# 5. POTENTIAL FOR HUMAN EXPOSURE

## 5.1 OVERVIEW

Endosulfan is released to the environment mainly as the result of its use as an insecticide. Significant contamination is limited to areas where endosulfan is manufactured, formulated, applied, or disposed of. The compound partitions to the atmosphere and to soils and sediments. Endosulfan can be transported over long distances in the atmosphere, but the compound is relatively immobile in soils. It is transformed by hydrolysis to the diol and by microorganisms to a number of different metabolites. It is bioconcentrated only to low levels and does not biomagnify in terrestrial or aquatic food chains.

The most important routes of exposure to endosulfan for the general population are ingestion of food and the use of tobacco products with endosulfan residues remaining after treatment. Farmers, pesticide applicators, and individuals living in the vicinity of hazardous waste disposal sites contaminated with endosulfan may receive additional exposure through dermal contact and inhalation.

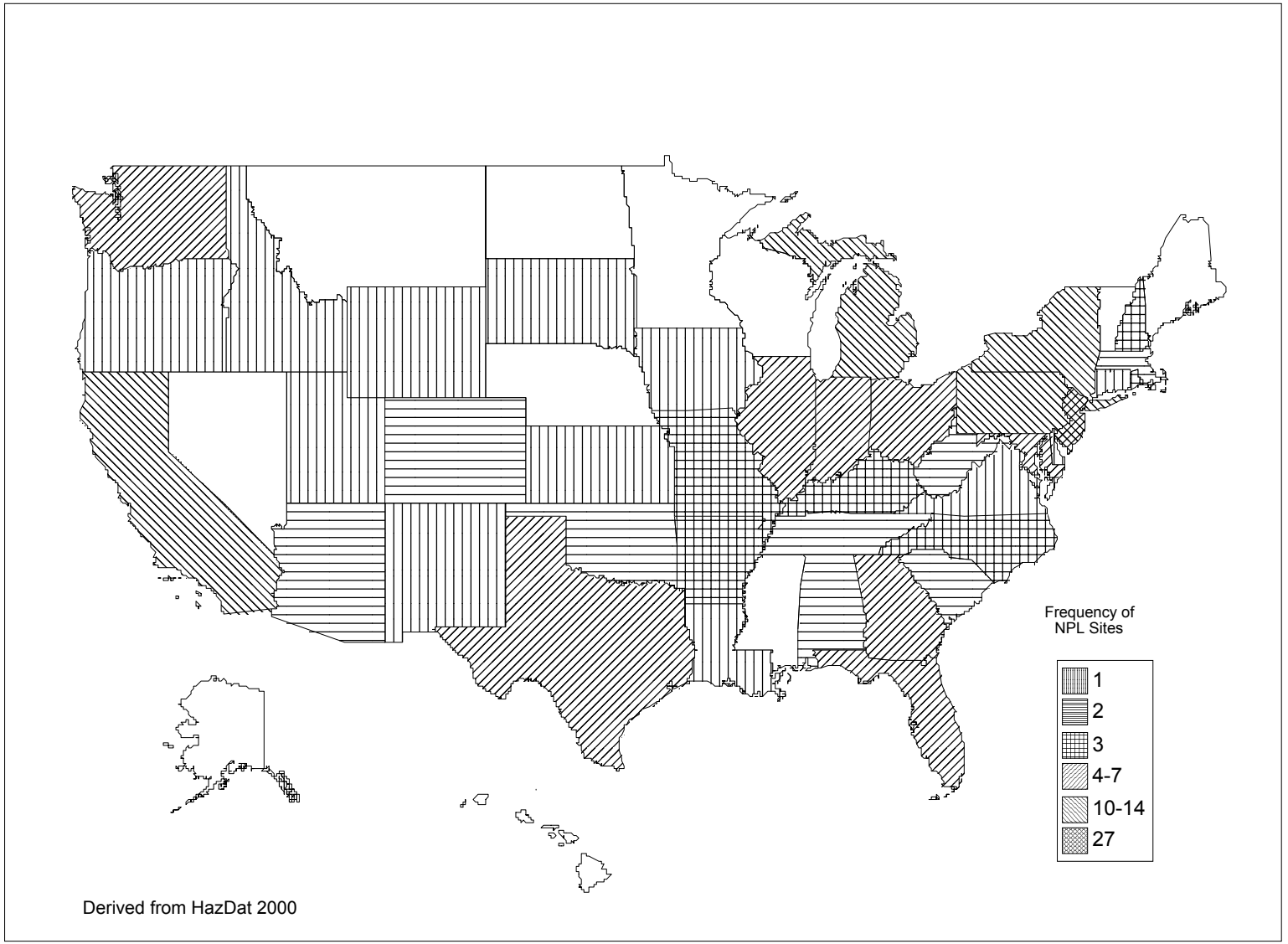
Endosulfan has been identified in at least 164 of the 1,577 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 2000). However, the number of sites evaluated for endosulfan is not known. The frequency of these sites can be seen in Figure 5-1. Of these sites, 87 are located in the United States, one is located in Guam, and one is located in the Virgin Islands (not shown).

## 5.2 RELEASES TO THE ENVIRONMENT

Endosulfan (one or both of its isomers) has been identified in a variety of environmental media (air, surface water, groundwater, soil, and sediment) collected at 164 of the 1,577 NPL hazardous waste sites (HazDat 2000).

Endosulfan has been released to the environment mainly as a result of its use as an insecticide. There are no known natural sources of the compound. Endosulfan and endosulfan sulfate are not contained in the list of chemicals for which releases are required to be reported to EPA for the SARA Section 313 Toxic Release Inventory (TRI) (EPA 1997a).

Figure 5-1. Frequency of NPL Sites with Endosulfan Contamination



The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

### 5.2.1 Air

Endosulfan (one or both of its isomers) has been identified in air samples collected at only 4 of the 164 NPL hazardous waste sites where it was detected in some environmental media (HazDat 2000).

As a result of its use as an insecticide on fruit trees, vegetables, and other crops, endosulfan is released directly to the atmosphere during application. The compound is applied principally by air-blast equipment or boom sprayers (WHO 1984). No information was found in the available literature regarding atmospheric releases from manufacturing or formulation operations, or occurrence of the compound in air samples collected at NPL sites.

### 5.2.2 Water

Endosulfan (one or both of its isomers) has been identified in 24 surface water and 103 groundwater samples collected from 164 NPL hazardous waste sites where it was detected in some environmental media (HazDat 2000).

Effluents from manufacturing and formulating facilities and surface runoff from treated croplands are sources of releases of the compound to surface waters. Endosulfan has been detected in rivers draining industrial areas where manufacturers or formulators of the compound are located (WHO 1984) and in streams adjacent to treated fields (NRCC 1975). For example, about 0.6% of the 5.6 kg/hectare of endosulfan applied to soybean fields in Mississippi was lost from the fields in runoff. Endosulfan residues were detected up to 3.5 kilometers (km) downstream from the treatment area for about 3 weeks following the last application of the compound (Willis et al. 1987).

The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

### 5.2.3 Soil

Endosulfan has been identified in 162 soil and 45 sediment samples collected at 131 of the 164 NPL hazardous waste sites where it was detected in some environmental media (HazDat 2000).

The main routes of release of endosulfan to soils are application of the compound to crops and land disposal of unused formulated pesticide products containing the compound.

The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

## 5.3 ENVIRONMENTAL FATE

### 5.3.1 Transport and Partitioning

Spray drift from aerial application of endosulfan is often the source of contamination of adjacent untreated croplands and streams (NRCC 1975). However, endosulfan released to the atmosphere may also be transported for long distances before being removed in wet and dry deposition. For example, endosulfan was detected in rainfall samples collected in 1976 and 1977 in Canada at sites inland from the Great Lakes and remote from any nearby industrial or urban contamination. Mean rainfall concentrations of 1–2 ng/L for the α-isomer and 4–5 ng/L for the β-isomer were associated with particulate deposition during rainfall events. A seasonal pattern was observed in the rainfall concentrations; endosulfan was detected in spring and summer rainfall samples but not in fall and winter samples (Strachan et al. 1980). α-Endosulfan was detected at concentrations of 0.1–1.34 ng/L in snowpack samples collected from 12 sites widely distributed throughout the Canadian Arctic in the spring of 1986 (Gregor and Gummer 1989). The source of the contamination was reported to be long-range atmospheric transport and subsequent deposition in snowfall The environmental distribution of organic chemicals in air has been characterized in terms of persistence and spatial range (Scheringer 1997). The model shows endosulfan to have a limited spatial range (approximately 15% of the earth's perimeter) and a persistence of less than 10 days. Spatial range is predicted to increase with increased sorption of the compound to particulate matter, a condition hypothesized to preclude the fast reaction of semivolatile compounds with OH radicals.

Endosulfan is also released to the atmosphere as the result of volatilization from treated plant surfaces and surface waters. The volatilization half-life from surface waters is greater than 11 days and possibly greater than 1 year (EPA 1979). The vapor pressure ($1x10^{-5}$ mmHg at 25 EC; 0.83 mPa at 20EC) and Henry's law constant ($1x10^{-5}$–$2.6x10^{-5}$ atm $m^3$/mol at 25 EC) values for endosulfan isomers and endosulfan sulfate presented in Tables 3-5 through 3-8 also suggest limited volatilization from surface waters. However, it has been reported that substantial volatilization losses from aqueous surfaces in seawater/sediment microcosm tests occur (Cotham and Bidleman 1989). The α-isomer volatilized to a much greater extent than the β-isomer during the initial 72 hours following introduction of the compounds to the test chambers. Air/water partitioning of endosulfan has a major influence on the fate of the material in the atmospheric compartment. The air/water distribution of the endosulfan isomers was determined using a wetted-wall-column apparatus.

When pure β-endosulfan was allowed to equilibrate in the apparatus, the ratio of the β-isomer to the α-isomer in the gas phase became 8:92 at 20 EC, suggesting that the β-isomer converts to the α-isomer (Rice et al. 1997). Several investigators have reported rapid initial losses of endosulfan residues from treated plant surfaces due to volatilization (Archer 1973; Terranova and Ware 1963; Ware 1967). One research group (Willis et al. 1987) attributed the limited runoff losses found in soybean fields treated with endosulfan to early losses of the compound during application and to volatilization/degradation of the compound from plant surfaces. Air sampling performed in a wind tunnel under defined conditions (20 EC; air velocity 1 m/sec; relative humidity 40–60%) showed that 60% of the initial dose of endosulfan is volatilized from French bean surfaces after 24 hours (Rudel 1997). Influences of various pesticide application formulations were not tested.

The results of several laboratory and greenhouse studies indicate that α- and β-endosulfan are strongly adsorbed to soil. In standard glass-column elution tests, both isomers were found to adsorb tightly to loamy sand, sandy loam, sandy clay loam, and sandy clay soils (Bowman et al. 1965; El Beit et al. 1981c). In model soil evaporation beds constructed to test the feasibility of treating pesticide wastes, endosulfan exhibited no movement in loamy sand soil beds up to 54 weeks after the start of the tests (Hodapp and Winterlin 1989). In air sampling studies done in a wind tunnel, 12% of the initial endosulfan application volatilized from a silty sand soil after 24 hours, as compared to 60% from plant surfaces in 24 hours (Rudel 1997). Endosulfan did not leach from sandy loam soil following incorporation of 6.7 kg/hectare of the compound (Stewart and Cairns 1974). After sampling periods of 503–828 days, 90% of the residues were found in the top 0–15 cm of soil, 9% at 15–30 cm, and 1% at 30–45 cm. In one report, an estimated $K_{oc}$ of 2000 was determined for endosulfan suggesting that

mobility in soil is expected to be slight (State of California 1991). The $K_{oc}$ values of α- and β-endosulfan in marine sediment were measured to be 3,981 and 19,953, respectively (Peterson & Batley 1993). Adsorption of α- and β-endosulfan to soil particulates is predicted based on the relationship between the octanol/water partition coefficient, $K_{ow}$ and $K_{oc}$. Using a regression-derived equation found in Lyman (1990) and the reported log $K_{ow}$ values found in Tables 3-6 and 3-7, the $K_{oc}$ values for α- and β-endosulfan can be estimated to be 2,887 and 1,958, respectively.

Adsorption is also important in aquatic systems. For example, 82–85% of the endosulfan residues in water samples taken from the Rhine River (0.2–0.6 ppb) were associated with the particulate phase (Greve and Wit 1971).

Endosulfan does not bioaccumulate to high concentrations in terrestrial or aquatic ecosystems. In aquatic ecosystems, residue levels in fish generally peak within 7 days to 2 weeks of continuous exposure to endosulfan. Maximum bioconcentration factors (BCFs) are usually less than 3,000, and residues are eliminated within 2 weeks of transfer to clean water (NRCC 1975). A maximum BCF of 600 was reported for α-endosulfan in mussel tissue (Ernst 1977). In a similar study, endosulfan, isomers not specified, had a measured BCF of 22.5 in mussel tissue (Roberts 1972). Tissue concentrations of α-endosulfan fell rapidly upon transfer of the organisms to fresh seawater; for example, a depuration half-life of 34 hours (Ernst 1977). Higher BCFs were reported for whole-body and edible tissues of striped mullet (maximum BCF=2,755) after 28 days of exposure to endosulfan in seawater (Schimmel et al. 1977). However, tissue concentrations decreased to undetectable levels 48 hours after the organisms were transferred to uncontaminated seawater. Similarly, a BCF of 2,650 was obtained for zebra fish exposed to 0.3 µg/L of endosulfan for 21 days in a flow-through aquarium (Toledo and Jonsson 1992). It was noted that endosulfan depuration by fish was rapid, with approximately 81% total endosulfan eliminated within 120 hours when the fish were placed in a tank of water containing no endosulfan.

In freshwater studies, mosquito fish, catfish, and freshwater eels were exposed to endosulfan in static tests. Maximum tissue concentrations in mosquito fish (933 µg/kg; α-isomer) were found in fish exposed to 16 µg technical-grade endosulfan/L for 24 hours. The maximum tissue concentrations in fish exposed to 2 µg technical-grade endosulfan/L for 7 days was 143 µg α-isomer/kg. Mean endosulfan residues in catfish were 61.3 µg/kg (α-isomer) following 7 days of exposure to 0.7 µg technical-grade endosulfan/L. After 43 hours of exposure to 1 µg technical-grade endosulfan/L, mean residues in freshwater eels were 0.145 µg/kg α-isomer, 0.138 µg/kg for the β-isomer, and 0.117 µg/kg for endosulfan sulfate (Novak and Ahmad 1989).

Plant tissue residues are usually the result of surface deposition of the compound (EPA 1992c). Very limited data indicate that endosulfan and its metabolites are translocated in plants. In one study, the above-soil portion of bean and sugar beet plants were immersed in a water solution containing endosulfan and then allowed to dry under both laboratory controlled and semi-controlled greenhouse conditions (Beard and Ware 1969). Both α- and β-endosulfan and its metabolites (endosulfan diol, ether, and sulfate) were found to penetrate plant tissue and were translocated from the leaves to the roots of both bean and sugar beet plants. Translocation occurred at a higher rate in greenhouse plants than in laboratory plants. Under semi-controlled greenhouse conditions for both beets and beans, the highest residues were found in the plant extracts (indicating penetration of the material), with lower concentrations deposited on leaves, and with the lowest levels in the roots. The residue levels on both the plant surface and in tissue extracts decreased during the course of the experiment, while the levels in the roots increased. In bean plant roots, translocation (day 4) was as follows: isomer β (0.28 ppm) > ether (0.18 ppm) > sulfate (0.08 ppm). No residue of the α-isomer or the diol appeared in bean roots by day 4. In sugar beet roots, residue levels were as follows: α-isomer (2.8 ppm) > β-isomer (0.5 ppm) > ether (0.1 ppm), sulfate (0.1 ppm) > diol (0 ppm) (Beard and Ware 1969).

The results of metabolism studies with laboratory animals and livestock indicate that endosulfan does not bioconcentrate in fatty tissues and milk. Lactating sheep administered radiolabeled endosulfan produced milk containing less than 2% of the label. Endosulfan sulfate was the major metabolite in milk (Gorbach et al. 1968). A half-life of about 4 days was reported for endosulfan metabolites in milk from survivors of a dairy herd accidentally exposed to acutely toxic concentrations of endosulfan; endosulfan sulfate accounted for the bulk of the residues detected in the milk (Braun and Lobb 1976). No endosulfan residues were detected in the fatty tissue of beef cattle grazed on endosulfan-treated pastures for 31–36 days (detection limits of 10 ppm for endosulfan, 40 ppm for endosulfan diol); the animals began grazing 7 days after treatment of the pastures. Some residues were detected in the fatty tissue of one animal administered 1.1 mg/kg/day of endosulfan in the diet for 60 days. No endosulfan residues were detected in milk from cows fed silage containing 0.41–2.35 ppm endosulfan for 21 days (Beck et al. 1966).

In field trials following multiple aerial applications of endosulfan for tsetse fly control in Africa over a 3-month period, residues of the compound in fish tissues decreased to low concentrations within 3 months after spraying. The fish tissue residues were still detectable after 12 months. Residue concentrations in fish-eating birds and crocodiles were similar to fish tissue residue levels; endosulfan did not biomagnify in the food chain (HSDB 1999).

### 5.3.2 Transformation and Degradation

#### 5.3.2.1 Air

The α- and β-isomers of endosulfan undergo photolysis in laboratory tests after irradiation in polar solvents and upon exposure to sunlight on plant leaves. The α-isomer also undergoes isomerization to the β-isomer, which is relatively more stable (Dureja and Mukerjee 1982). A photolytic half-life of about 7 days was reported for endosulfan by EPA (1982c). The primary photolysis product is endosulfan diol, which is subsequently photodegraded to endosulfan α-hydroxyether. Endosulfan sulfate is stable to direct photolysis at light wavelengths of >300 nm; however, the compound reacts with hydroxy radicals, with an estimated atmospheric half-life of 1.23 hours (HSDB 1999).

#### 5.3.2.2 Water

Endosulfan undergoes hydrolysis to endosulfan diol in surface water and groundwater. The rate of hydrolysis is influenced by pH. Half-life values reported in the literature vary somewhat. The chemical degradation of α- and β-endosulfan was studied under both anaerobic and aerobic environments. Under aerobic conditions, both hydrolysis and oxidation of endosulfan can occur, while under anaerobic conditions, only hydrolysis can occur. The hydrolytic half-lives for α- and β-endosulfan under anaerobic conditions at pH 7 were 35 and 37 days, respectively (Greve and Wit 1971). At pH 5.5 the half-lives were 151 and 187 days, respectively. Under aerobic conditions, the half-lives decreased. At pH 7, the half-lives of the chemical degradation (hydrolysis and oxidation) of both α- and β-endosulfan were 23 and 25 days, respectively, while at pH 5, the half-lives were 54 and 51 days, respectively. At T=20 EC and pHs of 5.5 and 8.0, the half-lives of α-endosulfan in distilled water were 11.3 and 5.3 days, respectively (Kaur et al. 1998). The half-lives at pH 7.23 and 69.5 EC for α- and β-endosulfan were 1.2 and 0.96 hours, respectively (EPA 1987f). Losses of endosulfan, at an initial concentration of 0.5 mg/L, from natural lake water and tap water were 89 and 69%, respectively (Ferrando et al. 1992). The natural water was more alkaline than the tap water; this finding is in agreement with other studies. The half-life of the pesticide in the tap water was approximately 68 hours.

Endosulfan in aqueous solutions is also expected to undergo biodegradation. In laboratory tests at pH 7 and 20 EC, *Pseudomonas* bacteria degraded endosulfan (isomers not specified) under aerobic conditions with a half-life of about 1 week (Greve and Wit 1971). Biotic and abiotic transformations of endosulfan in seawater/sediment microcosms have been reported (Cotham and Bidleman 1989). In biotic tests, half-

lives for the α- and β-isomers in seawater-only microcosms (pH$8) were about 5 and 2 days, respectively. In seawater-only microcosms under sterile conditions at a pH of 8 or higher, the half-life for the α-isomer was 2–3 days, whereas the half-life for the β-isomer was 1–2 days. Half-lives were longer in seawater/ sediment microcosms, possibly because of the lower pHs (7.3–7.7) in these test systems; half-lives were 22 and 8.3 days for the α- and β-isomers, respectively. Endosulfan diol was the main metabolite identified.

#### 5.3.2.3 Sediment and Soil

Endosulfan released to soil is most likely subjected to photolysis (on soil surfaces), hydrolysis (under alkaline conditions), or biodegradation. Endosulfan has been shown to be biodegraded by a wide variety of soil microorganisms in numerous studies. Sixteen of 28 species of fungi, 15 of 49 species of soil bacteria, and 3 of 10 species of actinomycetes metabolized radiolabeled endosulfan in a laboratory study under aerobic conditions (Martens 1976). Endosulfan sulfate was the major product of the fungal metabolism, whereas the bacterial transformation produced endosulfan diol. Degradation of endosulfan by soil fungi and bacteria has also been reported (El Beit et al. 1981b). Biotransformation occurs under both aerobic and anaerobic conditions. Aerobic incubation of soil with endosulfan yielded mainly endosulfan sulfate (30–60%), some endosulfan diol (2.6%), and endosulfan lactone (1.2%) (Martens 1977). Flooded (anaerobic) incubation produced mainly endosulfan diol (2–18%), endosulfan sulfate (3–8%), and endosulfan hydroxyether (2–4%). In aqueous nutrient media (20EC) containing a mixed culture of microorganisms isolated from a sandy loam soil, endosulfan was reported to be transformed to endosulfan diol with half-lives of about 1.1 and 2.2 weeks for the α- and β-isomers, respectively (Miles and Moy 1979).

A two-membered bacterial coculture was found to aerobically degrade α- and β-endosulfan efficiently without accumulating any of its metabolites. However, the degradation of soil-bound endosulfan was slower by 4-fold than in culture media; only 50% of the material (initially at 50 ppm) was degraded in 4 weeks (Awasthi et al. 1997). A field study report stated that endosulfan was transformed to endosulfan sulfate following incorporation of 6.7 kg/hectare of the pesticide into sandy loam soil (Stewart and Cairns 1974). The half-lives for the α- and β-isomers were reported to be 60 and 800 days, respectively. *Pseudomonad* microbes have been reported to isomerize β-endosulfan to α-endosulfan and biodegrade both isomers to endosulfan alcohol and endosulfan ether (U.S. Department of Interior 1978). In a field study conducted from 1989–1990 in northern India, dissipation of endosulfan in sandy loam soil was examined (Kathpal et al. 1997). It was found that α-endosulfan could be detected up to 14 and 28 days in

two different soil plots, while β-endosulfan could be detected up to 70 and 238 days. An overall half-life for endosulfan degradation ranged from 39.5 to 42.1 days. Endosulfan residues dissipated to an extent of 92–97% in the first 4-week period of application and by about 99% in 238 days. A residue half-life of 15 days for endosulfan (unspecified isomer) has been reported in Australian black soil when incubated at 30 EC at field capacity moisture level (Kathpal et al. 1997). Fate and movement of endosulfan isomers and endosulfan sulfate under field application conditions have been studied (Antonious and Byers 1997). New modes of cultivation showed reduced runoff water and sediment loss and reduced endosulfan movement from the site of application to the surface water runoff. Results indicated vertical movement of the pesticide through the vadose zone at a concentration of 0.63 µg/L. Soil core data shows endosulfan leaches from 23 to 46 cm into the soil (Antonious and Byers 1997).

On plant surfaces, as in soils, numerous studies have demonstrated that endosulfan is oxidized to endosulfan sulfate. Initial residues of endosulfan on treated vegetables generally range from 1 to 100 mg/kg. However, residue levels typically decrease to less than 20% of initial levels within 1 week after treatment (NRCC 1975). Residues of endosulfan isomers are generally negligible after 2–3 weeks; the α-isomer is much less persistent than the β-isomer. In most plant residue studies, endosulfan sulfate residue levels tend to increase relative to the parent isomers and other metabolites and appear to be very persistent (Coleman and Dolinger 1982).

## 5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to endosulfan depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. In reviewing data on endosulfan levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable.

### 5.4.1 Air

Endosulfan has been detected in only a limited number of ambient air samples taken in the United States. As part of EPA's National Pesticide Monitoring Program conducted between 1970 and 1972, in 1970, only 6.6 and 1% of the ambient air samples collected at selected sites in 14 states contained α- and β-endosulfan, respectively. Mean concentrations for the positive samples were 112 ng/$m^3$ for the α-isomer (maximum 2,257 ng/$m^3$) and 22 ng/$m^3$ for the β-isomer (maximum 55 ng/$m^3$). Sampling sites were selected for their potentially high concentrations of pesticides in ambient air. Endosulfan was not

detected in any of the ambient air samples collected from sites in 16 states in 1971 or 1972 (Kutz et al. 1976). α-Endosulfan was detected at a mean concentration of 0.078 ng/$m^3$ in ambient air samples collected in Columbia, South Carolina from June to mid-August 1978 (Bidleman 1981). Air samples obtained at a rural site near Egbert, Ontario, Canada in 1988–1989 contained an average of 3.7 ng/$m^3$ of the local and regionally used pesticide, endosulfan (Hoff et al. 1992). The average air concentration of α-endosulfan over a 14-month period in 1991–1992 in Bloomington, Indiana, was 86 pg/$m^3$ (0.086 ng/$m^3$) (Burgoyne 1993). Diurnal variations in ambient air concentrations of endosulfan were noted for samples taken in September 1994 near Bloomington, Indiana (Wallace and Hites 1996). Air samples taken over a 6-hour period in the morning had twice the concentration (0.031 ng/$m^3$) than those collected at midnight.

Rainfall samples collected in the Great Lakes area of Canada in 1976 and 1977 contained mean concentrations of 1–2 ng/L (parts per trillion) α-endosulfan and 4–5 ng/L β-endosulfan. Endosulfan was detected in spring and summer rainfall samples but not in samples collected during the fall and winter (Strachan et al. 1980). α-Endosulfan has also been detected in snowpack samples obtained from widely distributed sites in the Canadian Arctic. Endosulfan concentrations in samples collected in the spring of 1986 ranged from 0.1 to 1.34 ng/L (Gregor and Gummer 1989).

### 5.4.2 Water

Although endosulfan and endosulfan sulfate have been found at low concentrations in a few surface water and groundwater samples collected at hazardous waste sites (see Section 5.2.2), no information was found in the available literature regarding current concentrations of endosulfan or endosulfan sulfate in domestic surface waters not associated with these sites. The World Health Organization (WHO) reported that although endosulfan has been detected in agricultural runoff and in surface waters draining industrialized areas, contamination of surface waters with this compound does not appear to be widespread (WHO 1984). EPA (1982c) stated that endosulfan concentrations in surface water are generally <1 ppb.

In a survey of streams in the western United States conducted by the U.S. Geological Survey (USGS) from 1968 to 1971, endosulfan was detected in only 1 of the 546 surface water samples collected, at a concentration of 0.02 µg/L (EPA 1980a). α-Endosulfan was detected in water samples collected in 1980 from Inner Harbor Navigation Canal of Lake Pontchartrain (New Orleans, Louisiana). At ebb and flood tide, it was found at levels of 0.8 ppt (1.5 m ebb tide), 0.9 ppt (1.5 m flood tide), and 3 ppt (10 m flood tide) (McFall et al. 1985). Detection limits were not reported. α-Endosulfan was determined in the surface microlayer and suspended solids at 3 of 5 stations along the Niagara River in 1981 at levels

ranging from 0 to 0.0204 µg/L and from 0 to 0.025 mg/kg, respectively (level of detection, 0.0001 µg/L in water and 0.001 mg/kg in suspended solids) (Maguire et al. 1983). α-Endosulfan was not detected in subsurface water at any of the stations. Concentrations of β-endosulfan in the surface microlayer, subsurface water, and suspended solids were below the detection limits, except at one station where β-endosulfan was found at a level of 0.021 mg/kg in suspended solids (Maguire et al. 1983).

Rain samples collected from around the Great Lakes contained both α- and β-endosulfan (Strachan and Huneault 1979). Mean concentrations of α-endosulfan in rain samples from the Great Lakes ranged from 0.1 ng/L (n=13) to 3.8 ng/L (n=16). Mean concentrations of β-endosulfan in rain samples ranged from 1 (n=14) to 12 ng/L (n=16). The endosulfans were not found to any significant extent in snow-core samples (Strachan and Huneault 1979). Detection limits were not reported.

Runoff waters from agricultural areas have been found to contain low concentrations of endosulfan in the aqueous phase and higher concentrations in the particulate phase of the runoff. For example, runoff from a soybean field in Mississippi treated with 5.6 kg endosulfan/hectare was reported to contain maximum concentrations of 0.019 mg/L and 8.7 mg/kg (α- and β-isomers) in the aqueous and suspended sediment phases, respectively (Willis et al. 1987). The samples were collected within 3 weeks of the last application of the compound. Samples taken from runoff ditches from an agricultural area near Lake Erie in Ontario, Canada, contained endosulfan residue (unspecified isomer/sulfate content) concentrations of <0.002–0.18 µg/L in runoff water and 1–62 µg/kg in bottom mud. Soils from a farm located near the runoff ditch contained 640 µg endosulfan residues/kg (Miles and Harris 1971). Endosulfan was detected in stream waters collected from 11 agricultural watersheds in Ontario from 1975 to 1977 (Frank et al. 1982). The overall mean for all 11 watersheds was 3.7 ng/L in 1975–1976 and 2.0 ng/L in 1976–1977. Detection limits were not reported. Endosulfan exceeded the water quality criteria of 3.0 ng/L established by the International Joint Commission for lake and stream waters entering the Great Lakes in 14% of the samples. Endosulfan appeared in water samples throughout the year (outside the spray season); it entered water with storm runoff throughout the season because of its persistence in soil (Frank et al. 1982). In the early 1990s, endosulfan was found in the waters and sediment of the canals of South Florida (Miles and Pfeuffer 1997). α-Endosulfan and endosulfan sulfate residues as high as 0.22 and 0.45 µg/L, respectively, were observed in confined surface waters in the Homestead area. Such values exceed the Florida water quality criterion.

From February 1995 to June 1997, endosulfan concentrations (isomers not specified) in river, well, lagoon, and spring water samples were studied from the greater Cholutecan River Basin of Honduras

(Kammerbauer and Moncada 1998). Endosulfan was found predominantly in Choluteca well water and in Yeguare river water at approximately 0.06 mg/kg. It was also found in Choluteca river water, Zamorano well/lagoon water, and La Lima well/lagoon water at concentrations ranging from 0.01 to 0.02 mg/kg. In a study of water samples collected from the Segre river basin in Spain from May–June 1995, endosulfan (isomers not specified) was detected in four of six samples at approximately 0.01 µg/L (Planas et al. 1997).

Three out of nine groundwater samples extracted from Dobrich in northeastern Bulgaria contained endosulfan (isomers not specified) ranging from 0.020 to 0.025 µg/L in March 1996 (Pulido-Bosch et al. 1999). The suspected source of this pollution was from agricultural practices in the region.

### 5.4.3 Sediment and Soil

Endosulfan has been detected in only a limited number of urban and agricultural soils in the United States. The National Soils Monitoring Program conducted in 1972 included the collection of 1,483 soil samples from 37 states. The α- and β-isomers of endosulfan and endosulfan sulfate were each detected in only one sample at <0.01 ppm (Carey et al. 1979a). Endosulfan was not detected (method detection limit of 1 µg/kg) in sediments collected from the Central Columbia plateau of the United States (Munn and Gruber 1997). In soil samples collected from five metropolitan areas in the United States as part of the Urban Soils Monitoring Program, endosulfan sulfate was detected in samples from two cities: Macon, Georgia (in 1 of 43 samples) and Baltimore, Maryland (in 1 of 156 samples) at concentrations of <0.01 ppm (Carey et al. 1979b). Surveys of agricultural soils in North America have determined that endosulfan residue levels (α- and β-isomers and endosulfan sulfate) are typically less than 1 mg/kg (WHO 1984).

From February 1995 to June 1997, endosulfan concentrations (isomers not specified) in soil samples were studied from the greater Cholutecan River Basin of Honduras (Kammerbauer and Moncada 1998). Endosulfan was found in Choluteca and La Lima soil at concentrations ranging from 0.01 to 0.02 mg/kg.

Soils sampled at two sites in creek beds and drainage ditches in an agricultural area in the Point Mugu watershed near Oxnard, California, contained endosulfan at concentrations between 20 and 30 ppm. The majority of the other sites had much lower concentrations (Leung et al. 1998).

### 5.4.4 Other Environmental Media

Levels of endosulfan and endosulfan sulfate in domestic foodstuffs have been determined as part of FDA's Total Diet Studies series. The FDA's 1995 pesticide residue monitoring program found 81 instances of detection of endosulfan in 3 market baskets consisting of 783 items (FDA 1995). In the 1980–1982 survey of 27 cities (Gartrell et al. 1986), individual food items were separated into food groups, and foods in each group were blended in amounts proportional to weights consumed to yield homogeneous composites. α-Endosulfan, β-endosulfan, and endosulfan sulfate were detected only in the leafy vegetable, garden fruit, and fruit food groups. The isomers and the breakdown product were not found in the following food groups included in the survey: dairy products; meat, fish, and poultry; grain and cereal products; potatoes (α- and β-isomers); legume vegetables; root vegetables; oils and fats; sugar and adjuncts; or beverages.

Domestic and imported pears and tomatoes were collected and analyzed for pesticide residues from July 1992–July 1993 (Roy et al 1995). Endosulfan (both isomers) was found in 471 of 1,219 domestic tomato samples at a maximum concentration of 0.2 mg/kg and in 80 of 144 imported tomato samples at a maximum concentration of 0.55 mg/kg. In pears, endosulfan was found in 144 of 710 domestic samples at a maximum concentration of 1.1 mg/kg, and in 4 of 949 imported samples at a maximum concentration of 0.13 mg/kg.

Studies of carrot and tomato crops sprayed with endosulfan 2 to 8 days prior to harvest showed that more pesticide remains in the pulp than in the juices of these vegetables. Washing and peeling the vegetables lowered the endosulfan concentration considerably (Burchat et al. 1998).

Neither endosulfan nor endosulfan sulfate was detected in surveys of the milk supply of the southern region of Ontario, Canada conducted in 1970–1971 and 1973 (Frank et al. 1975). In Burley tobacco, when the crop was harvested immediately after treatment with 0.5 pound/acre of endosulfan, the total endosulfan residue levels (isomers and sulfate) were reported to average 23.2 ppm after curing for 4 months. Average total residues decreased to 2.2 ppm when the time between treatment and harvest was increased to 28 days (Dorough et al. 1973).

## 5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The main route of exposure to endosulfan for the general population is ingestion of food containing residues of endosulfan as a result of application or bioconcentration. Levels of endosulfan and endosulfan sulfate in domestic foodstuffs have been determined as part of FDA's Total Diet Studies series. The FDA's 1995 pesticide residue monitoring program found 81 instances of detection of endosulfan in 3 market baskets consisting of 783 items (FDA 1995). A total diet study conducted by the FDA from June 1984 to April 1986 studied the dietary intake of various pesticides by different age groups in the population (Gunderson 1995b). The mean daily intakes per unit of body weight (mg/kg body weight/day) for α-endosulfan were $1.3x10^{-6}$ for ages 14–16 years, $1.8x10^{-6}$ for ages 25–30 years and $2.0x10^{-6}$ for ages 60–65 years while for β-endosulfan, the mean daily intakes were $2.1x10^{-6}$ for ages 14–16 years, $2.5x10^{-6}$ for ages 25–30 years, and $2.9x10^{-6}$ for ages 60–65. In the same type of study conducted from July 1986 to April 1991, the mean daily intakes per unit body weight (mg/kg body weight/day) for α-endosulfan were $2.3x10^{-6}$ for ages 14–16 years, $3.0x10^{-6}$ for ages 25–30 years, and $3.8x10^{-6}$ for ages 60–65 years, while for β-endosulfan, the mean daily intakes were $6.5x10^{-6}$ for ages 14–16 years, $6.8x10^{-6}$ for ages 25–30 years, and $9.9x10^{-6}$ for ages 60–65 years (Gunderson 1995a). Studies of foods in India have identified endosulfan in okra at an average concentration of 0.22 µg/g (Mukherjee and Gopal 1996). Dietary characterization of food and beverages were made during a study of human exposure in the lower Rio Grande valley (Berry et al. 1997). A total of 30 different pesticides were detected in 54 local food samples; endosulfan was one of the most commonly found residues. Endosulfan sulfate, α-endosulfan, and β-endosulfan residues were found in 4–6 foods sampled in the spring at concentrations ranging from 0.005 to 0.072, 0.007 to 0.050, and 0.002 to 0.095 µg/g, respectively (Berry et al. 1997). Howard (1991) has estimated an average daily intake of endosulfan via food at 1.18 µg by averaging the average daily intake values for the years 1971–1976.

In Hsinchu, Taiwan, the dietary intake of α- and β-endosulfan was studied from June 1996 to April 1997 (Doong and Lee 1999). β-Endosulfan was not detected in any of the 14 different foods studied, including fruits, meats, seafood, and cereal, and α-endosulfan, by contrast, was found in 78 of 149 samples at an average concentration of 2.76 ng/g wet weight. Based on the average Taiwanese diet, the estimated daily intake of α-endosulfan was $6.24x10^{-4}$ mg body weight/day.

Exposure to endosulfan residues in tobacco products could be another important source of general population exposure. Endosulfan residues in tobacco leaves and finished tobacco products were reviewed by EPA (1982a). For example, auction market tobacco had a mean residue of <0.2–14 ppm endosulfan

and endosulfan sulfate in the early 1970s, and cigarettes sold in 1973 contained a mean residue of 0.83 ppm endosulfan. No information was found in the available literature regarding endosulfan concentrations in cigarette smoke.

In occupational settings, exposure to endosulfan is mainly via the dermal and inhalation routes. Although workers involved in the manufacture and formulation of pesticide products containing endosulfan are potentially exposed to high concentrations of the compound, actual exposure is probably limited by the use of engineering controls and personal protection equipment. The highest documented dermal and inhalation exposures have been reported for agricultural workers involved in the spray application of endosulfan products. Among these individuals, mixers and applicators have the highest potential for direct exposure. For example, during spray application of endosulfan on fruit orchards using air-blast equipment, a mean dermal exposure of 24.7 mg/hour (range, 0.6–95.3 mg/hour) and a mean inhalation exposure of 0.02 ng/hour (range, 0.01–0.05 ng/hour) were estimated in one study (Wolfe et al. 1972). In another study in which endosulfan was applied to fruit orchards using air blast equipment, total exposures of 0.27–2.2 mg/hour were reported during mixing operations, and 4.1–9.3 µg/hour were reported during spraying operations (Oudbier et al. 1974). Estimates of mean dermal exposure of workers who apply endosulfan to fields of tobacco in Kentucky have been made (Lonsway et al. 1997). The mean dermal exposures to mixers and sprayers of endosulfan via a tractor mounted boom sprayer and highboy were 16.18 and 8.06 mg/kg/day, respectively. Not using protective measures when spraying endosulfan can lead to poisoning. In the Punjab area, 8.6% of poisonings of all types admitted to the hospital in 1989 were due to endosulfan (Singh et al. 1992). Singh cautions that applications of oil to body surfaces before beginning work in the fields will increase the absorption of endosulfan. Furthermore, the presence of cuts on the legs or hands facilitates entry of pesticides to the body's circulatory system. Studies of pesticide penetration through protective clothing (Archibald et al. 1994a) indicated that rubber or tyvek provided the best protection.

In one study, the exposure of an individual involved in spraying the compound, while wearing protective overalls, gloves and breathing mask, was examined (Arrebola et al. 1999). The individual applied 300L of an endosulfan mixture to plants and later gave 10 urine samples over the course of 3 days. The study found that the highest concentrations occurred 4.3 hours after exposure with concentrations for α- and β-endosulfan reaching 4,289 and 1,079 pg/mL, respectively. The half-lives for the excretion of α- and β-endosulfan were determined to be 23 and 27 hours, respectively. Between October 1995 and September 1997, 18 cases of endosulfan poisoning by accidental overexposure during spray applications were reported at the medical center in Haryana, India (Chugh et al. 1998). Ten fatal cases of endosulfan

exposure were reported in a survey of pesticide poisoning incidents in Spain from 1991 to 1996 (Garcia-Repetto et al. 1998).

Endosulfan is a popular pesticide with greenhouse chrysanthemum producers. Surveys of usage patterns and potential exposure were conducted in Ontario (Archibald et al. 1994b). Collection and analysis of α- and β-endosulfan and endosulfan sulfate in greenhouse air have been described (Vidal et al. 1997). Results indicate that 7.5% of the initial concentration of endosulfan remained in the greenhouse atmosphere 24 hours after application.

The National Occupational Exposure Survey (NOES), conducted by NIOSH from 1980 to 1983, estimated that 3,205 workers in the agricultural services industry were exposed to endosulfan in the workplace in 1980 (NIOSH 1984). The NOES database does not contain information on the frequency, concentration, or duration of exposure of workers to any chemicals; the survey provides only estimates of the number of workers potentially exposed to chemicals in the workplace.

## 5.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in 2.7 Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

Infants are particularly sensitive to endosulfan due to their higher intestinal permeability and immature detoxification system. In a study of human breast milk conducted in the country of Kazakhstan in 1994, the concentration of various contaminants, including endosulfan, were determined (Lutter et al. 1998). Of the 91 samples of breast milk analyzed, only 2 had detectable quantities of endosulfan (concentrations not specified). In another study, the transfer of endosulfan and its metabolites were studied in breast milk of

lactating goats (Indraningsih et al. 1993). Endosulfan residues in milk of goats administered a daily dose of 1 mg/kg for 28 days reached 0.02 mg/kg on day 1. However, by day 8, no residues or metabolites could be detected. Likewise, no endosulfan residues could be detected in the tissues of kids except for α-endosulfan in the liver at a concentration of 0.0011 mg/kg. Analysis of milk from cows which ingested potentially poisonous amounts of endosulfan revealed a level of >1 ppm endosulfan immediately following the intoxication (Braun and Lobb 1976). This level decreased to 1 ppb at the end of 35 days with a half-life of about 4 days in milk. No endosulfan residues were detected (detection limit= 0.01 mg/L) in milk from cows fed silage containing 0.41–2.35 ppm endosulfan for 21 days (Beck et al. 1966).

The FDA pesticide residue monitoring program analyzes selected baby foods for endosulfan under its Total Diet Study. In the period 1991–1995, 29 incidences of detectable amounts of endosulfan were reported from analyses of 276 items purchased in 12 separate collections (FDA 1995).

A total diet study conducted by the FDA from June 1984 to April 1986 studied the dietary intake of various pesticides by different age groups (Gunderson 1995b). The mean daily intakes per unit of body weight (mg/kg body weight/day) for α-endosulfan were $2.6x10^{-6}$ for children 6–11 months of age and $4.5x10^{-6}$ for children 2 years of age, while for β-endosulfan the mean daily intakes were $5.4x10^{-6}$ for children 6–11 months of age and $8.1x10^{-6}$ for children 2 years of age. In the same type of study conducted from July 1986 to April 1991, the mean daily intakes per unit body weight (mg/kg body weight/day) for α-endosulfan were $3.2x10^{-6}$ for children 6–11 months of age and $7.6x10^{-6}$ for children 2 years of age, while for β-endosulfan, the mean daily intakes were $1.69x10^{-5}$ for children 6–11 months of age and $2.38x10^{-5}$ for children 2 years of age (Gunderson 1995a). From October 1984 through September 1991, 27 market basket samples of foods eaten by infants and children were collected and analyzed for pesticide residues (Yess et al. 1993). These foods included fruits/fruit juices, baked goods, cereals, combination meat/poultry dinners, desserts, infant formulas, and vegetables. Concentrations of endosulfan (both isomers) found in foods eaten by infants were 0.001 mg/kg in 1 sample of desserts; 0.004 mg/kg (maximum) in 5 samples of applesauce; 0.0007 mg/kg in 1 sample of strained orange/orange pineapple juice; 0.010 mg/kg (maximum) in 3 samples of peaches; 0.053 mg/kg (maximum) in 20 samples of pears/pineapples; 0.002 mg/kg in 1 sample of prunes/plums; and 0.004 mg/kg (maximum) in 2 samples of green beans. Concentrations of endosulfan (both isomers) found in foods eaten by both infants and children were 0.046 mg/kg (maximum) in 25 samples of apples and 0.041 mg/kg (maximum) in 20 samples of raw pears.

A similar survey conducted in 1977–1978 in 10 cities focused on infant and toddler diets (Podrebarac 1984a). Of 11 food groups included in that survey, β-endosulfan was found in the vegetables and fruit/ fruit juices food groups for the toddler diet at 0.001–0.004 ppm. Endosulfan sulfate was found in the potato and sugar and adjunct groups in the infant diet at 0.001–0.004 ppm and in the vegetable and potato groups in the toddler diet at 0.004–0.005 ppm. The compounds were not detected in the following food groups included in the survey: drinking water; fresh whole milk; other dairy products; meat, fish and poultry; grain and cereal products; oils and fats; or beverages. In a total of 98 infant diet composite samples, β-endosulfan was detected in 1 composite and endosulfan sulfate was found in 2 composites. Out of a total of 110 toddler diet composite samples, the α-isomer, β-isomer, and sulfate forms were detected in 1, 2, and 2 composites, respectively.

Although child exposure to endosulfan through inhalation has not been studied, it is anticipated that exposure through this route is extremely low. The vapor pressure of endosulfan is negligible ($1.0x10^{-5}$ mmHg at 25 EC) (Coleman and Dolinger 1982), suggesting that an extremely small amount is expected to exist in the vapor phase at environmental conditions (Bidleman 1988). Although the vapor density is reported as 14 (HCDB 1986), suggesting that vapor-phase endosulfan is heavier than air, inhalation exposure is not expected to be significant to children due to the extremely small amount of endosulfan that will exist in the vapor-phase at environmental conditions.

Since young children spend more time outdoors and have a tendency to ingest soil, it is important to examine child exposure through ingestion. Although no studies have been conducted concerning this subject, exposure through ingestion of soil is not expected to be significant. Endosulfan undergoes many degradative processes in the environment, such as hydrolysis, photolysis, oxidation, and biodegradation, that will reduce its concentration in soil. Degradation half-lives for the combined effects of hydrolysis and oxidation in moist soils range from 23 to 54 days depending on pH (Greve and Wit 1971). Photolysis on soil surfaces is expected to occur as well. The photolytic half-life of endosulfan on plant leaves was reported to be 7 days (EPA 1982a). Endosulfan has also been shown to be biodegraded by both bacteria and fungi in the soil environment (El Beit et al. 1981b; Martens 1976). Both abiotic and biotic processes are therefore expected to decrease endosulfan concentrations in soil environments. However, children may potentially be exposed to endosulfan from oral/dermal exposure if they play in the soil of contaminated areas such as hazardous waste sites. Based on degradation of endosulfan in the environment, child exposures to endosulfan through soil ingestion is not expected to be very significant.

No studies could be located discussing exposure of children to endosulfan after household use by parents. Likewise, no exposure studies could be located concerning the exposure of children whose parent(s) work with endosulfan on a daily basis. However, many studies suggest that pesticides used in the workplace can be brought home through contaminated clothing, shoes, and other materials (NIOSH 1995). Although no documented cases could be located, the possibility exists that endosulfan used in a work setting may be brought home by working parents. It is uncertain what amount of endosulfan exposure a child may encounter under these situations.

## 5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Farmers and pesticide applicators using endosulfan to control insects on crops appear to be the only workers currently exposed to potentially high concentrations of the compound. Members of the general population with potentially high exposure to endosulfan or endosulfan sulfate include people living near the 164 NPL sites currently known to be contaminated with these compounds. Exposure of the general population to higher concentrations of endosulfan may result from chemical contact with or ingestion of contaminated hazardous waste site media, principally soils. The size of these populations and the concentrations of endosulfan in the contaminated media to which these people would potentially be exposed have not been adequately characterized.

In addition to individuals who are occupationally exposed to endosulfan (see Section 5.5), there are several groups within the general population that have potentially high exposures (higher than background levels) to endosulfan. These populations include individuals living in proximity to sites where endosulfan was produced or sites where endosulfan was disposed of, and individuals living near one of the 164 NPL hazardous waste sites where endosulfan has been detected in some environmental media (HazDat 2000).

## 5.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of endosulfan is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (NTP), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of endosulfan.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

### 5.8.1 Identification of Data Needs

**Physical and Chemical Properties.** The physical/chemical properties of endosulfan are sufficiently well characterized to enable assessment of the environmental fate of the compound (Budavari 1996; Coleman and Dolinger 1982; EPA 1982c, 1987b; Hansch and Leo 1995; HSDB 1999; Metcalf 1995; NIOSH 1997; Sittig 1980; Suntio et al. 1988; Tomlin 1997). The relative persistence of the two isomers and the potential for conversion from one isomer to another may also deserve further study.

**Production, Import/Export, Use, Release, and Disposal.** Endosulfan is distributed in the environment as a result of its use as an insecticide (Gregor and Gummer 1989; NRCC 1975; Strachan et al. 1980). Humans may be exposed through the ingestion or use of contaminated food (Gartrell et al. 1986; Podrebarac 1984a) or tobacco products (EPA 1982a), contact with media from contaminated hazardous waste sites (principally soils), or insecticide application (Oudbier et al. 1974; Wolfe et al. 1972).

Although endosulfan is currently produced for use as an insecticide, information on the current production, import, and export of endosulfan by the United States is limited. Annual production volumes in the United States were 3 million pounds in 1980 (Sittig 1980), and 10,000 metric tons (approximately 22 million pounds) worldwide were reported in 1984 (WHO 1984). However, as of 1982, endosulfan was no longer produced in the United States (HSDB 1999). Although U.S. imports of endosulfan are reportedly substantial, the most recent import information (182,000 kg) was for the year 1982 (HSDB 1999). Additional information on the production/formulation, import, and export volumes for endosulfan would be useful in assessing the extent to which, and conditions under which, humans may be exposed to endosulfan or endosulfan sulfate.

Releases of the compound as an insecticide are typically to the atmosphere and land (WHO 1984). The medium of most importance to human exposure appears to be contaminated foods (Gartrell et al. 1986).

Methods suggested for the disposal of endosulfan, or more generally, pesticides, their residues and spillage, and contaminated containers include ground surface disposal, incineration, lagooning, and disposal in deep wells, sanitary landfills, and disposal pits (EPA 1974; FAO/WHO 1975a; Working Group on Pesticides 1970). However, no data on the amounts disposed of by each method were available. Regulations pertaining to the disposal of endosulfan include the requirement that containers contaminated with endosulfan residues be emptied, decontaminated, and either recycled or disposed of in landfills, depending on their condition (EPA 1974; FAO/WHO 1975a; HSDB 1999). Current information on disposal practices for endosulfan would be useful in evaluating the potential for exposure to endosulfan and endosulfan sulfate.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1993, became available in May of 1995. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

**Environmental Fate.** Endosulfan partitions to the atmosphere and soils and sediments. It is transported in the atmosphere (Gregor and Gummer 1989; Strachan et al. 1980), but it is immobile in soils (Bowman et al. 1965; El Beit et al. 1981c; Hodapp and Winterlin 1989; Stewart and Cairns 1974). It is transformed in surface waters and soils via hydrolysis (Greve and Wit 1971; Schoetteger 1970) and biodegradation (Cotham and Bidleman 1989; El Beit et al. 1981c; Greve and Wit 1971; Martens 1976; Miles and Moy 1979; Stewart and Cairns 1974). Endosulfan sulfate persists in soils (Coleman and Dolinger 1982). Additional information is needed on the extent to which the compound undergoes photochemical oxidation in the atmosphere. This information would be helpful in establishing the atmospheric half-life of the compound.

**Bioavailability from Environmental Media.** Endosulfan can be absorbed following inhalation of contaminated workplace air and ingestion of insecticide-contaminated food (Ely et al. 1967). Dermal contact with or ingestion of endosulfan that is tightly bound to soil particles is an exposure route of concern at hazardous waste sites. No information is available on the absorption of endosulfan in either adults or children following ingestion or dermal contact with contaminated soils. Therefore, additional information is needed on the uptake of endosulfan from contaminated soil following ingestion or dermal contact. This information would be useful in determining the bioavailability of soil-bound endosulfan.

**Food Chain Bioaccumulation.** Endosulfan is bioconcentrated by aquatic organisms (Ernst 1977; Novak and Ahmad 1989; NRCC 1975; Roberts 1972; Schimmel et al. 1977) but not by plants or animals (EPA 1982a). The compound is metabolized by terrestrial (Coleman and Dolinger 1982; El Beit et al. 1981c; Martens 1977; NRCC 1975) and aquatic organisms (Cotham and Bidleman 1989), and it does not biomagnify to any great extent in terrestrial or aquatic food chains (HSDB 1999). No additional information on the bioaccumulation of endosulfan is needed at this time.

**Exposure Levels in Environmental Media.** Endosulfan and endosulfan sulfate have been detected in ambient air (Bidleman 1981; Kutz et al. 1976), surface water (EPA 1980b, 1982c; Frank et al. 1982b; Maguire et al. 1983; McFall et al. 1985; Miles and Harris 1971; Willis et al. 1987), rain water (Strachan and Huneault 1979), cropland soils (Carey et al. 1979a, 1979b), and some foodstuffs (Gartrell et al. 1986; Podrebarac 1984a). However, with the exception of the food concentrations, the data are not current. Estimates of human intake of endosulfan or endosulfan sulfate are limited to ingestion of contaminated foodstuffs. Additional information is needed on the current levels of these compounds in ambient air, surface water, and soils, particularly at the 162 NPL hazardous waste sites known to be contaminated with these compounds. This information would be helpful in estimating human exposure to these compounds via contact with contaminated media.

Reliable monitoring data for the levels of endosulfan in contaminated media at hazardous waste sites are needed. This information could be used in combination with the known body burdens of endosulfan to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

**Exposure Levels in Humans.** Endosulfan and endosulfan sulfate can be measured in human blood, urine, and tissues following exposure to high levels in workplace environments or following accidental or intentional ingestion of insecticides containing endosulfan (Coutselinis et al. 1978; Demeter and Heyndrickx 1978; Demeter et al. 1977). However, no monitoring studies are available in which human fluids or tissues were used to assess occupational or general population exposure to endosulfan. Additional data on levels in human blood and urine are needed following occupational and general population exposure, particularly exposure at hazardous waste sites, in order to correlate concentrations in these media with those in environmental media and the subsequent development of health effects, if any.

This information is necessary for assessing the need to conduct health studies on these populations.

**Exposures of Children.** Data need to be developed to properly assess the exposure of infants who eat processed baby foods containing residues of pesticides such as endosulfan. Several studies have estimated exposure based on endosulfan concentration found in foods typically eaten by infants; however, no studies that directly studied infant exposure could be located. Attention should also be given to infant formulas and to the tap water used to prepare infant formulas from condensed or powdered forms. More data are also required to properly assess endosulfan exposure to children who live, play, or attend school near farmlands that are treated with endosulfan. Maps that catalog endosulfan use on crops and present average application rates would better allow an assessment of the potential for children in farming communities to be exposed. The possibility that farming parents' work clothes and shoes may carry endosulfan residues into the home also should be studied. In addition, home use of endosulfan, which may result in exposure of children, needs to be investigated.

Child health data needs relating to susceptibility are discussed in 2.1.2.2 Identification of Data Needs: Children's Susceptibility.

**Exposure Registries.** No exposure registries for endosulfan were located. This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

The compound will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this compound.

Information is particularly needed on the size of the populations potentially exposed to endosulfan through contact with contaminated media in the vicinity of hazardous waste sites. The development of an exposure registry would provide a useful reference tool in assessing exposure levels and frequencies. It would also facilitate the conduct of epidemiological or health studies to assess any adverse health effects resulting from exposure to endosulfan. In addition, a registry developed on the basis of exposure sources would allow an assessment of the variations in exposure levels from one source to another and the effect of geographical, seasonal, and regulatory action on the level of exposure within a certain source. These

assessments, in turn, would provide a better understanding of the needs for research or data acquisition on the current exposure levels.

### 5.8.2 Ongoing Studies

No ongoing studies regarding release, bioavailability, bioaccumulation or exposure registries were located. However, several ongoing studies regarding the fate and transport, disposal, and human exposure of endosulfan were located. Researchers from the University of Nevada are examining the atmospheric transport and deposition of endosulfan and its input to the Sierra Nevada mountains (FEDRIP 1999). At the University of California at Davis, researchers are examining an integrated approach to the bioremediation of pesticides at hazardous waste sites (FEDRIP 1999). This approach involves the use of flooded plots and rice plants to enhance degradation. In another study, researchers from Kentucky State University are analyzing the fate of endosulfan under field conditions in an artificial wetlands environment (FEDRIP 1999). They are studying the influence of landscape features and soil amendments on runoff and infiltration of water quality as well as the fate of pesticides found along the edge of fields. In New South Wales, a group of researchers are examining the impact of endosulfan on natural water systems as a result of industrial activity (FEDRIP 1999). At the Beltsville Agricultural Research Center, the atmospheric and surface interactions of endosulfan and its fate and transport are being studied (FEDRIP 1999).