

Section 7

ENVIRONMENTAL ASSESSMENT

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1. INTRODUCTION

The cyclodiene insecticide endosulfan is included among the first five chemicals selected for review under the National Registration Authority's Existing Chemicals Review Program. A history of aquatic contamination and fish kills contributed to the selection of endosulfan for review. The cyclodiene insecticides such as dieldrin and chlordane have largely been withdrawn from use because of persistent and bioaccumulative properties, but the structural features of endosulfan (inclusion of reactive functionality) moderate these tendencies significantly.

Endosulfan is a non systemic insecticide and acaricide with contact and stomach action. It is currently registered in 15 products that find widespread use for control of sucking, chewing and boring insects and mites in key agricultural industries, including control of *Helicoverpa* spp in cotton, and of insect pests (eg thrips, aphids and green vegetable bugs) on pome and stone fruit, strawberries, cole crops, cucurbits and other vegetables, cereals, maize, sorghum, linseed, lupins, tobacco, pastures, sunflowers, peanuts and tree crops.

Endosulfan is not manufactured in Australia, being sourced from Germany, India, South Korea or Israel. It is registered in many countries around the world, including the USA and most member countries of the European Union. Use has been restricted in a number of countries, although details are difficult to obtain. Probably the most notable example concerns attempts by the Philippines, successfully challenged by the registrant, to ban the use of endosulfan in rice production. Recent articles from the Swedish Board of Agriculture (Emmerman, 1996) and the National Chemicals Inspectorate (Bergkvist *et al*, 1996) indicate that endosulfan has been suspended/removed from the market in Sweden, and a recent Dutch publication (Teunissen-Ordelman and Schrap, 1997) records that endosulfan is now prohibited in The Netherlands. In this regard, advice to the NRA indicates that The Netherlands will not allow registration of the current forms of endosulfan due to fish toxicity and the cold climate metabolism characteristics. However, if these matters were to be overcome by formulation changes or modifications to use patterns, endosulfan may be acceptable. In relation to registration in Sweden, it is noted that endosulfan is listed as a restricted chemical for environmental and health reasons. However, it may be registered under certain conditions. Advice from an Australian registrant indicates that it is not a commercially viable product in Sweden and therefore registration has not been pursued.

2. CHEMICAL IDENTITY

Refer to Section 3 Chemistry Assessment for details.

3. PHYSICO-CHEMICAL PROPERTIES

Refer to Section 3 Chemistry Assessment for details.

4. FORMULATION OF END-USE PRODUCT

Endosulfan is mainly formulated as an emulsifiable concentrate or ultra-low volume liquid for Australian use. The principal registrant, AgrEvo, markets Thiodan ULV Insecticide and Thiodan EC Insecticide, and is investigating new formulations with extended residual activity on the crop and reduced volatility. The ULV formulation is almost exclusively used in cotton, and the EC formulation used predominantly in cotton but with significant use in tomatoes and vegetables and a broad range of minor uses.

5. ENVIRONMENTAL EXPOSURE

5.1 Environmental Release

5.1.1 Volume

Approximately 900 tonnes of technical endosulfan are imported into Australia annually. Use in the Queensland portion of the Condamine/Culgoa/Balonne catchment has been estimated at 157 tonnes (Rayment and Simpson, 1993). Annual consumption in NSW has been estimated at 400 tonnes (Sunderam *et al*, 1992). Global production in the early eighties was estimated to be in the order of 10^4 tonnes (IPCS, 1984). Current global production is likely to be significantly higher as use remains widespread (Simonich and Hites, 1995).

5.1.2 Application and use pattern

Endosulfan is used in a wide variety of agricultural situations including cotton, pome and stone fruit, tomatoes, vegetables, tobacco, cereals, legumes, oilseeds, strawberries, citrus, macadamias, tropical fruits and ornamentals. Home garden uses were discontinued on 31 March 1992.

Use patterns for Thiodan products were submitted in tabular form by AgrEvo. The ULV formulation is used almost exclusively in cotton, as tabulated below.

Crop	Rate (g/ha)	Use pattern	Estimated % use
Cotton	720	2-3 aerial ULV sprays at 5-10 day intervals from early squaring to end of squaring	98.7
Summer oilseeds and coarse grains (soybean, sunflower, sorghum).	720	A single aerial ULV application from flowering	1.2
Winter oilseeds and peas	720 (360 for peas)	A single aerial ULV application from flowering	0.1

The EC formulation has a much broader use pattern, but again cotton dominates consumption.

Crop	Rate (g/ha)	Use pattern	Estimated % use
Cotton	735	1-2 aerial LV or boom sprays at 5-10 day intervals from crop emergence to boll formation	72
Tomatoes	735	3-4 aerial LV or boom sprays from crop emergence to late fruit set	7
Vegetables (crucifers, cucurbits, capsicums, lettuce and leafy vegetables, root and stalk crops)	735 (or 190 mL per 100 L)	Up to 3 boom sprays, depending on crop	13.5
Winter oilseeds eg canola, lucerne, clover and medic seed crops	735 or 175-350	A single aerial LV or boom spray from flowering to seed set, or bare earth boom spray at reduced rate.	3.0
Summer oilseeds and coarse grains	735	A single aerial LV spray from emergence to flowering or seed set.	1.5
Pome and stone fruit	190 mL per 100 L	A single spray by high volume air blast from flowering to fruit set	2.0
Citrus	57 mL per 100 L	Up to 2 sprays by high volume air blast during spring to autumn	<0.5
Macadamia and tropical fruit	150 mL per 100 L	Up to 3 sprays by high volume air blast between flowering and fruit formation	1

Further detail follows on key crops or pests including those for which specific justifications were submitted in support of the use of endosulfan.

5.1.2.1 Cotton

Cotton is grown over about 200 000 hectares, mainly along the upper tributaries of the Darling and Fitzroy Rivers in NSW and Queensland. Significant increases in production were recorded in the 1996/97 season, when NSW planted 283 000 ha to cotton, and further increases are projected, particularly in dryland cotton. Much of the crop is irrigated, particularly in NSW. Endosulfan is applied when pests reach economic thresholds, with some 4-6 applications per crop at rates in the order of 700 g/ha during the early part of the season. This equates to around 700 tonnes per annum across the entire cotton crop. Application is predominantly by air, using micronairs to deliver fine droplets. Ground application occurs when the ground is not too wet or the canopy too thick, and some growers have indicated a preference for the ground based option as application rates can be reduced by applying as a banded spray.

It is recommended under the Australian insecticide resistance management strategy (Forrester *et al*, 1996) that endosulfan not be used in cotton during Stage III of the season (after 20 January in southern Queensland and northern NSW, 10 January for irrigated crops in central Queensland, and 1 February in the Macquarie Valley). The strategy is updated annually.

A range of industry and government bodies provided submissions on the value of endosulfan to the cotton industry. Endosulfan is the most frequently used insecticide in the industry for the control of the principal pests of Australian cotton, *Helicoverpa* spp, and is also effective in control or suppression of lesser economic pests, such as mirids. Endosulfan is considered to be a vital integrated pest management (IPM) compatible insecticide by all the above organisations. It allows direct and indirect economies, being much cheaper than alternatives and also useful in avoiding costs associated with secondary pest outbreaks.

Endosulfan is considered to be relatively soft on beneficial predators because its short residual activity permits repopulation, and is therefore important to IPM in cotton. Early season use in preference to "harder" alternatives helps conserve natural predators, thereby avoiding mid to late season flares of secondary pests, such as mites and aphids, that are associated with synthetic pyrethroid, organophosphate and carbamate insecticides.

The above organisations agree that in the absence of endosulfan, "harder" alternatives would be required early in the season, leading to greatly increased use of insecticides, particularly organophosphates, in mid to late season. This scenario may deteriorate further with the recent introduction into Australia of the "B type" silverleaf whitefly, *Bemisia tabaci*, a damaging pest that has established in cotton overseas and for which endosulfan is one of the most effective, non-flaring insecticidal controls.

Endosulfan is also vital to the Australian insecticide resistance management strategy, offering a control option from a distinct chemical class. The strategy relies for success on rotating the use of insecticides from different chemical classes, and would be likely to become unworkable with currently available chemistry but without the endosulfan option. There is resistance to endosulfan in *H armigera*, but at a much lower level than for the pyrethroids. The dominant early season pest, *H punctigera*, remains fully susceptible to endosulfan.

Current extension campaigns aim to maximise available non-chemical approaches to pest management and reduce the use of pesticides, particularly early in the season. Cultivation to destroy overwintering pupae is recommended. Insecticide application to cotton only occurs when monitoring indicates that standard thresholds for *Helicoverpa* larvae are reached. This allows maximum advantage from the high levels of natural mortality that can occur early in the season, and can avoid several early season insecticide applications. When thresholds are reached, cotton farmers are encouraged to use the least disruptive insecticide. Endosulfan is said to be the least disruptive conventional insecticide, after consideration of biological products such as *Bacillus thuringiensis* (*Bt*), and is considered vital to this extension campaign.

In the future, transgenic cottons are expected to reduce the need for chemical insecticides, including endosulfan. However, such chemical controls will need to be retained for conventional cotton grown as refugia to avoid *Bt* resistance, as well as for pest control late season in transgenic crops, when production of the *Bt* toxin declines. Endosulfan is proposed by the industry as the paramount chemical of choice for such late season use because of its soft reputation. Use of endosulfan could help preserve the benefits of important natural predators, particularly tachinid fly and ichneumonid/braconid wasp parasites, in such situations.

As well as the established industry in NSW and Queensland, cotton is making a comeback to the Ord River Irrigation Area, after previous attempts to introduce cotton to the region were defeated by heavy pest pressure and the rapid development of resistance, with some growers requiring 50 sprays per season.

Preliminary CSIRO research trials in Kununurra (Neales, 1996) suggest the possibility of an alternative to the current strategies of industry associations in the eastern States. Rather than relying predominantly on a diverse chemical arsenal including endosulfan, researchers at Kununurra believe, based on recent Vietnamese experience and local research results, that the key to successful cotton production in the area will be the development of new integrated management systems incorporating a variety of insect control techniques. Vietnam also had historical problems of high pest pressure and insect resistance that necessitated intensive spraying through the crop cycle, but CSIRO researchers visiting in 1992 found that Vietnamese cotton farmers only needed to spray twice per season following the adoption of an integrated pest management system relying on a virus and a parasitic wasp (*Trichogramma* spp).

CSIRO researchers, in conjunction with the Western Australian Department of Agriculture, have been conducting trials in the Ord using a number of integrated pest management systems involving such strategies as the use of food sprays to attract predators (ladybirds, lacewings and *Trichogramma*), and the use of companion crops that act as a nursery for beneficials and a trap crop for pest species. Early results are said to have been promising, with yields in experimental plots comparable with any cotton growing area in the world.

Further details of the Western Australian research were published recently (Strickland *et al*, 1998). Transgenic and conventional varieties were compared in the 1996 season, the latter in combination with food spray technology (Envirofeast) and lucerne, and the former with conventional chemicals. Transgenic cotton required an average 3.5 sprays, late in the season, compared with 10.5 for conventional cotton. Use of IPM soft chemicals (for example, endosulfan in place of dimethoate for mirid control) or Envirofeast, in combination with lucerne, reduced average requirements in transgenic crops to 3 sprays. Similar results were obtained in trials conducted over 230 ha in 1997, using transgenic varieties only because of the difficulties in managing conventional cotton in the Ord. Lucerne refuge crops were particularly effective in reducing spraying needs. Early planting is important, to help avoid damaging populations of *Helicoverpa armigera* that develop late in the season.

The promising results obtained in Western Australia offer the possibility that Australian cotton production may be able to reduce its reliance on toxic chemicals and reduce associated negative impacts. It needs to be stressed, however, that management strategies suitable for one geographic region with its unique environmental constraints and insect complexes may not be transferable to a different geographic region.

Industry submissions from the eastern States indicate that many of the approaches suggested by CSIRO researchers in Western Australia are already being pursued by some growers. In particular, the use of food spray technology to attract beneficial insects, together with trap crops such as lucerne, help defer early spraying by helping to maintain pest populations below economic thresholds. Such approaches have been quite successful in situations of low to moderate pest pressure but require augmentation by endosulfan when pest numbers are high. The development of crop varieties less attractive for heliothis breeding is also highlighted, in

particular new transgenic varieties. Natural and genetically modified viruses with specific activity against heliothis pests are also expected to be introduced over the next few years.

5.1.2.2 Pome and stone fruit

Endosulfan has traditionally been applied in high volumes as a full cover spray at rates in the order of 70 g per 100 L (equates to 1.4-2.1 kg/ha endosulfan for 2000-3000 L/ha spray) as required for control of thrips and aphids, and dimple bug in apples. Many users are moving to low volume applications, and labels and/or formulations need to be upgraded to reflect changing practices. Users need clear guidance on appropriate application rates. There would appear to be scope for reducing low volume rates as less chemical would be lost to the underlying soil using low volume application.

Apple and pear production is undertaken in all six states of Australia. The major producing regions for apples are the Huon Valley in Tasmania, Southern and Northern Victoria (eg Mornington and the Goulburn Valley), the Orange-Bathurst and Batlow regions of NSW, the south-west of WA, Stanthorpe in the south-east highlands of Queensland and the Adelaide Hills region of SA. The Goulburn Valley in Victoria is Australia's main pear producing region with around 80% of all production. Most of Australia's stone-fruits are grown in temperate areas of south-eastern Australia with irrigation.

High volume application to fruit trees uses airblast equipment, with application occurring between flowering and fruit set. As noted above, there is increasing use of low volume equipment, including electrostatic sprayers that deliver only 50-80 L/ha. Note that the principal registrant's estimate of a single spray in pome fruit is contradicted by the testimony of users. A respondent to the performance questionnaire reports up to five applications, depending on pest pressure, and that efficacy is marginal. Care must be taken when applications coincide with flowering in order to minimise impacts on bees. Endosulfan is generally considered to be very important or essential in apple orchards because of its IPM compatibility. Agriculture Victoria has noted that pyrethroid alternatives flare mites, with fluvalinate said to kill predatory mites for two seasons after a single application.

State coordinators report that endosulfan remains efficacious for this use, but some growers report marginal efficacy, particularly when applied under turbulent or windy conditions. This probably reflects the mode of application. Air assisted sprayers provide an airstream which propels droplets towards the target. For pomefruit and stonefruit, the equipment will project spray vertically upwards into a crop canopy. Gravity affects the trajectory of large droplets, increasing fallout which results in wastage of pesticide on the ground. To ensure good penetration of tree canopies small droplets are required. However, it is the small droplets that contribute principally to spray drift and contamination of soil and aquatic compartments outside the target area.

5.1.2.3 Tomatoes

Tomatoes are grown in all States, with Victoria the main producer. Endosulfan is applied as medium to fine droplets by boom spray or aircraft at rates in the order of 700 g/ha for control of *Helicoverpa* spp, thrips, aphids and bugs. Some 3-4 applications may be made to each crop between emergence and late fruit set, depending on pest pressure. Endosulfan is rotated with

synthetic pyrethroids, organophosphates and carbamates for resistance management, and is regarded as softer on beneficial insects than these alternatives.

5.1.2.4 Strawberries

Victoria is the main strawberry growing State, followed by Queensland and South Australia. Endosulfan is applied by boom spray at rates in the order of 70 g per 100 L as required for control of insect pests such as cutworms, thrips, aphids and bugs, and of strawberry mites. A Victoria growers' association has advised that alternative chemicals are available that would be equally acceptable from a marketing point of view.

5.1.2.5 Macadamia and tropical fruit

There are currently over 2 million macadamia trees in Australian orchards covering over 20 000 ha in subtropical areas of the east coast from the Atherton Tablelands to northern NSW. Approximately one-third of trees are mature, one-third are in the early bearing stage and one-third are immature.

A macadamia industry group has advised that endosulfan is vital to its IPM program, under which the annual number of insecticide sprays has been halved to 3 or 4 on participating farms. Endosulfan is used on an as needs basis as determined by pest monitoring between July and November. The group notes that nocturnal or late afternoon application is compatible with bee foraging which is important for pollination, and that the alternative trichlorfon does not have this essential capacity. Other alternatives (carbaryl, methidathion, chlorpyrifos) give rise to secondary outbreaks of Latania Scale and/or Macadamia Feltid Coccid.

An association representing custard apple growers made similar representations in July 1995, noting that many pests and diseases are controlled by non-chemical methods such as sticky bands to control ants or predatory wasps to control mealy bugs, but that endosulfan is the only registered chemical for use against fruit spotting bug, the major pest problem in this minor crop. Again, evening sprays are said to be compatible with bees. The growers' association further advised when responding to the performance questionnaire that Supracide (methidathion) is an acceptable alternative from the marketing perspective but is not recommended because of its harshness to natural predators.

The Queensland Department of Primary Industries has made similar representations regarding the crucial role played by endosulfan in control of fruit spotting bug on papaw.

Avocado growers have made similar representations since release of the draft review, noting the problems caused by fruit spotting bug, a native pest whose presence in avocado orchards can not be diagnosed until damage occurs, whereupon spraying takes place immediately. Some growers report using up to 16 sprays of endosulfan per season (mid-September to late April). Because the pest can not be detected, sprays are often poorly timed. The main alternative mentioned, methidathion, is regarded with disfavour due to its broad spectrum activity and tendency to flare secondary pests.

There may be scope to reduce the amounts of endosulfan used by adopting low volume application techniques. Such an approach has been investigated for citrus, which requires

high spray volumes to ensure thorough wetting of the dense foliage. Identification and synthesis of sex pheromones would also allow better timed and more efficient use of insecticides. The preliminary research that has been conducted in this area needs to continue.

5.1.2.6 Red legged earth mite

Agriculture Victoria provided details of use against this pest in emerging oilseed, legumes and pasture, and NSW Agriculture noted similar uses. Application occurs by boom spray. Endosulfan is regarded as a valuable tool in management of resistance in this pest. Some 300 000 ha of resown pasture is treated in Victoria at 500 mL/ha post-sowing, pre-emergence (an off-label use). Concerns are expressed for earthworms, but the rate is lower than the registered use of Crop Care Endosan 350 EC for earthworm control in turf, which entails application at 2.1 L/ha in autumn for extended control. New chemistry such as imidacloprid may offer an alternative. This new insecticide is registered as a seed dressing for canola and pasture, an efficient use pattern that results in much lower environmental exposure than the broadcast bare earth treatment used for endosulfan. It should be noted, however, that some State officials have advised that during periods of heavy pest pressure, endosulfan provides better control for red-legged earth mite and, significantly, simultaneously controls lucerne flea, an important pest in canola.

5.1.2.7 Earthworms

Apart from the use in turf, endosulfan is also used for earthworm control in flower pots. The Queensland Department of Primary Industries noted in its submission of July 1995 that endosulfan is the most effective chemical to control earthworms in pot plants for the ornamentals industry, and advised further following release of the draft review that this use is regarded as essential because there is no registered alternative.

5.1.3 Environmental monitoring

Endosulfan is a widespread environmental contaminant, particularly during the cotton season when significant contamination of waterways occurs downstream of cotton areas, sometimes attended by fish kills. Total endosulfan levels exceed, frequently by one and occasionally by two orders of magnitude, the Australian and New Zealand Environment and Conservation Council (ANZECC) guideline of 0.01 µg/L total endosulfan (both parent isomers and the sulfate metabolite) for protection of aquatic life. The guideline is derived by applying an assessment factor of 0.05 to the LC50 of 0.2 µg/L for the most sensitive native fish species (bony bream, see section 6.1.2.2) likely to be exposed.

Aerial transport is the main mode of riverine contamination during dry seasons, with the more volatile isomer α -endosulfan dominating detections. During wet years, both isomers may be detected in waterways as a result of runoff from sprayed areas, at significantly higher levels than when conditions are dry. In some parts of Australia, such as the upper Namoi valley, expansion of dryland cotton production onto flood prone land has exacerbated problems of riverine pollution associated with storm runoff. Such pollution continues after the spray season, with late summer storms washing soil contaminated with endosulfan sulfate into waterways. Low level contamination of waterways appears to persist through to the next season but limited investigations have found no evidence of build up from season to season. Studies from which these conclusions are drawn are described below.

5.1.3.1 Central and North West Regions Water Quality Program

The main sources of information on levels of endosulfan in the Australian environment are the annual reports on pesticide monitoring generated under the Central and North West Regions Water Quality Program. The reports cover areas of irrigated agriculture within the Border, Gwydir, Macquarie and Namoi valleys in NSW, with monitoring of surface waters typically conducted over the summer cropping season (September to April). Samples were taken from 25 cm below the surface and analysed for α and β isomers and the sulfate metabolite, but not for nontoxic metabolites such as the diol.

Endosulfan was the most commonly detected pesticide during the 1992/93 season, being present in all three toxic forms at 60% of sites downstream from irrigated agricultural areas, with a median concentration of 0.02 $\mu\text{g/L}$ total endosulfan and highest levels at the downstream ends of the basins. Low level detections also occurred in 40% of samples from the Darling River at Bourke. Overall levels were relatively low as prevailing conditions were dry leading to reduced cotton production and fewer runoff events.

The two parent isomers were detected during December and early January, when use occurs on cotton. Hydrolysis to the diol would be expected to be rapid in the alkaline waters of the region. The sulfate was present over longer periods (early October to mid-April) than the parent isomers, reflecting its greater persistence (Preece *et al.*, 1993).

Similar results were obtained during the 1993/94 season, which saw a continuation of drought conditions. Parent isomers first appeared in late November to early December, with the sulfate present at moderate levels from December to March. Very few detections of the β isomer occurred, in contrast to the 1991/92 season when significant rains fell, particularly during December. Both isomers of endosulfan, as well as its sulfate metabolite, can enter waterways with storm runoff during wet seasons, while the main inputs during dry seasons are of the more volatile α isomer, via the volatilisation route. Some 80% of samples taken from within areas of irrigated agriculture between November and March contained more than 0.01 $\mu\text{g/L}$ total endosulfan (Cooper, 1994).

The 1994/95 season was also characterised by low flow conditions and reduced cotton plantings brought about by drought. Endosulfan was present at moderate to high levels (0.1-0.6 $\mu\text{g/L}$) on occasion, but only 50% of samples taken from within areas of irrigated agriculture between November and March contained more than 0.01 $\mu\text{g/L}$ total endosulfan. Temporal patterns of contamination were similar to preceding dry years, with very few detections of the β isomer. Aerial transport is thought to be the main contributor during such dry years. Improved farm management practices in the Macquarie valley, where the drought had less impact, helped contribute to the better performance. These practices included the use of softer chemicals or EC formulations near waterways, with helicopters used close to rivers, relocation of fields away from rivers, and ongoing improvements to tailwater systems. Aerial operators in the Macquarie were also very conscious of the dangers of allowing drift to waterways and took care to avoid such occurrences, for example by not spraying under inversion conditions (Cooper, 1995).

Drought continued to impact on the four valleys during the 1995/96 season, particularly in the Macquarie where plantings were only 40% of the previous season. Good rains occurred soon

after planting in northern valleys. Groundwater was widely used for irrigation in the Namoi, and cotton production continued to expand in the upper Namoi. In keeping with previous seasons, very few detections of endosulfan occurred at reference sites upstream of irrigated areas. Some 72% of sites within irrigated areas exceeded 0.01 µg/L total endosulfan during November to March, and 32% exceeded 0.05 µg/L. Unusually early detections occurred on the Namoi, probably associated with aerial contamination as wind strengths were above average and there were localised areas of high pest pressure early in the season. Detections were far less frequent during the remainder of the year.

The frequency of detection of β-endosulfan increased compared to previous dry years, reflecting good rains during November and January in the northern catchments. Storm event sampling was conducted at Coxs Creek and Mooki River in the upper Namoi during two periods of high flow following localised storms. Parent isomers were often present at high concentrations (up to 0.34 µg/L for the α isomer and 0.13 µg/L for the β) at Coxs Creek. Peak residues of 0.82 µg/L total endosulfan were found when river flows had almost ceased, suggesting widespread resumption of spraying after the rains. In contrast, parent isomers were not detected at Mooki River, and total endosulfan residues peaked at 0.18 µg/L while the river was in high flow. The different results suggest that flood routing at the latter site does not impact on cotton plantings to the same extent as is apparent at Coxs Creek. Storm events also led to significant riverine contamination in the lower Namoi as evidenced by a large fish kill near Wee Waa during January when storm runoff could not be contained by on-farm storage (Cooper, 1996).

Results from the Central and North West Regions Water Quality Program are summarised in the table below, which lists 75 percentile values (total endosulfan) during the season (November to March inclusive) for the various rivers monitored. One fourth of all samples collected during the November to March period contained residues above the levels shown in the table below.

	Border	Gwydir	Namoi	Macquarie
1991/92	0.18 µg/L	0.34 µg/L	0.22 µg/L	0.06 µg/L
1992/93	0.06 µg/L	0.10 µg/L	0.07 µg/L	0.03 µg/L
1993/94	0.02 µg/L	0.14 µg/L	0.07 µg/L	0.04 µg/L
1994/95	0.03 µg/L	0.03 µg/L	0.05 µg/L	0.03 µg/L
1995/96	0.06 µg/L	0.08 µg/L	0.11 µg/L	0.04 µg/L
1996/97	0.07 µg/L	0.08 µg/L	0.06 µg/L	0.02 µg/L

The 1996/97 results have recently been released (Muschal, 1997). The season saw a sharp increase in NSW cotton production, from 183 000 to 283 000 ha. The Namoi and Gwydir valleys achieved reduced endosulfan levels, notwithstanding the increased production, but levels in the Border River and Darling River at Bourke continued the steady increase evident since 1994/95. Overall, the number of samples exceeding the ANZECC guideline of 0.01 µg/L endosulfan declined slightly to 63%.

Routine spot sampling may not record the peak levels occurring during high flow in the rivers. Storm event sampling on the Gwydir River at Brageen Crossing at the end of January 1997 found total endosulfan levels in excess of 1 µg/L for a day or two, with a peak of 1.75 µg/L (0.1 µg/L α, 0.35 µg/L β, 1.3 µg/L sulfate) while flow rates were about 1000-2000 ML/day. Flow increased markedly to about 8000 ML/day in early February as a result of heavy rains in

the upper part of the catchment, but total endosulfan levels remained relatively low at about 0.1 µg/L (Muschal, 1997). The peak residues were thought to have been introduced to the river in contaminated storm water from irrigated farms in the Moree area that had exceeded ponding capacity, or more frequently from dryland farms growing a variety of crops including cotton (Boydell, 1997). Storm event sampling on the Gwydir in December 1991 had found total endosulfan levels of about 7 µg/L (Schofield *et al*, 1998).

Only limited sediment sampling has occurred, but endosulfan residues may be assumed to be present throughout the year in sediments from rivers in cotton areas. Residues have been detected at 19 µg/kg in sediment of the Mehi River at the end of the spray season, at 500 µg/kg in sediment of Jabiru Lagoon, in on-farm sediment samples prior to the spray season, and in fish during the no-spraying season (Bowmer *et al*, 1996).

Recent surveys of cotton and other farmers in the Namoi basin help illuminate the aquatic contamination issue. Signs of an end to the drought led to a significant expansion of cotton production into more marginal areas, such as on flood prone land, during the 1995/96 season in the upper Namoi. This included an expansion of dryland farms, which are unable to contain any storm runoff. The survey also found that more than half of dryland cotton farmers in the upper Namoi would continue to spray if rain was forecast, and that irrigation shortly after spraying is widespread among irrigated cotton growers.

Heavy rains during late January caused increased river flow and an elevation of endosulfan levels, reflecting storm runoff and flows of flood water through recently sprayed fields. Disturbingly, some farmers in the upper reaches, mainly on Coxs Creek, reportedly sprayed their fields only hours before heavy rain was expected, including in situations where pest pressure was low. This may explain the high residues of parent isomers found at this site between the two flow events. These poor practices were motivated by the apprehension that some time may elapse after the rain before flood waters would recede and spraying could again be undertaken without violating the *Clean Waters Act* (O'Brien, 1996).

5.1.3.2 Murrumbidgee Irrigation Area

In the Murrumbidgee Irrigation Area, the main use of endosulfan is on canola, faba beans, maize, mungbeans, soybeans, sunflowers, tomatoes and citrus. Information obtained from a drainage monitoring program in the Murrumbidgee Irrigation Area showed that during 1994/95, endosulfan could be found in irrigation drainage water throughout the year. It was found at highest concentrations during the summer cropping season (December to March) when more than half of the samples taken exceeded 0.01 µg/L with the highest sample obtained in December at 2.51 µg/L total endosulfan.

However in the years since then, detected endosulfan concentrations have decreased substantially to be within or near the ANZEC guideline. The improvement is thought to be due to a decline in tomato production in the area, to a move to closed systems for remaining tomato production and to an improvement in the management of endosulfan use in citrus. Rainfall patterns during those years may also have reduced release of pesticides into the drainage system.

5.1.3.3 Queensland

The Queensland Department of Primary Industries (Central Region) reported in July 1995 that endosulfan moves downstream in low concentrations from the cotton growing areas at Emerald (Nogoa River) and Theodore (Dawson River). Concentrations detected are generally one or two orders of magnitude above 0.01 µg/L. Limited sampling indicates that levels in Queensland rivers seem at least as great, if not greater, than in NSW.

5.1.3.4 Residues in fish

Endosulfan residues were found in livers of freshwater catfish (*Tandanus tandanus*), bony bream (*Nematolosa erebi*) and European carp (*Cyprinus carpio*) collected from rivers and a dam in NSW cotton areas during 1987-89, but not in a remote reference area. Residues in catfish liver during the spraying season were between 0.15 and 0.31 mg/kg (wet weight) with highest levels during 1988, the wettest year. Winter residues did not exceed 0.03 mg/kg but indicate continuing exposure through the year (Nowak and Julli, 1991).

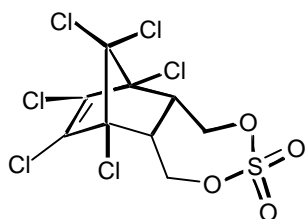
5.1.3.5 River monitoring with dialysis bags

Solvent filled dialysis bags (passive samplers) were used to collect endosulfan residues from the Namoi River in February 1996. The concentrations in the dialysis bags were used to estimate an average concentration in the Namoi during that month of 1.3 µg/L (Hyne *et al*, 1996).. Note that this estimate is based on conversion factors for two similarly hydrophobic chemicals, chlordane and dieldrin, but has not as yet been specifically validated for endosulfan. The estimate should be treated with caution as it exceeds concentrations determined by spot sampling in the Namoi River during that month. Routine monitoring found that total endosulfan residues were generally less than 0.2 µg/L, but with occasional excursions to as much as 0.6 µg/L. Endosulfan sulfate predominated. Similar behaviour has been noted more recently in exploratory studies with such devices, which accumulated various chemical contaminants including endosulfan that could not be detected by routine spot samples (Muschal, 1997).

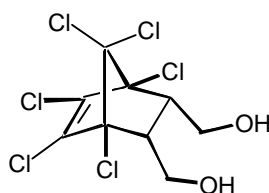
While the dialysis bags may not at this time be used to determine absolute endosulfan levels, they are useful for determining differences between upstream and downstream sites. Levels at exposed sites were about 25 times higher than concentrations at an upstream reference site. Over 80% of residues were present as endosulfan sulfate at this late stage in the season, suggesting entry to the river in storm runoff. Comparable concentrations were found at reference and exposed sites during November, but concentrations at the exposed sites increased from December through to February. Endosulfan was the main contaminant recovered from dialysis bags, and the dominant contributor to aquatic toxicity. Comparable levels of prometryn were present, and low levels of profenofos, trifluralin and chlorpyrifos (Hyne *et al*, 1996).

5.2 Environmental Chemistry and Fate

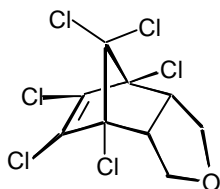
The degradation products of endosulfan in the environment are depicted below.



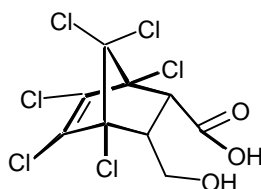
endosulfan sulfate



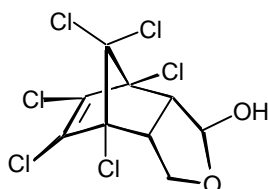
endosulfan diol



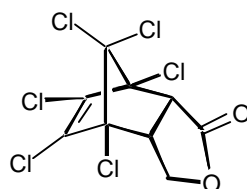
endosulfan ether



endosulfan hydroxycarboxylic acid



endosulfan hydroxyether



endosulfan lactone

Descriptions follow of the testing that has been conducted to define the environmental fate of endosulfan. Test reports were provided in the Hoechst TGAC submissions of 1986 and 1992, and the supplementary package provided by AgrEvo in March 1996. Selected recently published papers from the scientific literature have also been included, as have results available to date from the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program. The Land and Water Resources Research and Development Corporation is administering this joint program in collaboration with the Cotton Research and Development Corporation and the Murray-Darling Basin Commission (see section 5.2.5.14). Some of the older tests were conducted more than two decades ago, but results are generally consistent. Except where specifically noted, it would appear that tests have been conducted satisfactorily according to accepted international guidelines such as those of the US EPA (Hitch, 1982, and subsequent revisions) and OECD.

5.2.1 Hydrolysis

Two tests submitted by the principal registrant indicate that endosulfan is hydrolytically stable at acidic pH but hydrolyses to endosulfan diol with a half life of a few weeks at pH 7 and a few hours at pH 9. A literature study that took precautions to avoid volatilisation found hydrolytic half-lives at neutral pH in the order of months rather than weeks, but results may have been confounded by solubility limitations.

Hydrolysis of the individual isomers of endosulfan was studied in stoppered flasks containing sterile aqueous buffers with 1% acetone (from stock solution) at concentrations between 0.15

and 0.2 mg/L. Both were stable at pH 5 (half-life more than a year). Respective half-lives at 22°C for α - and β -endosulfan were 22 and 17 days at pH 7, shortening to 7.0 and 5.1 hours at pH 9. Analysis by HPLC indicated that both isomers hydrolysed to the same product, endosulfan diol. Analytical recoveries were close to quantitative (Grlitz and Kckner, 1982). Graphical analysis of the raw data for the pH 9 hydrolyses indicates that both isomers hydrolyse according to pseudo first order kinetics.

A second study conducted at 25°C in the dark found negligible degradation during 30 days at pH 5, but respective half-lives for α - and β -endosulfan of 19 and 10.7 days at pH 7, reducing to 6.2 and 4.1 hours at pH 9. The only product detected was endosulfan diol, although further breakdown is suggested by declining material balances after about 8 days at pH 9 (Grlitz and Rutz, 1989).

Hydrolysis test results have been criticised based on more recent tests conducted in teflon stoppered flasks. Endosulfan was dissolved in methanol and pipetted into sterile aqueous media (pH 7.0) to give a nominal concentration of 1 mg/L, in excess of the solubility. Extrapolated half-lives after 30 days of incubation at 30°C were 157 days for α -endosulfan and 90 days for β -endosulfan. The sulfate metabolite had an extrapolated half-life of 184 days at 5 mg/L. The diol was the only metabolite identified. Shorter half-lives reported in other studies are presumed by the authors to reflect volatilisation losses, and could be reproduced in unsealed tubes (respective half-lives of 19, 75 and 96 days). However, the results described above do not appear open to such criticism as material balances remained close to quantitative, while the present study can be criticised for using methanol as solvent mediator to achieve nominal concentrations in excess of the aqueous solubility. Results confirm earlier findings that β -endosulfan is more chemically labile than α -endosulfan, but less volatile (Guerin and Kennedy, 1992).

5.2.2 Photolysis

Endosulfan appears photostable in solution, apart from some photoisomerisation of the β isomer to the α , and photodegrades only slowly on soil surfaces. There is no evidence that photolysis occurs on leaf surfaces. Photoisomerisation also occurs in the gas phase, as does hydrolysis and, to a limited extent, mineralisation. Estimated atmospheric half-lives are in the order of a week. Details follow of photolysis studies in various media.

5.2.2.1 Water

A study was conducted for 120 hours at a concentration of 0.24 mg/L in buffered solutions at pH 5, in the presence of acetonitrile to aid dissolution. The estimated photolytic half-life (filtered high pressure mercury lamp) was in excess of a year for both isomers. Large quantities of radiolabel, identified as unchanged endosulfan, were recovered from methoxyethanol traps for α -endosulfan, reflecting the ready volatilisation of this isomer from water. Photostability was expected as endosulfan only absorbs light in significant quantities at wavelengths below 290 nm (Stumpf and Schink, 1988).

Photostability was confirmed in a second study conducted at similar concentrations in sterile acetate buffer and in river water, with irradiation for 101-142 hours using xenon arc lamp. The β isomer had an estimated half-life in sterile buffer of 633 days. Again, high losses of α -endosulfan to volatility were recorded, as well as significant losses of the β isomer, thought

to reflect dissolution in lubricating grease. Half-lives in river water were much shorter at 8 and 5 hours, compared with 16 and 9 hours in dark controls, hydrolytic breakdown to the diol being catalysed by the alkaline pH (Stumpf and Jordan, 1993).

Endosulfan is reportedly relatively stable to light under environmentally relevant conditions (NRCC, 1975) with some displacement of chlorine by hydrogen but no transformations of the heterocyclic ring. Photoisomerisation of β - to α -endosulfan has also been reported from laboratory studies (NRCC, 1975). The reverse isomerisation has been reported to occur in hexane solution in the presence of acetone as sensitiser (Dureja and Mukerjee, 1982).

Endosulfan lactone and endosulfan sulfate are reportedly susceptible to photolysis at wavelengths above 300 nm, but the products of reaction are not identified (NRCC, 1975).

5.2.2.2 Soil

Endosulfan, uniformly radiolabelled in the hexachlorocyclopentene ring, was spotted as acetone solution to a 0.5 mm film of sandy soil. The samples were enclosed in a quartz box, after evaporation of solvent, and irradiated in a SUNTEST apparatus at wavelengths above 290 nm for 45 hours (equivalent to 30 days under natural conditions). Photodegradation was rather slow, allowing only an approximate calculation of the half-life (more than 200 days). Some degradation was also observed in dark controls, suggesting competing thermal processes. No products were identified (Gildemeister and Jordan, 1983).

5.2.2.3 Plant surfaces

The oxidation product, endosulfan sulfate, is a commonly encountered metabolite on plant surfaces, but is thought to form through thermal rather than photochemical processes (NRCC, 1975).

5.2.2.4 Air

A half-life of 8.5 days, considered accurate to within an order of magnitude, has been calculated for reaction of endosulfan with hydroxyl radicals in air. The different isomers are expected to react at different rates (Palm and Zetzch, 1991).

Half-lives in the gas phase under xenon lamp irradiation through a water-cooled Pyrex filter ($\lambda > 290$ nm) were 6.4 hours for β -endosulfan, 2.7 hours for α -endosulfan, and 3.7 hours for endosulfan sulfate. The main reactions observed were isomerisation of β - to α -endosulfan, and photohydrolysis of endosulfan to endosulfan diol, and endosulfan sulfate to endosulfan ether. Some mineralisation also occurred. The test compounds were more labile than model substances acetone, toluene and cumene under these simulated tropospheric conditions. Reaction with hydroxyl radicals would be expected to further accelerate degradation in the natural environment (Parler, 1988).

A tropospheric half-life of 3.9-8.4 days has been calculated under Australian conditions (Bürkle *et al*, 1993). The calculations use a rate constant of 11.5×10^{13} mL/molecule/s for reaction of the double bond with hydroxyl radicals, and assume a hydroxyl radical concentration of $8.3-18 \times 10^5$ per mL between 45°S and 15°S. AgrEvo has since provided further information (Brauers *et al*, 1996, Hofzumahaus *et al*, 1996, Dorn *et al*, 1996) to

indicate that midday summer hydroxyl radical concentrations slightly in excess of 10^7 per mL have been measured in a clean rural environment in NE Germany, and that use of this measured concentration would reduce the half-life by an order of magnitude if used in calculations. However, it appears invalid to use a peak concentration in calculations given the large diurnal variation in hydroxyl radical concentrations.

5.2.3 Metabolism

A broad range of microorganisms isolated from agricultural soils are capable of degrading endosulfan. In general, fungi oxidise endosulfan to the sulfate, the major breakdown product in soils, and bacteria hydrolyse it to the diol, which is also an abiotic breakdown product under alkaline conditions. Microbial mineralisation is very inefficient.

Endosulfan degrades relatively rapidly in short term tests, with a few weeks to a couple of months required to reduce soil concentrations by 50% in the three soils tested. Corresponding times for breakdown of the sulfate metabolite are in the range of 4-6 months, and for total toxic residues (parent isomers and sulfate metabolite) about 4 months. Endosulfan also forms significant amounts of nonextractable residues in soils.

Short term tests on an Australian soil (alkaline grey cracking clay) found significant volatilisation, particularly of the α isomer from wet soils, and oxidation of up to 20% of applied α -endosulfan to the sulfate over the course of a week. The β isomer does not appear to undergo this conversion. Sulfate formation appears to be suppressed in dry soils.

Half-lives obtained from longer term studies on five soils are about 3-4 months for both parent isomers combined, with the α isomer typically dissipating about ten times faster. Projected half-lives for total residues are in the range of 9 months to 2 years, extending to over 6 years in one soil.

The diol degrades further in long term studies to a range of products with endosulfan lactone and a polar unknown predominant, significant production of non-extractable residues, and release of 18% of applied radiolabel as carbon dioxide over the course of a year.

Persistence of endosulfan increases in anaerobic soils, where the sulfate metabolite can revert to parent endosulfan. Anaerobic half-lives of parent endosulfan in the two soils studied are about 4-5 months, with similar results for the sulfate metabolite.

Microbial oxidation to the sulfate is also prominent in aquatic environments, followed by hydrolysis to the diol which can be fairly rapid in alkaline systems. The half-life for total toxic residues appears to be about 2 weeks in the single aquatic system (German river water with sediment) for which reliable results are available. Toxic residues partition to sediment over the course of a few weeks with a significant fraction becoming non-extractable.

Tests from which these conclusions were drawn are described below.

5.2.3.1 Soil microorganisms

Degradation of endosulfan (radiolabelled at the methylene carbons of the heterocyclic ring) by 28 soil fungi isolated from agricultural soils, and 49 soil bacteria and 10 actinomycetes, was

investigated at a concentration of 1 mg/kg in nutrient solution. Samples were incubated for 6 weeks at 22°C in the case of fungi, and 10 days at 27°C otherwise. A total of 16 fungi, 15 bacteria and 3 actinomycetes were found to be capable of degrading more than 30% of the applied endosulfan. Endosulfan sulfate was generally the main fungal metabolite and endosulfan diol the main bacterial metabolite, as well as forming through abiotic hydrolysis at alkaline pH. Mineralisation was absent or minimal, leading the author to conclude that the carbon skeleton of endosulfan is just as resistant to microbial degradation as other highly chlorinated cyclodiene insecticides (Martens, 1976).

Some soil fungi accumulate the sulfate metabolite while others, such as *Trichoderma harzianum*, appear to have the ability to further degrade this metabolite to endosulfan diol (Katayama and Matsumura, 1993).

Endosulfan (α and β) and its sulfate, diol, ether, hydroxyether and lactone were tested separately at concentrations of 1 mg/L in nutrient solution with a mixed culture of microorganisms isolated from a sandy loam. The pH was 6.5 initially, increasing to 7.6 with microbial activity. The α and β isomers underwent some interconversion, particularly from β to α , but the main reaction was hydrolysis to the diol, with some oxidation to the sulfate. Respective half-lives were 1.1 and 2.2 weeks, compared with 12.5 and 5.7 weeks in controls. The diol was mainly transformed into the hydroxyether with small amounts of the ether also detected as an intermediate. Transformation of ether to hydroxyether only occurred in the inoculated samples. The hydroxyether degraded further to the lactone, which was the most labile metabolite with a half-life for disappearance of 5.5 hours in controls and inoculated samples (Miles and Moy, 1979).

5.2.3.2 Short term aerobic soil tests

Endosulfan (α and β) radiolabelled at positions 5a and 9a was incubated at 22°C for a period of 60 days at levels in the range of 3.15-3.50 $\mu\text{g}/\text{kg}$ in silt loam (pH 6.4, 1.6% organic matter) and sandy loam (pH 4.7, 2.7% organic matter) soils. Half-lives for α - and β -endosulfan combined were 27 and 18 days, respectively. The main metabolite, endosulfan sulfate, was observed in both soils but its fate was not further investigated. Several minor metabolites were detected in small amounts, but only endosulfan ether and lactone were identified. Extractability declined markedly during the incubation. Evolution of CO_2 reached 1.8% and 2.8%, respectively, indicating slow mineralisation (Gildemeister and Jordan, 1984).

5.2.3.3 Stimulation of microbial activity in short term aerobic soil tests

A subsequent study was reported using sandy loam soil (pH 7.1, 5.1% organic matter). Endosulfan (α and β) radiolabelled at all chlorine bearing carbon atoms was added to a level of 3.5 mg/kg and incubated at 28°C for 60 days, with sampling at 10, 30 and 60 days. The α isomer was degraded more rapidly than the β , with respective first half-lives of 23 and 58 days. Endosulfan sulfate was the main metabolite detected, degrading further at a slow rate (first half-life 100-150 days). Traces of endosulfan diol, ether and lactone were also detected, together with an unknown metabolite apparently bearing fewer chlorine atoms. Mineralisation was assumed to be low, and non-extractable residues reached 28% after 60 days. Extraction under forcing conditions released β -endosulfan and endosulfan sulfate in 1:2 ratio.

To investigate the effect of increased microbial activity on the degradation, samples were amended with 0.5% alfalfa. The soil amendment with alfalfa reduced the half-life of the α isomer by 4 days and of the β isomer by 16 days. The half-life of endosulfan sulfate remained in the range of 100-150 days, presumably reflecting increased rates of formation as well as degradation. The first half-lives for total endosulfan residues were found to be 110 and 75 days for untreated and treated soil, respectively. Degradation of total residues (sum of α , β and sulfate) reached 90% after 366 and 248 days in untreated and amended soil, respectively (Gildemeister *et al*, 1988a).

5.2.3.4 Longer term aerobic soil tests

Testing of α - and β -endosulfan, separately and as 2:1 mixture, was conducted at concentrations of 1.3 mg/kg over a period of a year in five soils (see table) taken from the surface 10-15 cm of agricultural fields or grassed plots. Test materials were radiolabelled at all chlorine bearing carbon atoms. Extractability using 90:10 acetonitrile/water was quantitative at the beginning of the study, and non-extractable residues remained below 10% of applied during the first four months but increased to as much as 40% in some soils (those where mineralisation was more efficient) after a year.

Soil type	pH	Organic carbon (%)	Sand/silt/clay (%)	First half-life (days)	¹⁴ CO ₂ (%)
Sandy loam	5.5	0.95	59/32/9	98, 614	1.5
Loamy sand	5.0	2.9	85/9/6	128, 2241	0.4
Silt loam	5.6	0.72	15/67/18	90,454	2.4
Sandy loam	7.1	2.3	61/27/12	92, 288	9.7
Sandy loam	5.8	2.4	80/10/10	80, 339	6.4

The major components found were α - and β -endosulfan and the sulfate, but with α -endosulfan absent from later samples because of its much more rapid degradation. The two half-lives tabulated above are for α - and β -endosulfan and total residues (α - and β -endosulfan and the sulfate). With the exception of the silt loam where stabilities appeared similar, the rate of degradation for the α isomer was about an order of magnitude faster than for the β . Small amounts of the α isomer were recovered from traps, reflecting its greater volatility. Endosulfan sulfate reached 34-77% of applied by study end, and was accompanied by small amounts (generally below 2% and never exceeding 10%) of the diol and lactone, and unidentified polar metabolites. Evolution of ¹⁴CO₂ was variable, indicating that mineralisation of the chlorinated ring occurs, but at a very slow rate in some soils (Stumpf *et al*, 1995). It has been noted that laboratory half-lives for endosulfan can be unrealistically long because of difficulties in maintaining the activity of laboratory soils throughout a 1 year study (Stumpf and Dorn, 1994).

5.2.3.5 Australian soils

Metabolism studies have also been conducted on cotton soil (alkaline grey cracking clay) from Warren, NSW. Soil samples were spiked with endosulfan (17 μ g/kg α and 8 μ g/kg β) and incubated at 30°C under various moisture regimes in bottles equipped with carbon filters to trap volatiles, and through which air was pumped. Volatilisation was favoured by soil moisture, and reached 23 and 8%, respectively, for α and β isomers over a 7 day period. Endosulfan sulfate formation reached 20% at higher moisture levels but decreased towards

zero as moisture levels decreased. Concomitant decreases for the α but not the β isomer indicated the sulfate to be derived from the former. Sodium azide suppressed sulfate formation, indicating a biological mode of formation. Significant amounts (25-50% α and 50% β isomer) remained unaccounted for. These losses, thought to reflect formation of the diol or bound residues, are the subject of further investigation (Southan and Kennedy, 1996).

5.2.3.6 Endosulfan diol

Studies have also been conducted on endosulfan diol, radiolabelled in the ring at the two non-chlorinated positions, with the aim of determining the mineralisation rate of the bicyclic ring. The test substance was added to a loamy soil (pH 5.3) at a level of 1 mg/kg and incubated at 22°C for a year, with evolved CO₂ monitored on a fortnightly basis. The main degradation products found in the soil were endosulfan lactone and a polar unknown. Small quantities of the hydroxyether and ether were also detected. Evolution of CO₂ reached about 18% over the year. At the end of the study, the soil contained about 40% each of extractable and residual radioactivity (Martens, 1980).

5.2.3.7 Anaerobic soils

The parameters for this study were the same as for the corresponding aerobic study (Gildemeister and Jordan, 1984) except that the sandy loam (pH 7.2, 5.5% organic matter) was from another source. Soils were incubated under aerobic conditions for 24 days, and then flooded with water and purged with nitrogen. Sampling of soils occurred at the beginning and end of the aerobic period, and after 0, 13, 24, 28, and 59 days of anaerobic incubation. No attempt was made to trap volatiles in view of the expected low rates of mineralisation.

Endosulfan oxidised to endosulfan sulfate during the aerobic phase of the study, the α isomer being more rapidly transformed. This metabolite remained present during the anaerobic phase, although some reversion to the parent is apparent, and was accompanied by smaller amounts of diol, lactone and hydroxycarboxylic acid. Non-extractable residues were also formed at 7-22% of applied. Anaerobic half-lives were much longer than aerobic at 144 days in the sandy loam and 154 days in the silt loam, with little difference apparent between the isomers. Anaerobic half-lives for endosulfan sulfate were 120 days in the sandy loam and 165 days in the silt loam (Gildemeister *et al*, 1988b).

Results obtained from exploratory anaerobic studies are unreliable as anaerobic conditions were not satisfactorily established and analytical recoveries were erratic. However, they show that endosulfan sulfate can revert to endosulfan under anaerobic conditions (Gildemeister, 1985a).

5.2.3.8 Aquatic metabolism

Aquatic aerobic metabolic studies were conducted by adding acetone solutions of endosulfan, radiolabelled at positions 5a and 9a, to water samples containing 5% sediment obtained from a river and a gravel pit in Germany. The sediment in both samples contained 98% sand and 0.5% organic carbon, and had pH values in the range of 7.2 to 7.9. The test substance was applied at a rate equivalent to 0.229 mg/kg in the sediment. Replicated samples for each sampling time were incubated in the dark for 7 weeks at 22°C, with a further two pairs of replicates connected to volatile traps and aerated daily for 8 hours.

Analytical recoveries were consistently around 80%, suggesting some loss of volatile species during extraction procedures. There was only a slight excess of the α isomer, suggesting some such losses, and no significant change in the isomeric ratio, indicating a similar susceptibility to degradation.

Endosulfan was mainly present in the water phase of the river system at the first sampling, but became increasingly associated with the sediment. Oxidation to the sulfate metabolite became apparent after 1 day, again mainly in the water phase, with extractable residues increasing from about 20% of applied to a maximum of 30-50% after 8 days, split fairly evenly between water and sediment, before declining to around 10% at the final sampling, predominantly in sediment. The other main metabolite, endosulfan hydroxycarboxylic acid, was present at low levels in the 2 and 4 day samples, increasing to a maximum of about 30% at 16 days before declining to about 10% at the final sampling. This metabolite remained mainly in the water phase. Non-extractable residues in the sediment increased to about 20-27% at the final sampling. The ether, lactone, and diol were also identified in minute quantities, and some unidentified minor metabolites were indicated by HPLC. Less than 1% of the applied radioactivity was recovered as $^{14}\text{CO}_2$ indicating slow mineralisation under these conditions.

The half-life for parent endosulfan isomers was estimated at 4 days. Total endosulfan residues declined according to pseudo first order kinetics with an estimated half-life of about 2 weeks. It appears that a rapid biological oxidation is followed by a more gradual hydrolysis in these slightly alkaline systems. Hydrolysis would be expected to be retarded at lower pH.

An extremely rapid oxidation was apparent in the other system, with more than half the radioactivity recovered as endosulfan sulfate at the initial sampling in both replicates, all in the aqueous phase. This appeared to be followed by a more gradual hydrolysis as in the river system, and partitioning to sediment. A half-life of 8 days is reported for endosulfan during this period of slower decline. No comment is offered regarding the extraordinarily high level of endosulfan sulfate detected at the initial sampling. Results from this system will not be analysed in detail in view of the anomalous and unexplained initial results (Gildemeister, 1985b).

In an earlier literature report, the metabolite of endosulfan in river water samples (pH 7.3-8.3) was identified as endosulfan diol by infrared spectroscopy and flame photometry. Samples contained a mixture of α and β isomers (10 mg/L) and were incubated at ambient laboratory temperature for 8 weeks. No endosulfan remained after 4 weeks. Degradation under these conditions appears to be mainly abiotic as the sulfate metabolite was not found (Eichelberger and Lichtenberg, 1971).

5.2.3.9 Metabolism in sediment

No studies have been submitted on the fate of endosulfan in sediment, and little work appears to have been conducted in this area. Half-lives of α and β isomers in sediment have been reported as 34 and 47 weeks, respectively (Ghadiri *et al*, undated, cited in Bowmer *et al*, 1996). Other indications of persistence in sediment include detection at 19 $\mu\text{g}/\text{kg}$ in sediment of the Mehi River at the end of the spray season, at 500 $\mu\text{g}/\text{kg}$ in sediment of Jabiru Lagoon, in on-farm sediment samples prior to the spray season, and in fish during the no-spraying season. Accumulation may be occurring in river sediment, and this needs to be investigated

before giving consideration to any relaxation of water quality guidelines (Bowmer *et al*, 1996).

5.2.4 Mobility

Endosulfan is strongly sorbed and immobile in soils. Soil organic carbon partition coefficients from four soils and a sediment obtained from runoff water are in the order of 10^4 for endosulfan parent isomers and the sulfate metabolite, with the β isomer sorbing slightly more strongly than the α . Endosulfan diol has low mobility in soil with soil organic carbon partition coefficients in the order of 10^3 .

Leaching studies on two soil columns confirm that aged samples of endosulfan and metabolites do not leach through soil, with most retained in the surface 10 cm and less than 2% recovered from leachate.

Endosulfan is, however, mobile in the environment by virtue of its volatility. Significant amounts volatilise from soil and leaf surfaces, particularly soon after application. The α isomer is more volatile than the β isomer, which in turn is more volatile than the sulfate. Wind tunnel experiments found volatilisation half-lives for technical endosulfan of about a day from foliage and 3 days from soil. Deposition of volatilised endosulfan to water is favoured by high water/air partition coefficients. Endosulfan is a regional rather than global pollutant as its volatility appears too low to enable widespread global distribution, although detections have occurred in snowpack in the Canadian Arctic.

Tests from which these conclusions were drawn are described below.

5.2.4.1 Adsorption/desorption in soils

Standard batch adsorption studies were conducted on four soils (see table) equilibrated by shaking for 16 hours in the dark at 22°C with five volumes of aqueous solution (20-160 µg/L) of endosulfan, radiolabelled at the chlorine bearing carbons. Endosulfan in the aqueous phase was determined by analysis, with the balance assumed to be adsorbed to the soil. Two sequential desorptions were conducted according to the same procedure but with 24 hours equilibration. Soils were then analysed by combustion to determine mass balance.

Soil type	pH	Organic carbon (%)	Sand/silt/clay (%)	Koc (α isomer)	Koc (β isomer)
Silt loam	5.4	0.62	16/66/18	10200	11900
Sandy loam	5.9	1.28	59/31/10	8000	13900
Sandy loam	5.8	2.45	80/10/10	21300	8600
Loamy sand	5.8	2.66	80/11/9	13700	12200

Data obtained were well correlated with the Freundlich equation, with mass balance between 75 and 124%. Soil organic carbon partition coefficients indicate that both endosulfan isomers adsorb strongly to soils and can be considered immobile based on the McCall scale (McCall *et al*, 1980). The relative constancy of results indicates that sorption occurs predominantly to soil organic matter. Sorption is largely reversible over these timescales as generally small increases in sorption coefficients were found in the desorption phases (Görlitz, 1987a).

A parallel study to the above was conducted using the metabolites endosulfan sulfate and endosulfan diol, radiolabelled at positions 5a and 9a. The mass balance was 75-90% for the sulfate and 85-97% for the diol. Respective soil organic carbon partition coefficients were 7300, 9300, 5700 and 11400 for the sulfate, and 990, 1100, 720 and 1200 for the diol. Based on the McCall scale, endosulfan sulfate can be considered immobile in soils, and endosulfan diol of low mobility. Again, a slightly increasing trend was observed in two desorption steps (Görlitz, 1987b).

5.2.4.2 Adsorption/desorption with sediment

Endosulfan (α and β isomers) and its sulfate and diol metabolites were also tested under similar conditions with a sediment (pH 4.8, 1.8% organic carbon) obtained by centrifugation of a sample of runoff water. Similar results were obtained as for soils, with respective soil organic carbon partition coefficients of 8800, 16300, 25400 and 1180 (Sarafin, 1987).

5.2.4.3 Leaching

Mobility of endosulfan (uniformly labelled with ^{14}C) in soil was also investigated by leaching tests on packed columns (5 x 28 cm) of sand (pH 7.0, 0.8% organic matter), loamy sand (pH 6.8, 2.6% organic matter) and sandy loam (pH 5.2, 1.0% organic matter). Four samples, each containing 873 mg of the test substance and 100 g loamy sand, were aged for 30 days at 22°C. After the 30 day period, one sample was analysed for degradation and the other three samples were loaded on to three columns pre-packed with each of the three soil types. The columns were then eluted with 393 mL of water over a 48 hour period. At the end of the leaching period, elution aliquots were examined for radioactivity, and the columns were divided into 5 cm segments for extraction and analysis.

Greater than 96% of applied radiolabel was recovered from the top 10 cm of the three columns with the bulk of the material found in the acetonitrile/toluene extract. Non-extractable residues in the soil amounted to less than 2%. Practically no radioactivity (<0.2%) was found in the eluent. Characterisation of the radioactivity of the sample set aside for degradation studies revealed the presence of mainly endosulfan sulfate (95%), with small amounts of unchanged α and β isomers. Traces of endosulfan diol were also detected by thin layer chromatography. The studies indicated that neither the test substance nor its sulfate metabolite leached under the conditions of the tests (Gildemeister and Remmert, 1983).

5.2.4.4 Volatility

Volatilisation from silty sand soil (pH 6.1, 0.5% organic carbon) treated with 422 g/ha radiolabelled endosulfan and maintained at 60% field capacity was studied in a wind tunnel (21-22°C, 50% humidity, air speed 1 m/second) with volatilised material collected on polyurethane plugs. Analytical recoveries (total of extracted radioactivity from soil and plugs, application losses, and soil residues after combustion) were close to quantitative. Cumulative recoveries from the plugs for the 0-1, 1-3, 3-6 and 6-24 hour periods after application were 5.5, 11.0, 16.5 and 28.9% in one study, and 5.7, 11.7, 16.3 and 25.2% in a second. The ratio of α - to β -endosulfan declined from 91:9 during the first sampling period to 85:15 during the last. In soil, the corresponding ratios (for extractable material) were 62:38, declining to 56:44. Air concentrations declined from 0.26 to 0.03 $\mu\text{g}/\text{m}^3$ (Rüdel, 1992a).

Volatilisation from bush bean plants (*Phaseolus vulgaris*) treated at flowering/early fruit development (30-40 cm high with 70-80% canopy) at the same rate and held in a wind tunnel under similar conditions was also studied. Cumulative volatilisation losses over the same sampling periods were 10.4, 25.9, 39.7 and 63.6%, and 9.0, 23.2, 40.4 and 63.7%. Isomeric ratios in the plugs declined from 90:10 to 54:46. The β isomer was predominant in samples washed from the leaf surface with methanol 24 hours after application. Plant extracts (ethyl acetate) taken at this time contained equal amounts of the two isomers (Rüdel, 1992b).

Volatilisation studies from soil (silty sand) and foliage (bush beans) have recently been published (Rüdel, 1997). Experimental details are as reported above, except that non-radiolabelled material was used and soil residues were not determined. The reported volatilisation from soil in the 24 hours after application is only 12% of applied, but based on air sampling only (no mass balance was determined). The published and unpublished results for plants are roughly in agreement.

Analogous studies with endosulfan sulfate found a much lower tendency for volatilisation, with about 5% volatilised from plant surfaces over a 24 hour period (Rüdel, 1992c).

Modelling of volatilisation and dispersion produces predicted air concentrations within and adjacent to sprayed fields immediately after spraying of 2-5 $\mu\text{g}/\text{m}^3$. Although volatilisation rates are highest during daytime because of the higher temperatures, predicted and measured air concentrations are higher at night because of reduced dispersion. Deposition to water is favoured by high water-air partition coefficients, ranging from about 700 for the α isomer through 14000 for the β isomer to 56000 for the sulfate at 25°C, and declining with increasing temperature (Raupach *et al*, 1996). Note that these coefficients are probably underestimated by a factor of two as they are derived using a water solubility of 0.15 mg/L.

AgrEvo has criticised the above estimates of air concentrations on the basis that they exceed measurements from the wind tunnel experiments. However, concentrations would be expected to be lower in moving air because of kinetic factors. The estimated concentrations overlap with field data from the USA, as described below.

Sampling of ambient air in the US during the early seventies found α -endosulfan (mean 0.11 $\mu\text{g}/\text{m}^3$, maximum 2.26 $\mu\text{g}/\text{m}^3$) in about 2% of samples and β -endosulfan (mean 0.02 $\mu\text{g}/\text{m}^3$, maximum 0.06 $\mu\text{g}/\text{m}^3$) in about 0.3% (IPCS, 1984). More recently, sampling at Bloomington, Indiana, over a 14 month period found an average concentration for α -endosulfan of 86 pg/m^3 with a summer maximum of 890 pg/m^3 . Results, including those summarised from earlier studies, indicate that temperature is the major significant predictor of atmospheric concentration, with wind direction playing an important but secondary role (Burgoyne and Hites, 1993).

Aquatic concentrations have been calculated under Australian conditions for a river situated 1 km downwind from a single cotton field of 1 km^2 . Contributions from the various transport routes are tabulated below for different river depths. The estimates must be regarded as approximations as the runoff model and understanding of interactions with bottom sediments both need improvement. Also, the model considers only a single farm, and is therefore not representative of cotton growing areas where many farms would be applying endosulfan (Raupach and Briggs, 1996).

Route	0.5 m depth	1.0 m depth	2.0 m depth
Vapour	0.1 µg/L	0.05 µg/L	0.025 µg/L
Drift	1.4 µg/L	0.7 µg/L	0.35 µg/L
Dust	0.014 µg/L	0.007 µg/L	0.0035 µg/L
Runoff	0.2 µg/L	0.2 µg/L	0.2 µg/L

AgrEvo has criticised the above estimates for vapour transport on the basis that partitioning to water is an equilibrium process that would require a good mixing of the phases or a long time for the distribution. It is further argued that kinetic factors would not retard the uptake of endosulfan vapours into rain because of the good mixing. No data are submitted concerning the kinetics of transfer from air to water for endosulfan.

The estimates for drift and runoff have also been criticised as too high for a distance of 1 km. Assumptions for low, medium and high drift scenarios are 0.3, 1 and 3% at 1 km downwind, in good agreement with two validation measurement points. The runoff scenario is somewhat arbitrary and contains the greatest uncertainty. It assumes dilution factors of 200, 20 and 2 for low, medium and high scenarios, and direct entry into the river (rather than overland flow for 1 km).

Volatilisation appears to contribute to contamination of rainwater tanks by endosulfan. The 1997 State of the Environment report for NSW reports trace levels of endosulfan in a rainwater tank in the Narromine area located some 11 km from the nearest spraying. When responding to the draft review, the NSW EPA indicated that surveys in the Namoi valley have also found endosulfan in rainwater tanks, at peak levels of 0.27 µg/L in 1996 and 0.12 µg/L in 1997. Residues above 0.01 µg/L were found in 61% of tanks during the 1997 survey, at up to 3.6 km from the nearest source, with a maximum concentration beyond 1.3 km of 0.02 µg/L. A significant inverse relationship was found between minimum distance from spraying and endosulfan concentrations in tankwater.

5.2.4.5 Long range transport

Endosulfan is clearly a mobile chemical with the potential to contaminate non-target areas even when used according to label. This potential has been investigated on a global scale through analysis of tree bark samples, which accumulate airborne lipophilic pollutants because of their relatively high lipid content. Endosulfan was one of the compounds found throughout the world in highest amounts, at levels comparable to hexachlorocyclohexane (total isomers) and the common DDT metabolite, DDE.

Total endosulfan residues, normalised to lipid content, were high (100-1000 ng/g lipid) in samples from NSW and SW Western Australia but relatively low (10-100 ng/g lipid) in less agriculturally intensive areas, such as Tasmania. Very low residues (below 10 ng/g lipid) were only found at remote sites such as the Marshall Islands, while the highest residues (1000-10000 ng/g lipid or more) were found in the Pacific Rim and India (thought to be from use in rice production) and agriculturally intensive regions of the USA and Europe. Endosulfan, with its relatively low vapour pressure, appears to be a regional rather than global pollutant. Analysis of residues for the β isomer found no correlation with latitude, suggesting that the vapour pressure of this isomer is too low to facilitate global distribution, and that residues found reflect local usage (Simonich and Hites, 1995).

In general, the β isomer is present in tree bark around the world at slightly higher levels than the α , with endosulfan sulfate the dominant residue (Simonich and Hites, 1997).

Endosulfan is one of a number of chemicals that have been identified as persistent organic pollutants (POPs) based on their semi-volatility, environmental persistence, and tendency to associate with lipids. These properties enable the global distillation effect whereby substances used in tropical regions can contaminate cooler regions of the globe through long range atmospheric transport, with particularly high residues accumulating in Arctic wildlife and indigenous inhabitants. Endosulfan is considered capable of long range atmospheric transport as it has been measured in snowpack at Canadian Arctic stations, although there is little evidence for its widespread presence in remote environments. It also meets persistence criteria, as the β isomer has a reported soil half-life of 900 days. However, current thinking is that endosulfan does not qualify as a POP because its residues are readily eliminated from fish, limiting the bioaccumulation capacity (UNECE, 1996).

AgrEvo has provided further information on the detections of endosulfan in Canadian snowpack. Concentrations of α -endosulfan in surface snow samples taken at 12 locations across a wide geographic area during 1986 ranged between 0.1 and 1.1 ng/L (mean 0.4 ng/L). The contaminant was not detected in this layer the following season at the site where contamination was highest, a remote location where snowmelt was limited and no runoff occurred. Similarly, contamination was generally undetectable in deeper layers, leading the authors to conclude that endosulfan deposited during the winter is revolatilised and/or photolysed during the Arctic summer and does not become part of the glacial record (Gregor, 1990).

AgrEvo maintains also that endosulfan does not meet persistence criteria, and that the long half-life reported above for the β isomer would have been derived from a long term laboratory test in which microbial vitality had declined, or from a field study using exaggerated rates (Stewart and Cairns, 1974, see section 5.2.5.5).

5.2.5 Field Dissipation

Numerous field dissipation studies from around the world were submitted, and a considerable volume of Australian work has been reviewed, as outlined below.

Early studies in Asia and South Africa indicate large declines in endosulfan residues in soil and water in the few days following application. Endosulfan sulfate persists longer than parent isomers.

The significance of early volatilisation losses is reflected in field trials on bare ground in Germany, in which between 17 and 38 days were required for residues to decline by 50%, but extending to between 182 and 425 days for 90% dissipation. The α isomer declined more rapidly than the β isomer. Volatilisation does not appear to contribute significantly to losses of the sulfate metabolite, which declines according to pseudo first order kinetics with a half-life in the order of 6 months.

A multi-year study in a Dutch apple orchard found residues to be continually present, with a residue plateau in the 5 cm surface soil layer at the start of each season of about 100-200 $\mu\text{g}/\text{kg}$, mainly as the sulfate. Accumulation above this plateau was not apparent, even

after four years, but the use pattern appears less intense than in Australia. Residues were mainly confined to the surface 5 cm.

Studies on tomatoes involved three applications by boom spray, each at 1.1 kg/ha endosulfan, at fortnightly intervals, with monitoring of soil dissipation, spray drift, runoff, and contamination of two ponds occupying about 10% the area of the crop and receiving runoff from it. The half life for total toxic residues was about 2 months. Small spray drift losses (less than 1% of applied at 5 m downwind, including a volatilisation component) were associated with concentrations in the pond of 0.1-0.3 µg/L. Peak concentrations in runoff water were about 200 and 80 µg/L at the two sites, with respective peak concentrations in the receiving ponds of 1.3 and 0.6 µg/L and sediment concentrations of 50 and 99 µg/kg. Residues dissipated rapidly from water, with a 75% reduction from peak levels over a few days. Sediment residues dissipated to undetectable levels over about 3-6 months, with the β isomer predominant soon after runoff occurred, but the sulfate the main contaminant in later samples.

Studies on vegetables in Kentucky found reductions in runoff losses but increased leaching tendencies when turf was grown between rows. Endosulfan was found at significant levels in deeper soil and water from the vadose zone under these conditions. These results appear to reflect preferential flow through macropores under established groundcover.

Studies on cotton in South Carolina and California involving application at more than twice the rate used in Australia found half-lives in soil in the order of 1-3 months for the α isomer and 2-4 months for the β isomer. Half-lives for total toxic residues were about 2 months in South Carolina and 5 months in California. Losses with irrigation tailwater were very small, remaining well below 1% of applied.

Studies conducted in the cotton growing areas of NSW and Queensland confirm the importance of movement through the atmosphere with around 70% of applied endosulfan lost mainly to volatilisation in the 7 days after application. Particularly rapid losses occur in the first two days, especially when temperatures are high. The more volatile α isomer is lost more rapidly through volatilisation, and its formation by photoisomerisation appears to enable loss of the β isomer. Aerial transport losses include spray drift, which may approach 10% of applied at a distance 200-400 m downwind from the target. Losses with tailwater are typically in the order of 1-2%, with typical concentrations of 5-15 µg/L early in the season declining to 2-3 µg/L late in the season, although more than 10% of applied may be exported during large storms. For the alkaline clay soils where cotton is typically grown, residues approaching 10% of applied may be expected after a month, mainly in the soil, reducing to about 1% after a year. However, persistence can increase markedly in acidic soils and particularly when soils are dry. The balance (25-30%) is assumed to degrade.

Soil residues largely dissipate between seasons, but sulfate residues typically persist at levels in the range of 100-200 µg/kg in the surface 2.5 cm and the parent compound can also persist as residues, particularly the β isomer. Residues can also be found in silt at the tailwater outlet, at higher levels than in the soil from which they are transported. Residues in irrigation tailwater are mainly in the dissolved phase but partition to sediment with a half-life in the order of a week when ponded. Significant off-target movement of endosulfan sorbed to soil and suspended sediment occurs during major storms.

An early trial at Narrabri found total toxic residues of 620 µg/kg in the surface 10 cm soil layer, containing 65% sulfate and 20% β endosulfan. This equates to about half the theoretical residue from a single application to bare ground. Only a single application 12 months before sampling had occurred in the two years before these residues were discovered, indicating that the ready breakdown of endosulfan that occurs in most soils is by no means a consistent outcome, with dry conditions in particular favouring residue carryover from season to season.

Although volatilisation is the main route by which off-target movement occurs, it occurs gradually and off-target deposition via this route over short timeframes is some 200 times lower than can occur from spray drift. Off site contamination by dust movement is also relatively insignificant. Processes that can move large quantities of endosulfan in a short time, namely spray drift and especially storm runoff, appear to be the main contributors to major aquatic contamination incidents involving endosulfan. There is an urgent need to minimise export for endosulfan from cotton farms during major storms. For farms that do not retain storm runoff, irrigation and crop protection operations need to be carefully timed so that irrigation only occurs when soil residues are low. Other management techniques such as planting a cover crop of wheat that is killed just before the cotton season also appear to have promise for reducing export of endosulfan residues and need to be considered by farmers, particularly in erosion prone areas.

Tests from which these conclusions were drawn are described below.

5.2.5.1 Rice paddy in Java

Application to Javanese rice paddy at 490 g/ha endosulfan left residues in the water of between 68 and 500 µg/L. These declined to background (5-8 µg/L in this agriculturally intensive area) over 5 days in a field with no outlet, and over 2 days in a field through which water was flowing. Residues in the mud were about 50 µg/kg after application, declining over 5 days to 10-20 µg/kg in the isolated field and to below 8 µg/kg where water was flowing. Mortality of caged fish and disruptions to the biocenoses (kills of *Brachycura*, Coleoptera and larval Tipulidae) followed application, but lethal impacts were of short duration with the original biocenoses beginning to reappear after 5 days due to immigration (Gorbach *et al*, 1971). Note that background levels should have been toxic to some aquatic biota. The constant presence of toxic background levels may have selected for more resistant organisms.

5.2.5.2 Cotton in South Africa

Composite samples taken from the surface 10 cm of six cotton fields from the Loskop Dam irrigation area indicated that soil levels increase from July through March, with particularly rapid increases to about 2 mg/kg during December and January, before declining to lower levels (less than 100 µg/kg) from March to May. Firm conclusions regarding persistence could not be drawn because of different application patterns at the various sites. In the laboratory, endosulfan was found to volatilise rapidly from open systems but to be much more persistent when soils were enclosed. A lag phase of 120 days, indicative of microbial activity, preceded more rapid degradation (Van Dyk and Van der Linde, 1976).

5.2.5.3 Cotton in the Sudan

Soil sampling of irrigated cotton soils in the Sudan immediately after high volume knapsack application at a rate of 2.2 kg/ha found residues of 8.3 mg/kg in the surface 7.5 cm beneath the cotton plants. Surface residues decreased to below 1 mg/kg within 3 days in these tropical soils, presumably reflecting large and rapid volatilisation losses (El Zorgani, 1976).

5.2.5.4 Cotton, eggplant, rice in South India

Rapid declines in soil residues were observed in soils cultivated to rice paddy, dryland cotton and eggplant in southern India, again with a large volatilisation component. Endosulfan sulfate appeared as the main metabolite within 5 days of spraying, except in one of the dryland cotton soils that received a heavier application, where the alcohol and ether were dominant for 50 days before sulfate formation was detected, perhaps reflecting fungal inhibition at higher exposures. The authors support this observation with reference to earlier work in which the microflora of Indian paddy fields were temporarily reduced following endosulfan exposure (Rao and Murty, 1980).

5.2.5.5 Bare soil in Canada

Technical endosulfan (2:1 isomeric ratio) was applied as emulsion to sandy loam soil at a rate of 6.7 kg/ha and incorporated to a depth of 15 cm. Sampling was conducted for up to 828 days. The α isomer dissipated fairly rapidly (50% loss in 40-60 days), but the β isomer was more persistent (50% loss in 800 days). Losses of parent endosulfan were approximately equal to formation of endosulfan sulfate, which persisted through the study at concentrations in the order of 2 mg/kg. Foliar applications to potatoes (8 applications at 0.6 kg/ha from late July to mid September) left much lower soil residues (about 0.1 mg/kg each of the two parent isomers and sulfate metabolite) at harvest in mid-October (Stewart and Cairns, 1974). The lower soil residues from foliar application presumably reflect large volatilisation losses from the leaf surface. AgrEvo considers the soil incorporated data to be wrong because of the exaggerated application rate, but the residues found in the soil are consistent with those from foliar application if it is assumed that 80% of foliarly applied endosulfan is lost to processes such as volatilisation and does not become incorporated in the soil.

5.2.5.6 Bare ground in Germany

Endosulfan (EC formulation) was applied in early summer at 1056 g/ha in 600 L/ha water to two bare ground plots (sandy loam, pH 7.1, 1.5% organic carbon; sandy silty loam, pH 5.2, 1.0% organic carbon). Random soil samples were taken as two 20 cm segments immediately before and after application and on nine further occasions over the next 440 days, and analysed for α and β endosulfan and the sulfate metabolite with a limit of quantification of 10 $\mu\text{g}/\text{kg}$.

For the sandy loam, post-application residues of 200 $\mu\text{g}/\text{kg}$ α and 90 $\mu\text{g}/\text{kg}$ β isomer were reduced by 50% in 17 days, and by 90% in 183 days. The declining rate of dissipation suggests that volatilisation may have been significant soon after application. Small amounts (20 $\mu\text{g}/\text{kg}$ of each isomer) were also found in the 20-40 cm segment 7 days after application. Endosulfan sulfate reached a maximum of 110 $\mu\text{g}/\text{kg}$ 91 days after application before declining, with an estimated 175 days required for 50% dissipation, and 582 days for 90%. Note that these two results are both consistent with pseudo first order decay, as would be expected given that volatility should not interfere significantly. Continuing formation of the

sulfate metabolite would make these dissipation times an overestimate, but only slightly as the α isomer had declined to the limit of quantification at 91 days, and the more stable β isomer to 70 $\mu\text{g}/\text{kg}$. The sulfate metabolite was also detected in the 20-40 cm segment on a single occasion 31 days after application, at a concentration of 20 $\mu\text{g}/\text{kg}$.

For the sandy silty loam, α and β residues post application were 70 and 30 $\mu\text{g}/\text{kg}$, increasing to 230 and 150 $\mu\text{g}/\text{kg}$ after 14 days. Estimated times for 50 and 90% dissipation were 36 and 396 days, with volatilisation again appearing to contribute to a relatively rapid early rate of dissipation. Sulfate residues appeared relatively constant at about 50 $\mu\text{g}/\text{kg}$ after 61 days. No residues were detected in the 20-40 cm soil segment (Baedelt *et al*, 1992a). A separate analytical report was submitted for this study (Basaniak, 1990).

5.2.5.7 Bare ground in Germany

An analogous study to the above was conducted on loamy sand (pH 5.7, 2.0% organic carbon) and sandy loam (pH 5.7, 1.3% organic carbon).

In the loamy sand, α and β residues in the surface 20 cm post application were 168 and 144 $\mu\text{g}/\text{kg}$, declining by 50% in 38 days and 90% in 425 days. Again, volatilisation appears to contribute to the early dissipation, and the α isomer dissipates much more rapidly than the β . Traces of the sulfate (21 $\mu\text{g}/\text{kg}$) were present in the surface 20 cm before application, increasing to a peak of 175 $\mu\text{g}/\text{kg}$ at 28 days before declining. An estimated 201 days was required for 50% dissipation of this metabolite, and 669 days for 90%, consistent with pseudo first order decay. The sulfate metabolite was also found in the 20-40 cm segment in the few weeks after application, at peak levels of 45 $\mu\text{g}/\text{kg}$.

For the sandy loam, α and β residues in the surface 20 cm post application were 544 and 309 $\mu\text{g}/\text{kg}$, more than double the theoretical concentration. Times for 50 and 90% dissipation were 17 and 182 days. The post application sample also contained 309 $\mu\text{g}/\text{kg}$ of the sulfate metabolite. Reliable dissipation data could not be computed for this metabolite because of erratic results (Baedelt *et al*, 1992b).

5.2.5.8 Apple orchard in Holland

A wettable powder formulation of endosulfan was applied to apples in high volumes by mist blower at 0.7 kg/ha active ingredient three times per season (late bloom, early fruit set and 50% fruit size) for four consecutive seasons. Soil samples were taken within and between the rows before and after each application and on seven further occasions through the year, and analysed for α and β endosulfan and sulfate and diol metabolites. Results were consistent with α and β isomers both degrading to endosulfan sulfate, the former at a more rapid rate, and further to form the diol. Data were somewhat erratic as the bulk of the spray would have been intercepted by foliage or lost to drift, rather than reaching the soil, as indicated by the shortfalls from the theoretical residue of 1.2 mg/kg that would result in 5 cm soil from a single application. The following broad trends are apparent.

In the first year, highest residues of the α isomer in the surface 5 cm were recorded between the rows just after the third application, at 130 $\mu\text{g}/\text{kg}$ accompanied by 120 $\mu\text{g}/\text{kg}$ β isomer. The sulfate metabolite peaked in the row at 90 $\mu\text{g}/\text{kg}$ 28 days later, accompanied by the peak level of 130 $\mu\text{g}/\text{kg}$ for the β isomer. The diol remained at or below the limit of quantification

of 10 µg/kg. Residues were largely confined to the surface 5 cm of soil, and dissipated to background levels by the start of the next season, except for the sulfate which continued to be found at concentrations to 80 µg/kg in the surface 5 cm.

In the second year, highest residues of the α isomer in the surface 5 cm were recorded in the row just after the third application, at 40 µg/kg. The β isomer peaked between the row at 150 µg/kg 29 days later, accompanied by the peak sulfate detection of 300 µg/kg. While the sulfate was found in the row at 610 µg/kg 275 days after the third application, this result is an outlier and considered to be unrepresentative. The diol remained at or below the limit of quantification of 10 µg/kg, except for a single detection of 50 µg/kg 8 days after the last application.

In the third year, highest residues of the α isomer in the surface 5 cm were found between the row at 70 µg/kg just after the third application, accompanied by peak levels of β isomer (130 µg/kg) and sulfate (490 µg/kg, with a second detection at this level 29 days later, also between the row).

In the fourth year, α endosulfan peaked at 60 µg/kg 15 days after the second application, β endosulfan at 110 µg/kg 191 days after the third application, and the sulfate at 1000 µg/kg in the same sample, taken in late December. Diol levels remained below the limit of quantification.

The somewhat erratic results may reflect an inhomogeneity of endosulfan residues across the orchard. For example, the authors argue that high sulfate detection in the December of the final year of the trial may reflect additional inputs from leaf fall, which could accumulate in topographical hollows and give rise to sporadic high residues. This argument appears inconsistent with the high volatility of endosulfan from foliage.

Results indicate that residues in the surface 5 cm may be expected to be in the order of 100-200 µg/kg at the start of the season when endosulfan is applied under Dutch conditions three times per season, each at 700 g/ha. Endosulfan accumulates in the soil during the spray season, but does not appear to accumulate from year to year under Dutch conditions, as residues in the surface 5 cm were below 100 µg/kg 307 days after the final application of the trial (Tiirmaa *et al*, 1993). Residues under Australian conditions are likely to be significantly higher as Australian use patterns appear to involve up to five applications per season, each at 1.4-2.1 kg/ha endosulfan.

5.2.5.9 Tomatoes in Georgia, USA

Studies on farm pond ecosystems were conducted at two reference and two treatment sites in SW Georgia, USA. Ponds at treatment sites covered 1.4 and 0.9 ha and were exposed to runoff from tomatoes grown on both upstream sides of the pond to within 5 m of the margins. The crops occupied about ten times the area of the ponds and were grown on a 3-8% slope. Soils were sandy loams and loamy sands, with some sandy clay loam at the larger pond site. Sites were characterised for a year before endosulfan application and monitored for 6 months after. Endosulfan (emulsifiable concentrate formulation) was applied three times by boom spray at fortnightly intervals, each at 1.1 kg/ha.

Spray cards deployed in the crop and collected within 1 hour of spraying indicated an average deposition of about 790 g/ha at the larger pond site and 640 g/ha at the smaller, with losses from crop interception and, to a lesser extent, drift. Residues were recovered as α and β isomers in 2:1 ratio. Foliar residues were sampled about 6 hours later and found to contain α and β isomers and the sulfate (37:61:2). On average, about 70 g/ha was extracted from the crop, but deposition would probably have been higher given the apparent volatilisation of the α isomer prior to sampling. Drift cards (filter paper) retrieved within 3 hours of spray application returned variable results, depending on wind direction. Deposition at the pond edge was found to be below 10 g/ha, and at the pond surface generally below 2 g/ha but with a maximum of 3.6 g/ha. Drift samples contained α and β isomers in 3:1 ratio, suggesting a contribution from vapour transport. No biological effects were noted from these small amounts of drift.

Soil samples collected from both sites within 24 hours of the final spray contained comparable residues in the surface 5 cm. The average deposition per spray of 720 g/ha equates to about 1200 $\mu\text{g}/\text{kg}$ in 5 cm soil with density 1.2. Decomposing crop residues may have added further increments to the soil. Residues found at the two sites are tabulated below. Half-lives in the order of 2 months for total toxic residues are apparent from these data.

	Large pond		Small pond	
Sampling time	Residue	α , β , sulfate	Residue	α , β , sulfate
0 days	2300 $\mu\text{g}/\text{kg}$	38, 55, 7%	2500 $\mu\text{g}/\text{kg}$	45, 49, 6%
6 months	320 $\mu\text{g}/\text{kg}$	1, 54, 45%	350 $\mu\text{g}/\text{kg}$	9, 54, 37%

Seventeen runoff events occurred at the two treatment sites during the monitoring phase, but with only one preceding the final application, by 14 days at the smaller pond site. The average precipitation required to produce runoff was about 2.8 cm. Significant runoff occurred one day after the third application, either induced by irrigation or occurring naturally through rain (up to 30 mm in 8 hours). Runoff concentrations sampled at a flume are tabulated below (sampling times are relative to the final application).

Large pond		Small pond	
Sampling time	Concentration	Sampling time	Concentration
1 day, 1 hour	203 $\mu\text{g}/\text{L}$	-14 days, +1 hour	41 $\mu\text{g}/\text{L}$
1 day, 3 hours	191 $\mu\text{g}/\text{L}$	-14 days, +3 hours	26 $\mu\text{g}/\text{L}$
1 day, 5 hours	127 $\mu\text{g}/\text{L}$	1 day, 1 hour	75 $\mu\text{g}/\text{L}$
1 day, 7 hours	81 $\mu\text{g}/\text{L}$	1 day, 3 hours	80 $\mu\text{g}/\text{L}$
7 days, 1 hour	45 $\mu\text{g}/\text{L}$	40 days, 1 hour	5 $\mu\text{g}/\text{L}$
7 days, 3 hours	65 $\mu\text{g}/\text{L}$	40 days, 3 hours	11 $\mu\text{g}/\text{L}$
7 days, 5 hours	54 $\mu\text{g}/\text{L}$	40 days, 5 hours	10 $\mu\text{g}/\text{L}$
7 days, 7 hours	55 $\mu\text{g}/\text{L}$	46 days, 1 hour	9 $\mu\text{g}/\text{L}$
14 days, 1 hour	13 $\mu\text{g}/\text{L}$	46 days, 3 hours	12 $\mu\text{g}/\text{L}$
14 days, 3 hours	17 $\mu\text{g}/\text{L}$	65 days, 1 hour	8 $\mu\text{g}/\text{L}$
14 days, 5 hours	17 $\mu\text{g}/\text{L}$	70 days, 1 hour	3 $\mu\text{g}/\text{L}$
42 days, 1 hour	8 $\mu\text{g}/\text{L}$	70 days, 3 hours	5 $\mu\text{g}/\text{L}$
42 days, 3 hours	11 $\mu\text{g}/\text{L}$	119 days, 1 hour	0.3 $\mu\text{g}/\text{L}$
97 days, 1 hour	3 $\mu\text{g}/\text{L}$		
132 days, 1 hour	5 $\mu\text{g}/\text{L}$		

Pond water samples taken from the larger pond edge close to the runoff channel about 20 hours after the commencement of runoff were found to contain 1.3 $\mu\text{g}/\text{L}$ endosulfan

residues (28% α , 44% β , 28% sulfate). The β isomer remained dominant in runoff water for about 7 weeks after spraying ceased, with the sulfate metabolite the main component thereafter. The β isomer was the main component in early events at the smaller pond, with the sulfate metabolite dominant from about 14 weeks after the final application.

Mean concentrations in samples taken from six zones in the larger pond were in the order of 0.1-0.3 $\mu\text{g/L}$ for early spray applications, largely reflecting contamination by drift. Levels increased to 1.1 $\mu\text{g/L}$ in the runoff event following the final spray and peaked at 1.3 $\mu\text{g/L}$ 2 days later before declining sharply to 0.3 $\mu\text{g/L}$ over the next 3 days. A more gradual decline followed as occasional inputs to the pond continued, to below 0.1 $\mu\text{g/L}$ some 12 weeks after the main runoff event. The sulfate metabolite was the main contributor (>80%) to this persistent low level contamination, and the β isomer (40-50%) to the peak levels.

Sampling in the smaller pond revealed a similar pattern but with a smaller peak (0.6 $\mu\text{g/L}$) in the main runoff event, reflecting in part the smaller catchment area, declining over the next 3 days to 0.3 $\mu\text{g/L}$ and further over the next 2 days to below 0.1 $\mu\text{g/L}$. The two parent isomers were present at 78% of total residues when contamination peaked, but the sulfate metabolite was generally dominant in subsequent samples.

Residues in sediment remained undetectable for the larger pond until after the main runoff event, returning to background levels 24 weeks later. A peak of 50 $\mu\text{g/kg}$ occurred about a week after that event, with the β isomer predominant. The sulfate metabolite was the main contributor to sediment contamination in later samples.

Sediment residues in the smaller pond followed a similar pattern except that a detection (44 $\mu\text{g/kg}$) occurred on the day following the first spray, apparently reflecting spray drift as the residue consisted of parent isomers in close to original ratio. The absence of such contamination from spray drift in the larger pond may reflect its greater turbidity. Peak contamination of 99 $\mu\text{g/kg}$ occurred as a result of the main runoff event, declining to undetectable levels over the next 12 weeks. Again, the β isomer was the main component in early samples, and the sulfate in later.

Residues were only found in fish from the larger pond, being present as endosulfan sulfate at levels in the order of 10-20 $\mu\text{g/kg}$ in samples taken between 1 and 3 months after the final spray. No fish were sampled during the main runoff event, notwithstanding that mortality occurred in both ponds, as outlined in section 6.1.2.10 of this report (Cornaby *et al*, 1989).

5.2.5.10 Vegetables in Kentucky

These trials were conducted on small plots of silt loam soil (pH 6.7, 5% organic matter) situated on a 10% slope and planted along the contour to capsicum, or capsicum intercropped with tomatoes. Three different surface treatments were compared: bare soil, and 30 cm turf strips between every row, or alternate rows. Runoff and sediment losses were monitored, soils sampled in two consecutive 23 cm segments, and suction lysimeters installed to depths of 0.3, 0.6 and 1.5 m and equilibrated for a year prior to treatment.

Application by backpack at 0.61 kg/ha endosulfan occurred in July, with rain falling the following day giving rise to runoff of 13.5 kL/ha from the bare soil plot. A total of 86 mg/ha was exported, at an average concentration of 6.4 $\mu\text{g/L}$ (a potential cause of fish mortality in

the discharge zone before dilution). Alternating turf strips reduced endosulfan losses to 38 mg/ha, and turf between every row was particularly effective, reducing runoff volumes 13-fold and endosulfan losses to 0.7 mg/ha. Parent isomers and sulfate metabolite were in roughly equal abundance in water and sediment samples, except for the water sample from the plot with turf between every row, in which the β isomer was predominant.

Turf strips between every row greatly reduced losses in runoff but favoured leaching of endosulfan, notwithstanding that less endosulfan appeared to reach the soil. Average residues in the surface 23 cm of nine soil cores taken from the middle of the plots over a 3 month period were about 2200 $\mu\text{g}/\text{kg}$ under bare soil, 1400 $\mu\text{g}/\text{kg}$ under alternating turf strips, and 320 $\mu\text{g}/\text{kg}$ under maximum turf cover. The β isomer contributed more than 90% of these residues, and the sulfate was the dominant soil metabolite. Corresponding residues in the 23-46 cm segment were 19, 2 and 190 $\mu\text{g}/\text{kg}$, again with the β isomer predominant (>80%) except under alternating turf strips where only the α isomer was detected.

Suction lysimeters confirmed the increased tendency for leaching under turf. Water infiltration rates were higher under turf, and average residues detected in water samples collected from the vadose zone over the 3 months following application were 0.16, 0.28 and 0.63 $\mu\text{g}/\text{L}$, respectively, under bare soil, alternating turf, and maximum turf treatments. The authors note that the risk of leaching to groundwater may be higher in agricultural areas where endosulfan is used intensively, and cite a number of examples where endosulfan has been detected in groundwater following normal agricultural use (Antonious and Byers, 1997).

5.2.5.11 Cotton in South Carolina

Field trials in South Carolina involved two applications of Thiodan 3EC by ground equipment to cotton, each at 1.7 kg/ha endosulfan, the first at the 2-4 leaf stage and the second at flowering, 48 days later. Sprinkle irrigation to produce runoff followed 2 days after each application. The experimental plot was situated on a 3-5% grade slope and separated by a 62 m buffer zone with a single runoff point through a flume into a stream. The soil in the experimental plot was a sandy clay loam with about 1.6% organic matter and a pH of 5.1.

Soil residues (surface 15 cm) determined at three sampling points across the field were variable. For the α isomer, average peak residues recorded within 3 hours of the two applications were 180 and 153 $\mu\text{g}/\text{kg}$, or about a quarter of theoretical residues for a bare ground treatment. Residues dissipated with calculated half-lives of 25 and 44 days. Corresponding data for the β isomer were 117 and 223 $\mu\text{g}/\text{kg}$, the latter occurring 59 days after the second application. The authors suggest that the β isomer may be formed from the α . Residues declined from these peak levels with calculated half-lives of 72 and 83 days. Endosulfan sulfate was found from 4 days after the first application, reaching peak levels of 257 $\mu\text{g}/\text{kg}$ after 107 days before declining with a calculated half-life of 45 days. The diol was a minor and transient metabolite, with average peak soil residues of 50 $\mu\text{g}/\text{kg}$ immediately following the second application. Total residues soon after the initial application were about a third of theoretical residues for a bare ground treatment, dissipating with a calculated half-life of 54 days. The calculated half-life for the second phase, after total residues began to decline 59 days following the second treatment, was 93 days.

Drift cards located within the sprayed area found 65 and 102% of theoretical based on analysis for the α isomer, and 71 and 73% for the β . Buffer zone deposits from drift were well below

1%. Only 0.002% of the applied α -endosulfan was discharged into the stream during the first irrigated runoff event, compared with 0.27% discharged from the field to the buffer zone. Corresponding figures for the β isomer were 0.005 and 0.51%, and for the sulfate 0.0002 and 0.1%. Similar results were obtained for the second event. No detectable concentrations of endosulfan residue were found in the stream water or sediment following the runoff events (Mester, 1989).

5.2.5.12 Cotton in California

Californian field trials also involved two applications of Thiodan 3EC to cotton at 1.7 kg/ha endosulfan, but with applications made by helicopter (hollow cone nozzles delivering relatively large droplets) to furrow irrigated fields, initially at the cotyledon to 2 leaf stage, and 30 days later at early bloom. The field was graded with a 1% slope along the furrow. Soil was classified as clay loam with a pH of 6.8 and about 0.7% organic matter. The treated area was irrigated to saturation six times during the first 100 days of the study, in strips because of limited water supply.

Soil residues (surface 5 cm) determined at three sampling points across the field were variable. For the α isomer, average peak residues recorded within 3 hours of the two applications were 580 and 713 $\mu\text{g}/\text{kg}$, or about a third of theoretical residues for a bare ground treatment. Some detections occurred in the 5-35 and 35-65 cm soil segment, but at low levels ($< 10 \mu\text{g}/\text{kg}$) and even in untreated plots, suggesting that some may have been false positives. Residues dissipated with a calculated half-life of 69 days for the year following the second treatment. Corresponding data for the β isomer were 307 and 477 $\mu\text{g}/\text{kg}$, with traces again found in deeper fractions. Residues declined with a calculated half-life of 106 days for the 539 days following the second treatment. Endosulfan sulfate was found from 28 days after the first application, reaching peak levels of 477 $\mu\text{g}/\text{kg}$ after 63 days before declining. Traces (up to 50 $\mu\text{g}/\text{kg}$) were also found in deeper segments. A half-life was not calculated because of difficulty in differentiating between formation and dissipation. The diol was a minor and transient metabolite, with average peak soil residues of 133 $\mu\text{g}/\text{kg}$ one day following the second application. Total residues dissipated with a calculated half-life of 142 days in the 539 days following the second treatment.

Residues were higher in a bare ground plot, but dissipated at similar rates (calculated half-life of 147 days for total residues in the 539 days following the second treatment).

Tailwaters were collected 4 days after the first treatment and 3, 28 and 38 days after the second, and analysed for α and β isomers and the sulfate metabolite. Peak concentrations ($\mu\text{g}/\text{L}$) and total losses (%) from the paddock for these four events are tabulated below.

Event	α endosulfan	β endosulfan	endosulfan sulfate
1	4.06 $\mu\text{g}/\text{L}/0.0092\%$	2.21 $\mu\text{g}/\text{L}/0.0057\%$	3.75 $\mu\text{g}/\text{L}/0.029\%$
2	6.45 $\mu\text{g}/\text{L}/0.039\%$	4.70 $\mu\text{g}/\text{L}/0.042\%$	3.65 $\mu\text{g}/\text{L}/0.028\%$
3	0.73 $\mu\text{g}/\text{L}/0.011\%$	0.81 $\mu\text{g}/\text{L}/0.023\%$	3.40 $\mu\text{g}/\text{L}/0.047\%$
4	0.29 $\mu\text{g}/\text{L}/0.0053\%$	0.52 $\mu\text{g}/\text{L}/0.012\%$	2.00 $\mu\text{g}/\text{L}/0.047\%$

Total losses over these four events were about 0.3% of applied with around half contributed by the sulfate metabolite. Subsequent irrigations at 62 and 70 days after the second treatment mobilised very small quantities of the α and β isomers (combined peak concentrations of 0.4

and 0.04 µg/L) but continued to release the sulfate metabolite at constant levels in the order of 1 µg/L. Note that tailwater flows were larger than would occur in practice to facilitate sampling (Mester, 1990).

5.2.5.13 Cotton soil in India

Endosulfan (EC formulation) was applied by knapsack to two plots where cotton would normally be grown. The application rate was 875 g/ha, and the soil a sandy loam, pH 8.1. Plots were treated at different times and sampled for 238 days.

Residues in the surface 5 cm at application were about 2.3 mg/kg α isomer and 0.6 mg/kg β isomer, approximately double the theoretical residue of 1.5 mg/kg in 5 cm soil, density 1.2. The α isomer remained in detectable amounts for 14 days after the earlier treatment and 28 days after the later, and the β isomer for 70 and 238 days. Endosulfan diol was only found in one plot, at the 7 and 14 day samplings. The sulfate appeared in both plots at the 7 day sampling and persisted in detectable amounts through the study. The authors note that this is consistent with reports that endosulfan sulfate is the main breakdown product found in Australian cotton soils. Dissipation of endosulfan residues followed pseudo first order kinetics but in two phases. The first had a short half-life of 5.4 to 7.3 days because of rapid volatilisation losses, and the second a longer half-life of 78.6 to 115.3 days. No residues were found below 10 cm in soil (Kathpal *et al*, 1997).

5.2.5.14 Cotton in Australia (Narrabri/Moree, NSW)

A summary report covering various early field studies, including on cotton at Moree and Narrabri, has been presented by the principal registrant. Endosulfan had been used for at least five years at these two sites, where cotton and wheat were grown in rotation.

Soil at the Moree site was a clay with pH 7.2 and 1.12% organic matter in the surface 10 cm. Endosulfan had been applied 2-4 times per season for 5 years, generally at 0.73 kg/ha, with the last application occurring 23 months before sampling occurred in December 1985. A single detection of the sulfate at the limit of determination (20 µg/kg) occurred in the 10-20 cm segment, with all other residues below this limit. Higher levels were found in sediment at the irrigation outlet, with the β isomer at the limit of determination in each of two 5 cm segments, and the sulfate found at 40 and 50 µg/kg. Three more applications at 0.73 kg/ha occurred in the month following planting. Sampling 6 months later did not discover any parent isomers or lactone and diol metabolites, but found 30 µg/kg of the sulfate metabolite in 0-10 and 10-20 cm soil segments, and 40 µg/kg in the 30-40 cm segment.

Soil at Narrabri was a clay with pH 6.9 and 1.34% organic matter in the surface 10 cm. Endosulfan had been applied between 0 and 3 times per season over the preceding 6 years, generally at 0.73 kg/ha, with a single application 12 months before sampling following an interval of nearly two years without spraying. Residues of α and β isomers and sulfate metabolite recorded in mid-December 1985 were much higher in soils and sediment at this site, as tabulated below.

Sample	α -endosulfan	β -endosulfan	endo sulfate
Soil 0-10 cm	90 $\mu\text{g}/\text{kg}$	120 $\mu\text{g}/\text{kg}$	410 $\mu\text{g}/\text{kg}$
Soil 10-20 cm	30 $\mu\text{g}/\text{kg}$	100 $\mu\text{g}/\text{kg}$	150 $\mu\text{g}/\text{kg}$
Soil 20-30 cm	20 $\mu\text{g}/\text{kg}$	100 $\mu\text{g}/\text{kg}$	200 $\mu\text{g}/\text{kg}$
Sediment 0-5 cm	150 $\mu\text{g}/\text{kg}$	730 $\mu\text{g}/\text{kg}$	620 $\mu\text{g}/\text{kg}$
Sediment 5-10 cm	60 $\mu\text{g}/\text{kg}$	380 $\mu\text{g}/\text{kg}$	390 $\mu\text{g}/\text{kg}$

Two further applications at 0.72 kg/ha occurred in the month following sampling. The following residues were found in five consecutive 10 cm soil samples taken at the end of July 1986. Lactone and diol metabolites remained below the limit of determination (Tiirmaa and Dorn, 1988).

Sample	α -endosulfan	β -endosulfan	endo sulfate
Soil 0-10 cm	<20 $\mu\text{g}/\text{kg}$	30 $\mu\text{g}/\text{kg}$	80 $\mu\text{g}/\text{kg}$
Soil 10-20 cm	<20 $\mu\text{g}/\text{kg}$	20 $\mu\text{g}/\text{kg}$	50 $\mu\text{g}/\text{kg}$
Soil 20-30 cm	100 $\mu\text{g}/\text{kg}$	80 $\mu\text{g}/\text{kg}$	50 $\mu\text{g}/\text{kg}$
Soil 30-40 cm	100 $\mu\text{g}/\text{kg}$	70 $\mu\text{g}/\text{kg}$	40 $\mu\text{g}/\text{kg}$
Soil 40-50 cm	90 $\mu\text{g}/\text{kg}$	70 $\mu\text{g}/\text{kg}$	30 $\mu\text{g}/\text{kg}$

The persistence of endosulfan under Australian conditions appears from the above data to be highly variable. Thus residues in soil at Narrabri in July 1986 were much lower than those recorded in December 1985, notwithstanding a more recent history of endosulfan treatment. It would appear likely that, as for other insecticides that have been used in Australian cotton, the persistence of endosulfan in soils increases under dry conditions. Weather data for Moree and Narrabri indicate that 1983 and 1984 were wet years, and 1985 relatively dry.

Considerable further work has since been conducted in the cotton areas under the Minimising the Riverine Environmental Impact of Pesticides Research and Development Program. The Land and Water Resources Research and Development Corporation is administering this joint program in collaboration with the Cotton Research and Development Corporation and the Murray-Darling Basin Commission. The principal research activities for the cotton industry are pesticide movement, its fate from the point of application on crops to potential discharge in rivers, and its impact on aquatic fauna. Practical and cost-effective best management practice methods for pesticides use are being developed, with the initial focus on the cotton industry as a model for other primary industries. The target is to minimise the impact of pesticides on rivers and, ultimately, to meet the national guidelines for protection of the aquatic environment.

A review of the research and development program has concluded that it will produce valuable results, but will not exclude pesticides from rivers. The volatilisation route for riverine contamination makes the problem particularly intractable, and the program is unlikely to result in compliance with the water quality guideline for endosulfan. There is said to be considerable anxiety in the cotton industry that endosulfan may be abruptly withdrawn because current technology is insufficient to achieve compliance with water quality objectives. While new technology such as transgenic cotton may ease the problem, success is not guaranteed and the need remains to address presently occurring contamination. Best practice management based on findings from the research and development program but including all other useful inputs is proposed. A Best Practice Manual, to be updated regularly, would give practical advice to farmers concerning measures they can take to minimise riverine contamination. The project should aim for a high adoption rate in order to ensure that

the objective of minimising pesticide contamination is realised, and reduce the need for regulation (Doak, 1995). This initiative will be returned to in the conclusions and recommendations of this report.

Research findings available to date from the Minimising the Riverine Environmental Impact of Pesticides Research and Development Program are described below. Most of the results are of an interim nature and have yet to be fully reported, but the information available sheds considerable light on the behaviour of endosulfan in the Australian environment.

5.2.5.15 Cotton in Australia (Warren, NSW)

A site at Warren where cotton had not been grown the previous season was studied during the 1994-95 season, with three applications at 0.72 kg/ha on 30 November, 21 December and 7 January when the crop provided 4.6, 24.7 and 50.2% plant cover. Compositing soil cores were taken from the surface 5 cm throughout the spray period and for about a month after its completion. Total toxic endosulfan residues (α and β isomers and sulfate metabolite) were determined by immunoassay, and individual compounds by gas chromatography.

Residues of α and β isomers and sulfate metabolite found in soil samples taken 2 days after the first application and a day following the second and third were 99, 65 and 0; 209, 141 and 36; and 86, 149 and 109 $\mu\text{g}/\text{kg}$, respectively. The authors conclude from their data that the main mode of dissipation from foliage and soil for the α isomer is volatilisation during the 7 days following application, accounting for more than 75% of applied. The β isomer is less prone to volatilisation, with less than 25% lost in this way in the 7 days after application, and mainly degrades through oxidation to the sulfate or hydrolysis to the diol. The sulfate is more persistent than either the α or β isomer, as indicated by its increasing presence through the spray period. Half-lives of α and β endosulfan soil residues over the short timeframes used for sampling were in the range of 1.6-10 days, the smaller values obtained over shorter timeframes reflecting the influence of volatilisation.

Hydrological studies indicated that total endosulfan residues were in the order of 5 $\mu\text{g}/\text{L}$ in irrigation and storm runoff sampled a week after application, but with much higher concentrations possible in the first 2 hours, declining to around 2 $\mu\text{g}/\text{L}$ after a month. Seasonal runoff losses were estimated at 5.7%. One intense storm occurring 11 days after the final application transported 12% of total endosulfan residues present in the field at the time in runoff, at a concentration of 6.1 $\mu\text{g}/\text{L}$ (Kennedy *et al*, 1995).

5.2.5.16 Aerial transport and deposition at Warren

Half-lives for volatilisation from cotton foliage as determined by measurements of leaf deposits are strongly affected by temperature, reflecting the effects of temperature on vapour pressure. Respective half-lives of 12 and 36 hours were found for α and β isomers when the mean maximum temperature in the 48 hours following ULV application at 720 g/ha endosulfan was 40°C. These half-lives increased to 24 and 60 hours when the temperature dropped to 29°C. Declines of at least 80% were found in the 5 days following each spray. The α isomer declined much more rapidly than the β , while levels of endosulfan sulfate increased to reach about 50% of residues remaining after 5 days. Most of the volatilisation occurred soon after application, as indicated by air sampling above the crop. Cumulative

losses to 24 and 48 hours were 82 and 89% at the higher temperature, and 49 and 69% at the lower (Ahmad *et al*, 1995).

Deposition from the vapour phase was monitored with trays of water, and as particles using polybutene coated foil collectors, with drift collected for 1 hour after application and dust over the subsequent 24 hours. Peak concentrations in the order of 0.5 µg/L in 5 cm water (equivalent to 0.25 g/ha, or about 0.035% of the applied rate) were observed downwind in individual trays located 200 and 400 m from the sprayed field at the 48 hour sampling. Upwind concentrations were about one third of the peak levels found downwind. The peak concentration equates to 0.025 µg/L in 1 m water, in reasonable agreement with predicted values of 0.05 µg/L at 1 km downwind from a 1 km² cotton plot (see section 5.2.4.4).

Deposition over four trays to the N, S, E and W, summed over all directions for three consecutive 24 hour samplings, ranged between 0.6 and 1.5% of the applied rate for three ULV applications, with the highest concentrations associated with the highest temperatures. Volatilisation results were similar for EC formulations.

Drift was much more significant, depositing a total of 59 g/ha from ULV application and 41 g/ha from an EC spray on four collectors located 200 or 400 m to the N, S, E and W of the sprayed field. Dust collections were lower at about 2.4 g/ha for ULV and 3.6 g/ha for EC application (Ahmad *et al*, 1996).

5.2.5.17 Drift studies

Cumulative deposits on flat plates positioned above the crop at Warren during the 1994-95 season were 35 and 38% of total endosulfan applied for two ULV applications at 0.72 g/ha endosulfan, as determined by immunoassay. Up to 5.5% was recovered from permanent arrays of flat plates extending out to the N, S, E and W from the crop edge to 1 km. A tower situated 4-5 m downwind from the crop intercepted 28% in the first trial and 5.3% in the second (or 4.8 and 5.7% by gas chromatography). A second tower situated 550 m downwind collected just 0.95% of total endosulfan applied.

A second trial involving a single pass of an aircraft gave comparable results for both ULV and EC formulations, with 7 and 9% respectively collected on drift towers located 110 m downwind and much better recoveries within the crop (68 and 82% from flat plates above and 10 and 28% from ground sticks beneath the crop, extending out to 100 m downwind). The EC formulation was expected to deliver larger droplets that would be less prone to drift (Woods, 1995).

Average in crop deposition levels on flat plates located just above the crop canopy were approximately 3 µg/cm² for full field ULV treatments, presumably at 0.72 kg/ha (7.2 µg/cm²). In general, deposition reduced to less than 1 µg/cm² at 100 m downwind and less than 0.1 µg/cm² at 500 m downwind. Some 12% of applied typically leaves the field below 20 m height, with 7% depositing within 500 m.

Further single pass trials found that around 76% deposited on flat plates located downwind for EC application, compared with 43% for ULV formulations. Interception of airborne droplets using drift towers located 100 m downwind recovered 9% for the EC formulation compared with 24% for ULV (Woods *et al*, 1996).

5.2.5.18 Cotton in Australia (further studies at Warren, NSW)

Total toxic residues as determined by immunoassay are presented graphically for a site sampled in the 1995-96 season for about 12 weeks after receiving four applications (30 November, 12 and 23 December, 9 January). Highest residues (equivalent to about 1200 g/ha, or about half of the three preceding sprays summed together) were found after the third application, reflecting residue carryover. High residues (about 1000 g/ha) were also found after the final application, but had declined to about 450 g/ha after 14 days and remained at this level for the remainder of the sampling period.

Ponded irrigation tailwater collected on 20 December contained about 200 mg total residues in the water column (24.2 µg/L) declining over a 3 week period to about 60 mg, with concomitant increases in sediment to about 100 mg.

Furrow studies showed the highest concentration in runoff water to occur in the advancing water front, carrying five times more endosulfan. This effect was most noticeable in early samples when residues were highest at 25-30 µg/L. Later samples contained about 1-2 µg/L. About 20% of the pesticide load was found to be associated with suspended particulates (0.7 µm filter). A total of 1.5% of the seasonal application was lost from the field in runoff.

The overall conclusion from the studies at Warren is that some 70% of applied endosulfan is lost through volatilisation, with only about 8.5% remaining on the field after a month, mainly in the soil. Residues reduce to about 1% of applied by the start of the next season, mostly as the sulfate which has a half-life of 120-150 days in soil but only 3-4 days in plants. Barring major storms, runoff losses are restricted to 1-2%, with the balance (25-30%) assumed to degrade over the season in either plants or soil. Oxidation to the sulfate is exclusively a biological process, and does not occur through chemical oxidation in farm waters. Because of the extensive dissipation that occurs in the field, there is practically no residue accumulation between seasons under the conditions prevailing during this trial (Kennedy *et al*, 1996).

5.2.5.19 Cotton in Australia (Emerald, Queensland)

Endosulfan residues in the alkaline high clay soils of the Emerald Irrigation Area rise rapidly to about 2-3 mg/kg in the surface 2.5 cm soon after the first application of the season (720 g/ha) and decay with a half-life of about a week. The theoretical residue in 2.5 cm soil, density 1.2, is 2.4 mg/kg. A number of mechanisms contribute, including oxidation to the sulfate. Even with nine applications within less than 3 months, residues do not accumulate beyond the initial peak in these alkaline soils.

The lack of accumulation through the spray season is said to reflect rapid degradation between applications, but a number of other factors are clearly operating. Volatilisation appears to be a major pathway for dissipation, as the α isomer is predominant in early samples, and the β isomer in later. A gradual increase in sulfate residues is apparent through the spray season, reaching a peak of about 0.7 mg/kg about 2 weeks after the final spray. A single sample taken two weeks later showed signs of a gradual decline, but further sampling would be necessary to confirm this. Interception by the growing crop presumably also contributes to the lack of accumulation through the spray season. Crop deposits would be expected to largely volatilise

rather than reaching the soil, particularly under the dry conditions prevailing in the 1993 season when these data were generated.

Concentrations leaving the furrow or taildrain are typically in the range 8-15 µg/L during the peak of the season, declining to 2-3 µg/L towards the end of the season. Much higher levels may be expected from major storms in peak season (Simpson, 1994).

5.2.5.20 Effects of soil moisture and wheat stubble (Warren, Emerald)

Time required for endosulfan residues to decline by 50% after application to dry soil at Emerald in the early morning was 2.3 days for α and β isomers, with volatilisation thought to be the main pathway. Volatilisation was favoured by high temperatures. Photoisomerisation presumably contributes significantly to loss of the β isomer given its much lower vapour pressure. The second half lives were longer at 11.4 and 16.5 days, respectively. A second application 4 days later returned similar results, with 600 g/ha (60% of a single application) remaining in the surface 2.5 cm 12 days later.

Only small amounts of the sulfate were formed under the dry conditions prevailing during the study. The importance of water to biological degradation is evident from results obtained when rain was simulated following application using a rainulator. While endosulfan residues did not differ from those on the dry plot, sulfate formation was increased by a factor of 6-7 in the furrow where soil remained moist and eroded surface residues accumulated.

Volatilisation appeared much less important in an analogous study at Warren that involved application at night when temperatures are cooler, with no evidence for enhanced dissipation soon after application. Dissipation half-lives for each isomer were about a week. Again, very little oxidation to the sulfate occurred in dry soils, and overall dissipation was retarded in moist soils notwithstanding greater production of the sulfate metabolite.

Residues in soil were very much lower when endosulfan was applied in late 1994 to areas retaining wheat stubble. It appears that stubble intercepts much of the endosulfan. Residues in the stubble dissipated rapidly in the first 12 hours, presumably through volatilisation, and little sulfate formation occurred. Crop residues also reduce the amounts and rates of runoff. Stubble retention appears to offer promise as a management technique to minimise soil residues and reduce associated runoff risks (Silburn *et al*, 1996).

5.2.5.21 Reducing runoff (Emerald)

Three surface treatments (rake and burn, cotton stubble retention and addition of wheat straw) were investigated in the 1994/95 season but were found to offer no significant reductions in soil erosion. All significant runoff events were from irrigation because of the dry season. Erosion was more significant at higher slopes as would be expected.

Treatments evaluated in the following season were conventional tillage, minimum tillage, and pre-cotton wheat planting (killed prior to cotton planting). Soil erosion was significantly reduced by the wheat treatment, particularly in early to mid season. Losses of endosulfan were reduced to about 30% of those from conventional tillage during a heavy irrigation three days after the first application.

As noted above, concentrations leaving the furrow or taildrain are typically in the range 8-15 µg/L during the peak of the season, declining to 2-3 µg/L towards the end of the season. Similar levels occur in the main drainage channels of the Emerald irrigation Area. Much higher levels would be expected for major storm runoff in peak season, and studies on a main drainage channel indicate significant potential for exporting pesticides into riverine environments during storm events. The authors of this study recommend that erosion and runoff be minimised, for example by optimising timing of crop protection and irrigation so that the latter occurs only during periods of minimum pesticide concentration in the soil (Simpson *et al*, 1996).

5.2.6 Bioaccumulation

Information submitted indicates that endosulfan bioconcentrates in fish, particularly as its sulfate metabolite, but that residues depurate rapidly in clean water. Bioconcentration factors vary with species but appear to be in the order of 1000 over short timeframes (96 hours), increasing over longer timeframes. The β isomer appears to undergo preferential metabolism in fish, and tends to enter waterways only through spray or runoff contamination. Endosulfan residues in fish are mainly found as the α isomer and sulfate metabolite. Residues in fish from cotton farm dams are about 5-50 times higher than in fish taken from rivers downstream of cotton areas. Results are described below.

5.2.6.1 Goldfish

Sketchy details are provided of a study in which goldfish were exposed to 1 µg/L of radiolabelled endosulfan in water for 5 days. Subsequent chemical analysis revealed 0.4 ppm of residue in fish tissue, but depuration was complete in 14 days when the fish were transferred into fresh water (Gorbach, undated).

5.2.6.2 Zebra fish

Zebra fish (mean weight 0.27 g) were exposed under static renewal conditions to a nominal 0.3 µg/L endosulfan (initially 0.4, declining to 0.2 µg/L during 24 hours). Residues in fish increased rapidly at the start of the study, and then more gradually between days 7 and 21. Bioconcentration factors were about 2000 for the α isomer and 1400 for the β. The two parent isomers were accompanied by endosulfan sulfate, apparently formed *in vivo*, mainly from the β isomer. Depuration half-lives were 2.9 and 5.1 days for α and β isomers, and 5.9 days for the sulfate (Toledo and Jonsson, 1992).

5.2.6.3 Sheepshead minnows

Bioconcentration factors determined in early life-stage testing with sheepshead minnows (*Cyprinodon variegatus*) across seven laboratories varied between 350 and 3700. The variability is thought to reflect dietary influences on the lipid reserves of the fish (Hansen and Cripe, 1991).

5.2.6.4 Estuarine organisms

Endosulfan was bioconcentrated in the estuarine fish striped mullet (*Mugil cephalus*) during 28 days of flow-through exposure at a nominal concentration of 0.08 µg/L. Residues in fish

were mainly endosulfan sulfate, with smaller amounts of β -endosulfan. The bioconcentration factor based on measured concentrations (0.035 $\mu\text{g/L}$) was 2755 for whole fish after 28 days, with the rate of uptake highest during the first 2 days of exposure and a bioconcentration factor of 1000 after 96 hours. Steady state had not been reached after 28 days. Bioconcentration factors at 96 hours were similar in acute testing at lethal concentrations (0.49-0.87 $\mu\text{g/L}$). Residue levels in fish depurated to below detection limits after 48 hours in clean sea water.

Testing at concentrations extending into the lethal range was also conducted on other estuarine fauna, namely grass shrimp (0.24-2.4 $\mu\text{g/L}$), pinfish (0.24-0.75 $\mu\text{g/L}$) and spot (0.075-0.75 $\mu\text{g/L}$). Bioconcentration factors in surviving shrimp at 96 hours were dose dependent, ranging from 81 to 245. Dose dependence was not apparent in the fish, where bioconcentration factors were again in the order of 1000 (Schimmel *et al*, 1977).

5.2.6.5 Marine mussels

Endosulfan (α isomer) declined from an initial concentration of 2 $\mu\text{g/L}$ to a steady state of 0.14 $\mu\text{g/L}$ when added to aquaria containing mussels (4 L seawater/10-20 g soft tissue) and aerated gently (2.5 L/hour). Preliminary studies found negligible volatilisation (recoveries declined from 103% to 89% of applied during 67 hours). The time to equilibrium was about 50 hours, during which residues in mussels reached 84 $\mu\text{g/kg}$. The bioconcentration factor was 600, and the depuration half-life 34 hours (Ernst, 1977).

5.2.6.6 Australian data

A study conducted in the cotton growing area of NSW provides information on the seasonal pattern of endosulfan residue in fish. Three species, catfish (*Tandanus tandanus*), bony bream (*Nematalosa erebi*) and common carp (*Cyprinus carpio*) were collected from the Moree area during 1987-89. After dissection, liver tissue was analysed for total endosulfan residues (α and β isomers and sulfate metabolite).

Results indicated a seasonal variation in residues with highest concentrations recorded during the summer of 1988, which recorded the highest rainfall during the study period. Small concentrations were also detected during the non-spraying seasons. Endosulfan was detected mainly as the α isomer and endosulfan sulfate in catfish and bony bream, but as the α isomer with no detectable sulfate in carp. Low levels of the β isomer were found sporadically in all species collected in summer 1988, and in catfish collected in summer 1987 and bony bream collected in summer 1989. Fish collected from a farm dam had significantly higher levels than fish caught in rivers in cotton growing areas. Residue levels appeared to increase with increased lipid content in fish, which was highest during the wet summer of 1988. Levels were highest in bony bream, which had the highest lipid content. Mean residues in liver of bony bream reached 912 $\mu\text{g/kg}$ during summer 1988, compared with 29.5 $\mu\text{g/kg}$ in winter of that year and 63.5 $\mu\text{g/kg}$ in the following summer. In the farm dam, peak mean residues in liver approached 6 mg/kg, compared with about 1.3 and 0.2 mg/kg at downstream sites on the Namoi and Gwydir Rivers (Nowak & Julli, 1991).

Residues in fish generally consist of the α isomer and the sulfate, except in situations of recent exposure where the β isomer will also be present in the liver. It appears that preferential metabolism of β -endosulfan occurs in fish, but there are also exposure considerations.

Significant aquatic contamination with β -endosulfan only occurs in situations of direct overspray, spray drift or storm runoff soon after application. The β isomer is less volatile than the α , and sorbs slightly more strongly to soil and sediment. Background contamination of waterways and fish via the volatilisation route therefore involves primarily the more volatile α isomer.

Highest residues in liver and gills are found in lethally exposed fish. The percentage of β -endosulfan and ratio of β - to α -endosulfan in the liver are higher following lethal exposure than following sublethal exposure, and have been found to be higher in fish recovered from fish kills than in fish collected live from cotton areas. The proportion of the β isomer in the liver decreases with increasing time between exposure and sampling, while the proportion of the sulfate metabolite increases (Nowak *et al*, 1995).

5.2.7 Summary of Environmental Fate.

Endosulfan is applied to a broad variety of crops with the most intense use occurring on cotton during the months of November to January. A variety of processes operate to degrade endosulfan following release to the environment, and to mobilise endosulfan and its degradation products.

5.2.7.1 Hydrolysis

Two tests submitted by the principal registrant indicate that endosulfan is hydrolytically stable at acidic pH but hydrolyses to endosulfan diol with a half life of a few weeks at pH 7 and a few hours at pH 9. A literature study that took precautions to avoid volatilisation found hydrolytic half-lives at neutral pH in the order of months rather than weeks, but results may have been confounded by solubility limitations.

5.2.7.2 Photolysis

Endosulfan is photostable in solution, apart from some photoisomerisation of the β isomer to the α , and photodegrades only slowly on soil surfaces. There is no evidence that photolysis occurs on leaf surfaces. Photoisomerisation also occurs in the gas phase, as does hydrolysis and, to a limited extent, mineralisation. Estimated atmospheric half-lives are in the order of a week.

5.2.7.3 Metabolism

A broad range of microorganisms isolated from agricultural soils are capable of degrading endosulfan. In general, fungi oxidise endosulfan to the sulfate, the major breakdown product in soils, and bacteria hydrolyse it to the diol, which is also an abiotic breakdown product under alkaline conditions. Microbial mineralisation is very inefficient.

Endosulfan degrades relatively rapidly in short term tests, with a few weeks to a couple of months required to reduce soil concentrations by 50% in the three soils tested. Corresponding times for breakdown of the sulfate metabolite are in the range of 4-6 months, and for total toxic residues (parent isomers and sulfate metabolite) about 4 months. Endosulfan also forms significant amounts of nonextractable residues in soils.

Short term tests on an Australian soil (alkaline grey cracking clay) found significant volatilisation, particularly of the α isomer from wet soils, and oxidation of up to 20% of applied α -endosulfan to the sulfate over the course of a week. The β isomer does not appear to undergo this conversion. Sulfate formation appears to be suppressed in dry soils.

Half-lives obtained from longer term studies on five soils are about 3-4 months for both parent isomers combined, with the α isomer typically degrading about ten times faster. Projected half-lives for total residues are in the range of 9 months to 2 years, extending to over 6 years in one soil.

The diol degrades further in long term studies to a range of products with endosulfan lactone and a polar unknown predominant, significant production of non-extractable residues, and release of 18% of applied radiolabel as carbon dioxide over the course of a year.

Persistence of endosulfan increases in anaerobic soils, where the sulfate metabolite can revert to parent endosulfan. Anaerobic half-lives of parent endosulfan in the two soils studied are about 4-5 months, with similar results for the sulfate metabolite.

Microbial oxidation to the sulfate is also prominent in aquatic environments, followed by hydrolysis to the diol which can be fairly rapid in alkaline systems. The half-life for total toxic residues appears to be about 2 weeks in the single aquatic system (German river water with sediment) for which reliable results are available. Toxic residues partition to sediment over the course of a few weeks with a significant fraction becoming non-extractable.

5.2.7.4 Mobility

Endosulfan is strongly sorbed and immobile in soils. Soil organic carbon partition coefficients from four soils and a sediment obtained from runoff water are in the order of 10^4 for endosulfan parent isomers and the sulfate metabolite, with the β isomer sorbing slightly more strongly than the α . Endosulfan diol has low mobility in soil with soil organic carbon partition coefficients in the order of 10^3 .

Leaching studies on two soil columns confirm that aged samples of endosulfan and metabolites do not leach through soil, with most retained in the surface 10 cm and less than 2% recovered from leachate.

Endosulfan is, however, mobile in the environment by virtue of its volatility. Significant amounts volatilise from soil and leaf surfaces, particularly soon after application. The α isomer is more volatile than the β isomer, which in turn is more volatile than the sulfate. Wind tunnel experiments found volatilisation half-lives for technical endosulfan of about a day from foliage and 3 days from soil. Deposition of volatilised endosulfan to water is favoured by high water/air partition coefficients. Endosulfan is a regional rather than global pollutant as its volatility appears too low to enable widespread global distribution, although detections have occurred in snowpack in the Canadian Arctic.

5.2.7.5 Field dissipation

Numerous field dissipation studies from around the world were submitted, and a considerable volume of Australian work has been reviewed, as outlined below.

Early studies in Asia and South Africa indicate large declines in endosulfan residues in soil and water in the few days following application. Endosulfan sulfate persists longer than parent isomers.

The significance of early volatilisation losses is reflected in field trials on bare ground in Germany, in which between 17 and 38 days were required for residues to decline by 50%, but extending to between 182 and 425 days for 90% dissipation. The α isomer declined more rapidly than the β isomer. Volatilisation does not appear to contribute significantly to losses of the sulfate metabolite, which declines according to pseudo first order kinetics with a half-life in the order of 6 months.

A multi-year study in a Dutch apple orchard found residues to be continually present, with a residue plateau in the 5 cm surface soil layer at the start of each season of about 100-200 $\mu\text{g}/\text{kg}$, mainly as the sulfate. Accumulation above this plateau was not apparent, even after four years, but the use pattern appears less intense than in Australia. Residues were mainly confined to the surface 5 cm.

Studies on tomatoes involved three applications, each at 1.1 kg/ha endosulfan, at fortnightly intervals, with monitoring of soil dissipation, spray drift, runoff, and contamination of two ponds occupying about 10% the area of the crop and receiving runoff from it. The half life for total toxic residues was about 2 months. Small spray drift losses (less than 1% of applied at 5 m downwind, including a volatilisation component) were associated with concentrations in the pond of 0.1-0.3 $\mu\text{g}/\text{L}$. Peak concentrations in runoff water were about 200 and 80 $\mu\text{g}/\text{L}$ at the two sites, with respective peak concentrations in the receiving ponds of 1.3 and 0.6 $\mu\text{g}/\text{L}$ and sediment concentrations of 50 and 99 $\mu\text{g}/\text{kg}$. Residues dissipated rapidly from water, with a 75% reduction from peak levels over a few days. Sediment residues dissipated to undetectable levels over about 3-6 months, with the β isomer predominant soon after runoff occurred, but the sulfate the main contaminant in later samples.

Studies on vegetables in Kentucky found reductions in runoff losses but increased leaching tendencies when turf was grown between rows. Endosulfan was found at significant levels in deeper soil and water from the vadose zone under these conditions. These results appear to reflect preferential flow through macropores under established groundcover.

Studies on cotton in South Carolina and California involving application at more than twice the rate used in Australia found half-lives in soil in the order of 1-3 months for the α isomer and 2-4 months for the β isomer. Half-lives for total toxic residues were about 2 months in South Carolina and 5 months in California. Losses with irrigation tailwater were very small, remaining well below 1% of applied.

Studies conducted in the cotton growing areas of NSW and Queensland confirm the importance of movement through the atmosphere with around 70% of applied endosulfan lost mainly to volatilisation in the 7 days after application. Particularly rapid losses occur in the first two days, especially when temperatures are high. The more volatile α isomer is lost more rapidly through volatilisation, and its formation by photoisomerisation appears to enable loss of the β isomer. Aerial transport losses include spray drift, which may approach 10% of applied at a distance 200-400 m downwind from the target. Losses with tailwater are typically in the order of 1-2%, with typical concentrations of 5-15 $\mu\text{g}/\text{L}$ early in the season declining to

2-3 µg/L late in the season, although more than 10% of applied may be exported during large storms. For the alkaline clay soils where cotton is typically grown, residues approaching 10% of applied may be expected after a month, mainly in the soil, reducing to about 1% after a year. However, persistence can increase markedly in acidic soils and particularly when soils are dry. The balance (25-30%) is assumed to degrade.

Soil residues largely dissipate between seasons, but sulfate residues typically persist at levels in the range of 100-200 µg/kg in the surface 2.5 cm and the parent compound can also persist as residues, particularly the β isomer. Residues can also be found in silt at the tailwater outlet, at higher levels than in the soil from which they are transported. Residues in irrigation tailwater are mainly in the dissolved phase but partition to sediment with a half-life in the order of a week when ponded. Significant off-target movement of endosulfan sorbed to soil and suspended sediment occurs during major storms.

An early trial at Narrabri found total toxic residues of 620 µg/kg in the surface 10 cm soil layer, containing 65% sulfate and 20% β endosulfan. This equates to about half the theoretical residue from a single application to bare ground. Only a single application 12 months before sampling had occurred in the two years before these residues were discovered, indicating that the ready breakdown of endosulfan that occurs in most soils is by no means a consistent outcome, with dry conditions in particular favouring residue carryover from season to season.

Although volatilisation is the main route by which off-target movement occurs, it occurs gradually and off-target deposition via this route over short timeframes is some 200 times lower than can occur from spray drift. Off site contamination by dust movement is also relatively insignificant. Processes that can move large quantities of endosulfan in a short time, namely spray drift and especially storm runoff, appear to be the main contributors to major aquatic contamination incidents involving endosulfan. There is an urgent need to minimise export for endosulfan from cotton farms during major storms. For farms that do not retain storm runoff, irrigation and crop protection operations need to be carefully timed so that irrigation only occurs when soil residues are low. Other management techniques such as planting a cover crop of wheat that is killed just before the cotton season also appear to have promise for reducing export of endosulfan residues and need to be considered by farmers, particularly in erosion prone areas.

5.2.7.6 Bioaccumulation

Endosulfan bioconcentrates in fish, particularly as its sulfate metabolite, but residues depurate rapidly in clean water. Bioconcentration factors vary with species but appear to be in the order of 1000 over short timeframes (96 hours), increasing over longer timeframes. The β isomer appears to undergo preferential metabolism in fish, and tends to enter waterways only through spray or runoff contamination. Endosulfan residues in fish are mainly found as the α isomer and sulfate metabolite. Residues in fish from cotton farm dams are about 5-50 times higher than in fish taken from rivers downstream of cotton areas.

5.2.7.7 Overall conclusion

Hydrolysis and photolysis appear to be minor pathways for degradation of endosulfan, although hydrolysis is favoured by alkaline conditions and some photodegradation is likely to

occur in the vapour phase. The main mode of degradation in the environment is microbial metabolism to endosulfan sulfate, which retains the toxicity of endosulfan.

Parent endosulfan isomers and sulfate metabolite appear moderately persistent in soils, although dissipation in the field is generally rapid in the few days following application because of the volatility of α -endosulfan. Endosulfan contaminates terrestrial and aquatic compartments through vapour transport in regions in which it is used, but the vapour pressure appears too low to enable long range atmospheric transport.

Laboratory studies indicate that endosulfan and its sulfate metabolite are non-leachers, but some leaching through the vadose zone is evident in field studies, apparently because of preferential flow through macropores. Vapour transport is of concern in the field situation as both calculation and experiment indicate that transfer across water surfaces can give rise to concentrations that are relatively low but in excess of water quality objectives (0.01 $\mu\text{g/L}$). Such aquatic contamination occurs generally throughout areas where endosulfan is used, notably in cotton. Isolated but more serious pollution incidents also occur when runoff water enters waterways, or when rivers are contaminated directly by spray drift. Concentrations in irrigation or stormwater leaving sprayed areas frequently exceed 10 $\mu\text{g/L}$, particularly early in the season, and can give rise to acute impact in receiving waters.

Although endosulfan largely degrades over the course of a year in soils and aquatic sediments to which it partitions, low levels are carried over from season to season and aquatic and soil organisms have no relief from exposure. This is of particular concern for the aquatic environment given indications that endosulfan is bioaccumulative, although bioaccumulation capacity is limited by the ready elimination of residues from fish.

5.2.7.8 Current situation in Australia

Endosulfan is a widespread environmental contaminant, particularly during the cotton season when significant contamination of waterways occurs downstream of cotton areas, sometimes attended by fish kills. Information received from NSW and Queensland indicates that total endosulfan levels exceed, frequently by one and occasionally by two orders of magnitude, the ANZECC guideline of 0.01 $\mu\text{g/L}$ for protection of aquatic life. Aerial transport is the main mode of riverine contamination during dry seasons, with the more volatile isomer α -endosulfan dominating detections. During wet years, both isomers may be detected in waterways as a result of runoff from sprayed areas, at significantly higher levels than when conditions are dry. In some parts of Australia, such as the upper Namoi valley, expansion of dryland cotton production on to flood prone land has exacerbated problems of riverine pollution associated with storm runoff. Such pollution continues after the spray season, with late summer storms washing soil contaminated with endosulfan sulfate into waterways. Low level contamination of waterways appears to persist through to the next season.

Volatilisation from sprayed areas appears to contribute to a general low level aquatic contamination by endosulfan in areas where it finds widespread use, notably in cotton growing areas. From the environmental perspective, the export of endosulfan vapours from treated areas is undesirable. Registrants need to develop ways of reducing such losses.

Most instances of serious aquatic contamination appear to arise through export of endosulfan residues in storm runoff. Residues can also enter drainage systems with irrigation tailwaters,

to be subsequently mobilised into waterways by heavy rains. Sediment carried by tailwaters contains higher concentrations of endosulfan than the soil from which it is eroded as smaller particles containing higher proportions of surface sorbed endosulfan tend to be transported preferentially in overland flow. Because endosulfan tends to largely volatilise from soils in the one or two days following application, and to undergo significant degradation in moist alkaline soils within a week, losses with runoff can be reduced by timing applications to avoid storm runoff situations, and by irrigating only after soil residues have subsided. The planting of a wheat cover crop prior to cotton also appears to have promise as a technique for reducing off-target contamination by runoff.

Exclusion of endosulfan residues from Australian waterways is not possible with current technology while endosulfan continues to be used. Research into pesticide fate from the point of application on crops to potential discharge in rivers, and impacts on aquatic fauna, is approaching completion under the Minimising the Riverine Environmental Impact of Pesticides Research and Development Program, and promises to return useful results. Best practice management guidelines are being developed, based on the research program and other relevant considerations, with the aim of minimising pollution of waterways by endosulfan residues and deflecting calls for further regulation.

6. ENVIRONMENTAL EFFECTS

Results for the following tests are available. Data are taken from Hoechst TGAC submissions and the supplementary package provided by AgrEvo in March 1996. Selected recently published papers from the scientific literature have also been included, as have results from the Minimising the Riverine Environmental Impact of Pesticides Research and Development Program that has been jointly developed by the Land and Water Resources Research and Development Corporation, the Cotton Research and Development Corporation, and the Murray Darling Basin Commission. Some of the older tests were conducted more than two decades ago, but results are generally consistent. Except where specifically noted, it would appear that tests have been conducted satisfactorily according to accepted international guidelines such as those of the US EPA (Hitch, 1982, and subsequent revisions) and OECD.

6.1.1 Avian Toxicity

Test results indicate that endosulfan is moderately to highly toxic to bobwhite quail, Japanese quail and mallard ducks under conditions of acute oral exposure, and slightly to moderately toxic through the diet. Dietary toxicity appears to be balanced by repellent effects. Reproductive performance is impaired in quail and ducks under conditions of prolonged exposure to endosulfan in the diet at concentrations in the order of 100 ppm. Endosulfan does not appear to give rise to avian incidents under field use as no such incidents have been reported.

6.1.1.1 Acute oral

Results from testing conducted in 1972 and 1983 are tabulated below.

Test	Species	Result	Reference
Acute oral	Bobwhite quail	LD50 = 50 mg/kg (♂) LD50 = 56 mg/kg (♀)	Gough, 1972
Acute oral	Japanese quail	LD50 = 106 mg/kg (♂) LD50 = 85 mg/kg (♀)	Gough, 1972
Acute oral	Mallard duck	LD50 = 243 mg/kg (♂) LD50 = 205 mg/kg (♀)	Gough, 1972
Acute oral	Bobwhite quail	LD50 = 42 mg/kg	Roberts, 1983a
Acute oral	Mallard duck	LD50 = 28 mg/kg	Roberts, 1983b

The earlier tests involved oral intubation in corn oil to birds that had been fasted overnight, followed by 3 weeks observation for physiological reactions and mortality. Half the surviving birds were then sacrificed for gross pathological examination.

Mild lethargy and hypoactivity were noted in bobwhites after intubation, progressing at doses above 35 mg/kg to rapid breathing, regurgitation and ataxia followed by convulsions and death. Survivors returned to normal after several days of lethargy. Both males and females showed weight loss after the first week, correlated with reduced food consumption, but the body weight of surviving birds returned to normal in subsequent weeks. Post mortem investigations revealed considerable hemorrhage in lung, crop and stomach wall of dead birds but no such gross tissue changes for survivors. Similar observations are reported for Japanese quail.

In mallard ducks, the onset of toxic effects was apparent after 10-20 minutes with a jittery action progressing into a staggered gait followed by convulsions and death. All mortalities occurred within 2 hours of dosing. There appeared to be minimal effect of endosulfan on the body weight of both males and females. Post mortem investigations revealed that mallards dosed at 400 mg/kg showed severe hemorrhage in the crop and esophagus wall with a thick yellow mucus in the lower mouth and esophagus of most birds. Surviving birds examined at the end of the 3 week observation period appeared normal.

The later tests with bobwhite quail and mallards were conducted similarly but with 2 weeks observation after dosing. Results obtained for bobwhite were consistent with those from the earlier tests, except that gross necropsy revealed no abnormalities in any birds. The mallard result indicates high toxicity, compared with the moderate toxicity apparent in earlier testing. Again, gross necropsy revealed no abnormalities in any birds. As in the earlier test, mortality of mallards generally occurred within 2 hours of dosing. Reasons for the order of magnitude increase in toxicity are unclear. Both tests used young adults, but group mean body weights were a little lower in the later test (1.0-1.1 kg, compared with 1.1-1.5 kg). The later tests departed from the guideline requirement that partial kills be achieved for at least three dose levels surrounding the LD50. For bobwhites, partial mortality only occurred at the two highest doses (34 and 51 mg/kg) and for mallards only at 20 and 40 mg/kg, with complete mortality at the highest dose (80 mg/kg).

6.1.1.2 Dietary

Dietary studies involved 5 days of dietary exposure followed by 3 days with untreated feed, and indicate slight to moderate toxicity as indicated below. Data are taken from a review paper that includes no detail of toxic symptoms or of food consumption.

Test	Species	Result	Reference
Dietary	Bobwhite quail	LC50 = 805 ppm	Hill <i>et al</i> , 1975
Dietary	Japanese quail	LC50 = 1250 ppm	Hill <i>et al</i> , 1975
Dietary	Ring-necked pheasant	LC50 = 1275 ppm	Hill <i>et al</i> , 1975
Dietary	Mallard duck	LC50 = 1053 ppm	Hill <i>et al</i> , 1975

6.1.1.3 Repellency

A 0.1% aqueous emulsion of a 350 g/L EC formulation of endosulfan, freshly prepared each day, was offered as the only source of liquid over a period of 3 days to groups of Japanese quail housed at 30°C. Water consumption was reduced relative to controls by about a third for males and by half for females. No mortalities occurred, and there were no signs of intoxication apart from reduced food consumption in exposed birds, compensated by increased consumption over the first few days of the subsequent observation period (Ebert and Leist, 1987).

6.1.1.4 Reproduction

No significant adverse effects on reproductive performance were observed in bobwhites exposed through the diet for 24 weeks (12 weeks prior to and 12 weeks after egg production) at concentrations to 120 ppm. General behaviour and food consumption remained unaffected, and post mortem examinations of sacrificed birds revealed no marked treatment related effects (Roberts *et al*, 1984).

A second test returned similar results, with no effects on reproductive parameters but slightly depressed food consumption during the first week of exposure to the highest concentration of 120 ppm (Beavers *et al*, 1987).

A similarly conducted study using mallard ducks found that birds exposed to the highest dose (120 ppm) had impaired egg production and produced eggs with weaker shells. Again, general behaviour and food consumption remained unaffected, although there was some reversible weight loss during the first 14 days of exposure to 60 and 120 ppm, and post mortem examinations of sacrificed birds revealed no marked treatment related effects (Roberts *et al*, 1985).

It is not possible to determine whether the effects on reproduction reflect a direct disruption to endocrine function or an indirect consequence of toxic stress to the organism. Test birds were clearly stressed as food consumption was reduced relative to controls during the first week of exposure, with adverse consequences for body weight.

As for bobwhite, the mallard test was also repeated in a different laboratory, but the test report has not been submitted. Impaired egg production occurred at 60 ppm, according to an overseas review (Andersson and Hanze, 1992).

6.1.2 Aquatic Toxicity

Test results indicate endosulfan to be very highly toxic to aquatic fauna. Fish are killed by acute exposure to concentrations in the order of 1 µg/L, with a number of species more sensitive. The most sensitive native species tested is bony bream (96 hour LC50 = 0.2 µg/L). As endosulfan is a hydrophobic substance, its toxicity is thought to be moderated in turbid waters through sorptive interactions. However, evidence for this from the field is equivocal, and experimental attempts at confirmation have been unsuccessful.

Tests have mainly been conducted on the parent isomers as a mixture. Endosulfan sulfate is generally assumed to be of comparable toxicity but few results are available.

Aquatic invertebrates appear generally to be acutely susceptible to concentrations in the order of 100 µg/L, although considerable variation is evident. Cladocerans appear relatively insensitive, with acute and chronic endpoints of a few hundred ppb typical. An exception is *Ceriodaphnia dubia*, for which no effect concentrations in local reproductive testing over at least three broods were 3.3 µg/L at 20°C, decreasing to 0.1 µg/L at 30°C. The acute EC50 for this species was 2.4 µg/L at 30°C, increasing to 166 µg/L at 15°C. Sedimentary worms avoid sediment contaminated with endosulfan at levels of 50 µg/kg and above, and suffer 50% mortality in acute tests when exposed to dissolved concentrations of 100 µg/L. Estuarine crustacea and Australian freshwater mayfly nymphs appear to be as susceptible as fish, with acute endpoints of about 1 µg/L and below. No information is available regarding the chronic sensitivity of these organisms, but high acute to chronic ratios have been determined for daphnids.

Endosulfan appears highly toxic to algae, although these organisms can absorb endosulfan and metabolise it to the diol.

Overseas field studies confirm that fish kills are likely to occur when aquatic concentrations reach about 1 µg/L. Fish kills were documented following runoff from tomato fields into small ponds, but most of the fish in the ponds remained unaffected. Drift studies have shown that mortality of fish exposed in shallow water can occur 200 m downwind of the crop.

Biological monitoring in Australia finds that macroinvertebrate community structure is changed downstream from cotton areas during the season, with reduced diversity and abundance of sensitive species. A correlation can be made between on-farm impacts and endosulfan exposure, although physical factors such as turbidity appear better correlated with impacts in natural waterways during the dry seasons in which biomonitoring has been performed. Monitoring indicates that aquatic contamination exceeds water quality objectives (0.01 µg/L), frequently by one and occasionally by two orders of magnitude, raising the likelihood of biological impact. Although this aspect requires further study, populations of sensitive sediment dwelling organisms colonise upstream sites in significantly larger numbers during summer than at sites downstream from cotton production.

6.1.2.1 Fish acute toxicity

Endosulfan has long been known to be extremely toxic to many fish species, with the harlequin fish (*Rasbora heteromorpha*) apparently most sensitive (24 hour LC50 = 0.02 µg/L). High excitability, loss of equilibrium, spasmodic movement and erratic opercular

movements have been reported as general symptoms of endosulfan poisoning in fish (NRCC, 1975). A tendency to understate the toxicity of endosulfan has been noted, in that fish that survive acute bioassays tend to die unreported during the following week, even when returned to clean water (NRCC, 1975).

Results from testing in overseas laboratories are tabulated below. No data have been provided for endosulfan sulfate, but this metabolite is generally assumed to be of comparable toxicity to endosulfan.

Test	Species	Result	Reference
96 hour acute	Rainbow trout	LC50 = 1.6 µg/L	Knauf, 1977a
96 hour acute	Rainbow trout	LC50 = 0.9 µg/L	Fischer, 1983
96 hour acute	Rainbow trout	LC50 = 0.7 µg/L	Fischer, 1984a
96 hour acute	Rainbow trout	LC50 = 1.2 µg/L	Fischer, 1985a
96 hour acute	Rainbow trout	LC50 = 0.3-1.7 µg/L	Nebeker <i>et al</i> , 1983
96 hour acute	Common carp	LC50 = 6.9 µg/L	Knauf, 1978
96 hour acute	Bluegill sunfish	LC50 = 1.8-3.3 µg/L	Fisher, 1984b
96 hour acute	Bluegill sunfish	LC50 = 6-8 µg/L	Fisher, 1984c
96 hour acute	Fathead minnow	LC50 = 0.8-1.7 µg/L	Nebeker <i>et al</i> , 1983
7 day acute	Fathead minnow	LC50 = 0.9 µg/L	Macek <i>et al</i> , 1976
96 hour acute	Pinfish	LC50 = 0.3 µg/L	Schimmel <i>et al</i> , 1977
96 hour acute	Spot	LC50 = 0.09 µg/L	Schimmel <i>et al</i> , 1977
96 hour acute	Striped mullet	LC50 = 0.38 µg/L	Schimmel <i>et al</i> , 1977

With the exception of the last entry, tests on trout were conducted under static conditions with aeration. Results are expressed as nominal concentrations of endosulfan. Note that nominal concentrations are likely to be higher than the true concentrations to which fish were exposed given the volatility of endosulfan and aerated conditions. However, results are reasonably consistent with those from the published literature (1.6-1.7 µg/L) based on initial measured concentrations and static conditions. Under flow-through conditions, end-points reduced to 0.3-0.4 µg/L (Nebeker *et al*, 1983).

Similar cautionary comments pertain to the results for carp and bluegill sunfish. The bluegill results are expressed as a range because of the very steep dose-response curve, with no mortality occurring at any time at the lower concentration, but total mortality within 48-72 hours at the higher.

The 7 day acute test on fathead minnow used flow-through conditions, while the 96 hour tests used static and flow-through procedures, with each returning comparable results.

The estuarine species (last three entries in the table) were tested under flow-through conditions, with results expressed as measured concentrations.

6.1.2.2 Fish acute toxicity - Australian data

Native and introduced fish have also been tested over 96 hour periods in Australian laboratories, as tabulated below (Sunderam *et al*, 1992).

Test	Species	Result
Static 4°C	Rainbow trout	LC50 = 1.6 µg/L
Static 12°C	Rainbow trout	LC50 = 0.7 µg/L
Static 25°C	Mosquitofish	LC50 = 2.3 µg/L
Static 25°C	Eastern rainbow fish	LC50 = 5.0 µg/L
Semistatic	Common carp	LC50 = 0.1 µg/L
Semistatic	Bony bream	LC50 = 0.2 µg/L
Semistatic	Golden perch	LC50 = 0.5 µg/L
Semistatic	Silver perch	LC50 = 2.3 µg/L
Semistatic	Eastern rainbow fish	LC50 = 2.5 µg/L
Flow-through	Harlequin fish	LC50 = 0.2 µg/L
Flow-through	Eastern rainbow fish	LC50 = 0.5 µg/L

With the exception of the mosquitofish where concentrations were not measured, results from static tests are expressed as initial measured concentrations. Initial measured concentrations for rainbow trout were close to nominal (93-120% at 4°C and 76-98% at 12°C) but declining by the end of the test (64-90% at 4°C and 10-38% at 12°C). Significant departures from nominal occurred at the higher temperature used for the rainbow fish, with initial measured concentrations about half of nominal, declining to about one tenth of nominal at termination.

Semistatic tests were conducted at 25°C using either Sydney mains water as for the static tests, or turbid Mehi River water with aeration. Only the results in mains water are tabulated, as comparable results were obtained in three species tested regardless of test medium. Results are expressed as mean measured concentrations, which for mains water were 43% of nominal after renewal, declining to 7% over 24 hours. Corresponding figures for Mehi water were 34 and 12%.

The most reliable results are obtained using flow-through tests and measured concentrations, as indicated by the order of magnitude difference between static and flow-through results for rainbow fish, reflecting losses of test substance from the static system.

6.1.2.3 Fish sublethal effects

Exposure of developing eggs of the crimson-spotted rainbowfish to endosulfan did not diminish hatching success, but the frequency of spinal deformity was significantly elevated following static exposure to 2.2 µg/L. The LC50 for 10 day old fish of this species is in the order of 1 µg/L, suggesting that some protection is afforded to the developing embryos by the chorion. Embryonic period was reduced by exposure to 58 µg/L endosulfan. Actual exposure

times were relatively brief, as would be expected for field exposure to spray drift or runoff, because of the rapid sorption of the test substance to container walls (Barry *et al*, 1995a).

6.1.2.4 Pond studies at Narrandera

There are anecdotal reports of fish survival in turbid waters assumed to contain high endosulfan levels, such as drainage channels, and some accounts of fish survival in the presence of what should have been lethal concentrations of endosulfan, but few hard data exist. Conversely, fish kills have been recorded in situations of rising turbidity months after endosulfan spraying has ceased.

Pond mesocosm studies have been conducted to test the hypothesis that the toxicity of endosulfan is reduced in turbid water through sorptive interactions. Caged silver perch were acclimated for 24 hours in ponds stocked 10 weeks earlier with zooplankton. The laboratory 24 hour LC50 for this species is 4.7 µg/L. Ponds were then sprayed to provide a nominal concentration of 25 µg/L endosulfan. Cages were replaced every 24 hours with fresh cages containing acclimated fish.

All fish died within 6 hours of spraying, but mortality rates declined after 48 hours, with no further mortality by 96 hours in three of four ponds. Mortality did not decline for 288 hours in the remaining pond, which was comparatively less turbid and contained no macrophytes and little algae, with 384 hours required before mortality declined to zero.

Concentrations of endosulfan in the water column reduced from 18 to 1 µg/L over a 48 hour period, and were lower in filtered samples reflecting association with suspended particulates. Declines were particularly rapid in the ponds containing macrophytes and algae. Residue data have yet to be fully analysed, but available results indicate that the toxicity of endosulfan is not significantly attenuated by the presence of sediment. Indeed, a slight increase in toxicity was apparent, with the calculated LC50 in one pond approximately 3.5 µg/L (Hyne *et al*, 1995).

This counterintuitive result has been criticised on a number of grounds. Firstly, unplanned differences between ponds in such parameters as turbidity, algae, macrophytes and pH meant that ponds were effectively unreplicated. Given this shortcoming, results such as the faster breakdown in the presence of aquatic vegetation should be regarded as indicative rather than definitive. For the specific conclusion that toxicity may increase in the presence of sediment, it is noted that a static pond test was compared with a flow-through laboratory endpoint, and that comparisons are likely to be confounded as concentrations change with time, but at different rates in the different conditions. Finally, when the few data points recorded were again analysed, the two results fall well within statistical error, even without considering temperature effects on toxicity (Bowmer *et al*, 1996)

6.1.2.5 Fish chronic toxicity

No significant effects on growth or survival were observed in fathead minnows continuously exposed for 60 days under flow-through conditions to endosulfan concentrations between 0.04 and 0.4 µg/L. However, all fish died after 4-5 months of exposure to the highest concentration, one month before spawning when fish were undergoing rapid development of

secondary sex characteristics. Results need to be treated with some caution because mortality was higher in controls.

Spawning occurred after about 5 months of exposure. Mean numbers of eggs and spawn per female were highly variable, but there did not appear to be a treatment related effect. Likewise, no effects on hatchability were discerned. However, hatching success fell dramatically to about 1% when eggs from control tanks were incubated in the presence of 0.4 µg/L (Macek *et al*, 1976).

The LC50 in a 21 day semi-static study with rainbow trout was 0.21 µg/L (nominal concentration of endosulfan, but mean measured concentrations were 93-145% of nominal). No deaths were observed at 0.05 µg/L, but mortality was complete within 12 days at 0.5 µg/L (Knacker *et al*, 1991).

Continuous exposure for 28 days of sheepshead minnows (*Cyprinodon variegatus*) from embryos (less than 48 hours old) to the juvenile stage returned an average chronic value across seven laboratories of 0.6 µg/L (Hansen and Cripe, 1991).

Chronic endpoints are more sensitive than acute, but by a relatively small margin based on the above results. Preliminary data for larval Australian fish suggest a much higher acute to chronic ratio, but results need to be confirmed (Kumar and Chapman, 1997).

6.1.2.6 Aquatic invertebrate acute toxicity

Acute results are tabulated below. Endosulfan has very high acute toxicity to aquatic invertebrates, particularly estuarine species.

Test	Species	Result	Reference
48 hour acute	<i>Daphnia magna</i>	LC50 = 160 µg/L	Knauf, 1976
48 hour acute	<i>Daphnia magna</i>	LC50 = 75 µg/L	Knauf, 1977b
48 hour acute	<i>Daphnia magna</i>	LC50 = 1.3 µg/L	Fischer, 1984d
48 hour acute	<i>Daphnia magna</i>	LC50 = 271-343 µg/L	Nebeker <i>et al</i> , 1983
48 hour acute	<i>Daphnia magna</i>	LC50 = 166 µg/L	Macek <i>et al</i> , 1976
48 hour acute	<i>Ceriodaphnia dubia</i>	LC50 = 2.4-166 µg/L	Patra <i>et al</i> , 1996
48 hour acute	<i>Daphnia carinata</i>	LC50 = 180 µg/L	Santaram <i>et al</i> , 1976
48 hour acute	<i>Daphnia carinata</i>	LC50 = 478 µg/L	Barry <i>et al</i> , 1995b
96 hour acute	<i>Jappa kutera</i>	LC50 = 1.20 µg/L	Hyne <i>et al</i> , 1996
96 hour acute	Pink shrimp	LC50 = 0.04 µg/L	Schimmel <i>et al</i> , 1977
96 hour acute	Grass shrimp	LC50 = 1.3 µg/L	Schimmel <i>et al</i> , 1977
12 day acute	<i>Nereis virens</i>	LC50 = 100 µg/L	McLeese <i>et al</i> , 1982

Acute daphnid tests were conducted under static conditions with results expressed as nominal concentrations. Daphnids were conspicuously affected as indicated by uncoordinated swimming. Reasons for the anomalously high sensitivity in the most recently conducted test are unclear. Published measurements (cited in Barry *et al*, 1995) of the 48 hour EC50 to this species range between 62 and 740 µg/L, while the most sensitive daphnid species is *Daphnia longispina* (48 hour EC50 = 0.3 µg/L). Also, the 48 hour EC/LC50s for *Daphnia magna* obtained in 14 static tests conducted across six laboratories ranged between 158 and 740 µg/L with a mean of 380 µg/L (Nebeker, 1982).

The broad concentration range obtained in testing with *Ceriodaphnia dubia* reflects the marked effect of temperature on toxicity in this species. The EC50 of 2.4 µg/L (measured concentration) was obtained at 30°C, and the EC50 of 166 µg/L at 15°C (Patra *et al*, 1996).

Local acute testing with *Daphnia carinata* neonates used static conditions with gentle aeration, renewal of test medium after 24 hours and no feeding during the exposure period. Endosulfan sulfate (LC50 = 756 µg/L) was less toxic than technical endosulfan in a parallel study. Individual isomers and their equimolar mixture were tested in a second series of studies and returned comparable results, with LC50s between 205 and 249 µg/L (Barry *et al*, 1995b).

The burrowing mayfly nymph *Jappa kutera* was tested in Namoi River water with a single dose of endosulfan. Average body length of test organisms was 5.5 mm. Results are expressed as initial measured concentrations. The LC50 was 1.2 µg/L, the EC50 based on loss of forward mobility 0.8 µg/L, and the no observed effect concentration 0.1 µg/L. Mayfly nymphs are considerably more sensitive to endosulfan than are daphnids. As noted below, these organisms appear to suffer major impact during the cotton season from endosulfan contamination introduced into local waterways by storm runoff (Hyne *et al*, 1996).

The estuarine shrimps were tested under flow-through conditions, with results expressed as measured concentrations. They appear to be considerably more sensitive than the freshwater daphnids tested (Schimmel *et al*, 1977).

The marine sedimentary polychaete worm *Nereis virens* was tested with or without sediment under semi-static conditions, with test organisms moved to new test chambers at 48 hour intervals. In terms of the concentration in the overlying water, results were independent of sediment, as the worms emerged soon after exposure to endosulfan. The LC50 in sediment was 340 µg/kg (McLeese *et al*, 1982).

6.1.2.7 Aquatic invertebrate sublethal effects

The effects of endosulfan exposure on emergence are reflected in studies on larval colonisation by the cosmopolitan euryhaline polychaete *Streblospio benedicti*. Larvae in the terminal 11 to 12 setiger planktonic stage were exposed to patches of contaminated sediment, taken from the field and serially diluted to give concentrations of 50, 100 and 200 µg/kg, and allowed to settle. About a quarter of the residues were endosulfan sulfate, and the remainder parent isomers. Larvae strongly discriminated against endosulfan contaminated sediments, with over half the larvae added settling into control sediments, metamorphosing and constructing tubes within 24 hours. The 50 and 100 µg/kg patches were selected by 26 and

20%, respectively, of larvae, while colonisation rates for the 200 µg/kg patch were less than 1%. Feeding activity was reduced in contaminated patches, as indicated by reduced faecal piles around the tubes and a general cessation of feeding after 3-4 days, and juveniles were lethargic. Associated growth effects were apparent after 7 days.

In contrast, the benthic harpacticoid copepods *Pseudobryda pulchella* and *Nannopus palustris* were only marginally affected by exposures of this magnitude, perhaps because of their more selective feeding habits. Survival and reproduction in the former species remained unaffected during 7 days of static exposure, with 80% renewal every 48 hours, while a 20% decrease in survival was apparent for the latter at the highest exposure (Chandler and Scott, 1991).

Sublethal exposure to endosulfan reduces filtration and feeding rates in *Daphnia magna*, with respective EC50s during a 5 hour exposure of 440 and 610 µg/L compared with a 24 hour LC50 of 620 µg/L (Fernandez-Casalderrey *et al*, 1994).

No mortalities were observed during life cycle testing of *Daphnia carinata* at nominal concentrations of 20-320 µg/L in the absence of food, but carapace length and brood size were reduced at the highest concentration. Losses of endosulfan from the water column amounted to 66% over 24 hours in the plastic beakers used for testing.

Carapace length and fecundity of the first brood were reduced when algal food resources were limited, but these effects were not pesticide related. However, pesticide effects were noted at higher food concentrations, with mean brood size reduced at a nominal concentration of 80 µg/L (Barry *et al*, 1995b).

Similar effects were noted in *Daphnia cephalata*. The no observed effect concentration based on growth and reproduction was 49 µg/L. Crest height was the most sensitive indicator of exposure, with a no observed effect concentration below 22 µg/L (Barry *et al*, 1995c).

Population studies with *Daphnia carinata* found fluctuations in chlorophyll *a* concentration coinciding with depressions in population density of daphnids. The amplitude of these cycles was dampened by exposure to endosulfan (nominal concentrations of 40, 80 and 160 µg/L; mean measured concentrations 3.0, 6.9 and 11.0 µg/L after 96 hours exposure). It appears that organisms compensate for endosulfan exposure under conditions of limited food availability by increasing the inter-molt period, which in turn reduces the rate of population growth (Barry, 1996).

6.1.2.8 Aquatic invertebrate reproduction

Survival and reproduction of *Daphnia magna* were recorded at weekly intervals during 3 weeks of flow-through exposure to concentrations between 2.7 and 79.7 µg/L. Second and third generations were tested similarly using ten randomly selected survivors from each replicate. Survival through 22 days was significantly reduced at 7 µg/L and above. The second generation had significantly lower survival rates than the first, and produced fewer young at concentrations of 37.7 µg/L and above. Poor control survival precludes firm conclusions regarding the third generation (Macek *et al*, 1976).

Poor control survival has been identified as one of the most common confounding factors in chronic testing of daphnids, with stress from handling a particular problem area that militates against use of static renewal procedures. Only one of six laboratories conducting a static test with *Daphnia magna* transferred weekly to fresh solutions obtained reliable 21 day LC50s (130 and 170 µg/L). Corresponding no observed/lowest observed effect concentrations based on mean offspring per day were 20/32 and 32/48 µg/L (Nebeker, 1982).

Reproductive testing of *Daphnia magna* with technical endosulfan used static conditions with feeding and transfer to fresh solutions three times per week. Acetone (0.1 mL/L) was used to aid dissolution. The lowest mean measured concentration was 63% of nominal, and all results are expressed as such. The 21 day LC50 was 300 µg/L, and the no observed effect concentration 63 µg/L. Impairment of growth rates, embryonic development and/or reproduction rate were observed at 200 µg/L (Heusel, 1991a).

An analogous study using an emulsifiable concentrate formulation returned similar results: 21 day LC50 350 µg/L; no observed/lowest observed effect concentration 70/220 µg/L endosulfan (Heusel, 1991b).

Local reproductive testing indicates *Ceriodaphnia dubia* to be more sensitive than *Daphnia magna* to the effects of endosulfan. Measured no observed effect concentrations in 12 day tests (at least 3 broods) were 3.3 µg/L at 20°C, decreasing to 0.1 µg/L at 30°C (Patra *et al*, 1996).

No information is available regarding the sensitivity of mayfly nymphs and estuarine crustacea to chronic endosulfan exposure, but chronic effects may be expected at much lower concentrations than acute. The ratio of acute EC50 to 12 day NOEC for *Ceriodaphnia dubia* is 24 at 30°C. An acute to chronic ratio (acute EC50/64 day NOEC) of 55.6 for *Daphnia magna* has been determined, based on original scientific publications that have fulfilled stringent criteria for inclusion on an industry database (Länge *et al*, 1998).

6.1.2.9 Algal toxicity

Little appears to be known regarding the algal toxicity of endosulfan. The Canadian review (NRCC, 1975) reports that aquatic plants, particularly green algae, readily absorb endosulfan from the water column and metabolise it, perhaps via the sulfate, releasing endosulfan diol back to the water column. Marine algae appear to respond to endosulfan exposure at 50 µg/L by slightly increasing respiration and reducing photosynthesis (IPCS, 1984).

The response of green algae (*Scenedesmus subspicatus*) to endosulfan exposure was not correlated with dose. Inhibition of growth during 72 hours was observed above 0.56 mg/L (nominal concentration of technical material with 0.1 mL/L acetone) with a maximum inhibition of 80% at 1 mg/L. At concentrations below the inhibition threshold there was a slight stimulation of growth relative to solvent controls, but a slight inhibition relative to control cultures without solvent, again with no dependence on dose (Fischer, 1985b).

AgrEvo reports no observed effect concentrations below 1 mg/L for two blue-green algae, a no observed effect concentration of 2 mg/L for a green alga, and an EC50 of 10 mg/L for another green alga. Reports of these studies have not been provided, nor identified.

6.1.2.10 Aquatic field studies

Studies on farm pond ecosystems were conducted at two reference and two treatment sites in SW Georgia, USA, as outlined in section 5.2.5.8 of this report. Ground based application of endosulfan (1.1 kg/ha) to within 5 m of the pond edge gave rise to low level contamination through drift (0.1-0.3 µg/L) and more significant contamination (0.6-1.3 µg/L) as a result of runoff. Some 447 dead fish were recovered from the larger pond and 227 from the smaller, mostly in the three days following the runoff event. Most of the dead fish were small, and recovered from the pond edges where peak endosulfan concentrations would have been highest (runoff concentrations of 200 µg/L were recorded). The behaviour of fish observed in the pond, including small fish near the margins, appeared normal notwithstanding the mortalities. Runoff from these relatively small catchment areas appears to have been insufficient to cause widespread fish mortality as the deaths observed were only a very minor proportion of the fish population.

No substance related effects on phytoplankton, aquatic macrophytes, zooplankton, benthic organisms, fish community structure, pond metabolism or autotrophic index of the periphyton was observed (Cornaby *et al*, 1989).

6.1.2.11 Drift studies

Endosulfan (wetable powder) was applied by aircraft to potatoes at 500 g/ha, with deposition in and downwind from the crop collected on glass fibre filters or in stainless steel bowls containing up to 10 L water from a nearby pond, the latter samples being used for bioassays with a range of aquatic organisms (three-spine stickleback, water boatmen, caddisfly larvae, bivalve molluscs, bloodworms and water fleas).

Mean deposits in-crop were about 350 g/ha for two applications and 820 g/ha for the third, the higher figure probably reflecting a different sampling configuration and the local practice of 'squaring off' with swaths sprayed at each end of the field at right angles to the regular swath direction. Corresponding aquatic residues were 0.61, 0.67 and 1.73 mg/L, indicating mean water depth to be about 5 cm (only a maximum depth of 10 cm is reported). Spray deposits of 12-27 g/ha (corresponding aquatic concentrations of 27-99 µg/L) were detected at 30 m from the edge of the field, decreasing to 2.5-4 g/ha (5-11 µg/L) at 100 m and 0.5 g/ha (4 µg/L) at 200 m.

Molluscs, bloodworms and water fleas remained unaffected by spray deposits, even within the crop, but the remaining organisms were susceptible to drift. The distance from the edge of the field at which 50% of exposed organisms suffered effects within 24 hours was 50 m for water boatmen (lethality) and 10-30 m for caddisfly larvae (emergence from case). The most sensitive organism was three-spine stickleback, suffering 90% mortality even at 200 m. Median effect concentrations from 24 hour laboratory bioassays were 7.5 µg/L for stickleback and 28 µg/L for boatmen (Ernst *et al*, 1991).

6.1.2.12 River monitoring with dialysis bags

As noted in section 5.1.3.5 of this report, solvent filled dialysis bags (passive samplers) were used to collect endosulfan residues from the Namoi River in February 1996. The concentrations in the dialysis bags were used to estimate an average concentration in the

Namoi during that month of 1.3 µg/L, 25 times higher than concentrations at an upstream reference site. Note that this estimate is based on conversion factors for two similarly hydrophobic chemicals, chlordane and dieldrin, but has not as yet been specifically validated for endosulfan. Over 80% of residues were present as endosulfan sulfate at this late stage in the season, suggesting entry to the river in storm runoff, and endosulfan was the dominant contributor to toxicity among the pesticides recovered from the bag. Comparable concentrations were found at reference and exposed sites during November, but concentrations at the exposed sites increased from December through to February.

Dialysis bag concentrations were inversely correlated with abundances of the burrowing mayfly nymph, *Jappa kutera*, and the non-burrowing nymph *Atelaphlebia australis* during January and particularly February. Abundances of *Atelaphlebia australis* were similar at reference and exposed sites during November. Low numbers of mayfly nymphs were recruiting at all sites during December with the easing of drought conditions, and the high fecundity of winged adults was expected to enable population recovery by the next monthly sampling (at least two generations). Thus numbers of *Jappa kutera* at reference sites increased 7-fold and *Atelaphlebia australis* 10-fold between November (drought conditions) and February (flood). However, no such recovery occurred at impacted sites (Hyne *et al*, 1996).

The weight of evidence strongly suggests to some that endosulfan is impacting on populations of mayfly nymphs in the Namoi River. However, others feel that such links are tenuous, as the linkage is no more than correlative and rigorous statistical proof of causation is lacking. It is argued that, if other factors of agricultural development are impacting on stream fauna, correlations with endosulfan concentrations would be expected, regardless of whether endosulfan (as opposed to such unmeasured parameters as riparian vegetation, bank stability, flow variation, sediment input or pollution by other pesticides) is actually playing a causative role (Quinn and Davies, undated). Put another way, the presence of endosulfan might only be incidental to other agricultural factors which may play a greater role.

As noted by Bowmer *et al* (1996), correlative analyses of this nature suggest that further studies are warranted to investigate causation *per se*. The main difficulty is finding appropriate control sites that are near cotton farms but not impacted by pesticide inputs. Larger data sets may allow other possible confounding variables to be excluded. Bowmer *et al* (1996) recommend that all cotton pesticide projects present correlations and regressions of biotic data on pesticide levels that are sampled at the same scale in both space and time.

Stream mesocosm studies are underway to assess effects on *Jappa kutera* and an early life stage of the native fish, *Macquaria ambigua*, with a view to providing information to assist in refining the ANZECC water quality guideline for endosulfan. Spray drift simulations were conducted in the season just past, and runoff simulations are proposed for the coming season (Hyne and Lim, 1996).

6.1.2.13 Biological monitoring

Changes in macroinvertebrate community structure were detected in rivers of central and north-west NSW during the 1995/96 season. There was a general decrease in diversity, with increases in populations of tolerant bugs and shrimps and decreases in sensitive midge larvae. Changes were not apparent at upstream sites. Significant correlations could be found with a

number of indicators of pollution, such as pH, turbidity and electrical conductivity, but not with concentrations of endosulfan in the water column as determined by random spot measurements (time-integrated passive samplers were not used). A correlation was found with sediment concentrations, and mesocosm studies were proposed to determine whether a causative link exists (Brooks and Cole, 1996a). However, this apparent correlation has since been discounted because of some invalid statistical assumptions (Brooks, personal communication).

Results from biological monitoring through the 1995/96 season are now publicly available (Brooks and Cole, 1996b). Statistical differences were found in invertebrate communities within irrigated agricultural areas before and after spraying, but not at upstream sites. No significant changes in diversity were found, except in the Macquarie which was sampled more intensively. Although there is some evidence of impacts on macroinvertebrate communities, no clear case has been established to implicate endosulfan, or other pesticides, as a causal factor. Other unmeasured factors may be responsible for the changes observed.

Studies downstream from an isolated cotton farm on the Macquarie found significant seasonal variations in macroinvertebrate and zooplankton community structure, but with temperature and turbidity apparently the main governing factors. Endosulfan was not found in the water column during the dry season (1994/95). However, endosulfan could be found in on-farm irrigation channels, and its concentration was correlated with reductions in macroinvertebrate diversity and abundance (Brooks *et al.*, 1996).

Earlier studies along the Mehi River found endosulfan at concentrations between 0.01 and 0.03 µg/L at six locations near an isolated cotton farm sampled in March, April and May of 1994. Sampling locations were 5 and 15 km upstream, just downstream from an old tailwater outlet, and 2.5 and 11 km downstream. There was no obvious relationship between concentrations detected and distance from the property. Although later samples suggested lower dissolved concentrations at upstream sites, the first sampling found highest sediment residues (19 µg/kg) at the upstream site, perhaps from the next farm 20 km upstream. There was little difference between sites in terms of the types of fauna present, but abundance was variable, and greatest at one of the sites nearest to the cotton farm. The authors caution that these results may not be representative of the situation during the spray season (Bales *et al.*, 1994).

6.1.2.14 Fish kills

Fish kills are often attributed to endosulfan pollution, but the cause generally remains unproven. Heavy rains and high water flow can give rise to anoxic conditions as well as to endosulfan contamination, either or both of which may kill fish. Nine fish kill incidents have been reported from the cotton growing areas of NSW during the 1983/84 to 1988/89 seasons, with endosulfan suspected to have played a role in at least four (Whyte and Conlon, 1990). Fish kills were also reported under the Central and North West Regions Water Quality Program in the 1995/96 season, after no such reports in the two preceding dry years. Three incidents were reported, one following intense rainfall that overwhelmed a number of cotton farms draining to Wee Waa lagoon, with the result that water contaminated with moderate to high levels of a number of pesticides, including endosulfan, was discharged (Cooper, 1996).

There is only circumstantial evidence as to the cause of many fish kills, with only a few being investigated in detail and many probably passing unobserved or unreported. For example, an incident estimated to have killed 10000 large fish on the Namoi in April 1995 was not reported to authorities until a week had elapsed and samples were too badly decomposed for analysis (Chapman, personal communication to Bowmer *et al*, 1996). This incident does not appear to have been picked up by the Central and North West Regions Water Quality Program.

Fish kills that have occurred in cotton areas have been compiled by Bowmer *et al* (1996) together with some incidents where fish have survived what should have been lethal endosulfan exposure. Many factors have been suggested to account for these discrepancies, including reduction of bioavailability through sorptive interactions, avoidance behaviour by fish in natural environments, protection by vegetation or physical features, or temporal variation in pesticide levels.

Fish kills have also been reported recently from Western Australia, where the deaths of hundreds of fish have been linked to endosulfan (The West Australian, 12, 13, 15 and 18 September 1997). The cause of the recent incident was first attributed to runoff from the Ord River Irrigation Area but later information indicates that it may have been caused by an accidental release over water from an aerial applicator.

More recently, a major fish kill in the Dawson River downstream from Theodore has been linked to endosulfan contamination, with preliminary findings of 0.96 µg/L endosulfan in a side creek. Significant levels of profenofos (also used on cotton) were also recorded (Queensland Country Life, 19 February 1998).

6.1.3 Non-target Terrestrial Invertebrates

Endosulfan is toxic to bees in the laboratory but appears generally to be without significant impact in the field, even when applied when bees are actively foraging.

Endosulfan is moderately toxic to earthworms in the laboratory, but there is evidence for protracted suppression of earthworm populations in the field at typical application rates.

Residues of endosulfan on foliage are toxic to predatory insects and mites, but the toxicity does not appear to persist beyond 1 day, allowing repopulation to occur from unsprayed areas.

Endosulfan exerts persistent adverse effects on soil arthropods, consistent with its use to control red legged earth mite.

Endosulfan residues do not appear to impair microbial processes in the soil, although some microbial species appear to be susceptible.

6.1.3.1 Bees

Acute contact toxicity to honey bees (*Apis mellifera*) was determined by applying endosulfan as acetone solution to the ventral thorax. Mortality generally occurred within 24 hours of dosing. The 48 hour contact LD50 for pure endosulfan was 2.4 µg per bee (Bock, 1986a) and for the emulsifiable concentrate formulation 0.8 µg endosulfan per bee (Bock, 1986b). The

48 hour acute oral LD50 as determined from feeding of sugar solution was 2 µg endosulfan per bee (Bock, 1986b). Endosulfan is moderately toxic to toxic to honey bees, according to Dutch criteria (Mensink *et al*, 1995).

Effects on bees in the field were investigated in several small plots (generally less than 1 ha) in Germany planted to winter rape, oil radish, or the cover crop phacelia. All applications (2.1 kg/ha endosulfan as EC formulation in 400 L/ha water) were made during daylight (11 am to 3 pm) while crops were in bloom and bees were actively foraging. In general, only marginal effects were noted, such as slight agitation in bees returning to the hive or a transient reduction in foraging. No damage to young bees from contaminated pollen was detected. Effects were more marked in two of the trials, with the appearance of damaged bees in front of the hive some 2 hours after spraying, and increased aggression and mortality. However, even in these cases where endosulfan proved hazardous to foraging bees, no significant weakening of the colonies was apparent (Bock, 1985).

Early research from New Zealand involved the application of endosulfan, apparently at 5.2 kg/ha although rates are unclear, to flowering broad beans (*Vicia faba*) inside portable cages containing a colony (four-frame nucleus) of young bees with brood. Application occurred at about 9 am, and bees were released from the nucleus an hour later. Bees appeared to be deterred from collecting nectar from the flowers for about 3 hours, with bee counts not returning to normal until the afternoon. No significant mortality occurred in bees picked from the beans about 4 hours after spraying and at subsequent intervals during the 2 days following the spray (Palmer-Jones, 1959).

A New Zealand field trial conducted in the same year involved spray application, apparently at 1.3 kg/ha, to 0.4 ha of a 10 ha flowering chou moellier crop. Brassica crops grown for seed can become infested with aphids during the spring flowering period, at a time when they are particularly attractive to honey bees. Forty medium strength hives were established about a kilometre from the crop. Bees continued to forage and did not discriminate between sprayed and unsprayed areas. Mortality rates over 48 hours of bees picked from the crop on the day of application and the day following were 60-70%, dropping to 8% by 6 days after application. The increased mortality relative to the bean study is thought to reflect the more open structure of brassica flowers, but there is no comment on the apparent lack of repellency. It may be that repellent effects only offer protection at the higher doses that appear to have been applied to beans, or simply that the brassica flowers were more attractive to the bees. No adverse effects were observed at the apiary on adult bees or brood, but the authors of this study consider that effects would have been more serious if a larger area had been sprayed (Palmer-Jones *et al*, 1959).

A review of field studies on bees conducted during the 1970s and early 1980s concludes that endosulfan can be used without causing significant damage to bees. From nearly 4000 reports of bee damage to German authorities over this period, only a single case could be attributed to endosulfan (Brasse, 1985).

6.1.3.2 Earthworms

The 14 day LC50 for *Eisenia fetida* exposed to technical endosulfan in an artificial soil test was 14 mg/kg, indicative of moderate toxicity according to Dutch criteria (Mensink *et al*,

1995). The no observed effect concentration was 0.1 mg/kg based on weight loss and reduced cocoon production. No reference substance was tested (Fischer, 1990).

Eisenia fetida is generally the least susceptible earthworm species to pesticides, but by a relatively small margin. The LC50 for *Lumbricus terrestris* in loamy sand soil is 9 mg/kg (Edwards and Coulson, 1992).

Testing with an Indian earthworm (*Pheretima posthuma*) found sublethal effects (swollen body, excessive mucous secretion and sluggish movement) from exposure to 10 mg/kg endosulfan, and instant death at 100 mg/kg. The 24 hour LC50 in soil pots was 5 mg/kg (Hans *et al.*, 1990).

Some product labels (for example Rhône-Poulenc Endosulfan Insecticide 350 g/L) carry a label claim for earthworm control in lawns and turf at a rate of 2.1 L/ha (735 g endosulfan). This rate would leave residues of 2-3 mg/kg in the surface 2.5 cm soil layer (density 1.2) although higher residues would be present on surface litter on which some earthworms may feed. Surface residues may be estimated as 160 mg/kg based on the short grass category of the modified Kenaga nomogram (Fletcher *et al.*, 1994). There is also a higher rate application (the equivalent of 4 L/ha) in Queensland for control of earthworms in potted plants, for which pots are to be drenched every 4-6 months when soil is semi dry. Average soil residues from such use would not be expected to exceed 1 mg/kg given the depth of soil in most pots, although residues will typically be inhomogeneous and exposure is likely to be more prolonged than in a 14 day laboratory test. It would appear that endosulfan is considerably more toxic to earthworms in practice than is indicated by the laboratory test with *Eisenia fetida*. One explanation may be that earthworms would be exposed to the sulfate metabolite in the field but not in the artificial substrate used for laboratory testing, and that this metabolite is more toxic to earthworms than the parent isomers.

Field and laboratory experiments conducted in Germany have been compared for a range of pesticides, including endosulfan as EC formulation. Although the individual products are not identified, only one contains 35% active ingredient, indicating it to be endosulfan (according to Brasse, 1985, German endosulfan containing products have since 1973 contained 35% endosulfan). Consistent with the above laboratory study, the LC50 obtained in an artificial soil test was 9.4 mg/kg. In the field, three applications were made at unspecified intervals, each at 6 kg/ha formulation, to square plots (100 m²) containing a high abundance and diversity of earthworms. Earthworm abundance in treated plots was heavily reduced (more than 75%) relative to control plots at 6 months and 1 year after application. The authors of this study estimated soil concentrations of 11 mg/kg in the top 2.5 cm (density 1.5) based conservatively on 100% of the initial application and 50% of subsequent treatments, and compared this with 10% of the LC50 (a tenfold compensation factor to cover inter-species variation in sensitivity). Endosulfan was one of only two pesticides for which this ratio exceeded 10 (or where the estimated environmental concentration exceeded the laboratory LC50). This threshold was found to be a reliable indicator of long term population impacts for the products studied (Heimbach, 1992).

6.1.3.3 Predatory mites

A range of acaricides, including endosulfan at 0.07%, were highly toxic as dried surface residue on glass substrates to 1-2 day old gravid female phytoseiid mites (*Amblyseius*

tetranychivorus) causing total mortality within 24 hours. For endosulfan, mortality reduced to 10% for 3 day old sprays, with no further toxicity recorded at subsequent exposures. The alternative acaricides (dicofol, carbaryl and a range of organophosphates) remained highly toxic even at 9 days after treatment. Persistent activity against phytoseiid mites would be expected to favour the development of secondary pests such as spider mites (Krishnamoorthy, 1983).

6.1.3.4 Beneficial arthropods

The effects of endosulfan on a broad range of beneficial arthropods (Coccinellidae, Staphylinidae, Carabidae, Chrysopidae, Syrphidae and Hymenoptera) have been reviewed. The review contains only sketchy details of the studies reported, generally in the form of testimonials rather than descriptive accounts, and does not include citation details. In general, no more than slight effects were observed in the field, although endosulfan was rated as strongly harmful to some species when tested in the laboratory, particularly in contact testing on waxed paper (Brasse, 1985).

AgrEvo has provided laboratory endpoints for a range of beneficial arthropods showing effects ranging from slightly harmful to harmful (52-100% mortality or reduction of beneficial capacity). Effects in the field ranged from no significant harm to significant mortality. The studies from which these conclusions were drawn have neither been provided nor identified.

6.1.3.5 Soil arthropods

Endosulfan had an immediate adverse impact on populations of soil microarthropods, and persisted in Indian field soils at levels toxic to Collembola for 45 days after application (rates are unclear, but appear to be in the order of 1 kg/ha) as indicated by lack of population recovery. Populations of Acarina showed signs of recovery after about 30 days. The persistent activity (more so than for aldrin) indicates that the degradation products of endosulfan remain toxic to sensitive soil arthropods (Joy and Chakravorty, 1991).

6.1.3.6 Soil microorganisms

No significant effects were observed over a 53 day period on carbon dioxide production from silt and silt loam soils amended with 0.47 and 4.67 mg/kg endosulfan, equivalent to 0.35 and 3.5 kg/ha endosulfan dispersed through 5 cm soil, density 1.5 (Taubel *et al*, 1982). Similarly, no effects were noted under these conditions on the nitrification of ammonium sulfate, added at 10 mg N per 100 g soil (Taubel *et al*, 1980). Further testing found no effect on ammonification and nitrification of horn meal nitrogen (20 mg N/100 g soil) in silty sand spiked at 0.47, 2.4 and 4.7 mg/kg endosulfan (Taubel *et al*, 1985).

While results are favourable, it needs to be noted that respiration, ammonification and denitrification are not good indicators of microbial toxicity. These soil processes can be maintained in the face of significant toxic impacts as resistant microbes increase their populations at the expense of sensitive species (van Beelen and Doelman, 1997). It will be recalled from section 5.2.5.4 that results in Indian field trials (Rao and Murty, 1980) were suggestive of fungal inhibition at higher endosulfan exposures.

6.1.4 Mammals

6.1.4.1 Acute toxicity

Endosulfan has been allocated to Schedule 7 of the Standard for the Uniform Scheduling of Drugs and Poisons. Rodent bioassays (rat LD50 18-355 mg/kg) indicate moderate to high acute mammalian toxicity (IPCS, 1984).

6.1.4.2 Estrogenic effects

Given the structural similarities, there have been suggestions that endosulfan may act as an exogenous sex hormone, as documented for certain persistent organochlorine pesticides. However, recent screening tests involving receptor binding and transcriptional activation *in vitro*, and effects in estrogen responsive tissue *in vivo*, returned consistent negative results, indicating that endosulfan lacks meaningful estrogenic activity (Shelby *et al*, 1996).

Possible estrogenic effects have also been investigated in non-mammalian species. The lack of appreciable interaction with estrogen receptors has been confirmed for endosulfan (both isomers) and its sulfate metabolite in a competition binding assay using a protein extract from oviductal tissues of the American alligator. Similarly, endosulfan did not inhibit binding of a synthetic progestin to the alligator progesterone receptor, although endosulfan sulfate at 30 µM gave rise to a 40-50% inhibition (Vonier *et al*, 1996).

6.1.5 Phytotoxicity

No specific data were submitted for terrestrial plants. Endosulfan has not been shown to be significantly toxic to plants in normal usage in a broad variety of crops, but some isolated reports of phytotoxic effects exist. Endosulfan at operational concentrations has been reported to reduce the viability of cucumber pollen, apparently by reducing pollen-tube length. Reduced viability and delayed germination of chickpea (*Cicer arietinum*) has also been reported, the inhibition being reversible at lower exposures (0.01-1 mg/L in an agar bed) but persisting at higher concentrations (10 mg/L) and affecting all stages of germination and seedling growth (IPCS, 1984).

6.1.6 Summary of Environmental Toxicity

6.1.6.1 Birds

Test results indicate that endosulfan is moderately to highly toxic to bobwhite quail, Japanese quail and mallard ducks under conditions of acute oral exposure, and slightly to moderately toxic through the diet. Dietary toxicity appears to be balanced by repellent effects. Reproductive performance is impaired in ducks under conditions of prolonged exposure to endosulfan in the diet at concentrations in the order of 100 ppm, but not in quail. Endosulfan does not appear to give rise to avian incidents under field use as no such incidents have been reported.

6.1.6.2 Aquatic organisms

Test results indicate endosulfan to be very highly toxic to aquatic fauna. Fish are killed by acute exposure to concentrations in the order of 1 µg/L, with a number of species more sensitive. The most sensitive native species tested is bony bream (96 hour LC50 = 0.2 µg/L). As endosulfan is a hydrophobic substance, its toxicity is thought to be moderated in turbid waters through sorptive interactions. However, evidence for this from the field is equivocal, and experimental attempts at confirmation have been unsuccessful.

Tests have mainly been conducted on the parent isomers as a mixture. Endosulfan sulfate is generally assumed to be of comparable toxicity but few results are available.

Aquatic invertebrates appear generally to be acutely susceptible to concentrations in the order of 100 µg/L, although considerable variation is evident. Cladocerans appear relatively insensitive, with acute and chronic endpoints of a few hundred ppb typical. An exception is *Ceriodaphnia dubia*, for which no effect concentrations in local reproductive testing over at least three broods were 3.3 µg/L at 20°C, decreasing to 0.1 µg/L at 30°C. The acute EC50 for this species was 2.4 µg/L at 30°C, increasing to 166 µg/L at 15°C. Sedimentary worms avoid sediment contaminated with endosulfan at levels of 50 µg/kg and above, and suffer 50% mortality in acute tests when exposed to dissolved concentrations of 100 µg/L. Estuarine crustacea and Australian freshwater mayfly nymphs appear to be as susceptible as fish, with acute endpoints of about 1 µg/L and below. No information is available regarding the chronic sensitivity of these organisms, but high acute to chronic ratios have been determined for daphnids.

Endosulfan appears highly toxic to algae, although these organisms can absorb endosulfan and metabolise it to the diol.

Overseas field studies confirm that fish kills are likely to occur when aquatic concentrations reach about 1 µg/L. Fish kills were documented following runoff from tomato fields into small ponds, but most of the fish in the ponds remained unaffected. Drift studies have shown that mortality of fish exposed in shallow water can occur 200 m downwind of the crop.

Biological monitoring in Australia finds that macroinvertebrate community structure is changed downstream from cotton areas during the season, with reduced diversity and abundance of sensitive species. A correlation can be made between on-farm impacts and endosulfan exposure, although physical factors such as turbidity appear better correlated with impacts in natural waterways during the dry seasons in which biomonitoring has been performed. Monitoring indicates that aquatic contamination exceeds water quality objectives (0.01 µg/L), frequently by one and occasionally by two orders of magnitude, raising the likelihood of biological impact. Although this aspect requires further study, populations of sensitive sediment dwelling organisms colonise upstream sites in significantly larger numbers during summer than at sites downstream from cotton production.

6.1.6.3 Non-target terrestrial invertebrates

Endosulfan is toxic to bees in the laboratory but generally without significant impact in the field, even when applied when bees are actively foraging.

Endosulfan is moderately toxic to earthworms in the laboratory, but there is evidence for protracted suppression of earthworm populations in the field at typical application rates.

Residues of endosulfan on foliage are toxic to predatory insects and mites, but the toxicity does not appear to persist beyond 1 day, allowing repopulation to occur from unsprayed areas.

Endosulfan exerts persistent adverse effects on soil arthropods, consistent with its use to control red legged earth mite.

Endosulfan residues do not appear to impair microbial processes in the soil, although some microbial species appear to be susceptible.

6.1.6.4 Mammals

Rodent bioassays indicate moderate to high acute mammalian toxicity. Recent *in vitro* and *in vivo* screening tests returned consistent negative results, indicating that endosulfan lacks meaningful estrogenic activity.

6.1.6.5 Plants

Endosulfan has not been shown to be significantly toxic to plants in normal usage in a broad variety of crops, but some isolated reports of phytotoxic effects exist.

7. PREDICTION OF ENVIRONMENTAL HAZARD

Endosulfan is applied using ground based or aerial equipment to a broad range of crops, with the main use on cotton and important uses in vegetable and fruit production. Typical application rates are about 700 g/ha endosulfan, for example in cotton, but high volume application in orchards may entail rates in excess of 2 kg/ha. Up to 5 applications may generally be made per season, at intervals of 5-10 days when pest pressure is high, with heavier use (up to 16 sprays) in some orchard crops such as avocados.

A high proportion of the applied endosulfan, including that intercepted by the crop, is lost to volatilisation in the few days following application. Endosulfan that does not disperse through the atmosphere as vapour or spray drift mainly becomes associated with the soil beneath the crop, where it is strongly adsorbed and subject to aerobic microbial metabolism. Metabolism either detoxifies endosulfan through conversion to the diol, a process that can also occur abiotically, or maintains toxicity through oxidation to the sulfate. The half-life for primary degradation in soils appears to be in the order of a few weeks to a couple of months, although more rapid dissipation is apparent in the field because of volatilisation. The sulfate metabolite appears to have a half-life in soil of about 4-6 months. Persistence can increase markedly in dry soils.

Riverine contamination occurs through aerial transport routes (drift and volatilisation) or transport of contaminated soil and dissolved residues in surface runoff. Residues entering water partition to sediment over a period of a few weeks. The half-life for total toxic residues appears to be about 2 weeks in the single aquatic system for which reliable results are available, but it should be noted that a significant proportion dissipates through the formation of non-extractable residues in the sediment. Furthermore, hydrolysis would have been

favoured by the alkaline pH in that test. Endosulfan and its sulfate would appear to have the potential to persist for extended periods in aquatic sediments, and this is borne out by the constant presence through the year of residues, albeit at low levels during winter months, in fish liver samples taken from cotton areas.

The following assessment of environmental hazard deals mainly with cotton, as this crop is the main consumer of endosulfan and use patterns are comparable to other cropping situations. Specific comment is also provided for higher rate uses, such as orchard applications.

7.1.1 Terrestrial hazard

Simple calculations indicate that application of endosulfan should not present a hazard to birds, even at the high rates that may be used in orchards. In contrast, even the lower rate used in crops such as cotton appears from calculation and field experience to represent a potential hazard for soil dwelling invertebrates, including earthworms, and for bees. A hazard is also apparent to beneficial parasitic and predatory insects, although the limited persistence of endosulfan allows repopulation to occur and is said to reduce this hazard relative to other broad spectrum insecticides (organophosphates and synthetic pyrethroids) such that endosulfan is included in IPM programs for a number of crops.

Note that the hazard calculations are for a single application only. In general, the hazard will largely dissipate between applications because of the volatility of endosulfan. Soil dwelling organisms are an exception. These organisms appear to be impacted by the sulfate metabolite, which increases in concentration in the soil with multiple applications through the season, and this has been specifically noted for earthworms. Even though acute hazard to most organisms will be of relatively short duration, further insults with repeat spraying will retard population recovery.

7.1.1.1 Hazard to birds

Residues on vegetation immediately after application may be estimated using the modified Kenaga nomogram (Fletcher *et al*, 1994). Highest residues following application at 2.1 kg/ha would be expected on short grass, at 450 ppm. This is about half the dietary LC50 to bobwhite quail, the most sensitive bird tested. Given the limited persistence of endosulfan on foliage, and likely repellent effects, the hazard to birds appears low.

7.1.1.2 Hazard to earthworms

Application at 700 g/ha would leave residues of 2-3 mg/kg in the surface 2.5 cm soil layer (density 1.2) or about 25% of the laboratory LC50 for earthworms. Soil residues of this magnitude have been detected in field studies, although residues generally remain below 1 mg/kg. While the hazard to earthworms appears relatively low based on laboratory toxicity data, field experience is that endosulfan is hazardous to earthworms, suppressing populations for a year after three applications, each at 2 kg/ha endosulfan. It appears that the sulfate metabolite is mainly responsible for this effect. Given that seasonal use may amount to a few kg/ha, similar impacts on earthworms would appear likely in cropping situations. A respondent to the draft review notes general agreement among orchardists that earthworm populations are significantly lower under avocado trees sprayed with endosulfan, but that

other microbiotic activity seems vigorous as indicated by rapid breakdown of vegetative mulch.

7.1.1.3 Hazard to soil arthropods

Significant impacts may be expected, given results available from testing, and the fact that endosulfan is used at low rates (175 g/ha) to control red legged earth mite in pasture. Long term effects on Australian soil dwelling organisms are unknown and require further research.

7.1.1.4 Hazard to bees

Application rates of 700 g/ha equate to $7 \mu\text{g}/\text{cm}^2$. Hazard may be estimated based on the assumption that a bee in a spray cloud has a target area of 1 cm^2 (Davis and Williams, 1990). Contact LD50s for bees are about $2 \mu\text{g}$ per bee, and exposure of bees may be expected to approximate deposition rates of $7 \mu\text{g}/\text{cm}^2$ if endosulfan is sprayed while they are actively foraging. Endosulfan is clearly hazardous and should not be used while bees are foraging, notwithstanding reports that in most situations significant damage to bee colonies will not occur.

7.1.1.5 Hazard to beneficial invertebrates

Endosulfan is toxic to predatory insects and mites, but the hazard from this toxicity appears relatively low compared with alternative insecticides because endosulfan dissipates rapidly from the crop through volatilisation.

7.1.1.6 Hazard to vegetation

Hazard to native vegetation exposed through drift appears relatively low given that only a few accounts of phytotoxicity have emerged following extensive use around the world in a broad variety of crops.

7.1.2 Aquatic hazard

Endosulfan enters riverine environments through aerial and waterborne pathways. Aerial transport involves spray drift and vapour transport, as well as some movement on dust particles, while waterborne transport occurs in dissolved and sorbed phases when storm runoff or irrigation tailwaters leave the farm. Highest concentrations in waterways arise through spray drift and runoff, but only in localised areas. Vapour transport is comparable in overall importance, but occurs throughout regions where endosulfan is used and does not contaminate water to such high levels. Transport on dust appears relatively insignificant.

The following analysis is based on a single application at 700 g/ha, such as occurs in cotton. Hazard would be expected to be higher in orchard situations, given the higher application rates and the use of airblast equipment producing high volumes of fine spray that would be prone to drift.

While the hazard will largely dissipate between applications, further insults with repeat exposures will retard population recovery. Populations of sediment dwelling organisms appear to be particularly vulnerable, given the sensitivity of some species in the laboratory and

the impacts apparent in the field. There is also likely to be more prolonged exposure of such organisms as endosulfan and its toxic sulfate metabolite partition to sediment and appear to persist there.

7.1.2.1 Hazard to fish and sensitive aquatic invertebrates

Direct application to 15 cm of standing water at the rate used for cotton (700 g/ha) would leave residues of 470 µg/L, which would be expected to exert toxic effects on most aquatic fauna so exposed. The same water body receiving drift equivalent to 10% of the target dose would be contaminated at about 47 µg/L, which again would be expected to impact significantly on fish given that many species are susceptible to concentrations in the order of 1 µg/L. A number of invertebrate species exhibit similar sensitivity. Even 1% drift to such a water body would leave residues that would be toxic to many fish species.

Off-target deposition from aerial application typically ranges from about 5% of applied at 30 m downwind to about 0.5% at 150 m. Drift potential from ULV applications in the USA is some 5-10 fold higher than from conventional spraying (Bird *et al*, 1996). For applications of 700 g/ha, this equates to concentrations of 24 µg/L in 15 cm water at 30 m, decreasing to 2.4 µg/L at 150 m downwind. Field experiments have shown deaths of fish to occur in shallow water, even at 200 m downwind from the crop.

In order to be able to predict with reasonable confidence that adverse effects should not arise, the predicted environmental concentration needs to be less than 10% of toxic endpoints. As endosulfan is acutely toxic to many aquatic species at levels in the order of 1 µg/L, these simple calculations indicate a hazard to aquatic fauna. The predicted environmental concentration would need to be reduced to at least 0.1 µg/L to protect most species, and lower still for sensitive species. This would entail a fifty-fold reduction, even assuming that drift can be restricted to only 1% of applied, as illustrated by the table below of predicted environmental concentrations in 15 cm water contaminated by drift from a 700 g/ha application.

The ratio of concentration to toxicity is generally known as Q (for quotient). Calculated values for Q in the table below are based on a toxic end-point of 1 µg/L, and would not be sufficiently protective of more sensitive species. However, they illustrate the severity of the problem. According to methodology used by the US EPA for its reregistration program (US EPA, 1994) a Q of less than 0.1 indicates that risk to aquatic organisms is minimal. A potential acute risk is indicated where Q falls between 0.1 and 0.5, but may be mitigated by restricted use classification. Higher Q values indicate high acute risk and a need for further use restrictions or special review. More detailed analysis is required for chronic exposure situations, such as presented by endosulfan during the spray season. The aquatic risks of endosulfan are clearly of great concern.

Spray drift (%)	10%	5%	1%	0.5%	0.1%
Concentration (µg/L)	47	24	4.7	2.4	0.47
Quotient, Q	47	24	4.7	2.4	0.47

Note that restriction of spray drift to 0.1% would require a buffer well in excess of 150 m, according to the data of Bird *et al*, 1996, particularly if ULV formulations are used.

Thus, standard evaluation procedures indicate high environmental risk for all uses of endosulfan. Endosulfan's history of use confirms that it readily moves off-target, and that concentrations in non-target areas so exposed can be high enough to elicit biological responses. Most of the field evidence for environmental impact comes from cotton production, reflecting the intensity of use in this crop. Adverse impacts are considered likely to attend use in other crops, given endosulfan's mobility and toxicity characteristics, but would be more localised and less likely to be noticed. Some orchard uses may cause local problems where higher application rates and airblast equipment producing high volumes of fine spray are used. High application rates per hectare to larger tree crops may lead to exposure of the ground surface. Since avocados and macadamias are commonly grown close to native habitat, it is especially important to avoid off-target impacts in these areas.

As noted earlier in this report (section 5.2.4.4) model calculations indicate that vapour transport can lead to aquatic contamination in excess of water quality objectives (0.01 µg/L), and this prediction has been confirmed by experiment. These observations suggest that it will not be possible to use endosulfan safely unless its volatility can in some way be controlled.

Vapour transport of endosulfan gives rise to low level aquatic contamination throughout cotton areas during the spray season. Spray drift and runoff events produce larger peak concentrations, but over limited areas.

Experience gained through use of endosulfan confirms that both drift and runoff are hazardous to aquatic life. Isolated fish kills have been reported after the release from cotton farms of both stormwater runoff and irrigation tailwater polluted with endosulfan, and are suspected to have occurred from spray drift or overspray.. Monitoring of sediment dwelling organisms through the summer months indicates major perturbations to populations of sensitive aquatic invertebrate in rivers downstream from Australian cotton growing areas, but no clear case has been established to implicate endosulfan, or other pesticides, as a causal factor. Other unmeasured factors may be responsible for the changes observed. However, given its documented widespread aquatic exposure and toxic properties, endosulfan, particularly on the scale of use occurring in cotton, must be suspected as a possible cause of widespread impacts on aquatic ecosystems. Even if the vapour transport of endosulfan is reduced, there will still be an urgent need to avoid situations conducive to spray drift and runoff.

The hazards of endosulfan are exacerbated by poor agricultural practices, such as described in the recent audit of the Namoi valley (O'Brien, 1996). These include opportunistic expansion of dryland cotton farming into marginal areas, such as flood prone land in the upper Namoi. Of particular concern is the tendency for dryland farmers in this region to continue to spray when rain is forecast, in some cases only hours before heavy rain and notwithstanding low pest pressure, and for irrigated cotton growers to irrigate shortly after spraying. These poor practices incur excessive and unnecessary environmental impacts, and need to be stopped if the advantages of endosulfan to crop production are to be retained.

8. CONCLUSIONS AND RECOMMENDATIONS

Endosulfan is used in high volumes, particularly in cotton, and has high aquatic toxicity. Although well retained once within the soil, endosulfan contaminates the broader environment

through spray drift, volatilisation and particle transport, both aerially on dust and more importantly by storm runoff leading to riverine contamination. The α isomer largely volatilises in the few days following application, while the β isomer can persist in the soil. Both isomers metabolise in soils to endosulfan sulfate, which retains the toxicity of endosulfan and persists in soil and sediment.

Pesticide monitoring in the cotton growing areas of NSW during the season has consistently found endosulfan at concentrations above the ANZECC guideline of 0.01 $\mu\text{g/L}$ in at least 50% of samples through the 1990s. There are indications that the situation may be improving in recent seasons, but contamination remains at unacceptably high levels. Particular problems occur with storm events that produce surface runoff, when total endosulfan levels in excess of 1 $\mu\text{g/L}$ are likely to prevail in rivers for a day or two. The limited information available suggests a comparable situation in Queensland rivers.

Laboratory testing has determined that acute LC50s for Australian native fish can be as low as 0.2 $\mu\text{g/L}$, and that some native invertebrate species are acutely sensitive at concentrations below 1 $\mu\text{g/L}$. Consideration of exposure and effects information indicates that acute impacts of endosulfan on fish are likely during the spray season. Isolated fish kill incidents have been reported after the release from cotton farms of both stormwater runoff and irrigation tailwater polluted with endosulfan. More subtle chronic effects on aquatic fauna are also considered possible given the frequency with which endosulfan breaches environmental guidelines and the high acute to chronic ratio determined for this substance. Low level aquatic exposure, particularly to the sulfate metabolite, persists throughout the year.

Endosulfan residues in the soil appear to exert protracted adverse impacts on earthworm populations and are likely to similarly affect sensitive soil arthropods.

8.1.1.1 Quality of the studies submitted

Sufficient information has been submitted in most areas to enable an understanding of the behaviour and effects of endosulfan in the environment. However, uncertainties remain concerning the persistence of endosulfan residues in sediment, and their bioavailability. Some information is available from the farm pond study (Cornaby *et al*, 1989) but little is known of behaviour under Australian conditions. This report has assumed that endosulfan residues are persistent in sediment, and to some degree bioavailable, as residues can be found in fish livers from cotton areas throughout the year. There is also a shortage of toxicity information for endosulfan sulfate, which is assumed in this report to be of similar toxicity to parent endosulfan, although the earthworm evidence suggests that some species may be particularly sensitive to this metabolite.

As noted earlier in this report, many of the Australian findings under the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program are of an interim nature. Completion of this program will allow a more detailed evaluation of the environmental fate and effects of endosulfan in Australia and enable better management of the problem. However, the final results are unlikely to significantly alter the overall conclusions of this report.

8.1.1.2 Balancing risks and benefits

Endosulfan is mobile in the environment, persistent in soils and sediment, and toxic to aquatic and terrestrial organisms. There is evidence for adverse impacts on the Australian environment at current levels of use, and indications that some degree of impact is unavoidable. From the environmental perspective, the likelihood that endosulfan is exerting significant impacts on the Australian environment indicates that environmental exposure needs to be reduced, and that endosulfan should be phased out as soon as suitable alternatives become available that do not suffer from these disadvantages.

Barring other considerations, a rapid phase-out of endosulfan might be warranted on environmental grounds. However, there are reasons to be cautious in implementing such an outcome. An abrupt phase-out would likely lead to an increased use of other toxic chemicals. Furthermore, the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program is approaching completion. The preparation of a Best Management Practices Manual for the cotton industry under the auspices of this program is likely to result in greatly improved management practices that will ease the immediate problem and may allow endosulfan to continue to be used, albeit on a reduced scale. The latest version of this manual was published on 31 December 1997.

The cotton industry argues that endosulfan currently has advantages in helping to reduce overall chemical use in the broader context of cotton production. Similar benefits are claimed in other industries. In such situations, the NRA is empowered to vary the registration to satisfy itself of environmental safety, and may cancel the registration. The difficulty here is that restrictions to the use of endosulfan will necessarily result in use of alternative chemicals, which in general kill more beneficial insects and mites and tend to cause subsequent population explosions in secondary pests. Restrictions to endosulfan are also likely to be detrimental to resistance management. The outcome is likely to be increased use of other chemicals, with no obvious reductions in environmental risks.

It is apparent that reduction of chemical impacts may be achieved through the inclusion of insecticide use in integrated pest management programs that make maximum possible use of mechanical, biological and cultural methods. As noted earlier in this report, mechanical methods are widely practised, such as cultivation as soon as practicable after cotton harvest and the use of sticky bands on tropical fruit trees, and endosulfan plays a key role in integrated pest management programs that seek to minimise impacts on beneficial organisms and retain maximum advantages from biological control.

Given the broader benefits of endosulfan, including as an essential input to production of a number of crops, and the absence of alternatives with similar characteristics, an abrupt and indiscriminate phase out would cause problems which could be greater than those associated with current use. Where use has been identified as critical because of a lack of alternatives, or particularly important as part of resistance management or integrated pest management programs, management requires that endosulfan be used more responsibly and in smaller volumes, rather than not at all. The number of applications per crop per season should be, therefore, restricted to the minimum necessary to maintain the crop. Additionally, time intervals between applications should be as long as possible, determined by monitoring of pests, to give populations of aquatic species maximum time to recover.

8.1.1.3 Improvements to labels

All labels contain warnings of toxicity to aquatic organisms (“Extremely dangerous to fish. DO NOT contaminate ponds, waterways and drains with this chemical or used container”) and bees (“Harmful to bees. DO NOT spray any plants in flower while bees are foraging”).

Only the labels for Crop Care Endosan ULV and EC carry a drift warning, and there are no label warnings concerning the other route of greatest concern with respect to aquatic contamination, namely runoff. All labels should carry the following restraints:

- DO NOT apply under meteorological conditions or from spraying equipment which could be expected to cause spray to drift onto adjacent areas, particularly wetlands, waterbodies or watercourses.
- DO NOT apply to waterlogged soil or while water remains in furrows.
- DO NOT apply if heavy rains or storms that are likely to cause surface runoff are forecast within two days of application unless stormwater can be captured.
- DO NOT irrigate while spraying, or for at least two days after application.

There is also a need to alert users to the volatility problem, for example as follows:

- Avoid application during hot conditions (above 30°C).

Labels also need to be upgraded to provide helpful advice to users concerning application rates for fruit, whether in low or high volumes, in order to avoid the use of excessive rates. For pome and stone fruit, use should be restricted to a single application per season, in line with the principal registrant’s advice regarding current use patterns, and for citrus to a maximum of two applications per season.

8.1.1.4 Reducing environmental exposure

One approach to reducing environmental exposure to endosulfan is to reduce the range of registered uses. If specific uses are to be restricted, alternatives that are acceptable from environmental and agronomic perspectives must be available to replace them. Where such alternatives exist, present uses of endosulfan should be questioned in light of the persistence of endosulfan and metabolites in the environment, their mobility through air and waterborne routes, high toxicity to aquatic and terrestrial fauna, and the evidence presented in this report concerning the contamination of the Australian environment by endosulfan and consequent impacts on non-target biota.

Industry should be encouraged to minimise the present use of endosulfan pending the availability of acceptable alternatives. For example, the avocado industry needs to conduct further research into the ecology of fruit spotting bug with a view to improving the timing of spray controls. Identification and synthesis of sex pheromones would assist efforts to improve the efficiency of spray operations. It may also be possible to reduce application rates by adopting low volume application methods. Integrated pest management systems need to be widely adopted. The macadamia industry, for example, may be able to reduce its overall use of endosulfan by increasing the number of IPM participating farms. For minor orchard crops such as these, where environmental impacts from use of endosulfan are likely to be localised,

reduced volumes of use may be used in place of monitoring data to demonstrate reduced environmental impact.

It may be possible to phase out use in some crops. For example, industry advises that alternative chemicals are available for strawberries that would be acceptable in the marketplace. However, it should be noted that Tasmania nominated strawberries as an essential use for endosulfan. Earthworm control would also appear to be a non-essential use and undesirable given the benefits conferred by these organisms. For example, earthworms contribute to turf health by feeding on the thatch layer and preventing excessive build up of thatch. Control in such situations would appear counterproductive and should be removed from the label. Other crops where alternatives appear feasible include some vegetable and fruit applications.

8.1.1.5 Best Management Practice In Agriculture

Findings from the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program have been particularly important in developing best management practice guidelines which now appear in the cotton industry's Best Management Practices Manual, the first version of which was launched on 31 October 1997. These guidelines should be circulated widely within the industry and to other industry organisations to help promote the adoption of improved agricultural practices. Some of the elements of the Manual are discussed in more detail below.

Considerable variation is apparent in agricultural management practices between different regions of Australia. Surveys to date indicate that practices are relatively well advanced in the Macquarie valley, although problems remain with timing of irrigation relative to spraying, and that the Macquarie could be used as a benchmark for other areas, such as the Namoi where poor practices appear to be widespread. Other cotton growing areas need to be surveyed to determine the scope of any problems that may exist and provide motivation to improve farming practices.

8.1.1.6 Management of spray drift

Some growers have expressed a preference for using ground rigs early in the season as this enables spray to be directed at the crop, thereby reducing application rates and the potential for off-target contamination. Ground rigs should be the preferred application method whenever it is possible to reduce overall rates through band application techniques and should especially be used whenever possible near sensitive areas. Wide swath ULV applications should be avoided wherever possible because of their increased propensity to drift from the site of application compared with conventional methods. Placement applications using large droplets should be the preferred method for aerial application, particularly near sensitive areas.

Evidence presented by O'Brien (1996) indicates current spray practices to be deficient in a number of areas. Although aerial spraying should be conducted only under environmental conditions which ensure minimum spray drift, in practice up to 10% of farmers (or their aerial operators) would spray in unfavourable conditions. Further, 15-20% had sprayed during inversions, and such practices continue, albeit at reduced rates because of increased

awareness. Application may also occur under gusty conditions, noticeably more so in dryland cotton (20%) compared to other cotton farmers (6-7%) in the Namoi.

Application of endosulfan, particularly by aircraft, should not occur in high winds or when the air is highly turbulent, under temperature inversion or in calm conditions, or when winds are light and variable. Spray should only be released when aircraft are flying straight and level. Growers should consider planting trees along boundaries to help intercept any spray drift that may arise.

Buffer zones should be observed adjacent to environmentally sensitive areas such as waterways downwind of the crop. An example of appropriate strategies in relation to use of buffer zones can be found in the cotton industry's Best Management Practices Manual (p AP-10), the latest version of which was launched on 31 December 1997.

8.1.1.7 Management of runoff

Control measures also need to be improved with respect to runoff. For irrigated agriculture, irrigation efficiency should be improved in order to minimise contamination of drains by tailwater. As one component, drainage recirculation systems should be installed to capture irrigation tailwater and at least, until better information is available, the first flush of storm runoff. This is particularly important for dryland cotton farmers, as many do not currently contain contaminated stormwater.

Early season band spraying where possible can also help in reducing runoff losses, as overall application rates are reduced and a much higher proportion of the spray will be intercepted by the crop and not reach the soil.

Evidence presented by O'Brien (1996) indicates current spray practices to be deficient in a number of areas. If rain appeared likely, 77% of farmers in the Upper Namoi and 55% of dryland cotton farmers would continue to spray, compared to 11% and 13% of farmers in the Macquarie Valley and Lower Namoi. There were numerous reports during the 1995/96 season of farmers spraying their field just hours before inundation with water, including precautionary sprays for fields with low pest thresholds, being motivated by the apprehension that future spraying would violate the *Clean Waters Act 1970* (which applies only in NSW and is administered by the NSW EPA). Of particular concern is the common practice among cotton farmers of applying pesticides while irrigating. As many as 90% of lower Namoi farmers and 73% of upper Namoi farmers spray while water is in the furrow. Such practices are also commonplace in the Macquarie valley.

Application of pesticides should not occur while irrigating, and should be delayed after irrigation has occurred. Endosulfan should not be applied where soils are waterlogged, and irrigation should be withheld for 48 hours after application unless tailwater can be captured.. The objective should be to irrigate only when pesticide residues in the soil reach their minimum level. Neither application nor irrigation should be contemplated if heavy rains or storms are expected. Failure to observe these basic precautions will lead to increased environmental contamination, and will inevitably strengthen the case for withdrawal of pesticides such as endosulfan which are known to contaminate the environment and impact adversely on non-target species, particularly when not used responsibly.

Some growers of irrigated cotton in NSW have objected to restrictions on application while irrigating or to waterlogged paddocks. A complete field irrigation may require up to 5 days, during which pest pressures may intervene. It is argued that such restrictions are not needed for irrigated cotton farms with the ability to recirculate tailwater and capture storm runoff.

Even if irrigated farms are able to contain tailwater and storm runoff, the practice of spraying while irrigating is likely to lead to contamination of drains, which must be periodically desilted. It is acknowledged that large irrigated farms are able to manage the movement of endosulfan from cotton fields in irrigation or storm water, except in large storms. Large storms are not always predictable, however, and spraying while irrigating can not be supported. It is better practice to prevent pollution, rather than to manage it. Acceptance of inherently poor practices such as spraying while irrigating detract from the concept of best management practice. A recent review (Schofield *et al*, 1998) of potential best practices that are currently being formulated notes that “the runoff off pesticide-contaminated water is to be minimised by controlling and scheduling irrigation to take account of soil and weather conditions”. The Best Management Practices Manual is silent on the practice of spraying while irrigating.

Dryland farms are of particular concern because of their inability to contain storm runoff and their expansion into risky areas such as floodways, from which heavy rains can wash large quantities of contaminated soil into waterways. Planning authorities need to consider whether expansion of dryland cotton production into such marginal areas, as has occurred recently in the upper Namoi valley for example, is appropriate. In any event, dryland farms need to develop the capacity to withhold at least the first flush of storm runoff.

Prior planting with a wheat crop may be of assistance in reducing runoff problems, although this may not be practical in NSW as the wheat could not be harvested before the beginning of the cotton season. When completed, the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program should be able to provide further advice on the feasibility of this option.

High volume applications, for example in orchards, should be discouraged given their inefficiency compared with low volume techniques.

8.1.1.8 Management of vapour transport

Large volatilisation losses following application of endosulfan represent inefficiency and contribute to widespread low level environmental contamination in regions where endosulfan is used. Registrants need to actively investigate low volatility formulations of endosulfan. It seems logical to assume that application rates could be reduced if endosulfan remained on the crop rather than volatilising and dispersing. Contamination of the broader environment with persistent and toxic metabolites of a volatile insecticide will be difficult to justify should alternatives with equivalent performance become available that do not suffer from this undesirable side effect.

8.1.1.9 Water quality guidelines

The current ANZECC water quality guideline for protection of aquatic life is 0.01 µg/L, derived by applying an assessment factor of 50 to the lowest acute LC50 for native Australian

fish. The guideline has been criticised as unrealistically low given that it is frequently exceeded by one and occasionally by two orders of magnitude during the cotton season without causing noticeable fish kills. It is also hard to measure endosulfan at such low levels, which are around the limit of detection.

Application of an assessment factor to acute toxicity data is a well established method for deriving water quality guidelines, but may be criticised for overlooking chronic effects or attenuating factors such as sorption to sediment that operate in natural environments. Further work is being conducted under the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program to overcome such criticisms. As noted earlier in this assessment, stream mesocosm studies are underway to assess effects on the freshwater mayfly nymph *Jappa kutera* and an early life stage of the native fish, *Macquaria ambigua*, with a view to providing information to assist in refining the ANZECC water quality guideline for endosulfan (Hyne and Lim, 1996).

A guideline for endosulfan in marine and estuarine waters has been established in South Australia. Under the Environment Protection (Marine) Policy 1994, endosulfan is not at any time to exceed an acute criterion of 0.034 µg/L. The average concentration over 24 hours is not to exceed a chronic criterion of 0.0087 µg/L.

Ambient water quality criteria established by the US EPA for protection of freshwater organisms are relatively relaxed at 0.22 µg/L (acute) and 0.056 µg/L (chronic). However, the US National Academy of Sciences recommends a more stringent criterion of 0.003 µg/L. The Canadian guideline is 0.02 µg/L (Bowmer *et al*, 1996).

Outstanding questions concerning the persistence of endosulfan (including its toxic sulfate metabolite) in aquatic sediment and its effects on resident biota need to be addressed before consideration can be given to relaxing the water quality guideline. Key questions for resolution are the persistence of residues in sediment, for which sediment monitoring data would be valuable, the role of sediment in ameliorating the aquatic toxicity of endosulfan (and its sulfate metabolite), and the aquatic toxicity of the sulfate metabolite, for which few data are available.

8.1.1.10 Further Development of IPM and Resistance Management Strategies

The general conclusion of this assessment is that the use of endosulfan is acceptable only in crops where such use is crucial to avoid escalating chemical use from the development of resistance or further pest outbreaks resulting from impacts on beneficials, and only until environmentally and agronomically acceptable alternatives become available. There is a widely held view that such factors make endosulfan crucial at the present time in a number of crops, most notably cotton.

The view that multiple sprays of insecticides, including endosulfan, are essential to cotton production is not shared by all, however. As noted earlier in this assessment, preliminary research conducted by the CSIRO in the Ord River Irrigation Area (Neales, 1996; Strickland *et al*, 1998) indicates that modified integrated pest management systems that include much lower pesticide use than is currently the case may be feasible, particularly with transgenic varieties. Essentially, a minimal spraying sustainable program is being evaluated. The key is to integrate many different elements into a planned program effective against other problem

insects such as aphids, jassids, mirids and whitefly, rather than focussing on chemical control of heliothis. Vietnamese cotton growers have reportedly reduced pesticide applications per crop from as many as twenty to just two following adoption of this approach, and average requirements for transgenic cotton in the Ord are about 3 sprays per crop. It is acknowledged, however, that management techniques suitable for the Ord River area or Vietnam may not be directly transferable to the eastern States, but some elements may have potential for reducing reliance on endosulfan.

Industry submissions from the eastern States indicate that many of the approaches suggested by CSIRO researchers in Western Australia are already being pursued by some growers. In particular, the use of food spray technology to attract beneficial insects, together with trap crops such as lucerne, help defer early spraying by helping to maintain pest populations below economic thresholds. Such approaches have been quite successful in situations of low to moderate pest pressure but require augmentation by endosulfan when pest numbers are high. The development of crop varieties less attractive for heliothis breeding is also highlighted, in particular new transgenic varieties. Natural and genetically modified viruses with specific activity against heliothis pests are also expected to be introduced over the next few years.

The cotton industry recognises that its present pest management systems require further development to reduce chemical inputs, but remains firmly of the view that endosulfan is the key insecticide at the present time. Without endosulfan, the current pest management systems would become significantly more costly, resistance management in *H. armigera* and mites would deteriorate, and IPM systems would be more difficult to develop and maintain.

In conclusion, the cotton industry's position that endosulfan is critical to the success of current pest management systems that rely on insecticides as a principal management technique is accepted. However, there is scope for further development of the integrated pest management and resistance management strategies currently used in cotton, as a result of research carried out under the Minimising the Impact of Pesticides on the Riverine Environment Research and Development Program. The publication of a Best Management Practices Manual for the cotton industry is evidence of the industry's commitment to such development.

As noted in this report, calculations indicate that endosulfan will contaminate water to levels above water quality guidelines for protection of aquatic life as a result of volatilisation from the crop. Higher levels of contamination arise through spray drift and runoff. Population impacts are apparent for sensitive non-target aquatic invertebrates, and isolated fish kills continue to occur. Argument continues as to whether endosulfan should be implicated in these incidents, but it seems unreasonable to maintain that endosulfan is involved in none of them, given its widespread exposure and toxic properties. Given these undesirable side effects, the use of endosulfan on the scale that currently occurs in Australian cotton production should only continue as an interim measure, for such time as use remains essential to avoid escalating use of alternative chemicals. Current indications are that viable alternatives to endosulfan should become available in Australia in the next 3-5 years.

Endosulfan should also be phased out from other crops as suitable alternatives become available. At the present time, a phase out appears feasible for some vegetable and fruit crops, possibly for strawberries and for control of some soil invertebrates such as red legged earth mite and earthworms. However, the agronomic implications and particularly the likely need for alternative chemicals will need careful consideration.

Guidelines on best management practices which now appear in the cotton industry's Best Management Practices Manual should be circulated widely within the industry and to other industry organisations to help promote the adoption of improved agricultural practices.

The registration status of endosulfan in Australia needs to be revisited, say in 3 years, in order to consider remaining uses in the light of data developed in the interim. The success of best management practices in reducing environmental contamination by endosulfan would also be evaluated, with a view to determining whether some limited uses where endosulfan has particular performance advantages may be retained. Significant overseas regulatory or scientific developments should also trigger such review.

In the interim, industries need to manage the use of endosulfan in a more responsible way and demonstrate improved practices and reduced environmental contamination. Endosulfan will be under close scrutiny, and any ongoing environmental problems will inevitably strengthen calls for its phase out, particularly in crops where it is applied frequently using inefficient application methods.

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