UF | UNIVERSITY of FLORIDA

Center for Environmental & Human Toxicology

PO Box 110885
Gainesville, FL 32611-0885
352-392-2243, ext. 5500
352-392-4707 Fax

January 14, 2009

Ligia Mora-Applegate
Bureau of Waste Cleanup
Florida Department of Environmental Protection
2600 Blair Stone Road
Tallahassee, FL 32399-2400

Re: Methodology for the development of irrigation water risk-based criteria

Dear Ms. Mora-Applegate:

At your request we have developed a methodology for the derivation of groundwater cleanup target levels for organic chemicals that are protective of human health under an irrigation scenario (IGCTLs). In the irrigation scenario, receptors are exposed to contaminated groundwater outdoors while irrigating lawns, ornamental beds, and vegetable crops. From this scenario, separate criteria were developed based upon: 1) exposure for residents using contaminated water for lawn and ornamental bed irrigation, including exposure from recreational use of the lawn sprinklers by children; 2) exposure for landscape maintenance workers using contaminated water for the irrigation of lawns and ornamental beds at commercial facilities; and 3) exposure for residents who use contaminated water to grow fruit and vegetables for personal consumption.

Irrigation of lawns and ornamental beds

The exposure models used to derive groundwater cleanup target levels for the irrigation (IGCTLs) of lawns and ornamental beds are shown in Figure 1. These models consider potential intake of contaminants in groundwater through inhalation, dermal contact, and incidental ingestion. Conservative exposure assumptions were taken from standard sources (e.g., U.S. EPA guidance) or selected based on professional judgment.

Air concentrations resulting from irrigation of lawns and ornamental beds were estimated using a simple box model and were dependent upon water usage rate, water-to-air stripping efficiency, and the volume of the box. There are several non-technical publications aimed at informing residents on the proper watering of Florida lawns. According to the University of Florida Institute of Food and Agricultural Sciences (IFAS), lawns in Florida need to be watered on the average 2 d/wk during spring, 1 d/wk during summer, and every two weeks during fall and winter. These seasonal watering rates correspond to an annual average of 1 d/wk or 52 d/yr. IFAS recommends irrigating at a rate of 1-2" per watering event. A value of 2" per watering event was selected so as not to underestimate the watering rate. The recommended irrigation rate is a total water rate and was meant to include rainfall events. Average yearly rainfall for central and south

Florida taken over the last 25 years average 1" of rainfall per week (Ali et al., 2000). Therefore, total irrigation is estimated at 1" per week of contaminated groundwater and 1" per week of rainfall for a total of 2" of water per watering event. For a sprinkler covering a radius of 10 ft., this irrigation rate requires a total of approximately 1450 L water per event, which corresponds to a water flow rate of 50 L/min for 29 min. For the box model, the dimensions of the box were determined by the width of the sprinkler area (20 ft., or 6 m) times the breathing height of the adult receptor (1.5 m), the assumed wind speed (2 m/sec), and the duration of the watering event (29 min), which corresponds to 31,320 m^3.

The proportion of a contaminant volatilizing into the air depends on many factors specific for the contaminant in question and factors related to the physical characteristics of the water-air interface through which the chemical moves. The chemical concentration in air was estimated using data from empirical studies relating the decrease in the water concentration that occurs by the stripping effect caused by the passage of contaminated water through a shower system. It is assumed that stripping of contaminants passing through a sprinkler head is similar to that occurring in a shower. The relationship between the dimensionless Henry's law constant (H) of a chemical and the stripping efficiency (SE) of a typical shower has been found to be adequately predicted by the equation (Moya et al., 1999):

$$SE = [7.95*\ln(H)]+68.17$$

This stripping efficiency was multiplied times the total volume of water used per event (1450 L, see above) to derive the amount of chemical released to air. This amount was assumed to be distributed equally in the volume of air specified by the box model (31,320 m^3) to obtain the breathing zone air concentration.

Inhalation rates for children and adults (as appropriate for the scenario examined) were combined with exposure frequency, exposure duration, and air concentration values to estimate inhalation exposure. Dermal exposure for a child playing in the sprinkler was estimated based on the dermal permeability coefficient for each chemical and the skin surface area assumed to be in contact with water. A small volume of water was assumed to be ingested incidentally for both children and adults each time there was contact with irrigation water. The exposure frequency and duration of contact were assumed to equal the frequency and duration of irrigation events.

Homegrown fruit and vegetable consumption

Several models are available for estimating the concentration of chemicals in fruit and vegetables cultivated on contaminated soil or using contaminated water (Briggs et al., 1982, 1983; McKone, 1994; Ryan et al., 1988; Trapp and Pussemier, 1991). Based upon our evaluation of these models, we consider the Briggs model to have the greatest utility in estimating uptake of a contaminant into produce from known concentrations in irrigation water. Equations for the Briggs model are presented in Figure 2 and inputs are listed in Table 1. The Briggs model develops criteria based on contaminant concentrations in soil solution. It is assumed that the concentration of contaminant in soil solution equals the concentration in irrigation water minus the loss from volatilization to air during the irrigation process. The relationships between soil solution concentration and concentration in plant tissues are calculated based on the K_{ow} for the chemical using the expressions shown in Figure 2.

Calculation of a contaminant intake rate from homegrown produce requires assumptions regarding consumption rate. Values for root and shoot fruit and vegetable consumption were obtained from the U.S. EPA's Exposure Factors Handbook (1997). The Exposure Factors Handbook recommends using a daily average adult root consumption rate of 0.0418 kg (or about 1.5 oz) per day and a shoot ingestion rate of 0.3132 kg (or about 11 oz) per day. The recommended child root consumption rate is 0.0099 kg (or about 0.5 oz) per day and the shoot consumption rate is 0.0604 kg (or about 2 oz) per day.

The calculations from the Briggs model are conservative in that they do not include estimates of contaminant loss from the plant due to transpiration or metabolism. Additionally, the model does not estimate loss of the contaminant from preparation techniques such as washing, peeling, or cooking. The amount of contaminant lost from these practices varies depending upon the vegetable and the habits of the consumer. The worst-case scenario assumes that washing, peeling, and cooking do not occur.

Please let us know if you have any questions regarding this methodology.

Sincerely,

Stephen M. Roberts, Ph.D. Leah D. Stuchal, Ph.D.

References:

Ali, A., Abtew, W., Van Horn, S., and Khanal, N. Temporal and spatial characterization of rainfall over central and south Florida. *Journal of the American Water Resources Association* **36**(4): 833-848, 2000.

Briggs, G.G., Bromilow, R.H., and Evans, A.A. Relationships between lipophilicity and root uptake and translocation of non-ionised chemicals by barley. *Pestic. Sci.* **13**: 495-504, 1982.

Briggs, G.G. Bromilow, R.H., Evans, A.A., and Willams, M. Relationships between lipophilicity and the distribution of non-ionised chemicals in barley shoots following uptake by roots. *Pestic. Sci.* **14**: 492-500, 1983.

McKone, T.E. Uncertainty and variability in human exposures to soil contaminants through home-grown food: a Monte Carlo assessment. *Risk Anal.* **14**(4): 449-463, 1994.

Moya, J., Howard-Reed, C. and Corsi, R.L. Volatilization of chemicals from tap water to indoor air from contaminated water used for showering. *Environ. Sci. Technol.* **33**: 2321-2327, 1999.

Ryan, J.A., Bell, R.M., Davidson, J.M., and O'Connor, G.A. Plant uptake of non-ionic organic chemicals from soils. *Chemosphere* **17**(12): 2299-2323, 1988.

Trapp, S. and Pussemier, L. Model calculations and measurements of uptake and translocation of carbamates by bean plants. *Chemosphere* **22** (3-4): 327-339, 1991.

US EPA. Exposure Factors Handbook. National Center for Environmental Assessment. Office of Research and Development. 1997.

Figure 1 – IGCTLs for irrigation of lawns and ornamental beds

Residential scenario, carcinogens:

$$IGCTL = \frac{TR \times AT_c}{\left[\left(\frac{EF_i \times CSF_o \times IR_o \times ED_{ag}}{BW_{ag}}\right) + \left(\frac{EF_i \times CSF_d \times SA \times T_t \times K_p \times \left(1 - \frac{SE}{100}\right) \times 10^{-3} L/cm^3 \times ED_c}{BWc}\right) + \left(\frac{EF_i \times CSF_i \times IR_{iag} \times T_t \times V_w \times \frac{SE}{100} \times ED_{ag}}{BW_{ag} \times V_a}\right)\right]}$$

Residential scenario, non-carcinogens:

$$IGCTL = \frac{THI \times AT_{nc}}{\left[\left(\frac{EF_i \times IR_o \times ED_c}{RfD_o \times BW_c}\right) + \left(\frac{EF_i \times SA \times T_t \times K_p \times \left(1 - \frac{SE}{100}\right) \times 10^{-3} L/cm^3 \times ED_c}{RfD_d \times BW_c}\right) + \left(\frac{EF_i \times IR_{ic} \times T_t \times V_w \times \frac{SE}{100} \times ED_c}{RfD_i \times BW_c \times V_a}\right)\right]}$$

For this scenario, residential exposure is based on the “aggregate resident”, which is an individual that lives at the residence as a child, adolescent, and young adult. Exposure to contaminants by inhalation and incidental ingestion is assumed to occur throughout this period. However, dermal exposure (from playing in the sprinklers) occurs only as a child.

Landscape maintenance worker scenario, carcinogens:

$$IGCTL = \frac{TR \times AT_c}{\left[\left(\frac{EF_i \times CSF_o \times IR_o \times ED_w}{BW_w}\right) + \left(\frac{EF_i \times CSF_i \times IR_w \times T_t \times V_w \times \frac{SE}{100} \times ED_w}{BW_w \times V_a}\right)\right]}$$

Landscape maintenance worker scenario, non-carcinogens:

$$\mathrm{IGCTL} = \frac{\mathrm{THI} \times \mathrm{AT}_{nc}}{\left[\left(\dfrac{\mathrm{EF}_i \times \mathrm{IR}_o \times \mathrm{ED}_w}{\mathrm{RfD}_o \times \mathrm{BW}_w}\right) + \left(\dfrac{\mathrm{EF}_i \times \mathrm{IR}_w \times \mathrm{T}_t \times \mathrm{V}_w \times \dfrac{\mathrm{SE}}{100} \times \mathrm{ED}_w}{\mathrm{RfD}_i \times \mathrm{BW}_w \times \mathrm{V}_a}\right)\right]}$$

This scenario corresponds to a landscape worker at a commercial facility. The worker is assumed to be an adult exposed through inhalation and incidental ingestion

Figure 2 – IGCTLs for homegrown produce; Briggs model

Carcinogens:

$$\mathrm{IGCTL} = \frac{\mathrm{TR} \times \mathrm{AT_c}}{\left(\dfrac{\mathrm{EF_v} \times \mathrm{CSF_o} \times \left[(\mathrm{RCF} \times \mathrm{Ir_r}) + (\mathrm{SCF} \times \mathrm{Ir_s})\right] \times \left(1 - \dfrac{\mathrm{SE}}{100}\right) \times \mathrm{RD} \times \mathrm{ED_{ag}}}{\mathrm{BW_{ag}}}\right)}$$

Non-carcinogens:

$$\mathrm{IGCTL} = \frac{\mathrm{THI} \times \mathrm{AT_{nc}}}{\left(\dfrac{\mathrm{EF_v} \times \mathrm{ED_c} \times \left[(\mathrm{RCF} \times \mathrm{Ir_r}) + (\mathrm{SCF} \times \mathrm{Ir_s})\right] \times \left(1 - \dfrac{\mathrm{SE}}{100}\right) \times \mathrm{RD}}{\mathrm{RfD_o} \times \mathrm{BW_c}}\right)}$$

Supporting Equations:

$$\mathrm{SE} = \left[7.95 \times \ln(\mathrm{H})\right] + 68.17$$

$$\mathrm{RCF} = 10^{0.77 \log \mathrm{K_{ow}} - 1.52} + 0.82$$

$$\mathrm{SCF} = \left(10^{0.95 \log \mathrm{K_{ow}} - 2.05} + 0.82\right)\left(0.784 \times 10^{-0.434(\log K_{ow} - 1.78)^2 / 2.44}\right)$$

Table 1 – Values used in the derivation of irrigation GCTLs

Abbreviation	Definition	Value
AT_c	Carcinogenic Averaging Time	25550 d
AT_{nc}	Non-carcinogenic Averaging Time	(365 x ED) d
BW_a	Adult Body Weight	70.0 kg
BW_{ag}	Aggregate Resident Body Weight	51.9 kg
BW_c	Child Body Weight	15.0 kg
CSF_d	Dermal Cancer Slope Factor	chemical-specific $(mg/kg\text{-}d)^{-1}$
CSF_i	Inhalation Cancer Slope Factor	chemical-specific $(mg/kg\text{-}d)^{-1}$
CSF_o	Oral Cancer Slope Factor	chemical-specific $(mg/kg\text{-}d)^{-1}$
ED_a	Adult Exposure duration	24 y
ED_{ag}	Aggregate Resident Exposure Duration	30 y
ED_c	Child Exposure Duration	6 y
EF_i	Irrigation Exposure Frequency	52 d/y
EF_v	Vegetable Exposure Frequency	350 d/y
H	Dimensionless Henry's Law Constant	chemical-specific
IGCTL	Irrigation GCTL	(mg/L)
IR_{iag}	Aggregate Resident Inhalation Rate	1.04 m^3/h
IR_{ic}	Child Inhalation Rate	1.2 m^3/h
IR_o	Water Incidental Ingestion Rate	0.01 L/d
Ir_f	Aggregate Ingestion of Root Vegetables	0.0354 kg/d
Ir_{rc}	Child Ingestion of Root Vegetables	0.0099 kg/d
Ir_s	Aggregate Ingestion of Shoot Vegetables	0.2626 kg/d
Ir_{sc}	Child Ingestion of Shoot Vegetables	0.0604 kg/d
K_{oc}	Octanol-Carbon Partition coefficient	chemical specific (L/kg)
K_{ow}	Octanol-Water Partition Coefficient	chemical-specific
K_p	Permeability Coefficient	chemical-specific (cm/h)
RCF	Root Concentration Factor	chemical-specific (L/kg)
RD	Rainfall Dilution	0.5
RfD_d	Dermal Reference Dose	chemical-specific (mg/kg-d)
RfD_i	Inhalation Reference Dose	chemical-specific (mg/kg-d)
RfD_o	Oral Reference Dose	chemical-specific (mg/kg-d)
SA	Child Surface Area	7023 cm^2
SCF	Shoot Concentration Factor	chemical-specific (L/kg)
SE	Water-to-air Chemical Stripping Efficiency	chemical-specific
THI	Target Hazard Index	1
TR	Target Cancer Risk	1.00E-06
T_t	Irrigation Time	0.483 h/d
V_a	Volume of Air for Volatilization	31320 m^3
V_w	Volume of Water Used	1450 L

Chlorinated Solvent Irrigation Water Guidance Levels

Contaminants	CAS #s	Residential Criteria (ug/L)	Industrial Criteria (ug/L)	Produce Criteria (ug/L)	Non-Cancer Target Organs/Systems or Effects†	Carcinogen
Carbon tetrachloride	56-23-5	230	540	7.7	-Liver	-yes
CFC 113 [see Trichloro-1,2,2-trifluoroethane, 1,1,2-]						
Chloroethane [see Ethyl chloride]						
Chloroform	67-66-3	850	960	8400	-Liver	-yes
Chloromethane [see Methyl chloride]						
Dichloroethane, 1,1-	75-34-3	390000	*	110000	-Kidney	
Dichloroethane, 1,2- [or EDC]	107-06-2	370	620	19	-None Specified	-yes
Dichloroethene, 1,1-	75-35-4	150000	810000	57000	-Liver	
Dichloroethene, cis-1,2-	156-59-2	28000	170000	9300	-Blood	
Dichloroethene, trans-1,2-	156-60-5	65000	320000	18000	-Blood -Liver	
EDC [see Dichloroethane, 1,2-]						
Ethyl chloride [or Chloroethane]	75-00-3	10000	16000	920	-Developmental	-yes
Methyl chloride [or Chloromethane]	74-87-3	4000	6900	290	-Neurological	-yes
Methyl chloroform [see Trichloroethane, 1,1,1-]						
Methylene chloride	75-09-2	7000	13000	300	-Liver	-yes

Chlorinated Solvent Irrigation Water Guidance Levels

Contaminants	CAS #s	Residential Criteria (ug/L)	Industrial Criteria (ug/L)	Produce Criteria (ug/L)	Non-Cancer Target Organs/Systems or Effects†	Carcinogen
PCE [see Tetrachloroethene]						
TCE [see Trichloroethene]						
Tetrachloroethene [or PCE]	127-18-4	480	2400	8.9	-Liver	-yes
Trichloro-1,2,2-trifluoroethane, 1,1,2- [or CFC 113]	76-13-1	*	*	*	-Neurological	
Trichloroethane, 1,1,1- [or Methyl chloroform]	71-55-6	780000	*	190000	-None Specified	
Trichloroethene [or TCE]	79-01-6	2800	5900	110	-None Specified	-yes
Vinyl chloride	75-01-4	81	180	4.8	-Liver	-yes

† = These default Target Organ(s)/Systems or Effects are those reported to occur at the doses used to derive the reference dose. Non-default Target Organ(s)/Systems or Effects may be justified through a detailed toxicological analysis of the chemicals present at a specific site.

* = Contaminant is not a health concern for this exposure scenario.

** = Contaminant does not have toxicity values listed in the February 2005 "Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C."

*** = TRPH does not have toxicity values applicable for criteria development in water.

= These chemicals have a logKow > 4.5 and are highly unlikely to be taken up by plants from water. The produce scenario is not of concern for these chemicals.

NA = Not applicable. The Briggs plant uptake model utilized for this scenario is not applicable to inorganic chemicals.

None Specified = Target organ(s) not available at time of criteria development.

Note: Freshwater and marine surface waters, and groundwater at the point of discharge into surface water, shall pass acute and chronic toxicity bioassay tests: The user should consult the standard definitions for acute and chronic toxicity given in FAC 62-302.200(1) and FAC 62-302.200(4), respectively.