location	Soil profile Chinese name	Depth (cm)	Gravel 2.0-0.2	**Sand 0.2-0.02**	**Silt 0.002-0.02**	**Clay <0.002**	**Sand 2-0.05**	**Silt 0.002-0.05**	**clay <0002**
Xinmin	**泥甸淤土**	0-18	55.42	-	26.62	17.96	44.39	37.65	17.96
	草甸土亚类甸泥砂土土属	18-45	53.16	-	26.35	20.49	42.58	36.93	20.49
		45-94	50.76	-	28.45	20.79	40.66	38.55	20.79
		94-140	52.46	-	24.29	23.25	42.02	34.73	23.25
Urumchi	**淡棕灰土**	0-8	4.9	29.4	45.2	20.5	22.60	56.90	20.50
	淡棕钙土亚类淡棕钙泥砂土土属	8-30	7.4	27.8	38.9	25.9	24.14	49.96	25.90
		30-65	5.8	33.4	41.3	19.5	25.91	54.59	19.50
		65-90	6.4	32.8	45.0	15.8	26.15	58.05	15.80
Tongxin	**老牙村淤**绵土	0-20	2.8	43.3	35.2	18.7	28.87	52.43	18.70
	黄绵土亚类绵土土属	20-136	2.2	40.7	36.0	21.1	26.70	52.20	21.10
Weifang	临淄立黄土	0-22	1.1	46.7	31.7	20.5	29.22	50.28	20.50
	褐土亚类褐黄土土属	22-38	0.3	46.8	31.8	21.1	28.48	50.42	21.10
		38-74	-	46.5	29.4	24.1	28.00	47.90	24.10
		74-97	-	46.2	30.0	23.8	27.82	48.38	23.80
		97-120	-	53	25.4	21.6	31.91	46.49	21.60
Shangqiu	**底砂两合土**	0-20	0.4	34.6	44.5	20.5	21.23	58.27	20.50
	潮土亚类潮壤土土属	20-38	0.2	34.3	42.6	22.9	20.85	56.25	22.90
		38-68	0.8	51.8	30.6	16.8	31.99	51.21	16.80
		68-100	2.0	69.5	22.3	6.2	43.84	49.96	6.20
Wugong	**斑斑黑油土**	0-14	-	31.22	43.3	25.48	18.80	55.72	25.48
	塿土亚类塿粘土土属	14-23	-	31.46	43.21	25.33	18.94	55.73	25.33
		23-97	-	28.95	45.0	26.05	17.43	56.52	26.05
		97-180	-	28.76	44.2	27.04	17.32	55.64	27.04
		180-200	-	28.78	45.06	26.16	17.33	56.51	26.16

Table 16

Measured soil texture (Chinese classification system) and soil texture converted to the USDA soil texture classification system for the soil profiles of the locations selected for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

	Soil profile		Soil texture (mm); Chinese classification system				Soil texture (mm); USDA classification system		
Location	**Chinese name**	**depth**	**gravel**	**sand**	**silt**	**clay**	**sand**	**silt**	**clay**
		(cm)	2.0-0.2	0.2-0.02	0.002-0.02	<0.002	2-0.05	0.002-0.05	<0.002
Nanchang	水稻土	0-15	1.55	15.85	52.55	30.06	11.08	58.86	30.06
	潴育水稻土亚类黄泥田土属	15-24	1.85	20.72	53.11	24.13	14.51	61.36	24.13
		24-36	3.3	19.16	50.73	28.62	13.03	58.35	28.62
		36-100	1.75	18.86	55.29	24.11	13.09	62.80	24.11
Lianping	水稻土	0-14	31.6	24.99	28.4	14.31	47.35	38.34	14.31
	潴育水稻土亚类潮泥砂田土属	14-21	31.2	24.53	28.44	15.83	45.97	38.20	15.83
		21-42	28.4	21.54	30.84	19.22	41.37	39.41	19.22
		42-67	32.68	24.19	24.33	18.8	47.24	33.96	18.80

10.2.1.5 Van Genuchten parameters

To simulate soil water flow with the SWAP model (soil hydrological model coupled to PEARL) a moisture retention function and a hydraulic conductivity function of the soil are necessary. In the SWAP model these functions are specified using the Van Genuchten-Mualem relationships (often called pedotransfer functions). As hydraulic properties of soils change with depth, it was necessary to estimate the van Genuchten parameters for each horizon of each soil.

Databases of moisture retention functions and conductivity functions of Chinese soils are not available and measurements of the function for the soil at the locations selected would be too time consuming given the limited time of this project. It was therefore decided to estimate the van Genuchten parameters using the Rosetta Lite Version 1.1 program (Schaap *et al*., 2001) which is implemented in the RETC program (Van Genuchten *et al.,* 1991). More information on Rosetta Lite Version 1.1. can be found in Annex I.

Model 3 (sand, silt, and clay fractions and dry bulk density as input data) in the Rosetta Lite Version 1.1 program (Schaap *et al*., 2001) was used to estimate the van Genuchten parameters for the Chinese soil profiles. Dry bulk densities given in Tables 11 and 12 and soil texture data converted to the USDA classification (Tables 15 and 16) are used as input in Model 3 of the Rosetta Lite Version 1.1 program to estimate the van Genuchten parameters. Estimated van Genuchten parameters for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China are given in Table 17. Table 18 gives the van Genuchten parameters for the scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

Table 17
Estimated van Genuchten parameters for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China

Soil profile			Soil hydraulic characteristics: Van Genuchten parameters					
Location	Chinese name	Depth (cm)	theta res $m^3\ m^{-3}$	theta sat $m^3\ m^{-3}$	Alpha cm^{-1}	N -	Lambda -	Ksat cm/da
Xinmin	泥甸淤土	0-18	0.0584	0.4055	0.0104	1.5195	0.5	19.37
	草甸土亚类甸泥砂土土属	18-45	0.0583	0.3751	0.0126	1.4449	0.5	8.28
		45-94	0.0632	0.4037	0.0099	1.515	0.5	12.72
		94-140	0.0651	0.3966	0.0121	1.4575	0.5	9.06
Urumchi	淡棕灰土	0-8	0.0622	0.3712	0.0069	1.5619	0.5	6.72
	淡棕钙土亚类淡棕钙泥砂土土属	8-30	0.0684	0.377	0.0084	1.4888	0.5	4.28
		30-65	0.0574	0.3545	0.0079	1.5151	0.5	5.68
		65-90	0.0517	0.3472	0.0078	1.5307	0.5	7.82
Tongxin	老牙村淤绵土	0-20	0.0567	0.3592	0.0079	1.53	0.5	7.06
	黄绵土亚类绵土土属	20-136	0.0607	0.3641	0.0079	1.5203	0.5	5.69
Weifang	临淄立黄土	0-22	0.0691	0.4401	0.0059	1.6338	0.5	31.6
	褐土亚类褐黄土土属	22-38	0.0666	0.4073	0.0065	1.6028	0.5	14.11
		38-74	0.0686	0.394	0.0078	1.5387	0.5	7.39
		74-97	0.0607	0.351	0.01	1.4277	0.5	3.37

Location	Soil profile Chinese name	Depth (cm)	Soil hydraulic characteristics: Van Genuchten parameters theta res m^3 m^{-3}	theta sat m^3 m^{-3}	Alpha cm^{-1}	N -	Lambda -	Ksat cm/da
		97-120	0.0553	0.3401	0.0114	1.3998	0.5	3.68
Shangqiu	底砂两合土	0-20	0.0628	0.373	0.0067	1.5685	0.5	6.83
	潮土亚类潮壤土土属	20-38	0.0659	0.3758	0.0071	1.5437	0.5	5.5
		38-68	0.0505	0.3424	0.0095	1.479	0.5	6.84
		68-100	0.0301	0.3082	0.0226	1.3611	0.5	15.25
Wugong	斑斑黑油土	0-14	0.0705	0.3857	0.0073	1.5318	0.5	5.03
	塿土亚类塿粘土土属	14-23	0.0699	0.3829	0.0074	1.5274	0.5	4.83
		23-97	0.0717	0.3885	0.0073	1.5307	0.5	4.95
		97-180	0.0734	0.393	0.0075	1.5248	0.5	4.95
		180-200	0.0719	0.3888	0.0073	1.5298	0.5	4.93

Table 18

Estimated van Genuchten parameters for the soil profiles of the locations selected for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China

Location	**Soil profile** **Chinese name**	**Depth** **(cm)**	**Soil hydraulic characteristics: Van Genuchten parameters** **theta res** **m^3 m^{-3}**	**theta sat** **m^3 m^{-3}**	**Alpha** **cm^{-1}**	**N** **-**	**Lambda** **-**	**Ksat** **cm/d**
Nanchang	水稻土 潴育水稻土亚类 黄泥田土属	0-15	0.0835	0.4441	0.0073	1.5442	0.5	9.76
		15-24	0.0736	0.4107	0.0062	1.5948	0.5	8.93*
		24-36	0.0751	0.3915	0.0077	1.5003	0.5	3.86
		36-100	0.0691	0.3801	0.007	1.5353	0.5	4.56
Lianping	水稻土	0-14	0.0504	0.3907	0.0116	1.507	0.5	24.37
	潴育水稻土亚类 潮泥砂田土属	14-21	0.0512	0.3759	0.0126	1.4788	0.5	15.21*
		21-42	0.0558	0.3682	0.012	1.4557	0.5	8.21
		42-67	0.0542	0.3691	0.0156	1.4142	0.5	10.11

* These values are not the Ksat values of this layer (the plough pan) used in the scenario. The Ksat of the plough pan is calibrated to be 0.118 cm/d for Nanchang and 0.102 cm/d for Lianping (see Section 10.2.9).

10.2.1.6 pH of the soil profiles

Measured pH_{H2O} values are given in Table 19 for the scenarios in the three Northern China scenario zones and in Table 20 for the scenarios of the scenario zones Yangtze River Basin and South China.

Table 19

Measured pH for the soil profiles of the locations selected for groundwater scenarios for dry land agriculture in the scenario zones Northwest China, Northeast China and North China

Location	Soil profile Chinese name	depth (cm)	pH H_2O (1:1)
Xinmin	泥甸淤土	0-18	6.9
	草甸土亚类甸泥砂土土属	18-45	7.1
		45-94	6.8
		94-140	7.1
Urumchi	淡棕灰土	0-8	8.1
	淡棕钙土亚类淡棕钙泥砂土土属	8-30	8.4
		30-65	8.3
		65-90	8
Tongxin	老牙村淤绵土	0-20	8.3
	黄绵土亚类绵土土属	20-136	8.4
Weifang	临淄立黄土	0-22	7.9
	褐土亚类褐黄土土属	22-38	7.9
		38-74	7.8
		74-97	7.8
		97-120	7.7
Shangqiu	底砂两合土	0-20	8.4
	潮土亚类潮壤土土属	20-38	8.4
		38-68	8.4
		68-100	8.5
Wugong	斑斑黑油土	0-14	8.4
	塿土亚类塿粘土土属	14-23	8.6
		23-97	8.6
		97-180	8.4
		180-200	8.5

Table 20

Measured pH for the soil profiles of the locations selected for groundwater scenarios for paddy rice in the scenario zones Yangtze River basin and South China.

Location	Soil profile Chinese name	depth (cm)	pH H_2O (1:1)
Nanchang	水稻土	0-15	5.3
	潴育水稻土亚类黄泥田土属	15-24	5.5
		24-36	6.4
		36-100	7.3
Lianping	水稻土	0-14	5.7
	潴育水稻土亚类潮泥砂田土属	14-21	6.6
		21-42	6.9
		42-67	7

10.2.1.7 Depth of soil profile in the model

The depth of the soil profile of every scenario was set to 4 m. The soil properties (texture, van Genuchten parameters, organic matter content, pH and dry bulk density) of the last horizon of each soil profile were used for additional horizons up to 4 m depth.

10.2.1.8 Soil profile in the model for scenarios with land use paddy rice (locations Nanchang and Lianping)

A typical vertical cross-section through a puddled rice field shows a layer of 0–10 cm of ponded water, a puddled, muddy topsoil of 10–20 cm, a plow pan that is formed by decades or centuries of puddling, and undisturbed subsoil (Bouman *et al.*, 2007). The plow pan reduces the hydraulic conductivity and percolation rate of rice fields dramatically (Bouman *et al.*, 2007). The plough pan or hard pan is a thin soil layer with a low permeability (Figure 22). This low permeability is the result of specific agricultural practices for rice cultivation (Figure 23). After flooding the fields, the soil is puddled at a water content between field capacity and saturation, comprising repeated ploughing, harrowing and finally leveling (Kukal and Aggerwal, 2002 and Wopereis *et al.*, 1992).

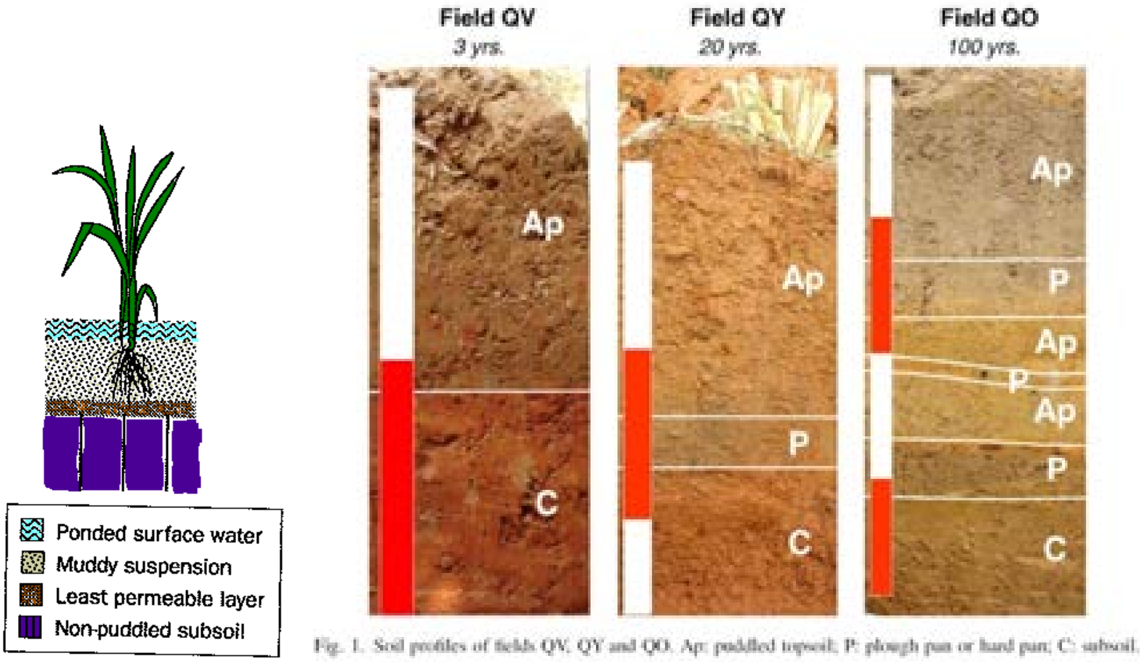

Figure 22 *Illustrations of the soil profile beneath a paddy field. The least permeable layer is called the plough pan or hard pan. Picture on the right hand side: from Janssen and Lennartz, 2007 (with permission): AP: puddle topsoil, P: Plough pan or hard pan, C: subsoil.*

Figure 23 *Land preparation practices for paddy rice cultivation (pictures from www.shutterstock.com).*

The soil profile of the locations Nanchang and Lianping were constructed as described in Table 21.

Table 21
Soil profile of the locations Nanchang and Lianping

Soil layer	Description
Layer 1 (top layer of puddled soil)	Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the first layer (0-15 cm Nanchang, 0-14 cm Lianping) were used to represent the top layer of puddled soil.
Layer 2 (plough pan)	A 5 cm thick plow sole was assumed below the top layer (15-20 cm Nanchang, 14 – 19 cm Lianping). Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the second layer (15-24 cm Nanchang and 14-21 cm Lianping) was used. However the saturated conductivity of the plough pan or hard pan was calibrated as this is the most important calibration parameter determining the amount of percolation (see Section 10.2.9). For Nanchang a value of 0.118 cm/day was calibrated and for Lianping a value of 0.102 cm/day was calibrated.
Layer 3 (subsoil)	20 – 24 cm Nanchang, 19 – 21 cm Lianping. Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the second layer (15-24 cm Nanchang and 14-21 cm Lianping) was used.
Layer 4 (subsoil)	24 – 36 cm Nanchang, 21 - 42 cm Lianping. Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the third layer (24 – 36 cm Nanchang and 21 - 42 cm Lianping) was used.
Layer 5 (subsoil)	36 – 60 cm Nanchang, 42 – 60 cm Lianping. Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the fourth layer (36 – 100 cm Nanchang and 42 – 67 cm Lianping) was used.
Layer 6 (subsoil)	60 – 100 cm Nanchang, 60 – 100 cm Lianping. Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the fourth layer (36 – 100 cm Nanchang and 42 – 67 cm Lianping) was used.
Layer 7 (subsoil)	36 – 400 cm Nanchang, 41 – 400 cm Lianping. Data (bulkdensity, pH, organic matter content, soil texture and van Genuchten parameters) of the fourth layer (36 – 100 cm Nanchang and 42 – 67 cm Lianping) was used.

10.2.2 Lower boundary conditions

10.2.2.1 Lower boundary condition for groundwater scenarios for dry land north of the Yangtze River

For each dry land agriculture scenario free drainage was assumed. This is justified for the scenario zones North China, North East China and North West China because groundwater tables are a few or more metres below soil surface

10.2.2.2 Lower boundary condition for groundwater and surface water scenarios for paddy rice south of the Yangtze River

The Neumann condition is used as lower boundary condition in the PEARL/SWAP model meaning that a flux at bottom (q_{bot}) is prescribed:

$$q_{bot} = a_{bot} \exp^{b_{bot}|h|} \qquad \text{(eq. 20)}$$

Where q_{bot} [cm d^{-1}] is the downward flux at het bottom of the soil column, h [cm] is the groundwater head with respect to soil surface and a_{bot} (cm d^{-1}) and b_{bot} (cm^{-1}) are empirical coefficients.

Coefficients a_{bot} and b_{bot} were calibrated to fulfil the requirements that have been defined for parameterization of the soil-hydrological situation of Nanchang and Lianping (see Section 10.2.9 for more details). For Nanchang the calibrated value for a_{bot} was -6.025 and the calibrated value for b_{bot} was -0.0236. For Lianping the calibrated value for a_{bot} was -10.0 and the calibrated value for b_{bot} was -0.0436.

10.2.3 Runoff from paddy fields

Surface runoff from either a dry land field or a drained paddy field and runoff overflow from a flooded paddy field (see Table 4 for definitions and Figure 24) are calculated by PEARL/SWAP as follows: Surface runoff or runoff overflow occurs when the water storage in the ponding layer exceeds the critical depth of $Z_{pnd,threshold}$:

$$q_{runoff} = \frac{1}{\gamma}\left(Z_{pnd} - Z_{pnd,threshold}\right)^{\beta} \quad for \quad Z_{pnd} > Z_{pnd,threshold} \tag{eq. 21}$$

Where q_{runoff} is the surface runoff flux or the runoff overflow flux (cm d^{-1}), Z_{pnd} is the ponding depth of water (cm) on the soil surface, γ is a resistance parameter (cm$^{\beta-1}$ d) and β is an exponent (-) of the empirical relation.

For surface runoff from a dry land field (Northern groundwater scenarios) a ponding depth of 0.2 cm is assumed and typical values of $\gamma = 0.5$ and $\beta = 1.0$ are used. These values correspond to those used for the FOCUS groundwater scenarios (FOCUS, 2000).

For runoff overflow from flooded paddy rice fields (locations Nanchang and Lianping) a ponding depth of 10 cm (corresponding to the height of the barrier in the outlet of the field) is used and parameters γ and β are calibrated such that defined requirements are met (see Section 10.2.9; calibrated values: $\gamma = 0.1$ and $\beta = 4$). For surface runoff from the drained paddy fields (during tillering period and after harvests of rice) a ponding depth of 0.5 cm (expert judgement Alterra) is assumed. $\gamma = 0.1$ and $\beta = 4$ are also used for these drained fields. This means that surface runoff of the drained paddy fields might be overestimated in periods the paddy field is not flooded.

Figure 24 *Flooded paddy rice fields (pictures from www.shutterstock.com).*

10.2.4 Meteorological data

Table 22 lists the meteorological data needed for running the PEARL model. The PEARL model needs either data on reference evapotranspiration or data on solar radiation, minimum and maximum air temperature, air humidity and wind speed at 2 m height to calculate evapotranspiration according Penman-Monteith (Monteith, 1965, 1981).

Table 22

Meteorological input data of the PEARL model

Parameter	Unit	Range
solar radiation	kJ m^{-2} d^{-1}	0~5E6
minimum air temperature	°C	-50~35
maximum air temperature	°C	-30~60
air humidity	kPa	0~10
wind speed at 2 m height	m/s	0~50
precipitation	mm/d	0~1000
reference evapotranspiration	mm/d	0~100

Comparative studies have shown a good performance of the Penman-Monteith approach under varying climatic conditions (Jensen *et al*., 1990). Potential and even actual evapotranspiration calculations are possible with the Penman-Monteith equation, through the introduction of canopy and air resistance to water vapour diffusion (Kroes *et al*., 2008). However, canopy and air resistance may not be available and therefore PEARL uses a slightly modified version of the Penman-Monteith equation to calculate the potential evapotranspiration (Allen *et al*., 1998). This comes down to a two-step approach: (1) the calculation of the potential evapotranspiration, using the minimum value of the canopy resistance and the actual air resistance, and (2) the calculation of the actual evapotranspiration using a reduction function. More details about the approach can be found in Kroes *et al*. (2008).

The PEARL/SWAP model offers three methods to calculate potential evapotranspiration: i) the potential evapotranspiration is given as input to the model by users, ii) apply the Penman – Monteith method with actual crop data and input of basic meteorological data, and iii) apply the Penman–Monteith method with reference crop data, a crop factor and basic meteorological data.

For the PERAP project option iii) the Penman–Monteith method with reference crop data, a crop factor and basic meteorological data. In this option the Penman-Monteith method is applied for the reference crop grass, in combination with crop factors. This method has been extensively discussed by Allen *et al*., (1998). The crop factors belong to a certain crop and depend on its development stage.

The TOXSWA model needs data on precipitation as well. Monthly average water temperatures are input in TOXSWA and calculated from minimum and maximum air temperatures. Furthermore TOXSWA requires open water evaporation. This is calculated using the Penman-Monteith method in the PEARL model (see Section 10.3.4).

The calculation or the collecting of the meteorological data needed for the modelling are discussed in the sections below.

10.2.5 Source and/or calculation of the meteorological input data for the modelling

Solar radiation

Solar radiation was calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration (*n/N*):

$$R_s = \left(a_s + b_s \frac{n}{N} \right) R_a \qquad \text{(eq. 22)}$$

where R_s is the solar or shortwave radiation (kJ m^{-2} day^{-1}), n is the actual duration of sunshine (hour), N is the maximum possible duration of sunshine or daylight hours (hour), n/N is the relative sunshine duration (-), R_a is the extraterrestrial radiation (kJ m^{-2} day^{-1}), a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0) and a_s+b_s is the fraction of extraterrestrial radiation reaching the earth on clear days ($n = N$) (Allen *et al.*, 1998). Sunshine duration is observed as the sum of time when solar direct irradiance is equal or greater than 120 W m^{-2} (hour).

In China, the Angstrom values can be computed with the latitude (degrees) by the following equation (Zuo, 1985; Tong, 2005).

$$a_s = 0.4885 - 0.0052\varphi_{\deg} - 0.06$$
$$b_s = 0.1563 + 0.0074\varphi_{\deg} + 0.06 \qquad \text{(eq. 23)}$$

In which, ϕ_{deg} is the latitude in degrees.
The possible duration of sunshine or daylight hours, N (hours), is given by:

$$N = \frac{24}{\pi}\omega_s \qquad \text{(eq. 24)}$$

where, ω_s is the sunset hour angle (rad)
The sunset hour angle expresses the day length and is given by (Kroes *et al.*, 2008):

$$\omega_s = \arccos\left[-\tan(\varphi_{rad})\tan(\delta)\right] \qquad \text{(eq. 25)}$$

The extraterrestrial shortwave solar radiation (R_a) depends on the latitude and the day of the year. R_a (kJ m^{-2} d^{-1}) is calculated with (Kroes *et al.*, 2008):

$$R_a = \frac{G_{sc}}{\pi} d_r \left[\omega_s \sin(\varphi_{rad})\sin(\delta) + \cos(\varphi_{rad})\cos(\delta)\sin(\omega_s)\right] \qquad \text{(eq. 26)}$$

where G_{sc} is the amount of solar radiation striking a surface perpendicular to the sun's rays at the top of the Earth's atmosphere, called the solar constant (0.11808 E^6 kJ m^{-2} d^{-1}), d_r is the inverse relative distance Earth-Sun (-), ω_s is the sunset hour angle (rad), ϕ_{rad} is the latitude (rad) and δ is the solar declination (rad) (Kroes *et al.*, 2008). The inverse relative distance Earth-Sun and the solar declination are given by (Kroes *et al.*, 2008):

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \qquad \text{(eq.27)}$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \qquad \text{(eq. 28)}$$

where J is the number of the day in the year (1-365 or 366, starting January 1).
We refer to Annex J for the code used to calculate the solar radiation.

Air humidity
The (average) daily actual vapour pressure, e_a, in kilopascals (kPa) is required for applying the Penman-Monteith method. For the PERAP project e_a was not available, but the relative humidity, RH (%), was available.
Actual vapour pressure was calculated using the relationship between relative humidity and saturation vapour pressure:

$$e_a = e_{sw}RH \qquad \text{(eq. 29)}$$

where e_a (hPa) is the actual vapour pressure, e_{sw} (hPa) is the saturation vapour pressure and RH (%) is the relative humidity observed at 1.5m above ground.

Several relationships have been developed to calculate saturated vapour pressure from the air temperature. Magnus formulation (Murray, 1967) is recommended by the China Meteorological Administration for its simplicity.

$$Log10e_{sw} = \frac{7.5T}{T + 237.3} + 0.7858 \qquad \text{(eq.30)}$$

where T (°C) is the daily average air temperature:

$$T = \frac{T_{\max} + T_{\min}}{2} \qquad \text{(eq. 31)}$$

where, T_{max} is the maximum daily air temperature (°C) and T_{min} is the minimum daily air temperature (°C).

Elimination the logarithm in the left hand side of eq. 30 results in:

$$e_{sw} = 10^{\frac{7.5T}{237.3+T} + 0.7858} \qquad \text{(eq. 32)}$$

Note that the unit of vapour pressure in Magnus formulation is hPa while that required by PEARL is kPa.

Wind speed at 2 m height

The average wind speed available is measured at 10 m above the ground surface. Measured wind speed is adjusted to the standard height of 2 m using the recommended FAO approach (Allen *et al.,* 1998):

$$u_2 = \frac{4.87u_z}{\ln(67.8z - 5.42)} \qquad \text{(eq. 33)}$$

where, u_2 (m s^{-1}) is the wind speed at 2 m above ground surface, u_z (m s^{-1}) is the measured wind speed at z m above ground surface and, z (m) is the height of measurement above ground surface. In the PERAP project the value of z is 10 m because wind speed was measured at 10 m.

Others

Values of minimum and maximum air temperature, precipitation, sunshine duration and relative humidity (Table 23) were downloaded from the website of the China Meteorological Data Sharing Service System and used in the PEARL input file for meteorological data after transformation of unit if necessary.

Table 23

Non calculated meteorological input data of the PEARL model

Parameter	Description
minimum air temperature	observed at 1.5m above ground (°C)
maximum air temperature	observed at 1.5m above ground (°C)
precipitation	precipitation from 20 p.m. of the last day to 20 p.m. (mm)

10.2.6 Meteorological stations

10.2.6.1 Meteorological data for groundwater scenarios for dry land north of the Yangtze River

Table 24 gives an overview of the meteorological stations of which data is used and the period for which meteorological data was available.

Table 24
Meteorological stations of the scenario locations and the period for which data was available

Scenario location	Station number	Years
Xinmin	54333	1987 - 2001
Urumchi	51463	1970 – 2001
Tongxin	53810	1970 – 2001
Weifang	54842	1970 – 2001
Shangqiu	58005	1970 – 2001
Wugong	57034	1970 – 2001

For one pesticide application per year, 26 years of meteorological data are needed. These 26 years include 6 warming up years and 20 years for calculation of the 90th percentile. To enable the option of 1 application per 2 or 3 years meteorological data of respectively 46 and 66 years are needed. This time series includes 6 years for warm-up and respectively 2 or 3 times a weather sequence of 20 years for calculation of the 90th percentile.

For Urumchi, Tongxin, Weifang, Shangqiu and Wugong 26 years of meteorological data were available. Xinmin was the only scenario location with only 15 years of meteorological data available. An extra 11 years of meteorological data was needed for Xinmin to extent the data series to 26 years. It was decided to repeat the available data, but to skip for the first 11 years, the 4 years containing the most extreme (2 lowest and 2 highest) annual average precipitation amounts (1989, 1991, 1994, 2001).

For each scenario location, the 66 years weather files were constructed as follows:
- Delete the years 1970-1975.
- Extend the time series to 66 years: It was decided to repeat the 20 years weather sequence 1982-2001 twice.
- Renumbering of the data years: It was decided to start renumbering from 1901. When doing so, problems are encountered for 'leap' years. If a record for the 29-th of February is in a non-leap year, then this record was omitted. If a record for the 29-th of February is not available for a leap year, the record for the 28-th of February was duplicated.

10.2.6.2 Meteorological data for groundwater and surface water scenarios for paddy rice south of the Yangtze River

Annex F explains in detail how the meteorological stations for the groundwater and surface water scenarios for paddy rice in the scenario zones Yangtze River Basin and South China were selected. For the selected meteorological stations Nangchang (Yangtze River Basin) and Shaoguan (South China, meteorological data of Shaoguan is used for scenario location Lianping) the 20 wettest years are selected from the period 1970-2009 (see Annex F). These years are put in a random order to create a 20 year meteorological file. Furthermore six years are randomly selected from the 20 wettest years to be used as warm-up years. For one pesticide application per year, 26 years of meteorological data are needed. These 26 years include 6 warming up years and 20 years for calculation of the 90th percentile. To enable the option of 1 application per 2 or 3 years meteorological data of respectively 46 and 66 years are needed. This time series includes 6 years for warm-up and respectively 2 or 3 times a weather sequence of 20 years for calculation of the 90th percentile.

For each scenario location, the 66 years weather files were constructed as follows:
- Select 20 wettest years (highest amount of annual precipitation) from the period 1970-2009 and put these 20 years in a random order.
- Randomly select 6 years from the 20 wettest years to be used as 6-year warm-up period.

- Extend the time series to 66 years: It was decided to repeat the 20 years weather sequence twice (so 6 warm-up years + 3 times the 20 wettest years in random order)
- Renumbering of the data years: It was decided to start renumbering from 1901. When doing so, problems are encountered for 'leap' years. If a record for the 29-th of February is in a non-leap year, then this record was omitted. If a record for the 29-th of February is not available for a leap year, the record for the 28-th of February was duplicated.

Table K.1 and K.2 in Annex K give per meteorological station an overview of the years used to construct the 26 year weather file and the adjustments needed to handle leap years.

10.2.7 Irrigation

10.2.7.1 Irrigation data for groundwater scenarios for dry land north of the Yangtze River

Only data on the periods of irrigation were found (Annex L) not on the amounts of irrigation. It was therefore decided to assume that irrigation is applied once a week on a fixed day during crop growth. The PEARL-SWAP model calculates the irrigation amount in such a way that the required amount of water brings the soil water content in the root zone back to field capacity. However, irrigation is applied only if the amount required exceeded 15 mm.

10.2.7.2 Irrigation data for groundwater and surface water scenarios for paddy rice south of the Yangtze River

For the groundwater and surface water scenarios for paddy rice south of the Yangtze River, the automatic irrigation option in the PEARL/SWAP model is used to calculate irrigation as follows. A pressure head threshold value h_{min} (cm) and a corresponding depth for which the threshold value is valid (z_{sensor}) are specified (Kroes *et al.*, 2008). Irrigation is applied whenever the threshold is exceeded:

$$h_{sensor} \leq h_{min} \qquad \text{(eq. 34)}$$

where h_{sensor} is the threshold value for pressure head at depth z_{sensor}.

The depth of the sensor z_{sensor} is set to zero cm and h_{min} is defined as function of development stage (0-1). The values used for Nanchang and Lianping are given in Tables 25 and 26 respectively. Whenever the pressure head threshold values are exceeded the model automatically gives an amount of irrigation (I in mm) which is specified by the user. The calibrated amounts of irrigation used for the Nanchang and Lianping scenario are given in Tables 25 and 26 respectively (as function of development stage).

Table 25

Values for h_{min} and the amount of irrigation (I) as function of development stage of the two different crop cycles in the Nanchang scenario

Date 1st crop cycle	Crop age (d)	Development stage (0-1)	Date 2nd crop cycle	Crop age (d)	Development stage (0-1)	event	h_{min} (cm)	I (mm)
22-Apr	1	0.0000	11-Jul	1	0.0000	Planting rice in paddy field (flooded paddy)	2.5	85
06-May	15	0.1765	25-Jul	15	0.1471	Last day flooded period. Irrigation is stopped 5 days before tillering	2.5	85
11-May	20	0.2353	30-Jul	20	0.1961	Start tillering period (drained paddy)	-10000.0	0
20-May	30	0.3412	08-Aug	29	0.2843	Last day tillering period (drained paddy)	-10000.0	0
21-May	31	0.3529	09-Aug	30	0.2941	Start flooding after tillering (flooded paddy)	2.5	85
05-Jul	80	0.9412	15-Oct	97	0.9510	Last day of flooded paddy. Irrigation is stopped 5 days before harvest	2.5	85
10-Jul	85	1.0000	20-Oct	102	1.0000	Harvest (drained paddy)	-10000.0	0

Table 26

Values for h_{min} and the amount of irrigation (I) as function of development stage of the two different crop cycles in the Lianping scenario

Date 1st crop cycle	Crop age (d)	Development stage (0-1)	Date 2nd crop cycle	Crop age (d)	Development stage (0-1)	event	h_{min} (cm)	I (mm)
13-Apr	1	0.0000	16-Jul	1	0.0000	Planting rice in paddy field (flooded paddy)	2.5	85
27-Apr	15	0.1596	30-Jul	15	0.1500	Last day flooded period. Irrigation is stopped 5 days before tillering	2.5	85
02-May	20	0.2128	04-Aug	20	0.2000	Start tillering period (drained paddy)	-10000.0	0
11-May	29	0.3085	13-Aug	29	0.2900	Last day tillering period (drained paddy)	-10000.0	0
12-May	30	0.3191	14-Aug	30	0.3000	Start flooding after tillering (flooded paddy)	2.5	85
10-Jul	89	0.9468	18-Oct	95	0.9500	Last day of flooded paddy. Irrigation is stopped 5 days before harvest	2.5	85
15-Jul	94	1.0000	23-Oct	100	1.0000	Harvest (drained paddy)	-10000.0	0

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Timing of h_{min} and I before tillering and harvest (5 days before) were chosen in such a way that it was tried to prevent runoff overflow of irrigation water due to controlled drainage. Chinese experts indicated that it is normal agricultural practice in China that farmers stop irrigation several days before the tillering and harvest in order to drain the water from the field by percolation.

10.2.8 Crop related aspects

10.2.8.1 Interception of water on the plant canopy

For agricultural crops and grassland, PEARL/SWAP calculates the interception following Von Hoyningen-Hüne (1983) and Braden (1985):

$$P_i = a_{\text{int}} LAI \left(1 - \frac{1}{1 + \frac{b_{\text{int}} P_{gross}}{a_{\text{int}} LAI}} \right) \quad \text{(eq. 35)}$$

Where P_i is the intercepted precipitation (cm d^{-1}), LAI is the leaf area index, P_{gross} is the gross precipitation (cm d^{-1}), a_{int} is an empirical coefficient (cm d^{-1}) and b_{int} represents the soil cover fraction (-). For increasing amounts of precipitation, the amount of intercepted precipitation asymptotically reaches the saturation amount $a_{int}LAI$ (Kroes *et al.*, 2008). Coefficient a_{int} should be determined experimentally, however for PERAP we assume a_{int} = 0.025 cm d^{-1}, which is a proper estimate for ordinary agricultural crops (Kroes *et al.*, 2008). The coefficient b_{int} is estimated by PEARL/SWAP as $b_{int} = LAI/3$. The method of Von Hoyningen-Hüne Braden is based on daily precipitation values.

10.2.8.2 Interception of pesticides on the plant canopy

The Chinese risk managers decided that spray interception data as used by FOCUS (2001) should be used for the Chinese groundwater scenarios north of the Yangtze river. These spray interception data are specified in Table 27, expressed as percentage of the applied dose (areic mass), for the different crop development stages. This table is taken from Anonymous (2011). For the groundwater and exposure scenarios for pesticide use in rice south of the Yangtze river the Chinese risk managers preferred spray interception data based on data of the Agro-database of China Meteorological Data Sharing Service System and field experiments. The resulting spray interception data are specified in Table 28, expressed as percentage of the applied dose (areic mass), for the different crop development stages.

Table 27
Spray interception (% of applied dosage) by crop type and growth stage (BBCH) (after Anonymous, 2011).

BBCH code*	00–09	10–19	20–29	30-39	40–89	90–99
Beans	0	25	40	40	70	80
Cabbage	0	25	40	40	70	90
Carrots	0	25	60	60	80	80
Cotton	0	30	60	60	75	90
Grass	0	40	60	60	90	90
Grass, established	90	90	90	90	90	90
Linseed	0	30	60	60	70	90
Maize	0	25	50	50	75	90
Oilseed rape	0	40	80	80	80	90
Onions	0	10	25	25	40	60
Peas	0	35	55	55	85	85
Potatoes	0	15	50	50	80	50
Soybean	0	35	55	55	85	65
Cereals	0	25	50	70	90	90
Strawberries	0	30	50	50	60	60
Sugar beets	0	20	70	70	90	90
Sunflower	0	20	50	50	75	90
Tobacco	0	50	70	70	90	90
Tomatoes	0	50	70	70	80	50

*) 00-09 is bare soil until emergence, 10-19 is leaf development, 20-29 is tillering, 30-39 is stem elongation, 40-89 is flowering and 90-99 is senescence to ripening.

Table 28

Spray interception (% of applied dosage) for rice cultivation in the scenario location Nanchang and Lianping as function of growth stage (BBCH) (the data was provided by Dr. Li Wenjuan, CAAS).

		Nursing*	Transplanting & recovering	Tillering	Stem elongation	Flowering	Senescence to ripening
	BBCH	0-9	10-19	20-29	30-39	40-89	90-99
Nanchang 1st crop cycle	period	1 Jan – 21 Apr	22 Apr –27 Apr	28 Apr –17 May	18 May – 1 Jun	2 Jun - 8 Jun	9 Jun - 10 Jul
	Interception (fraction of the applied dose)	0	0.25	0.50	0.70	0.90	0.90
Nanchang 2nd crop cycle	period	21 Oct – 31 Dec**	11 Jul– 16 Jul	17 Jul – 08 Aug	09 Aug – 24Aug	25 Aug - 3 Sep	4 Sep - 20 Oct
	Interception (fraction of the applied dose)	0	0.25	0.50	0.70	0.90	0.90
Lianping 1st crop cycle	period	1 Jan – 12 Apr	13 Apr – 19 Apr	20 Apr – 10 May	11 May – 25 May	26 May – 2 Jun	3 Jun - 15 Jul
	Interception (fraction of the applied dose)	0	0.25	0.50	0.70	0.90	0.90
Lianping 2nd crop cycle	period	24 Oct – 31 Dec**	16 Jul - 21 Jul	22 Jul – 13 Aug	14 Aug – 28 Aug	29 Aug – 6 Sep	7 Sep - 23 Oct
	Interception (fraction of the applied dose)	0	0.25	0.50	0.70	0.90	0.90

* For the Nanchang and Lianping scenario it is assumed that nursing of the rice plants is done in another field. This means that up to the date of transplanting, bare soil and consequently zero interception is assumed.

** Bare soil and consequently zero interception is assumed for the period between the harvest of the second rice crop and 31 December.

10.2.8.3 Dissipation of pesticides on the plant canopy and uptake of pesticides by the plant.

The wash-off factor is set to 0.1 mm^{-1} (EFSA, 2012). Analogous to FOCUS (2000) the uptake factor of pesticides by plants is set to 0.0. It is advised to select the canopy process option 'Lumped' in the PEARL model and to set the half-life at the crop surface at 10 days (EFSA, 2012).

10.2.9 Calibration

10.2.9.1 Introduction

For the groundwater scenarios in dry land north of the Yangtze River calibration of model parameters was not necessary because all model parameters were derived from actual data. For the groundwater and surface water scenarios for paddy land south of the Yangtze River calibration of several SWAP/PEARL model parameters was necessary. This section describes the principles of the calibration and the requirements for this calibration as defined by experts of Alterra, CAAS and ICAMA. Furthermore the compliance of the developed scenarios to the requirements is discussed.

10.2.9.2 Principles

1. Simulation period 1901-1926
2. Meteorological data are derived by selecting the 20 wettest years from the meteostations Nanchang en Lianping (Section 10.2.6).
3. The soil hydraulic parameters were calculated as specified in Section 10.2.1. The value of the saturated conductivity of the plough pan was calibrated.
4. The bottom boundary condition was calculated according eq. 24.
5. Surface runoff or runoff overflow occurs when the water storage in the ponding layer exceeds the critical depth of $Z_{pnd,threshold}$ and is calculated according eq. 25.

10.2.9.3 Requirements

The following requirements have been defined for the parameterization of the hydrological situation of Nanchang and Lianping:

1. According to experts of CAAS and ICAMA a traditional water depth regime (Figure 25) is common practice in China. Therefore a traditional water depth regime for the flooded paddy layer as given in Figure 25 will be simulated. The minimum water depth of the flooded paddy is 1 a 2 cm. The maximum depth is 10 cm. During the tillering period, the flooded paddy layer is allowed to drain (controlled drainage). In Tables 29 and 30 significant dates for crop paddy layer management are given.
2. Irrigation is approx. 1460 mm/yr (1200-1600 mm/yr; because of uncertainty). This is based upon the information given by Prof. Zhu Defeng (China National Rice Institute). Early/late rice crop needs about 300-500 m^3/mu (= 450 - 750 mm) of irrigation and sandy soils need about 50 – 100 mm more irrigation than clayey soils per growing cycle.

To estimate the irrigation demand for rice scenarios the 90^{th} percentile value of 450 – 700 mm irrigation was taken while assuming uniform distribution and 2 rice crop cycles:
900 + 0.9(1500-900) = 1460 mm irrigation on annual basis. In case of sandy soil 2*75 mm was added to this amount.

1. Runoff: approximately one runoff overflow event per month during the growing season (controlled drainage is excluded here) (personal communication Prof. Zhu Defeng, China National Rice Institute).
2. Runoff overflow events only occur due to precipitation.
3. ET equals potential ET in the growing season
4. Annual ET: 1000 mm/yr (expert judgement Alterra)
5. The groundwater level fluctuates between 50-150 cm below soil surface (personal communication Prof. Zhu Defeng, China National Rice Institute).
6. The percolation is 2000mm/ yr (1700-2300 mm/yr; because of uncertainty). This is based upon a simple water balance calculation (Table 31) and data from literature (Table 32).

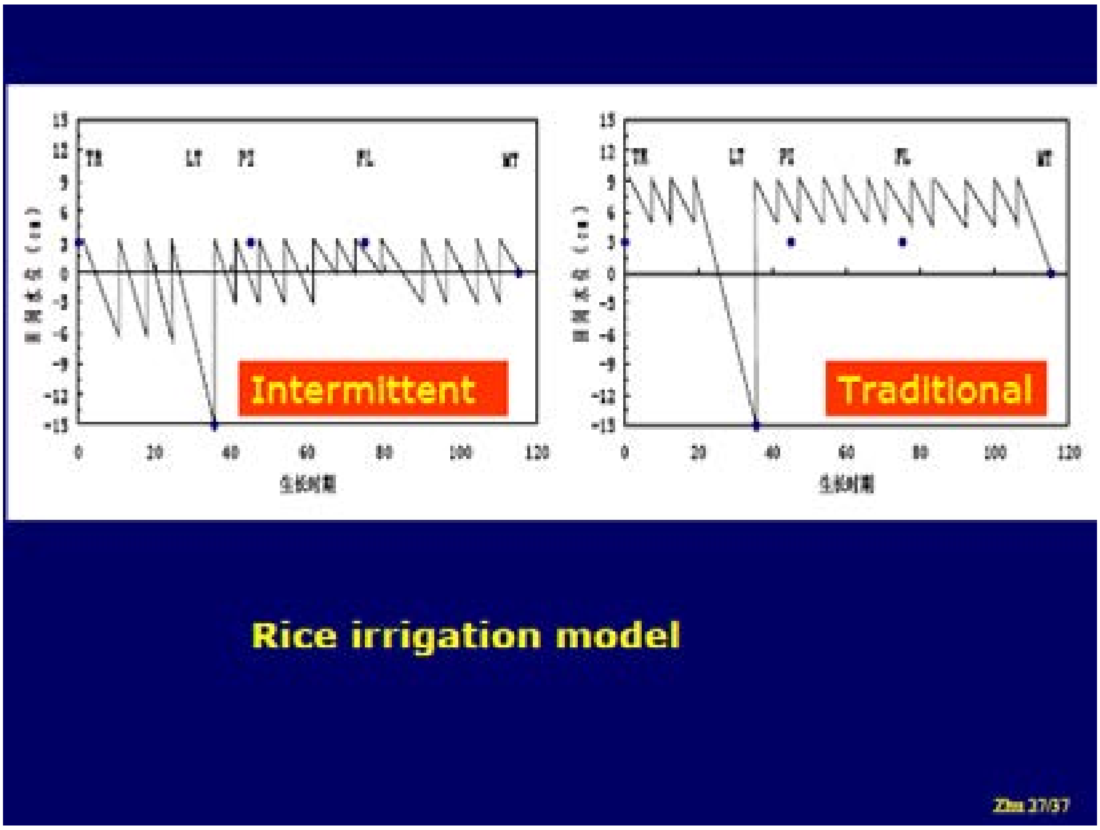

Figure 25 *Irrigation practices of paddy rice fields in China (from Prof. Zhu Defeng, China National Rice Institute).*

Table 29
Significant dates for crop and paddy flooding management for the Nanchang scenario

Day in Year	Description	Crop age (d)
22 April	Start crop 1, start flooded paddy (depth is 1-10 cm). Before 22 April no paddy flooding occurs.	1
11 May	Start tillerage, drained paddy	20
21 May	End tillerage, start flooded paddy	30
10 July	End flooded paddy (remove barrier in outlet) and harvest	80
11 July	Start crop 2, start flooded paddy (depth is 1-10 cm)	1
30 July	Start tillerage, drained paddy	20
09 August	End tillerage, start flooded paddy	30
20 October	End flooded paddy (remove barrier in outlet) and harvest	102

Table 30
Significant dates for crop and paddy flooding management for the Lianping scenario

Day in Year	Description	Crop age (d)
13 April	Start crop 1, start flooded paddy (depth is 1-10 cm). Before 13 April no paddy flooding occurs.	1
02 May	Start tillerage, drained paddy	20
12 May	End tillerage, start flooded paddy	30
15 July	End flooded paddy (remove barrier in outlet) and harvest	94
16 July	Start crop 2, start flooded paddy (depth is 1-10 cm)	1
4 August	Start tillerage, drained paddy	20
14 August	End tillerage, start flooded paddy	30
23 October	End flooded paddy (remove barrier in outlet) and harvest	100

Table 31

Rough calculation of the annual water balance of a paddy rice field in China (South of Yangtze River)

In (mm/year)		Out (mm/year)	
90th percentile precipitation	~ 2000	evapotranspiration	~ 1000
Irrigation	~ 1400	Runoff overflow (guess 20 mm/month, so about 200 mm/year)	~ 200
		Flow through bunds	ignored
		percolation	?
Total	~ 3400		~ 1200 + ?

? = ~ 2200 mm

Table 32

Information from literature on percolation values (mm/d) under a flooded paddy rice field

Percolation under a flooded paddy rice field	References
5 – 46 mm/d	Walker and Rushton, 1984 Compilation of literature from period 1965 – 1981
0.2 – 5 mm/d - Philippines. well puddled	Wopereis *et al*., 1992
3 – 8 mm/d - Taiwan. well puddled	Chen and Liu, 2002
2.7 mm/d - well puddled	Tuong *et al*., 1994
280 mm/d - 3 year old paddy 7.9 mm/d - 20 year old paddy 1.6 mm/d - 100 year old paddy	Janssen & Lennartz, 2007 Younger paddies show more percolation because the hard pan/plow sole is not well developed
Zanghe Irrigation System, Hubei, China 4.0 - 6.0 mm/d - Field experiment 1.6 – 2.8 mm/d - Farmers' fields 4.0 – 8.0 – irrigation system level Shimen, Zhejiang, China – 6.0 mm/d	 Cabangon *et al.* (2001, 2004) Dong *et al.* (2004), Loeve *et al.* (2004a,b) Dong *et al.* (2004), Loeve *et al.* (2004a,b) Cabangon *et al.* (2001, 2004)
12.5 – 32.8 mm/d – experiments Guimba, Philippines 5.2 – 7.0 mm/d - Muñoz, Philippines 1.1 – 4.4 mm/d - Muñoz, Philippines 0.3 – 2.0 mm/d – Talavera, Philippines 0.3 – 2.0 mm/d – experiments, San Jose, Philippines	Tabbal *et al.* (2002) Tabbal *et al.* (2002) Belder *et al.* (2004) Tabbal *et al.* (2002) Tabbal *et al.* (2002)
1-2 mm/d	Expert judgment of Prof. Zhu Defeng (China National Rice Institute). Based upon intermittent irrigation scheme (= water saving irrigation scheme)

10.2.9.4 Results calibration of PEARL/SWAP parameters

Bottom boundary flux parameters

Coefficients a_{bot} and b_{bot} in eq. 20 were calibrated manually in order to fulfil the requirements given in Section 10.2.9.3 Figure 26 shows the calibrated bottom boundary flux as function of groundwater level, for the two locations.

For Nanchang the calibrated value for a_{bot} was -6.025 and the calibrated value for b_{bot} was -0.0236. For Lianping the calibrated value for a_{bot} was -10.0 and the calibrated value for b_{bot} was -0.0436.

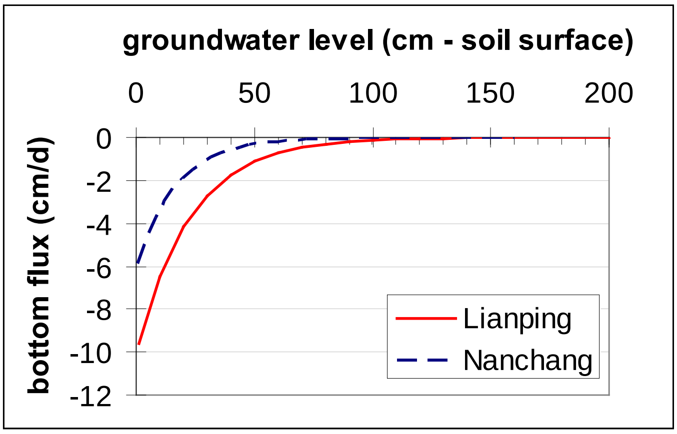

Figure 26 *Calibrated bottom flux as a function of the groundwater level for the groundwater scenarios for land use paddy rice.*

Surface runoff from a drained paddy field and runoff overflow from a flooded paddy field
Both the resistance parameter (γ) and is an exponent (β) of the empirical relation of eq. 21 are calibrated manually. For both Nanchang and Lianping the same values of γ and β are used.
The resistance parameter γ was set to 0.1 day. This is a very low value necessary in order to guarantee a quick response of runoff. Calibrated values of γ = *0.1* and β = 4 are also used for the calculation of surface runoff from the drained paddy for locations Nanchang and Lianping, because the PEARL/SWAP model does not provide the possibility to use time depended values of γ and β. This means that surface runoff of the drained paddy fields might be overestimated in periods the paddy field is not flooded.

Saturated conductivity of plough pan/ hard pan
The saturated conductivity of the plough pan/hard pan is the most important calibration parameter determining the amount of percolation. This parameter was calibrated manually. For Nanchang a value of 0.118 cm/day was calibrated and for Lianping a value of 0.102 cm/day was calibrated. These values are in the range of those found in literature (Table 33).

Table 33
Values of the saturated conductivity of the plough pan/hard pan found in literature

Value	Source	information
0.03 – 0.122 cm/d	Wopereis *et al.*, 1994	Measured in the field
0.034 – 0.083 cm/d	Chen and Liu, 2002	Measured in the field
Ca 0.26 cm/d	Aimruan and Amin, 2009	Calculated according to pedo- transfer function for saturated hydraulic conductivity of lowland paddy soils, determined by the authors

10.2.9.5 Compliance to the requirements
The scenarios have been calibrated according to the eight requirements as described in Section 10.2.9.3. The compliance of the calibrated scenarios to the requirements is described for each requirement in Table 34.

The simulation results for the year 1919 (about a 90th percentile weather year with respect to the number of runoff overflow events) are given for Nanchang in Figures 27 and 28 for crop cycle 1 and 2, respectively. The simulation results for the year 1915 (about a 90th percentile weather year with respect to the number of runoff overflow events) are given for Lianping in Figures 29 and 30 for crop cycle 1 and 2, respectively.

The average annual water balances over 20 relevant years (1907 – 1926) are given in Table 35 and the annual balances of the 90th percentile percolation years are given in Table 36. In Table 37 the number of runoff overflow events are given for each simulated year (period 1907- 1926, so without the first 6 warm-up years) for each location and crop cycle number.

Table 34

Compliance of the calibrations of the model to the requirements

Req.	Compliance	Conclusion
1	After the start of the paddy layer the saw tooth pattern due to the irrigation management starts in accordance with the traditional water management regime (see Figure 25). The paddy layer fluctuates between 1- 11 cm. Sometimes the paddy layer is not entirely filled up to 10 cm to reduce the risk of a runoff overflow event due to irrigation only (see requirement 4).	Okay (for Nanchang and Lianping)
2	The annual irrigation for Nanchang is ca. 1595 mm/yr and for Lianping ca. 1582 mm/yr.	Okay
3	Runoff overflow of the paddy water layer as result of precipitation excess occurs on average (period 1907-1926) 5.9 times a year for Nanchang (6 months of growing season). Runoff overflow of the paddy water layer as result of precipitation excess occurs on average (period 1907-1926) 6.8 times a year for Lianping (6 months of growing season). The 90^{th} percentile year[4] contains 8 runoff overflow events for Nanchang and 9 for Lianping. See also Table 37 for the number of runoff overflow events for each simulated year. The average annual water flux (period 1907-1926) related to runoff overflow (during the growing season and excluding controlled drainage) is 244 mm for Nanchang and 250 mm for Lianping. Runoff overflow of the paddy water layer as result of precipitation excess occurs on average (period 1907-1926) 14 days a year (in total 5.9 events) for Nanchang and 17 days a year in total (6.8 events) for Lianping.	Okay for first crop cycle in Nanchang and Lianping, but lower than required for the second crop cycle in both locations See Table 37 for average number of runoff overflow events
4	Runoff overflow should only occur in growing season due to precipitation excess	Runoff overflow due to controlled drainage and or surface runoff happens
5	In the growing season ET is equal to the potential ET. The variation of ET due to seasonal fluctuation of radiation and precipitation is low. Soil evaporation is reduced when the crop starts transpiring.	Okay
6	The annual ET is around 1000 mm for Nanchang and Lianping	Okay
7	During the growing season the groundwater level fluctuates between 65 en 226 cm – surface level below soil surface for Nanchang and between 50 and 203 cm – surface level for Lianping.	Okay, but slightly lower than required
8	The average annual percolation (1907-1926) is 1895 mm/yr for Nanchang and 1815 mm/yr for Lianping. The annual percolation for 90^{th} percentile years is 1959 mm and 1906 mm for Nanchang and Lianping, respectively. The annual water balance for the 90^{th} percentile with respect to the percolation is given in Table 36.	Lower than required

4 The 90th percentile has been selected by ranking the annual number of overflow events and selecting the 90th percentile year.

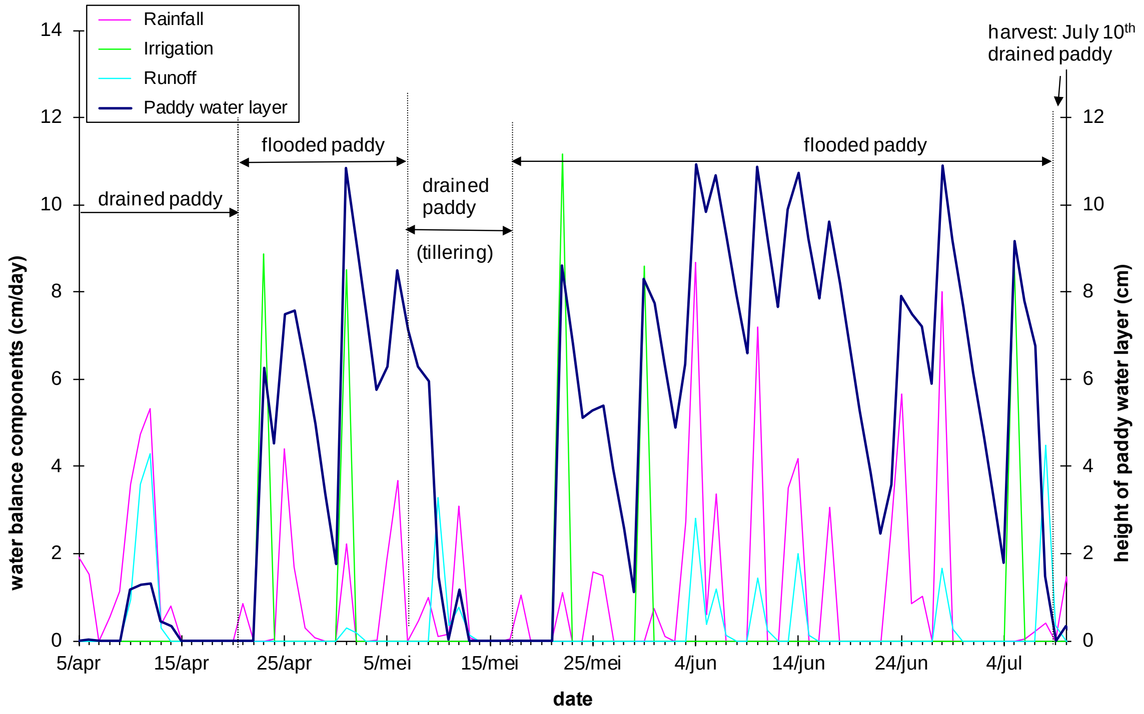

Figure 27 *Simulation result of SWAP for Nanchang for 1919 and crop cycle 1. Precipitation, Irrigation and Runoff (all types of runoff) are given in cm/day. The depth of the paddy water layer is given in cm. 1919 is one of the years in which 8 runoff overflow events occur (about 90th percentile).*

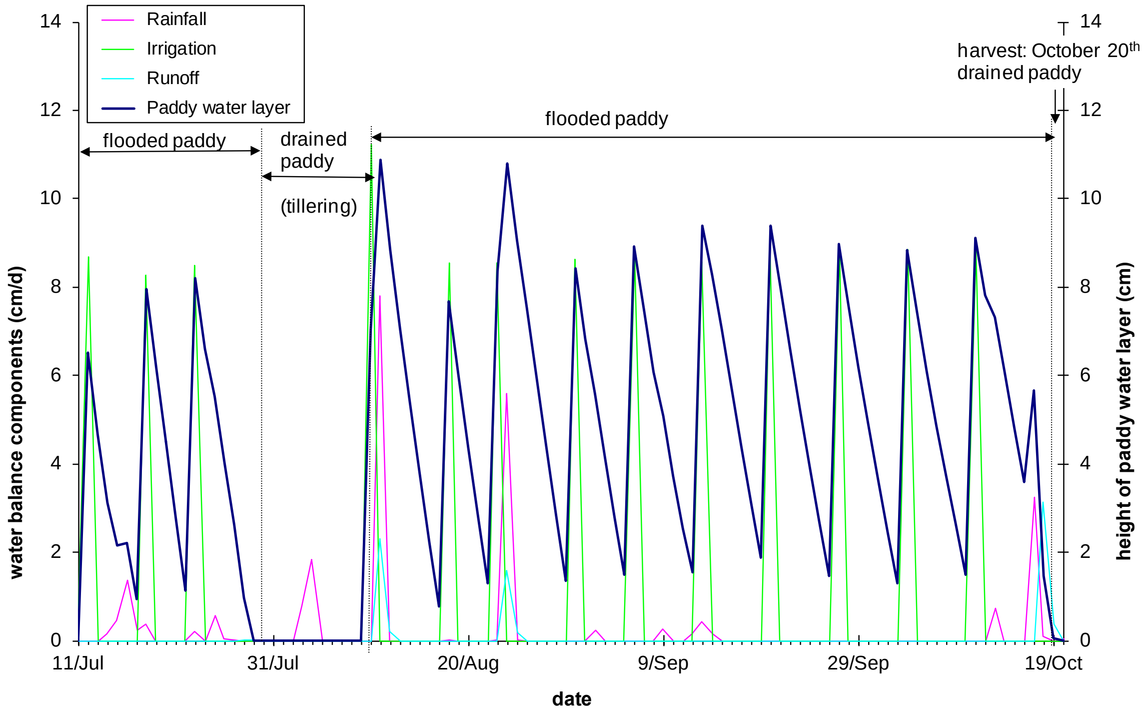

Figure 28 *Simulation result SWAP Nanchang for 1919 and crop cycle 2. Precipitation, Irrigation and Runoff (all types of runoff) are given in cm/day. The depth of the paddy water layer is given in cm. 1919 is one of the years in which 8 runoff overflow events occur (about 90th percentile).*

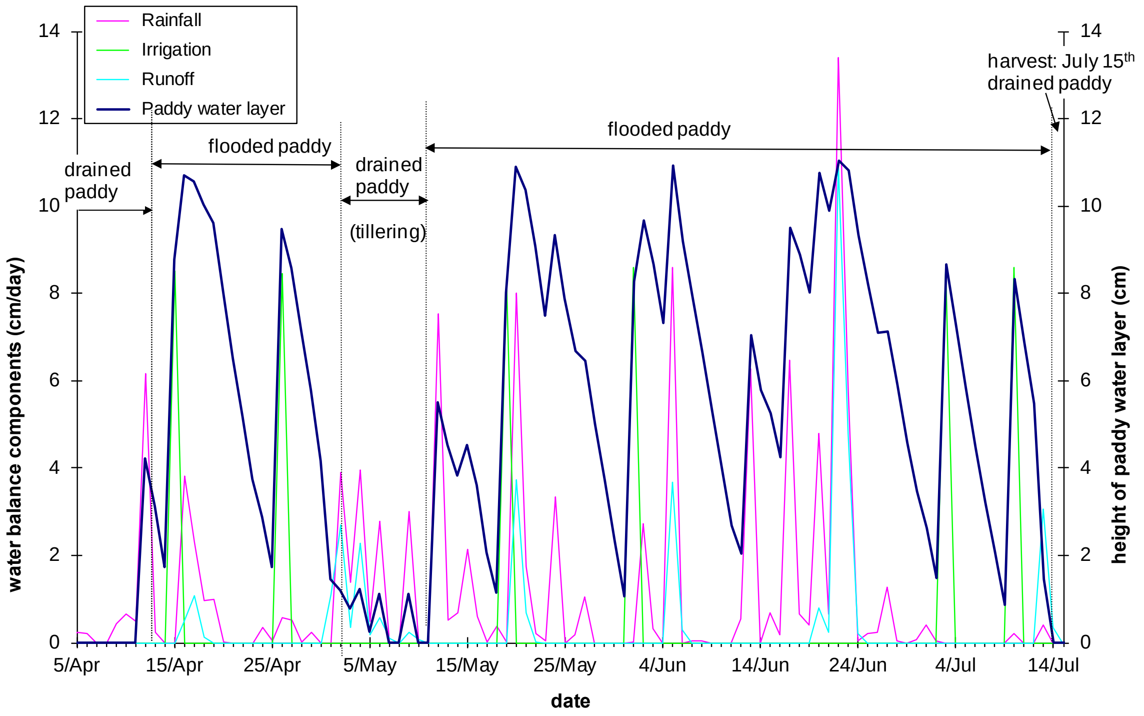

Figure 29 *Simulation result of SWAP for Lianping for 1915 and crop cycle 1. Precipitation, Irrigation and Runoff (all types of runoff) are given in cm/day. The depth of the paddy water layer is given in cm. 1915 is one of the years in which 9 runoff overflow events occur (90th percentile).*

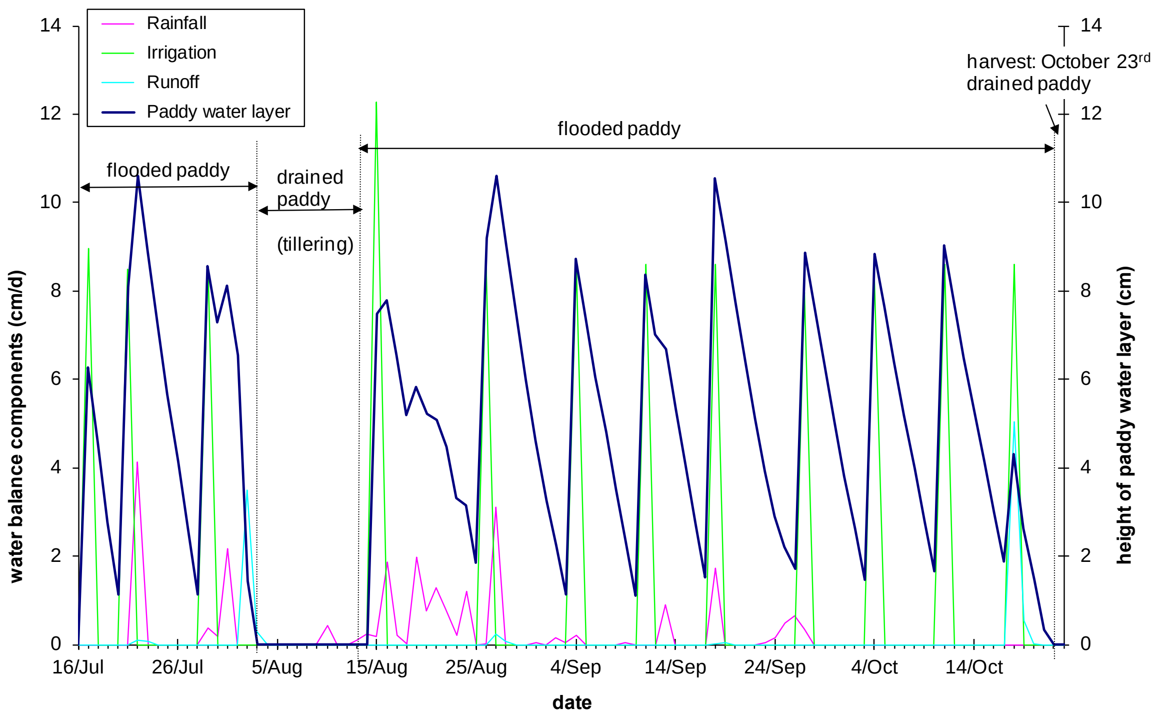

Figure 30 *Simulation result SWAP Lianping for 1915 and crop cycle 2. Precipitation, Irrigation and Runoff (all types of runoff) are given in cm/day. The depth of the paddy water layer is given in cm. 1915 is one of the years in which 9 runoff overflow events occur (90th percentile).*

Table 35

Average annual water balances of the period 1907 – 1926 (warm up years not included).

	Nanchang	Lianping
In (mm):		
Precipitation	1860	1815
Irrigation	1595	1582
Total in:	3455	3397
Out (mm):		
Runoff[5]	586	537
Percolation	1903	1855
ET	966	1095
Total out:	3455	3487

Table 36

Annual water balances of 90th percentile years with respect to percolation

	Nanchang	Lianping
Year[6]:	1918	1923
In (mm):		
Precipitation	1763	2038
Irrigation	1644	1486
Total in:	3407	3524
Out (mm):		
Runoff	492	600
Percolation	1965	1906
ET	941	1001
Total out:	3398	3507
Storage (mm):	9	17

Table 37

Number of runoff overflow events as result of precipitation excess per year*

year	Crop cycle	Number of runoff events in growing season		year	Crop cycle	Number of runoff events in growing season	
		Nanchang	Lianping			Nanchang	Lianping
1907	1	5	5	1917	1	3	4
	2	1	2		2	1	3
1908	1	4	2	1918	1	2	4
	2	1	3		2	3	2
1909	1	4	4	1919	1	6	6
	2	1	1		2	2	2
1910	1	4	4	1920	1	2	2
	2	2	2		2	1	2
1911	1	2	6	1921	1	6	5
	2	0	1		2	2	3
1912	1	7	3	1922	1	6	7
	2	1	2		2	1	1
1913	1	3	7	1923	1	5	5
	2	1	2		2	0	2
1914	1	5	4	1924	1	5	5
	2	1	2		2	2	2
1915	1	3	5	1925	1	7	5
	2	0	4		2	2	3
1916	1	5	5	1926	1	4	8
	2	5	3		2	3	3

* Note that runoff overflow events due to controlled drainage and surface runoff events are not taken into account in Table 37.

[5] Three types of runoff may occur: (1) surface runoff before growing season (no paddy rice crop), (2) runoff due to controlled drainage (i) before tillering stage and (ii) at end of each paddy rice crop cycle , (3) a runoff overflow event due to excess rainfall. This term represents the sum of all types of runoff.

[6] The year has been selected by ranking the annual percolation of the last 20 years (1907 – 1926) and select the 90th percentile year.

- Average number of runoff overflow events as result of precipitation excess for Nanchang: 88/20=4.4 for the first crop cycle, 30/20=1.5 for the second crop cycle
- Average number of runoff overflow events as result of precipitation excess for Lianping: 106/20=5.3 for the first crop cycle, 45/20=2.3 for the second crop cycle

10.2.9.6 Conclusions

It can be concluded that the developed scenarios comply with the requirements as formulated in during the PERAP workshops. However:

a) the number of runoff events in the second crop cycle is low. Increasing the number of runoff events is not feasible as these are directly related to the frequency of the precipitation events.
b) The average annual percolation flux is lower than required. One can argue though that the requirements represent a 90th percentile year. For the 90th percentile with respect to percolation the percolation flux is just within the formulated range.

10.2.9.7 Artefact of the used models

The occurrence of a paddy water layer depends on the crop cycle of the rice. The paddy water layer starts no earlier than one day after emergence and ends after the rice harvest. In between, there is a tillering period in which the paddy layer is temporally removed.

Due to the fact that in the SWAP/PEARL model irrigation is coupled to the crop cycle (irrigation parameters should be entered as function of development stage of the crop) it is not possible to set up a water layer on field on the day of transplanting (22 April and 22 July). This is illustrated in Figure 31. This Figure shows that the height of the water layer is zero on the April 22nd and has a value of about 6 cm on April 23rd. These are the values valid at the end of that particular day. This means that for April 23rd the height of the paddy water layer on the field is still zero at the beginning of the day (00:00 hours). This is an important fact needed to explain a second artefact of the model.

In the PEARL model substances can be applied before or after emergence of the crop. Substance are in principle applied to the soil (and partly to the crop), however, if a paddy layer exist, the substance is applied to the paddy water layer. A paddy water layer is defined to exist when (1) the crop is present and (2) the paddy water layer is greater than zero at the beginning of the day.

In case a water layer is present, the concentration in the paddy water layer is updated for each PEARL timestep[7]. However, for computational stability of the model, the substance in the water layer is assigned to the upper soil layer and runoff and infiltration mass fluxes from the water layer are set to zero, in case (1) the water layer is decreasing and (2) the water layer thickness at the start of the day is smaller than 1 mm or (3) the water layer thickness decreases below 1 mm during the day.

This means that if a substance is applied on the day of transplanting or one day after transplanting the model assumes that 100% of the substance is penetrated into the soil. If a runoff overflow events happens shortly after, the runoff overflow water will not contain the substance. In case calculations are performed with a pesticide label specifying application of the pesticide on the day of transplanting or one day after, it is advised to perform a second run applying the pesticide two days after application (for evaluation of risks of pesticide use in aquatic ecosystems in ponds) and use the highest PEC of the two runs.

[7] This can occur outside the crop season, as the definition of occurrence is: the water layer thickness at the beginning or the end of the day is greater than zero.

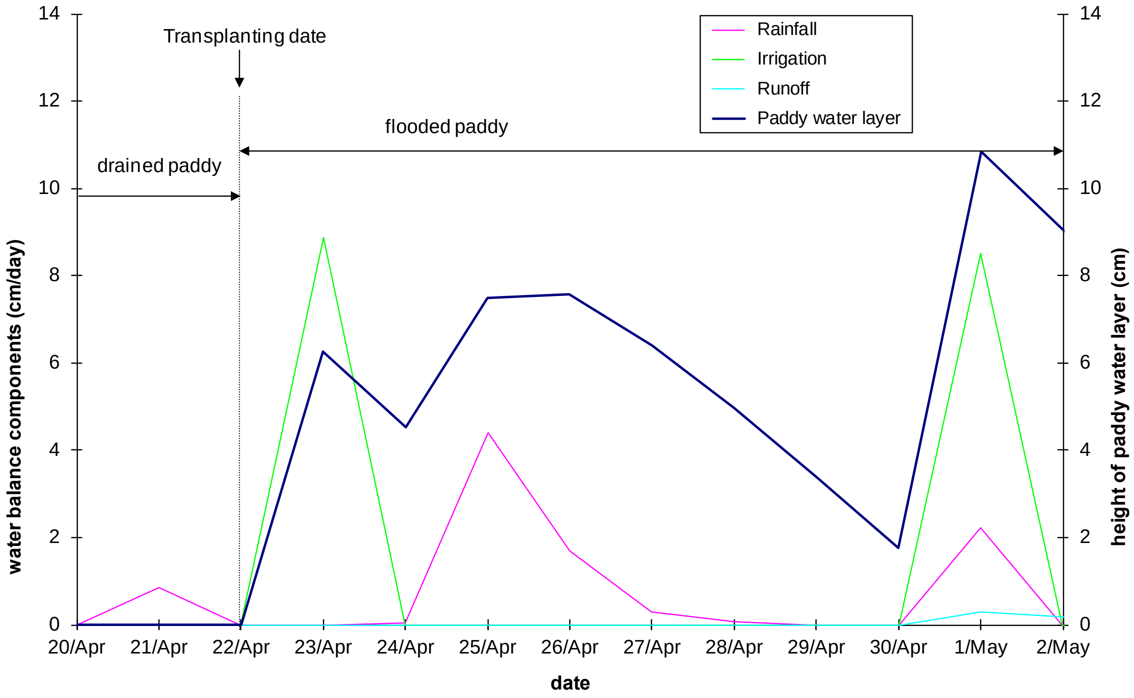

Figure 31 *Simulation result of SWAP for Nanchang for 20 Apr –2 May 1919. Precipitation, Irrigation and Runoff (all types of runoff) are given in cm/day. The paddy ponding depth is given in cm. 1919 is one of the years in which 6 runoff overflow events occur (90th percentile).*

10.3 Parameterisation of the TOXSWA model

TOXSWA has been parameterised for the protection goal 'Aquatic ecosystems in natural ponds south of the Yangtze river' for the scenario zones Yangtze river and South China.

10.3.1 Dimensions of the pond

The selected Chinese natural pond is assumed to be an rectangular reservoir with vertical sides; 20 x 33 m (1 mu = 1/15 ha) in surface area, with a water depth between 0.5 – 3 m.

10.3.2 Sediment

Parameterization of the sediment properties of the scenario was not necessary. As mentioned in Section 9.2, in the scenarios no interaction with the sediment does occur. Water is leaving the pond directly via seepage without passing a sediment layer.

10.3.3 Suspended solids and macrophytes

Data on the concentration of suspended solids in Chinese natural ponds were not available. Therefore a conservative approach, in line with the European surface water scenarios (FOCUS, 2001) was chosen, assuming that the concentration of suspended solids in the Chinese natural pond scenario is 15 g m^{-3}.

Data on the mass of macrophytes in Chinese natural ponds were not available. Therefore a conservative approach, in line with the European surface water scenarios (FOCUS, 2001) was chosen, assuming that the Chinese natural pond scenario does not contain macrophytes.

10.3.4 Meteorological data

10.3.4.1 Introduction

This section gives information on the meteorological data used in the TOXSWA model. The TOXSWA model for the Chinese natural pond needs data on daily precipitation and evaporation and average monthly temperatures as input.

10.3.4.2 Precipitation and evaporation as input in the TOXSWA model

Daily precipitation data of meteorological stations Nanchang and Shaoguan (scenario location Lianping) was used as input in the TOXSWA model, for the scenario zones Yangtze river basin and South China respectively. The method for constructing the 26 year weather file is described in Section 10.2.6.2. Values of precipitation were downloaded from the website of the China Meteorological Data Sharing Service System and used in the TOXSWA input file for meteorological data.

The Penman-Monteith formula in the PEARL model was used to calculate evaporation from open water. Runs with the PEARL model were executed for the locations Nanchang and Lianping (for the 26 years of weather data) using a value of zero for the crop height and the minimum canopy resistance and a value of 0.08 for the albedo (Ahrens, 2008). Using Penman-Monteith means that the heat capacity term G in this equation (see Chapter 2, Allen *et al*., 1998) is neglected. This is valid for a layer of water of several centimetres, but not for a water layer in order of meters. Neglecting the heat capacity term G results in an overestimation of the evaporation from open water. Given the limited time in the project and the limited amount of available meteorological data (wet bulb temperature is needed to calculate G) it was decided that an overestimation of the evaporation in the pond is acceptable because it will result in a more conservative scenario (less water in the pond so higher concentrations).

10.3.5 Runoff

Runoff is one of the components of the water balance of the paddy rice field (Figures 4 and 10). Runoff includes both surface runoff from a drained paddy field and runoff overflow from a flooded paddy field (see Table 4 for definitions).

For the groundwater and surface water scenarios for land use paddy rice south of the Yangtze River the same two locations were selected. Therefore, the calculated runoff (water + substance) of the leaching scenarios of Nanchang and Lianping were used as input for the Chinese natural pond scenarios. More information on the parameterization and calibration of the input of the two scenarios for the SWAP/PEARL model can be found in Section 10.2 of this report.

The daily runoff entering the pond (per m^2 pond) are shown in Figures 32 and 33 for Nanchang and Lianping, respectively. Runoff is the sum total of runoff overflow, surface runoff and controlled drainage entering the pond. Since this is the total runoff originating from 20 mu of contributing area surrounding the ponds, the daily amount of runoff entering a pond can become very high.

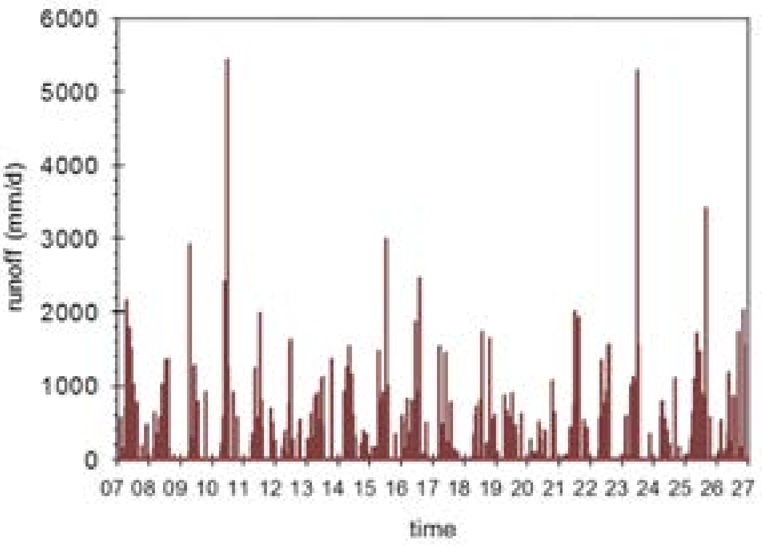

Figure 32 *Daily runoff per m2 pond entering the Nanchang pond, calculated with SWAP/PEARL for 20 years of simulations. Runoff is the sum total of runoff overflow, surface runoff and controlled drainage entering the pond.*

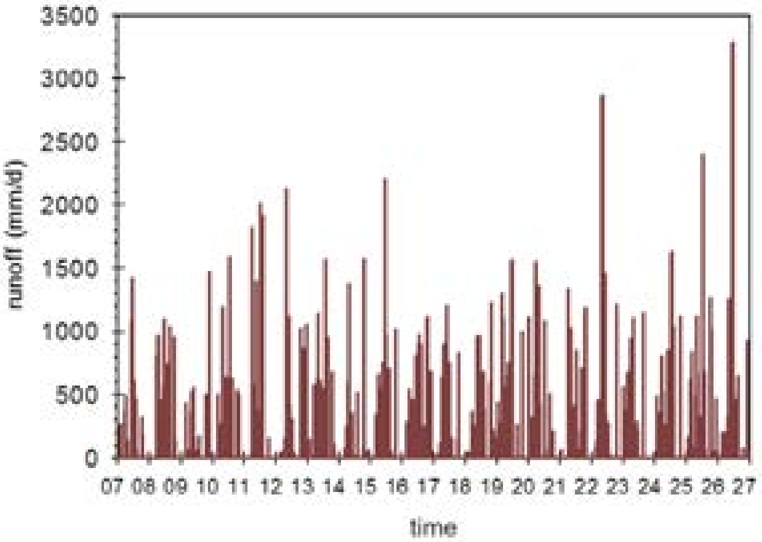

Figure 33 *Daily runoff per m2 pond entering the Lianping pond, calculated with SWAP/PEARL for 20 years of simulations. Runoff is the sum total of runoff overflow, surface runoff and controlled drainage entering the pond.*

10.3.6 Time step

The calculation time step of the simulation is set at 100 s for the water layer.

10.3.7 Calibration of the hydrology of the natural pond in TOXSWA for the scenario locations Nanchang and Lianping

10.3.7.1 Requirements for the calibration of the pond hydrology

The only specific requirements for the calibration of the pond hydrology are:

- Water can only leave the pond through seepage, i.e. downward flux into the groundwater and evaporation
- Water depth in the pond should never be less than 0.5 m and should never be higher than 3 m.

This implies that the pond will always contain at least 0.5 m of water, and that the pond is not allowed to overflow.

10.3.7.2 Calibration of the pond hydrology

Only the minimum water depth ($h_{pond,min}$) and the seepage rate coefficient *a* were obtained by calibration. Other parameters remained constant. The initial value for the water depth ($h_{pond,ini}$) had to be chosen, which was set at 1 m. The depth defining perimeter, i.e. the depth through which exchange with groundwater occurs through the side walls of the pond (P_{pond}, see explanation alongside eq. 8), was set to 0.4 m.

The choice of $h_{pond,min}$ is governed by the requirement that the water depth should never be lower than 0.5 m. $h_{pond,min}$ was calibrated to be 0.51 m for both scenarios. The effect of varying the values of *a* and $h_{pond,min}$ was investigated for the Nanchang and Lianping scenario locations, by retrieving the minimum and maximum water depth in the output generated (Table 38). On the basis of these results it was decided to use a value of a = 2.0 d^{-1} for Nanchang and a value of a = 1.0 d^{-1} for Lianping. The value of the seepage rate coefficient may be adjusted if new information on the dynamics of water height in ponds becomes available.

Table 38

Maximum water depth (of period 1906-1926) in ponds at the scenario locations Nanchang and Lianping for various values of the seepage rate constant a.

Scenario location	Value of seepage rate coefficient, *a* (d^{-1})	Minimum water depth over 26 years (m)	Maximum water depth over 26 years (m)
Nanchang	1.2	0.504	3.93
	1.8	0.506	3.01
	2.0	0.506	2.90
Lianping	0.8	0.501	3.18
	1.0	0.503	2.84
	1.2	0.504	2.59

10.3.7.3 Results of the calibration of the pond hydrology

The results for the selected values of the minimum water depth $h_{pond,min}$ (0.51 m for both locations), initial water depth $h_{pond,ini}$ (1.0 m for both locations) and the seepage rate constant *a* (2.0 d^{-1} for Nanchang and 1.0 d^{-1} for Lianping) are summarized below.

Water depths over 20 years (excluding the first 6 warm up years) are given in Figure 34. The water depth is near the minimum level during periods that only little rain and runoff overflow occur and the water depth rises during periods of rain and runoff (not visible in Figure 34).

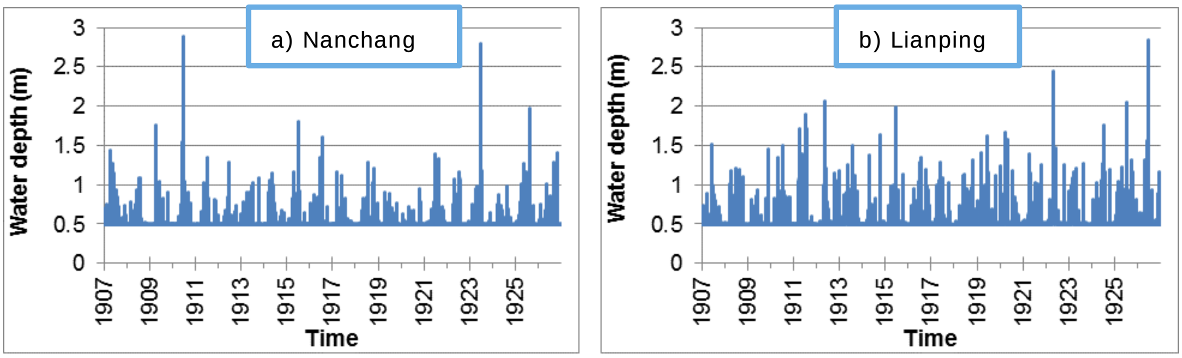

Figure 34 *Water depths as function of time for 20 years of simulations with TOXSWA for Nanchang (a) and Lianping (b).*

The requirements that were formulated in Section 10.3.7.1 are both met. When using the calibrated parameter values of the minimum water depth $h_{pond,min}$ (0.51 m for both locations), the initial water depth $h_{pond,ini}$ (1.0 m for both locations) and the seepage rate constant *a* (2.0 d^{-1} for Nanchang and 1.0 d^{-1} for Lianping), the ponds do not overflow (i.e. water depth is never > 3 m over the entire 26 years of simulation) and the water height is never below 0.5 m during the 26 year period of simulation.

10.3.7.4 Water balances for Nanchang and Lianping

Figure 35 gives for Nanchang the cumulative water balance of the pond over 20 years (1907 – 1926; so warm up years not included and the yearly water balance of the pond over the same 20 years. Figure 36 shows the same graphs for Lianping.

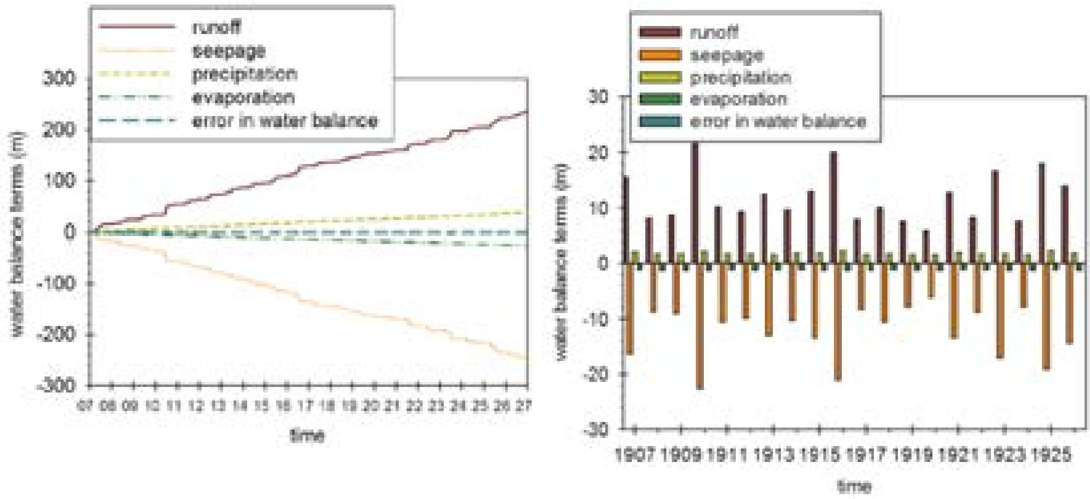

Figure 35 *Cumulative water balance of the pond (in m3/m2 pond) of the Nanchang scenario over 20 years (1907 – 1926) and the annual water balance of Nanchang over the same 20 year.*

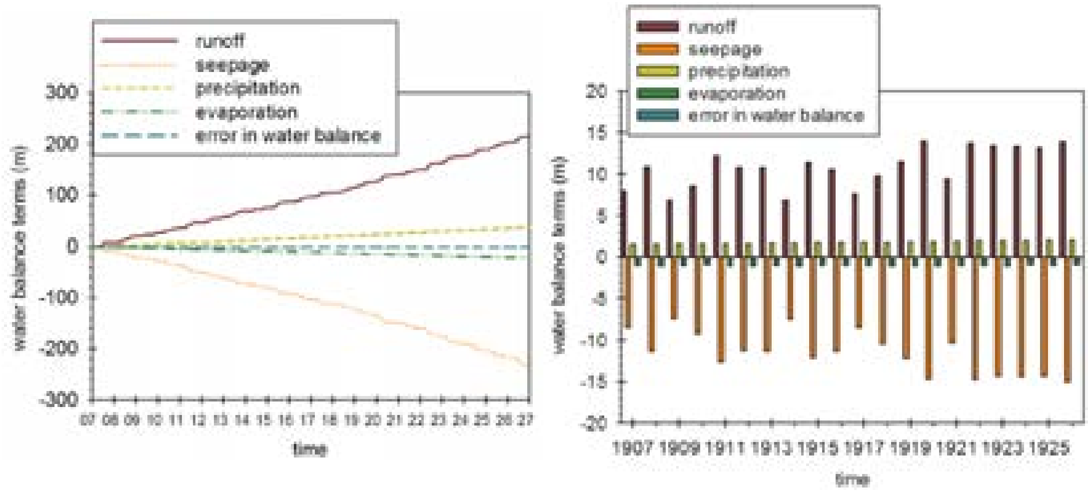

Figure 36 *Cumulative water balance of the pond (in m3/m2 pond) of the Lianping scenario over 20 years (1907 – 1926) and the annual water balance of Lianping over the same 20 year.*

The calculated annual seepage is very high for both Nanchang and Lianping, resulting from the size of the surrounding area (20 mu) combined with the requirement that water height in the pond is not allowed to exceed 3 m. The seepage in the Nanchang pond is on average higher than the seepage in the Lianping pond, which is because runoff overflow is higher in the Nanchang scenario. The average annual water balance in the ponds (Figures 35 and 36) shows that any incoming water flux (runoff overflow plus rain) is quickly balanced by outgoing water flux (seepage plus evaporation).

Figures 37 to 40 show water fluxes of runoff and seepage and the resulting water depth in more detail for the 90th percentile years with respect to the number of runoff overflow events for Nanchang (1919) and Lianping (1915), distinguishing between the first crop cycle (April – July) and the second crop cycle (July – October) for both scenario locations.

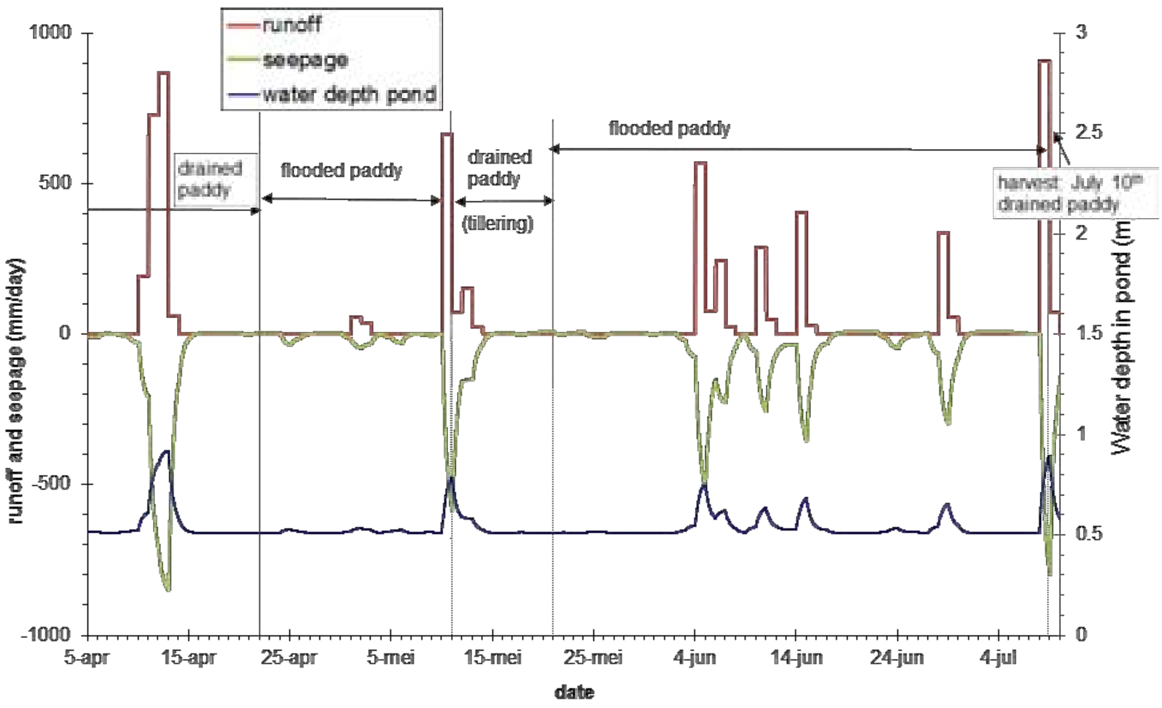

Figure 37 *Simulation result of TOXSWA for Nanchang for 1919 and crop cycle 1; runoff and seepage are given in mm/day, water depth is given in m; 1919 is one of the years in which 8 runoff overflow events occur (90th percentile). Inflow into the pond is defined positive and outflow is defined negative.*

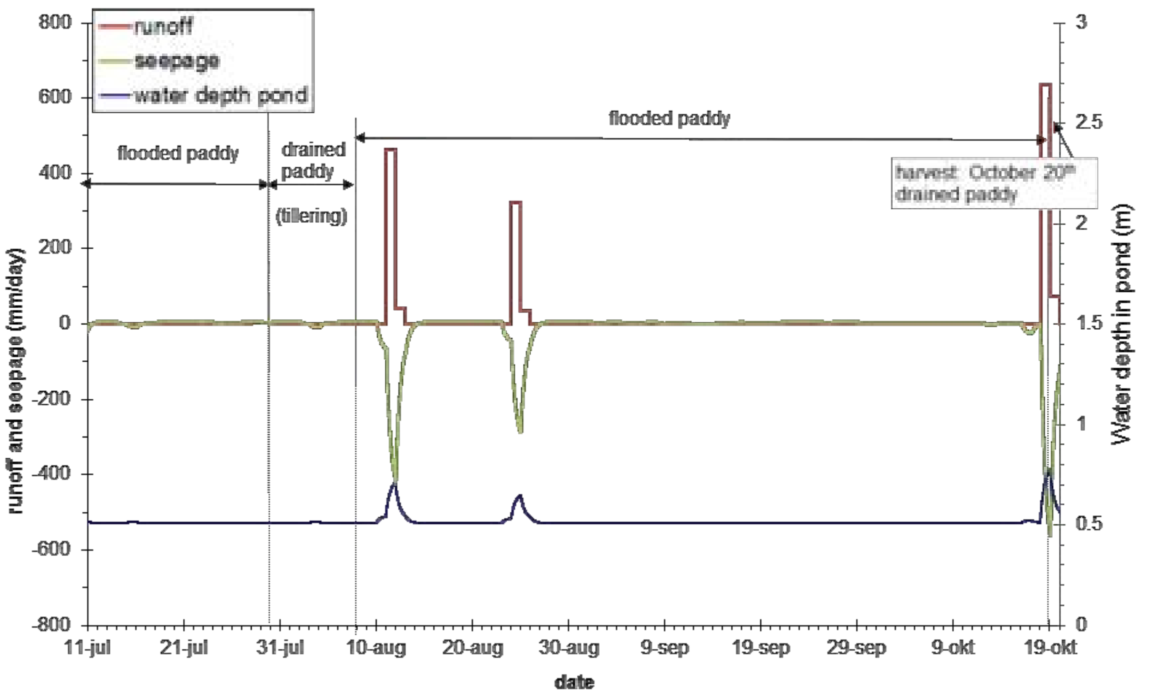

Figure 38 *Simulation result of TOXSWA for Nanchang for 1919 and crop cycle 2; runoff and seepage are given in mm/day, water depth is given in m; 1919 is one of the years in which 8 runoff overflow events occur (90th percentile). Inflow into the pond is defined positive and outflow is defined negative.*

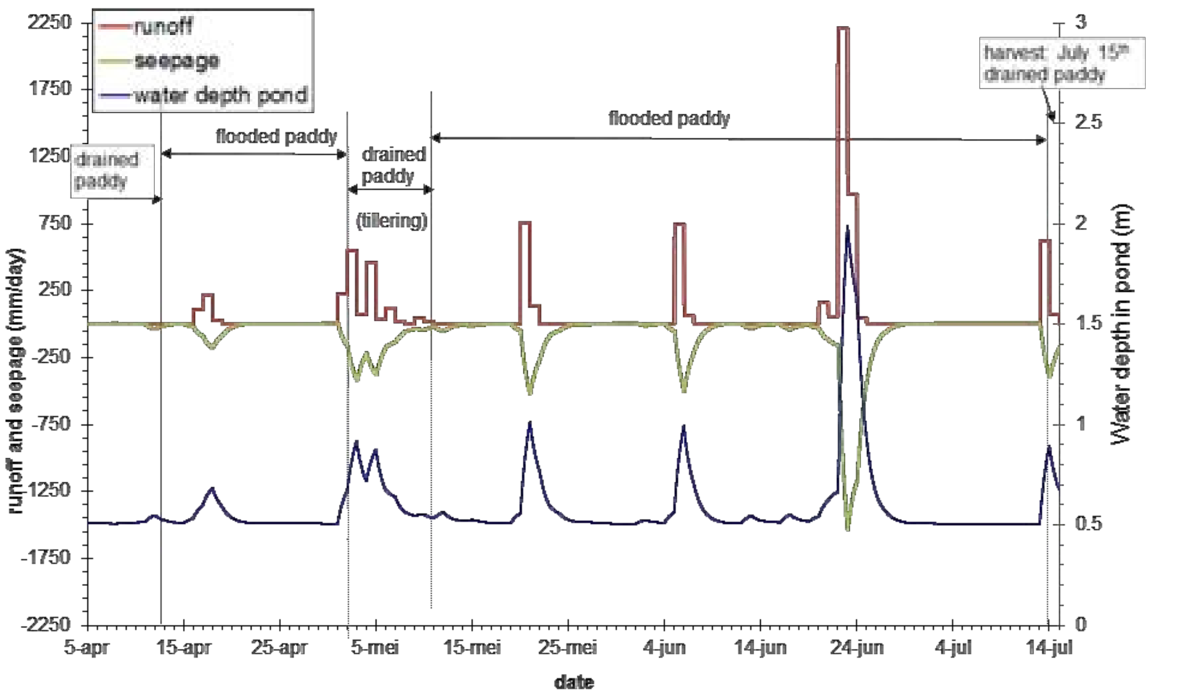

Figure 39 *Simulation result of TOXSWA for Lianping for 1921 and crop cycle 1; runoff and seepage are given in mm/day, water depth is given in m; 1921 is one of the years in which 9 runoff overflow events occur (90th percentile).*

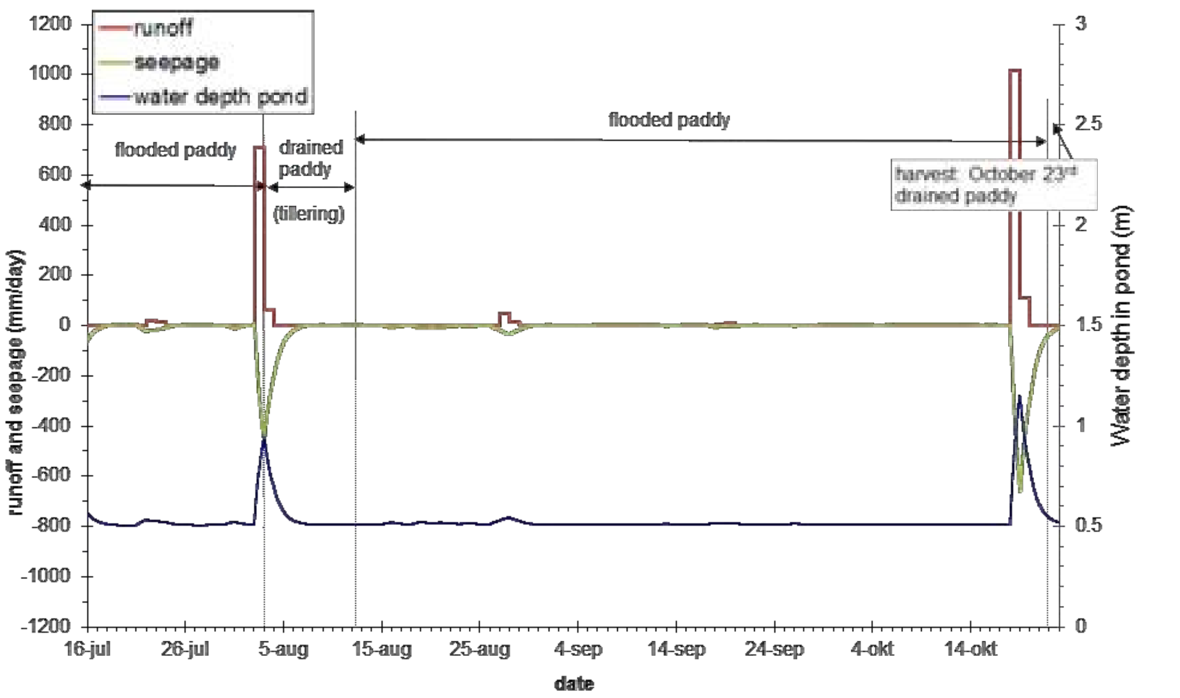

Figure 40 *Simulation result of TOXSWA for Lianping for 1921 and crop cycle 2; runoff and seepage are given in mm/day, water depth is given in m; 1921 is one of the years in which 9 runoff overflow events occur (90th percentile). Inflow into the pond is defined positive and outflow is defined negative.*

Table 39 summarizes the average annual water balances (in mm = L/m^2 pond) for Nanchang and Lianping ponds over the period 1907 – 1926 (excluding the warm up years), whereas Table 40 summarizes the annual water balance for the 90th percentile years (1919 for Nanchang and 1915 for Lianping respectively).

Table 39

Average annual water balance terms (in mm = L/m^2 pond) for the period 1907 – 1926.

	Nanchang	Lianping
In (mm):		
Runoff overflow	11842	10837
Precipitation	1860	1815
Total in:	13702	12652
Out (mm)		
Seepage	12456	11612
Evaporation	1245	1041
Total out:	13701	12653

Table 40

Annual water balance terms (in mm = L/m^2 pond) for the 90^{th} percentile years with respect to the number of runoff overflow events

	Nanchang (1919)	Lianping (1915)
In (mm):		
Runoff overflow	7584	11387
Precipitation	1567	1772
Total in:	9151	13159
Out (mm)		
Seepage	7863	12120
Evaporation	1291	1040
Total out:	9154	13160

11 Examples and test runs

11.1 Introduction

Vulnerability of the Chinese groundwater scenarios north of Yangtze river was compared to the vulnerability of relevant (EU) FOCUS groundwater scenarios. This work was presented at *"XIV Symposium in Pesticide Chemistry: Pesticides in the environment: fate, modelling and risk mitigation"* in Piacenza, Italy, 30th August – 1st September 2011. A summary of this work is given in Section 11.2.

A sensitivity analysis was done for the Chinese groundwater scenario south of the Yangtze river and the two most important pesticide properties for leaching: half-life in soil at reference temperature ($DegT_{50,soil}$ in d) and the coefficient of sorption on organic matter ($K_{om,soil}$ in L kg^{-1}). The relation between the leaching concentration and the annual average percolation was studied as well for these scenarios. This work was also presented at *"XIV Symposium in Pesticide Chemistry: Pesticides in the environment: fate, modelling and risk mitigation"* in Piacenza, Italy, 30th August – 1st September 2011. A summary of this work is given in Section 11.3.

Section 11.4 shows the results of a plausibility test of TOXSWA simulations with the Chinese scenarios for the natural pond. This test aims at identifying the frequency and size of concentrations in the water layer of the pond exceeding the runoff concentration due to high evaporation after runoff events.

11.2 Comparison of the vulnerability for leaching of the Chinese groundwater scenarios north of the Yangtze river and the relevant (EU) FOCUS groundwater scenarios

Below follows a summary of the work regarding a comparison of the vulnerability for leaching of the Chinese groundwater scenarios north of the Yangtze river and the relevant (EU) FOCUS groundwater scenarios (http://convegni.unicatt.it/meetings_3667.html; last entered 4 December 2012).

Within the PERAP project in China standard scenarios for dry land farming systems were developed to assess the risk of pesticide leaching to groundwater. Dry land farming systems are distributed mainly in the northern part of China. Based on maps of the annual average precipitation and air temperature three zones are distinguished, i.e. North, North East and North West China. Scenarios describing an overall leaching vulnerability approximating the 99^{th} percentile of all possible situations were determined. With respect to soil the 90^{th} percentile locations were selected from the organic matter map, while for weather the 50^{th} percentile locations were selected. Simulations were performed using multi-year weather data, selecting the 90^{th} percentile leaching concentration. These percentiles locations were combined and a total of six locations that represented the overall 99^{th} percentile vulnerability were selected.

In Europe the FOCUS (FOrum for the Co-ordination of pesticide fate models and their Use) groundwater working group defined nine standardised realistic worst-case scenarios in order to perform a Tier 1 level assessment of the leaching potential of pesticides (FOCUS, 2000). These scenarios represent agriculture in the EU and describe an overall vulnerability of the 90^{th} percentile of all possible situations. This vulnerability was approximated using a 80^{th} percentile value for soil selected by expert judgement, and a 80^{th} percentile value for weather determined by performing simulations using multi-year weather data. In 2009 the FOCUS working group improved the original scenarios (e.g. a new irrigation schedule, new crop factors, new evapotranspiration factors were introduced, runoff was eliminated, etc.) (FOCUS, 2009). These improved scenarios were used in the present study.

The Chinese leaching assessment is based on human toxicological criteria instead of the 0.1 µg/L criterion used in the EU. The aim of the present study was to compare the vulnerability of the Chinese and European scenarios.

In order to reach the aim of the study calculations were performed using FOCUS_PEARL_4.4.4 for the EU and ChinaPEARL_1.1.1 model for China. Leaching concentrations were calculated as a function of the half-life in soil ($DegT50_{,soil}$, d) and the coefficient of sorption on organic matter ($K_{OM,soil}$, L/kg). All other pesticide properties were equal to substance A defined by FOCUS (FOCUS, 2000).

The crop chosen for carrying out the comparison was maize. In all the Chinese and in several of the European scenarios maize is irrigated. Irrigation was applied once a week on a fixed day during crop growth and the irrigation amount was based on the requirement to bring back the soil water content in the root zone to field capacity. Pesticide was applied every year at 1 kg/ha on the day before emergence.

For Europe three irrigated scenarios (Châteaudun, Piacenza, and Sevilla) were chosen. For China calculations were carried out first for all six scenarios to identify the worst-case scenarios. Results indicated that Urumchi scenario in the North West zone was the worst case, Xinmin scenario in the North East zone was a medium case and Wugong scenario in the North zone was the best case. Therefore, these three scenarios were used to perform the comparison. Characteristics of the selected European and Chinese scenarios are presented in Table 41.

Table 41.
Characteristics of the selected European and Chinese scenarios.

Location	Texture class (USDA) 0-25 cm	Clay (%) 0-25 cm	Organic matter (%) 0-25 cm	Annual average water input (mm) precipitation+ irrigation	Annual average temperature (°C)
Châteaudun (EU)	Silty Clay loam	30	2.40	913	11.3
Piacenza (EU)	Loam	15	2.17	1044	13.2
Sevilla (EU)	Silt clay	14	1.60	872	17.9
Wugong (CN)	Silt loam	26	0.65	757	14.0
Xinmin (CN)	Loam	20	1.18	914	9.1
Urumchi (CN)	Silt loam	23	0.62	1043	7.6

Table 41 shows that organic matter content in the Chinese scenarios is lower than in the European scenarios. The scenarios with the lowest annual average temperature are Xinmin and Urumchi, while the scenarios with the highest percolation are Piacenza and Urumchi.

All the simulations showed a similar trend. The results obtained for Châteaudun and Xinmin scenarios are shown Figure 41 as an example. The overall 90^{th} for EU and 99^{th} percentiles for China of the leaching concentration of 20 year simulations were plotted as function of $DegT50_{,soil}$ and $K_{OM,soil}$.

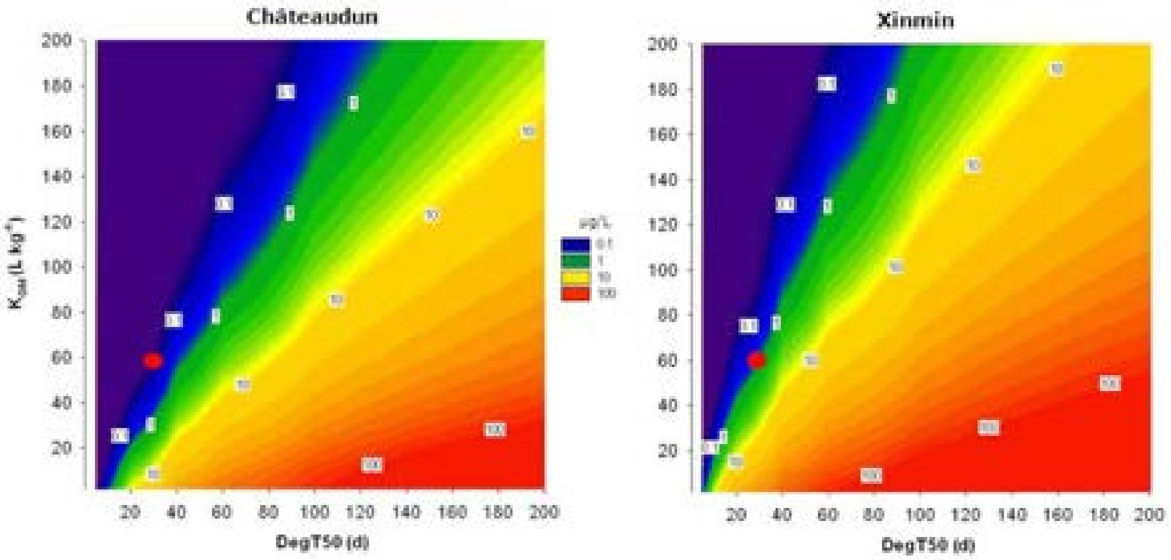

Figure 41 *Contour plot of the overall 90th and 99th percentiles leaching concentration (µg/L) as a function of DegT50,soil and KOM,soil for Châteaudun and Xinmin scenarios. The red dots indicate the combination DegT50=30 (d) and KOM,soil =60 (L/kg).*

The results indicated that the Chinese scenarios were in general more vulnerable to pesticide leaching than the European scenarios. Considering a $DegT50_{,soil}$ of 30 (d) and a $K_{OM,soil}$ of 60 (L/kg) the range of concentrations was 0.00-0.23 µg/L for the European scenarios and 0.55-9.96 µg/L for the Chinese scenarios. This result could be attributed to the lower organic matter and lower temperatures of the Chinese scenarios.

However, it has to be considered that the Chinese regulatory leaching assessment is based on human toxicological criteria, while the European one is based on the concentration limit in ground water of 0.1 µg/L. The guideline values derived by the World Health Organization for residues in drinking water for several pesticides are on average about 12 µg/L (WHO, 2008). Therefore, the higher vulnerability of the Chinese scenarios may be compensated by the use of human toxicological criteria for Chinese decision making.

11.3 Sensitivity analysis for the Chinese groundwater scenario south of the Yangtze river and $DegT50_{soil}$, $K_{om,soil}$ and annual percolation

Below follows a summary of the work regarding a sensitivity analysis for the Chinese groundwater scenario south of the Yangtze river and $DegT50_{soil}$, $K_{OM,soil}$ and annual percolation (http://convegni.unicatt.it/meetings_3667.html; last entered 25 July 2013).

The main aim of the study was to assess the sensitivity of Chinese paddy rice scenarios to the half-life in soil at reference temperature ($DegT50_{,soil}$ in d) and the coefficient of sorption on organic matter ($K_{OM,soil}$ in L kg-1). Furthermore, the sensitivity of the leaching concentration to annual average percolation was investigated.

The PEARL model (Leistra *et al*., 2001) was extended to describe the fluctuating water level of a paddy water layer and pesticide behavior in this layer including degradation and runoff of water and pesticide. Two scenarios for pesticide use in paddy rice in China (south of the Yangtze River) were developed to represent the overall 99th percentile leaching concentration at 1 m depth: Nanchang and Lianping.

In the present study simulations were carried out using PEARL model with 20 years weather data and soil data of the Nanchang scenario. The organic matter content in the top 25 cm of the soil in Nanchang scenario is 1.87%. Furthermore, this scenario is characterized by: 1860 mm of annual averages of precipitation, 1595 mm of irrigation, 1903 mm of percolation and the annual mean air temperature is 18.3 °C.

The substance used was substance A defined by the FOCUS groundwater working group (FOCUS, 2000), only $DegT50_{,soil}$ and $K_{OM,soil}$ were varied.
Two rice crop cycles were simulated per year and the substance was applied once per crop cycle during tillering at 1 kg/h. The substance was injected at 1 cm depth in the soil in order to exclude other dissipation processes like runoff or volatilisation from crop surfaces or degradation in the paddy water layer.

With the aim to investigate the relation between the leaching concentration and annual average percolation, series of simulations were done using the same model input described above, but using a limited set of $DegT50_{,soil}$ - $K_{OM,soil}$ combinations and varying the saturated conductivity values of the low permeable plow layer at 15-24 cm depth (range of 0.01 – 0.25 cm d^{-1}). By manipulating the saturated conductivity values of the low permeable plow layer the percolation can be varied.

In Figure 42 the overall 99th percentile of the leaching concentration of 20 years of simulations was plotted as function of $DegT50_{,soil}$ and $K_{OM,soil}$. For the Nanchang scenario this percentile was the 77th percentile in time considering as the main drivers for leaching both organic matter and percolation.

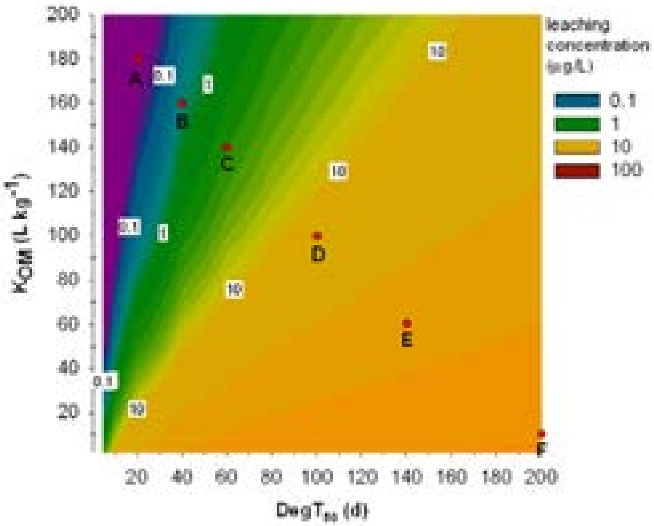

Figure 42 *Contour diagram of the 77th percentile leaching concentration in time (µg L-1) as a function of the DegT50,soil and KOM,soil. Red dots indicate the DegT50,soil – KOM,soil combinations tested in Figure 43. The dotted line represents the 0.1 µg/L line of the Dutch leaching scenario for maize.*

The 0.1 µg L^{-1} line in Figure 43 is found at a $K_{OM,soil}$ /$DegT50_{,soil}$ ratio around 4 L kg^{-1} d^{-1}, whereas Boesten and van der Linden (1991) found it at a ratio of about 1 L kg^{-1} d^{-1} for a Dutch maize scenario. Compared to this Dutch scenario, leaching concentrations of substances with short $DegT50_{,soil}$ and high $K_{OM,soil}$ are much higher in the paddy rice scenario. However, the paddy rice scenario shows relatively low leaching concentrations for substances with high $DegT50_{,soil}$ and low $K_{OM,soil}$ despite the annual dosage used in rice was two times higher than the dosage used by Boesten and van der Linden (1991).

Since the main difference between the paddy rice scenarios and other crop scenarios is the annual percolation (about 2000 mm versus 200-500 mm), the effect of percolation was analysed by performing simulations with varying percolation amounts (achieved by manipulating the saturated conductivity values of the low permeable plow layer).

The average substance concentration at 1 m depth of a single year (1912) was plotted as function of annual percolation (Figure 43). This year had 1880 mm percolation and its leaching concentration was on average about 94% of the 77th percentile in time.

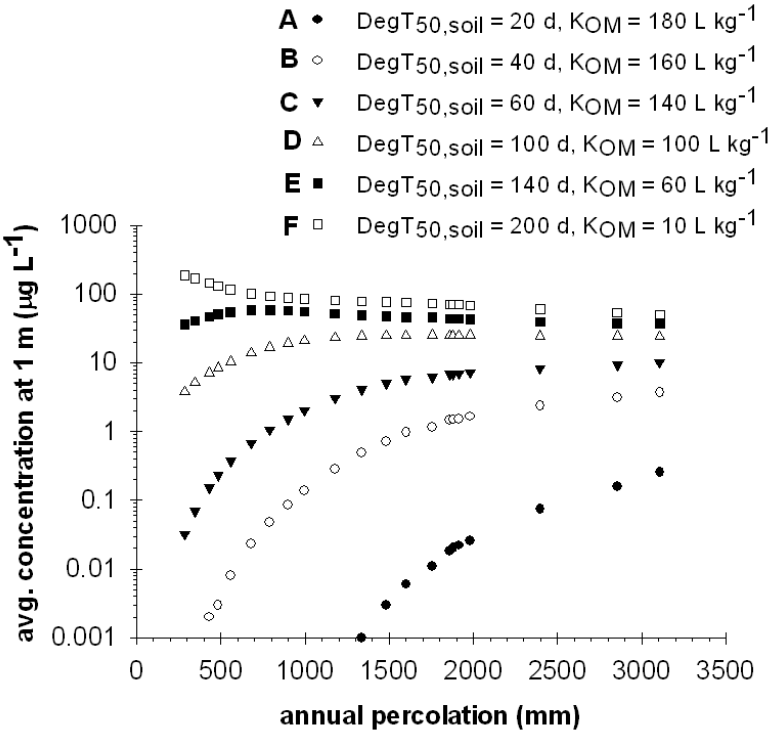

Figure 43 *Average substance concentration at 1 meter depth in 1912 as function of the annual percolation (1880 mm).*

Figure 43 shows that percolation affects the leaching concentration in two opposing ways. The first effect is that higher percolation causes an increase of leaching, producing an increase in concentrations. While the second effect is that higher percolation leads to dilution for a fixed percentage of the dose, and therefore a decrease in the concentration. For short $DegT50_{,soil}$ and high $K_{OM,soil}$ the first effect prevails for the entire range of percolation investigated (300 – 3100 mm). For long $DegT50_{,soil}$ and low $K_{OM,soil}$ the second effect prevails also for the entire range of percolation. For the intermediate case of $DegT50_{,soil}$ (140 d) and $K_{OM,soil}$ (60 L kg^{-1}) the first effect prevails for lower percolation (300 – 800 mm), while for higher percolation (>800 mm) the second effect prevails.

In general this study shows that leaching concentrations of substances with short $DegT50_{,soil}$ and high $K_{OM,soil}$ are higher for paddy rice scenarios than those reported for scenarios for other crops (i.e. scenarios with less percolation). However, leaching concentrations of substances with long $DegT50_{,soil}$ and low $K_{OM,soil}$ are relatively low for paddy rice scenarios compared to those reported for other crops scenarios. These relatively low concentrations are caused by the diluting effect of the large annual percolation of paddy rice scenarios.

11.4 Example runs Chinese natural pond scenarios

The example substance (EXTR) in the TOP-RICE_CN_2 software was used for the example runs. Properties of this substance are given in Table 42. The user-friendly software package was developed to support easy simulation of the pesticide concentration for the Chinese paddy rice scenarios.

Table 42

Substance properties of the example substance (EXTR) in the TOP-RICE_CN_2 software and used for the example runs.

DESCRIPTION (units)	value
Tab General	
Substance Molar Mass (g.mol-1)	300
Saturated vapour pressure of substance (Pa)	0.0001
Temperature of reference at which the saturated vapour pressure was measured (°C)	20
Molar enthalpy of the vaporization process (kJ.mol-1)	95
Water solubility of substance (mg.L-1)	90
Temperature of reference at which the water solubility was measured (°C)	20
Molar enthalpy of the dissolution (kJ.mol-1)	27
Coefficient of diffusion of the substance in water (m2.d-1)	4.3E-5
Coefficient of diffusion of the substance in air (m2.d-1)	0.43
Temperature of reference at which diffusion coefficients were measured (°C)	20
Tab Sorption - soil	
Option to choose between pH-dependent or pH-independent sorption	pH-independent
Coefficient of equilibrium sorption of substance on organic matter (Kom) (L.kg-1)	35
Temperature of reference at which the sorption coefficient was measured (°C)	[0.0 – 40]
Reference liquid content for the sorption coefficient (mg.L-1)	1
Molar enthalpy of sorption (kJ.mol-1)	0
Freundlich exponent (-)	0.9
Rate of desorption (d-1)	0
Factor relating coefficient for equilibrium and non-equilibrium sorption (-)	0
Tab Sorption - water	
Coefficient of equilibrium sorption in suspended solids (L.kg-1)	35
Reference concentration in liquid phase in suspended solids (mg.L-1)	1
Freundlich exponent in suspended solids (-)	0.9
Coefficient for linear sorption on macrophytes (L.kg-1)	0
Tab Sorption - sediment	
Not relevant for Chinese natural pond scenarios	
Tab transformation soil - aerobic	
Half-Life of transformation in soil; aerobic (d)	20
Temperature of reference at which the half-life of transformation in soil (aerobic) was measured (°C)	20
Option to use the moisture	OptimumConditions
Coefficient describing the relation between the transformation rate of the substance and the volume fraction of liquid (-)	0.7
Molar activation enthalpy of transformation in soil (aerobic) (kJ.mol-1)	65.4
Tab transformation soil - anaerobic	
Half-Life of transformation in soil; anaerobic (d)	1000
Temperature of reference at which the half-life of transformation in soil (anaerobic) was measured (°C)	20
Molar activation enthalpy of transformation in soil (anaerobic) (kJ.mol-1)	65.4
Tab transformation water	
Half-Life of transformation in water (surface water)(d)	10
Temperature of reference at which the half-life of transformation water was measured (°C)	20
Molar activation enthalpy of transformation in water (kJ.mol-1)	75
Half-Life of transformation in paddy water (d)	1000
Tab transformation sediment	
Not relevant for Chinese natural pond scenarios	
Tab transformation crop processes	
Factor for the wash-off of substance from the crop by precipitation or irrigation (mm-1)	0.1
Option for the description of the loss routes of substance from the crop surface	Lumped
Half-life for the disappearance of the substance on the crop (d)	10
Coefficient for uptake by plant roots (-)	0

Each year at 2 May and at 21 July, 1 kg ha^{-1} of substance EXTR is applied to the rice crop on the paddy rice field. The drift percentage assumed was 3.73 % of the applied dosage (see Section 3.4.1). The 77 percentile peak concentration of EXTR in the pond of 20 years of simulations is 318.4 ug L^{-1}, as calculated by the TOXSWA model in the TOP-RICE_CN_2 software package.

For the Lianping scenario yearly applications of 1 kg ha^{-1} of substance EXTR are at 23 April and at 26 July. The drift percentage assumed was 3.73 % of the applied dosage (see Section 3.4.1). The 89^{th} percentile peak concentration of EXTR in the pond of 20 years of simulations is 341.6 ug L^{-1}, as calculated by the TOXSWA model in the TOP-RICE_CN_2 software package.

Figure 44 and 45 show the concentration in the water layer of the pond for the period 1907 – 1926 for respectively the Nanchang and Lianping scenario. In each year two peaks due to the drift events occur. Often this relatively small peak due to spray drift is followed by a larger peak in the concentration due to a runoff overflow event. The maximum concentration in to the pond due the drift event is about 7.5 ug L^{-1}. The maximum concentration possible in the pond due to a runoff overflow event is 4040 ug L^{-1} (assuming that 1 kg/ha of 20 mu enters a pond of 33x20x0.5 m). Figure 44 and 45 show that for substance EXTR concentrations due to runoff events are at least a factor 10, but generally a factor 20 lower than this maximum concentration possible of 4040 ug L^{-1}. Concentrations in the pond are roughly a factor 10-80 lower than the maximum possible concentration due to runoff because of several reasons: interception of the substance by the crop on the paddy field, a larger time interval between application and runoff event causes infiltration of paddy water including the substance in to the soil and dilution in the pond incase runoff events are relatively small compared to the volume of the pond.

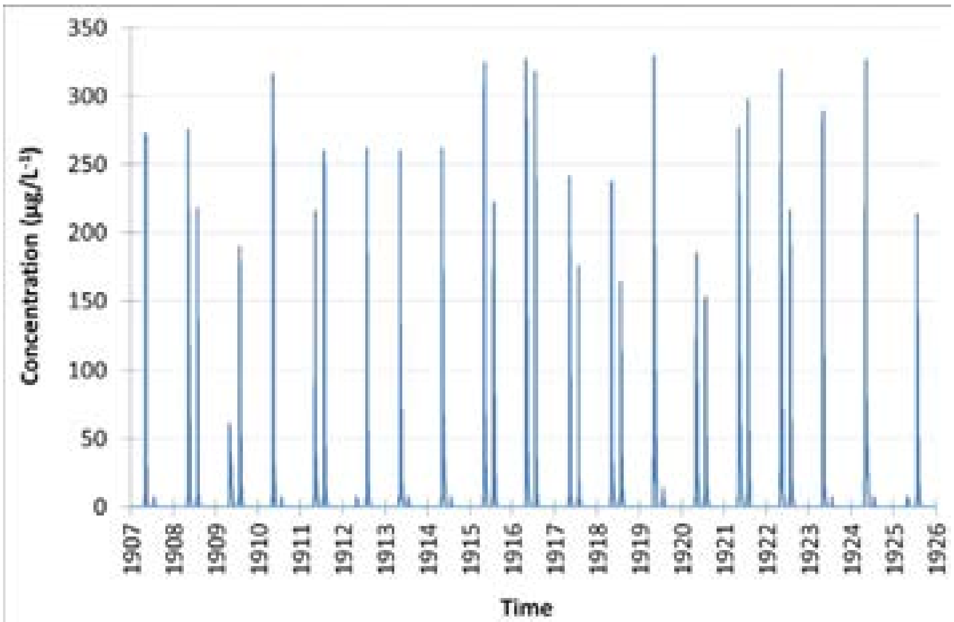

Figure 44 *Concentration of substance EXTR in the water layer of the pond of the Nanchang scenario for 20 years of TOXSWA simulations.*

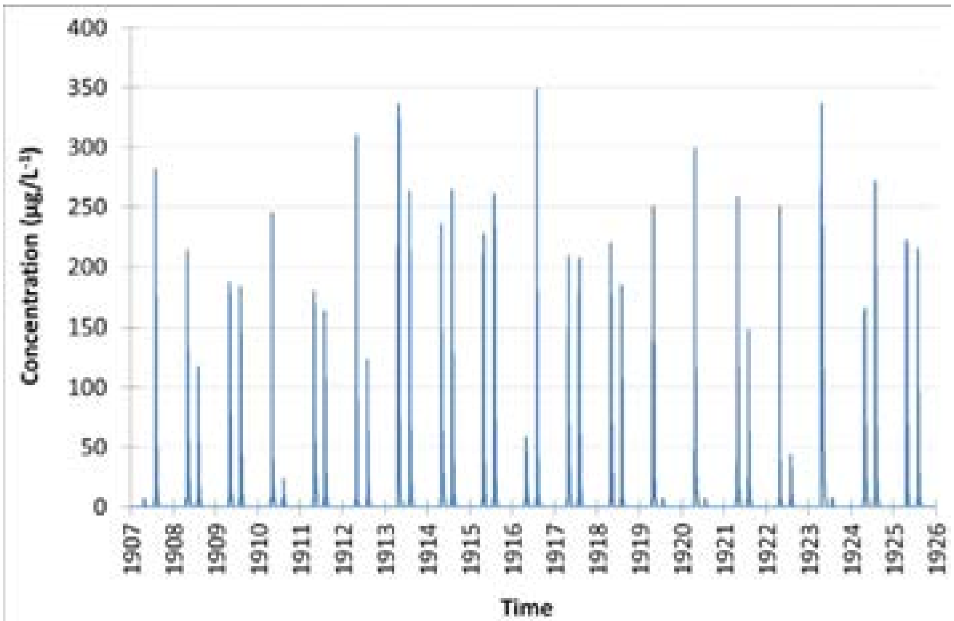

Figure 45 *Concentration of substance EXTR in the water layer of the pond of the Lianping scenario for 20 years of TOXSWA simulations.*

Figure 46 and 47 show the concentration EXTR in the water layer of the pond for the year 1908 of the Nanchang and Lianping scenario, respectively. The two small peaks in the concentration beginning of May/end of April and end of July are caused by spray drift. They are both followed by a peak in the concentration caused by a runoff overflow event.

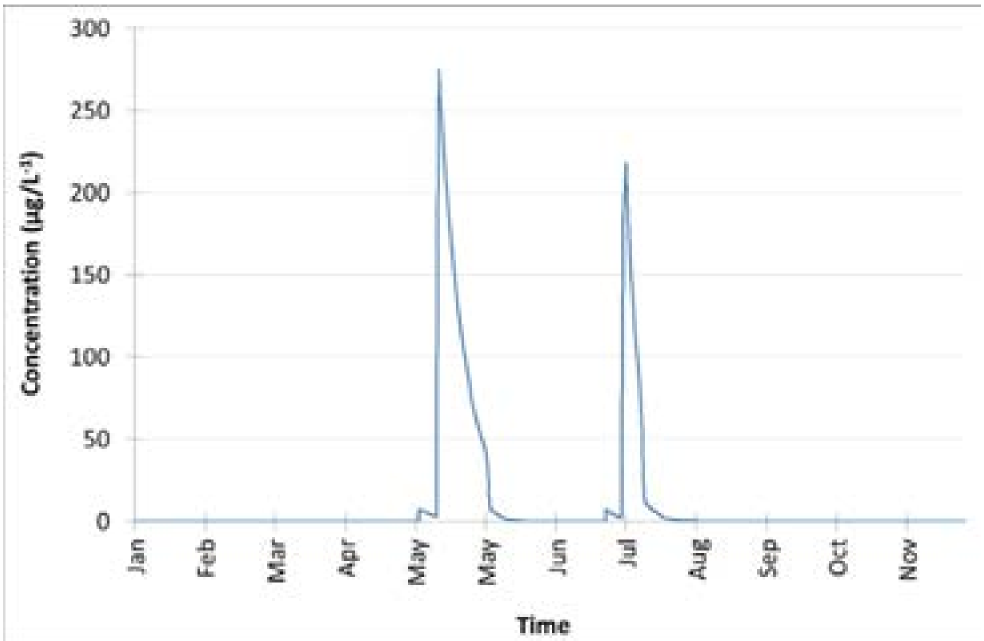

Figure 46 *Concentration of substance EXTR in the water layer of the pond of the Nanchang scenario for the year 1908.*

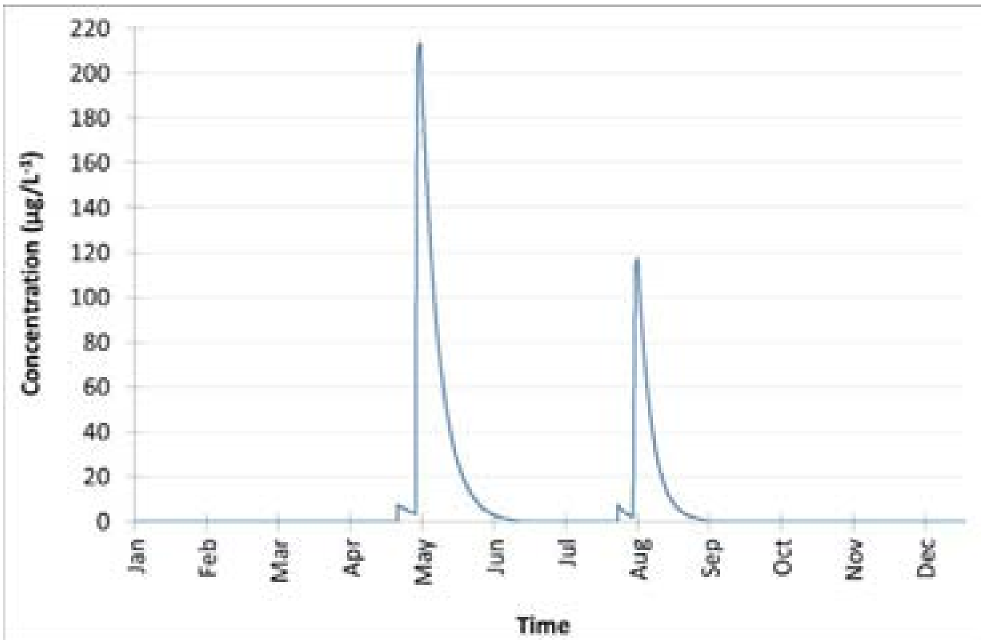

Figure 47 *Concentration of substance EXTR in the water layer of the pond of the Lianping scenario for the year 1908.*

11.5 Test on correctness TOXSWA output

It is not totally unrealistic that concentrations in a non-flowing water system rise in case evaporation is high and water is not replenished (consider the salinization of the Aral lake as a large scale example). However, for the Chinese natural pond scenarios frequently higher concentrations in the pond compared to the concentrations in the runoff water might point towards an overestimation of the open water evaporation. As indicated in Section 10.3.4.2 open water evaporation for input in TOXSWA is calculated in such a way that it may result in an overestimation of the actual open water evaporation.

To test whether concentrations in pond could exceed concentrations in the runoff water we performed TOXSWA simulations in the following way: i) using the TOP-RICE_2_CN example substance EXTR of which the $DegT_{50,water}$ was changed from 10 to 10000d, to minimize degradation and ii) all runoff concentrations were set to 1000 µg/L for each runoff overflow event. Hence when runoff fluxes enter the water body they always contained 1000 µg/L of the substance.

Figures 48 and 49 show the results of the simulations for Nanchang as well as Lianping. For Nanchang the concentration in the water layer of the pond exceeds the 1000 µg/L threshold for 2.8% of the 20 years of simulation. The maximum concentration is 1043 µg/L for Nanchang. For Lianping the concentration in the water layer of the pond exceeds the 1000 µg/L threshold for 1.2 % of the time and the maximum concentration is 1049 µg/L. The frequency of exceeding the 1000 µg/L threshold and the size of the exceedance of the concentration (max. 5%) was considered low enough to confide that the results of TOXSWA simulations with the Chinese natural pond scenarios are plausible.

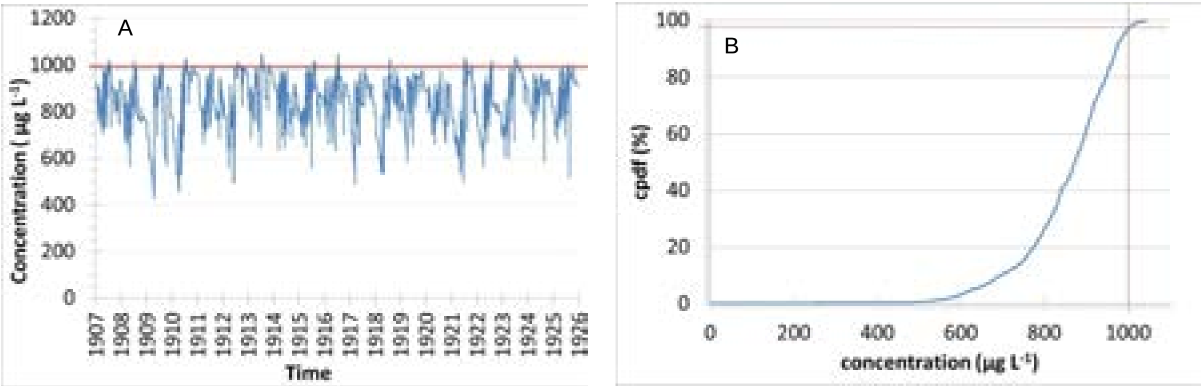

Figure 48 *(A) Concentration in the water layer of the pond of the Nanchang scenario and (B) cumulative probability density function in time of the concentration in the water layer of the pond of the Nanchang scenario, both are results of the simulation with substance EXTR (however, DegT50,water was changed from 10 to 10000d) and setting the concentration of each runoff flux to 1000 µg/L.*

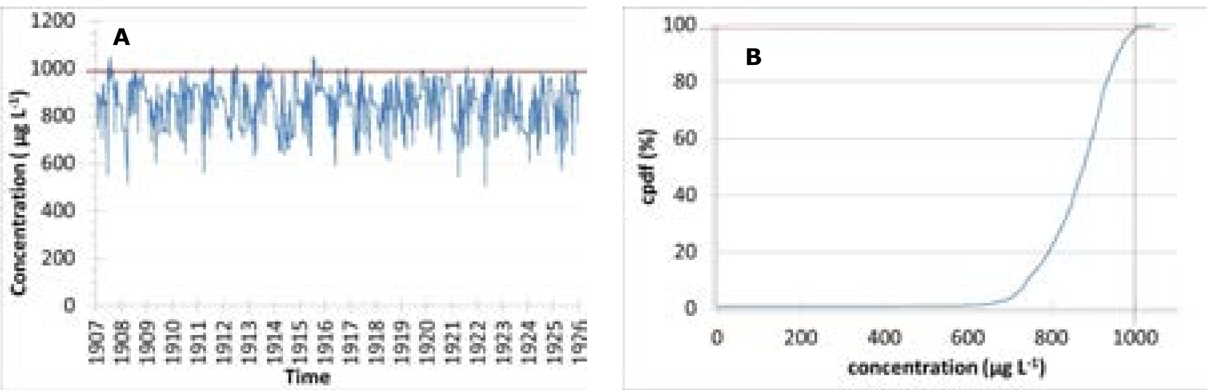

Figure 49 *(A) Concentration in the water layer of the pond of the Lianping scenario and (B) cumulative probability density function in time of the concentration in the water layer of the pond of the Nanchang scenario, both are results of the simulation with substance EXTR (however, DegT50,water was changed from 10 to 10000d) and setting the concentration of each runoff flux to 1000 µg/L.*

12 Conclusions and recommendations

12.1 Conclusions

The groundwater and surface water scenarios presented in this report are the result of a close collaboration between the PERAP partners Alterra, Chinese Academy of Agricultural Sciences and the China Agricultural University. They were realized using the best methods available at the time of the project and within the limitations of time, budget and data availability. Very valuable output of the project is the creation of "the roadmap for developing leaching and exposure scenarios". The structured approach enabled:

(i) A proper identification of Chinese scenario zones with similar climate and soil types and cropping systems,
(ii) the identification and adoption by the risk managers of appropriate protection goals for groundwater and surface water,
(iii) development of specific conceptual models for Chinese groundwater leaching and exposure scenarios, including the work done on identification of the different land use options for paddy fields,
(iv) the identification of sensitivity and vulnerability drivers for each protection goal
(v) the selection of scenarios for a number of protection goals
(vi) the adaption and parameterisation of existing fate models to enable the calculation of relevant environmental concentrations for the elaborated scenarios

The selected protection goals for groundwater were:

a) Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River,
b) Groundwater in drinking water wells at 10 m deep in paddy land north of the Yangtze River,
c) Groundwater at 2 m depth in paddy land south of the Yangtze River,
d) For the protection goals (a) and (c) scenarios were developed and parameterised.

The selected protection goals for surface water were:

a) Aquatic ecosystems in natural ponds south of the Yangtze River,
b) Aquatic ecosystems in natural ponds north of the Yangtze River,
c) Aquatic ecosystems in level 3 drainage channels south of the Yangtze River,
d) Aquatic ecosystems in level 7 rivers north of the Yangtze River,
e) Aquatic ecosystems in rivers in the valley of hilly area south of the Yangtze River.

For the protection goals (a) scenarios were developed and parameterised.

This output provides a good basis which the Chinese partners might use to improve and further develop the work done on development of standard scenarios for assessing the risk of pesticide use on leaching to groundwater and exposure of aquatic ecosystems in surface waters. Recommendations for improvements and continuation of the scenario developing process are done in Section 12.2.

12.2 Recommendations

1. Develop scenarios for the remaining protection goals defined for the protection of aquatic ecosystems in small surface waters in China.

In the PERAP project we developed two scenarios for protection of aquatic ecosystems in natural ponds south of the Yangtze River. However, together with Chinese experts from ICAMA, CAAS and CAU four other protection goals for the protection of aquatic ecosystems in small surface waters in China were defined:

i. Aquatic ecosystems in natural ponds north of the Yangtze River.
ii. Aquatic ecosystems in level 3 drainage channels south of the Yangtze River.

iii. Aquatic ecosystems in level 7 rivers north of the Yangtze River.
i. Aquatic ecosystems in rivers in the valley of hilly area south of the Yangtze River.

A rough calculation showed that concentration of pesticides in the level 3 drainage channels south of the Yangtze River (see Annex A) might be similar to concentrations in the water layer of the paddy rice field. These concentrations might therefore be 10 – 20 times higher than the concentrations calculated for the natural pond south of the Yangtze River. We therefore recommend developing scenarios for the other protection goals as well because the scenarios for protection of aquatic ecosystems in natural ponds south of the Yangtze River do probably not result in the most conservative exposure concentration in small surface waters in China.

2. Develop groundwater scenarios for paddy land south of the Yangtze River for vegetables or other crops (e.g. wheat) grown on drained paddy land.

Within the PERAP project the vulnerability concept applied for groundwater scenarios for paddy rice south of the Yangtze River was that percolation is the main vulnerability driver. A scenario was developed assuming two irrigated rice crops on a flooded paddy field and fallow land (no flooding) for the rest of the year. This scenario was considered to be conservative due to the high percolation amounts. However, the sensitivity analysis presented in Section 11.3 shows that for persistent but mobile pesticides (high value for $DegT50_{,soil}$ and low value for $K_{OM,soil}$) the high percolation from two crop cycles of rice on flooded paddy fields might cause dilution and thus lower concentrations leaching to the groundwater. This means that the present scenario might not be protective for situations where less percolation is possible. Such a situation can be the cultivation of one rice crop on a flooded paddy field followed by two crop cycles of vegetables or other crops (e.g. maize or wheat) on a drained paddy field. It is recommended to develop scenarios for pesticide application in other crops (i.e. cereals, vegetables) in the cropping system double/triple harvests on paddy land. The same vulnerability concept as used for the situation of pesticide applications in two crop cycles of paddy rice is applicable. The 90th percentile location with respect to annual average percolation will however differ, because percolation amounts for this situation are different.

3. Improve soil-hydraulic parameters of the scenarios

Soil-hydraulic parameters of the scenarios are estimated using the Rosetta database, containing mainly data from the USA and some of Europe. It is unknown to which extent this database is also representative for Chinese soils. It is therefore recommended to compare the data in the Rosetta database to data in Chinese databases on soil properties.

4. Carry out field experiments for paddy rice

The SWAP-PEARL model that was adapted to simulate the hydrology and pesticide behaviour of a (flooded) paddy field has not been evaluated against a field dataset. The validation status of the model for this particular type of agricultural system is therefore low. We recommend to search suitable field data sets or to carry out such field experiments and subsequently test the SWAP-PEARL model against these datasets to increase the confidence in the SWAP-PEARL model for simulating hydrology and pesticide behaviour of a (flooded) paddy field.

5. Develop scenarios for protecting the aquatic ecosystem in natural ponds south of the Yangtze River according the phased approach given in Section 7.5

Within the PERAP project scenarios for the protection of the aquatic ecosystem in natural ponds south of the Yangtze River are developed for the first phase (i.e. assuming that the pond is surrounded by 100% paddy rice) only. In an average situation the pond will be surrounded by other crops than paddy rice alone. Any new scenarios to be developed for the following phases indicated in Section 7.4 (i.e. land use is part of the vulnerability concept) can be used as higher tiers or replace the scenario developed during the PERAP project.

6. Incorporate metabolites into the risk assessment for aquatic ecosystems in surface water.

Chinese risk managers decided not to incorporate metabolites into the risk assessment for aquatic ecosystems in the natural pond. Reason for not incorporating metabolites in to the risk assessment for aquatic ecosystems in the natural pond is that deriving half-lives of metabolites in water and sediment is not straight forward. Chinese contract laboratories are at the moment not ready yet to derive reliable half-lives of metabolites in water and sediment. We recommend to use where possible existing data on half-lives of metabolites to incorporate metabolites into the risk assessment for aquatic ecosystems in the natural pond.

7. Improve the groundwater scenarios for leaching to groundwater in dry land North of the Yangtze river.

For this particular protection goal first a 90th percentile location with respect to soil and a 50th percentile location with respect to climate is combined because we assumed that the spatial component of weather was less relevant. However, this assumption is not scientifically sound. The spatial component of climate is just as relevant as the temporal component of climate. It is thus more defensible to calculate the 90th percentile of the annual average precipitation of all meteorological stations in a particular scenario zone (for instance 800 mm) and select from this pool of meteorological stations a station that has a similar 90th percentile of the annual average precipitation as the 90th percentile of the annual average precipitation of the scenario zone. We therefore recommend to redo the scenario selection procedure using 90th percentile locations with respect to climate.

8. Substances with pH adsorption or degradation in paddy soils.

If a substance shows pH dependent adsorption or degradation, then perform degradation and sorption studies with three paddy soils with pH-$CaCl_2$ of 4-5 and with three paddy soils with pH-$CaCl_2$ of 7-8 and take most unfavorable end result as input in the model.

9. Improvement of the PEARL model for rice paddies

For future versions of PEARL for rice paddies, it is recommended to include the course of time of the redox potential in the top layer and to use a DegT50 that is a function of this redox potential. This would enable a more smooth transition between the degradation rate under anaerobic and aerobic conditions (which is more realistic).

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Annex A Surface water systems in China

A.1 Surface water systems

Different surface water systems containing water bodies from which the aquatic ecosystem might need to be protected from contamination with pesticides were identified during PERAP. The large diversity considering landscapes, soils and climate in China and the lack of detailed spatial data made the identification of different surface water systems difficult. Four major systems were selected after discussions with Chinese experts and some GIS (Geographical Information System) exercises performed by CAAS using the limited spatial data available:

i. Ponds
ii. River basins south of the Yangtze River
iii. River basins north of the Yangtze River
iv. River systems in the valley of hilly areas south of the Yangtze River

A1.1 Ponds

Considering ponds a distinction was made between fish ponds for commercial use and natural ponds (Figure A1). Fish ponds are usually quite large, hand-made (sometimes of concrete), grouped together and well protected by large dikes from floods and therefore also protected from spray drift from pesticide applications or runoff events. In the PERAP project, natural ponds are defined as single ponds larger than 1 mu (= 667 m^2) and surrounded by agricultural fields. For natural ponds a difference was made between ponds north of the Yangtze River and ponds south of the Yangtze River. Ponds north of the Yangtze River are assumed to be fully surrounded by dikes protecting the pond from floods and possibly spray drift. Natural ponds south of the Yangtze River are assumed to be located in natural low areas in the landscape and are not surrounded by dikes and thus unprotected from floods and spray drift.

Figure A1 *Commercial fish pond (A) and natural pond (B) in China.*

A.1.2 River basins south of the Yangtze River

River basins south of the Yangtze River contain a dense network of irrigation and drainage channels of different sizes, due to the high annual precipitation amounts (between 1000 – 2050 mm/yr) and the local agricultural. A classical structure of such a system is given in Figure A2. The different types of irrigation and drainage channels are indicated as 'levels'. A level 5 channel is the smallest drainage or irrigation channel in the system and a level 1 channel is the largest channel in the system. Irrigation channels transport water from the river via level 1 to the smaller channels (level 2 - 5) to the fields. Drainage channels transport water from the fields via the smallest channels (level 5) towards the larger drainage channels to the river.

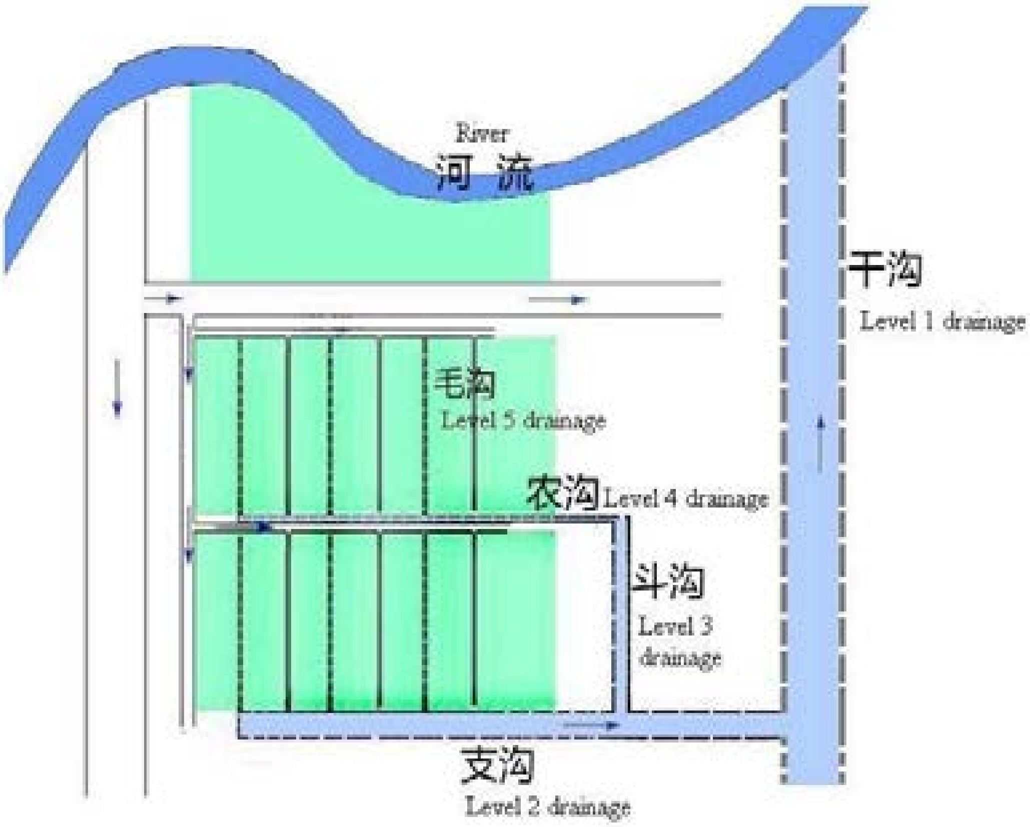


Figure A2 *Overview of the irrigation/drainage systems in river basins south of the Yangtze River. Five levels of waterways for irrigation and drainage are found (only Chinese names available): 干渠(沟) gangqu(gou), 支渠(沟) zhiqu(gou), 斗渠(沟) douqu(gou) , 农渠(沟) nongqu(gou), 毛渠(沟) maoqu(gou).*

The dimensions of the irrigation and drainage channels differ per area. In PERAP there were discussions on in which level of channel in Figure A2 to protect the aquatic ecosystem. The Chinese risk managers decided to protect the aquatic ecosystems in all level 3 drainage channels in a scenario zone. This decision was based on the fact that the Chinese risk managers whished the chosen level of channel to be a permanent and a natural or semi-natural water course. Level 5 channels are for instance mostly non-permanent and handmade (expert judgement Chinese members of the PERAP project group).

A.1.3 River basins north of the Yangtze River

North of the Yangtze River hand dug irrigation and drainage systems exist, however these are mostly non-permanent and therefore considered te be not appropriate as a protection goal. The smallest permanent water courses north of the Yangtze rivers are the smallest rivers in a river basin. The PERAP project group considered these smallest rivers to be most vulnerable for exposure to pesticides.

CAAS possesses a digital map of rivers in China. The rivers in this map are divided into 5 classes (level 5 to level 9). The classification is mainly based on discharge, size and branch type. Level 5 indicates the head branch, so the largest unit in the basin and level 6 to level 9 indicate sub-branches. For instance a level 6 river is a branch of a level 5 river and a level 7 river is a branch of a level 6 river. To illustrate this system and to test whether necessary data was available in China CAAS performed a GIS exercise using the Jiaban River (located in Binxian, Harbin and a branch of the Songhua River) as an example. Table A1 specifies the information found from the GIS exercise, an additional literature research and the consulting of Chinese experts.

Table A1
Information found by CAAS on different levels of water courses in the catchment of the Jiaban River (Binxian, Harbin)

	Level 5	Level 6	Level 7	Level 8/9
Name river(s)	**Jiaban**	*****	*****	*****
Average catchment size (ha)	**90 000**	**~ 25 500**	**~ 4000**	**~ 200**
Average dimensions	Rainy season: 2.7 m deep, 50 -100 m wide, max 2.43 m/s Dry season: 0.5 m deep, 10 m wide, 0.37 m/s	*	*	*
Yearly discharge (m3/y)	~ 134 400 000	*	*	*
Permanent?	Yes, all year round water bearing	Permanent rivers but much less water in winter, but still flowing	Permanent rivers but little water in winter and not flowing	Not permanent (dry in winter)

* No information found

From a regulatory point of view it would be reasonable to assume that the protection goal should be considered in the smallest river (level 9). However, Chinese experts explained that the sizes of the different levels of river differ per catchment. For a scenario selection procedure it would therefore be necessary to identify for each scenario zones the smallest rivers still fulfilling the criteria set by the Chinese risk managers (i.e. permanent and natural or semi-natural). Within PERAP it was decided not to continue the work on this item due to the lack of spatial data and a need to prioritise.

A.1.4 River basins in the valley of hilly areas south of the Yangtze River

River basins in the valley of hilly areas south of the Yangtze River were identified as a system containing watercourses from which the aquatic ecosystem might need to be protected from contamination with pesticides. CAAS made a rough sketch of such a system to explain its nature and to feed the discussions on the selection of protection goals (Figure A3). However, no more work was done on this surface water system due to the lack of spatial data and a need to prioritise.

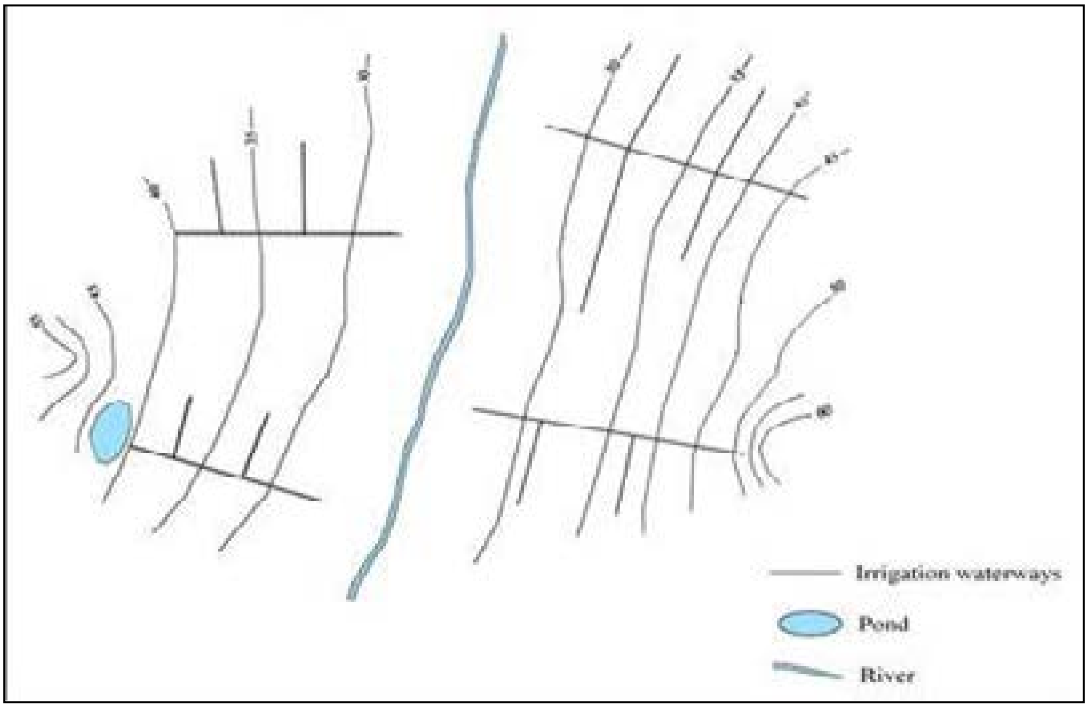


Figure A3 *Rough sketch of a typical Chinese catchment type in the hilly regions south of the Yangtze River.*

Annex B Establishing scenario zones in China

The climatic data from 580 meteorological stations was used to calculate the averages of annul precipitation and temperature from 1970 to 2005. The 'Spatial interpolation' tool in ArcGis (Desktop 9.2) was applied to the two variables for generating continuous data covering the whole country. By using 400mm and 1000mm precipitation isopleths China was divided into 3 zones (Figure B1) and by using 8 °C, 12 °C, 16 °C and 20 °C isotherms China was divided into five zones (Figure B2).

The two maps shown in Figure B1 and Figure B2 were overlaid by ArcGis to create a new map as shown in Figure B3.

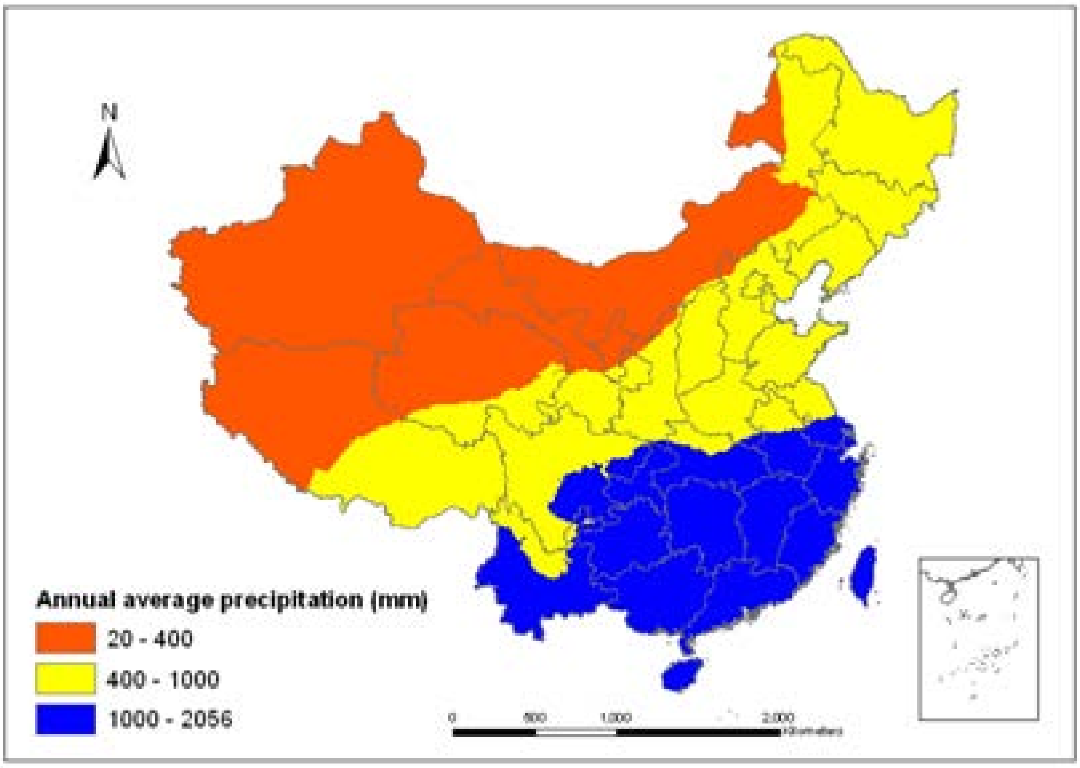


Figure B1 *Annual average precipitation in China.*

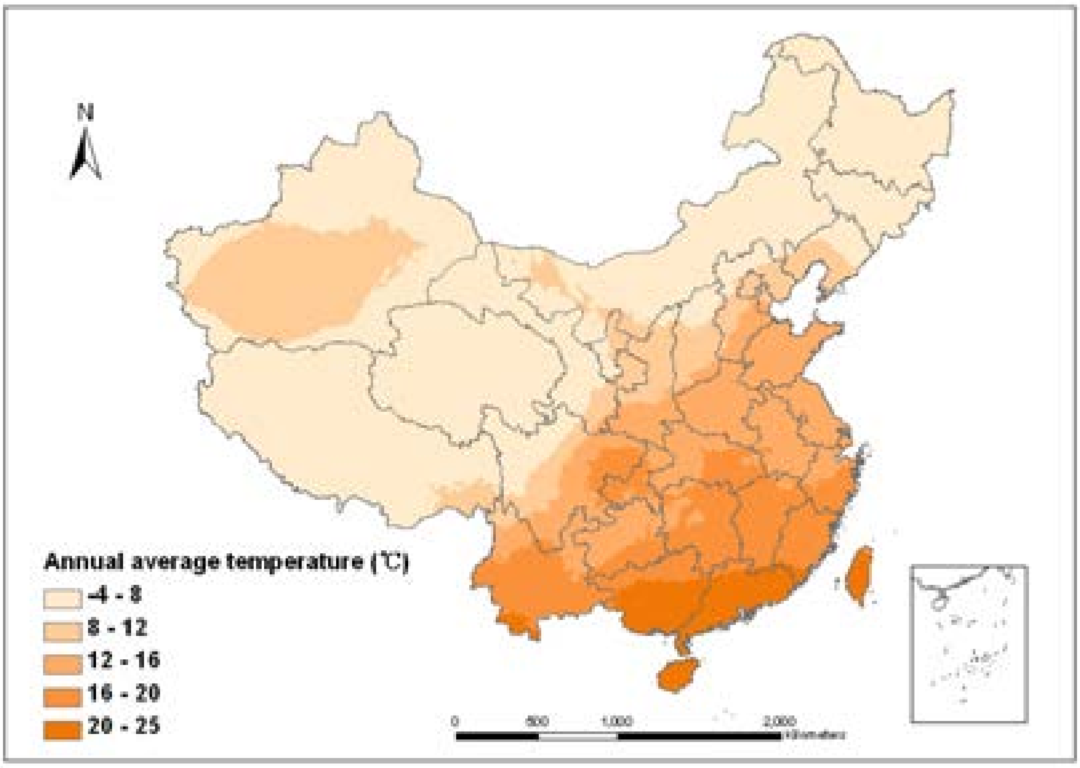


Figure B2 *Annual average temperature in China.*

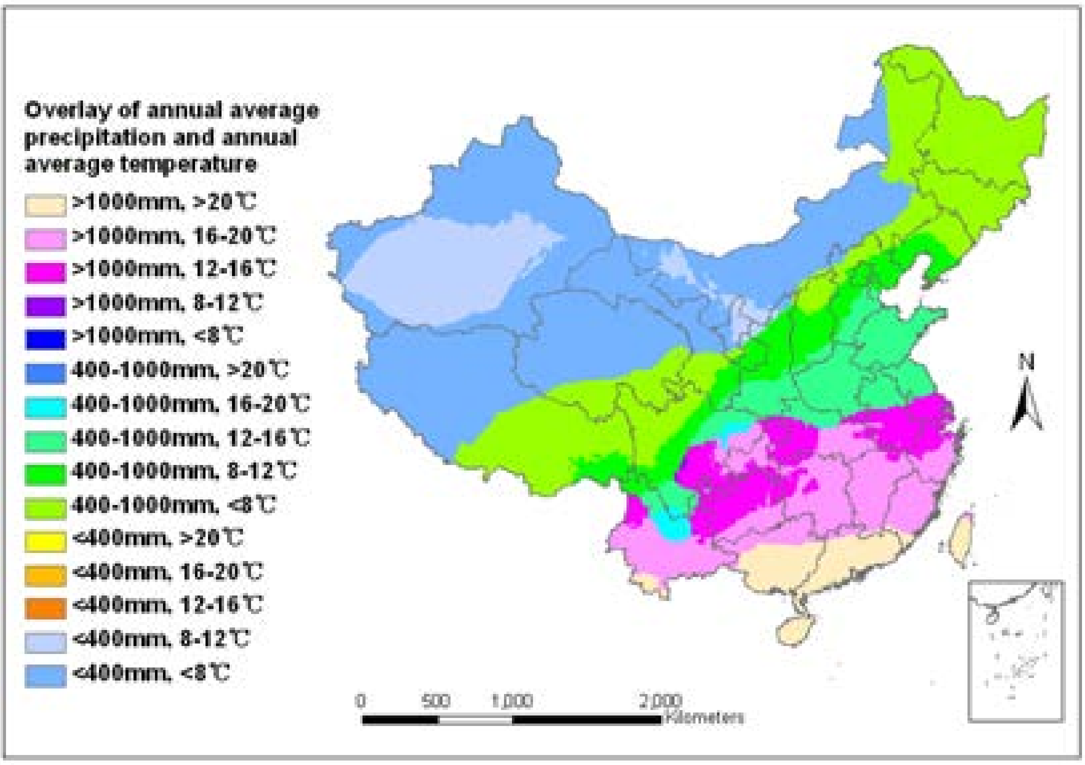


Figure B3 *Overlay of the annual average precipitation map and the annual average temperature map in China.*

Based on geographical, agricultural and meteorological regionalization in China and for the sake of generalization and simplification, some small precipitation and temperature zones are merged together or joined into neighbouring zones. The adjusted overlay of the annual average precipitation map and the annual average temperature map in China is shown in Figure B4.

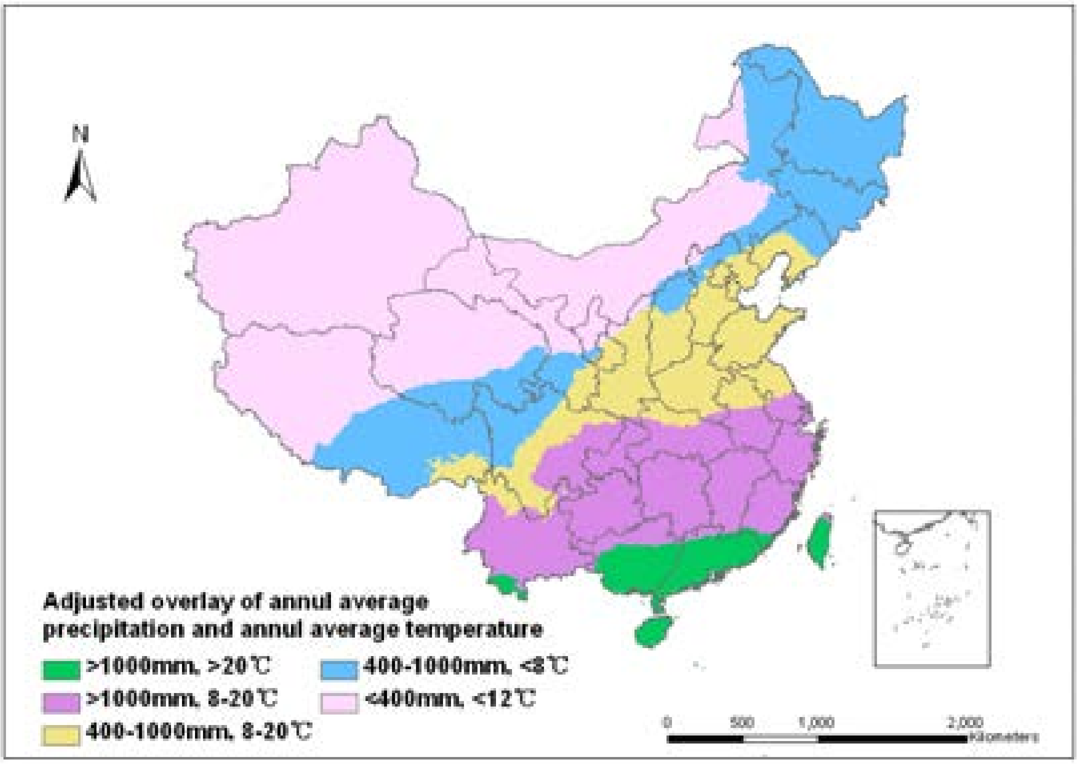


Figure B4 *Adjusted overlay of the annual average precipitation map and the annual average temperature map in China.*

Because of the high altitude and cold weather in Qinghai-Tibet Plateau, agriculture in the plateau has its unique characteristics. Based on China meteorology regionalization and after consulting with experts in CAAS and ICAMA, it was decided to consider the Qinghai-Tibet Plateau as one scenario zone. Finally China was divided into six scenario zones, as shown in Figure 7 of this report.

Annex C Selecting scenario locations for the protection goal 'Groundwater in drinking water wells at 10 m deep in dry land north of the Yangtze River'

In each of the three Northern scenario zones locations were selected that represent the 90th percentile of organic matter content and average climatic conditions in that particular scenario zone.

The scenario zone 'North China' is given here as an example to show the method used to select suitable locations in this scenario zone. The land use map (NatiData, 2000) is used to determine the areas with dry land agriculture as land use (Figure C1).

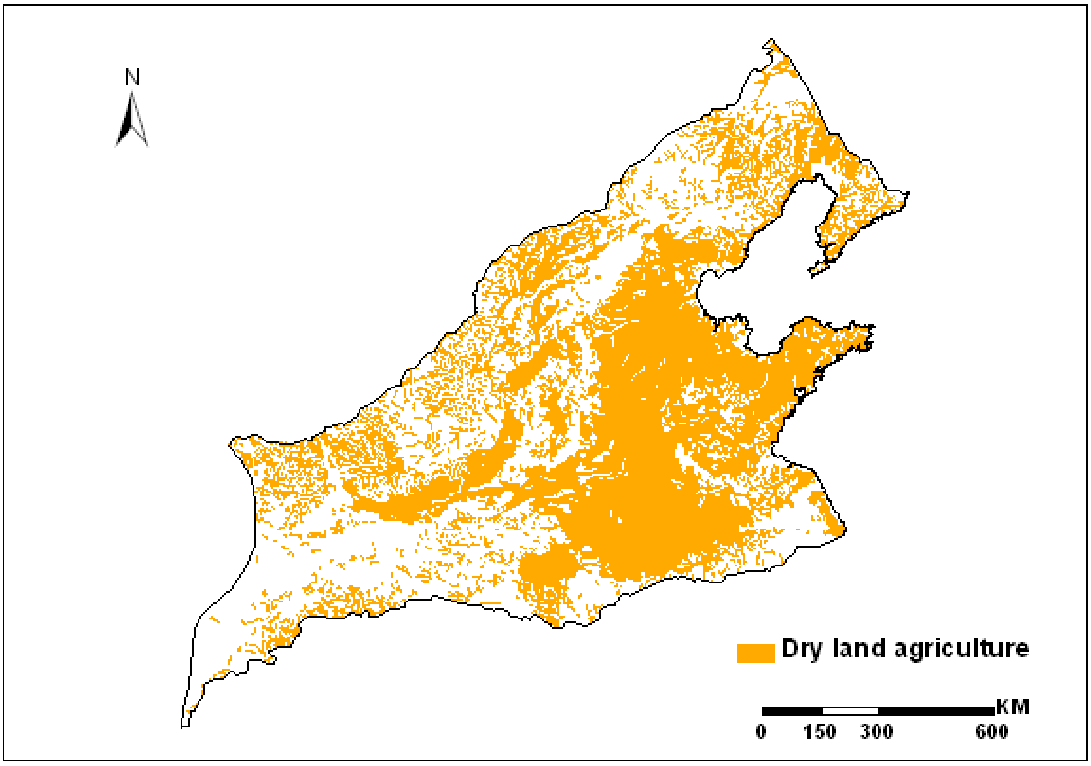


Figure C1 *Area with dry land agriculture as land use in North China Scenario Zone*

An overlay was made of the land use map (Figure C1) and the organic matter map (Digital Soil Lab, Chinese Academy of Agricultural Sciences, 2005), resulting in different subareas representing a particular organic matter class for the land use pattern dry land agriculture. The overlay is shown in Figure C2.

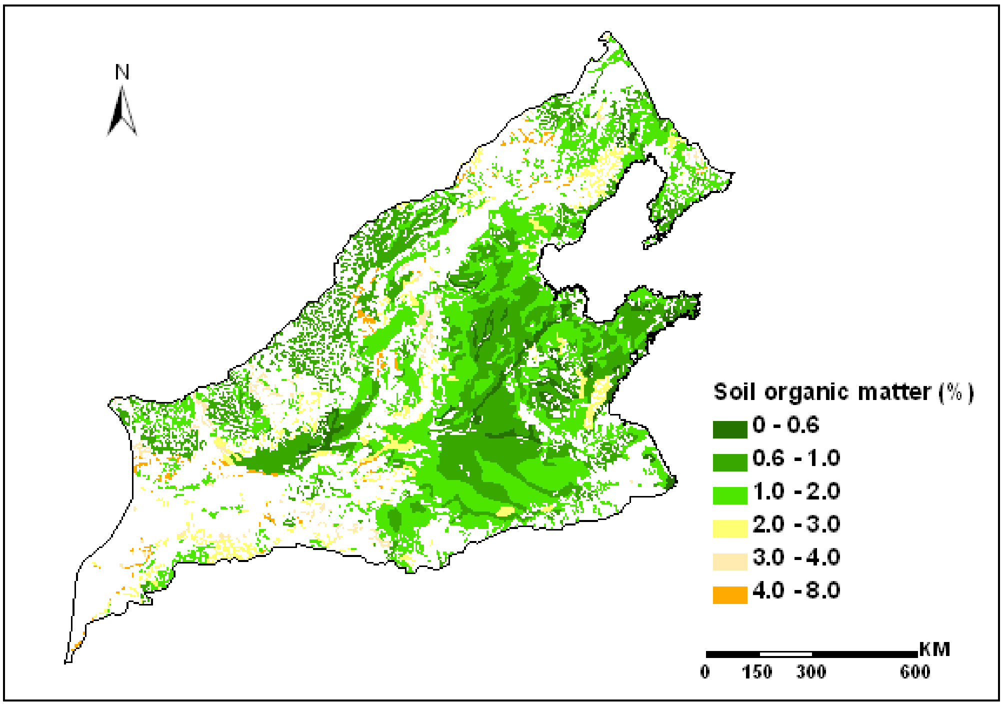


Figure C2 *The distribution of soil organic matter content for land use type dry land agriculture in the North China scenario zone.*

The digital map of the overlay has an attribute list including area, organic matter content class and average organic matter content of each sub area (Table C1). The average organic matter content is calculated per organic matter content class. Using the data in this attribute list first the fraction of the total area (land use dry land agriculture in scenario zone North China) is calculated per subarea. Next the subareas and their data are sorted according the average organic matter. Finally the cumulative fraction of total area is calculated (Table C1).

Table C1
Part of the attribute list of the different sub areas in North China Scenario Zone

Sub area	Area (ha)	OM class (%)	Average OM (%)	Fraction of total area	Cumulative fraction of total area
1964	14862.00886	0 - 0.6	0.3	0.000214934	0.000214934
1965	11171.39984	0 - 0.6	0.3	0.000161561	0.000376495
……					
2092	6771.071757	0 - 0.6	0.3	9.79232E-05	0.042693694
1179	0.03701915	0.6-1.0	0.8	5.35371E-10	0.042693695
……					
1962	36914.64471	0.6-1.0	0.8	0.000533859	0.445839489
1963	71123.28809	0.6-1.0	0.8	0.001028584	0.446868073
439	6295.769653	1-2	1.5	9.10494E-05	0.446959123
……					
1178	3048.819484	1-2	1.5	4.4092E-05	0.890587388
153	30.59464035	2-3	2.5	4.42459E-07	0.89058783
……					
2242	0.573150069	4-8	6	8.28889E-09	0.999838767
2243	11148.71951	4-8	6	0.000161233	1
Total area of scenario zone	69146769.95				

In Table C2, the cumulative fraction of the total area is given per organic matter content class.

Table C2
The cumulative fraction of total area of different organic matter content class in North China Scenario Zone

OM class	cumulative fraction of total area	
0.6	0.042693694	(fraction of total area with om 0- 0.6)
1	0.446868073	(upper range of class 0.6 -1.0)
2	0.890587388	(upper range of class 1-2)
3	0.959289463	(upper range of class 2-3)
4	0.982168607	(upper range of class 3-4)
8	1	(upper range of class 4-8)

A cumulative density function was plotted by plotting the cumulative fraction of total area per organic matter class against the upper boundary of each organic matter class (Figure C3). The 10th percentile of organic matter is found at the intersect of the plotted line and the 0.1 cumulative density function on the y-axis.

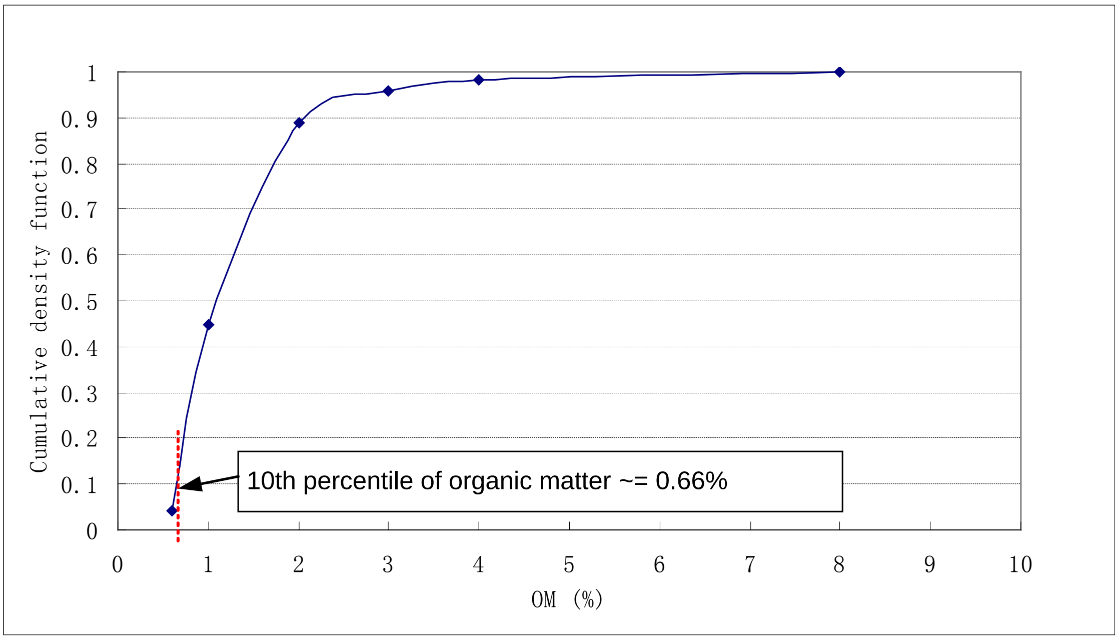


Figure C3 *The cumulative density function of organic matter content in the scenario zone North China.*

The cumulative density functions of the scenario zones Northwest China and North East China are shown in Figures C4 and C5 respectively.

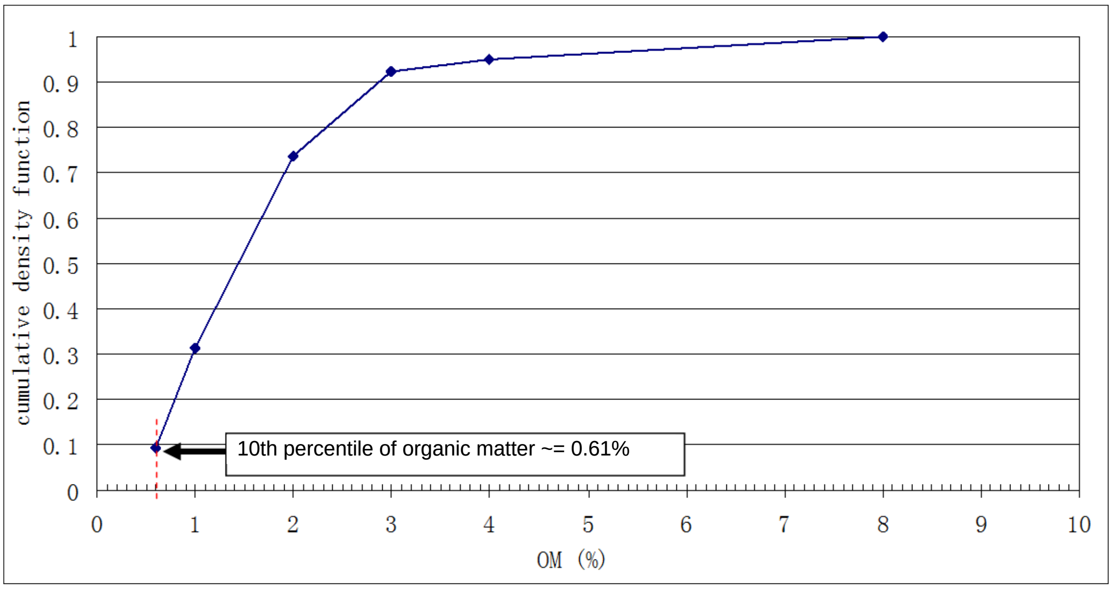


Figure C4 *The cumulative density function of organic matter content in the scenario zone Northwest China.*

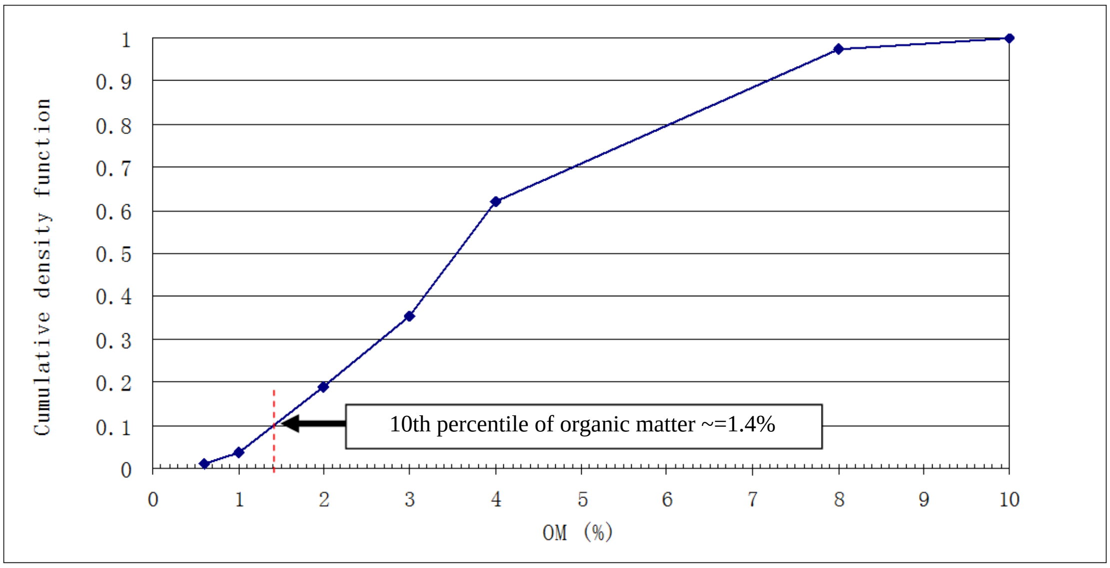


Figure C5 *The cumulative density function of organic matter content in the scenario zone Northeast China.*

Next a digital map was made showing those areas of dry land agriculture with the organic matter class representing the 10^{th} percentile of organic matter in the scenario zone North China (Figure C6). The locations of the meteorological stations are shown in Figure C6 as well. From the meteorological stations those stations were selected that represent average climatic conditions in the scenario zone North China and the selected stations should be located in an area with organic matter content class to which the 10^{th} percentile belongs.

The method described above was also used to select scenario locations for groundwater and dry land agriculture in the scenario zones Northwest China and Northeast China.

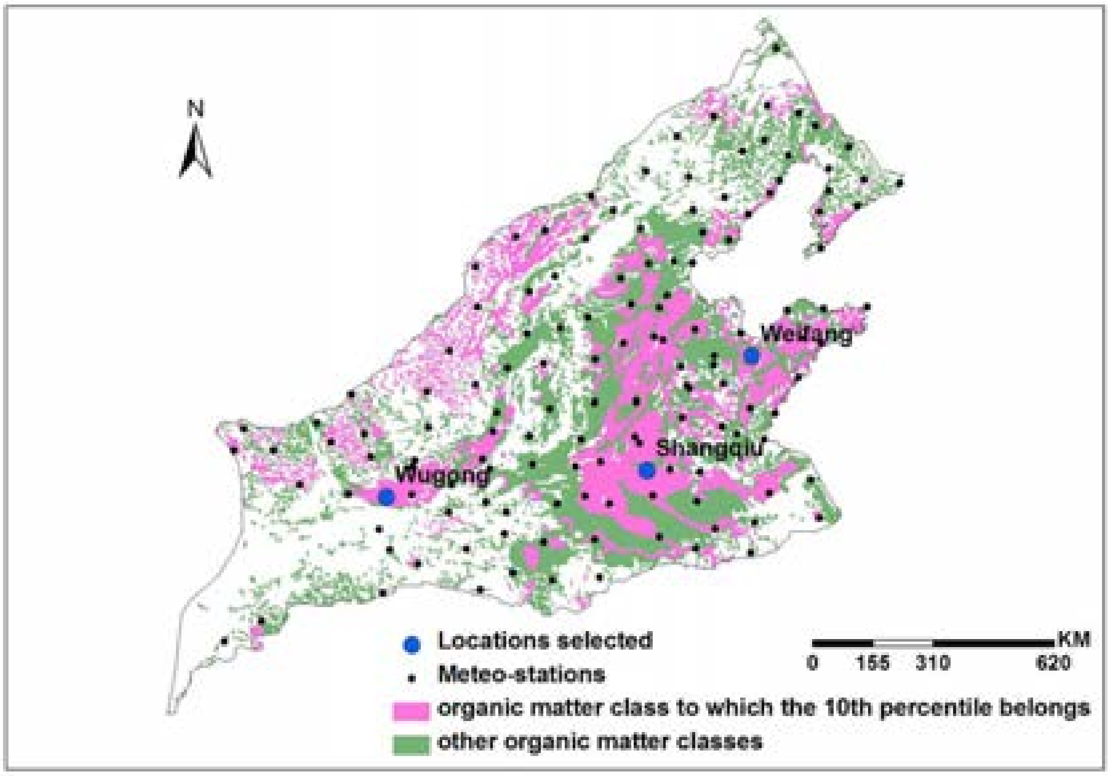


Figure C6 *Soil organic matter content for dry land a (pink: organic matter class to which the 10th percentile belongs (0.6 -1.0); green: all other organic matter classes), locations of meteorological stations (small black dots) and the locations selected for groundwater scenarios of dry land agriculture in scenario zone North China (large blue dots).*

Annex D Models considered for simulating pesticide leaching and exposure in the paddy rice field

For simulations of pesticide leaching and exposure in the paddy rice field it was considered to use models of different providers and a small review of several models was done to explore this path.
In order to fulfil our objectives the following criteria for simulation of pesticide fate in paddy rice were set:

- preferably the model simulates both exposure of pesticides in the paddy water as leaching of pesticides to the groundwater
- the model should be able to simulate the outflow of water via runoff overflow (see Figure 4) and seepage
- the model should be able to simulate zero water depth on the paddy field

The following models were seriously considered and reviewed by the PERAP project group: PFAM of the EPA, RICEWQ of Waterborne Environmental, Inc. and PCPF-1 of Tokyo University of Agriculture and Technology in Japan. Below we present a small summary of the review of each model, containing only the key items for the selection process.

The PFAM model principally aims at simulating pesticide concentrations in paddy water and sediment. In spring 2009 the PFAM model was still under development and documentation was kindly provided by its developer Dirk. F. Young of the EPA. At that moment seepage was not simulated by the model. Although the PFAM model seemed very promising, the model being under development and not including a seepage term was for the PERAP project group the reason for not selecting this model at that time.

Information of the RICEWQ model was found in Karpouzas and Capri (2006), Karpouzas *et al.* (2006), Miao *et al*. (2004) and the RICWQ manual (Williams *et al*., 2008). Although the model has a very user-friendly GUI, the PERAP project group did not select the RICEWQ model because the mathematical description of the model was not adequate. The input parameters of the model were not line with the mathematical description.

The mathematical description of the PCPF-1 model is given in Wanatabe and Takagi (2000a) and tests against field data are described by Wanatabe and Takagi (2000b), Wanatabe *et al.* (2006) and Karpouzas *et al.* (2006). The model itself was kindly provided by H. Wanatabe of Tokyo University of Agriculture and Technology. The model was regarded less suitable for regulatory purposes because there is no strict version control and the model lacks an user-interface. Data has to be filled in in a Microsoft Excel spreadsheet and calculations are performed by running a MACRO program in the spreadsheet. Although, outflow of water and pesticide mass via seepage (i.e. vertical percolation) and runoff overflow are simulated, the model needs adaption to provide these simulation results in an output file. Furthermore, Karpouzas *et al.* (2006) mentioned that the model is unable to simulate environmental fate of pesticides in those cases where the water depth on the paddy field becomes zero. The sum of these disadvantages made the PCPF-1 model according the PERAP project group less suitable for the purposes of the PERAP project and it was therefore decided not to select this model.

In this respect it is important to mention that the review of these models took place in the period autumn 2008 – spring 2009. Our reasons for not selecting these models for our purposes might not be valid at the moment of writing this report due to ongoing model developments. For instance, since spring 2009 the PFAM model has been improved considerably and a seepage term was included (Young, 2012).

Annex E Average (50th percentile) situations of land use around ponds in the Yangtze River basin (double harvests) and in the South China region (double and triple harvests) need for the vulnerability concept for exposure scenarios for the natural pond south of the Yangtze River.

Tables E1 a, b and c contain information on average (50th percentile) situations of land use around ponds in the Yangtze River basin (double harvests) and in the South China region (double and triple harvests) for the 2nd phase. Tables E2 a, b and c give the same information for the 3rd phase.

Table E1a
Average (50th percentile) situation of land use around a pond in Yangtze River basin (% of area paddy land)

	1st Harvest	2nd Harvest
Peri – Urban	R=50%, V=20%, O=30%	R=5%, V=50%, O=40%, F=5%
Rural – Rice	R=60%, V=15%, O=25%	R=55%, V=20%, O=20%, F=10%
Rural - Other	R=50%, V=20%, O=30%	R=0%, V=35%, O=55%, F=10%

Table E1b
Average (50th percentile) situation of land use around a pond in South China with double harvests (% of area paddy land)

	1st Harvest	2nd Harvest
Peri – Urban	R=50%, V=20%, O=30%	R=20%, V=30%, O=45%, F=5%
Rural – Rice	R=50%, V=25%, O=25%	R=50%, V=25%, O=20%, F=5%
Rural - Other	R=45%, V=25%, O=30%	R=0%, V=30%, O=50%, F=20%

Table E1c
Average (50th percentile) situation of land use around a pond in South China with triple harvests (% of area paddy land)

	1st Harvest	2nd Harvest	3rd Harvest
Peri – Urban	R=60%, V=20%, O=20%	R=60%, V=25%, O=15%	V=50%, O=35%, F=15%
Rural – Rice	R=65%, V=15%, O=20%	R=65%, V=20%, O=15%	V=45%, O=40%, F=15%
Rural - Other	R=60%, V=10%, O=30%	R=40%, V=30%, O=30%	V=40%, O=40%, F=20%

R denotes paddy rice, V denotes vegetables, O denotes other crops, and F denotes fallow land/bare soil.

Table E2a

Average (50th percentile) situation of land use around a pond in Yangtze River basin (% of area agricultural land)

	1st Harvest	2nd Harvest
Peri – Urban	R=30%, V=40%, O=30%	R=15%, V=50%, O=25%, F=10%
Rural – Rice	R=15%, V=25%, O=60%	R=15%, V=15%, O=25%, F=45%
Rural - Other	R=25%, V=25%, O=50%	R=20%, V=0%, O=40%, F=40%

Table E2b

Average (50th percentile) situation of land use around a pond in South China with double harvests (% of area agricultural land)

	1st Harvest	2nd Harvest
Peri – Urban	R=10%, V=15%, O=75%	R=5%, V=30%, O=35%, F=30%
Rural – Rice	R=30%, V=10%, O=60%	R=30%, V=15%, O=15%, F=40%
Rural - Other	R=10%, V=10%, O=80%	R=0%, V=30%, O=40%, F=30%

Table E2c

Average (50th percentile) situation of land use around a pond in South China with triple harvests (% of area agricultural land)

	1st Harvest	2nd Harvest	3rd Harvest
Peri – Urban	R=30%, V=20%, O=50%	R=40%, V=20%, O=40%	V=50%, O=25%, F=25%
Rural – Rice	R=30%, V=15%, O=55%	R=35%, V=20%, O=45%	V=30%, O=40%, F=30%
Rural - Other	R=15%, V=15%, O=70%	R=5%, V=15%, O=80%	V=30%, O=40%, F=30%

R denotes paddy rice, V denotes vegetables, O denotes other crops, and F denotes fallow land/bare soil.

Peri-urban areas are defined as circular areas around cities with a radius of a certain distance from the city center. For metropolitan areas and large cities, such as Beijing, Shanghai and the provincial capital cities, the radius is 50 km. For middle-sized municipalities and county level towns the radius is 25 and 10 km respectively. Agricultural fields within the peri-urban area usually are used for growing more cash crops than cereal crops. About 27.5% of total land use paddy and 13.2% of total land use dry land are located in the peri-urban area in Yangtze River basin and South China.

Rural-rice areas are defined as agricultural fields outside the peri-urban areas from cities, where at least 2 crop cycles of rice per year are grown.

Rural-other areas are defined as agricultural fields outside the peri-urban areas, where other crops than irrigated rice or vegetables are grown during at least one crop cycle per year.

Annex F Selecting scenario locations for the protection goals "Groundwater in drinking water wells at 2 m deep in paddy land south of the Yantze river" and "Aquatic organisms in natural ponds surrounded by paddy land south of the Yangtze River"

10th percentile organic matter content
CAAS made an overlay of the land use map (Figure 3) and the organic matter map (Figure F1).

The ArcGis program was used to overlay the land use map (NatiData, 2000) and organic matter map (CAAS, 2005), a new layer of paddy land with organic matter attributes was extracted from the two original maps. The result of GIS exercise is shown in Figure F2 where only the soil organic matter of land use paddy land is show for the scenario zones Yangtze River basin and South China.

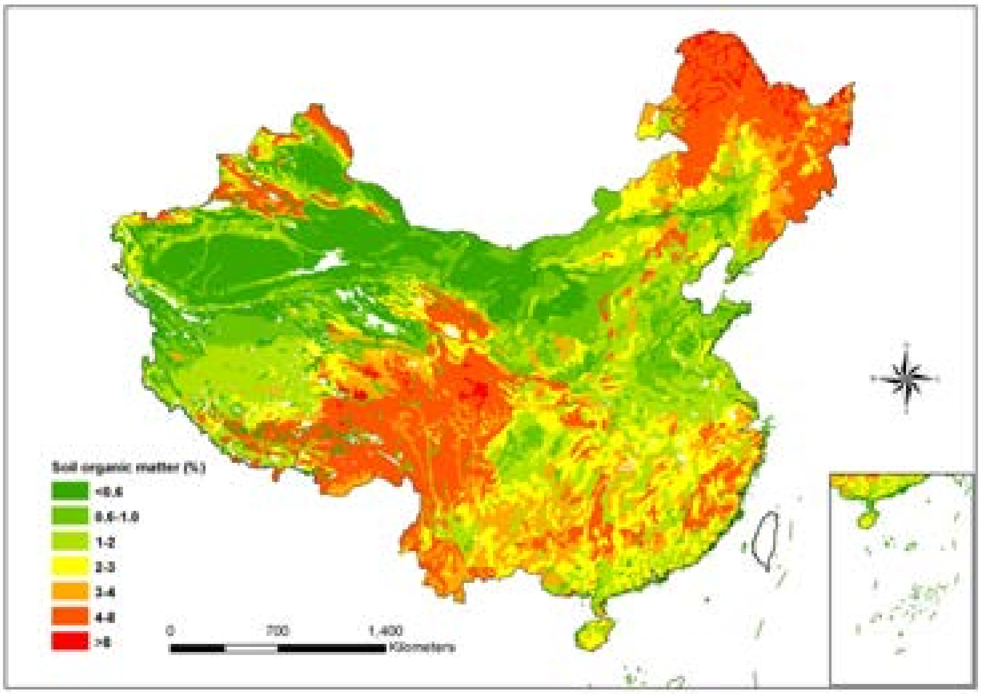


Figure F1 *Soil organic matter map of China.*

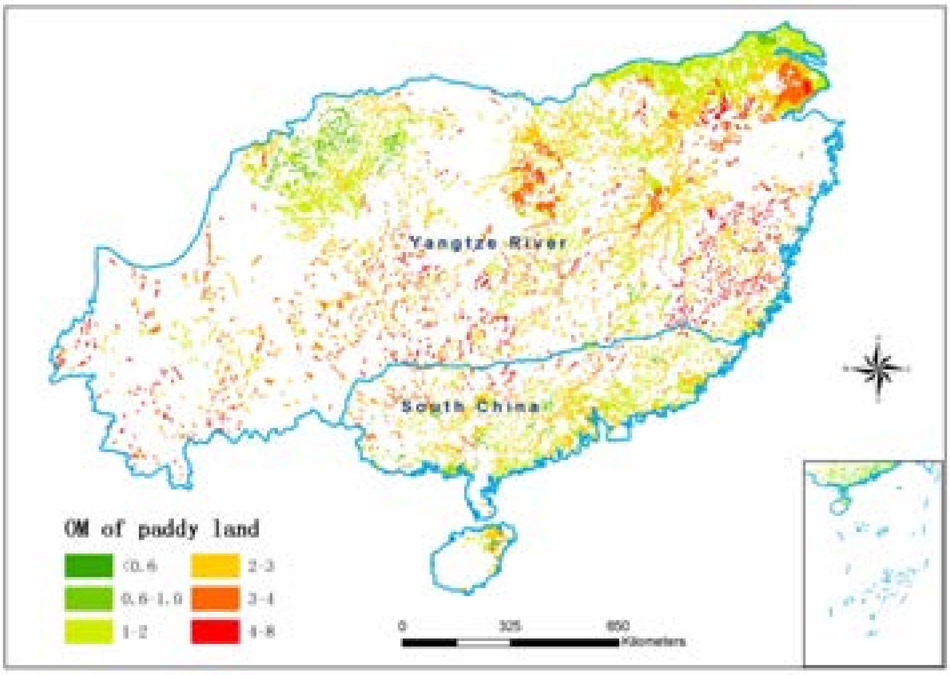


Figure F2 *Result of the overlay of the organic matter map with the land use map. Only the soil organic matter of land use paddy land is shown for the scenario zones Yangtze River basin and South China.*

From the attribute table of the organic matter content map shown in Figure F1, detailed information of organic matter of paddy land, such as organic matter content class and area of each organic matter class was extracted as an Excel file. Using Microsoft Excel, the detailed information was sorted ascending by organic matter class, then cumulative fractions of the total area of each organic matter class were calculated. The results of the calculations are listed in Tables F1 and F2 for Yangtze River basin and South China respectively.

Table F1
The cumulative fraction of total area of different organic matter content class in Yangtze River basin scenario zone

OM class	Cumulative fraction of total area	
0.6	0.000348113	(faction of total area with OM 0-0.6)
1	0.054292128	(upper range of class 0.6-1.0)
2	0.3951038	(upper range of class 1-2)
3	0.724248156	(upper range of class 2-3)
4	0.915730252	(upper range of class 3-4)
8	1	(upper range of class 4-8)

Table F2
The cumulative fraction of total area of different organic matter content class in South China scenario zone

OM class	Cumulative fraction of total area	
0.6	0.00135622	(faction of total area with OM 0-0.6)
1	0.072098766	(upper range of class 0.6-1.0)
2	0.434800806	(upper range of class 1-2)
3	0.864409509	(upper range of class 2-3)
4	0.980907223	(upper range of class 3-4)
8	1	(upper range of class 4-8)

Based on the data in Tables F1 and F2, two cumulative density functions, one for Yangtze River basin and another for South China, were plotted (see Figure F3 and Figure F4). The X-axis of the plot is the upper boundary of each organic matter class, and the Y-axis is the cumulative fraction of total area per organic matter class. Furthermore, the 10^{th} percentile of soil organic matter content for each zone was calculated, the 10^th^ percentile of soil organic matter content~=1.33% in Yangtze River basin, and the 10th percentile of soil organic matter content~=1.07%. As a coincidence, the 10th percentile of soil organic matter in the both zones fall into the organic matter content class 2, which means the soil organic matter content in the two zones are between 1-2%.

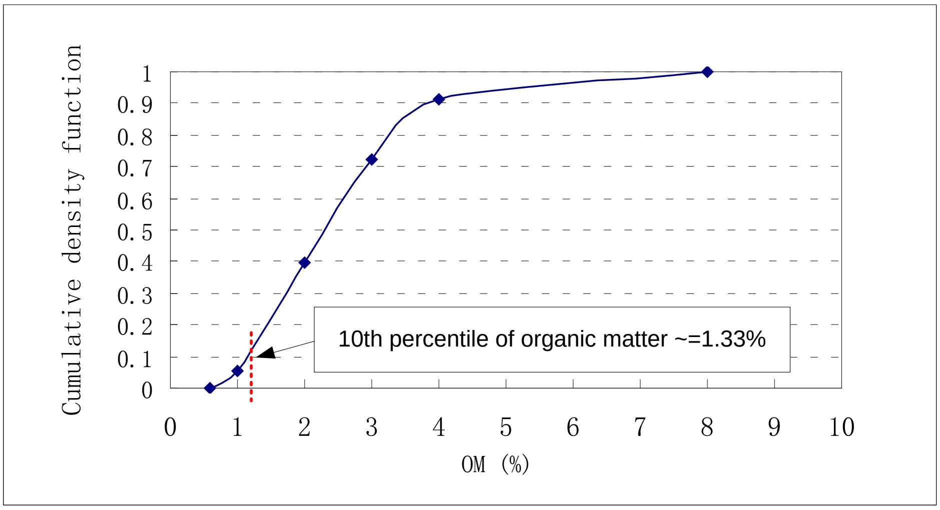


Figure F3 *The cumulative density function of organic matter content in Yangtze River basin.*

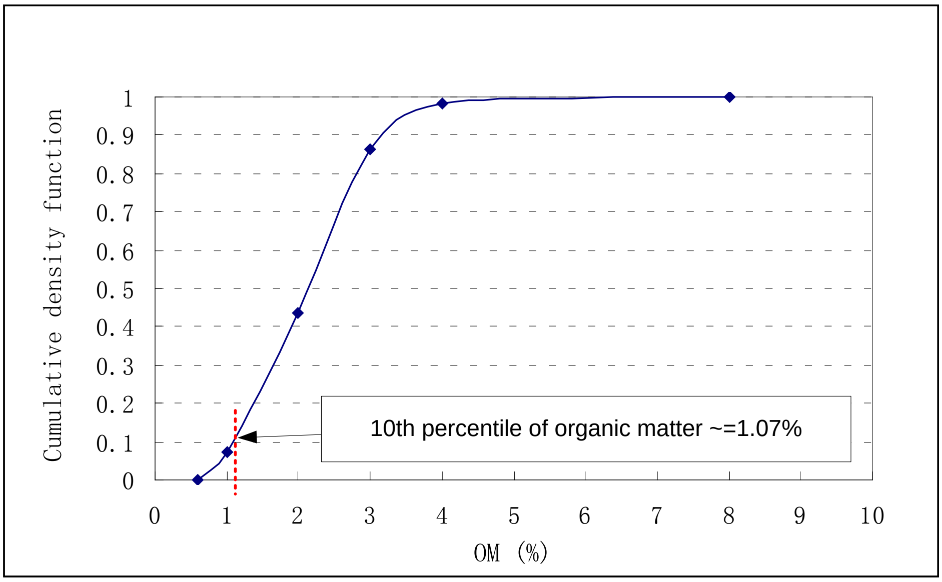


Figure F4 *The cumulative density function of organic matter content in South China zone.*

For the sake of simplification, the map of organic matter of paddy land Yangtze River basin and South China zones are re-mapped as shown Figure F5, in which the 10th percentile of organic matter content (pink colour) was separated from the other classes (green colour).

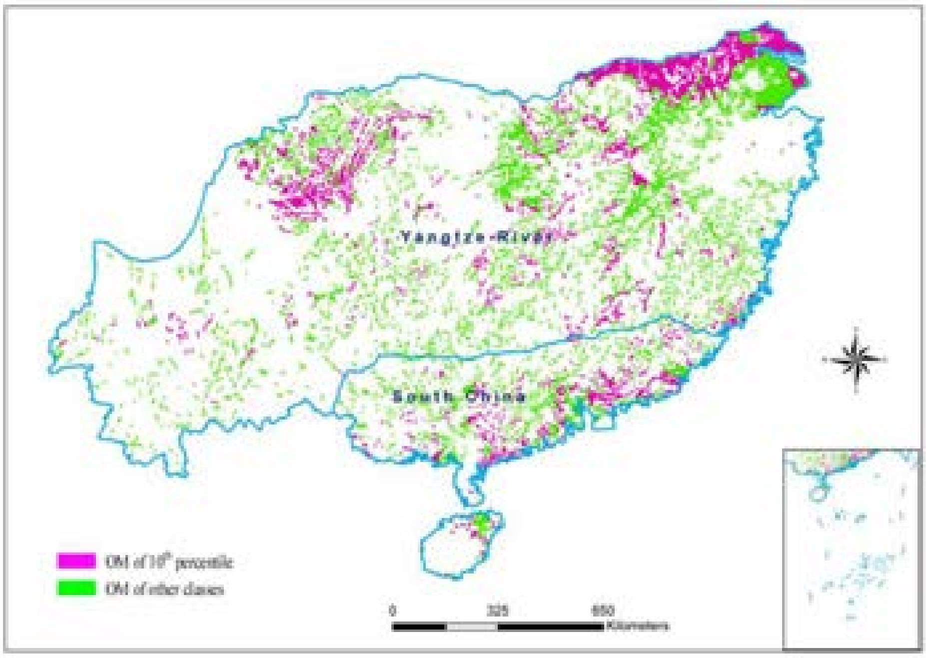


Figure F5 *Organic matter of paddy land in Yangtze River basin and South zones (Pink: the 10th percentile of organic matter content. Green: other classes of organic matter content).*

Selecting candidate meteorological stations
Next step was to map the meteorological stations on paddy land and find the candidate stations for selecting leaching and pond scenario locations. Figure F6 shows all meteorological stations in Yangtze River basin and South China of which at least 20 years of data is available. Totally there are 24 stations in Yangtze River basin and 5 stations in South China zones (see the black and blue dots in Figure F6). From these 29 stations we selected those stations that are located in or nearby areas with land use paddy land and organic matter content belonging to the organic matter class representing the 10^{th} percentile organic matter (organic matter class 1-2%). The selected meteorological stations are called candidate meteorological stations. There are 3 candidate meteorological stations in Yangtze River basin and 4 candidate meteorological stations in South China (see the blue dots in Figure F6). The names and ID number of the candidate meteorological stations are listed in Table F3.

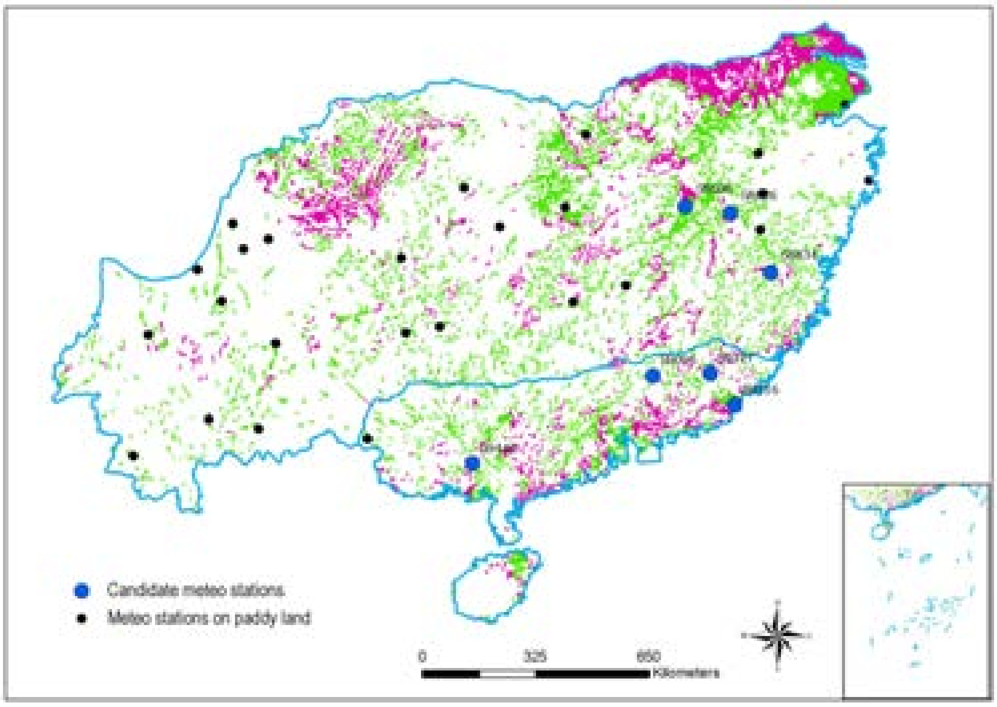


Figure F6 *Meteo stations in Yangtze River basin and South China scenario zones.*

Table F3
The names and ID numbers of the candidate meteorological stations

Yangtze River basin zone (3 candidates)	South China zone (4 candidates)
58834 -- Nanping	59446 -- Lingshan
58606 -- Nanchang	59096 -- Lianping
58626 -- Guixi	59117 -- Meixian
	59316 -- Shantou

90th percentile precipitation

The following step was to calculate the overall 90th percentile of annual average precipitation for each scenario zone. In order to find the 90th percentile of annual average precipitation in Yangtze River basin and South China, 20 years data (period 1988 – 2007) of annual precipitation of the 24 stations in Yangtze River basin and the 5 stations in South China was used to calculate the cumulative probability function of the two zones. The results are shown in Figure F7 and Figure F8. The 90th percentile of annual precipitation is 2020 mm in Yangtze River basin and 2050 mm in South China.

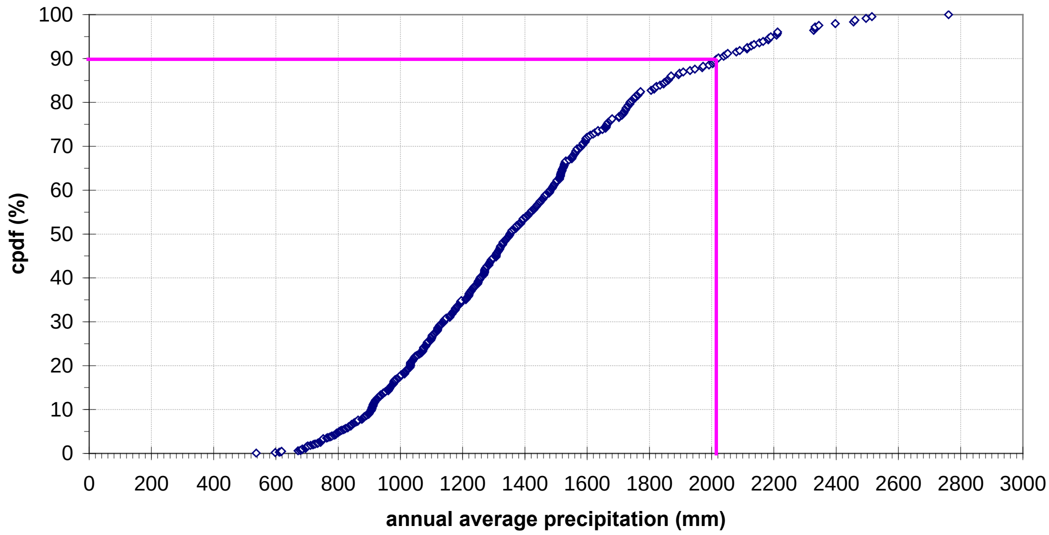


Figure F7 *Cumulative probability density function of 24 meteorological stations in Yangtze River basin and 20 years of data (period 1988 – 2007) for each meteorological station.*

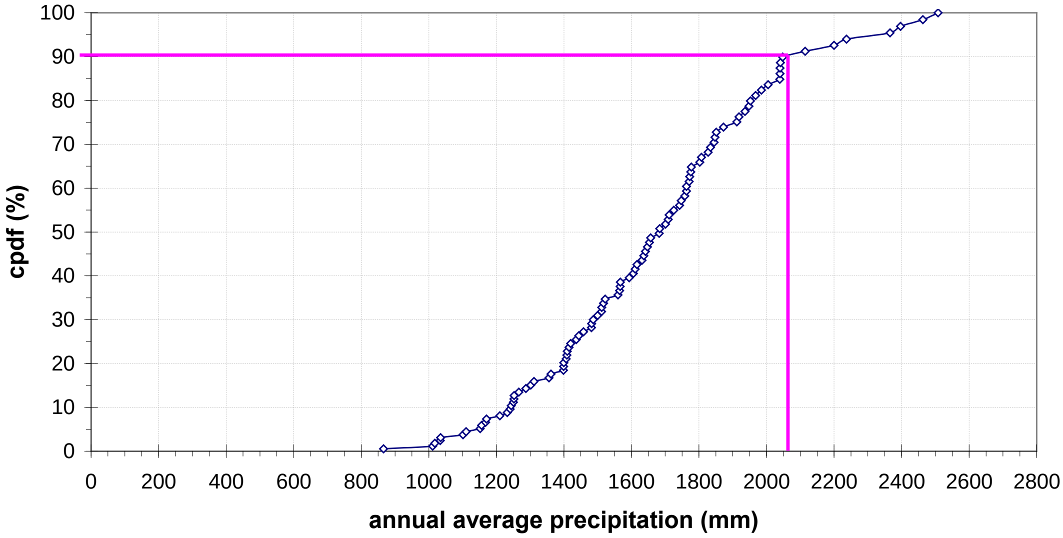
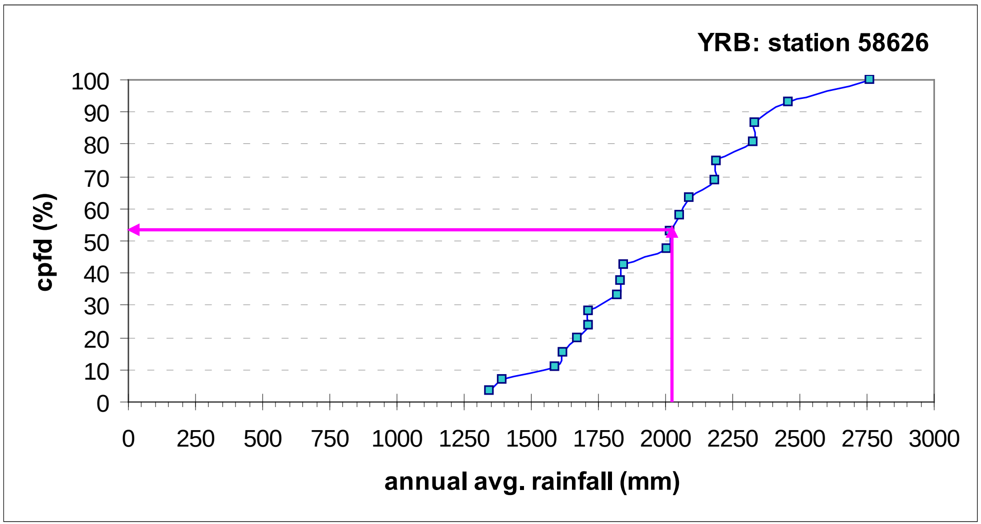


Figure F8 *Cumulative probability density function of 5 meteorological stations in South China and 20 years of data (period 1988 – 2007) for each meteorological station.*

Results: selected locations

Per scenario zone the from the candidate meteorological station the meteorological station where the overall 90th percentile precipitation is the lowest percentile in time was selected as a suitable location for both the leaching and the pond scenario. The reason for selecting the lowest percentile is that you do not want to select an extreme year. With only 20 years of meteorological data the 90th percentile can easily be a very extreme year. Selecting a year from the centre of the distribution (50th percentile) is much more robust. The location Guixin (54th percentile in time) was selected for Yangtze River basin (Figure F9 and Table F4). The location Lianping (82th percentile in time) was selected for South China (Figure F9 and Table F4).



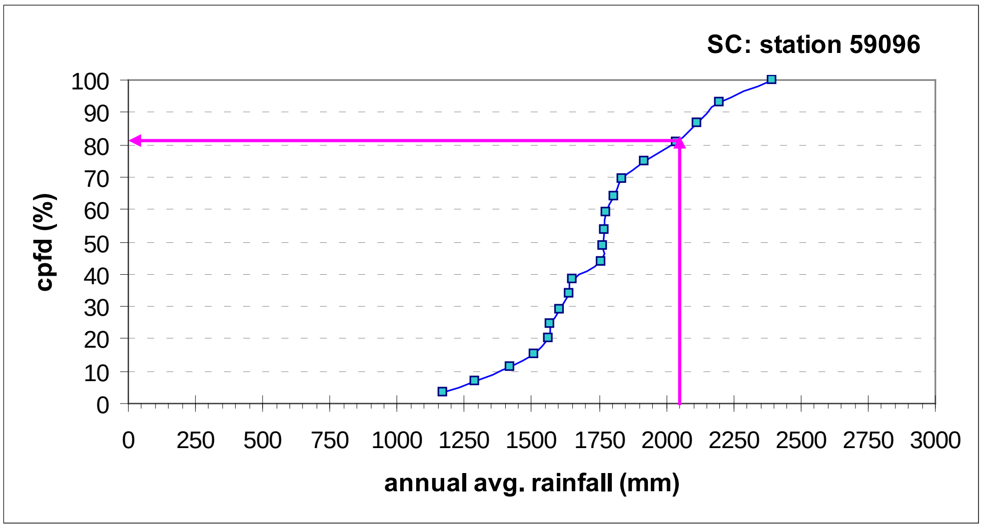


Figure F9 *Cumulative probability density function (in time) of station Guixin in Yangtze River basin (upper graph) and Lianping in South China (lower graph). Vertical pink arrow indicates the overall 90th percentile annual precipitation (2020 mm for Yangtze River basin and 2050 mm for South China) and horizontal arrow indicates the corresponding percentile of annual precipitation in time of each meteorological station.*

Table F4

Cumulative probability density function (in time) of the overall 90th percentile precipitation

Yangtze River basin		South China	
Meteo station ID - name	cpdf in time of overall 90th percentile	Meteo station ID - name	cpdf in time of overall 90th percentile
58834 -- Nanping	84%	59446 -- Lingshan	86%
58606 -- Nanchang	87%	59096 -- Lianping	82%
58626 -- Guixi	54%	59117 -- Meixian	94%
		59316 -- Shantou	86%

Unfortunately data of both selected stations (Guixi and Lianping) was not available for the Dutch partner in the project (Alterra) for confidentiality reasons and moreover for the same reason data of none of the candidate meteorological station of South China was available for the Dutch partner in the project. Therefore the meteorological station Nanchang was selected for scenario zone Yangtze River Basin and for scenario zone South China it was decided to keep Lianping as location for the soil, but to use meteorological data of another meteorological station which fulfilled the following criteria:

1. 2020 mm of annual average precipitation is within a reasonable range of the cpfd
2. (so between about 50 and 90%, but preferably close to the 50th percentile).
3. long term yearly average temperatures (average over many years) are
4. comparable to those of Lianping (deviation +1C of -1C).
5. Daily maximum precipitation patterns are not to different from those of Lianping

Applying the criteria above the meteorological station Shaoguan was selected to replace the meteorological station of Lianping (see Figure F10).

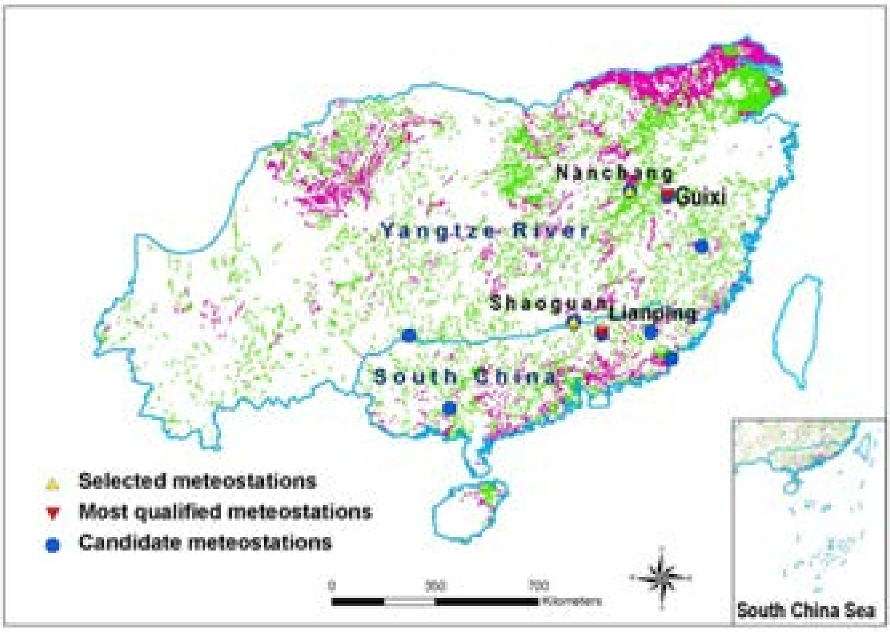


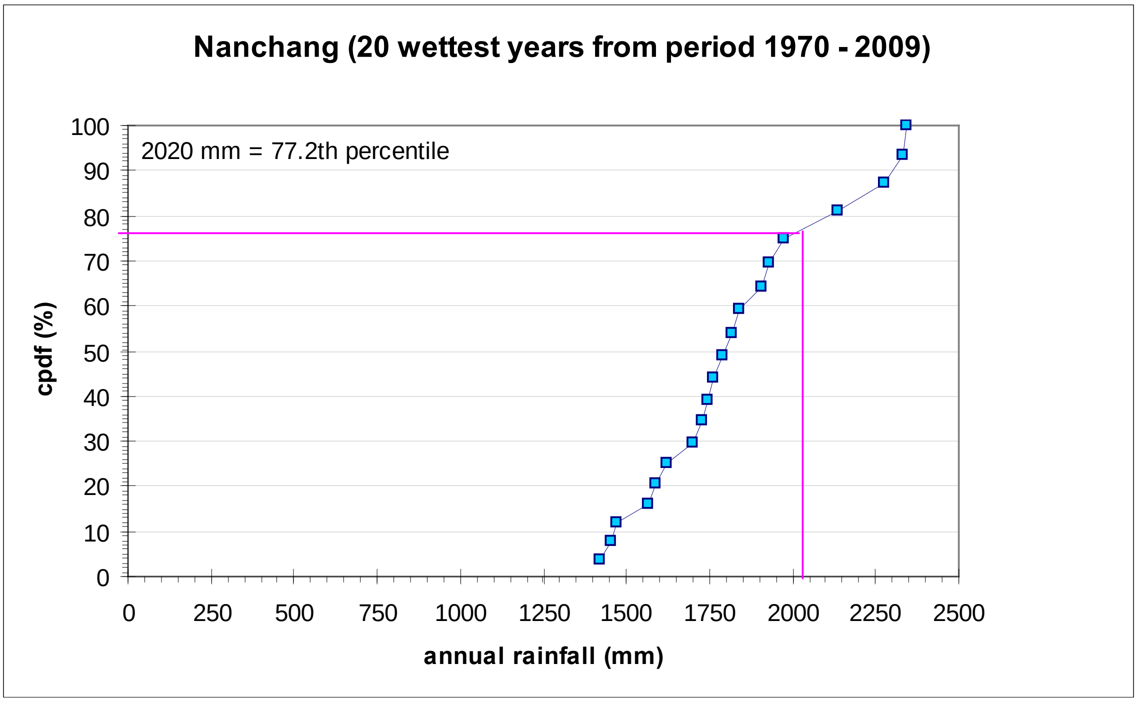
Figure F10 *Selected locations for leaching scenarios and pond scenarios in Yangtze River basin and South China.*

For both Nanchang and Shaoguan meteorological stations data was available for the period 1970 – 2009. Next step was to make the cumulative frequency distributions of the annual precipitation for each meteorological station. It is important that these cumulative frequency distributions are made using the meteorological data of 20 years which will also be used in the scenario for PEARL. Most important question was how to selected 20 years (+ 6 warm up years) from this 39 year period. It was preferred to select a meteorological station where the 90th percentile annual precipitation is the lowest percentile in time. The reason for selecting the lowest percentile is that one does not want to select an extreme year. With only 20 years of meteorological data a high percentile (for instance 90th percentile) can easily result in an extreme year, causing the timing of application to become a determining parameter for selection of the xth percentile (x = any of the numbers given in Table F5) PEC in surface water. This is undesirable, so selecting a year from the centre of the distribution (50th percentile) is more robust.

The method that resulted in the lowest percentiles in time was selecting the 20 wettest years from the period 1970-2009 (Table F5) (however still close to 90 for Shaoguan). Figure F10 shows cumulative probability density function (in time) of the 20 wettest years in the period 1970-2009 of station Nanchang in Yangtze River basin (upper graph in Figure F10) and Shaoguan South China (lower graph in Figure F11).

Table F5
Cumulative probability density function (in time) of the overall 90th percentile annual precipitation

Option	Nanchang (2020mm) cpdf (%)	Shaoguan (2050 mm) cpdf (%)
Select the 20 wettest years from the period 1970-2009	77.2	88.6



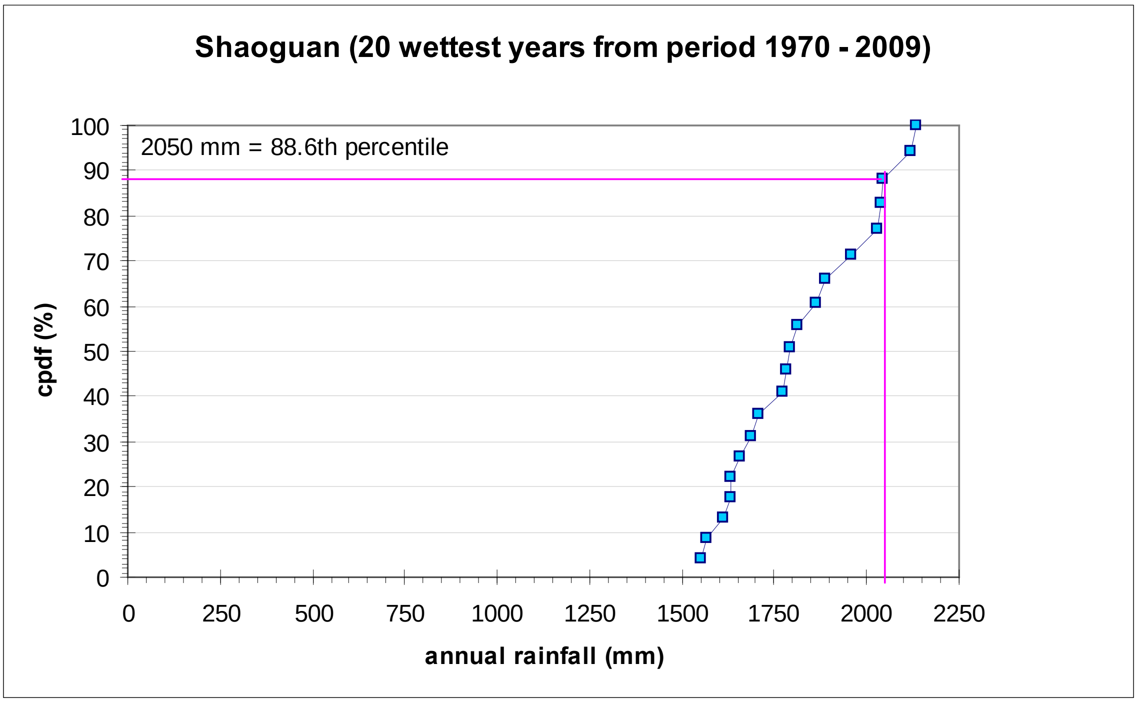


Figure F11 *Cumulative probability density function (in time) of the 20 wettest years in the period 1970-2009 of station Nanchang in Yangtze River basin (upper graph) and Shaoguan South China (lower graph). Vertical pink arrow indicates the overall 90th percentile annual precipitation (2020 mm for Yangtze River basin and 2050 mm for South China) and horizontal arrow indicates the corresponding percentile of annual precipitation in time of each meteorological station.*

Annex G Numerical aspects for the paddy water layer

The submodel described in Section 9.2 implies that the water layer is coupled “at distance” to the soil system. As a consequence, the numerical scheme for the soil does not need to be changed. However, it has to be prevented that the concentration in the water layer becomes negative.

Eq. 1 can be rewritten as:

$$\frac{d\,c_{wl}}{d\,t} = + \frac{J_w}{Z} - \xi\, c_{wl}$$

(eq. G1)

where ξ is defined as:

$$\xi = \frac{q_{\inf} + q_{over} + \left(\frac{1}{k_{liq}} + \frac{1}{K_H\, k_{gas}} \right)}{Z} + k_{t,wl}$$

(eq. G2)

The integration of c_{wl} in PEARL is performed as follows:

$$c_{wl,\,t+\Delta t} = c_{wl,t} + \Delta t \left(\frac{dc_{wl}}{dt} \right)_t$$

(eq. G3)

If we require that the concentration after integration has to be larger than zero, it can be shown that this is always the case as long as:

$$\Delta t < \frac{1}{\xi}$$

(eq. G4)

To avoid small time steps the substance in the paddy water layer is attributed to the uppermost compartment of the soil in case the depth of the paddy water layer, Z, is smaller than 1 mm.

Annex H Method to scale the measured organic matter content per soil layer to the calculated 90th percentile organic matter content

The scaling factor for organic matter content is calculated according eq. H1:

$$S = \frac{OM_{90th}}{OM_{0-20cm}} \qquad \text{(eq. H1)}$$

where:

S	scaling factor	-
OM_{90th}	90th percentile of organic matter content valid for 0-20 cm layer	%
OM_{0-20cm}	organic matter content of the 0-20 cm soil layer	%

If Δz_1 < 20 cm then

$$OM_{0-20cm} = \frac{\Delta z_1}{20} OM_1 + \frac{20 - \Delta z_1}{20} OM_2 \qquad \text{(eq. H2a)}$$

If $\Delta z_1 \geq$ 20 cm then

$$OM_{0-20cm} = OM_1 \qquad \text{(eq. H2b)}$$

For each layer (i) the scaled organic matter content is calculated according eq. H3:

$$OM_{scaled(i)} = S \cdot OM_i \qquad \text{(eq. H3)}$$

where:

Δz_1	depth of the first layer of the soil profile specified	-
OM_1	organic matter content valid the first layer of the soil profile specified	%
OM_2	organic matter content valid the second layer of the soil profile specified	%
OM_i	organic matter content valid the i^{th} layer of the soil profile specified	%
$OM_{scaled(i)}$	scaled organic matter content valid the i^{th} layer of the soil profile specified	%

Example 1: Urumchi

90th percentile of organic matter = 0.61%
The following information of the soil profile is available:

i	depth of soil layer, z_i (cm)	measured organic matter content, OM_i (%)
1	0-8	0.97
2	8-30	0.8
3	30-65	0.58
4	65-90	0.58

Δz_1 < 20 cm, so applying eq. H2a gives:

$$OM_{0-20cm} = \frac{\Delta z_1}{20} OM_1 + \frac{20-\Delta z_1}{20} OM_2$$

$$= \frac{8}{20} 0.97 + \frac{20-8}{20} 0.8 = 0.388 + 0.48 = 0.868$$

Applying eq. H1 gives: $$S = \frac{OM_{90th}}{OM_{0-20cm}} = \frac{0.61}{0.868} = 0.703$$

Applying eq. H3 for each soil layer gives:

i	depth of soil layer, zi (cm)	measured organic matter content, OMi (%)	scaled organic matter content, OMscaled(i) (%)
1	0-8	0.97	0.682
2	8-30	0.8	0.562
3	30-65	0.58	0.408
4	65-90	0.58	0.408

Example 2: Weifang

90th percentile of organic matter = 0.66 %
The following information of the soil profile is available:

i	depth of soil layer, z_i (cm)	measured organic matter content, OM_i (%)
1	0-22	1.07
2	22-38	0.89
3	38-74	0.3
4	74-97	0.32
5	97-120	0.26

$\Delta z_1 \geq$ 20 cm, so applying eq. H2b gives:

$$OM_{0-20cm} = OM_1 = 1.07$$

Applying eq. H1 gives: $$S = \frac{OM_{90th}}{OM_{0-20cm}} = \frac{0.66}{1.07} = 0.6168$$

Applying eq. H3 for each soil layer gives:

i	depth of soil layer, z_i (cm)	measured organic matter content, OM_i (%)	scaled organic matter content, $OM_{scaled(i)}$ (%)
1	0-22	1.07	0.660
2	22-38	0.89	0.549
3	38-74	0.3	0.185
4	74-97	0.32	0.197
5	97-120	0.26	0.160

Annex I Information on Rosetta Lite Version 1.1.

Schaap *et al*. (1998) calibrated hierarchical neural network pedotransfer functions for the van Genuchten–Mualem relationships on a large database of soil hydraulic and related properties, and implemented the resulting pedotransfer functions into the Rosetta software package (Schaap *et al*., 2001). The Rosetta Lite Version 1.1 program (a simplification of Rosetta) of Schaap *et al*. (2001) predicts van Genuchten soil hydraulic parameters (van Genuchten, 1980) using five different levels of input data. The most simple model (Model 1) uses the average of fitted hydraulic parameters within a textural class in the USDA textural triangle. The four other models in Rosetta use progressively more detailed input data, starting with the sand, silt, and clay fractions (Model 2), then adding a measured bulk density value (Model 3), and additionally requiring water contents at 33 (Model 4) and 1500 (Model 5) kPa suctions (*i.e.,* at 330 and 15,000 cm), which are traditionally considered to be the field capacity and permanent wilting point, respectively. All five models have been calibrated on the same data set. The calibration data set contained 2134 samples for water retention and 1306 samples for saturated conductivity (Schaap and Leij, 1998). The samples were obtained from a large number of sources and involve agricultural and non-agricultural soils in temperate climate zones of the northern hemisphere (mainly from the USA and some from Europe). Note, that usage of Rosetta for other climate zones, and hence other pedogenic processes, might lead to inaccurate predictions.

Annex J Fortran program for converting the extraterrestrial radiation and relative sunshine duration to solar radiation

```
************************************************************************
      Program SunhrsToRadns
************************************************************************
** PROGRAM:
**    program SunhrsToRadns - program to convert sun-hrs to net incoming radiation
** SYNOPSIS:
**    PROGRAM Swa2Ani
**    IN:
**       integer      -
**       real         -
**       file usage:  SunhrsToRadns.inp
**    OUT:
**       integer      -
**       real         -
**       file usage:  SunhrsToRadns.log, SunhrsToRadns.out
**    USE OF SUBPROGRAMS:
**       Subroutines: TTUtil
**       Functions:
**
**
**    USE OF COMMON BLOCKS:
**       -
** DESCRIPTION:
*  content : input-parameters to convert sunshine hrs to Rn
*            input according to TTUTIL (http://www.alterra.nl/models/ttutil)
*            Input: latitude, coef_a, coef_b, tabel with dayrns,sunhrs
*            Output: tabel with daynr, Rn (Kjoule/m2/d), Ra (Kjoule/m2/d)
*  procedure: see http://www.fao.org/docrep
*  Example from FAO:
*   Input:
*    latitude = -20.0           ! FAO-example
*    coef_a = 0.25              ! FAO-example
*    coef_b = 0.50              ! FAO-example
*    daynr  sunhrs
*     246    12.0
*   Output:
*       daynr  Rn(Kj/m2/day)   Ra(Kj/m2/day)
*         246   24613.13       32203.69
** HISTORY:
**    May 2002  J.G. Kroes - creation
* Rn is wat in foa doc Rs is, Zonne- of kortgolvige straling in Kj m-2 dag-1
* dus de netto inkomende kortgolvige straling.
************************************************************************
*
```

```
C---- Declarations
      IMPLICIT NONE
      Integer maxdat
      parameter (maxdat=50000)
      Integer ui, uolg, uo, daynr(maxdat), iday, ifnd
      integer*4 getun2, getun
      Real    coef_a, coef_b, latitude, sunhrs(maxdat), Rn(maxdat)
      real    solardeclination, SolarHourAngle, solardistance
      real    Ra(maxdat), sunhrsmax, latitude_deg, pi


C --- constants
      pi = 3.14159



C --- open log file
      uolg = getun (10,19)
      call fopens(uolg,'SunhrsToRadns.log','new','del')

C --- Read input file
      ui = getun2 (10,19,2)
      call rdinit(ui,uolg,'SunhrsToRadns.inp')
      call rdsrer ('latitude',-55.0,55.0,latitude_deg)
      call rdsrer ('coef_a',0.0,1.0,coef_a)
      call rdsrer ('coef_b',0.0,1.0,coef_b)
      call rdainr ('daynr',0.0,366.0,daynr,maxdat,ifnd)
      call rdfrer ('sunhrs',0.0,24.0,sunhrs,maxdat,ifnd)
      close(ui)
      close(ui+1)

C --- initialise
      latitude = latitude_deg*pi/180. ! convert from degrees to rads

c --- calculate

         do iday = 1,ifnd
c           solardeclination (rad)
           solardeclination = 0.409 *
     &                       sin( (2.0*pi/365.0)*daynr(iday)-1.39 )
c           solardistance (relative)
           solardistance = 1.0 + 0.033 * cos (0.0172 * daynr(iday))
c           SolarHourAngle (rad)   latitude inpunt in degr. -> rad
           SolarHourAngle = acos (-tan(latitude)*tan(solardeclination))
c            Extra terrestrial shortwave solar radiation (Ra in W/m2/day)
           Ra(iday) = 435.2 * solardistance *(SolarHourAngle*
     &         sin(latitude)*sin(solardeclination) +
     &         cos(latitude)*cos(solardeclination)*sin(SolarHourAngle))
c             max sunshine hours
           SunhrsMax = 7.64 * SolarHourAngle
c           at-surface net incoming shortwave radiation Rn (W/m2/day)
           Rn(iday) = (coef_a + coef_b * sunhrs(iday)/sunhrsmax)
     &                * Ra(iday)
c                    Rn from W/m2/day to KJoule/m2/day, by 86.4
           Rn(iday) = 86.4 * Rn(iday)
      end do
```

```
c --- output
         uo = getun (20,30)
         call fopens(uo,'SunhrsToRadns.out','new','del')
         write(uo,*) '      daynr  Rn(Kj/m2/day)   Ra(Kj/m2/day)'
         do iday = 1,ifnd
           ra(iday) = ra(iday)*86.4
           write(uo,*) daynr(iday), Rn(iday), Ra(iday)
         end do

c --- close files
      close(uolg)
      close(uolg-1)
      close(uo)
      close(uo+1)

      end
```

Annex K Details on the construction of the meteorological input for Nanchang and Lianping

Table K.1
Details on the construction of the meteorological input for Nanchang for simulation of 26 years

Year no	Years in simulation	Year no	Years in simulation	Year no	Years in simulation	Year of which meteorological data is used	comment
1	1901					2005	-
2	1902					1983	-
3	1903					1991	-
4	1904*					1993	data of 28 Feb. (0 mm rain) is used to create an entry for 29 Feb.
5	1905					1994	-
6	1906					1989	-
7	1907	27	1927	47	1947	1975	-
8	1908*	28	1928*	48	1948*	1980*	-
9	1909	29	1929	49	1949	1994	-
10	1910	30	1930	50	1950	1973	-
11	1911	31	1931	51	1951	1997	-
12	1912*	32	1932*	52	1952*	1995	data of 28 Feb. (0 mm rain) is used to create an entry for 29 Feb.
13	1913	33	1933	53	1953	1989	-
14	1914	34	1934	54	1954	1970	-
15	1915	35	1935	55	1955	1983	-
16	1916*	36	1936*	56	1956*	1998	data of 28 Feb. (0 mm rain) is used to create an entry for 29 Feb.
17	1917	37	1937	57	1957	1991	-
18	1918	38	1938	58	1958	2002	-
19	1919	39	1939	59	1959	2006	-
20	1920*	40	1940*	60	1960*	1972*	-
21	1921	41	1941	61	1961	1993	-
22	1922	42	1942	62	1962	1977	-
23	1923	43	1943	63	1963	2003	-
24	1924*	44	1944*	64	1964*	1984*	-
25	1925	45	1945	65	1965	1999	-
26	1926	46	1946	66	1966	2005	-

* leap year

For Year no. 7 – 26 → 20 wettest years from period 1970-2009 were put in random order. From these 20 wettest year randomly 6 years were selected and used as warm up years (year no. 1-6). For Year no. 27-46 and 47-66 the same years and year order as for the period year no 7-26 were used.

Table K.2

Details on the construction of the meteorological input for Shoaguan (metestation used for location Lianping) for simulation of 26 years

Year no	Years in simulation	Year no	Years in simulation	Year no	Years in simulation	Year of which meteorological data is used	comment
1	1901					1996*	data of 29 February (1.6 mm rain) is deleted.
2	1902					2006	-
3	1903					2005	-
4	1904*					2000*	-
5	1905					1992*	data of 29 February (0.9 mm rain) is deleted.
6	1906					1982	-
7	1907	27	1927	47	1947	2006	-
8	1908*	28	1928*	48	1948*	2005	data of 28 Feb. (15.7 mm rain) is used to create an entry for 29 Feb.
9	1909	29	1929	49	1949	2001	-
10	1910	30	1930	50	1950	1976*	data of 29 February (0 mm rain) is deleted.
11	1911	31	1931	51	1951	2008*	data of 29 February (0.8 mm rain) is deleted.
12	1912*	32	1932*	52	1952*	2002	data of 28 Feb. (0 mm rain) is used to create an entry for 29 Feb.
13	1913	33	1933	53	1953	1981	-
14	1914	34	1934	54	1954	1993	-
15	1915	35	1935	55	1955	1982	-
16	1916*	36	1936*	56	1956*	1972*	-
17	1917	37	1937	57	1957	1970	-
18	1918	38	1938	58	1958	1983	-
19	1919	39	1939	59	1959	2000*	data of 29 February (0 mm rain) is deleted.
20	1920*	40	1940*	60	1960*	1992*	-
21	1921	41	1941	61	1961	1998	-
22	1922	42	1942	62	1962	1975	-
23	1923	43	1943	63	1963	1973	-
24	1924*	44	1944*	64	1964*	1996*	-
25	1925	45	1945	65	1965	1994	-
26	1926	46	1946	66	1966	1997	-

* leap year

For Year no. 7 – 26 → 20 wettest years from period 1970-2009 were put in random order. From these 20 wettest year randomly 6 years were selected and used as warm up years (year no. 1-6). For Year no. 27-46 and 47-66 the same years and year order as for the period year no 7-26 were used.

Annex L Parameterisation of the PEARL model for the selected crops

X.PRL

RepeatCrops	Option to repeat growth of same crop each year	Yes	
OptLenCrp	Option to make the length of the crop cycle dependent on temperature sum	Fixed	
table RootDensity	Table that specifies the root density distribution over the rooting depth using the format: - relative rooting depth (i.e. depth divided by rooting depth) - relative root density	For both crops: 0.0 1.0 1.0 1.0 Default values from SWAP	
RstEvpCrp	Canopy resistance (s/m)	70	Source: Van Dam et al. (1997, p. 72)
CofExtDif	Extinction coefficient for solar radiation (-)	0.39	Feddes et al. (1978); Ritchie (1972)
CofIntCrp	Interception coefficient (cm)	0.0001	This value implies zero interception in practice
ZTensiometer	Depth of virtual tensiometer (m)	0.2	
PreHea IrrSta	Critical head for irrigation (cm)	-100	

TableApples

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-500
HLim3L	Lower dry reduction point (cm)	-800
HLim4	Wilting point (cm)	-16000

Table: Winter cereals

Parameter	Description	
HLim1	Anaerobisosis point (cm)	0
HLim2	Wet reduction point (cm)	-1
HLim3U	Higher dry reduction point (cm)	-500
HLim3L	Lower dry reduction point (cm)	-900
HLim4	Wilting point (cm)	-16000

Table: Spring cereals

Parameter	Description	
HLim1	Anaerobisosis point (cm)	0
HLim2	Wet reduction point (cm)	-1
HLim3U	Higher dry reduction point (cm)	-500
HLim3L	Lower dry reduction point (cm)	-900
HLim4	Wilting point (cm)	-16000

Table: vines

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-700
HLim3L	Lower dry reduction point (cm)	-750
HLim4	Wilting point (cm)	-16000

Table: Soybean

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-750
HLim3L	Lower dry reduction point (cm)	-2000
HLim4	Wilting point (cm)	-16000

Table: Potatoes

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-320
HLim3L	Lower dry reduction point (cm)	-600
HLim4	Wilting point (cm)	-16000

Table: cotton

Parameter	Description	
HLim1	Anaerobisosis point (cm)	100
HLim2	Wet reduction point (cm)	100
HLim3U	Higher dry reduction point (cm)	-1000
HLim3L	Lower dry reduction point (cm)	-2000
HLim4	Wilting point (cm)	-16000

Table: Spring and summer maize

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-15
HLim2	Wet reduction point (cm)	-30
HLim3U	Higher dry reduction point (cm)	-325
HLim3L	Lower dry reduction point (cm)	-600
HLim4	Wilting point (cm)	-8000

Table: Alfalfa

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-200
HLim3L	Lower dry reduction point (cm)	-800
HLim4	Wilting point (cm)	-8000

Table: Sugarbeet

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-10
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-300
HLim3L	Lower dry reduction point (cm)	-600
HLim4	Wilting point (cm)	-16000

Table: Tobacco

Parameter	Description	
HLim1	Anaerobisosis point (cm)	-16
HLim2	Wet reduction point (cm)	-25
HLim3U	Higher dry reduction point (cm)	-300
HLim3L	Lower dry reduction point (cm)	-800
HLim4	Wilting point (cm)	-16000

Table: Paddy rice

Parameter	Description	
HLim1	Anaerobisosis point (cm)	100
HLim2	Wet reduction point (cm)	100
HLim3U	Higher dry reduction point (cm)	-10000
HLim3L	Lower dry reduction point (cm)	-10000
HLim4	Wilting point (cm)	-16000

The table below lists the information found on irrigation period per crop. The exact start and end dates of the irrigation period in each scenario are given in the section 'Crop parameters...' in this Annex.

Table Irrigation period for the crops of the groundwater scenarios for dry land north of the Yangtze River

Crop	Irrigation Period	Source
Apple	emergence date – 60 days after harvest date	China Agricultural Encyclopedia, Orchard Volume, China Agricultural Press 1993
Alfalfa	emergence date—30 days after harvest	Xu Bin *et al*, Alfalfa climate subdivision in China, ACTA AGRESTIA SINICA, 2007 Vol. 15, No.4
Cotton	15 days before emergence-30 days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Dr. Ma Xinlin, Institute of Crop Science, CAAS
Potatoes	3 days after emergence – 7 days before harvest	http://fpb.xxz.gov.cn/189.html, retrieved in November 2009
Soybean	15 days before emergence – 20 days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Chen Changli, Associate professor in Institute of Crop Science, CAAS
Spring Maize	15 days before emergence-20 days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Chen Changli, Associate professor in Institute of Crop Science, CAAS
Spring Wheat	15 days before emergence-20 days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Chen Changli, Associate professor in Institute of Crop Science, CAAS
Sugarbeet	15 days before emergence - 15 days before harvest	http://www.plant.ac.cn and http://www.bzncw.gov.cn, retrieved in November 2009
Summer Maize	15 days before emergence-20 days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Chen Changli, Associate professor in Institute of Crop Science, CAAS
Tobacco	In the same day of transplanting (emergence date) - 10days before harvest	Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Wang Xianjun, division deputy chief, China Tobacco.

Crop parameters Xinmin

Table: Xinmin, planting, emergence and harvest dates

Crop	Growth stage Planting dd/mm	Emergence dd/mm	Harvest dd/mm	Source
Spring wheat		15/04	20/08	MOA crop calendar database 2008
Spring maize		15/05	20/09	China National Meteorological Information Centre, NMIC
Soybean		25/05	28/09	China National Meteorological Information Centre, NMIC
Sugar Beet		25/04	28/09	MOA crop calendar database 2006

Table: Xinmin, irrigation period start- and end date

	Start Irrigation period	End Irrigation Period
Spring wheat	31/03	31/07
Spring maize	30/04	31/08
Soybean	10/05	08/09
Sugar Beet	10/04	13/09

Table: Xinmin, crop parameters

Crop	Development stage -	LAI $m^2 m^{-2}$	Crop factor -	Root depth m	Source
Spring wheat	0	0	1	0	HAMB-SCEREALS in PEARL 3.3.3
	0.465	3.9	0.8	0.9	
	1	3.9	0.8	0.9	
Spring maize	0	0	1	0	HAMB-MAIZE in PEARL 3.3.3
	0.625	4.2	0.86	1.2	
	1	4.2	0.86	1.2	
Soybean	0	0	1	0	PIAC Soybean in PEARL 3.3.3
	0.555	6.5	0.81	0.6	
	1	6.5	0.81	0.6	
Sugar beet	0	0	1	0	HAMB-SUGARBEET in PEARL 3.3.3
	0.78	4.2	0.87	1.2	
	1	4.2	0.87	1.2	

Crop parameters Wugong

Table: Wugong, planting, emergence and harvest dates

Crop	Growth stage Planting dd/mm	Emergence dd/mm	Harvest dd/mm	Source
Winter wheat		20/10	05/06	China National Meteorological Information Centre
Summer maize		18/06	25/09	China National Meteorological Information Centre
Cotton		15/04	20/10	MOA crop calendar database 2007
Soybean		15/05	05/10	MOA crop calendar database 2008
Vine	perennial	01/04	30/08	He Puchao, China Grapevine, China Agricultural Press 1999

Table: Wugong, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Winter wheat	05/10	16/05
Summer maize	03/06	05/09
Cotton	31/03	20/09
Soybean	30/04	15/09
Vine	01/04	29/10

Table: Wugong, crop parameters

Crop	Development stage -	LAI m^2 m^{-2}	Crop factor -	Root depth m	Source
Winter wheat	0	0	1	0	CHAT-WCEREALS in PEARL 3.3.3
	0.655	0.1	1	0.2	
	0.829	7.5	0.74	0.8	
	1	7.5	0.74	0.8	
Summer maize	0	0	1	0	CHAT-MAIZE in PEARL 3.3.3
	0.695	4.5	0.86	0.8	
	1	4.5	0.86	0.8	
Cotton	0	0	1	0	SEVI-COTTON in PEARL 3.3.3
	0.22	5	0.87	0.6	
	1	5	0.87	1.4*	
Soybean	0	0	1	0	PIAC SOYBEAN in PEARL 3.3.3
	0.551	6.5	0.81	0.6	
	1	6.5	0.81	0.6	
Vine	0	0	1	1.9	CHAT-VINES in PEARL 3.3.3
	0.25	0	1	1.9	
	0.58	6	0.79	1.9	
	0.835	6	0.79	1.9	
	0.8355	0	1	1.9	
	1	0	1	1.9	

*FAO: http://www.fao.org/landandwater/aglw/cropwater/cotton.stm#descrip retrieved November, 2009.

Crop parameters Weifang

Table: Weifang, planting, emergence and harvest dates

Crop	Growth stage			Source
	Planting dd/mm	Emergence dd/mm	Harvest dd/mm	
Winter wheat		10/10	05/06	China National Meteorological Information Centre
Summer maize		20/06	25/09	China National Meteorological Information Centre
Cotton		05/04	20/10	MOA crop calendar database 2004
Soybean		15/06	05/10	MOA crop calendar database 2007
Apple	Perennial	01/04	01/09	China Agricultural Encyclopedia, Orchard Volume, China Agricultural Press 1993

Table: Weifang, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Winter wheat	25/09	16/05
Summer maize	05/06	05/09
Cotton	21/03	20/09
Soybean	31/05	15/09
Apple	01/04	31/10

Table: Weifang, crop parameters

Crop	Development stage -	LAI $m^2 m^{-2}$	Crop factor -	Root depth m	Source
Winter wheat	0	0	1	0	CHAT-WCEREALS in PEARL 3.3.3
	0.655	0.1	1	0.2	
	0.829	7.5	0.74	0.8	
	1	7.5	0.74	0.8	
Summer maize	0	0	1	0	CHAT -MAIZE in PEARL 3.3.3
	0.695	4.5	0.86	0.8	
	1	4.5	0.86	0.8	
Cotton	0	0	1	0	SEVI-COTTON in PEARL 3.3.3
	0.22	5	0.87	0.6	
	1	5	0.87	1.4*	
Soybean	0	0	1	0	PIAC-SOYBEAN in PEARL 3.3.3
	0.555	6.5	0.81	0.6	
	1	6.5	0.81	0.6	
Apple	0	0	1	1.9	CHAT -APPLES in PEARL 3.3.3
	0.25	0	1	1.9	
	0.415	4	0.98	1.9	
	0.75	4	0.98	1.9	
	0.7505	0	1	1.9	
	1	0	1	1.9	

*FAO: http://www.fao.org/landandwater/aglw/cropwater/cotton.stm#descrip retrieved November, 2009.

Crop parameters Urumqi

Table: Urumchi, planting, emergence and harvest dates

Crop	Growth stage			Source
	Planting dd/mm	Emergence dd/mm	Harvest dd/mm	
Spring wheat		05/05	25/08	MOA crop calendar database 2002
Spring maize		05/05	25/09	MOA crop calendar database 2006
Potatoes		05/05	05/10	Personal communication*
Cotton		25/04	15/10	MOA crop calendar database 2007
Alfalfa	Perennial	28/04$	19/09$	China National Meteorological Information Centre

* Personal communication of Dr. Li Wenjuan (CAAS) with Prof. Lua Qiyou and Dr. Gao Mingjie, Institute of Agricultural Resource and Regional Planning, CAAS.

$ harvest" and "emergence" dates represent the cutting and subsequent regrowth, and so affect above ground biomass but not rooting depth

Table: Urumchi, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Spring wheat	20/04	05/08
Spring maize	20/04	05/09
Potatoes	08/05	28/09
Cotton	10/04	15/09
Alfalfa	28/04	19/10

Table: Urumchi, crop parameters

Crop	Development stage -	LAI $m^2\,m^{-2}$	Crop factor -	Root depth m	Source
Spring wheat	0	0	1	0	
	0.465	3.9	0.8	0.9	HAMB-SCEREALS in PEARL 3.3.3
	1	3.9	0.8	0.9	
Spring Maize	0	0	1	0	HAMB -MAIZE in PEARL 3.3.3
	0.625	4.2	0.86	1.2	
	1	4.2	0.86	1.2	
Potatoes	0	0	1	0	HAMB - Potatoes in PEARL 3.3.3
	0.56	3	0.83	0.7	
	1	3	0.83	0.7	
Cotton*	0	0	1	0	SEVI-COTTON in PEARL 3.3.3
	0.22	5	0.87	0.6	
	1	5	0.87	1.4*	
Alfalfa	0	1	1	0.6	HAMB - GRASS in PEARL 3.3.3
	0.23	1	1	0.6	
	0.415	5	1	0.6	
	0.4155	1	1	0.6	
	0.535	5	1	0.6	
	0.5355	1	1	0.6	
	0.665	5	1	0.6	
	0.6655	1	1	0.6	
	1	5	1	0.6	

*FAO: http://www.fao.org/landandwater/aglw/cropwater/cotton.stm#descrip retrieved November, 2009.

Crop parameters Tongxin

Table: Tongxin, planting, emergence and harvest dates

Crop	Growth stage Planting dd/mm	 Emergence dd/mm	 Harvest dd/mm	Source
Spring maize		25/04	20/09	MOA crop calendar database 2007
Spring wheat		05/04	08/07	MOA crop calendar database 2007
Potatoes		05/05	05/10	Personal communication*
Vine	perennial	10/05	30/08	Personal communication**

* Personal communication of Dr. Li Wenjuan (CAAS) with Prof. Luo Qiyou and Dr. Gao Mingjie, Institute of Agricultural Resource and Regional Planning, CAAS.

*** Personal communication of Dr. Li Wenjuan (CAAS) with Prof.Li Chongjiu, China Agricultural University.

Table: Tongxin, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Spring maize	10/04	31/08
Spring wheat	21/03	18/06
Potatoes	08/05	28/09
Vine	10/05	29/10

Table: Tongxin, crop parameters

Crop	Development stage	LAI and interception Max. LAI $m^2 m^{-2}$	 dd/mm	Crop factor	Root depth m	Source
Spring maize	0	0		1	0	HAMB - MAIZE in PEARL 3.3.3
	0.625	4.2		0.86	1.2	
	1	4.2		0.86	1.2	
Potatoes	0	0		1	0	HAMB -SPOTATOES in PEARL 3.3.3
	0.56	3		0.83	0.7	
	1	3		0.83	0.7	
Spring Wheat	0	0		1	0	HAMB -SCEREALS in PEARL 3.3.3
	0.465	3.9		0.8	0.9	
	1	3.9		0.8	0.9	
Vine	0	0		1	2.4 (1.0)*	HAMB-VINES in PEARL 3.3.3
	0.33	0		1	2.4 (1.0)	
	0.535	3		0.79	2.4 (1.0)	
	0.83	3		0.79	2.4 (1.0)	
	0.8305	0		1	2.4 (1.0)	
	1	0		1	2.4 (1.0)	

* 1.0 is the measured root depth of vine in Ningxia, and 2.4 is the root depth of vine in Hamburg. Root depth measured in Ningxia is used for the Tongxin groundwater scenario.

Crop parameters Shangqiu

Table: Shangqiu, planting, emergence and harvest dates

Crop	Growth stage			Source
	Planting dd/mm	Emergence dd/mm	Harvest dd/mm	
Winter wheat		25/10	30/5	China National Meteorological Information Centre
Summer maize		10/06	15/09	China National Meteorological Information Centre
Cotton		25/4	25/10	MOA crop calendar database 2008
Tobacco		15/04	25/08	Personal communication*
Soybean		15/5	25/9	MOA crop calendar database 2008

*Personal communication of Dr. Li Wenjuan (CAAS) with Mr. Wang Xianjun, division deputy chief, China Tobacco.

Table: Shangqiu, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Winter wheat	10/10	20/05
Summer maize	26/05	26/08
Cotton	10/04	25/09
Tobacco	15/04	15/08
Soybean	30/04	05/09

Table: Shangqiu, crop parameters

Crop	Development stage	LAI	Crop factor	Root depth	Source
	-	$m^2\ m^{-2}$	-	m	
Winter wheat	0	0	1	0	CHAT -WCEREALS in PEARL 3.3.3
	0.655	0.1	1	0.2	
	0.829	7.5	0.74	0.8	
	1	7.5	0.74	0.8	
Summer maize	0	0	1	0	CHAT -MAIZE in PEARL 3.3.3
	0.695	4.5	0.86	0.8	
	1	4.5	0.86	0.8	
Cotton	0	0	1	0	SEVI-COTTON in PEARL 3.3.3
	0.22	5	0.87	0.6	
	1	5	0.87	1.4*	
Tobacco	0	0	1	0	PIAC-TOBACCO in PEARL 3.3.3
	0.445	4	0.94	1	
	1	4	0.94	1	
Soybean	0	0	1	0	PIAC SOYBEAN in PEARL 3.3.3
	0.555	6.5	0.81	0.6	
	1	6.5	0.81	0.6	

*FAO: http://www.fao.org/landandwater/aglw/cropwater/cotton.stm#descrip retrieved November, 2009.

Crop parameters Nanchang and Lianping

Table: Nanchang and Lianping, planting, emergence and harvest dates

Crop	Growth stage			Source
	Planting dd/mm	Emergence dd/mm	Harvest dd/mm	
Paddy rice 1st crop cycle	22/04		15/07	CAAS
Paddy rice 2nd crop cycle	22/07		14/10	CAAS

Table: Nanchang and Lianping, irrigation period start- and end-date

Crop	Start Irrigation period	End Irrigation Period
Paddy rice 1st crop cycle	21/4	13/07
Paddy rice 2nd crop cycle	21/7	12/10

Table: Nanchang and Lianping, crop parameters

Crop	Development stage	LAI	Root depth	Crop factor	Source
	-	$m^2 m^{-2}$	m	-	
Paddy rice 1st crop cycle and Paddy rice 2nd crop cycle	0.0	0.0699	0.05	1.1	LAI: Based upon measurements of CAAS Root depth: based upon measurements CAAS and IRRI, 1982 Crop Factor: FAO, 1986
	0.05	0.1254	0.07	1.1	
	0.1	0.2462	0.09	1.1	
	0.15	0.5812	0.11	1.1	
	0.2	0.9695	0.13	1.1	
	0.25	1.4236	0.15	1.1	
	0.3	2.0676	0.18	1.1	
	0.35	2.5611	0.21	1.1	
	0.4	3.0359	0.24	1.1	
	0.45	3.4423	0.27	1.05	
	0.5	3.7879	0.3	1.05	
	0.55	3.8770	0.36	1.05	
	0.6	4.0753	0.42	1.05	
	0.65	3.9879	0.48	1.05	
	0.7	3.9634	0.54	1.05	
	0.75	3.9047	0.6	1.05	
	0.8	3.7751	0.6	1.05	
	0.85	3.4975	0.6	1	
	0.9	3.3362	0.6	1	
	0.95	3.0960	0.6	1	
	1.0	2.9174	0.6	1	

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