Attachment:

Evaluation of Impacts on the Christina River

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## APPENDIX

## 1.0 LOADING CALCULATIONS

The Duffield RI Report identified metals and petroleum as substances of potential concern for impact to the river. Arsenic, lead, cobalt, copper, selenium, calcium, iron, manganese, mercury, nickel, potassium, thallium and zinc are present above expected background concentrations on at least some portions of the site. According to the report, the transport of metals dissolved in water is the primary mode of migration for metals in the site subsurface soils to the river. This form of transport is dependent on the types of metal present, the texture and geochemical character of the soil, the volume of water infiltrating through the soils and the dynamics of the local groundwater flow regimes.

The calculation of loading to the river assumes that all shallow groundwater discharges to the river and the total discharge is controlled by the rate of precipitation minus runoff and evaporation. The discharge could be either direct to the river on the northeast side of the site or via surface drainage features. Using this method, Duffield Associates calculated that approximately 17 million gallons of water fall on the 60.7 acres per year and percolate through the contaminated soil. Under the assumptions used in the method, this volume of water becomes contaminated at concentrations equal to the average concentration of all of the groundwater wells sampled for the RI. Groundwater movement from the site is further qualified by the hydrogeologic properties of the fill soils. A Darcy velocity was calculated using the parameters of hydraulic conductivity and hydraulic gradient. Using this velocity, a flow was then estimated by assuming an average width and saturated thickness of the fill soils.

Duffield calculated that the median flow of the Christina River at the site is 523 cubic feet per second. Concentrations of contaminants are more critical under low flow conditions. State regulations (**State of Delaware, Surface Water Quality Criteria, 1993**) recognize three different low flow conditions characterized by duration and frequency as well as the median flow. Critical flows are expressed in terms of days of duration and recurrence interval in years. For example, the lowest flow of a 7-day duration with a 10-year occurrence interval is known as 7Q10. The resulting concentration of the mixed water can then be compared with the "Water Quality Criteria" for aquatic life and human health established by DNREC. Table A1 below gives the critical flow relevant to each set of quality criteria and the result of Duffield's calculation of Christina River flow at the Potts Property site.

Table A1 Christina River flow volume

| Water Quality Standard[1] | Critical Flow | Flow in Christina River at Potts Property Site[2] (cubic feet per second) |
|---|---|---|
| Human Health Carcinogen | **Median** | **523.8** |
| Human Health Systemic | **30Q5** | **168.27** |
| Aquatic Life Acute | **1Q10** | **85.16** |
| Aquatic Life Chronic | **7Q10** | **106.25** |

[1]State of Delaware *Surface Water Quality Standards*, February 1993
[2]Calculated by Duffield Associates.

Duffield concluded that, after complete mixing with the river water, the contaminant contribution from the Potts Property would, by itself, not cause an exceedence of the surface water quality criteria. (See Duffield Tables 8A to 8C attached.) Based on the data obtained during the RI, the shallow groundwater system at the Potts site is indicated to be a perched, unconfined aquifer, which is hydrologically isolated from adjacent shallow groundwater systems. For this reason, Duffield assumed that there was no "flow through" shallow groundwater component at the Potts site.

The assumption that discharge to the river is driven by precipitation would not be affected by the drought conditions that caused critical flow in the river is quite conservative. The State of Delaware typically assumes that the mixing zone area shall not occupy more than 25% of the receiving water area, based on "thermal mixing" of line discharges with surface water bodies. This regulatory requirement is partially based on the assumed differences in density and temperature of the mixed "line" discharge water and the surface water body. Duffield concluded that, since the parameters of temperature and density of shallow groundwater at the Potts site and the Christina River are likely to be similar, this requirement is not applicable to the Potts site.

In order to evaluate the potential loading of inorganic contaminants from groundwater beneath and/or adjacent to the shallow groundwater system at the Potts site, DNREC estimated discharges from the Columbia and Upper Potomac formations to the Christina River. Based on these calculations (attached), groundwater is discharged from the Columbia and Upper Potomac at approximately 222 and 435 cubic feet per day (0.0025 and 0.005 cubic feet/sec), respectively. Using the formational groundwater quality data obtained from the Halby RI Report and the estimated dilution factors for 1Q10 and 7Q10 flows, the estimated concentrations in the Christina River were compared to the Water Quality Standards. (For this calculation, DNREC used 25% of the estimated volume of both 1Q10 and 7Q10 flows.) Criteria for both fresh and marine water have been included on Tables A2 and A3. The result of the loading calculation for discharge of contaminated groundwater to the river suggests that neither of the groundwater systems evaluated

- The Shallow, Perched Groundwater System at the Potts Site,
- The Unconfined Columbia Aquifer and the Upper Potomac Aquifer at Potts and Halby

appear to impact surface water quality in the Christina River significantly. The contaminant that most nearly approaches its SWQC in fresh water is zinc for chronic exposure. However, combining the zinc contribution from the perched system (2 ug/L), the Columbia and the Upper Potomoc (21 ug/L), the resulting concentrations in the Christina are below the criterion (59 ug/L).

Table A2 Impact of groundwater on contaminant concentration in the Christina River (Acute Exposure)

| | Columbia Formation | Upper Potomac Formation | Christina River | SWQS (acute) | |
|---|---|---|---|---|---|
| | | | | Marine | Fresh |
| **Volatiles (ug/L)** | | | | | |
| 2-Butanone | 3.2E+01 | | 0.004 | | |
| Benzene | 2.9E+01 | | 0.003 | 5100* | 5300* |
| Carbon disulfide | 6.0E+01 | 9.7E+00 | 0.009 | | |
| 1,1-Dichloroethane | 6.2E+01 | | 0.007 | | |
| 1,1-Dichloroethene | 2.2E+01 | | 0.003 | 224000* | 11600* |
| Tetrachloroethene | 2.9E+01 | | 0.003 | | |
| Toluene | 6.7E+02 | | 0.079 | 6300* | 17500* |
| Trichloroethene | 1.5E+01 | | 0.002 | 2000* | 45000* |
| Vinyl chloride | 5.4E+01 | | 0.006 | 2244000S | 11600S |
| **Pesticides (ug/L)** | | | | | |
| Aldrin | 3.5E-02 | 3.5E-02 | 0.000012 | 1.3 | 3 |
| **Inorganics (ug/L)** | | | | | |
| Ammonia | 8.6E+04 | 1.6E+04 | 13.856 | | |
| Antimony | 2.3E+01 | | 0.003 | | |
| Arsenic | 2.6E+02 | 7.1E+00 | 0.032 | 69 | 360 |
| Barium | 1.2E+02 | | 0.014 | | |
| Beryllium | 1.7E+00 | 1.4E+00 | 0.001 | | |
| Cadmium | 8.8E+01 | 3.3E+00 | 0.011 | 43 | 1.79 |
| Chromium | 3.8E+00 | | 0.000 | 1100 | 16 |
| Cobalt | 3.9E+03 | 7.8E+03 | 2.290 | | |
| Cyanide | 1.4E+01 | | 0.002 | | 22 |
| Manganese | 5.4E+04 | 2.2E+04 | 11.508 | | |
| Nickel | 3.0E+02 | 5.3E+02 | 0.160 | 75 | 789 |
| Se/enium | | 2.7E+00 | 0.001 | 300 | 20 |
| Silver | 8.0E+00 | 1.3E+01 | 0.004 | 2.3 | |
| Thallium | 1.2E+01 | 2.0E+01 | 0.006 | 2130* | 1400* |
| Thiocyanate | 8.7E+04 | 4.9E+03 | 11.367 | | |
| Vanadium | | 6.6E+01 | 0.016 | | |
| Zinc | 6.1E+04 | 8.00E+04 | 25.951 | 95 | 65 |

1. Ground water concentration from the Halby RI Report, Table E-GWO5.
2. A blank in columns 2 and 3 indicates that the contaminant was not considered a potential contaminant of concern because of concentration or frequency of detection. A blank in columns 5 and 6 indicates that no Water Quality Criterion has been established by DNREC.

*No Water Quality Criterion has been established. The value is the NOAA “no observable effects concentration”.

Table A3 Impact of groundwater on contaminant concentration in the Christina River (Chronic Exposure)

| | Columbia Formation | Upper Potomac Formation | Christina River | SWQS (chronic) | |
|---|---|---|---|---|---|
| | | | | Marine | Fresh |
| **Volatiles (ug/L)** | | | | | |
| 2-Butanone | 3.2E+01 | | 0.003 | | |
| Benzene | 2.9E+01 | | 0.003 | 700* | |
| Carbon disulfide | 6.0E+01 | 9.7E+00 | 0.007 | | |
| 1,1-Dichloroethane | 6.2E+01 | | 0.006 | | |
| 1,1-Dichloroethene | 2.2E+01 | | 0.002 | | |
| Tetrachloroethene | 2.9E+01 | | 0.003 | 450* | 840* |
| Toluene | 6.7E+02 | | 0.063 | 5000* | |
| Trichloroethene | 1.5E+01 | | 0.001 | | 21900* |
| Vinyl chloride | 5.4E+01 | | 0.005 | | |
| **Pesticides (ug/L)** | | | | | |
| Aldrin | 3.5E-02 | 3.5E-02 | 0.000010 | | |
| **Inorganics (ug/L)** | | | | | |
| Ammonia | 8.6E+04 | 1.6E+04 | 11.106 | | |
| Antimony | 2.3E+01 | | 0.002 | | |
| Arsenic | 2.6E+02 | 7.1E+00 | 0.026 | 36 | 190 |
| Barium | 1.2E+02 | | 0.011 | | |
| Beryllium | 1.7E+00 | 1.4E+00 | 0.0004 | | |
| Cadmium | 8.8E+01 | 3.3E+00 | 0.009 | 9.3 | 0.66 |
| Chromium | 3.8E+00 | | 0.0004 | 50 | 11 |
| Cobalt | 3.9E+03 | 7.8E+03 | 1.835 | | |
| Cyanide | 1.4E+01 | | 0.001 | 1 | |
| Manganese | 5.4E+04 | 2.2E+04 | 9.224 | | |
| Nickel | 3.0E+02 | 5.3E+02 | 0.128 | 8.3 | 88 |
| Se/enium | | 2.7E+00 | 0.001 | 71 | 5 |
| Silver | 8.0E+00 | 1.3E+01 | 0.003 | | 0.12 |
| Thallium | 1.2E+01 | 2.0E+01 | 0.005 | | 40* |
| Thiocyanate | 8.7E+04 | 4.9E+03 | 9.111 | | |
| Vanadium | | 6.6E+01 | 0.012 | | |
| Zinc | 6.1E+04 | 8.00E+04 | 20.801 | 86 | 59 |

1. Ground water concentration from the Halby RI Report, Table E-GWO5.
2. A blank in columns 2 and 3 indicates that the contaminant was not considered a potential contaminant of concern because of concentration or frequency of detection. A blank in columns 5 and 6 indicates that no Water Quality Criterion has been established by DNREC.

*No Water Quality Criterion has been established. The value is the NOAA “no observable effects concentration”.

## 2.0 WATER QUALITY STUDIES IN THE CHRISTINA RIVER

Surface water data is available from the Halby RI Report and from studies done for the Army Corps of Engineers maintenance dredging projects.

Surface water data cited in the Halby RI Report shows that a number of contaminants associated exclusively with the Halby Site are present in the lagoon and marsh areas. These include ammonia, cyanide, and thiocyanate. Arsenic, which is also associated with the Potts Property, is elevated in the lagoon and marsh areas. Most of the surface water samples for the Halby RI were taken in these contaminated areas. However, two samples were taken in the Christina River near the I-495 drainage ditch (sample # SW 11 and SW 12) and one in the Lobdell Canal (SW 10). All three had detectable levels of ammonia ranging from 300 to 900 ug/L. Arsenic was not detected in any of them. A figure showing water contaminant distribution from the Halby RI is attached.

Other water quality data is available from studies performed by the Army Corps of Engineers for dredging activity in the area of the Port of Wilmington (*Final Report: Water Quality Monitoring for Wilmington Harbor Maintenance Dredging Operations, Winter 1994*, prepared by The Greeley-Polhemus Group, Inc., October 1994). A map of the sample locations is attached.

Table A4 below shows analytical results of the EPA and Army Corps of Engineers studies with the Surface Water Criteria for Protection of Aquatic Life (chronic) in fresh and marine water. Of the five samples, the highest concentrations of contamination are found at location SW10 in the Lobdell Canal. At that location however, arsenic and nickel were not detected. Copper was present at 9.9 ug/L (estimated) in the filtered sample which is slightly above the SWQC. Zinc was present at 117 ug/L in the filtered sample. All three unfiltered samples from the Halby RI approach or exceed the standard for iron, about two times the SWQC. The filtered samples are much lower in iron concentration—below the SWQC.

Copper and nickel were absent in all four of the river samples. Arsenic was absent in all but location S-1 where it was present at 2 ug/L, significantly below the SWQC of 190 ug/L. Unfortunately, the Halby RI sample analysis for zinc was compromised by contamination in the blank sample, but it appears that there is a zinc contribution from the Potts Property which may be transported through the I-495 drainage ditch and the Lobdell Canal. At location S1, where the river water would reflect a more mixed condition than at SW11 and SW12, zinc was not detected in two samples.

Table A4 Results of water quality samples in the Christina River (ug/L)

| | HALBY RI (1988) | | | | | | Army Corps of Engineers (1994) | | Water Quality Criteria[1] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Parameters | SW 11 | | SW 10 | | SW 12 | | S 1 Flood Tide | S 1 Ebb Tide | Chronic | |
| | FILTERED | UNFILTERED | FILTERED | UNFILTERED | FILTERED | UNFILTERED | UNFILTERED | UNFILTERED | Fresh | Marine |
| Aluminum | ND U | 400 B | [ 162 B | 412 B | [45.2 B | 499 | | | -- | -- |
| Antimony | ND U | ND U | ND U | ND U | ND U | ND U | | | -- | -- |
| Arsenic | ND UL | ND UL | ND UL | ND UL | [3.4 B | ND UL | 2 | ND | 190 | 36 |
| Barium | [ 87 | [115 | [ 98.7 | [ 122 | [ 87 | [ 115 | ND | ND | -- | -- |
| Beryllium | ND U | [ 0.65 | ND U | [ .69 | ND U | ND U | | | -- | -- |
| Cadmium | ND U | ND U | ND U | ND U | ND U | ND U | | | 0.66 | 9.3 |
| Calcium | 25000 | 28100 J | 27500 | 31300 | 28300 | 30800 J | | | -- | -- |
| Chromium | ND UL | ND UL | ND UL | ND UL | ND UL | ND UL | 6 | 10 | 11 | 50 |
| Cobalt | ND UL | ND UL | [ 39 | [ 34.8 | [ 36.6 | [ 25.4 | | | -- | -- |
| Copper | ND UL | ND UL | [ 9.9 | 34.8 | ND U | ND U | ND | ND | 6.54 | 2.9 (acute) |
| Iron | [ 54.5 B | 908 | 137 B | 1430 | [ 49 B | 1400 | | | 1000 | --- |
| Lead | [1.2 B | [ 3.3 B | [ 2.9 B | 9.3 | [ 1.1 B | 8.4 | ND | ND | 1.32 | 5.6 |
| Magnesium | 21600 | 21500 | 18900 | 19300 | 27400 | 26600 | | | -- | -- |
| Manganese | 43 | 83.1 | 186 | 211 | 94.2 | 106 | | | -- | -- |
| Mercury | ND U | ND U | ND U | ND U | ND U | ND U | | | 0.012 | 0.025 |
| Nickel | ND U | ND U | ND U | ND U | ND U | ND U | ND | ND | 87.7 | 8.3 |
| Potassium | 7310 | 7180 | 6780 | 6670 | 8780 | 8540 | | | -- | -- |
| Selenium | ND U | ND UL | ND UL | [ 3.2 | ND U | ND U | ND | ND | 300 | 71 |
| Silver | ND U | ND U | ND UL | ND UL | ND UL | ND U | | | 0.12 | 2.3 (acute) |
| Sodium | 123000 | 116000 | 92500 | 89600 | 177000 | 161000 | | | -- | -- |
| Thallium | ND R | ND R | ND R | ND R | ND R | ND R | | | -- | -- |
| Vanadium | ND U | ND U | ND U | ND U | ND U | ND U | | | -- | -- |
| Zinc | [ 9.4 B | 41.5 B | 117 | 170 | 57 B | 81.6 B | ND | ND | 58.9 | 86 |

ND – Not detected; U- Below detection limit; --- - Not requested

NR – analysis requested but not reported; J – Estimated

R – Rejected; L – Lower than actual value; B – Analyte is found in the blanks as well as a sample
K – Higher than actual value; [ - Estimated value; below Contract Required Detection Limit

[1]State of Delaware "Surface Water Quality Standards" February 1993
Some fresh water criteria are calculated using hardness value of 50 mg/L.
("—" indicates that no standard has been determined)

## 3.0 SEDIMENT QUALITY STUDIES

In 1995, the Department invetigated sediment contamination problems in the Christina River. Sediment samples were taken approximately every 500 feet from near the confluence of the Christina and Delaware Rivers to 15 river miles upstream. Contaminants of concern at the Potts Site such as arsenic and were found throughout river. The mouth of the river, where the Potts Property Site is located, was identified as one of eight areas where sediment contamination reaches levels that could impact aquatic life. Three samples taken near the Potts Property site were analyzed for some of the inorganic and organic contaminants, which have been associated with site soils. The results are reported in Table A5 below and are labeled "DNREC" samples.

Sediment samples were taken for the Halby RI in the lagoon, marshes, and ditches on the Halby and Potts Sites. A limited number were also taken in the Christina River and Lobdell Canal. They are designated "EPA" on Table A5. Sediment samples taken in the marsh and ditches on the Potts Property show high levels of site related contamination including arsenic, cadmium, copper, and zinc. (These areas will be remediated as part of the Halby project.)

The Army Corps of Engineers Report referenced above also included composite sediment samples from two areas immediately downstream from the Potts Property Site. They are labeled on Table A5 as "ACE".

Sediment contaminant concentrations are compared to sediment quality guidelines known as "Effect Range—Low" (ERL) and "Effect Range—Median" (ERM). (See *The Potential for Biological Effects of Sediment-sorbed Contaminants Tested in the National Status and Trends Program*. NOAA Technical Memorandum NOS OMA 52 by the U.S. National Oceanic and Atmospheric Administration.) At concentrations below the ERL, contaminants are not expected to have adverse biological affects. Between the ERL and the ERM, adverse effects are possible and occasionally occur. Adverse affects occur frequently when contamination is present at concentrations above the ERM.

The data shown in Table A5 suggests that adverse affects are possible from arsenic, lead, zinc and copper concentrations in sediment both upstream and downstream from the Potts Property. Although the data is limited, it appears that the most heavily contaminated sediment immediately adjacent to the river is in the Lobdell Canal. There is a significant exceedence of the ERM there for copper as documented in the Halby RI report. Sediment in the marsh immediately upstream of the Lobdell Canal sample shows high levels of arsenic, cadmium, and zinc. It is apparent that there has been transport of contamination in suspended solids from the marsh system to the sediment of the Lobdell Canal. The area dredged by the Army Corps of Engineers for the Port of Wilmington from the river has much lower concentrations in sediment.

Table A 5. Selected results of sediment samples from three studies (mg/kg)

| | Sample Location | Arsenic | Lead | Zinc | Selenium | Copper | PAHs[3] |
|---|---|---|---|---|---|---|---|
| **Sample 1 (DNREC)** | Right bank, opposite Port of Wilmington | 16.2 | 74.2 | 193 | .73 | 31.6 | ND[4] |
| **Sample 5 (DNREC)** | Left bank, just downstream from Lobdell Canal | 21.7 | 79.8 | 272 | 1.4 | 40.9 | ND |
| **Sample 9 (DNREC)** | Right bank, at I-495 bridge | 8.37 | 72.9 | 228 | .48 | 38.1 | 71 |
| **Station 1 (ACE)** | Composite sample from area downstream from Lobdell Canal | 2.83 | 19.6 | 150 | .262 | 24.8 | |
| **Station 2 (ACE)** | Composite sample from area near disposal area outfall | 2.12 | 13.8 | 109 | .303 | 18.6 | |
| **SED-22 (EPA)** | Upstream of I-495 drainage ditch | ND | 234 | 573 | 3.5 | 48.7 | |
| **SED-23 (EPA)** | Downstream of I-495 drainage ditch | 23.7 | | | | 47.6 | |
| **SED-16 (EPA)** | End of Lobdell Canal | 45.2 | | | | 202 | |
| **SED-17 (EPA)** | Mouth of Lobdell Canal | 54.4 | | | | 368 | |
| **EPA-11 (EPA)** | End of Lobdell Canal (1990) | 42 | | | | 830 | |
| **ERL[1]** | | 8.2 | 46.7 | 150 | | 34 | 4022 |
| **ERM[2]** | | 70 | 218 | 410 | | 270 | 44792 |

Notes for Table A5:
A blank indicates that the substance was not analyzed for or that the result was not available.
[1]Effect Range – Low (Long and Morgan, 1991)
[2]Effects Range – Medium (Long and Morgan, 1991) ER-L and ER-M are not established for Selenium
[3]Total polynuclear aromatic hydrocarbons (PAHs) determined by immuno-assay in DNREC study
[4]Non-detect

## 4.0 CONCLUSIONS

This evaluation of impacts of the Potts and Halby Sites on the Christina River considered calculated loading from contamination in the shallow perched groundwater system of the Potts Property Site and in the Columbia and Upper Potomoc aquifers. It also reviewed surface water and sediment data from studies performed by the EPA, the Army Corps of Engineers and DNREC.

The loading calculations indicated that groundwater at the Potts and Halby sites is a source of zinc contamination in the Christina River. However, the contribution of the sites to zinc contamination in the river is less than half of the SWQC. There is not a known exceedence of any SWQC in the study area of the river. There are exceedences for copper and zinc in the Lobdell Canal.

The surface water data review showed that the surface water flowing through the drainage system across the Potts and Halby Sites is a probable source of water contamination by zinc and copper in the Lobdell Canal which joins the Christina River. These contaminants are not present at detectable levels in center of the river immediately downstream of the Lobdell Canal.

Ten sediment samples from locations in the Christina River and Lobdell Canal showed extensive contamination by arsenic, lead, zinc and copper at levels that possibly affect aquatic life. Adverse biological effects are probable in the Lobdell Canal due to copper contamination. Sediment contamination in the areas dredged by the Army Corps of Engineeers is not expected to adversely affect aquatic life.

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