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Ethylene

CAS Registry Number: 74-85-1

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Chapter 1 Summary Tables

Table 1 provides a summary of health- and welfare-based values resulting from an acute and chronic evaluation of ethylene. Table 2 provides summary information on ethylene's physical/chemical data.

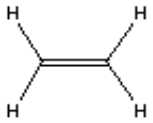
Table 1 Health - and Welfare-Based Values

Short-Term Values	**Concentration**	**Notes**
$^{acute}ESL_{veg}$	1,400 µg/m^3 (1,200 ppb) * **Short-Term ESL for Air Permit Reviews**	This value is a sub-threshold concentration that is protective of all crop plants including flowering plants
$^{acute}ESL$ [1 h] (HQ = 0.3)	170,000 µg/m^3 (150,000 ppb)	**Critical Effect:** hepatic damage in male Holtzman rats, based on a free-standing NOAEL
acute ReV (HQ = 1.0)	570,000 µg/m^3 (500,000 ppb) *	**Critical Effect:** Same as above
$^{acute}ESL_{odor}$	- - -	Faint sweet
Long-Term Values	**Concentration**	**Notes**
$^{chronic}ESL_{veg}$	34 µg/m^3 (30 ppb) * **Long-Term ESL for Air Permit Reviews**	This value is a threshold concentration that is protective of all crop plants including flowering plants
$^{chronic}ESL_{nonlinear(nc)}$ (HQ = 0.3)	1,800 µg/m^3 (1,600 ppb)	**Critical Effect:** hepatic damage in Fischer 344 rats based on free-standing NOAEL
chronic ReV (HQ = 1.0)	6,100 µg/m^3 (5,300 ppb) *	**Critical Effect:** Same as above
$^{chronic}ESL_{linear(c)}$ $^{chronic}ESL_{nonlinear(c)}$	- - -	No evidence of carcinogenic potential

* Values that are used for evaluation of ambient air monitoring data

Abbreviations used: **ppb**, parts per billion; **µg/m^3**, micrograms per cubic meter; **h**, hour; **ESL**, Effects Screening Levels; **ReV**, Reference Value; **$^{acute}ESL$,** acute health-based ESL; **$^{acute}ESL_{odor}$**, acute odor-based ESL; **$^{acute}ESL_{veg}$,** acute vegetation-based ESL; **$^{chronic}ESL_{nonlinear(nc)}$,** chronic health-based ESL for nonlinear dose-response noncancer effects, **$^{chronic}ESL_{linear(c)}$,** chronic health-based ESL for linear dose-response cancer effects; **$^{chronic}ESL_{nonlinear(c)}$,** chronic health-based ESL for nonlinear dose-response cancer effect; and **$^{chronic}ESL_{veg}$,** chronic vegetation-based ESL; **HQ**, Hazard Quotient.; **NOAEL**, no-observed-adverse-effect level

Table 2 Chemical and Physical Data

Parameter	Value	Reference
Molecular Structure		ChemFinder 2004
Molecular Formula	C_2H_4	ChemFinder 2004
Molecular Weight	28.05	ChemFinder, 2004
Physical State	Volatile gas, highly flammable and a dangerous fire risk, liquid under pressure	ACGIH 2005[a], ACC 2004[b]
Color	Colorless	ACGIH 2005[a], ACC 2004[b]
Odor	Faint Sweet	ACGIH 2005[a], ACC 2004[b]
CAS Registry Number	74-85-1	ACGIH 2005[a], ACC 2004[b]
Synonyms	Acetene; Elayl; Olefiant Gas; Refrigerant 150; Ethene; UN1038 (refrigerated liquid), UN1962 (compressed liquid), Athyllen [German], Bicarburretted hydrogen; Caswell No. 436; EINECS 200-815-3; EPA Pesticide Chemical Code 041901; Etileno; HSDB 168	ACC 2004[b]
Solubility in water	26 g/L- Slightly soluble	ChemFinder 2004
Log K_{ow} or P_{ow}	Log P_{ow}= 1.13	ACC 2004[b]
Vapor Pressure	760 mmHg @ -104°C	Matheson Tri-Gas[c]
Relative Vapor Density @ 32º F (gas; air =1)	0.975	ACC 2004[b]
Density (liquid) @ Critical Temperature (48.54 ºF)	13.36 lb/ft^3; 1.786 lb/gal; 0.21 g/cm^3	ACC 2004[b]
Melting Point	-169.14°C	ChemFinder 2004
Boiling Point	-103.7°C	ChemFinder 2004
Conversion Factors at 25ºC and 1 atmosphere	1 ppb = 1.15 µg/m^3 1 µg/m^3 = 0.87 ppb	Alberta Environment 2003 Toxicology Section

[a]American Conference of Governmental Industrial Hygienists (ACGIH)

[b]American Chemistry Council (ACC) 2004

[c]Matheson Tri-Gas Material Safety Data Sheet

Chapter 2 Major Uses and Sources

Ethylene is produced through both natural and anthropogenic activity. Microbes and higher plants naturally produce ethylene. Ethylene is also released during forest fires and active volcanic events. In higher plants, ethylene functions as a plant hormone and ethylene production can either increase or decrease in response to a variety of environmental stressors such as flooding, wounding (e.g., mechanical and/or pathogenic attack), chemical exposure (e.g., ozone), and mechanical bending (*e.g.*, lodging) (Health Canada 2001).

Ethylene is also produced endogenously in mammals through lipid peroxidation of unsaturated fats, oxidation of free methionine, oxidation of hemin in hemoglobin, and metabolism of intestinal bacteria (Health Canada 2001). However, ethylene production in mammals is only a minor contributor to atmospheric ethylene when compared to the relative contribution from microbial, vegetative, and industrial sources (Health Canada 2001).

In occupational settings, very high concentrations of ethylene can lower oxygen concentrations and has been reported to function as an asphixiant (Cavender 1994). Ethylene is primarily used as an intermediate in the production of other chemicals and as an agent to enhance the ripening process of fruits, vegetables, and flowers. Ethylene is also a high-production-volume chemical product of the petrochemical industry, produced mainly by the steam-cracking of hydrocarbons. Industrial contribution to ambient ethylene is primarily due to fugitive emissions from stacks, flares, and leaks in pipe fittings that can result in a discontinuous exposure scenario (Health Canada 2001).

Ambient ethylene is also produced during incomplete combustion of biomass and fossil fuels. While gasoline itself does not contain ethylene, the combustion of gasoline causes ethylene to be emitted into the ambient air. A relatively large proportion of ethylene in urban air is due to vehicular traffic emissions (Abeles and Heggestad 1973).

Chapter 3 Acute Evaluation

3.1 Health-Based Acute ReV and ESL

3.1.1 Physical/Chemical Properties and Key Studies

3.1.1.1 Physical/Chemical Properties

Ethylene is a highly-flammable volatile gas that is considered to be a fire hazard at sufficiently high concentrations. It is a colorless gas with a faint sweet odor, is a liquid under pressure, and is slightly soluble in water (Chemfinder 2004). The main physical and chemical properties of ethylene are summarized in Table 2. Ethylene has been reported to be relatively non-toxic, has a low blood-gas partition coefficient and does not accumulate in the body.

3.1.1.2 Essential Data and Key Studies

The inhalation toxicity studies conducted by Conolly et al. (1978) and Guest et al. (1981) were selected as key studies to determine the acute Reference Value (ReV) and the acute Effect Screening Level (^{acute}ESL). The study conducted by Conolly and Jaeger (1977) was selected as a supporting study.

3.1.1.2.1 Conolly et al. (1978)

In the Conolly et al. (1978) studies, a group of male Holtzman rats were exposed to 10,000, 25,000, or 50,000 ppm ethylene for 4 h. A second group of rats were administered a combined exposure protocol with polychlorinated biphenyl (PCB) mixture (300 µmoles of PCB/kg of body weight) *via* gavage once daily for 3 days followed by 4 h of inhalation exposure to the various concentrations of ethylene. In addition, control groups were included with rats exposed to PCB alone.

In the study, hepatic damage was assessed by conducting histopathology of the liver and by measuring the levels of hepatic enzymes including sorbitol dehydrogenase (SDH) and serum alanine-alpha-ketoglutarate transaminase (SAKT). Elevated levels of SAKT and SDH are often indicative of liver damage. The authors reported ethylene concentrations at 10,000 ppm to be hepatotoxic only when the rats were pre-treated with the PCB mixture. Specifically, rats that were exposed to ethylene after exposure to PCB mixture were reported to have elevated levels of SDH and the liver of the rats had severe degenerative necrosis.

The authors reported no increase in hepatic enzymes and no liver damage in rats exposed to ethylene alone. A no-observed-adverse-effect-level (NOAEL) of 50,000 ppm was determined from the exposure group of rats exposed only to ethylene. As the studies did not provide any other toxicological information, such as lowest-observed-adverse-effect-level (LOAEL), the NOAEL will be considered a free-standing NOAEL.

3.1.1.2.2 Guest et al. (1981)

Guest et al. (1981) also studied the toxicity of ethylene alone and in conjunction with PCBs. For the ethylene-only exposure group, the authors exposed Fisher rats for 5 h to 10,000 ppm ethylene. For the combined exposure (i.e., PCB mixture + ethylene), the authors administered 500 mg/kg PCB mixture *via* gavage five days prior to exposing the rats for 5 h to 10,000 ppm of ethylene. Control groups included rats exposed either to ethylene alone or rats exposed to only the PCB mixture.

Similar to the Conolly et al. studies, Guest et al. (1981) reported no increase in serum enzyme activities and no necrotic tissue for the ethylene only exposure groups. Exposure only to the PCB mixture, without subsequent exposure to ethylene, resulted in slight hypertrophy of centrolobular liver cells with no hepatocellular necrosis. However, animals exposed to 10,000 ppm ethylene after pre-treatment with the PCB mixture, had uniform hepatic centrolobular necrosis. In addition, the authors also reported elevated hepatic enzyme levels in the combined exposure

group (PCB mixture + 10,000 ppm ethylene). As no LOAEL information was available, a free-standing NOAEL of 10,000 ppm was determined from the group exposed only to ethylene.

The results from the acute exposure studies indicate that very high doses of ethylene coupled with high doses of the PCB mixture are required to elicit hepatotoxic responses in rats. Guest et al. (1981) hypothesized that the PCB mixture induced the hepatic mixed-function oxidase (MFO) system that then resulted in hepatotoxicity in the rats.

3.1.1.2.3 Conolly and Jaeger (1977)

The study conducted by Conolly and Jaeger (1977) was selected as a supporting study. Similar to Conolloy et al. (1978) studies, Conolly and Jaeger (1977) studied the acute hepatotoxicity of ethylene and other chemicals with and without PCB pre-treatment. Male Holtzman rates were exposed up to 50,000 ppm ethylene. In addition to hepatic injury, the authors also studied the effects of changes in environmental parameters (i.e., changes in temperature during exposure and food deprivation. The authors reported ethylene to be more acutely toxic in rats that were fasted when compared to rats that were fed and PCB –pre-treated. The authors attribute depletion of glutathione to be higher in the fasted rats.

3.1.1.2.4 Other Studies Reviewed by TS

Aveyard and Collins (1997) conducted a reproductive/developmental toxicity screening study with head only exposures to rats. A total of 10 animals/sex/group were exposed to 5,000 ppm of ethylene for 6 h/day for 2 weeks prior to mating and during the mating period. Female rats were also exposed to ethylene until gestational day 20. No effects on weight gain, food intake, fertility, fecundity, sex ratio, and pup weight or pup growth were reported. This study was described in the Organization for Economic Co-Operation and Development (OECD) dossier on ethylene.

3.1.2 Mode-of-Action (MOA) Analysis and Dose Metric

Ethylene is metabolically converted to ethylene oxide (EtO) *via* the cytochrome P-450 pathway (Filser and Bolt 1983). Concern about the potential toxicity of ethylene stems from the fact that EtO is a suspected human carcinogen and a genotoxicant (ACGIH 2005 and Tornqvist 1994). In addition, EtO is also a potent alkylating agent and can form adducts by interacting with cellular macromolecules such as DNA, RNA, and protein (e.g., hemoglobin). Similar adduct formation has been reported on direct exposure to EtO (ACGIH 2005).

While adducts have been used as biomarkers of DNA damage, their use is controversial. There is some controversy in regards to whether adduct formation is indicative of exposure, and if adducts can be unequivocally utilized as precursors of diseases such as cancer (Selinski et al. 2000). A few studies reported the detection of hemoglobin adduct formation on exposure to ethylene. One example is the identification of hemoglobin adducts (i.e., hydroxyethylvaline adducts) in the serum of fruit storage workers exposed to approximately 0.3 ppm ethylene

(Tornquist et al. 1989). Similar results have also been reported in plastic industry workers exposed to ethylene (Granath et al. 1996).

Very few human exposure studies using ethylene have been conducted. The majority of ethylene exposure studies have been conducted using animals. When using animal studies, it is beneficial to extrapolate the risks observed in animals to humans using physiologically-based-pharmacokinetic (PBPK) models. Filser et al. (1992) measured ethylene uptake by exposing 6 human subjects for 2 h in controlled chambers to 5 and 50 ppm of ethylene. The authors reported 98% of the ethylene to be exhaled unchanged and only 2% of the ethylene was absorbed and metabolized to EtO. Similar to humans, most of the inhaled ethylene (83%) in rats was exhaled unchanged. Further, the relatively smaller fraction of ethylene that was actually absorbed was also reported to be eliminated unchanged in rats (Filser and Bolt 1983).

The metabolic conversion of ethylene to EtO has been reported to be a rate-limiting step resulting in only an insignificant amount of EtO being produced during the process (Bolt and Filser 1987 and Csanady et al. 2000). At 37 ppm ethylene exposure in rats, Bolt and Filser (1987) estimated a 1 ppm equivalent exposure to EtO in humans, while Csanady et al. (2000) have reported an exposure of 45 ppm ethylene in rats to be equivalent to a 1 ppm EtO exposure in humans.

3.1.3 Points of Departure (PODs) for the Key Studies

A POD of 50,000 ppm based on a free-standing NOAEL was determined from the Conolly et al. studies, and a POD of 10,000 ppm based on a free-standing NOAEL was determined from the Guest et al. (1981) study. In the toxicity study selected as the key study, data on the exposure concentration of the parent chemical are available. Since the MOA of the toxic response is not fully understood and data on other more specific dose metrics are not available (e.g. blood concentration of parent chemical, area under blood concentration curve of parent chemical, or putative metabolite concentrations in blood or target tissue), the exposure concentration of the parent chemical was used as the default dose metric.

3.1.4 Dosimetric Adjustments

3.1.4.1 Default Exposure Duration Adjustments

In accordance to the ESL Guidelines, a duration adjustment for 1 h is recommended if the data are obtained from acute toxicity studies with greater than 1 h exposure (TCEQ 2006). However, as the reported PODs in the key studies were relatively very high (i.e., indicative of low toxicity) and because no adverse effects were observed in the key studies at either the 4 h and/or 5 h study, the Toxicology Section (TS), did not conduct duration adjustments and considered the POD for 1 h to be the same as the POD determined for exposure durations greater than 1 h (i.e., 50,000 ppm from the Conolly et al. and 10,000 ppm from the Guest et al. (1981) study).

The POD determined from the Conolly et al. studies (50,000 ppm) is higher than the POD

determined from the Guest et al. (1981) study and is selected by the TS as the POD to derive a health-based acute reference value (acute ReV) and effects screening level (ESL). The TS selected the higher POD based on the fact that the key and supporting studies only determined a free-standing NOAEL and on US. EPA's (2002) definition of a NOAEL,"The highest exposure level at which there are no biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control". Some effects may be produced at this level, but they are not considered adverse or precursors to adverse effects".

3.1.4.2 Default Dosimetry Duration Adjustments from Animal-to-Human Exposure

As no duration adjustments are required, the POD becomes POD_{ADJ} and is 50,000 ppm. The POD_{ADJ} is then adjusted to human equivalent POD or $POD_{HEC.}$ Ethylene is relatively non-toxic even at high concentrations as it does not produce point of entry (POE) respiratory effects and the critical effect is hepatotoxicity. The TS will consider ethylene as a Category 3 gas and the duration exposure adjustments from animals to humans will be conducted with the following equation:

$$POD_{HEC} = POD_{ADJ} \times ((H_{b/g})_A / (H_{b/g})_H)$$

Where:

POD_{HEC} = Point of Departure at Human Equivalent Concentration

POD_{ADJ} = Adjusted Point of Departure

$H_{b/g}$ = Ratio of blood:gas partition coefficient

A = Animal

H = Human

According to USEPA (1994), if the animal blood:gas partition coefficient is greater than the human blood:gas partition coefficient, a default value of 1 is used for the regional gas dose ratio $[(H_{b/g})_A / (H_{b/g})_H]$, (RGDR). Csanady (2000) reported the tissue:air partition coefficients for rat and humans to be very similar and the blood:gas partition coefficients for rats to be double that of human values. The TS will therefore conservatively consider a default blood:gas partition coefficient of 1. The POD_{HEC} calculated based on the Conolly et al. studies is:

$$POD_{HEC} = POD_{ADJ} \times (H_{b/g})_A / (H_{b/g})_H$$

$$POD_{HEC} = 50{,}000 \text{ ppm} \times 1$$

$$POD_{HEC} = 50{,}000 \text{ ppm}$$

3.1.5 Critical Effect and Adjustments of the POD_{HEC}

3.1.5.1 Critical Effect

Potential hepatotoxicity is the critical effect in the animal studies discussed in Section 3.1.1.2, although the POD_{HEC} is a free-standing NOAEL, and no adverse effects were noted in any

ethylene-only exposure group.

3.1.5.2 Uncertainty Factors (UFs)

The TS applied the following UFs to the POD_{HEC} of 50,000 ppm to derive an acute Reference Value (acute ReV) under the assumption of a threshold/nonlinear MOA in accordance with the ESL Guidelines (TCEQ 2006). For detailed information on the MOA, please see Section 3.1.2. A interspecies UF of 3 was applied to account for extrapolation from animals to humans (UF_A), a UF of 10 is applied to account for intraspecies variability (UF_H), and a database UF of 3 was applied to account for deficiencies in the database (medium database confidence) of the referenced studies (UF_D). A total UF of 100 (i.e., 3 x 10 x 3 = 100) was applied to POD_{HEC} of 50,000 ppm.

$$\text{acute ReV} = POD_{HEC} / (UF_A \times UF_H \times UF_D)$$
$$= 50{,}000 \text{ ppm}/(3 \times 10 \times 3)$$
$$= 50{,}000 \text{ ppm}/100$$
$$= 500 \text{ ppm } (500{,}000 \text{ ppb or } 570{,}000 \text{ } \mu g/m^3)$$

A UF_A of 3 was used because default dosimetric adjustments from animal-to-human exposure were conducted which accounts for toxicokinetic differences but not toxicodynamic differences. A UF_H of 10 was used to account for potentially sensitive subpopulations, and a UF_D of 3 was used because of the availability of several toxicity studies with a wide range of end points The confidence in the acute database is medium.

3.1.6 Health-Based Acute ReV and ^{acute} ESL

As discussed in the previous section, UFs were applied to the POD obtained from the Conolly et al. studies to derive the acute ReV. The acute ReV was rounded to two significant figures. Rounding to two significant figures, the 1-h acute ReV is 500,000 ppb (570,000 $\mu g/m^3$) The rounded acute ReV was then used to calculate the ^{acute}ESL using a target hazard quotient of 0.3 (Table 3).

$$^{acute}\text{ESL} = 0.3 \times \text{acute ReV}$$
$$^{acute}\text{ESL} = 0.3 \times 500{,}000 \text{ ppb}$$
$$^{acute}\text{ESL} = 150{,}000 \text{ ppb } (170{,}000 \text{ } \mu g/m^3)$$

Table 3 Derivation of the Acute ReV and ^{acute}ESL

Parameter	Summary
Key Studies	Conolly et al. (1978)
Study population	Male Holtzman rats
Study quality	Medium-high
Exposure Method	Inhalation
Critical Effects	Hepatic effects
POD (original animal study) NOAEL	50,000 ppm (free-standing NOAEL)
POD_{ADJ} (No adjustment necessary)	50,000 ppm
POD_{HEC}	50,000 ppm (gas with systemic effects based on default RGDR =1)
Exposure Duration	4 h
Total Uncertainty Factors (UFs)	100
Interspecies UF	3
Intraspecies UF	10
LOAEL UF	Not applicable
Incomplete Database UF	3
Database Quality	Medium
acute Rev[1hr] (HQ = 1)	**570,000 µg/m^3 (500,000 ppb)**
^{acute} ESL [1h] (HQ= 0.3)	**170,000 µg/m^3 (150,000 ppb)**

3.1.7 Information from Other Organizations

The USEPA Office of Prevention, Pesticides and Toxic Substances has reported the maximum exposure rate to ethylene under current use as a pesticide to be 1000 ppm (USEPA 1992). This limit is for the post-harvest exposure of stored commodities (USEPA 1992). The Screening Information Data Set (SIDS) program operated under the auspices of the Organization for Economic Cooperation and Development recommends no further testing of ethylene toxicity based on the reports of low toxicity of ethylene and no risk to human health either through direct exposure or through indirect exposure *via* the environment (OECD SIDS 1994).

3.2. Welfare-Based Acute ESLs

3.2.1 Odor Perception

Ethylene has a sweet odor and taste. The ACGIH (2005) reported odor threshold is 290,000 ppb and is based on the Amoore and Hautala (1983) study. A 50% odor detection value of 310,000 µg/m^3 (270,000 ppb) has also been reported by Hellman and Small (1974). Since ethylene has a

sweet odor, an $^{acute}ESL_{odor}$ was not developed (TCEQ 2015).

3.2.2 Vegetation Effects

3.2.2.1 Summary of Ethylene Induced Vegetative Effects

Interest in ethylene research spiked when it was identified to be phytotoxic to greenhouse plants (Crocker 1948). Later, many investigators documented the adverse effects of ethylene on plant species (Darley et al. 1963, Air Quality Criteria for Hydrocarbons 1970) and reported the effects of ethylene to be dependent on the types of plant species and the stage of plant growth (Tonneijck et al. 2003, Reid and Watson 1985). Fruits (e.g., apples, oranges, and avocados) release ethylene as they approach maturity which in turn promotes the ripening of the fruits.

The majority of ethylene research has been conducted in growth chambers and very few studies exist for field grown plants. Abeles et al. (1992) reported 10 ppb as the threshold concentration for physiological effects from studies in greenhouse experiments with ethylene. However, there is some controversy regarding the relevance of the threshold concentrations reported by Abeles et al. (1992) to field grown plants. Amongst the issues surrounding the applicability of the results reported by Abeles et al. (1992) is the fact that greenhouse plants are normally exposed to very high concentrations of ethylene in a continuous manner. Field grown plants generally experience lower concentrations of ethylene and the exposure pattern is said to be discontinuous (Tonneijck et al. 1999, 2000, and Dueck et al. 2004). Greenhouse plants are also less hardy when compared to the field-grown plants and, may experience more adverse effects (Tonneijck et al. 2003).

Ethylene is a plant hormone that is produced naturally at many of the stages of plant growth. As a plant hormone, ethylene has been reported to regulate both the morphological (e.g., leaf abscission and epinasty (leaf curling)) and physiological effects (e.g., bud formation, inhibition of flowering, photosynthesis, senescence, sprouting of buds, seed germination, and flower formation). In addition, ethylene can stimulate or inhibit the growth process, influence other plant hormones (e.g., giberillic acid), or itself be influenced by other hormones (Grossmann and Hansen 2001).

Tonneijck et al. (2000) reported epinasty or leaf curling in potatoes grown in the vicinity of polyethylene manufacturing plants. However, the authors reported that the epinasty did not translate to a loss in tuber yield. In a review on the effects of air-borne volatile organic compounds such as ethylene, Cape (2003) reported epinasty to be a reversible effect if the exposure ended. Nutritional deficiencies and stress factors (i.e., water stress, temperatures, and diseases) can cause vegetative effects (i.e., leaf and flower abscission) that are similar to the effects caused by exogenous ethylene. Also, plants undergoing stress are reported to be more susceptible to ethylene (Munne-Bosch et al. 2004, Guinn 1982, and Jordan et al. 1972). It therefore becomes difficult to differentiate subtle physiological and morphological effects caused by naturally produced ethylene (i.e., endogenous) versus ambient ethylene (i.e., exogenous).

Fugitive emissions from leaks around industrial facilities and vehicular traffic can create a discontinuous exposure scenario in the ambient environment. Meteorological factors (i.e., wind direction and velocity) can further aid in the movement and dispersal of the emissions and result in subsequent exposures to field-grown plants. During the discontinuous exposure, field-grown plants often have a chance to recover from the exposure. Green-house plants on the other hand are constantly exposed to ethylene from generators that are housed within the green-houses. For this reason, Tonneijck et al. (2003) indicated that the field-grown plants may be less responsive to ethylene when compared to the greenhouse plants where continuous exposure is the norm.

3.2.2.2 Summary of Ethylene Induced Effects in Flowering plants

Many investigators consider flowering plants such as petunias (*Petunia nyctaginiflora*), marigolds (*Tagetes erecta*), orchids (*Cattleya spp*), and carnations (*Dianthus caryophyllus L.*) to be sensitive to ethylene (Tonneijck et al. 2003, Posthumus 1983, and Davidson 1949). Leaf senecessence and flower abscission have been reported to occur due to ethylene exposure (Tonneijck et al. 2003). In addition, decreased flower size and increased abortion of flower buds in petunias have been used as indicators of plant response to pollution (Posthumus 1983 and Cape 2004). While petunias have been used as indicator plants to assess ethylene sensitivity, orchids have been reported to exhibit severe dry sepal injury at exposures of 100 ppb of ethylene for up to 8 h (Davidson, 1949).

The flowering plant studies are limited by the fact that they often included relatively high ethylene exposure concentrations (2 to 4 ppm) when compared to what is expected in an ambient setting (Underwood et al. 2005, Onozaki et al. 2004, Woodson et al. 1988). Ambient ethylene levels vary widely. For example, while the median concentration of ethylene was reported to be 10.79 ppb in 39 US cities from 1984 – 1985 (Seila et al. 1989), Abeles and Heggestad (1973) reported a maximum value of 700 ppb of ethylene in Washington DC. In some of the reported flowering plant studies, longer exposure durations ($\geq$ 8 and/or $\geq$ 12 h) were required before adverse effects could be recorded. In a multi-year study conducted by Tonneijck et al. (2003), a quantitative relationship between short-term ethylene exposure and plant response was not adequately addressed. In another short-term exposure study, excised flowering petunias were exposed to 4 ppm ethylene for 0, 2, 4, 8, or 10 h (Underwood et al. 2005). Similar exposure protocols with excised flowers were reported in carnations and geraniums (Evensen K 1991). While the more recent ethylene exposure studies in flowering plants included adequate dose-response information, the inclusion of excised flowers in the exposure protocols in the opinion of TS is not an appropriate scenario to depict normal vegetation conditions. For this reason, TS has not chosen these flowering plant studies as key studies for the development of the short-term vegetation ESL.

Woltering and Van Doorn (1988) conducted an extensive assessment of ethylene flower sensitivity amongst 93 species of plants from 22 plant families. However, the study included high exposure concentrations (3,405 $\mu g/m^3$) that are not relevant to ambient conditions. In addition, the reported exposure durations (22-24 h) were greater than the acute exposure

scenarios defined in the ESL guidelines (TCEQ 2006). As such, the TS have not chosen the study conducted by Woltering and Van Doorn (1988) as a key study for the development of the short-term vegetation ESL for ethylene.

3.2.2.3 Key Studies

Since ethylene-related vegetative effects have been documented, a short-term vegetative based ESL for ethylene exposure was determined according to the ESL Guidelines (TCEQ 2006). The Alberta Canada's Ethylene Research Project (i.e., The Alberta Canada Study) was identified as a key study and the study conducted by Pallas and Kays (1982) was identified as a supporting study to develop the vegetation based acute ESL ($^{acute}ESL_{veg}$).

3.2.2.3.1 The Alberta Canada Study

The Alberta Canada Study was a multi-stake holder initiative that was jointly sponsored by the Provisional Government and petrochemical industries in Alberta, Canada (Alberta Research Council 2001). The project was initiated to determine the concentration threshold at which short-term exposures to ethylene would cause significant effects on vegetative and reproductive parameters in selected cultivars of agricultural crops of interest to Alberta, Canada. Archambault and Li, the investigators of the Alberta Canada study, conducted extensive preliminary screening experiments with Ethephon ((2-Chloroethyl) phosphonic acid) to determine which plant species in each of 3 plant categories (i.e., cereal, legumes, and oilseeds) and 2 tree species were most sensitive to ethylene (Archambault et al. 2006, Archambault and Li 2001, 1999a, and 1999b). In their studies with field crops, sensitivity of seed yield to ethylene was the critical effect that was used to determine the relative sensitivity of the crop species. However, for the tree species, sensitivity to ethylene was based on the vegetative characteristics because vegetative characteristics are important parameters that determine the marketability of seedlings.

Table 4 Information on the Plants and Trees included in the Alberta Canada Study

Category	Plant	Species	Sensitive Stage of Growth	Vegetative Effects
Cereal	Barley	*Hordeum vulgare* cv. Harrington	Spike emerging stage	Decrease in photosynthesis, vegetative effects, and decreases in seed yield.
Legumes	Field pea	*Pisum sativum* cv. Carrera	Flat pod stage	Decrease in photosynthesis, vegetative effects, and decreases in seed yield
Oilseeds	Canola	*Brassica napus* cv. Quantum	Many flowers open stage	Decrease in photosynthesis, vegetative effects, and decreases in seed yield
Trees	White spruce	*Picea gluca*	Vegetative growth	Effects on seed germination, seedling vigor, growth, and seedling marketability.
Trees	Lodgepole pine	*Pinus Contorta*	Vegetative growth	Effects on seed germination, seedling vigor, growth, and seedling marketability.

Information on the plants and trees included in the Alberta Canada Study is provided in Table 4. All the plants included in the experiment were grown in the greenhouse until the appropriate stage was reached at which time they were transferred to exposure chambers and left for one day to acclimate prior to the start of the exposures. Plants were moved back to the greenhouse and grown to maturity after exposures were completed. For a detailed description of the treatments and exposure regimens, please see the Alberta's Ethylene Crop Research Project Report titled, "Response of Barley, Field peas, Canola, and Tree seedlings to Ethylene Exposure (2001)".

Treatments included exposing barley, field pea, canola, white spruce, and lodgepole pine to six concentrations of ethylene (10, 75, 150, 300, 600, and 1,200 ppb) at four exposure durations (1.5, 3, 6, and 12 h). In their studies, the investigators defined short-term exposures as being equal to or less than 12 h. In all the experiments, the order of exposures was randomly selected. In addition, the investigators of the Alberta Canada Study considered the 10 ppb exposure concentration as a background concentration based on the findings by Reid and Watson (1985), who reported that complete removal of ethylene from atmosphere would lead to detrimental effects on plant growth.

The investigators of the Alberta Canada Study reported barley from the cereal category, field pea from the legume category, and canola from the oil seed category to be the most sensitive species in their respective categories. In addition, the investigators also reported white spruce and lodgepole pine to be the most sensitive tree species for ethylene exposure.

The investigators conducted analysis of variance (ANOVA) and reported no significant effects on photosynthetic rates or vegetative, or reproductive effects for all exposure durations (up to 12 h) at all the exposure concentrations (up to 1,200 ppb) for all the plant species (barley, field peas, and canola). In the case of the trees (i.e., lodge pine and white spruce), the investigators reported no effects on seed germination, seedling vigor, growth, or seedling marketability after an exposure to 1,200 ppb of ethylene for exposure durations up to 12 h. The investigators reported that after short-term exposures (≤ 12 h) the plants and trees recovered from decreases in photosynthesis and growth.

In addition, the investigators also conducted additional statistical analysis (e.g., linear regression) to further understand the relationship between several plant parameters and ethylene dose expressed as a product of ethylene concentration (ppb) and exposure duration (h). The investigators reported a poor correlation between the various plant parameters measured and the ethylene dose. In the case of the tree seeds/seedlings, the investigators reported a poor correlation between germination and ethylene indicating that there was no significant dose effect.

However, the Alberta Research Council established a different short-term (i.e., 1-h) Ambient Air Quality Objective when compared to the results of the Alberta Canada Study. The Alberta Research Council established a short-term Ambient Air Quality Objective of 1,200 µg/m^3 (1,044 ppb) to be protective of all plant species (Alberta Research Council Report 2001).

3.2.2.3.2 Pallas and Kays (1982) Study

Pallas and Kays (1982) studied the effect of ethylene on photosynthesis by exposing leaves of a variety of plants to 1 microliter per liter (µl/L) or 1,000 ppb of ethylene for 0, 0.25, 0.5, 1, 2, 4, and 6 h (Table 5). The investigators also reported including a day without treatment between the treatments to measure any "carry-over effects" on photosynthesis. The Pallas and Kays study (1982) is a well-conducted study as the inhibition of photosynthesis was examined in many plants at exposure durations representative of short-term exposure scenarios. However, in the TS's opinion, the study is limited because it included only a single exposure concentration (1,000 ppb). For this reason, the TS considered the Pallas and Kays (1982) study as a supporting study to develop the $^{acute}ESL_{veg}$.

Table 5 Information on the Plants Included in the Pallas and Kays Study

Plant Common Name	Scientific Classification
Green bean	*Phaseolus vulgaris* L. cv. Contender
Pea	*Pisum sativum* L. cv. Wando
Peanut	*Arachis hypogea* L. cv. Florunner
Scarlet runner bean	*Phaseolus coccineus* L.
Sensitive plant (according to the study authors)	*Mimosa Pudica L.*
Irish Potato	*Solanum tuberosum* L.
Sunflower	*Helianthus annus* L. line CM90RR
White Clover	*Trifolium repens L.*
Jerusalem artichoke	*Helianthus tuberosus* L.

Pallas and Kays (1982) reported a wide range of responses in photosynthesis amongst the various cultivars exposed to ethylene. The net decrease in photosynthesis was dependent both on the genotype of the cultivar and the exposure duration. Pallas and Kays (1982) reported a decrease in photosynthesis with an increase in the exposure duration from 0.25 to 6 h in peanuts. In addition, the authors also reported a net decrease in photosynthesis when Jerusalem artichoke, sunflower, and sweet potato were exposed to 1,000 ppb ethylene for 2.5 h. However, the authors reported no effects on photosynthesis in green bean, scarlet runner bean, pea, Irish potato, or white clover. Amongst the various plant species tested in the study, peanut cultivars were reported to be relatively more sensitive to ethylene exposure. With an increase in the duration of exposure, the inhibitory effect on photosynthesis increased, especially for peanut. Pallas and Kays (1982) reported a 68% decrease in photosynthesis after a 6 h exposure period. However, the investigators also reported a rapid recovery after short–term exposure durations and the plants did not exhibit any carry-over effect on photosynthesis. The photosynthetic rates after the short-term exposure treatments (0.5 - 6 h) returned to normal or pre-exposure levels within 24 h following treatments. Plants in the 6 h treatment required an additional day for recovery. Overall, Pallas and Kays (1982) concluded the decrease in photosynthesis to be a reversible effect.

3.2.2.4 Derivation of the $^{acute}ESL_{veg}$

According to the ESL Guidelines, $^{acute}ESL_{veg}$ is set at a threshold concentration for adverse effects (TCEQ 2006). However, the results from the Alberta Canada Study and the Pallas and Kays (1982) study indicate that short-term exposures ($\leq$ 12 h and/or $\leq$ 6 h) of plants to ethylene either at 1,200 ppb or 1,000 ppb respectively to result in no adverse vegetative effects. While the TS acknowledges the absence of adverse vegetative effects at the reported exposure concentrations and durations in both the key and supporting studies, TS conservatively recommends a 1-h $^{acute}ESL_{veg}$ of 1,400 µg/m^3 (1,200 ppb) as a sub-threshold concentration to be protective for all plant species.

The $^{acute}ESL_{veg}$ of 1,400 µg/m^3 was rounded to the two significant figures and is based on the results of the short-term exposures from the Alberta Canada Study (Table 6). In recommending a 1-h $^{acute}ESL_{veg}$ of 1,400 µg/m^3 (1,200 ppb), the TS has taken into consideration that the reported exposure concentration (1,200 ppb) was the highest exposure concentration at exposure durations up to 12 h (i.e., 1.5, 3, 6, and 12 h) and the limited database of well-conducted ethylene exposure field studies for crops. The proposed screening value should also adequately protect vegetation from potential intermittent exposures.

Table 6 Derivation of the $^{acute}ESL_{veg}$

Parameter	**Summary**
Study	Alberta's Ethylene/Crop Research Project Report III
Study population	Barley, field pea, canola, and tree seedlings
Exposure Method	Growth Chambers
Critical Effects	Vegetative effects and decrease in photosynthesis
POD (Sub-Threshold Concentration)	1,400 µg/m3 (1,200 ppb)
Exposure Duration	1.5, 3, 6, 12 h
$^{acute}ESL_{veg}$	**1,400 µg/m3 (1,200 ppb)**

3.3 Short-Term ESL and Values for Air Monitoring Evaluation

The acute evaluation resulted in the derivation of the following acute values:

- $^{acute}ESL_{veg}$ = 1,400 µg/m^3 (1200 ppb)
- acute ReV = 570,000 µg/m^3 (500,000 ppb)
- $^{acute}ESL$ = 170,000 µg/m^3 (150,000 ppb)

The short-term ESL for air permit reviews and air monitoring evaluations is the $^{acute}ESL_{veg}$ of 1,400 µg/m^3 (1,200 ppb) as it is lower than the $^{acute}ESL$. (Table1). The acute ReV is used for air monitoring evaluations. The $^{acute}ESL$ (HQ = 0.3) will not be used by the TS to evaluate air monitoring data.

Chapter 4 Chronic Evaluation

4.1 Noncarcinogenic Potential

4.1.1 Physical/Chemical Properties and Key Studies

Physical/chemical properties of ethylene are discussed in Chapter 3. Due to the unavailability of chronic inhalation exposure studies in humans, the TS selected well-conducted animal studies to develop the chronic ReV. A two-year inhalation study conducted by Hamm et al. (1984) was

selected as a key study to determine the chronic ReV. In the study, Hamm et al. (1984) randomly divided 960 Fischer-344 rats into 4 groups of 120 animals for each sex and exposed them to 0, 300, 1,000, or 3,000 ppm of ethylene for 6 h/day, 5 days per week for 106 weeks. There were no reports of any chronic toxicity or oncogenicity at any of the concentrations tested. Comprehensive analysis of various tissues (e.g., kidney and nasal turbinates) indicated no signs of carcinogenic effects. While a variety of proliferative, degenerative, and inflammatory lesions were observed in both the control and treatment groups, the authors reported that these types of lesions are typical of the animal. A discussion on the high concentrations of ethylene is warranted based on previous findings that 3,000 ppm is the highest concentration that could be safely studied for long-term chronic studies (CIIT, 1980). Ethylene is explosive when it reaches 3% or higher in air composition. However, for acute exposure experiments, investigators were able to use higher concentrations of ethylene safely even up to 50,000 ppm (Section 3.1.3.1). Based on safety issues, Hamm et al. (1984) reported 3,000 ppm as the NOAEL for long-term chronic studies. TS will therefore consider 3,000 ppm as a free-standing NOAEL.

A 90 day sub-chronic study reported by Rhudy et al. (1978) was selected as a supporting study to determine the chronic ReV. Rhudy et al. (1978) exposed Sprague-Dawley rats to various concentrations of ethylene (0, 300, 1,000, 3,000, or 10,000 ppm) for 6 h/day, 5 days/week for 14 weeks. The authors reported no toxic effects related to ethylene exposure on conducting a comprehensive microscopic analysis of tissue specimens. In addition, the authors also did not report any changes or abnormalities in hematology, clinical chemistry, and urinalysis. A free-standing NOAEL of 10,000 ppm was determined from the Rhudy et al. (1978) study.

4.1.2 MOA Analysis and Dose Metric

The MOA of ethylene is described in detail in Section 3.1.2. For the key and supporting studies, data on concentration of the parent chemical is used as the default dose metric.

4.1.3 POD for Key and Supporting Studies

The NOAEL reported in the Rhudy et al. (1978) study (10,000 ppm) was higher than the NOAEL reported in the Hamm et al. (1984) study (3,000 ppm). However, the TS selected the NOAEL (3,000 ppm) from the Hamm et al. (1984) study because it was a chronic, rather than a sub-chronic exposure study.

4.1.3.1 Default Exposure Duration Adjustments

The TS conducted an adjustment from the discontinuous animal exposure regimen to a continuous exposure regimen with the following equation to determine the POD_{ADJ}. The POD_{ADJ} was determined to be 535.71 ppm (see below).

$$POD_{ADJ} = POD \times (D/24\ h) \times (F/7\ d)$$

where:

POD_{ADJ} = POD from animal studies adjusted to a continuous exposure scenario

POD = POD from animal studies based on discontinuous exposure scenario

D = Exposure duration, h per day

F = Exposure frequency, days per week

POD_{ADJ} = 3,000 ppm x (6/24) x (5/7) = 535.71 ppm

4.1.3.2 Default Dosimetry Adjustments

Similar to section 3.1.4.2, the TS considered ethylene as a Category 3 gas and the duration exposure adjustments from animals to humans was conducted to determine the human equivalent POD or POD_{HEC} with the following equation:

$$POD_{HEC} = POD_{ADJ} \times ((H_{b/g})_A / (H_{b/g})_H)$$

Where:

POD_{HEC} = Point of Departure at Human Equivalent Concentration

POD_{ADJ} = Adjusted Point of Departure

$H_{b/g}$ = Ratio of blood: gas partition coefficient

A = Animal

H = Human

The POD_{HEC} based on the Hamm et al. (19784) study:

$POD_{HEC} = POD_{ADJ} \times (H_{b/g})_A / (H_{b/g})_H$

= 535.71 ppm x 1

= 535.71 ppm

4.1.4 Application of Uncertainty Factors to the POD_{HEC} based on MOA Analysis

TS applied appropriate UFs to derive a Chronic ReV in accordance with the ESL Guidelines (TCEQ 2006). The POD_{HEC} of 535.71 ppm is based on a 2-Year study conducted by Hamm et al. (1984). The following UFs are applied: A UF of 3 is applied to account for extrapolation from animals to humans (inter-species variability, UF_A), a UF of 10 is applied to account for intraspecies variability (UF_H), and a UF of 3 to account for deficiencies in the database (UF_A). The total UF was equal to 100 (3 x 10 x 3).

$ReV = POD_{HEC} / (UF_A \times UF_H \times UF_D)$

ReV = 535.71 ppm / (3 x 10 x 3);Rev = 535.71 ppm/100

ReV = 5.3571 ppm (5,300 ppb or 6,100 µg/m^3) (rounding up to two significant figure)

A UF_A of 3 was used because default dosimetric adjustments from animal-to-human exposure were conducted which account for toxicokinetic differences but not toxicodynamic differences. A UF_H of 10 was used to account for potentially sensitive subpopulations, and a UF_D of 3 was used because of the availability of well-conducted chronic and sub-chronic toxicity studies with

a wide range of end points The confidence in the chronic database is medium.

4.1.5 Health-Based Chronic ReV and $^{chronic}ESL_{nonlinear(nc)}$

The chronic ReV of 6,100 µg/m^3 (5,300 ppb) rounded to two significant figures was used to calculate the $^{chronic}ESL_{nonlinear(nc)}$ by using the following formula and a hazard quotient (HQ) of 0.3 (Table 7):

$$^{chronic}ESL_{nonlinear(nc)} = \text{chronic ReV} \times HQ$$
$$= 5{,}300 \text{ ppb} \times 0.3$$
$$= 1{,}600 \text{ ppb } (1{,}800 \text{ µg/m}^3)$$

Table 7 Derivation of the Chronic ReV and $^{chronic}ESL_{nonlinear(nc)}$

Parameter	**Summary**
Study	Chronic toxicity and oncogenicity bioassay of inhaled ethylene in Fischer-344 rats
Study population	Fischer-344 rats
Study Quality	Medium
Exposure Method	Inhalation
Critical Effects	Hepatic damage
POD (original animal study)	3,000 ppm, NOAEL
Exposure Duration	6 h/day, 5 days/wk, 2 years
Extrapolation to continuous exposure (POD_{ADJ})	535.71 ppm
POD_{HEC}	535.71 ppm (gas with systemic effects based on default RGDR =1)
Total UFs	100
Interspecies UF	3
Intraspecies UF	10
LOAEL UF	Not Applicable
Subchronic to chronic UF	Not Applicable
Incomplete Database UF (Database Quality)	3 (Medium)
Chronic ReV (HQ = 1)	**6,100 µg/m^3 (5,300 ppb)**
$^{chronic}ESL_{nonlinear(nc)}$ (HQ = 0.3)	**1,800 µg/m^3 (1,600 ppb)**

4.2 Carcinogenic Potential

Concern over the toxicity of ethylene is due to the metabolic conversion of ethylene to EtO

which has been designated as a carcinogen and a genotoxicant (Bolt and Filser 1987). However, the percentage conversion of ethylene to EtO is insignificant (See Section 3.12). According to the ACGIH report published in 2005, "the potential toxicity due to EtO formation from the metabolic conversion of ethylene to EtO will not likely pose a cancer risk based on the current knowledge of the significance of adducts". In conclusion, ethylene is a relatively non-toxic chemical and is assumed to have a threshold, non-linear MOA. ACGIH (2005) has designated ethylene as A4 (i.e., it is not classified as a human carcinogen).

The International Agency for Research on Cancer (IARC) (1994) has classified ethylene as a Group 3, which indicates that it is a not classified as a human carcinogen. The German Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area (MAK Commission) has classified ethylene as a 3B (Deutsche Forschungsgemeinschaft 2004 in ACGIH 2005). The TS has determined that the data are inadequate for an assessment of human carcinogenic potential by the inhalation pathway.

4.3. Welfare-Based Chronic ESL

4.3.1. Development of Vegetation-Based Chronic ESL ($^{chronic}ESL_{veg}$)

Four key studies were identified to determine the $^{chronic}ESL_{veg}$. The first study was the Alberta Ethylene Research Project in which barley, field peas, and canola were exposed to various concentrations of ethylene for different durations (Alberta Canada Study). The second key study was conducted by Klassen and Bugbee (2002) in which they evaluated the sensitivity of wheat (*Triticum aestivum* L.) and rice (*Oryza sativa*) to various concentrations of ethylene. The third study was conducted by Reid and Watson (1985) who examined the sensitivity of oats (*Avena Sativa* L. cv. Random) and canola to chronic exposure to ethylene. In the fourth key study, Blankenship and colleagues (1993) conducted experiments to study the effects of continuous low levels of ethylene on growth and flowering of Eastern lily (*Lillium longiflorum* Thumb. Culitvar 'Nellie White').

4.3.1.1 The Alberta Canada Study

Archambault and Li (2001) wanted to determine the critical duration of exposure and long-term vegetative effects based on yield when plants are exposed to ethylene during a sensitive stage of growth. The Alberta Environment (2003) report includes various ethylene exposure scenarios and is discussed below. For short-term exposure scenarios (less than or equal to 12 h) please see Section 3.4. Two of the exposure scenarios are discussed below. For a detailed description of the treatments and exposure regimens, please see the Alberta's Ethylene Crop Research Project Report titled "Response of Barley, Field Peas, Canola, and Tree Seedlings to Ethylene Exposure (2001)".

Exposure Scenario 1:

In this scenario, Archambault and Li exposed barley plants to 50 ppb of ethylene for 0, 3, 6, 12,

18, and 24 days, and field peas to 50 ppb of ethylene for 0, 12, 16, 20, 24, and 28 days in growth chambers according to standard laboratory protocols. In the case of barley, the seed yield decreased by 41% when the plants were exposed to 50 ppb for 3 days and by 89% when the plants were exposed for 24 days. However, there were no effects on the above ground and root biomass, plant height, or tiller number after exposure to 50 ppb for 24 days. Field peas on the other hand were found to be relatively more insensitive to long-term exposures to ethylene. Exposure of field peas to 50 ppb of ethylene did not result in significant effects in plant height, number of pods, weight of pods, number of seeds, or seed yield. A threshold concentration of 50 ppb for long-term exposures was therefore determined from the studies on barley.

Exposure Scenario 2:

A second exposure protocol included a summary of long-term ethylene exposures in barley, field peas, and canola where barley plants were exposed to a range of ethylene concentrations (10 – 250 ppb). The investigators reported a 63% reduction in seed yield of barley when barley plants were exposed to 34 $\mu g/m^3$ (30 ppb) for 14 days. A threshold concentration of 34 $\mu g/m^3$ (30 ppb) for long-term exposures was therefore determined from the second set of exposure scenarios.

4.3.1.2 Klassen and Bugbee (2002)

Klassen and Bugbee (2002) evaluated the sensitivity of wheat (*Triticum aestivum* L.) and rice (*Oryza sativa*) to continuous ethylene levels ranging from 0 to 1,000 ppb in a growth chamber throughout the growing season. The authors reported anthesis (flowering stage) to be the most sensitive period for the crop plants. Exposures that stopped at the flowering stage were found to have lower reductions in yield. In this experiment, the authors reported that exposure to 50 ppb of ethylene reduced the yield by 36% in wheat and 63% in rice, respectively. In addition, plants that were exposed to 1000 ppb were found to be completely sterile. A threshold concentration of 50 ppb for long-term exposures was therefore determined from the studies on wheat and rice.

4.3.1.3 The Reid and Watson Study (1985)

Reid and Watson (1985) conducted a suite of experiments to determine the effect of various concentrations of ethylene on plant growth in oats (*Avena sativa* L. cv. Random) and canola (*Brassica campestris* L. cv. Candle) plants. Reid and Watson exposed oats for 100 days to 0, 8, 40, 81, and 173 $\mu g/m^3$ of ethylene and canola plants to 0, 12, 40, 173, and 690 $\mu g/m^3$ of ethylene for 87 days. At the 40 $\mu g/m^3$ concentration, the authors reported per plant floret number to decrease by 26% in oats and per plant seed yield to decrease by 57%. The authors therefore reported 40 $\mu g/m^3$ (34 ppb) to be the threshold concentration at which negative effects occur.

4.3.1.4 The Blankenship study (1993)

Blankenship and colleagues (1993) studied the effects of continuous, low levels of ethylene on growth and flowering of Easter lily (*Lilillum longiflorum*) Thumb, cultivar ‘Nellie White’ by exposing Easter lilies to 0, 0.01, 0.05, or 0.1 µl/l (ppm) ethylene for 77 days. The authors reported that the Easter lilies continuously exposed to 50 ppb (0.05 µl/l) had greater than 50%

decrease in dry weight in both shoots and inflorescences. In addition, both the 50 and 100 ppb exposure groups were unmarketable. The plants in the 10 ppb were reported to not be affected and were reported to be marketable. Therefore, the reported threshold concentration for long-term exposure for flowering plants is 50 ppb.

4.3.1.5 Determination of ^{chronic} ESL$_{veg}$

Vegetation-based ESLs are set at the threshold concentration for adverse effects and are determined in accordance with ESL Guidelines (TCEQ 2006). Amongst all the key studies identified by the TS, the barley exposure studies (Exposure Scenario 2) reported the lowest threshold concentration of 34 µg/m^3 (30 ppb). The TS, therefore, determined the ^{chronic} ESL$_{veg}$ to be 34 µg/m^3 (30 ppb).

Table 8 Derivation of the ^{chronic}ESL$_{veg}$

Parameter	**Summary**
Study	Alberta's Ethylene/Crop Research Project Report III, 2001 (Exposure Scenario 2)
Study population	Barley
Exposure Method	Growth Chambers
Critical Effects	63% reduction in seed yield for barley
POD (Threshold Concentration)	34 µg/m^3 (30 ppb)
Exposure Duration	14 days
^{chronic}ESL$_{veg}$	**34 µg/m^3 (30 ppb)**

4.3.1.6 Other V*egetation-Based* Studies Reviewed by TS

Among crop plants, vegetative effects of cotton (*Gossypium hirsutum*) and potato (*Solanum tuberosum*) have been studied on exposure to ethylene. Hall et al. (1957) reported extensive plant damage in cotton plants in the vicinity of a polyethylene manufacturing plant in Texas. The reported ambient concentrations of ethylene ranged from 0.04 to 30 ppm. In addition to reduction in yield, cotton plants exhibited leaf abscission, scattered seedling death, vine-like growth habit, and abscission of squares. In a growth chamber experiment, Heck et al. (1961) exposed cotton to constant levels of 40 or 100 ppb ethylene for 27 days. While no severe plant injury or death was reported, the authors reported a 25–50% reduction in yield (Heck et al. 1961). Cotton leaf and fruit abscission were also investigated by Hall et al. (1957). TS did not consider these studies as key studies because these studies were reported either in a review article or limited dose-response information was presented.

4.4 Long-Term ESL and Values for Air Monitoring Evaluation

The chronic evaluation resulted in the derivation of the following chronic values:

- $^{chronic}ESL_{veg}$ = 34 µg/m^3 (30 ppb)
- chronic ReV= 6,100 µg/m^3 (5,300 ppb)
- $^{chronic}ESL_{nonlinear(nc)}$ = 1,800 µg/m^3 (1,600 ppb)

The long-term ESL for air permit reviews and air monitoring evaluations is the $^{chronic}ESL_{veg}$ of 34 µg/m^3 (30 ppb). The chronic ReV of 6,100 µg/m^3 (5,300 ppb) may also be used in air monitoring evaluations (Table 1). The $^{chronic}ESL_{nonlinear(nc)}$ (HQ= 0.3) will not be used by the TS to evaluate air monitoring data.

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