Report of the OECD Pesticide Aquatic Risk Indicators Expert Group

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Executive Summary

1. Introduction

This report presents the results of an OECD project on pesticide aquatic risk indictors, initiated in March 1998 at the recommendation of the April 1997 OECD Workshop on Pesticide Risk Indicators (Copenhagen). The project was carried out by an Expert Group nominated by the OECD Pesticide Programme, assisted by staff from the Central Science Laboratory of the UK Ministry of Agriculture, Fisheries and Food.

The project developed, tested, and evaluated three contrasting indicators of aggregate aquatic risk resulting from agricultural pesticide use, usable by OECD governments to assess progress in risk reduction. Risk indicators were defined as systems to combine information on pesticide risk and use, in order to track risk trends over time at a national or regional level. The project focused on aquatic exposure resulting from the direct application of pesticides in agriculture; it did not consider exposure from misuse, disposal, cleaning of equipment, or spills.

In Phase 1 the Expert Group evaluated existing indicators, designed three new ones that represent contrasting approaches, and identified the data needed to test the new indicators. The Expert Group also identified a method for converting pesticide sales data into estimates of use.

In Phase 2 the indicators were tested, evaluated, and refined.

In Phase 3 the Expert Group analysed the results, drew conclusions, and prepared this report.

2. Defining the Indicators

Building the Database

Based on the recommendations of the Copenhagen workshop and additional analysis, the Expert Group identified a set of data to be used for testing the indicators. A special database was correspondingly built, with information on:

- **pesticide use,** derived from farmer surveys done in the United Kingdom from 1977 through 1997, covering 307 pesticides used on arable crops or orchards;
- **environmental conditions**, such as water index (the proportion of the treated area that is bordered by surface water), slope, rainfall, water depth, soil type;
- **toxicity, fate, and physico-chemical properties** of the 307 pesticides, drawn from government files.

Designing the Indicators

The Expert Group identified two main approaches for combining the data in indicators:

- **scoring**, which first converts the pesticide data into scores that reflect their general contribution to risk, then combines them in ways that give appropriate weight to each variable; and

- using a **mechanistic model** that combines the actual data values through a series of mathematical equations that mirror scientific understanding of environmental processes that contribute to risk.

The Expert Group designed three aquatic risk indicators that represent different combinations of the mechanistic and scoring approaches. REXTOX (**R**atio of **EX**posure to **TOX**icity), is entirely mechanistic. ADSCOR (**AD**ditive **SCOR**ing) uses a simple additive scoring system for most exposure variables, but incorporates toxicity and treated area as unscored variables. SYSCOR (**SY**nergistic **SCOR**ing) links scored exposure variables using a more complex process, and also includes toxicity as an unscored variable.

All three indicators:

- combine risks from multiple agricultural uses of multiple pesticides to estimate overall aquatic risk.

- can calculate risk trends for:
  - an individual hectare, a region, or a whole country
  - selected crops or all crops
  - selected pesticides or all pesticides
  - a single aquatic organism or several organisms combined.

- can show trends for acute, or short-term, aquatic risk. Two of the indictors also show chronic, or long-term trends, and the third could be modified to do so, as well.

- have the same basic structure, a ratio of pesticide **exposure** to **toxicity,** scaled by the '**area treated**'. This calculation produces a numerical value called a 'risk index' for each use and year. Changes in the risk index from one year to another show risk trends.

- produce results that are 'relative' estimates of risk.

- use elements of existing indicators but are unique.

All three indicators treat toxicity the same way and include the same variables. The indicators differ in how they estimate exposure and how they incorporate the area treated.

3. Description of the Indicators

REXTOX

REXTOX requires 22 variables to calculate short-term risk indices and 23 to calculate long-term risk indices. REXTOX uses direct (unscored) values for all variables. It applies mechanistic models similar to those used for risk assessment to combine the variables related to exposure. The models enable REXTOX to calculate specific values for spray drift and runoff, which are then used to estimate the concentration of applied pesticide likely to occur in adjacent water bodies. (REXTOX does not consider other routes of exposure such as leaching and drainage, but could be amended to do so.) The exposure estimate (adjusted as appropriate for long-term exposure) is then divided by toxicity. Many of the variables in REXTOX relate to environmental conditions and are therefore not pesticide-specific, permitting use of national default values. They allow REXTOX to distinguish the risks in different areas (hilly or flat, rainy or dry), or to be modified to fit national/regional conditions of environment, landscape or application method, with relative ease.

ADSCOR

ADSCOR uses 10 variables to calculate short-term risk indices and 15 to calculate long-term risk indices. ADSCOR does not explicitly model the exposure processes but instead assigns scores to ranges of values of variables that affect exposure, including pesticide physico-chemical properties, fate and use. The scores are added together, multiplied by the area treated, and divided by toxicity to calculate risk indices. The scoring system allows ADSCOR to reflect all routes of exposure, but it relies on expert judgment about the importance of different factors.

SYSCOR

SYSCOR uses 13 variables to calculate short-term risk indices (it was not designed to calculate long-term risk indices, but could be modified to do so). SYSCOR begins by arranging all variables related to exposure -- including 'area treated,' which is not scored in ADSCOR -- in a hierarchy based on their importance. It divides each variable into categories to reflect low, medium or high contribution to exposure. Then it develops a score for each variable using a system of rules that is intended to capture both the importance of and the 'synergy' between different variables. (For example, more important variables can influence the scores of lesser variables.) The scores for all the variables are then added together to produce a total score called an exposure rank or 'penalty'. Finally the exposure rank is divided by toxicity. SYSCOR's approach, derived from the French SIRIS system, relies on expert judgements about both the importance of individual variables and the way they interact.

4. Evaluation of the Indicators

The project's most important finding was that ***different indicators can produce different risk trends***, even when they use the same input data. This is because of differences in indicator structure that give more or less weight to certain variables. The different structures of REXTOX, ADSCOR and SYSCOR led them to show divergent risk trends. The causes of these differences were identified by comparing the risk trends with the underlying data on pesticide use, and by analysing how the three indicators treat specific variables such as buffer zones, which are given much more weight in REXTOX and SYSCOR than in ADSCOR.

The project also found that:

- The three indicators are relatively insensitive to ***missing values*** for specific pesticides, as long as there are not too many gaps. When there are many gaps, as for long-term toxicity, the results of the indicators are unreliable.

- It is possible to ***extrapolate from pesticide sales data*** when actual pesticide usage data are not available. A German method for converting sales data to use estimates was tested, and produced usable results. Indicator results are far more credible, however, when they are based on actual usage data.

- Indicators are most useful when constructed at the lowest practicable level of data aggregation, i.e. by calculating risk trends for selected groups of aquatic organisms as a result of using individual pesticides on specific crops with specific application methods in particular regions. The trends can later be combined to show trends at any higher level of aggregation. But without the ability to 'drill down' to the original data at the lowest level, it may be impossible to understand or explain the causes of risk trends.

- Indicators can be constructed to reflect *directly* the impact of a number of ***risk reduction measures*** (such as imposition of buffers and other use restrictions or cancellations of specific pesticides or uses). Other risk reduction measures (such as uptake of IPM, pesticide taxes or market substitution over time of lower risk pesticides for higher risk pesticides) would be reflected *indirectly* by causing a change in the pesticides used which would then show up in the indicator. Some risk reduction practices—such as caution exercised by individual farmers who spray only if the wind is blowing away from water bodies—cannot be incorporated into the indicators at all.

- It is possible to approximate risk trends with ***simplified versions of the three indicators***, but additional testing and analysis would be needed before the simplified indicators could be accepted with confidence. Moreover, simplified versions would lose much of the ability to drill down and identify causes of risk changes.

- The relation of indicator results to actual risk in the environment is very hard to assess, largely because aggregate risk is not directly measurable on a large (landscape) scale. It is important to use indicators with awareness of their limitations, and to validate as much as possible indicator results with data on pesticide use, environmental monitoring, and expert advice.

- Indicators are built on the same experience/knowledge about pesticide fate processes and environmental toxicology as regulatory assessments, and should be modified as knowledge improves.

5. Conclusions

The Expert Group concluded that pesticide risk indicators could be useful to national regulatory authorities because:

- Indicators make use of actual data on pesticide usage, instead of the conservative assumptions underlying registration decisions.

- Indicators permit aggregation of risk trends across pesticides, uses, or regions, giving insights not available from case-by-case registration risk assessments.

- Indicators can show whether pesticide use is getting more or less risky, and why.

- Indicators permit comparison of the risk potential of alternative pest management regimens.

- Indicators can quickly and confidently identify major contributors to aggregate risk—whether trouble spots (crops or regions) or trouble-makers (pesticides.)

- Indicators can simulate the impacts of some policy measures before they are taken, such as cancellation of a pesticide, increasing the size of a buffer zone, or improving compliance with a use restriction.

- Indicators can show graphically the effect on risk of the ever-changing mix of agricultural pesticides and use practices.

- Indicators may encourage national governments to improve their pesticide databases. Complete and reliable databases are good in themselves, and once the data are compiled and managed electronically, they are more easily and economically maintained.

- Indicators encourage collection of actual usage data, essential for understanding actual risk, and useful for many other purposes as well.

6. Lessons Learned

The Expert Group learned the following 'lessons' about designing indicators:

- It is possible to design indicators that provide insights about aggregate pesticide risk, although it is a difficult task requiring many decisions and compromises.

- Designing such indicators takes time to do well and must include testing with an extensive amount of real data.

- Missing data – particularly data on actual pesticide use – is a major barrier to using pesticide risk indicators. Without good data, indicator results are unreliable.

- Pesticide sales data can be used to estimate use, but real use data give better results.

- Indicators are limited tools, despite their supposed complexity. It is difficult to verify their results, because possibilities and means to measure real-life risk on a large scale are limited.

- Indicators can nevertheless be useful in conjunction with other tools, can add value to pesticide risk assessment, and can be very useful in setting priorities for pesticide re-evaluation (see above, bullet 5 of Conclusions).

- Indicators can and should be 'customised' to suit the needs of individual countries or regions.

- Further expert groups formed to design pesticide risk indicators should comprise a similar range of experience, including pesticide evaluators and indicator experts, with some members knowledgeable about policy issues.

1. Introduction

This report presents the results of a project carried out by the OECD Pesticide Programme to develop and test aquatic risk indicators that could be used as policy tools by national governments. 'Risk indicators' were defined as systems to combine information on pesticide hazard and use, in order to track risk trends at a national or regional level. Their main purpose would be to help governments evaluate progress in pesticide risk reduction.

Project Scope

The project was guided by criteria developed at an OECD workshop in Copenhagen in April 1997, which stated that indicators should be:

- As simple as possible but scientifically valid,
- Consistent with the principles of pesticide risk assessment but not duplicative of the risk assessment process, and
- Designed to help national governments measure progress in risk reduction.

The project focused exclusively on pesticide aquatic risk indicators that met these criteria. It did not examine other types of indicators such as hazard indicators, farmer decision tools, classification and labeling criteria, risk ranking of individual pesticides, pesticide product labels, or monitoring data.

The project also focused specifically on aquatic risks resulting from pesticide use in agriculture, considering only the consequences of intentional application of pesticides. For simplicity the project excluded other potential sources of contamination, such as disposal of pesticides or containers, cleaning of application equipment, misuse, or accidental spillage.

Finally, the project addressed hazard to the three types of aquatic organisms typically tested for pesticide registration assessments and for which the most complete and consistent data are available: algae, *Daphnia*, and fish.

The indicators developed by the project incorporate some pesticide registration data and concepts also used in government risk assessments. The indicators also include, however, other information not available for pre-registration decisions, and they combine information in ways that differ from regulatory risk assessments. Specifically, the indicators are driven by post-registration data on the actual use of pesticides over time, and they permit aggregation of risk across pesticides or crops, providing insights not generally available from risk assessments, which consider pesticides one at a time.

Participants

The project was carried out by an Expert Group nominated by the Pesticide Programme, composed of 12 experts in aquatic toxicology, modeling, pesticide risk assessment, risk indicator development, and pesticide policy and regulation. Staff from the Central Science Laboratory (CSL) of the UK Ministry of Agriculture, Fisheries and Food served as consultants to the Expert Group, providing expertise in collection of pesticide usage data, data base design, computer programming, sensitivity analysis, and risk indicator development. Annex 1 includes a list of the Expert Group members and the participating CSL staff.

Project Phases

In Phase 1 the Expert Group:

- Reviewed existing indicators and assessed their suitability for the project.
- Designed three new indicators for testing, representing contrasting approaches.
- Identified the data needed to test the new indicators.
- Identified a method for extrapolating from pesticide sales data to an estimate of pesticide use.

Phase 1 results are reported in Annex 2.

In Phase 2 the CSL consultants, working closely with the Expert Group:

- Built a database with information on 307 pesticides applied to orchards and arable crops in the UK, and on environmental conditions where the crops were grown.
- Built computer programmes to perform the calculations required for each indicator.
- Ran the data on pesticides and environmental conditions through each indicator and produced reports and graphs showing risk trends for various pesticides and crops.
- Helped the Expert Group to refine the indicators based on preliminary results.
- Compared the indicators' performance at different levels of aggregation.
- Assessed the indicators' sensitivities to changes in data values and to the imposition of risk reduction measures such as un-treated buffer strips.
- Developed and evaluated simplified versions of the indicators.
- Evaluated the reliability of the method for estimating pesticide use from pesticide sales.

Phase 2 results are reported in Annex 3.

In Phase 3 the Expert Group reviewed the results of the indicator testing and prepared this report, summarising the entire experience of the project.

2. Defining the Indicators

Building the Database

Starting with the proposals made by the Copenhagen workshop, the Expert Group analysed the range of data on pesticide toxicity, fate, exposure and use that might be used in aquatic risk indicators. The Group agreed on a limited data set that they believed most OECD governments should be able to gather and that would produce useful indicator results. The data used in each of the three indicators are detailed in Chapter 3.

The Group also agreed that the data base of pesticide use built for this project would be limited to pesticide use in the United Kingdom, for the simple reason that the UK already had an extensive, well-organised data base on pesticide use. Much of the other data collected for the project (e.g. on pesticide toxicity and fate) would be universally applicable.

A database for the project was correspondingly built, as follows:

- Data on the **actual use** of 307 pesticides were derived from the UK pesticide usage surveys, using data specific to England and Wales for orchard crops from 1983, 1987, 1992 and 1996, and for arable crops from 1977, 1982, 1988, 1990, 1992, 1994 and 1996. The surveys collected information on the crop treated, the area grown, the area treated with each pesticide, and the rate of application used by the farmer. All of the surveys used a sample of farmers and growers, stratified by region and farm size group, to reflect accurately the variable cropping patterns across England and Wales. The data were statistically 'raised' to provide national estimates of pesticide use, using the UK national census statistics for areas of crops grown in each survey year.

  These data were stored in a database and were then converted to give, for each active substance on each crop:
  - the actual area of crop treated, irrespective of the number of times treated (Basic Area Treated)
  - the average number of applications per season (Average Frequency of Treatment)
  - the Actual Dose Rate per application
  - the Recommended Dose Rate (label rate) per application
  - the area of crop grown
  - the method of application
  - the timing of application.

- Values for **environmental conditions** in England and Wales, such as water index (the proportion of the treated area bordered by surface water), slope, rainfall, water depth and soil type, were derived by consulting with national institutes. Expert judgment was used to derive values that most closely reflected regional and national averages for each parameter.

- Data on **toxicity, fate, and physico-chemical properties** of pesticides were drawn primarily from government files. Most were provided by the UK Ministry of Agriculture, Food and Fisheries; the rest came from the US Department of Agriculture, the US Environmental Protection Agency, the Netherlands National Institute for Public Health and the Environment, the French Ministry of the Environment, and the German Federal Biological Research Centre for Agriculture and Forestry. Values not available from government files were taken from the Pesticide Manual (10^{th} & 11^{th} and earlier editions) published by the British Crop Protection Council, a standard reference manual. For both long- and short-term toxicity, values were taken for algae, *Daphnia* and fish. Missing values were estimated by taking the average value for other pesticides in the same chemical group (e.g., carbamates), or, if many values were missing within the group, by taking a broader average (e.g., all insecticides).

Designing the Indicators

The Expert Group identified two main approaches that could be used to combine data in an aquatic risk indicator. One converts the data into **scores** before combining them. The other combines actual data values with a **mechanistic model**. Either approach makes it possible to combine input variables with very different ranges and units of measurement – such as degradation in water, measured in days and typically between one and 100, and area treated, measured in hectares in a range from one to millions.

> ***Scoring indicators*** assign scores to the data to approximate their general contribution to risk, rather than using direct endpoint values. Each variable is divided into categories to reflect, for example, low, medium or high contribution to risk, and a score is assigned to each category (e.g. 1 for low risk contribution, 5 for medium, 10 for high). Scoring systems can give more or less weight to different variables by:
>
> - setting the 'breakpoints' that divide each variable into several risk contribution categories in such a way that small changes in the values have more or less effect (e.g. by rapidly pushing the value into a higher category, or not).
>
> - giving a wider range of scores to variables considered to contribute most to risk. For example, method of application, if deemed more important than degradation time, might be given a range from zero to 5, whereas scores for degradation might be given a range from zero to 2.
>
> - rapidly increasing the scores for individual variables as their corresponding values increase: for example, setting scores for DT_{50} (the time for 50% of the pesticide to disappear) as: <15 days = 1; 15 days to 6 months = 5; > 6 months = 10.

- ranking the variables in a hierarchy of 'classes' according to perceived contribution to risk, then giving more weight to the higher classes. (This is done in the SYSCOR indicator, described in Chapter 3.)

Indicators that use a ***mechanistic model*** to combine the data can use pesticide hazard and exposure values directly, without first converting them into scores, and at the same time can account for the weight of the different variables. The model does this using a series of mathematical equations that are designed to mirror current scientific understanding of processes contributing to pesticide risk, such as environmental fate and distribution. Mechanistic models have been used in some reported indicators, and are also frequently used in government risk assessments (for pesticide registration), to calculate leaching potential and runoff, for example.

Development of mechanistic models requires an understanding of how the different variables interact and behave in the environment, and how this interaction can be captured in mathematical equations. In other words, the person building the model must understand how all the wheels turn together in the box; hence the term 'mechanistic'.

The three aquatic risk indicators designed for this project represent different combinations of the mechanistic and scoring approaches. One indicator is entirely mechanistic; the other two score most exposure variables but incorporate some unscored variables as well.

Despite these differences, the three indicators share several basic features.

- All three combine risks from multiple agricultural uses of multiple pesticides to estimate overall aquatic risk.

- All three indicators can calculate risk trends in several ways:
  - for an individual hectare, a region, or a whole country
  - for selected crops or all crops
  - for selected pesticides or all pesticides
  - for a single aquatic organism or for several organisms combined.

- All three indicators can show trends for acute, or short-term, aquatic risk; two of the indictors can also show chronic, or long-term trends (and the third could be modified to do so, as well).

- The basic structure of all three indicators is a ratio of pesticide ***exposure*** to ***toxicity*** (i.e. the relation between the level of pesticide estimated to occur in water bodies adjacent to farm fields, and the level that would be harmful to aquatic organisms), combined with the ***'area treated'*** (i.e. the number of hectares on which the pesticide was used). This produces a numerical value called a 'risk index' for each use and year. Changes in the risk index from one year to another show risk trends.

- The risk indices produced by all three indicators are only ‘relative’ estimates of risk. Comparisons are valid only among indices produced by the same indicator, unless the indices are first ‘normalised’ to a base value.

- All three indicators share some of the characteristics of indicators previously developed in OECD countries, but none is an exact replica of any previously reported indicator.

3. Description of the Indicators

The three indicators developed by the Expert Group, named REXTOX, ADSCOR and SYSCOR, are described below. Included in the description of each indicator is a table listing all the variables required and showing, as appropriate, the default values assumed for Phase 2 testing, the scoring categories and breakpoints, and the use of the variable in the short- or long-term versions of the indicator. These tables follow a generally consistent format to facilitate comparison of the indicators. At the end of this chapter, Table 3.4 compares the main characteristics of the three indicators, and Table 3.5 summarises their hierarchical structures, showing the information provided at each level of the indicators and how it can be used.

As previously noted, all three indicators use the same basic formula of Exposure / Toxicity. In addition, all three deal with toxicity in the same way and include the same variables, using short-term or long-term values as appropriate. That would normally be the 96-hr fish LC_{50}, 48-hr Daphnia EC_{50}, or 96-hr Algae EC_{50} for the short-term indicator, and the 21-day fish NOEC, 21-day Daphnia NOEC, or 96-hour Algae NOEC for the long-term indicator. However, where more relevant - or just other - data exist, those can be used instead of this standard set (e.g., an NOEC from fish early life stage study instead of the 21-day test; or a 14-day NOEC where no 21-day test is available). Selection of alternative data would require expert judgement.

The most important difference between the three indicators is the way they deal with ***exposure***, or the amount of pesticide that reaches surface water after each application. All three indicators consider the crop, the amount of pesticide used, how the pesticide is applied, the mobility and persistence of the pesticide, and environmental factors. However, the indicators combine these variables differently. REXTOX ***combines the direct values mathematically*** using mechanistic models. Alone among the three indicators, REXTOX produces a precise value for the environmental concentration of the pesticide, as is done in regulatory risk assessment. ADSCOR ***converts the value for each variable into a score reflecting its general risk contribution***, then combines these scores by addition. SYSCOR ***links the variables in a hierarchy, in a way that reflects both their importance and their interaction,*** to generate scores for the different variables that are then added together.

All three indicators calculate separate risk indices for each of the three standard aquatic organisms. These must then be added together to obtain risk indices for aquatic risk generally (as determined by the combined risk to the three organisms). This approach preserves the ability to identify each organism’s contribution to overall risk, which would be lost if only toxicity to the most sensitive organism were used, or the average of the toxicity values for multiple organisms.

Similarly, all three indicators do separate calculations for each combination of pesticide, crop, application method, etc. These calculations are then aggregated to obtain results for larger groupings, such as a particular pesticide on all cereals, or all pesticides on all cereals, or all pesticides on all arable crops.

REXTOX

REXTOX (**R**atio of **EX**posure to **TOX**icity) is a ***mechanistic*** indicator, using direct, unscored values for all its input variables, which it combines using mathematical equations. REXTOX is based on an indicator developed in the Netherlands to assess trends in acute risk to aquatic ecosystems. REXTOX also includes features of the German indicator 'SYNOPS,' developed to evaluate the environmental impact of crop protection practices. REXTOX resembles but is more complex than the Danish indicator developed to measure progress in meeting Denmark's risk reduction goals. The Dutch, German and Danish indicators are all described in the OECD Survey of National Pesticide Risk Indicators (available on the internet).

REXTOX is the most sophisticated and sensitive of the three indicators, because of its large number of input variables, its use of direct values rather than scores, and its use of models similar to those used in risk assessment to estimate exposure. REXTOX includes substantially more input variables than either ADSCOR or SYSCOR, especially for environmental factors. For example, REXTOX includes such variables as slope, precipitation, water depth and soil type, which are not used in the other two indicators. This makes REXTOX 'data-hungry' but considerably increases its flexibility and usefulness. (In addition, many of these variables are not pesticide-specific, permitting use of national or regional default values.)

To estimate exposure, REXTOX first calculates the amount of pesticide likely to end up in water bodies due to spray drift and/or run off, accounting for the risk reduction effects of buffer zones, differentiating between buffers of different widths, and accounting for estimated farmer compliance with buffer zone requirements. (The estimates give more weight to spray drift buffers than to run-off buffers, as the former have been shown to be more effective.) This figure is then combined with the amount of pesticide used, the water index, the water depth, and (to calculate national risk indices) the total amount of agricultural land treated. The resulting exposure estimate is then divided by toxicity to obtain a 'risk index' for one or more aquatic organisms.

It should be noted that, while REXTOX is very precise in estimating spray drift and runoff, it does not consider other routes of exposure such as leaching and drainage, because of the lack of agreed methods to calculate them. (Once available, such methods could be added.) Thus, REXTOX is likely to underestimate risks from pesticides that are very mobile in soil, and takes no account of those incorporated into the soil via seed treatment, soil sterilisation, or incorporation of granules.

Construction of the Indicator

REXTOX uses 22 variables to produce short-term risk indices and 23 to produce long-term risk indices (assuming all three aquatic organisms are used to calculate toxicity). These variables are listed in Table 3.1 below, along with the default values assigned to 12 of the environmental factors for Phase 2 testing. The default values represent a national average for each factor. REXTOX can be used to analyse differences among regions within a country, in which case separate values would need to be assigned for each region.

Table 3.1
REXTOX Variables and Default Settings

Data Type	Variable		Use of Variable	
	Variable Name	Default Setting	Short Term	Long Term
Pesticide Toxicity	Fish, 96-hr LC_{50}		X	
	Fish, 21-day NOEC			X
	Daphnia, 48-hr EC_{50}		X	
	Daphnia, 21-day NOEC			X
	Algae, 96-hr E_rC_{50}		X	
	Algae, 96-hr NOEC			X
Pesticide Use	Basic area treated (hectares treated at least once per season)		X	X
	Recommended dose rate (label rate)		X	X
	Average dose rate (actual rate)		X	X
	Treatments per season		X	X
	Method of application		X	X
	Width of spray drift buffer	1 m when buffer not required; 6 m when buffer required.	X	X
	Width of runoff buffer	0 m	X	X
	Compliance with spray drift buffer requirement	1 (full compliance)	X	X
	Compliance with runoff buffer requirement	1 (full compliance)	X	X
Environmental Factors	Water index	0.1 for all regions	X	X
	Water depth	0.3 m for all regions	X	X
	Slope of treated area	5% for all regions	X	X
	Precipitation	30 mm for all regions	X	X
	% organic carbon	1.6 % for all regions	X	X
	Soil type	Loamy for all regions	X	X
	Crop stage	1 (Early, primarily on the soil) for all herbicides, molluscicides, nematicides and soil sterilants. 2 (Late, primarily on the crop) for all acaricides, biological controls, dessicants, repellents, fungicides, growth regulators, insecticides, and pruning paints	X	X
	Plant interception (%)	0 % when crop stage = 1 70% when crop stage = 2	X	X
Fate	DT_{50} in water			X
	$LogK_{ow}$		X	X
	K_{oc} & K_d		X	X

REXTOX can calculate risk indices at three levels, as shown in the text and formulas that follow. (In these formulas, ‘LOSS’ means the percentage of applied pesticide that makes its way by spray drift (s.d.) and/or runoff (r.o.) to surface water bodies adjacent to the site of use. Its calculation is explained below.) For all three levels, the first step is to calculate exposure:

- **Level 1**. $REXTOX_{potential}$: Potential risk per application per hectare (or other unit) treated, based on pesticide label rates (i.e. the recommended dose rate). Exposure is calculated as follows, where RDR is the recommended dose rate.

  $Exposure_{potential}$ = RDR * (LOSS via s.d. & r.o./ Water depth) * Water index

- **Level 2**. $REXTOX_{unscaled}$: Intensity of risk per hectare (or other unit) treated, based on actual dose rates (i.e. the amount farmers have actually applied, often lower than label rates) and the number of applications. Exposure is calculated as follows, where ADR is the actual dose rate and AFT is the average frequency of treatments. The calculation is ‘unscaled’ because it is done at the unit level rather than being ‘scaled’ up to a regional or national level.

  $Exposure_{unscaled}$ = ADR * (LOSS via s.d. & r.o/ Water depth) * Water index * AFT

- **Level 3**. $REXTOX_{scaled}$: Extent of overall risk, considering actual dose rates, average frequency of treatments, and basic area treated (BAT), the total area receiving at least one pesticide treatment. The calculation is ‘scaled’ to the regional or national level. Exposure is calculated as follows:

  $Exposure_{scaled}$ = ADR * (LOSS via s.d. & r.o / Water depth) * Water index * AFT * BAT

Once exposure is calculated, it is divided by the appropriate toxicity value to obtain the risk index for all three levels of REXTOX. However, for the long-term risk indices (at all three levels), exposure is first multiplied by a ‘Long Term Factor’ (LTF). This is simply the ratio of the weighted average concentration (<c>) of the pesticide over the period considered and the initial concentration (c_{init}):

$$LTF = <c>/c_{init}$$

The period considered should correspond to the long-term toxicity tests; hence the default of 21 days was used. When toxicty test of a different duration are more relevant, the calculation can be done for any time period of ***t*** days.

The weighted average concentration (<c>) itself is calculated with a standard formula, requiring the $DT_{50\ water}$, the duration of the period considered, and assuming first-order degradation kinetics.

In more detail, LTF is calculated as:

$$LTF = \frac{<c>}{c_{init}} = \frac{\int_0^t c_{init} \cdot e^{-kt} dt}{c_{init}} = \frac{1-e^{-kt}}{kt}$$

For small values of t (short periods) and/or small values of the k (slow degradation), LTF is close to 1 (<c> ≈ c_{init}). LTF becomes 0.5 (<c> = c_{init}/2) for a 21-day period, and a DT_{50} of ≈9 days. Generally, for a 21-day period (t=21), and a half life in water of DT_{50} (k = ln 2/DT_{50}), LTF follows from

$$LTF = \frac{1-e^{-\frac{\ln 2}{DT_{50}} \cdot 21}}{\frac{\ln 2}{DT_{50}} \cdot 21}$$

Hence, the final REXTOX formulas at all three levels are:

REXTOX $_{\text{Short-term}}$ = Exposure / Short-term Toxicity

REXTOX $_{\text{Long-term}}$ = (Exposure * LTF) / Long-term Toxicity

In this project, all REXTOX results were multiplied by 10 for presentation, to eliminate decimal points in the graphs and tables for the unscaled indicators.

Calculation of LOSS

Loss via spray drift

In REXTOX the loss via spray drift is calculated from a table showing the percentage of applied pesticide moving beyond the boundary of a treated field, depending on the crop/crop stage treated and on the distance from the last nozzle of the spray equipment to the edge of the field (Ganzelmeier et al. 1997).[1]

To improve consistency of the look-up values used in pilot testing, the following equations were derived from Ganzelmeier's table by regression analysis:

[1] Ganzelmeier, H., 1997: Abtrift und Bodenbelastung beim Ausbringen von Pflanzenschutzmitteln. Mitt. Biol. Bundesanstalt Land- u. Forstwirtschaft, Berlin-Dahlem, H.328, S. 115-124

Fruit Trees Early	$L\%=(a-b*\ln(x))^2$	a=7.08298	b=1.68712	$r^2=0.990$
Fruit Trees Late	$L\%=1/(a+bx^2)$	a=0.03597	b=0.00179	$r^2=0.991$
Arable Early	$L\%=(a+b/x)^2$	a=0.32397	b=1.73651	$r^2=0.991$
Arable Late	$L\%=EXP(a-b*\ln(x))$	a=1.58074	b=1.17817	$r^2=0.992$

where L% = Loss due to spray drift
x = Width of Buffer Zone (meters)
a and b are constants
r^2 = the proportion of variation in L% which is accounted for by the equation (if it provided an exact fit to the Ganzelmeier tables then r^2 would be 1.0).

In addition to improved consistency, which is particularly important for sensitivity analyses, using these formulae permits a more accurate calculation of drift for buffer zones of any width.

Spray drift was assumed to be 100% for aerial applications (i.e. overspraying of water body). The equations for ‘arable’ relate to ground-spray applications. The equations for ‘fruit trees’ relate to air-blast applications, and were used for all sprays in orchards except herbicides. The ‘arable’ equations were used for herbicides in orchards because these were ground sprays applied between the trees.

The spray drift buffer compliance factor is incorporated by calculating $L\%_{spraydrift}$ with and without a buffer, and putting the values into the following formula:

$$L\%_{spraydrift} = (L\%_{SDNB})\times(1-\mathit{Compliance}_{SDB}) + (L\%_{SDB})\times(\mathit{Compliance}_{SDB})$$

where $L\%_{SDNB}$ = The % spray drift with no spray drift buffer
$L\%_{SDB}$ = The % spray drift with spray drift buffer
$Compliance_{SDB}$ = the spray drift buffer compliance (default value = 1)

Loss via run-off

REXTOX calculates $L\%_{run\text{-}off}$ from the following formulae:

$$L\%_{run\text{-}off} = (Q / P) * Cr_{soil\ surface} * f1(Slope) * f2(Run\text{-}off\ buffer\ zone) * 100$$

By this formula the percentage of loss via run-off is proportional to:

- *The ratio between the volume of water on soil surface available for run-off (Q) and the volume of precipitation (P).* This ratio divides total precipitation into two parts—one part available for run-off (considered here) and another part available for leaching (not considered here). The run-off volume is obtained from a look-up table based on models by Lutz and Maniak.[2] The look-up table

[2] Lutz, W. 1984: Berechnung von Hochwasserabflüssen unter Anwendung von Gebietskenngrößen. Mittlg. Inst. Hydrologie Wasserwirtschaft, Univ. Karlsruhe, Heft 24
Maniak, U. 1992: Regionalisierung von Parametern für Hochwasserabflußganglinien. In: Regionalisierung der Hydrologie (H.B. Kleeberg), DFG, Mittlg. Senatskomm. für Wasserf. 11, S. 325-332

covers two soil types (sandy, loamy) and three scenarios concerning application time, crop and soil moisture:

Scenario 1: application in autumn on bare soil with high soil moisture
Scenario 2: application in early spring on bare soil with low soil moisture
Scenario 3: application in early summer on cereals with low soil moisture

Depending on soil type and scenario, the corresponding run-off volume can be picked up from the table for each value of *precipitation* between 1 and 100 mm. (For the Expert Group's testing, precipitation was assigned a default value of 30 mm.)

- *The amount of pesticide (*$Cr_{soil\ surface}$ *) relative to the dose applied that is available for run-off three days after application:*

$$Cr_{soil\ surface} = \exp(-3 * \lambda) * (1 / (1 + K_d)) * (1 - \textit{plant interception} / 100)$$

Where $\lambda = \ln(2) / DT_{50soil}$
plant interception = default values (see Table 4.1)
$K_d = (K_{oc} * \%OC) / 100$
$\log K_{oc} = 1.09 + 0.47 * \log K_{ow}$

We consider the contribution of run off to the dissolved concentration in water only ($c_{diss} = c_{tot} \cdot (1 / (1 + K_d))$). Within the first three days the compound is degraded under a first order kinetics ($\exp(-3 * \lambda)$). Finally, the proportion of pesticide reaching the soil depends on how much is intercepted by the plant when it is applied: (1 – *plant interception* / 100).

- *The slope of fields* according to:

$f1(Slope) = 0.02153 * slope + 0.001423 * slope^2$ if slope< 20%
$f1(Slope) = 1$ if slope ≥ 20%

- *The width of a run-off buffer*. Only a foliage-covered site is defined as a run-off buffer. The loss via run-off decreases exponentially with the width of the buffer in meters according to the formula:

$$f2(\text{Run-off buffer zone}) = 0.83^{\text{buffer width}}$$

As is done for spray drift, runoff buffer compliance is incorporated by calculating $L\%_{runoff}$ with and without a buffer, according to the following formula:

$$L\%_{runoff} = (L\%_{RONB})\times(1\text{-}Compliance_{ROB}) + (L\%_{ROB})\times(Compliance_{ROB})$$

where $L\%_{SRONB}$ = The % runoff with no buffer
$L\%_{ROB}$ = The % runoff with buffer
$Compliance_{ROB}$ = the runoff buffer compliance (default value = 1)

Use of the Indicator

REXTOX's three levels can be used for the following analyses:

- Level 1 identifies the (worst case) risk associated with a single application of the recommended dose of a pesticide on one hectare. It can be used to identify pesticides or application methods with a particularly high contribution to risk. Level 1 can also be used in conjunction with Level 2 to help interpret the national trends identified in Level 3.

- Level 2 identifies the risk associated with the typical treatment of one average hectare in agricultural practice. This can be used to compare the risk of alternative treatment regimes on a crop—for example, to compare an integrated crop protection scheme with a 'conventional' scheme by looking at a typical hectare under each scheme. It can also help interpret trends identified in Level 3 by showing changes in risk on a typical treated hectare.

- Level 3 identifies the total extent of risk from all applications of pesticide in a larger area (e.g. the entire country). It can be used to determine risk indices at a national or regional level for one crop, for groups of crops, or for all crops, or for one pesticide, for groups of pesticides, or for all pesticides. Indices calculated for different time periods can be compared to identify trends. Level 3 cannot, however, tell whether trends reflect changes in agricultural practice, in the pesticides used, or in the area cultivated.

Strengths and Weaknesses

REXTOX has significant strengths, generally resulting from use of the mechanistic approach:

- Because REXTOX includes precise endpoint values rather than scores, it is the most responsive of the three indicators to changes to any of the input values. It can also be easily adapted to different regional conditions, such as weather, soil, and landscape features like slope.

- REXTOX is relatively objective and transparent. By using direct input values and familiar models to calculate pesticide levels in water bodies, REXTOX minimises reliance on expert judgement to set scores, weight variables, and so forth. This objectivity is of course only relative, because expert judgement was required to set up the indicator and to choose which models to incorporate. Nevertheless, people already familiar with the models used in REXTOX can easily understand how it works.

- Of the three indicators in this project, REXTOX most closely resembles risk assessment in its basic structure and concept. It uses similar models to calculate the amount of pesticide in spray drift and runoff, then the specific concentration of pesticide expected to occur in water bodies, and finally the change in this concentration over time under the influence of degradation.

REXTOX also has weaknesses:

- While including precise information for spray drift and runoff, REXTOX ignores altogether other routes of potential aquatic exposure (e.g. drainage). This means that the trends produced by REXTOX describe only a portion--albeit the main portion--of the real risk.

- The precise estimates produced by the exposure models rely on various assumptions about exposure processes that may or may not be perfectly correct. The indicator results may thus imply a 'false precision.'

- REXTOX is quite complex. Although scientists and risk assessors may consider it transparent and familiar, its formulae may be difficult for others to understand.

ADSCOR

ADSCOR (**AD**ditive **SCOR**ing) is a hybrid ***scoring*** indicator, using scores for most variables but direct values for toxicity and area treated. It is the simplest of the three indicators developed in this project, although it shares a number of characteristics with the others and uses similar input data. ADSCOR is typical of many pesticide hazard and risk indicators currently published, and shares several characteristics with the indicator used by the Swedish government to measure progress in meeting national risk reduction goals. (The Swedish indicator is described in the OECD Survey of National Pesticide Risk Indicators.)

ADSCOR's structure is quite simple. It begins by deriving scores for the values of the variables related to exposure (including spray drift and/or runoff buffers). These scores are added together and divided by toxicity to obtain an *unscaled* risk index for each aquatic organism. Finally, the unscaled risk index is multiplied by the total area treated to obtain a *scaled* risk index.

ADSCOR was originally defined by the Expert Group as a pure scoring indicator, but preliminary testing showed that scoring toxicity and area treated distorted the indicator results by exaggerating the contribution to risk from small-scale uses and underestimating the contribution of major uses, for example. These distortions resulted in part from the initial choice of relatively few scoring categories, and could have been reduced by using more categories. The Expert Group chose instead to use actual values for both toxicity and area treated.

Although ADSCOR does not explicitly model the exposure process, the scoring process incorporates a general understanding of exposure and implicitly includes all routes of exposure (not just spray drift and run off). For example, the scores assigned to application methods would be lower for 'cleaner' methods that are not likely to contribute to aquatic exposure and higher for 'dirtier' methods that are more likely to contribute. When spray drift or runoff buffers are required, ADSCOR offsets high scores for the 'dirtier' application methods by assigning negative scores for buffers. To accommodate less than perfect compliance with buffer zone requirements, these negative scores can be reduced by the estimated probability of compliance, expressed as a decimal fraction.

Construction of the Indicator

ADSCOR uses 10 variables to calculate short-term risk indices and 15 to calculate long-term risk indices. Each scored variable is divided into categories reflecting levels of contribution to risk (e.g., low—medium—high), and a score is assigned to each category. Breakpoints between categories were set which (1) divided the data available for the project into the appropriate number of categories, (2) assigned roughly equal numbers of pesticides to each category, and (3) fell at convenient round numbers (e.g. 1, 10, 100 etc.). The categories, breakpoints and scores for each ADSCOR variable are shown in Table 3.2 below.

Table 3.2
ADSCOR Variables, Categories, and Scores

Data Type	Variable			Use of Variable	
	Variable Name	Category Break-Points	Score	Short Term Index	Long Term Index
Pesticide Toxicity (not scored)	Fish, 96-hr LC_{50}			X	
	Fish, 21-day NOEC				X
	Daphnia, 48-hr EC_{50}			X	
	Daphnia, 21-day NOEC				X
	Algae, 96-hr E_rC_{50}			X	
	Algae, 96-hr NOEC				X
Pesticide Use (all but BAT are scored)	Basic area treated (BAT)–hectares treated at least once per season			X	X
	Average dose rate	≤ 0.1 kg/ha > 0.1 & ≤ 1.0 kg/ha > 1.0 & ≤ 3.0 kg/ha > 3.0 & ≤ 10.0 kg/ha > 10.0 kg/ha	0 1 2 3 4	X	X
	Frequency of treatments per season	≤ 1.1 > 1.1 & ≤ 3 > 3	0 1 2	X	X
	Method of application	Seed treatment, bio-control, pruning paint Soil sterilant, granular incorporated Granular broadcast Ground spray Aerial, air-blast, application to aquatic crops	0 1 2 3 4	X	X
	Spray Drift buffer zone required and observed	For application by ground spray For aerial or airblast application	-1* -2*	X	X
	Runoff buffer zone required and observed	For granular broadcast, ground spray, aerial or air-blast application	-1*	X	X

* the default values for these variables are as follows:

- spray drift buffer zone: 1 m for all applications without buffer, 6 m for all pesticides with obligatory buffer
- spray drift buffer zone compliance: full compliance = 1 (to be changed proportionally if compliance is less than 100%, e.g. 50% compliance = 0.5)
- runoff buffer zone: 0 m
- runoff buffer zone compliance: full compliance = 1 (to be changed proportionally if compliance is less than 100%
- water index: 0.1 for all regions

To incorporate an estimate of the degree of compliance with buffer requirements, the 'bonus' for spray drift or runoff buffers can be reduced by multiplying the score by the probability of compliance, expressed as a decimal fraction.

Table 3.2 continued
ADSCOR Variables, Categories, and Scores

Fate/Environmental Factors (all scored)	Water index	≤ 0.2 > 0.2	0 1	X	X
	DT_{50} in water	≤ 1.5 months > 1.5 months & ≤ 6 months > 6 months	0 1 2		X
	Photolysis in water	≤ 5 days > 5 days	0 1		X
	$LogK_{ow}$ (for bioaccumulation potential)	≤ 100 > 100 & ≤ 1000 > 1000	0 1 2		X
	DT_{50} in soil	≤ 1.5 months > 1.5 months & ≤ 6 months > 6 months	0 1 2		X
	K_{oc} (derived from K_{ow}, for runoff potential)	> 150 > 50 & ≤ 150 ≤ 50	0 1 2		X

Like REXTOX, ADSCOR first calculates an ‘unscaled’ index for each specific use, and then ‘scales’ the index by factoring in the area treated. The ADSCOR index is calculated in three steps:

- In Step 1 an exposure score is calculated for a specific use of a specific pesticide in a specific geographic area by summing the appropriate scores for pesticide use, pesticide fate and environmental factors.

- In Step 2, +1 is added to the exposure score (to ensure it is not zero) and the sum is divided by the actual toxicity value of one of the three organisms of concern. This calculation yields the ‘unscaled’ risk index for the specific use and organism of concern, comparable to Level 2 of REXTOX.

- In step 3 the unscaled risk index is multiplied by the unscored basic area treated (i.e. the number of hectares treated). This calculation yields a ‘scaled’ risk index, comparable to Level 3 of REXTOX.

Illustrating in somewhat more detail, the calculations for the ADSCOR risk indicator for a single use of a specific pesticide in a specific geographic area are as follows:

Step 1

- The ***short-term exposure score*** is the sum of:

  Average dose rate score
  + Frequency of treatments per season score
  + Method of application score
  + Spray drift buffer score (adjusted by compliance)
  + Runoff buffer score (adjusted by compliance)
  + Water index score

- The ***long-term exposure score*** is the short-term exposure score plus:

  DT_{50} water score
  + photolysis in water score
  + LogKow score
  + DT_{50} soil score
  + Koc score

Step 2

- To calculate the ***unscaled short-term index***, add +1 to the short-term exposure score and then divide it by the actual toxicity value for each organism:

$$\text{unscaled index (short-term)} = \frac{\text{(short-term exposure score + 1)}}{\text{short-term toxicity}}$$

- The ***unscaled long-term index*** is calculated similarly, substituting the long-term exposure score in the numerator of the fraction, and the appropriate long-term toxicity value in the denominator:

$$\text{unscaled index (long-term)} = \frac{\text{(long-term exposure score + 1)}}{\text{long-term toxicity}}$$

<u>Step 3</u>

- To calculate the ***scaled short-term index***, multiply the unscaled short-term index formula by the actual value in hectares of the basic area treated (BAT):

$$\text{scaled index (short-term)} = \frac{\text{BAT * (short-term exposure score + 1)}}{\text{short-term toxicity}}$$

- To calculate the ***scaled long-term index***, substitute the long-term exposure score and toxicity values:

$$\text{scaled index (long-term)} = \frac{\text{BAT * (long-term exposure score + 1)}}{\text{long-term toxicity}}$$

These calculations generate an unscaled or scaled ADSCOR aquatic risk index for a specific use of a specific pesticide, within a specific geographic area. Aggregation by use or groups of uses, by pesticide or groups of pesticides, or into larger geographic regions is accomplished simply by adding together the index values for all the specific uses contained within the aggregate.

Use of the Indicator

ADSCOR can be used to calculate both national risk trends and trends for an individual hectare, and to conduct similar analyses and answer similar questions to those discussed above for REXTOX. Like REXTOX, with ADSCOR it is possible to drill down into the underlying data to find the cause of a change in the index.

Strengths and Weaknesses

ADSCOR offers several strengths common to scoring indicators.

- It expresses risk factors in a qualitative way (low, medium, high), which may be easier to grasp than, for example, a precise value for water solubility (is 2 mg/liter good or bad?).

- The use of scores makes ADSCOR more ‘forgiving’ for databases that include ranges rather than exact values for some parameters (e.g. DT_{50}>60 days).

- The scores allow ADSCOR to include implicitly all routes of exposure (based on judgement), without calculating precise levels for each.

- ADSCOR's basic structure and equation are easy to understand, even by people without technical expertise.

- ADSCOR is relatively easy to modify, if a user wants to add new parameters or delete existing ones. Such changes require a consideration of the relative risk contribution of any added parameters, but do not involve complicated mathematical models.

ADSCOR also has several limitations, shared by other scoring indicators:

- Converting the input values into scores results in a loss of precision and 'sensitivity' to minor changes in the values. Scoring indicators can over- or under-react to such changes depending on where the values fall in relation to the 'breakpoints' between the scores. For example, ADSCOR defines a breakpoint at 6 months for degradation time in soil. Pesticides with degradation times in the range from 1.5 months through 5.9 months would all get the same score of 1. But a change from 5.9 to 6.0 months would double the assigned score from 1 to 2.

- Assigning scores and weighting the different variables is subjective (based on expert judgement) and dependent upon local conditions that affect pesticide risk.

- ADSCOR and other scoring indicators do not come ready-to-use. The equation to combine the scores will remain constant, but each user will need to review--and in many cases re-set--breakpoints and scores.

SYSCOR

SYSCOR (**SY**nergistic **SCOR**ing) is a ***scoring*** indicator adapted from a system of hierarchical linkage of variables developed in France. The French system, called SIRIS (for System of Integration of Risk with Interaction of Scores), has been used to rank pesticides according to their intrinsic properties, as a basis for ground- and surface-water monitoring. (SIRIS is described in the OECD Survey of National Pesticide Risk Indicators.) SYSCOR retains some of SIRIS's main characteristics, but was modified to facilitate comparison with the other indicators.

Like ADSCOR, SYSCOR uses direct values for toxicity, and thus is not a pure scoring indicator. SYSCOR does however score exposure, including the total area treated as well as dose, application method, buffer zones, and the variable of 'farmer training' (for products to be applied only by *professional* applicators, not the ordinary farmer) not included in the other two indicators. As with ADSCOR, scoring is used in place of an explicit calculation of spray drift and runoff, and implicitly includes not only these two routes of exposure but other possible routes as well. SYSCOR deals with buffer zones by modifying the score for method of application, but does not take into account the size of the buffer zone or degree of farmer compliance.

SYSCOR develops scores for exposure using a unique system that: (1) ranks the relevant variables in order of their importance; (2) divides each variable into different categories reflecting low, medium or high contribution to risk; (3) derives scores for the variables based on their own category *and* on the categories of higher ranked variables, using a system of rules intended to capture the respective importance and interaction of the different variables; and (4) adds the scores together to obtain a total exposure score. The final exposure score is divided by toxicity to obtain a 'risk index' for one or more aquatic organisms.

The unique feature of SYSCOR -- captured in (1) and (3) above -- is its complex, hierarchical scoring system that both weights some variables more than others and also accounts for the interaction between related variables. Most notably, the system allows for variables ranked high in the hierarchy (i.e. considered to have high importance to exposure) to influence variables with a lower rank. For example, SYSCOR will give a higher 'solubility' score (and a higher final score) to a highly soluble pesticide when it is used adjacent to water than when it is used elsewhere, because 'solubility'-- ranked 3 -- is influenced by 'water index' -- ranked 2. The method used to capture this 'synergy' between variables, as developed by the French, is intended to provide a closer approximation of real risk than if variables are treated independently and their scores simply added up, as in ADSCOR.

SYSCOR also differs from the other two indicators in the following respects:

- SYSCOR does not calculate an unscaled risk index for the individual hectare treated, and then 'scale up' based on the area treated. Instead, SYSCOR works with the total area treated from the very beginning in calculating an exposure score, and never deals with the unscaled individual hectare. As will be seen later, 'cumulative area treated' is in fact one of the top ranked variables in the exposure hierarchy, together with application method and dose rate. This approach was used in the original French indicator to enable these three variables to interact at a higher rank with the pesticides' intrinsic properties. The authors of SIRIS reasoned that application using a drift-prone or other ‘dirty’ method, or use of a pesticide over a vast area, is likely to contribute more to risk than, for example, relatively greater solubility in water.

- Due to time limitations, SYSCOR was designed to calculate only short-term risk indices. The capability to calculate long-term risks could be added by including variables for long-term toxicity, adjusting the breakpoints between the categories, and adjusting the weighting of pesticide properties that influence long-term exposure.

Construction of the Indicator

SYSCOR uses 13 variables to calculate short-term risk indices. These variables, their class in the exposure ‘hierarchy,’ and the categories into which each class is divided are presented in Table 3.3. This table lists 4,860 possible combinations of categories, resulting in final exposure scores ranging from 0 to 382 (some combinations share the same score). The categories are combined and scores produced using a table similar to the one used by SIRIS. Extracts from the scoring table are given below, and the full table is available on request.

SYSCOR is built in the following steps:

- **Step 1** ranks the exposure variables in seven Classes based on their perceived importance to risk. Class 1 variables are considered most important, and will have more weight in the calculations. Classes 2-6 will have progressively less influence. Class 1 contains three variables: area treated, dose rate, and application method (including buffer zones). These variables were combined in one Class because they are statistically related. All other Classes contain only one variable.

- **Step 2** divides each variable into broad categories (using mostly only one or two breakpoints) which reflect low, medium or high contribution to exposure. The categories are called *‘o’* for ‘OK,’ low contribution to exposure, *‘m’* for medium contribution, and *‘d’* for ‘de-favourable,’ high contribution. Most variables are given just three possible categories: *o, m* and *d*. However, ‘method of application,’ ‘water index’ and ‘trained users’ have no category *m*, and ‘method of application’ has extra categories for methods thought highly likely to contribute to exposure (given multiple *d’s*).

- **Step 3** adds up the three categories in Class 1 to create a single Class 1 category (in adding up, category *o* counts as zero and category *m* as *½d*, being the average between *o* and *d*). As shown in Table 3.3, the category for ‘method of application’ is strongly influenced by use of a buffer zone. Application methods that would normally receive a higher category (*2d - 5d*) are instead given the category *d (*i.e. *1d)* when a buffer is used.

- **Step 4** derives a score for the respective category identified in each Class. This is done using the scoring table, which goes one-by-one through the Classes, starting with Class 1 and ending with Class 7. The table is designed so that the scores for Classes ranked lower in the hierarchy are influenced by the categories of the higher Classes. More specifically, each time a higher-ranked variable has a category greater than *o*, the scores for the remaining variables will increase. For example, if the score for untrained users (Class 7) is 4 when DT_{50}soil (Class 6) is <1.5 months (*o*), the score will be greater than 4 for untrained users when the DT_{50}soil is >1.5 months *(m)*. The table below demonstrates this change, in a case where Class 4 (DT_{50}water) remains at category *m* with a score of 5, and Classes 1-3 remain at category *o*.

Row	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6		Class 7		Total
	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Score
26	*o*	0	*o*	0	*o*	0	*m*	5	*m*	4	***o***	**0**	***d***	**4**	13
28	*o*	0	*o*	0	*o*	0	*m*	5	*m*	4	***m***	**3**	***d***	**5**	17

A more dramatic increase can be seen in the score for Class 7 (as well as Classes 4 and 5) when the category of Class 1 increases:

Row	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6		Class 7		Total
	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Score
26	***o***	0	*o*	0	*o*	0	*m*	5	*m*	4	*o*	0	***d***	**4**	13
1970	***3d***	93	*o*	0	*o*	0	*m*	8	*m*	7	*o*	0	***d***	**10**	118

One additional feature of the scoring system is that, other values being equal, the maximum score in any Class will be greater than the maximum score for a lower Class. This is illustrated in the table below, which shows the highest possible categories for all Classes, and thus the highest possible final exposure penalty:

Row	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6		Class 7		Total
	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Score
4860	*7d*	**217**	*d*	**30**	*d*	**29**	*d*	**28**	*d*	**27**	*d*	**26**	*d*	**25**	382

- **Step 5** adds up all the individual scores to derive a total penalty for exposure. This has already been illustrated in the tables above, and is shown in a bit more detail in the two tables below, which reproduce the first and last ten lines of the full penalty table:

Row	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6		Class 7		Total
	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Score
1	o	0	o	0	o	0	o	0	o	0	o	0	o	0	0
2	o	0	o	0	o	0	o	0	o	0	o	0	d	2	2
3	o	0	o	0	o	0	o	0	o	0	m	2	o	0	2
4	o	0	o	0	o	0	o	0	o	0	m	2	d	3	5
5	o	0	o	0	o	0	o	0	o	0	d	5	o	0	5
6	o	0	o	0	o	0	o	0	o	0	d	5	d	4	9
7	o	0	o	0	o	0	o	0	m	4	o	0	o	0	4
8	o	0	o	0	o	0	o	0	m	4	o	0	d	3	7
9	o	0	o	0	o	0	o	0	m	4	m	3	o	0	7
10	o	0	o	0	o	0	o	0	m	4	m	3	d	4	11

Row	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6		Class 7		Total
	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Cat.	Score	Score
4851	7d	217	d	30	d	29	d	28	m	13	m	12	o	0	329
4852	7d	217	d	30	d	29	d	28	m	13	m	12	d	23	352
4853	7d	217	d	30	d	29	d	28	m	13	d	25	o	0	342
4854	7d	217	d	30	d	29	d	28	m	13	d	25	d	24	366
4855	7d	217	d	30	d	29	d	28	d	27	o	0	o	0	331
4856	7d	217	d	30	d	29	d	28	d	27	o	0	d	23	354
4857	7d	217	d	30	d	29	d	28	d	27	m	13	o	0	344
4858	7d	217	d	30	d	29	d	28	d	27	m	13	d	24	368
4859	7d	217	d	30	d	29	d	28	d	27	d	26	o	0	357
4860	7d	217	d	30	d	29	d	28	d	27	d	26	d	25	382

- **Step 6** divides the final penalty by toxicity to produce a ‘scaled’ risk index for each pesticide use.

Hence, the formula for SYSCOR is:

exposure score = based on combined scores for cumulative area treated, actual dose rate, method of application, trained users, water index (a default value of 0.1 was used for all regions), solubility in water, DT_{50} water, DT_{50} soil, LogKd

scaled index = $\frac{\text{exposure score}}{\text{toxicity}}$

The breakpoints and categories for the variables in SYSCOR, shown in Table 3.3, were decided in the same way as for ADSCOR.

Table 3.3
SYSCOR Variables, Class Hierarchy, Break-Points and Categories

Data Type	Variable			
	Class	Variable Name	Break-Points	Category
Toxicity (unscored)	n/a	Fish, 96-hr LC_{50}		n/a
		Daphnia, 48-hr EC_{50}		n/a
		Algae, 96-hr E_rC_{50}		n/a
Pesticide Use (scored)	1a	Method of application	Seed treatment, biological control, pruning paint Soil sterilant, granular incorporated, and any other application method with buffer zone Granular broadcast w/o buffer Ground spray w/o buffer Aerial, air-blast w/o buffer Direct application to water	o d 2d 3d 4d 5d
	1b	Actual dose rate	≤ 0.1 kg/ha > 0.1 kg/ha & ≤ 0.5 kg/ha > 0.5 kg/ha	o m d
	1c	Cumulative area treated	≤ 450 ha > 450 ha & ≤ 3500 ha >3500 ha	o m d
Fate/Environmental Factors (scored)	2	Water index	≤ 0.2 > 0.2	o d
	3	Solubility in water	≤ 1 mg/l > 1 mg/l & ≤ 100 mg/l > 100 mg/l	o m d
	4	DT_{50} in water	≤ 30 days > 30 days & ≤ 60 days > 60 days	o m d
	5	$LogK_d$	≥ 4 < 4 & ≥ 1 < 1	o m d
	6	DT_{50} in soil	≤ 1.5 months > 1.5 months & ≤ 6 months > 6 months	o m d
Pesticide Use (scored)	7	Trained users	Trained users required Trained users not required	o d

n/a: not applicable; unscored values are used
o = OK, low contribution to exposure (when adding categories, value = O)
m = medium contribution to exposure (value = ½d)
d = 'defavourable,' high contribution to exposure

Use of the Indicator

SYSCOR can be used, like REXTOX and ADSCOR, to track short-term risk trends for pesticides at the national level. With modifications, an indicator much like SYSCOR could also calculate trends in long-term risk, and trends at the hectare or regional level.

As with REXTOX and ADSCOR, it is possible to drill down into SYSCOR's data to obtain information about specific crops and pesticides of concern.

Strengths and Weaknesses

SYSCOR shares most of the advantages and disadvantages identified for ADSCOR. In addition, it has these unique strengths and weaknesses:

- With its synergistic scoring system SYSCOR incorporates better than most scoring indicators scientific understanding of the interactions among environmental fate and exposure processes. The disadvantage is that the system is complicated and not fully transparent.

- SYSCOR's complex scoring system makes it difficult to remove or add variables, or to change the number of categories, or the assignment of a variable to a class (if scientific understanding about its importance changes). It is, however, easy to change the actual breakpoints between categories.

Comparing the Indicators

The two tables that follow summarise and compare the main elements of three indicators. Table 3.4 compares their main characteristics. Table 3.5 compares their hierarchical structure, showing the different levels at which they can calculate risk indices, the data used at each level, and the results produced.

Table 3.4
Comparison of Main Characteristics of the Indicators

Characteristic	Indicator		
	REXTOX	ADSCOR	SYSCOR
Toxicity	All indicators consider toxicity to algae, *Daphnia,* and fish. Toxicity is not scored in any of the indicators.		
Short- or long-term risk	All indicators could calculate short-term and long-term risk using the appropriate exposure factors and endpoints for toxicity. For this project SYSCOR was only used to calculate short-term risk.		
Pesticide use	All indicators are designed to use pesticide use data at the level of individual pesticide, crop, method and timing of application.		
Exposure: Runoff and Drift	Runoff explicitly included by using formulae or sub-models. Spray drift explicitly included by using drift tables.	Runoff, spray drift, and leaching implicitly included through scoring of properties and application methods.	
Buffer Zones	Includes buffer width and estimate of farmer compliance	Scores run-off and spray drift buffers separately. Includes estimate of farmer compliance	Adjusts score for method of application when buffer is required.
Farmer training	Not considered, except as factor in compliance with buffers		Scored separately if application only by professionals, at low priority
How are variables combined?	Through mechanistic models analogous to those used for regulatory risk assessment	Additively. Breakpoints set based on knowledge of exposure mechanisms	Synergistically, reflecting expert judgment of relative importance of variables
How are variables weighted?	Determined by mechanistic models	Variables with more categories have greater weight than those with fewer categories	Variables judged more important have greater weight than those judged less important
How are variables scored?	No variables scored.	Most exposure factors scored. Direct (unscored) values used for toxicity and area treated.	All exposure factors scored, including area treated. Direct values used for toxicity.
How are variables aggregated?	All indicators initially calculate risk indices for individual pesticide, crop, method and timing of application. All indices can be aggregated by pesticide, by crop, or geographically.		
What factors may differ for each country and should be adjusted where appropriate?	Use data and area treated. Models for spray drift and runoff. Models for other routes of contamination if data are available. Water index, water depth, slope, soil properties, amount of rainfall, width of buffers, fate in soil and water.	Data and breakpoints for pesticide use, water index, fate in soil and water. Data for area treated.	Data and breakpoints for pesticide use, area treated, water index, fate in soil and water.

Table 3.5
Hierarchical Structure of the Indicators

	Local: Worst Case	**Local: Realistic Intensity (unscaled)**	**Area- or Country-wide (scaled)**
	$REXTOX_{potential}$	$REXTOX_{unscaled}$ $ADSCOR_{unscaled}$	$REXTOX_{scaled}$ $ADSCOR_{scaled}$ $SYSCOR_{scaled}$
What does the indicator estimate?	Worst case potential risk of one label-rate application per hectare.	Realistic risk of one typical application per hectare.	Realistic risk over the total geographic extent considered.
What data are considered?	Toxicity. Fate/Exposure factors. Maximum label rate.	Toxicity. Fate/Exposure factors. Actual dose rate. Probability of treatment. Frequency of treatment.	Toxicity. Fate/Exposure factors. Actual dose rate. Probability of treatment. Frequency of treatment. Area treated. Water index.
What does a change in the indicator results mean?	Trends reflect changes in the mix of pesticides used and their label dose rates, independent of agricultural practice or changes in the area treated or grown.	Trends reflect changes in the mix of pesticides used and in agricultural practice, independent of changes in the area treated or grown.	Trends reflect changes in the area treated or grown, and to a lesser degree, changes in the mix of pesticides used and in agricultural practice.

4. Evaluation of the Indicators

Scope of the Evaluation

REXTOX, ADSCOR and SYSCOR were evaluated using the database described in Chapter 2 (containing information on 307 pesticides used on arable crops (since 1977) and orchard crops (since 1983) in the UK). The project tested short-term risk versions of all three indicators, and long-term risk versions of REXTOX and ADSCOR. The common data set was run through each indicator to calculate risk indices for different years and for various combinations of pesticides and crops.

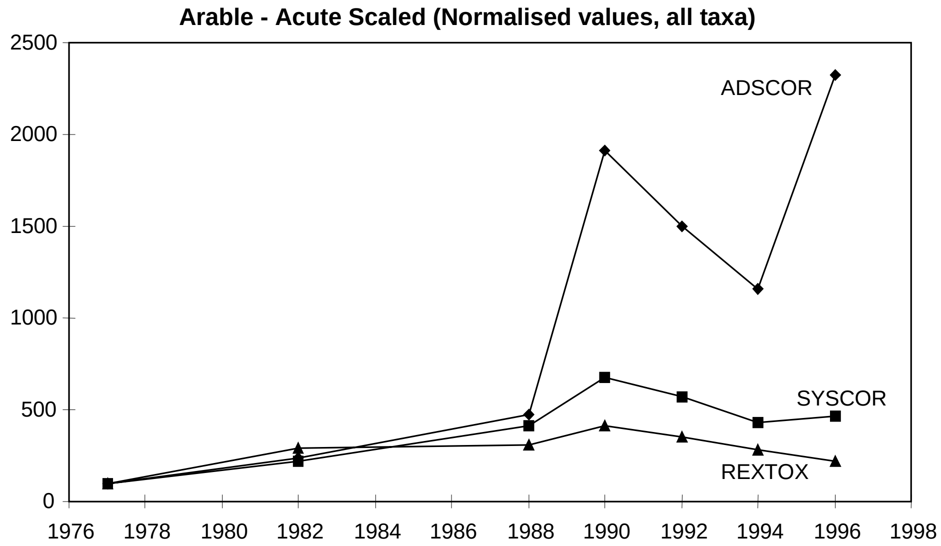
Presentation of Results

Results of the indicator calculations were presented in graphs showing risk trends over time, and in 'top ten' tables showing which pesticides contributed most to the risk index each year. The top ten tables proved to be very useful in understanding why risk trends went up or down. The EG noted that the tables could also help to identify pesticides to be considered for risk reduction measures. Examples of the graphs and tables, taken from Annex 3, are shown below.

Comparison of Trends Produced by REXTOX, ADSCOR and SYSCOR

The most important outcome of the project, made by comparing the trends produced by the three indicators, was that different indicators can produce different risk trends even when using the same input data. As explained below, this is mainly due to differences in the structure of the indicators, which result in different variables having more or less weight. Examples of the divergent trends that can result are illustrated in Figures 4.1, 4.3 and 4.4.

Figure 4.1



[Note: This is Figure 7.1(d) in Annex 3.]

As seen in Figure 4.1, all three indicators show a gradual but steady rise in risk due to pesticide use on arable crops from 1977 to 1988, a peak in 1990, and a decline in 1992 and 1994. However, the risk trend for ADSCOR is quite different from the other two indicators, showing much greater fluctuations after 1988. All three indicator trends then diverge from 1994 to 1996, with REXTOX continuing to decline, ADSCOR rising steeply to a new peak, and SYSCOR rising slightly.

To understand the trends, it is useful to look first at the top ten tables to determine which pesticides are contributing most to risk, then at data on the use of these pesticides during the years of concern. The top ten tables for arable crops (Tables 4.1, 4.2 and 4.3) are attached, followed by Figure 4.2, which shows the use of cypermethrin, the pesticide that contributed most to risk in the top ten tables for REXTOX and ADSCOR, and also figured importantly in the SYSCOR tables. Figure 4.2 shows that cypermethrin use rose steeply between 1988 and 1990, dropped in 1994, then rose again sharply in 1996.

What explains the divergence among the three indicator trends? Why, if cypermethrin use increased sharply in 1996, did the REXTOX risk trend decline and the SYSCOR trend increase only slightly? The answer is that the three indicators give different weight to the use of buffer zones, which were required for cypermethrin use in the UK starting in 1992. As shown in Figure 4.3, REXTOX and SYSCOR give buffers very high weight, whereas ADSCOR gives them relatively little weight.

Table 4.1

Top Ten Pesticides on Arable Crops by Contribution to Risk Index with Percent Contribution of Each Pesticide: REXTOX, Short-term, all taxa

Pesticide	1977	1982	1988	1990	1992	1994	1996
Chlorfenvinphos		8				5	
Chlorothalonil					2	2	
Chlorotoluron	5	12	5	3	3		2
Chlorpyrifos	12	17	13	10	24	24	7
Cyanazine	2						
Cypermethrin			6	30	4	3	10
Deltamethrin				2			
Fenpropidin			8	9	11	13	3
Fentin acetate	24	13	8	4	8	8	8
Fentin hydroxide							2
Gamma-HCH	8	4					
Isoproturon	5	8	13	11	12	13	22
Lenacil	3						
Linuron		2					
Monolinuron	16	6	5	4	4	6	7
Pendimethalin			5	4	8	3	12
Phosalone		2					
Pirimicarb	6						
Pyrazophos			3				
Tri-allate	2						
Trifluralin		8	7	5	7	6	12
Other Pesticides	17	20	27	18	17	17	15

[Note: This is Table 7.1 in Annex 3.]

Table 4.2

Top Ten Pesticides on Arable Crops by Contribution to Risk Index with Percent Contribution of Each Pesticide: ADSCOR, Short-term, all taxa

Pesticide	1977	1982	1988	1990	1992	1994	1996
Alpha-cypermethrin			5	2	4	3	2
Bifenthrin			2	2	3		1
Chlorfenvinphos	14	14					
Chlorpyrifos	6	10	5	1	3	22	2
Cyanazine	2						
Cyfluthrin				3			
Cypermethrin		7	35	66	60	43	64
Deltamethrin		3	19	16	10	8	4
Demeton-S-methyl	1						
Esfenvalerate						3	10
Fenpropidin			3	1	2	3	2
Fentin acetate	11	10	4	1	1	1	1
Fenvalerate			3	2	3		
Fluroglycofen-ethyl						1	
Gamma-HCH	23	10		1			
Lambda-cyhalothrin					4	4	10
Monolinuron	5						
Permethrin		3					
Phenylmercury acetate	17	8					
Phorate	5	9	3				
Pirimicarb	7		2				
Tefluthrin					2	2	
Trifluralin		4					1
Other Pesticides	9	22	19	5	8	10	3

[Note: This is Table 7.2 in Annex 3.]

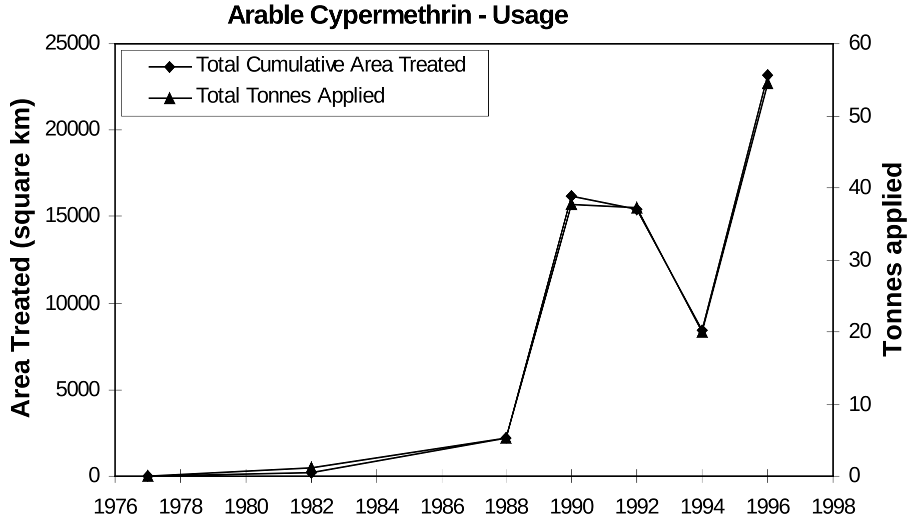
Table 4.3

Top Ten Pesticides on Arable Crops by Contribution to Risk Index with Percent Contribution of Each Pesticide: SYSCOR, Short-term, all taxa

Pesticide	**1977**	**1982**	**1988**	**1990**	**1992**	**1994**	**1996**
Alpha-cypermethrin			4	4	2	3	4
Bifenthrin			12	12	9	6	7
Chlorfenvinphos	3	5	4		3		3
Chlorpyrifos	32	22	11	13	25	17	17
Cyfluthrin			10	22	12		
Cypermethrin		9	16	17	11	14	14
DDT	2						
Deltamethrin		9	13	10	11	8	8
Esfenvalerate						15	16
Fentin acetate	9	4					
Fenvalerate		1	4	3	4	4	
Fluroglycofen-ethyl						3	
Gamma-HCH	6	3					
Lambda-cyhalothrin				2	5	9	10
Monolinuron	5	3					
Permethrin		3					
Phorate	21	28	8	4	5		4
Phosalone	2						
Pirimicarb	2						
Pyrazophos			3	2			
Tefluthrin						3	3
Trichlorfon	2						
Other Pesticides	16	13	15	11	13	18	14

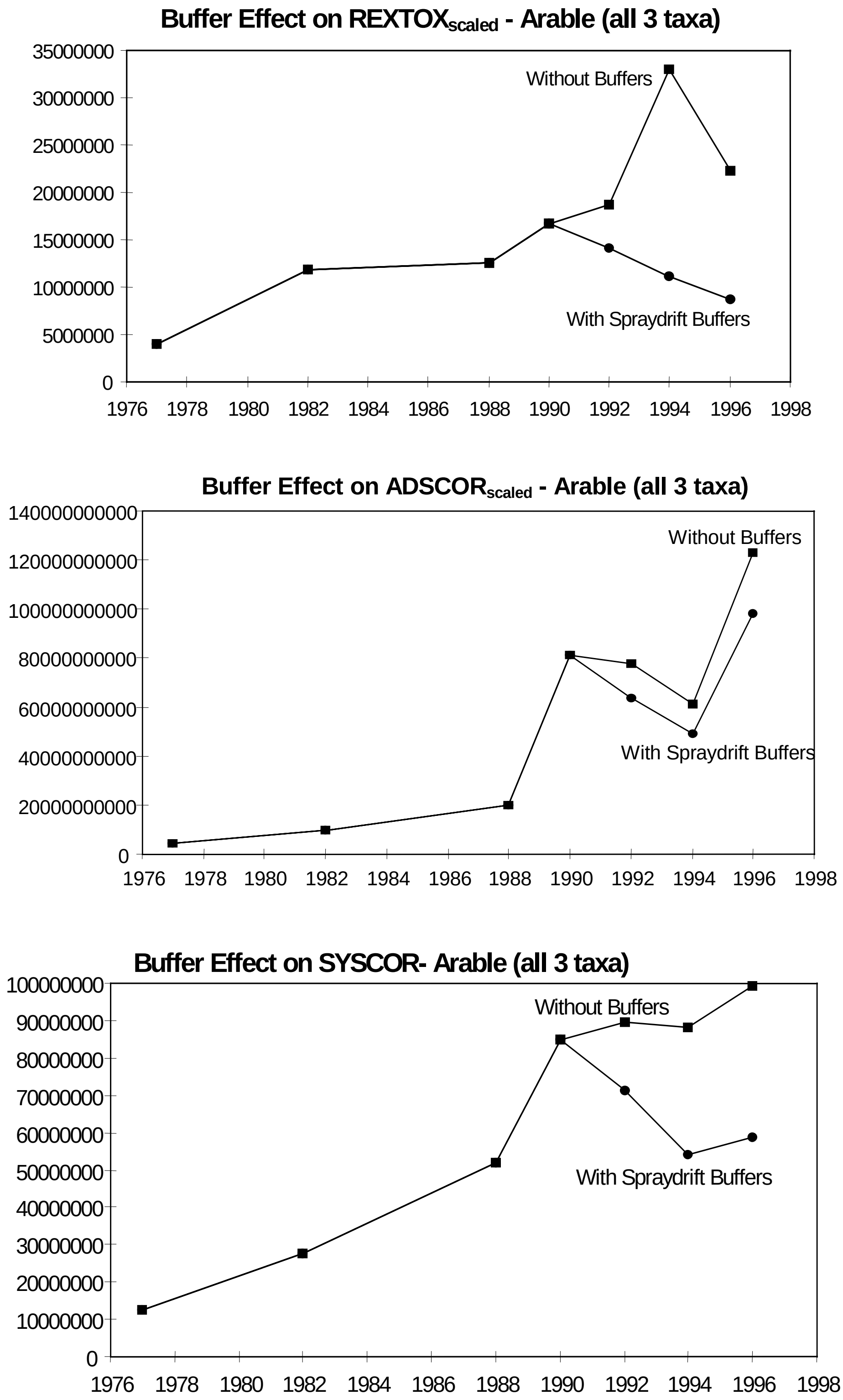
[Note: This is Table 7.3 in Annex 3)]

Figure 4.2



[Note: This is Figure 7.6(a) in Annex 3.]

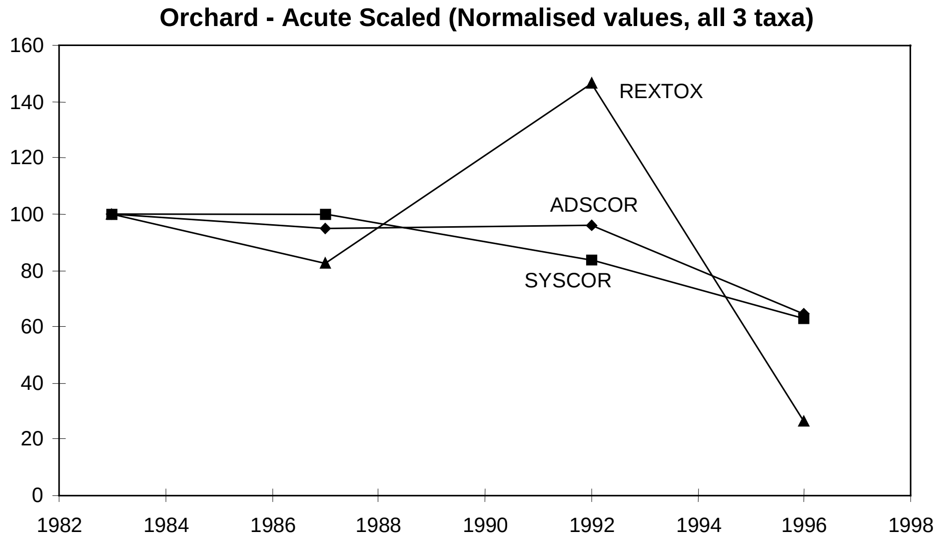
Figure 4.3
Comparison of the effects of spray drift buffer zones on the three scaled indicators
(The 'With Buffers' line indicates 100% compliance by farmers)



[Note: This is Figure 7.25 in Annex 3.]

As shown in Figure 4.4, the risk trends produced by the three indicators are more similar for orchards, though again there are important differences. ADSCOR and SYSCOR both show a gradual decline in aggregate risk over time, whereas REXTOX shows a slight decline in 1986, a sharp increase in 1992, and a precipitous decline in 1996.

Figure 4.4



[Note: This is Figure 7.4(d) in Annex 3.]

The top ten tables for pesticides in orchards produced by each of the three indicators (see Annex 3, Tables 7.4, 7.5, 7.6) help to explain the divergent trends. The tables show significant differences in the top ten pesticides identified and in their percentage contributions to risk.

In analysing these and other results of the indicator testing, the EG found that (1) in calculating short-term risk, the indicators reliably reflect the assumptions and information they include; and (2) the risk trends can be explained by drilling down into the data to identify likely causes of any changes. However, the EG found it was not possible to determine which indicator's trends corresponded most closely to actual risk. The reason is that aggregate aquatic risk from agricultural pesticide use is not directly measurable (unlike pesticide concentration in water bodies and effects on individual aquatic organisms, which *are* measurable locally). This means there is no known reality to compare with aggregate indicator results. Thus, the interpretation and evaluation of aggregate risk trends calls for consideration of a wide range of collateral data and thoughtful judgment.

The EG also found it was not possible to determine the extent to which a precise change shown by the indicators, e.g. a 50% decrease in risk to *Daphnia*, reflected a proportionate change in the real world, either for the risk trend over time or for the contribution of an individual pesticide. It was especially difficult to interpret trends calculated at a high level of aggregation because the specific causes of changes—e.g., a change in the area treated, the pesticides used, or the ways they were used—were often hidden.

Factors Influencing the Indicators

Effects of Structural Factors: Scoring and Multipliers

Analysis showed that structural differences between REXTOX, ADSCOR and SYSCOR contributed significantly to the divergence in aggregate risk trends. These differences are especially evident at lower levels of aggregation, e.g. when examining risk associated with a single taxon, a single crop, or a single pesticide. The differences are less evident at higher levels of aggregation, e.g. all aquatic organisms, all crops, or all pesticides. The differences are due primarily to two characteristics of indicator structure:

- **Whether the input data are used as direct values or converted into scores**. The importance of this factor depends on the characteristics of the specific input variable. If the range of values for a particular variable is narrow, as for 'average frequency of treatment' on wheat and orchards, conversion to scores will not significantly affect the risk index. But if the range of values for a particular variable is wide, as for 'area treated' or 'dose rate,' the effects of scoring or not scoring will be much more significant. If a wide range of actual values is reduced to just a few scores, the variable's influence on the risk index will be greatly reduced.

- **Whether the data are used as 'multipliers' in the indicator equation, or are included as part of an additive or hierarchic score**. A variable used as a multiplier will always have a much greater influence on the risk index than one that is incorporated into a scoring scheme. This was illustrated by the variable for 'area treated,' which had a greater influence as a multiplier in REXTOX and ADSCOR than it did in SYSCOR, where it is part of the hierarchy of scored variables.

Most differences between the three indicators can be explained by whether they score 'area treated' and 'average dose rate.' The differences can be quite dramatic, as was shown in the early stages of development of ADSCOR, when area treated was scored. Although scored area was used as a multiplier, the ADSCOR index at this stage appeared to exaggerate the contribution to overall risk of small-scale pesticide uses relative to large-scale uses. The EG therefore revised ADSCOR to include unscored actual values for 'area treated,' still as a multiplier. This change resulted in an increase in the contribution of the 'top ten' pesticides to the overall index value—from about 20 percent with scored area to about 90 percent of the total with unscored area. It also changed the percentage contribution to the overall index of each of the top ten pesticides from a uniform 2 or 3 percent to a more realistic range from 1 to 66 percent.

Driving forces

Analysis showed that despite their differences, all three indicators are driven by the same variables *when used at the national level*. These 'driving forces' are area treated, toxicity, and use of buffer zones.

- **Area treated** is the most important driving force for all three indicators, due to the use of its large values as a multiplier in REXTOX and ADSCOR, and its high importance in the hierarchy of the variables in SYSCOR.

- **Toxicity** is a driving force because direct values (rather than scores) are used in all three indicators, and these values are incorporated in the indicator equations as a divisor. All three indicators respond to changes in toxicity for all three taxa, especially *Daphnia*. REXTOX is more sensitive to risks to algae and fish than ADSCOR or SYSCOR because, among the pesticides in the test data base, risk to algae comes mostly from pesticides with high dose rates. Dose rate is scored in ADSCOR and SYSCOR, so these indicators are less responsive to changes in dose rate than REXTOX.

- **Use of buffer zones** reduces the risk indices produced by all three indicators, although the effect is much greater for REXTOX and SYSCOR than for ADSCOR. In REXTOX, a buffer zone directly affects the amount of spray drift or runoff contributing to water contamination and is therefore included directly in the exposure calculation. ADSCOR responds to buffer zones by reducing the score for a drift-prone method of application to a score equal to a less drift-prone method. This has a lesser impact on the index because it addresses only one factor in ADSCOR's overall exposure score. SYSCOR places buffer zones in the most important class of exposure variables, which leads to a result intermediate between REXTOX and ADSCOR.

- **Average frequency of treatment** is an additional driving force for levels 1 and 2 of REXTOX.

- Other variables also affect the indicators, but to a lesser extent. **Average dose rate** has more impact in REXTOX than in ADSCOR and SYSCOR, because REXTOX uses actual values as a multiplier. ADSCOR and SYSCOR both convert average dose rate to a score, thereby diminishing its impact. Because there was little variation in **application methods** for the crops included in the test database, the responsiveness of the three indicators to application method was not tested, although it is believed that this could have a marked affect on the indices.

Sensitivity to Missing Data

Analysis found that all three indicators are relatively insensitive to missing values for particular pesticides, as long as there are not too many gaps. Obviously the indicators will be affected if large proportions of data are missing, or if data are missing for the pesticides that are most widely used and would thus contribute most to the overall risk trend. Otherwise the project found that, when aggregated at high levels, the indicators are not very sensitive to variations in the input data. At low levels of aggregation (e.g., looking at a single pesticide), where even small changes in particular variables for a pesticide can influence the result, the indicators were more sensitive.

Missing Long-Term Hazard and Fate Data

Missing data was such a problem for the long-term versions of REXTOX and ADSCOR that it was difficult to interpret their results. Of the 307 pesticides included in the project, only 45 used on arable crops and 14 used on orchards (49 different pesticides in all) had enough long-term data to permit their inclusion in the long-term analysis.

In general, data were more likely to be available for new pesticides and those of recent regulatory concern, and less likely to be available for older pesticides. Thus the long-term risk indices undoubtedly exaggerate the risk contribution of new and problematic pesticides, and exclude entirely the risk contribution of most older pesticides.

The uneven availability of data led to certain long-term risk index results that were clearly not representative of real-world risks. The impact of missing or inappropriate data on indicator results was shown in the long-term risk trends for fish, produced by REXTOX and ADSCOR for the 1990s. After 1992, the trends rise sharply. The top ten tables show that this rise is almost entirely due to the introduction of the pesticide esfenvalerate, which is much more toxic to fish than the other pesticides with complete enough data sets to be included in the analysis. But this clearly exaggerates the true risk contribution of esfenvalerate. For one thing, no other pyrethroids were part of the calculation because they did not have complete data sets, although they were used by farmers and hence contributed to overall risk. Moreover, this is a case where more appropriate data would probably change the risk picture. If DT_{50} from field studies or water/sediment studies could have been used instead of the standard hydrolysis and photolysis DT_{50}, the indicator results would have taken account of the strong adsorption and reduced long-term bioavailability of esfenvalerate.

Reliability of Use Estimates Based on Sales Data

The project found that pesticide sales data offer a possible, but imperfect, substitute for data on actual pesticide usage (from farmer surveys). To determine the usefulness and reliability of sales-to-use estimates, the consultant tested a method developed in Germany by Gutsche and Rossberg (see Annex 2). This method supplements pesticide sales data with other information such the area under cultivation for each major crop (from national agricultural statistics) and pest pressure during particular growing seasons (from agricultural extension advisors).

Method of testing

The project could only test the method indirectly, because the database used had only actual use data, taken from farmer surveys. Hence a set of data covering the use of pesticides on wheat (for the years 1992, 1994, and 1996) and barley (1996) was selected and converted into estimates of sales. The resulting sales estimates were then converted into estimates of use, following the German method. The resulting use estimates were then compared with the original actual use data. The comparison focused on 10 pesticides with substantial use on wheat and barley: chlormequat, fenpropidin, fenpropimorph, isoproturon, mecoprop-P, flusilazole, metrosulfon-methyl, tebuconazole, chlorothalonil and cypermethrin. The first eight pesticides are used on only a few other crops in addition to wheat and barley, whereas the last two are used on 25 and 28 crops, respectively.

Results

Comparison of the two data sets, illustrated in Tables 4.5, 4.6 and 4.7, showed that:

- In 23 of the 39 pesticide/crop/year combinations the estimated use values were within 10% of the original actual use values. However, some estimated values were considerably off: from 51% below to 24% higher than the original values. As would be expected, there was a greater chance for discrepancy when the pesticide was used on more crops.

- An overestimate of the use of a particular pesticide on one crop results, not surprisingly, in an under-estimate for other crops.

- The accuracy of use estimates is diminished considerably if sales data are not supported by information on the likelihood of pest infestations and pesticide treatment.

Impact of Estimates on Indicator Results

The analysis showed that the use of estimates derived from sales data has varying effects on indicator results. In some cases the effect is minimal. For example, despite an important underestimation of mecoprop use on wheat during 1992-1996, the risk trends produced using the estimates differed from trends produced using actual use data by only a factor of two. More highly aggregated risk trends (for more crops and/or pesticides) would be expected to have even better agreement, because estimation errors would tend to average out.

On the other hand, the use of estimates rather than actual use data has important disadvantages.

- The indicator can not incorporate actual dose rates, which often are quite different from recommended label rates.

- Reliance on estimates makes it much more difficult to gain insight by drilling down into the index to determine the causes of change in aggregate trends. Drilling down will only reveal the estimates calculated from sales data.

- The estimates are likely to incorporate many applications that never occurred, while under-estimating the scale of major uses. This is because the estimation assumes that all approved uses of each pesticide actually occurred, in proportion to planted area of the crops involved.

Table 4.5
Comparison of surveyed pesticide use with estimates from simulated sales data, using the method of Gutsche and Rossberg. Results are for total weight applied (kg) of each active substance to wheat in Great Britain in 1992, 1994 and 1996.

	chlormequat	chlorothalonil	fenpropidin	Fenpropi-Morph	flusilazole	isoproturon	mecoprop-P	metsulfuron-methyl	tebucon-azole	cyper-methrin
Wheat 1992										
Calculated weight	1 796 856	730 756	238 565	420 966	94 228	2 031 606	240 417	2 346	0	20 161
Surveyed weight	1 776 621	704 599	204 048	400 085	88 693	2 085 415	359 373	2 069	0	19 759
% variance from surveyed weight	+1.1	+3.7	+16.9	+5.2	+6.2	-2.6	-33.1	+13.4	0.0	-2.0
Wheat 1994										
Calculated weight	1 817 046	610 412	207 923	157 492	63 794	1 782 924	247 428	3 226	158 802	7 935
Surveyed weight	1 799 111	585 468	167 190	144 038	56 110	1 830 578	355 244	3 035	161 262	7 831
% variance from surveyed weight	+1.0	+4.3	+24.4	+9.3	+13.7	-2.6	-30.3	+6.3	-1.5	+1.3
Wheat 1996										
Calculated weight	1 983 697	651 897	314 602	205 468	58 883	2 411 390	178 064	2 238	135 581	29 050
Surveyed weight	1 927 599	656 338	271 435	188 531	56 086	2 543 595	234 430	2 016	134 044	27 741
% variance from surveyed weight	+2.9	-0.7	+15.9	+9.0	+5.0	-5.2	-24.0	+11.0	+1.1	-4.7

[Note: This is Table 9.1 in Annex 3]

Table 4.6
Comparison of surveyed pesticide use with estimates from simulated sales data, using the method of Gutsche and Rossberg.
Results are for total weight applied (kg) of each active substance to barley in Great Britain in 1996.

Winter barley, 1996

	chlormequat	chlorothalonil	fenpropidin	Fenpropi-Morph	flusilazole	isoproturon	mecoprop-P	metsulfuron-methyl	tebucon-azole	cyper-methrin
Calculated weight	531 000	15 699	19 182	126 375	66 144	895 519	40 651	442	7 294	10 357
Surveyed weight	553 412	20 291	38 890	122 822	76 664	757 158	66 071	486	8 068	10 025
% variance from surveyed weight	-4.0	-22.6	-50.7	+2.9	-13.7	+18.3	-38.5	-9.1	-9.6	+3.3

[Note: This is Table 9.2 in Annex 3]

Table 4.7
Comparison of surveyed pesticide use with estimates from simulated sales data, using the method of Gutsche and Rossberg, assuming a probability of 1 for each permissible dose.
Results are for total weight applied (kg) of each active substance to wheat in Great Britain in 1996.

Wheat, 1996 (probability of treatment fixed to 1)

	chlormequat	chlorothalonil	fenpropidin	Fenpropi-Morph	flusilazole	isoproturon	mecoprop-P	metsulfuron-methyl	tebucon-azole	cyper-methrin
Calculated weight	1 598 394	402 135	253 234	241 609	109 976	2 392 328	71 947	2 340	82 530	24 027
Surveyed weight	1 927 599	656 338	271 435	188 531	56 086	2 543 595	234 430	2 016	134 044	27 741
% variance from surveyed weight	-17.1	-38.7	-6.7	+28.2	+96.1	-5.9	-69.3	+16.1	-38.4	-13.4

[Note: This is Table 9.3 in Annex 3]

Levels of Aggregation

The EG found that as a general rule, it is best to begin indicator calculations at a low level of aggregation, by calculating the risks to individual aquatic organisms caused by individual pesticides, crops, application methods and regions. These can then be combined to calculate trends for any higher level of aggregation, and the indicator user will still be able to drill down into the data to find the causes of the risk trends. It is especially important to calculate trends for individual pesticides rather than for classes or groups of pesticides, because factors that differ greatly between pesticides--toxicity, dose rate, area treated, and application method—all exert a strong influence on the indices.

The project also showed that high levels of aggregation can hide trends at lower levels which may be of interest. A highly aggregated national risk index, such as use of all insecticides on all crops, is likely to be driven by the crops with the largest area. Hence, any conclusions are likely to be correct for the biggest crop(s), but may well be wrong for smaller crops. For example, the risk trend for potatoes differed substantially from the trend for wheat, but the difference was masked by the much larger area of wheat when the two crops were aggregated in the broader category of 'arable crops.'

Sensitivity to Risk Reduction Measures

All three indicators were designed to reflect the impact of specific risk reduction measures. All three account for the use of buffer zones and different application rates and methods, although they do not respond equally to these changes. The only other risk reduction practice or policy directly included in any of the indicators is farmer training, as the lowest-weight variable in SYSCOR.

Although no other risk reduction practices are directly included in the indicators, all three should nonetheless respond to any policy measure that affects the area treated, or the choice or quantity of pesticide applied. Use of integrated pest management or the imposition of hazard-based pesticide taxes are examples of such measures. It would be difficult, however, to isolate the impact of such measures on the risk indices, since many other factors, including changing weather and pest pressure, also affect the choice and use of pesticides.

Some risk reduction practices—such as caution exercised by individual farmers who spray only if the wind is blowing away from water bodies—cannot be incorporated into the indicators at all.

Simplification of the Indicators

The project developed and evaluated simplified versions of all three indicators, to determine whether simpler indicators would produce similar risk trends and could be a viable alternative. The approach used was to recalculate the indices repeatedly, retaining the variables that 'drove' each indicator, while removing other, less important variables one at a time to determine how the new versions of the indicators performed. Results at each stage of simplification were then compared to the full indicator as originally specified.

This exercise dealt only with the national (scaled) versions of the indicators, and focused on simplifying the exposure component, because this requires the most data. The other components, toxicity and area treated, were not simplified because they included few variables (three for toxicity and one for area treated).

At the extreme of simplification the indicators were as follows:

REXTOX became: $\dfrac{\text{Area treated x Frequency of application x Dose rate}}{\text{Toxicity x Buffer}}$

which is equivalent to: $\dfrac{\text{Tonnes applied}}{\text{Toxicity x Buffer}}$

ADSCOR became: $\dfrac{\text{Area treated x Buffer}}{\text{Toxicity}}$

SYSCOR became: $\dfrac{\text{Score (Area treated, Buffer)}}{\text{Toxicity}}$

Using the same special data sets, the simplified indicators performed similarly to the full indicators from which they were derived. The trend lines were of very similar shape, and the lists of the top ten pesticides were similar, though not identical. Moreover, the simplified indicators had the same main differences that distinguish the full indicators:

- REXTOX is sensitive to dose rate and therefore reflects trends in tonnes of pesticides applied, whereas ADSCOR and SYSCOR, which are not sensitive to dose rate, reflect trends in area treated.

- SYSCOR's scoring of area treated is the main reason why it gives different results from the other two indicators.

It is premature, however, to conclude that the simplified indicators could or should be used in place of the full indicators. Their close correspondence to the full indicators in this project might simply be an artifact of the data used: for example, each of the crop groups tested was dominated by a single method of application – ground spray in arable crops and air-blast in orchards. Much more comprehensive testing would be needed to support a general conclusion of equivalence. Furthermore, the EG stressed that simplifying the indicators would deprive them of much of their capacity for drilling down to identify the causes of changing risk trends - and hence, of much of their utility.

5. Conclusions

The Expert Group concluded that pesticide risk indicators could be useful to national regulatory authorities for many reasons, including the following:

- They use actual data on pesticide use, instead of the worst-case assumptions relied on in registration decision making.
- They permit aggregation across pesticides, uses, and regions, giving insight not available from case-by-case registration risk assessments.
- They can indicate whether pesticide use is getting more or less risky over time, and why.
- They permit comparison of the risk potential of alternative pest management regimens.
- They can identify trouble spots (crops or regions) or trouble-makers (pesticides) quickly and confidently based on their contribution to overall risk.
- They can be used to simulate the impacts on risk of some policy measures before they are implemented, such as cancellation of a pesticide, increasing the size of a buffer zone, improving compliance with a use restriction.
- They can show graphically the effect on risk of the ever-changing mix of agricultural pesticides and use practices.
- They encourage national governments to clean up their pesticide databases (a good thing in itself and, once done electronically, more easily maintained).
- They encourage collection of actual usage data, essential for understanding actual risk, and useful for many other purposes as well.

The EG cautioned that governments should use indicators with full awareness of their limitations, and should validate indicator results with data on pesticide use, environmental monitoring data and expert advice. It advised governments not to take action on the basis of indicator results before confirming the validity of the risk trends.

The EG concluded provisionally that simplified national indicators with relatively few input variables could be used as an alternative to more complex indicators. However, the EG cautioned that further testing with additional data would be needed, and that the resulting indicators would lose much of the ability to drill down and identify causes of risk changes.

Finally the EG concluded that pesticide sales data, supported by agricultural statistics and information on pest pressure, could be used in indicators as a substitute for actual use data, with acceptable reliability so long as aggregation is at a high level.

6. Lessons Learned for Indicator Development

It can be done

Despite many challenges the EG developed three indicators of aggregate aquatic risk from agricultural use of pesticides. Any of the indicators can provide insights that are not possible from case-by-case registration risk assessments. The indicators can be used to produce graphs of risk trends and tables of the top-ten pesticides contributing most to risk. All three indicators allow for drilling down into the underlying data to understand why trends are going up or down.

It takes time to do well

Developing indicators is difficult and time-consuming. Although the EG and Consultants worked relatively continuously during the 15-month project, meeting four times (for a total of 11 days), and communicating frequently by electronic mail and fax, all agreed that more time was needed:

- To investigate various queries that arose as the analysis of the indicators progressed.
- To expand the sensitivity analysis to explore the effect of different scoring schemes.
- To seek a way to make the indicators sensitive to the difference between small areas of high risk and large areas of low risk.
- To determine which indicator best characterises the effects of buffers on actual risk.
- For additional discussion after the sensitivity analysis and before writing the final report, to address the new questions that surfaced from the testing and the sensitivity analysis.
- For the EG to have hands-on experience using the indicators and the database, to better understand the indicators, agree on their structure, increase comfort with their results, and increase confidence in the project conclusions.

Better pesticide data are badly needed

Missing data is a major barrier to using pesticide risk indicators. The EG found existing data sets for pesticides properties (toxicity, fate, physico-chemical characteristics) to be poor, inconsistent, and ridden with gaps. This is especially true for older pesticides. The EG agreed that it would be extremely useful for countries to work together to compile a complete and reliable shared database of pesticide properties. With regard to data on pesticide use and environmental conditions, the EG noted that each country would need to compile its own database, and that this would likely be labour intensive. However, the EG noted that good data on pesticide use and environmental conditions would have many uses beyond pesticide risk indicators.

Sales data can be used to estimate use, but real use data give better results

It is possible to combine data on volumes of pesticides sold with registration data to estimate use by pesticide and crop, but this is far from a perfect substitute for actual pesticide use data. Estimating use data from sales data is laborious, relies on a number of problematic assumptions (see Annex 2), and may produce misleading results. Consideration of actual scale and practices of use in the indicators allows them to add significantly to regulatory risk assessment, and much of their potential value is lost if they are not based on actual use data. Extrapolation from sales data should be used only if there is no other choice, and the results should be used with caution.

Indicators can be "customised" to suit the needs of individual countries

Indicators can be designed to be easily modified to accommodate individual countries' methods of risk assessment. For example, the models used in REXTOX to estimate runoff and spray drift could be modified or replaced by other models with relative ease. Toxicity endpoints can also be linked to exposure factors in various ways to meet the indicator user's preference. A separate indicator value can be calculated for algae, *Daphnia*, and fish, or a single indicator value can be calculated for the most sensitive of the three taxa, or for the geometric mean of like studies.

Indicators do add value to risk assessment

Some OECD governments have expressed concern that indicators might simply duplicate risk assessment. The EG found that indicators do offer something different. For example, they:

- Incorporate actual use data (i.e., post-registration information) and not just worst-case assumptions about pesticide use, as are generally applied in regulatory risk assessments.
- Permit comparison of the risk potential of alternative pest management regimens.
- Allow a view of the "whole picture", unlike all the single-pesticide risk assessments. Especially helpful is their ability to visualise (and communicate!) information of relative risks and risk trends.
- Help to identify trouble spots, i.e., particularly problematic pesticides or uses, deserving closer attention. These may be evident as a sudden change in a risk index over time. "Drilling down" into the underlying data or using top ten lists can reveal the cause.

Can simulate the effect on risk of some policy measures before they are implemented, so long as the indicator takes the measure into account. Examples might include cancellation of a pesticide, increasing buffer size, or improving farmer compliance with a use restriction.

Indicators have important limitations

People who use pesticide risk indicators should be aware of their limitations. This project revealed two important ones.

The first is that, despite their apparent complexity, indicators are actually quite simplistic and imprecise. They could not really be otherwise, given that they must (1) summarise risk trends at a highly general level, (2) demand relatively few data (far fewer than are used in a risk assessment, for example), and (3) be easy to use and understand. Indicators can be quite good at answering the questions they are designed to answer, e.g. about overall risk trends. The danger is that people might want to use them for other purposes for which they are not appropriate. In particular, the EG recommends that indicators not be used as a basis for regulatory action, without further analysis of all the available data.

The second important limitation of indicators is that their results cannot be validated, because risk cannot be measured on a broad scale in the real world. This means it is virtually impossible to verify the extent to which risk trends shown by an indicator correspond to real-life trends. This does not mean that indicator users should have no confidence whatsoever in indicator results. If properly designed, using current knowledge about pesticide toxicity, fate and use, indicator results should correspond generally to reality. For example, if an indicator shows risk dropping by 50%, risk in the real world is likely dropping - but maybe not by 50%. Indicator users must simply be aware that they are working with tools that give only approximate results.