ATTACHMENT 3
INPUT PARAMETERS

This Attachment discusses the sources and derivation of input parameters that were used to apply the Nevada Division of Environmental Protection's (NDEP's) *Soil to Groundwater Leaching Guidance* (guidance) dated January 16, 2010 at the Tronox LLC facility in Henderson, Nevada (the Site). These input parameters are used for the calculation of leaching-based, basic comparison levels (LBCLs) and leaching-based, Site-specific levels (LSSLs), as outlined in the guidance and described in this Attachment. The following two-step screening evaluation was performed:

1. Comparison of Site soil concentration data with LBCLs, which are derived using default values for input parameters in the soil-water partitioning (SWP) equations (Equations 1 and 2 of the guidance, for inorganic and organic chemicals, respectively);

2. For chemicals that exceed LBCLs, Site soil concentration data are compared with LSSLs, which are calculated using chemical-specific source lengths and dilution attenuation factors (DAFs), and Site-specific soil properties and hydrologic parameters in the SWP equation.

Attachment Tables 1A-B summarize the input parameters used to calculate LBCLs, DAFs, and LSSLs using equations presented in the guidance.

Attachment Tables 2A-B summarize the LBCLs published by NDEP in November 2009, for comparison with Site soil concentrations in the first step of the leaching evaluation. The LBCLs are provided for DAFs equal to 1 and 20. For some chemicals, NDEP did not provide LBCLs for comparison with Site soil concentrations, and "generic LBCLs" for these chemicals were calculated using default soil properties and available chemical properties. For certain inorganic chemicals, the LBCLs were adjusted to use the risk-based groundwater concentrations (RBGCs) approved by NDEP for this project, as discussed below.

In conference calls with NDEP on February 12 and 17, 2010, NDEP stated that the following hierarchy of published groundwater standards should be used to set the target RBGCs used to calculate LSSLs:

i. U.S. Environmental Protection Agency (U.S. EPA) Primary Maximum Contaminant Levels (MCLs; U.S. EPA, 2009);

ii. Residential Water Basic Comparison Levels (RWBCLs; NDEP, 2009); and

iii. Secondary MCLs (U.S. EPA, 2009).

This hierarchy of water quality standards was used to determine the RBGCs that are used in Attachment 3 Tables 2A-B, 3A-B, 4A-B, and 5A-B, as discussed under the description of input parameters used for the calculation of DAFs and LSSLs, below.

Attachment 3 Tables 3A and 3B present the chemical properties used to calculate LSSLs for inorganic chemicals and organic chemicals, respectively, including the RBGC, distribution coefficient (K_d), and dimensionless Henry's Law constant (H'). For some inorganic chemicals, K_d is sensitive to soil pH, which generally ranges from pH 8-10 at the Site, while published values for K_d are available up to pH 8. The measured soil pH for all the soil samples in the Phase A and B data set are tabulated in Attachment 3 Table 6, which indicates that soil pH was greater than 8 pH units in over 90 percent of soil samples, and greater than 7.8 pH units in 97 percent of soil samples. For those chemicals sensitive to soil pH (10 out of 29 chemicals), K_d values for pH 8 were used, as indicated on Attachment 3 Table 3A. The literature sources of these chemical properties are also shown in Attachment 3 Tables 3A-B. For organic chemicals, K_d is calculated from the soil-organic carbon distribution coefficient (K_{oc}), multiplied by the fraction of organic carbon (f_{oc}), which corresponds to Equation 2 of the guidance. A Site-specific value of 0.001 was used for f_{oc} to calculate K_d in Attachment 3 Table 3B.[1]

Attachment 3 Tables 4A-B present the chemical-specific and Site-specific values for the DAF for inorganic and organic chemicals, respectively. The calculation of DAFs is described in more detail below.

Attachment 3 Tables 5A-B present the calculations of LSSLs for inorganic and organic chemicals, respectively. The input parameters used to calculate LSSLs are further described below.

Input Parameters for Calculation of Dilution Attenuation Factors

The DAF is calculated using Equation 3 of the guidance:

---

[1] The mean fraction of organic carbon for all Phase A and Phase B soil samples without organic contamination is 0.0006, and the 95% upper confidence limit of the means (95% UCL) is 0.0007. The criteria for selecting samples for calculating the Site-specific *foc* were that total petroleum hydrocarbons (TPH) were non-detected and VOCs, SVOCs, and PCBs were all below the basic comparison levels (BCLs). In accordance with discussions with NDEP on July 16, 2010, a Site-specific value of *foc* of 0.001 was used for leaching calculations. According to the guidance, values of *foc* less than 0.001 in the SWP equation may underestimate the amount of organic chemicals that adsorb to the soil mineral particles and lead to overestimation of leaching by the SWP equation.

$$DAF = 1 + \frac{Kid}{IL} \tag{1}$$

The DAF expresses the reduction in contaminant concentration that occurs as a soil leachate mixes with, and dilutes into, groundwater. The amount of dilution (e.g., the magnitude of the DAF) is dependent on the aquifer hydraulic properties, including the horizontal hydraulic conductivity (K) and gradient (i), and thickness of the mixing zone (d); infiltration rate (I); and contaminant source length (L). Attachment 3 Tables 4A-B present the chemical-specific DAFs for each chemical of potential concern (COPC), using the input parameters described below.

The shallow water-bearing zone (WBZ) beneath the Tronox facility is first encountered in the Upper Muddy Creek formation (UMCf) in the southern, upgradient portion of the Site. Groundwater flow from the upgradient UMCf begins to "daylight" into the overlying Quaternary alluvium (Qal) northeast of the Unit Buildings within a discrete alluvial paleochannel cut into the UMCf. The average beginning point of this "daylighting" occurs approximately 1,200 feet south of the Interceptor Well Field (IWF). The width of this zone is approximately the length of the barrier wall. In addition, the vertical hydraulic gradient has been shown to be upward from the UMCf into the alluvium (Northgate, 2010). This upwelling groundwater contributes to the saturated thickness of alluvium. Saturated alluvial thicknesses vary, based on the topography of the UMCf erosion surface. The thickness of saturated alluvium generally increases as groundwater within the shallow WBZ moves downgradient. At the northernmost boundary of the Site, the saturated alluvial thickness exceeds 30 feet within the main paleochannel incised into the UMCf (at wells H-48 and PC-40), and is an average of approximately 7 feet along the remainder of the northern boundary. An average saturated thickness of 13.5 feet was estimated for the Qal based on the groundwater elevations in wells along the northern Site boundary (Attachment 3 Table 1B).

Density-adjusted vertical hydraulic gradients measured at the Site, including on both ends of the barrier wall, are upward. This suggests that any contaminants present in the deeper UMCf that pass beneath the barrier wall will eventually "daylight" into the alluvium and be captured downgradient at the Athens Well Field (AWF). Therefore, we assumed that chemicals that could potentially leach into groundwater from vadose zone soil sources will eventually be mixed into groundwater flowing within the saturated alluvium, downgradient from the northern boundary of the Site.

Northgate used the following input parameters to calculate the chemical-specific DAFs presented in Attachment 3 Tables 4A-B:

Aquifer Hydraulic Properties—Conductivity, Gradient, and Saturated Thickness: For the purpose of this screening evaluation, Northgate calculated the DAF using hydraulic properties of the saturated Qal. An average hydraulic conductivity (K; 47,500 ft/yr) and hydraulic gradient (i, 0.02) from measurements conducted at the Site were used (Tronox, 2010). For the aquifer thickness, we used a value of 13.5 feet to represent an approximate average thickness of saturated Qal along the northern boundary of the Site, where groundwater impacted by chemicals that have leached from vadose zone soil sources is anticipated to flow before moving downgradient (off-Site).

Infiltration Rate: The default infiltration rate for undeveloped areas in the vicinity of the BMI Complex is 0.08 inch per year (NDEP, 2010a). For developed areas of the Tronox facility (which include Remediation Zones A through E, shown in Figure 1 of the memorandum), a Site-specific infiltration rate for industrial land use (1.7 inches/ year [in/yr], or 0.14 foot per year [ft/yr]) was estimated and used in the DAF calculations, following procedures discussed with NDEP on July 16, 2010, and described below.

Rainfall is not considered to be a significant source of recharge to the Qal at the Site, due to the minimal amount of annual precipitation (4 to 5 inches/ year) combined with high rates of evaporation. The primary source of infiltration in the general plant area of the Site is attributed to leaks from the water distribution lines that service the facilities. The majority of the older water distribution lines at the facility carry untreated Lake Mead water. These lines were installed in the 1940s and have been the source of line failures and leaks in the past. Although subsurface water delivery line leaks have occurred and are occurring on-Site, the volume of water released to the subsurface has not been quantified.

As discussed with NDEP on July 16, 2010, three primary sources of evidence were used to estimate the infiltration rate for industrial land use at the Tronox Site:

1. Literature regarding the effects of urban development on recharge rates in various climates;

2. Model calibration values from related groundwater flow models; and

3. Percentage of water deliveries to the Tronox physical plant.

Literature studies of the effects of urban development on recharge generally fall under two main categories: 1) estimates of leakage rates from urban water distribution systems; 2) estimates of the multiplier effect on recharge rates for developed land compared to undeveloped land. Both categories of these studies include focused studies of specific urban developments, as well as broad survey studies of recharge rates for urban water systems with varying levels of infrastructure in a variety of climates.

Estimates of water leakage from urban water systems typically range from approximately 10 percent to 20 percent of water deliveries. For example, a study of 57 water agencies in the United States found a 10 percent average water loss due to leakage (Water Engineering and Management, 1987). Another survey of 469 water agencies in the United States found an average of 16 percent water loss (Thornton, 2002). A study of California water agencies estimated a 10 percent average rate of water loss (California Department of Water Resources, 1994).

Studies comparing infiltration rates for developed and undeveloped land have found multipliers for urban development generally ranging from 2 to 24 times the infiltration rate for undeveloped land (Garcia-Fresca, 2005 and Milczarek et al., 2004 and 2005). Recharge multipliers for urban developments in arid climates tend to be higher than the multipliers in humid climates because the natural infiltration rate for undeveloped land is less for arid than for humid climates. Consequently, the sources of recharge associated with urban development are relatively larger in magnitude compared to the natural recharge rates for undeveloped land in arid climates than in humid climates.

A flow model developed for the BMI Upper and Lower Ponds Area provides a second source of data from which to derive an infiltration rate for developed areas in the vicinity of the Site. It was found that adequate calibration statistics for this flow model were obtained using either of two values for infiltration, 0.57 inches per year (inches/year) or 1.87 inches/year, in areas developed for residential land use (Daniel B. Stephens & Associates, 2009). Although the lower infiltration value (0.57 inches/year) was chosen for the purpose of calibrating the flow model, the calibration statistics indicated that the higher infiltration value (1.87 inches/ year) could also represent the infiltration rate for developed land use. Comparison of these calibrated infiltration rates for developed land to the infiltration rate for undeveloped land at the BMI complex (0.08 inches/ year, or 2 percent of average annual rainfall, according to NDEP's leaching guidance) results in recharge multipliers of 7 times to 23 times the rate for undeveloped land. Comparison of these values with the recharge multipliers derived in

literature studies of urban development cited above suggests that an infiltration rate of approximately 1.9 inches/ year could represent a reasonable upper constraint on the infiltration rate for developed land areas in the vicinity of the BMI Complex.

The third approach for constraining the infiltration rate for the Tronox facility is based on the likely percentage of leakage from water deliveries to the Tronox physical plant. The majority of the older water distribution lines at the facility carry untreated Lake Mead water. These lines were installed in the 1940s and have been the source of line failures and leaks in the past. Even though subsurface water-line leaks have occurred and are likely occurring on-Site, the volume of water released to the subsurface has not been quantified. However, literature studies cited above provide some basis on which to estimate the likely range of contribution of water-line leaks to the flow budget for the IWF. These studies estimate the rates of leakage from urban water systems to range from approximately 10-20 percent of water deliveries. The volume of leakage from water delivered to the Tronox physical plant in 2009 is estimated to range from approximately $7.4x10^6$ to $1.5x10^7$ gallons per year or 14 to 28 gallons per minute. [2] Assuming that these leaks are distributed over the Tronox plant area (estimated to be approximately 160 acres), the potential infiltration rate due to water-line leaks is estimated to range from 1.7 to 3.4 inches/ year, or 0.14 to 0.28 foot per year. Dividing this range of potential values of water-line leakage by the infiltration rate for undeveloped land (0.08 inches or 0.0067 foot per year) results in multipliers that range from 21 to 42 times the infiltration rate for undeveloped land. Based on literature studies of the range of recharge multipliers for urban water systems cited above, a leakage rate of 10 percent of water deliveries (0.14 foot per year) appears reasonable and is used in the calculation of LSSLs.

Contaminant Source Lengths: Contaminant-specific source lengths were estimated for each COPC evaluated for its leaching potential. COPCs were selected by comparing concentrations in soil to the LBCLs for a DAF of 20 (Attachment 3 Tables 2A-B). For lead, strontium, perchlorate, and several organic chemicals for which LBCLs are not available, the source length was based on generic LBCLs calculated using default soil parameters and assuming a DAF of 20 (Attachment 3 Tables 2A-B).

The soil samples evaluated include all samples from the Qal, which generally includes samples collected at maximum depths within or slightly above the capillary fringe.

---

[2] The total annual water delivered to the Tronox general plant for 2009 was 74,297,000 gallons or 9,933,000 ft^3 (personal communication from Mr. Keith Bailey on April 30, 2010).

For certain inorganic COPCs, it was necessary to adjust the LBCLs published by NDEP to reflect the hierarchy of sources of published drinking water standards approved by NDEP for this leaching study (NDEP meeting minutes for February 12 and 17, 2010). This hierarchy uses the following values for RBGCs, in decreasing order of priority: a) U.S. EPA Primary MCLs; b) RWBCLs; and c) U.S. EPA Secondary MCLs (for taste and odor concerns). The RBGCs values derived from this hierarchy of standards are used in Tables 2A-B, 3A-B, 4A-B, and 5A-B of this Attachment. These LBCLs were adjusted so that the target RBGCs from which the LBCLs are calculated would be based primarily on human health risks and secondarily on aesthetic (taste and odor) concerns. Chemicals that exceed the LBCLs for DAF=20 were selected for further leaching evaluation, as described below.

For each COPC that exceeds the LBCL (for DAF=20), a map was constructed using Thiessen polygons to show the lateral extent of soil sources, allowing measurement of source lengths (Figures 3-2 through 3-29). For each soil boring and chemical represented by the polygons, the maximum soil concentration between the ground surface and the top of the Upper Muddy Creek formation was used to represent the soil source concentration for that location, after incorporating the results of the background evaluation for inorganics (Attachment 2), as follows: Soil samples in remediation zones and depth intervals determined to be consistent with background concentrations for each chemical were excluded from the data set used for comparison with LBCLs. The remaining soil concentration data were compared to LBCLs for DAFs of 1 and 20, and the polygon maps were shaded accordingly. Concentrations greater than the LBCL for DAF 1 are shaded blue and the ones greater than DAF 20 are shaded green.

The calibrated steady-state, three-dimensional Tronox groundwater flow model recently developed as part of the Capture Zone Evaluation Report (Northgate, 2010) was used to define the flow paths for the source-length calculations. The Qal and UMCf units were represented by a total of six layers. Layers 1 and 2 of the model represent the Qal and Layers 3 through 6 represent the UMCf. To generate the flow paths, forward particle tracking was performed on the Tronox model using MODPATH, the particle tracking companion code to MODFLOW. A line of particles that extended across the property width was released in Layer 3 of the model immediately upgradient of the southern edge of the Tronox property, as shown in Figure 3-1. The particle tracks were superimposed on each polygon map, and the lengths of polygons with soil concentrations greater than the LBCL (for DAF=20) were measured parallel to the groundwater flow direction along each particle flow path. The total lengths of polygons exceeding the LBCL (for DAF=20) along a given flow path were added, and the maximum total length of polygons along each measured flow path was used to represent the source

length. The particle tracks with the longest measured source length are shown with a yellow line on Figures 3-2 through 3-29.

Input Parameters Used for Calculation of Leaching-Based, Site-Specific Levels

Leaching-based, Site-specific levels were calculated using the Soil-Water Partitioning Equation (SWP), which is provided in two versions for inorganic and organic COPCs (Equations 1 and 2, respectively, in the guidance). The SWP for inorganic COPCs is:

$$LSSL = RBCG \times DAF \left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b} \right) \tag{2}$$

The SWP for organic COPCs is:

$$LSSL = RBCG \times DAF \left(K_{oc} f_{oc} + \frac{\theta_w + \theta_a H'}{\rho_b} \right) \tag{3}$$

Measured or estimated Site-specific physical and chemical values were used for the calculations, where available, as shown in Attachment 3 Tables 1A-B, 3A-B, and 4A-B. LSSL calculations using the above two equations for each COPC evaluated are presented in Attachment 3 Tables 5A (for inorganics) and 5B (for organics).

The LSSL equation multiplies the target RBGC by a DAF to account for dilution and mixing of a leachate from a given chemical source with groundwater, and a third term which estimates the concentration of a leachate solution in equilibrium with a vadose zone COPC. The LSSLs represent Site-specific estimates of allowable unsaturated zone soil concentrations of COPCs that will be protective of groundwater quality.

Northgate used the following input parameters for the LSSL equations:

- **RBGCs:** The hierarchy approved by NDEP for selecting RBGC values is described above, under the discussion of input parameters for the chemical-specific DAF calculations. LSSLs were not calculated for COPCs that do not have an established RGBC.

- **DAF:** The chemical-specific DAF calculations estimate the dilution of a leachate based on mixing with the shallow WBZ in the saturated Qal at the Site. The average thickness

of saturated Qal at the northern Site boundary (13.5 feet) was used for the aquifer thickness (d_a), and chemical-specific source lengths (L) were measured. The input parameters for the chemical-specific DAF calculations are described previously in this Attachment (see "Input Parameters for Calculation of Dilution Attenuation Factors").

- **Leachate Concentration:** The leachate concentration is calculated using physical soil properties (e.g., soil porosity, water-filled porosity, air-filled porosity, and dry bulk density) presented in Attachment 3 Table 1A. Site-specific soil properties are mean values of the measured properties of core samples collected from the Qal. Attachment Tables 3A-B present the chemical properties used to calculate LSSLs for inorganic chemicals and organic chemicals, respectively.

Attachment Tables

1A   Input Parameters for Soil-Water Partition Equation

1B   Thickness of Saturated Alluvium in Northern Boundary Wells

2A   Leaching-Based, Basic Comparison Levels (LBCLs) for Inorganics

2B   Leaching-Based, Basic Comparison Levels (LBCLs) for Organics

3A   Inorganic Chemical Properties for Soil-Water Partition Equation for Calculating Leaching-Based, Site-Specific Levels (LSSLs)

3B   Organic Chemical Properties for Soil-Water Partition Equation for Calculating Leaching-Based, Site-Specific Levels (LSSLs)

4A   Calculation of Dilution Attenuation Factors for Inorganics

4B   Calculation of Dilution Attenuation Factors for Organics

5A   Calculation of Leaching-Based, Site-Specific Levels for Inorganics

5B   Calculation of Leaching-Based, Site-Specific Levels for Organics

REFERENCES

California Department of Water Resources (DWR), 1994. Bulletin 166-4, Urban Water Use in California, August 1994.

Daniel B. Stephens & Associates, 2009. Summary Report for Updated Groundwater Flow Model Calibration, BMI Upper and Lower Ponds Area. November 2, 2009.

Garcia-Fresca, B., 2005. Urban-enhanced groundwater recharge: review and case study of Austin, Texas. In: KWF Howard (ed) Groundwater management in urban areas. Proceedings of the 32nd International Geological Congress, Florence, August 20-28, 2004. International Association of Hydrogeologists.

Milczarek, M., A. Graham, D. Toy, 2005. Preliminary Assessment of Increased Natural Recharge Resulting from Urbanization and Stormwater Retention within the City of Chandler, 12th Biennial Symposium on Artificial Recharge of Groundwater, Tucson, AZ, June 8-11, 2005.

Milczarek, M., T. Yao, J. Harding, D. Goodrich, and L. Levick., 2004. Predicting Recharge Rates in Small Urbanized Watersheds, Southwest Hydrology, pg. 6-7.

Nevada Division of Environmental Protection (NDEP), 2010a. BMI Plant Sites and Common Areas Projects, Henderson, Nevada, Soil to Groundwater Leaching Guidance. January 16, 2010.

Northgate Environmental Management, Inc. (Northgate), 2010. Capture Zone Evaluation Report, Tronox LLC, Henderson, Nevada. December 10, 2010.

Thornton, J., 2002. Water Loss Control Manual, McGraw-Hill, New York.Tronox, 2010. Interim Groundwater Capture and Vertical Delineation Report, Tronox LLC, Henderson, Nevada. March 23, 2010.

Water Engineering and Management, 1987. "Statewide Water Audit Shows Way to Savings." May 1987, cited in California Department of Water Resources Bulletin 166-4, Urban Water Use in California, August 1994.