APPENDIX J

GROUNDWATER FLOW AND OFFSITE DOSE CALCULATION DETAILS

Overview:
Site hydrologists have verified the overall direction of groundwater flow at IPEC to be ultimately into the Hudson River. From this established understanding, two independent models are applied to determine groundwater flowrates from the site into the river, the precipitation mass balance and the Darcy's Law models.

The precipitation mass balance model applied prior to 2007 was enhanced and further validated for 2007 and beyond by a calibration process involving the Darcy's Law model. A total of six zones on site are evaluated to better partition the distribution of flow across the site. Each zone was also further subdivided into a shallow flow regime and a deeper flow regime based on the depth-specific differences in formation hydraulic conductivity. In addition, the groundwater flow values before and after the Discharge Canal were computed and compared to estimate the amount of groundwater flowing into the canal as well as that discharging directly to the river. The overall precipitation mass balance model was also validated through calibration against a Darcy's Law model relative to groundwater flow through each zone. This calibration was also used to provide the basis for the depth specific and pre-canal/post-canal differentiation of flow values in each zone. 6/08

The concentrations at groundwater to surface water discharge points were updated using wells specifically drilled at these points for a more accurate assessment of the plume boundaries, limits and release concentrations. Average concentrations are used, and based on multiple samples, generally at least one per quarter per elevation per well. The additional wells, and the instrumentation installed therein, also provides further definition of groundwater elevations to enhance the Darcy's Law calibration of the precipitation mass balance model. The hydrology portion of the final model was produced by IPEC's hydrological consultant, GZA GeoEnvironmental, Inc. The specific processes for release and dilution flow evaluation are defined in the following text.

The precipitation mass balance model partitions the precipitation falling on the watershed catchment area (i.e., that portion of the Facility area where the surface topography is sloped towards the river) into water that infiltrates the ground to become groundwater (GW), water which infiltrates but then moves back into the atmosphere via evaporation / transpiration and other processes, and water that flows off the surface as storm water (SW).

There are five parameters required by the precipitation mass balance method of computing radionuclide release rate to the Hudson River via the groundwater pathway.

1. Overall direction of groundwater flow - The surface topography shows that the IPEC facility is located in a significant depression in the eastern bank of the Hudson River. Given that groundwater elevations generally mirror ground surface topography and groundwater flow is from high elevations to lower elevations, the groundwater flows from the north, east and south towards the facility, with ultimate discharge to the Hudson River to the west.

2. Facility-specific groundwater flow paths - To establish facility-specific groundwater flow paths relative to on-site release areas, facility ground surface topography mapping was used. These flow paths were refined based on groundwater contours developed from the groundwater elevations measured with transducers installed in groundwater monitoring installations. The groundwater flow in each zone was then proportioned into shallow flow and deeper flow regimes based on relative hydraulic conductivities measured for the geologic deposits in each zone.

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3. Rate of groundwater flow - The groundwater flow rates through the individual zones were computed using mass-balance relationships that begin with the overall average yearly precipitation for the watershed area and then subtract out precipitation volumes reflecting removal mechanisms such as:

   - Direct evaporation;
   - Vegetative transpiration;
   - Paved and roof surfaces - transport precipitation directly to the river via storm drains;
   - Footing drains.

   The net precipitation infiltration rates resulting in groundwater flow were adopted from a USGS study performed specifically for the Westchester County area, the location in which the facility is sited. The total groundwater flow rate was initially proportioned relative to the catchment areas associated with individual groundwater flow zones.

   These groundwater flow values were subsequently refined using the relative flow values computed using the Darcy's Law model (changes in hydraulic pressure). The gradient was computed from the groundwater elevation contours. For this computation, each flow zone was segregated into two depth regimes; a higher hydraulic conductivity shallow regime and a lower conductivity deeper regime. Finally, the zone-specific flow rates before the Discharge Canal were compared to those after the canal to evaluate the groundwater flux to the river via the Discharge Canal as compared to that discharging directly to the river.

4. Groundwater radionuclide concentration - A number of multi-level groundwater monitoring installations are in place up-gradient of the Discharge Canal and along the waterfront, thus allowing the radionuclide concentrations to be measured for groundwater flowing into the canal as well as that near the groundwater/river interface.

5. Radionuclide release rate to river - Once the groundwater flow rates were established, the zone-specific radionuclide release rates to the Hudson River were computed by multiplying the area/depth-specific groundwater flow rates times the associated radionuclide concentrations; these individual zone-specific values were then summed to arrive at the total radionuclide release rate to the river.

Over the entire watershed catchment area of 3.2 million ft^2, the GW and SW has been segmented relative to areas of the facility through which it flows (primarily established based on the relative concentrations and types of contaminants in the various facility areas). The bulk of the GW activity is identified down gradient of the Unit 2 transformer yard. While tritium is suspected to have originated at both Unit 2 and Unit 1 leaks, most of the offsite dose has been demonstrated to originate from Unit 1 contamination from Sr-90 and other radionuclides (tritium has little dose effect). Stream tubes have been drawn through the boundaries of these areas to define six individual groundwater flow zones:

ZONES:

- **Northern Clean Zone**, the area north of Unit 2;
- **Unit 2 North Zone**, the northern areas of Unit 2, including some low levels of tritium;
- **Unit 1 and 2 Zone**, the area encompassing most of the known plume, between units 1 and 2;
- **Unit 3 North Zone**, the area between Unit 1 and Unit 3;
- **Unit 3 South Zone**, the area that primarily includes operating areas of Unit 3;
- **Southern Clean Zone**, south of Unit 3 to the edge of the property line.

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Overall, the partitioning is established for groundwater and storm water, including recharge rates where storm drains and ground water communicate. In each zone, the groundwater flow is further subdivided into a shallow flow regime and a deeper flow regime based on the depth-specific differences in formation hydraulic conductivity. In addition, the groundwater flow values determined from hydraulic pressure differences before and after the Discharge Canal, were computed and compared to estimate the amount of groundwater flowing into the canal as well as that discharging directly to the river.

Source Terms:
Concentrations of identified radionuclides for all Zones (from quarterly groundwater sampling data from Monitoring Wells and the accumulated Storm Drain sample data) are then applied for routine offsite dose cacluations per ODCM Part II, Section 2. All wells and storm drains are analyzed for gamma spectroscopy and tritium by liquid scintillation. Additionally, groundwater analyses are completed for beta emitters, such as Ni-63 and Sr-90. Quarterly results from effected wells in the effluent locations are evaluated to compute an average source term for each area or zone.

If a result is *below MDC* (whether positive or negative) it was *not* included in the computed average, so as *not* to drive the computed average value down. Therefore more conservative average values, based on only those results above MDC, should be used to avoid averaging in zero and negative values (below MDC) for any location that had at least one identified value above MDC. However, if all the sampling locations assigned to a given stream tube provided results below the MDC, then an average concentration value of zero can be assigned to the effected portion of the stream tube. (This mathematically allows the calculation to proceed in the absence of positive detections).

Ground Water and Storm Drain Source Term selection to the canal is as follows:

Streamtube	Manholes	Monitoring Wells, upper zone	Monitoring Wells, lower zone
Northern Clean Zone	NA	*Background*	*Background*
Unit 2 North	None	*MW-52-11 MW-52-48*	*MW-52-64 MW-52-122 MW-52-162 MW-52-18 MW-52-181*
Units 1and 2	MH-4A	*MW-36-24 MW-36-41 MW-36-52 MW-50-42 MW-50-66 MW-54-37 MW-57-11 MW-57-20 MW-57-45*	*MW-32-92 MW-32-140 MW-32-165 MW-32-196 MW-53-120 MW-54-58 MW-54-123 MW-54-144 MW-54-173 MW-54-190*
Unit 3 North	CB-14, CB-34	*MW-58-26 MW-58-65*	*MW-54-58 MW-54-123 MW-54-144 MW-54-173 MW-54-190*
Unit 3 South	B8	*U3-T2 U3-T1*	*MW-44-102 MW-41-63 U3-4D*
Southern Clean Zone	C1, D1, E6, E10, E13	*MW-40-27 MW-40-46 MW-51-40 MW-51-79*	*MW-40-81 MW-40-100 MW-40-127 MW-40-162 MW-51-104 MW-51-135 MW-51-163 MW-51-189*

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Ground Water and Storm Drain Source Term selection directly to the river is as follows:

Streamtube	Manholes	Monitoring Wells, upper zone	Monitoring Wells, lower zone
Northern Clean Zone	NA	*Background*	*Background*
Unit 2 North	MH-1 MH-12	*MW-60-35 MW-37-22 MW-37-32 MW-49-26 MW-49-42*	*MW-60-53 MW-60-72 MW-60-135 MW-60-154 MW-60-176*
Units 1and 2	MH-14	*MW-37-22 MW-37-32 MW-49-26 MW-49-42 MW-49-65 MW-66-21 MW-66-36 MW-67-39*	*MW-67-105 MW-67-173 MW-67-219 MW-67-276 MW-67-323 MW-67-340*
Unit 3 North	CB-15	*MW-62-18 MW-62-37 MW-62-53 MW-62-71 MW-63-18 MW-63-34 MW-63-50 MW-63-93*	*MW-62-92 MW-62-138 MW-62-182 MW-63-112 MW-63-121 MW-63-163 MW-63-174*
Unit 3 South	none	*U3-T1 U3-T2*	*MW-41-63 MW-44-102 U3-4D*
Southern Clean Zone	C2	*MW-40-27 MW-40-46 MW-51-40 MW-51-79*	*MW-40-81 MW-40-100 MW-40-127 MW-40-162 MW-51-104 MW-51-135 MW-51-163 MW-51-189*

Flow Rates:

Determination of flow rates to the canal and the river through each zone depend on infiltration rates as well as rainfall and measured hydraulic pressure differences. The infiltration rate in non-paved areas (or building areas) was computed at 0.87 feet/year, and consistent with the range provided in the USGS report: *Water Use, Groundwater Recharge and Availability, and Quality in the Greenwich Area, Fairfield County, CT and Westchester County, NY, 2000 - 2002.*

The precipitation rate for the IPEC area is recorded each year, and averages approximately 3 feet per year. A long-term onsite meteorological average should be used for a starting point in determining annual effluent flow rate. All precipitation falling on paved/building areas is assumed to result in SW flow.. Although some of this water actually evaporates directly to atmosphere from pavement and buildings, no credit for this evaporation is taken to ensure conservativism in the model. Some of the Stormwater, however, naturally recharges the groundwater.

The following values are currently applied in the flow model:

Streamtube	Percent of Stormwater Flow Recharging Groundwater
Northern Clean Zone	0%
Unit 2 North	50%
Unit 1/2	30%
Unit 3 North	50%
Unit 3 South	1%
Southern Clean Zone	1%

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Known extration rates from existing pathways need to be subtracted from the zones applicable to these specific pathways, as follows:

- Five gallons per minute (gpm) from the Unit 2 Footing Drain is removed from the Unit 2 North streamtube.
- Five gpm from the Unit 1 North Curtain Drain and 7.5 gpm from the Unit 1 Chemical Systems Building Foundation Drain are removed from the Unit 1/2 streamtube.
- Seven and a half gpm from the Unit 1 Chemical Systems Foundation Drain are removed from the Unit 3 North streamtube

Beyond the known flow and/or extraction rates, the model uses Darcy's Law to determine the flow contours for each of the six zones. Groundwater elevation contours and measurements of hydraulic conductivity are developed from the wells on site, recognizing that flow is perpendicular to the contours. This effort also provides knowledge of facility-specific flow paths. Measurments of pressure differential are then applied (per Darcy's Law) to determine flow rate:

$$Q = K * i * A$$

Where:

Q is groundwater flow (cubic feet/day). This value is calculated.

K is the hydraulic conductivity (ft/day). This value is a log normal average of hydraulic conductivity values measured within the appropriate portion of the streamtube. In other words, the ease of which flow can be forced through sub-surface media.

A is the cross sectional area through which groundwater is moving (ft^2).

i is the change in head over a distance (ft/ft), or a measure of the pressure driving the flow. This value is calculated for the shallow and deep zones both upgradient and downgradient of the canal.

The data above was applied to calibrate the precipitation mass balance model in 2007 and will be similarly applied in subsequent dose determination, with potential minor updates in pararmetes, such as the change in head (*i*) defined above, as the model is further refined. This calibration routine consists of the following steps, as they applied in the 2007 effluent determination:

1) Groundwater elevation data was downloaded from transducers and/or recorded manually with an electronic water level indicator or equivalent. Following download, the data was reduced and evaluated by the site Hydrologists.

2) A period of time was selected to evaluate the groundwater at key elevations and positions along all three axes, such that the maximum number of working transducers were included. Evaluations were also optimized by selecting readings during low-low tide on the targeted day.

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3) Two sets of groundwater contours were prepared. Shallow groundwater contours were drawn based on groundwater elevation data collected generally at elevations higher than 40 feet below top of bedrock. Deep groundwater contours were drawn based on groundwater elevation data from sampling locations deeper than 40 feet below the top of rock, although preference was given to data from the upper portion of that zone.

4) Using the groundwater contours within each streamtube, the groundwater flux was calculated within each zone using Darcy's Law as described above.

5) The total flow, both upgradient and downgradient of the Discharge Canal, was summed separately. The difference between these flows constitutes that groundwater which is recharging the Discharge Canal.

6) The total flow downgradient of the Discharge Canal discharges into the Hudson river.

7) The percentage of groundwater flow in the upper and lower zones of each streamtube was calculated for proportioning of groundwater flow in the upper and lower zones in the Precipitation Mass Balance Model.

> NOTE:
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> The groundwater contours used for the Darcy's Law calibration are based on data collected in calendar year 2007. Seasonal variations in precipitation and runoff are expected to cause variations in the groundwater contours for individual quarterly monitoring rounds. It is anticipated that quarterly data will be collected and reviewed through 2008 to update the model as required. The set of groundwater contours that provide the highest release rate (i.e. those with the steepest gradients) will ultimately be used to provide a final calibration of the Precipitation Mass Balance Model.

8) A final determination of offsite dose can be performed with the previously compiled data (dilution flow, effluent flow rates, and source terms) using an integrated dose calculation model (electronic Excel spreadsheet) identified in Reference 44. This spreadsheet, called the Master Groundwater Dose Calculator, is available from Chemistry Management.

   - The distribution of flow rates to the canal and the river, from each zone, is determined within this asset as a result of calibrations of the rainfall model with Darcy's Law and transducer data. Its purpose is to bound the effluent flow rate in a conservative fashion, until there is evidence of a need to recalibrate the precipitation mass balance method.

   - Averaged or conservative assessments of source term are entered for each zone from a list of required input locations (wells or drains in each effected area).

   - Dose calculations are performed with this information per ODCM Part II, Section 2.4, in the same fashion as other liquid effluents.