Homegrown Produce Consumption Pathway
Exposure Assessment for Method 1 Standards

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Introduction:

As part of the 2006 revisions to the MCP regulations, the Office of Research and Standards (ORS) has undertaken an effort to assess the health risks posed to people that eat homegrown produce grown in soils that might be contaminated with oil or hazardous materials (OHM). Homegrown produce exposure estimates are incorporated in the Method 1 S-1 standards that came into effect on April 3, 2006. This is a new component of the MCP Method-1 standards. Previously, this pathway was only assessed under Method-3 risk characterization.

A methodology for estimating risk from homegrown produce consumption in Method 3 risk assessments was outlined in MassDEP's 1995 Guidance for Disposal Site Risk Characterization. The exposure factors and methodology were updated for the purpose of incorporating this exposure pathway into the Method 1 Standards. Changes to the risk characterization of homegrown produce consumption include the use of new USDA consumption data and the derivation of updated plant uptake factors (PUFs) from the available scientific literature.

Currently, there are nine PUFs (sometimes referred to as bioconcentration factors) listed in the spreadsheets for calculating Method 1 Standards, including seven metals, chlordane, and PCBs. While ORS acknowledges that our understanding of plant uptake of specific chemicals is not complete, we have attempted to provide reasonable PUF estimates for contaminants that have existing data in order to more accurately assess the risks these contaminants may pose to people that consume homegrown produce.

General Equation for the Produce Consumption Component of the Method 1 Standards:

The equations for calculating soil concentrations associated with the Method 1 risk limits are:

For non-cancer:

$$[OHM_{soil}] = \frac{HI \times RfD}{ADPIR \times PUF}$$

For cancer:

$$[OHM_{soil}] = \frac{CR}{LADPIR \times PUF \times CSF}$$

Where:

[OHMsoil]	=	Concentration of OHM in soil (mg OHM/kg soil)
HI	=	Hazard Index (0.2 for Method 1)
RfD	=	Reference Dose (mg OHM / $kg_{body\ weight}$ day)
ADPIR	=	Average Daily Produce Intake Rate $kg_{produce}$ / ($kg_{body\ weight}$ x day)
PUF	=	Plant Uptake Factor (mg OHM per kg plant / mg OHM per kg soil)
CR	=	Cancer Risk (10^{-6} for Method 1)
LADPIR	=	Lifetime Average Daily Produce Intake Rate ($kg_{produce}$ / ($Kg_{body\ weight}$ x day)
CSF	=	Cancer Slope Factor ($[mg/(kg \times day)]^{-1}$)

Derivation of Produce intake rates and plant uptake factors are discussed in the sections that follow.

Produce Consumption Estimation:

The new homegrown produce consumption pathway assumes that a home gardener will consume 25% of their annual produce intake from their home garden. This percentage is then applied to fruit and vegetable consumption data presented in the *USDA Food and Nutritional Intakes by Individuals in the United States, by Region, 1994-1996*. ORS used the Northeast regional data subset of the USDA database. Conversion of wet-weight consumption rates to dry-weight consumption rates assumed produce consisted of 90% water (wet weight values multiplied by 0.1 to obtain dry-weight ingestion).

To obtain produce intake rates for each age group homegrown produce species were sorted into 8 categories that parallel the USDA categories with adjustments to reflect produce that is often raised by home gardeners (e.g., tomatoes):

1. Potatoes
2. Dark green vegetables: spinach, kale, broccoli, chard, etc.
3. Deep-yellow vegetables: pumpkin, winter squash, carrots, sweet potato, etc.
4. Tomatoes
5. Lettuce
6. Green beans
7. Corn, peas, and legumes
8. Melons and berries

Produce intake rates for each category were summed to obtain total daily produce intake rates for all produce categories for each age group in the study. Intake rates for the age groups evaluated in the studies were then adjusted to obtain intake rates for the age groups in the MCP standards (1-8, 8-18, and 18-30 years old). The rate for each age group was then multiplied by 0.25 to obtain age group-specific PIR values for homegrown produce, which are summarized in the following table.

	Produce Intake Rate (PIR), dry weight		
	Child 1-8 years g/day	Child 8-18 years g/day	Adult 18-31 g/day
All Produce:	48.4	79.8	97.2
Homegrown Produce:	12.1	20.0	24.3

The Average Daily Produce Ingestion Rate (ADPIR) for each age group is calculated by using the following equation and exposure assumptions:

$$ADPIR = \frac{PIR \times EF_1 \times EF_2 \times EP}{BW \times AP \times C_1 \times C_2}$$

Where:
ADPIR = Average Daily Produce Intake Rate (Kg/day) – dry weight
PIR = Produce Intake Rate (g/day) – dry weight
EF_1 = Exposure Frequency (7 days/week)
EF_2 = Exposure Frequency (52 weeks/year)
EP = Exposure Period (years in each age group)
BW = Body Weight (Kg)

AP = Averaging Period (years in each age group)
C_1 = Conversion (365 days/year)
C_2 = Conversion (1000 g/kg)

The lifetime average daily produce intake rate (LADPIR) for estimating cancer risk is calculated by summing the ingestion rates for three age groups (1-8 years, 8-15 years, and 15-31 years) and then averaging the ingestion rate over a lifetime.

The calculation of ingestion rates used to derive the new Method-1 soil standards can be found in more detail on sheet #4 (produce) of the MCP Soil.xls spreadsheet which can be downloaded via zip file at (http://www.mass.gov/dep/cleanup/laws/pubnot04.htm) under the caption (Spreadsheets Detailing the Development of the MCP Numerical Standards).

<u>Plant Uptake Factor Derivation:</u>

A literature search was conducted to obtain relevant Plant Uptake Factor (PUF) information for OHM. The plant uptake factor relates the edible plant tissue concentration of OHM to the soil concentration of OHM. A number of databases and over 40 journal articles or reports have been reviewed for uptake factors. Efforts were made to find papers where both the soil concentration and concentration in the edible portion of the plants are presented.

After identifying appropriate studies, each produce PUF was assigned to one of the 8 vegetable/fruit groups and a mean was calculated for each of the eight produce groups. The PUF produce groupings used to derive the PUF are the same groupings used in the produce consumption calculation discussed above. Then a mean was calculated from the mean of the 8 produce groups to derive the PUF for that specific OHM. In some cases (e.g., chlordane) only one data point per vegetable type was used. For others (e.g., cadmium) there are many data points for each vegetable group.

The PUF is expressed on a dry weight basis as follows:

$$PUF = \frac{[\ mg\ OHM\ \ per\ kg_{dry}\ \ plant\ ]}{[\ mg\ OHM\ \ per\ kg_{dry}\ \ soil\ ]}$$

Current list of OHM with derived Plant Uptake Factors

Chemical	Plant Uptake Factor (mg OHM per kg plant / mg OHM per kg soil)
Arsenic	0.05
Cadmium	1.9
Chlordane	11.104
Chrome III	0.095
Chrome VI	0.095
Lead	0.15
Nickel	0.38
PCBs	0.839
Zinc	1.52

Discussion of Plant Uptake Studies:

The majority of the plant uptake literature focuses on the uptake of chemicals from sludge or biosolids. Additional information exists for vegetables cultivated in mine tailings (waste rock), while other studies done were surveys of vegetables from particular geographical areas. ORS compiled this data with an emphasis on pertinent article information such as:

- vegetable common name and species
- chemical of concern
- type of application or study design
- chemical concentration in the soil and edible plant tissue
- uptake factor
- soil type, pH, and organic carbon content
- length of study
- method of chemical analysis
- author and date
- and any relevant comments

Soil by its nature is a heterogeneous mixture of minerals, organic matter, and microorganisms. Garden soils can be improved for the cultivation of crops by adding compost, lime, peat, or fertilizer. Many of these amendments can affect the uptake of chemicals by plants. For instance, the addition of lime can increase the pH of acidic soils whereas addition of elemental sulfur can decrease the pH. Plants generally function better in slightly acidic soils (pH 6.0 – 7.0) because at lower pH many of the minerals needed for optimal growth are more soluble and thus available for plant uptake. However, not all plants respond to pH in the same way for example, Dudka and Miller, 1999 found that metals uptake in response to liming varied among plants species. Organic matter also plays an important role in that it can act as a binder to metals and organic chemicals, but should not be considered permanent as it has a half-life of 10 years (McBride, 1995). In short, PUFs can vary significantly based on the crops cultivated, the nature of the soil, and how the gardener manages their plot.

ORS focused on literature and research in this field since 1992, although some earlier studies were considered. It was ORS' goal to use studies that included soil physical factors such as pH and organic carbon. Due to data limitations for some chemicals, data from studies without organic carbon content or pH measurements were included in the PUF calculations in some instances. ORS also recognized that studies conducted in a pot or greenhouse may yield uptake factors that are biased high because the chemical is concentrated in a relatively small volume of soil. Under normal conditions, leaching and aerobic degradation would be an important part of the chemical's fate and transport but this scenario would be minimized in pots in greenhouse conditions. Nevertheless, there are several studies that do not include soil pH, organic carbon, and were conducted in pots in a greenhouse. While these studies are perhaps less than ideal, they are presently *included* in the data set due to a lack of alternatives.

Collecting data from the appropriate portion of the plant is an important consideration for PUF derivation. While some studies do not specify which portion of the plant they are analyzing for OHM, others analyze the whole plant, in some cases including the non-edible portion of the plant. For some plants this is not an issue, but for others, different parts of the plant may uptake OHM differently. For example, several investigators have determined that PAHs are preferentially deposited in the peels of carrots rather than the cores (Simon and Wild, 1992). For other fruits and vegetables, only a certain portion of the plant is normally consumed. For example, most people only eat the leafy portion of Swiss Chard. If a study combined the leaves and roots and presented their chemical concentrations lumped together, this data would not be useful for purposes of deriving a chemical specific PUF for the homegrown produce consumption pathway.

Several authors present data in histogram form, but do not provide corresponding raw data to verify the histograms. This is another source of uncertainty in several of the PUFs. While less than ideal, it is important to stress that if the PUFs were collected only from papers that had information on the soil physical factors, were conducted in an agricultural setting, and presented data in table form rather than histogram form, the project would have significantly fewer data points.

Some papers showed exceptionally high PUFs and deserved further examination. For example, Sajwan et al. (1996) examined bush beans and the propensity for selenium, along with cadmium and nickel, uptake into those tissues. The PUFs found were several orders of magnitude greater than what would normally be expected for selenium. An inquiry to the lead author failed to resolve the outstanding unresolved issues. For this case, the paper was dropped from the dataset.

A vast of amount of the literature is concerned with the uptake of cadmium into crops. Cadmium is naturally present in soils and can be added to agricultural fields in any number of ways such as in fertilizer (Jinadasa *et al.* 1997), sludge applications (Brown *et al*. 1998), and mine tailings (Cobb *et al*. 2000). Consequently, there are more data points for this chemical than any other.

Questions and comments can be directed to:

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