Attachment 1

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Memorandum

From: Dave Dilks, Kathy Hall

Date: September 28, 2019

Project: DC2019

To: John Cassidy, Ron Bizzarri

SUBJECT: DRAFT Re-calculation of Ammonia Effluent Limits for Blue Plains WWTP

Limno-Tech calculated the permit limits necessary for the Blue Plains WWTP to maintain compliance with proposed water quality standards for ammonia at the edge of the regulatory mixing zone, assuming an expanded flow of 384 MGD.

The permit limit calculations were made following the procedures listed in EPA's Technical Support Document for Water Quality-based Toxics Control (1991). The wasteload allocation calculations used as input for the permit limit derivation were calculated using EPA's CORMIX model to predict ammonia concentrations in the acute mixing zone, and the Dynamic Estuary Model to predict the impact of Blue Plains effluent ammonia concentrations on "upstream" Potomac River concentrations. The resulting permit limits are as follows:

	November 1 – April 30	May 1 - October 31
Average Monthly Limit (mg NH3-N/l)	5.4	1.7
Average Weekly Limit (mg NH3-N/l)	7.8	2.5

Note that these values were calculated using prior assumptions regarding background water quality conditions; actual future permit limits could be slightly different if updated data on background water quality and effluent variability are used.

The remainder of this memorandum describes how the permit limits were derived. It is divided into sections of:

- Background
- Applicable Standards
- Environmental Conditions
- Wasteload Allocation
- Permit Limit Derivation

Background

The renewal of the NPDES discharge permit for the Blue Plains WWTP will require effluent limitations for ammonia that result in compliance with water quality standards for the Potomac River regarding ammonia toxicity. The steps involved in deriving these permit limits are as follows:

Define Applicable Water Quality Standards: The intent of the permit calculations is to specify effluent concentrations that will maintain compliance with water quality standards in the Potomac River. Specification of the water quality standards is a necessary first step in this process.

Define Environmental Conditions: The water quality standards for ammonia toxicity vary as a function of pH and temperature; calculation of water quality standards therefore also requires specification of pH and temperature values representative of critical environmental conditions.

Perform Wasteload Allocation: This step of the process uses mathematical models to predict the relationship between effluent concentration and the resulting receiving water concentration. It also addresses the concept of "mixing zones", allocated impact zones where concentrations may exceed the water quality standard while the effluent undergoes initial mixing with the receiving water.

Calculate Permit Limits: The wasteload allocation calculated above must be converted into permit limits, which define the maximum concentration that may be observed via effluent monitoring. Permit limit derivation uses statistical procedures to account for natural variability in effluent concentrations, and determines the maximum effluent concentration expected to be observed which still represents overall compliance with the wasteload allocation.

The remainder of this memorandum is divided into discussion of each of the above steps.

Water Quality Standards

The proposed water quality standards for ammonia currently applicable to the District of Columbia are based upon EPA (2013) recommendations, which provide separate acute criteria, depending upon whether salmonids in the Genus *Oncorhynchus* are present. Criteria are provided both in equation and tabular form. Equation 1 is used to determine the acute criterion (also called the criterion maximum concentration, or CMC) when salmonids in the Genus *Oncorhynchus* are present.

$$CMC = MIN\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39.0}{1+10^{pH-7.204}}\right),\left(0.7249\times\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\times\left(23.12\times 10^{0.036\times(20-T)}\right)\right)\right) \quad (1)$$

Criteria values resulting from a range of pH and temperature values when salmonids in the Genus *Oncorhynchus* are present are shown in Table 1.

Equation 2 is used to determine the acute criterion when salmonids in the Genus *Oncorhynchus* are absent.

$$CMC = 0.7249 \times \frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\times MIN\left(51.93, 23.12\times 10^{0.036\times(20-T)}\right) \quad (2)$$

Acute criteria values resulting from a range of pH and temperature values for the case where salmonids in the Genus Oncorhynchus are absent are shown in Table 2. It is noted that the

September 2017 Proposed Rulemaking inconsistently represents the acute criterion between when shown in the equation form (which displays the criterion when salmonids in the Genus *Oncorhynchus* are present) and the tabular form (which displays the criterion when *Oncorhynchus spp.* are absent). The July 2019 Second Proposed Rulemaking consistently used the equation and table representing the presence of *Oncorhynchus*, although neither document mentions any assumptions about the presence or absence of *Oncorhynchus.*

The chronic water quality criterion for ammonia does not depend upon the presence of *Oncorhynchus spp*., with a single equation provided for all waters (Equation 3).

$$CCC = 0.8876 \times \left(\frac{0.0278}{1 + 10^{7.688-pH}} + \frac{1.1994}{1 + 10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right) \quad (3)$$

Chronic criteria values resulting from a range of pH and temperature values are shown in Table 3.

Environmental Conditions

Water quality criteria for ammonia, as well as the wasteload allocation calculations, depend upon the ambient environmental conditions. Values for all relevant environmental parameters for existing water quality standards were determined using data from 2005-2012 for the two seasonal periods represented in existing water quality standards, defined as:

- **Winter:** November 1 - April 30
- **Summer:** May 1 - October 31

Selection of appropriate values is described below, and divided into discussions of: pH and temperature; upstream flow; and background ammonia concentration.

pH and Temperature

The water quality standards for ammonia toxicity shown in Tables 1, 2, and 3 vary as a function of pH and/or temperature. Calculation of water quality standards therefore also requires specification of representative pH and temperature values. Guidance from Virginia DEQ (Guidance Memo No. 00-2011; Guidance on Preparing VPDES Permit Limits; August, 2000) recommends the use of the 90th percentile temperature and the 90th percentile pH to represent critical environmental conditions. A statistical analysis was conducted using observed Potomac River data from the Naval Research Laboratory monitoring station (2005-2012), which is located immediately upstream of the Blue Plains outfall.

Because of the small amount of dilution available for acute and chronic toxicity considerations, the critical pH at the edge of the mixing zone was calculated from the mix of effluent and background water. These calculations defined the mixed pH in the acute and chronic toxicity mixing zones, following the same protocol used for prior permits. This consists of using the observed 90th percentile in-stream pH and alkalinity, the observed 90th percentile effluent alkalinity, the observed 99th percentile effluent pH, and the predicted dilution at the edge of each mixing zone (discussed below in the wasteload allocation section). It is important to note that pH units represent a logarithmic scale, and must be converted prior to determining the pH resulting from the mixture of two waters. In addition, the alkalinity of the source waters also affects the resulting pH. These considerations were accounted for when calculating the mixed pH.

Table 1. EPA (2013) Acute Ammonia Criteria (mg NH3-N/l) - *Oncorhynchus spp.* Present

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	8.0	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3.0
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	2.6	2.6	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.59	0.54
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.2	1.2	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.0	1.0	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	0.88	0.88	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

Table 2. EPA (2013) Acute Ammonia Criteria (mg NH3-N/l) - *Oncorhynchus spp.* Absent

pH	Temperature (°C) 0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7.0	6.4	5.9	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	6.0	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2.0	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

Table 3. EPA (2013) Chronic Ammonia Criteria (mg NH3-N/l)

Temperature (°C)

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99
7.1	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95
7.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.96	0.90
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.96	0.90	0.85	0.79
7.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	0.98	0.92	0.86	0.81	0.76	0.71	0.67
7.7	2.6	2.4	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60
7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.44	0.44	0.41
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.92	0.87	0.81	0.76	0.71	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35
8.2	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.84	0.79	0.74	0.70	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30
8.3	1.1	1.1	0.99	0.93	0.87	0.82	0.76	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26
8.4	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22
8.5	0.80	0.75	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.20	0.18
8.6	0.68	0.64	0.60	0.56	0.53	0.49	0.46	0.43	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.16	0.15
8.7	0.57	0.54	0.51	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13
8.8	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11
8.9	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.09
9.0	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08

The critical pH and temperature values used in the calculations, and the resulting mixed pH values are presented in Table 4. The mixed pH and critical river temperature values were used to calculate the water quality criteria for ammonia; pH and temperature values used and the resulting criteria are provided below in Table 5. This analysis uses the version of acute criterion that assumes salmonids in the Genus *Oncorhynchus* are present. As will be shown subsequently, however, assumptions regarding which form of the acute criteria are used do not affect resulting permit limits, which depend solely on the chronic criterion.

Table 4. Critical Effluent and Upstream pH and Temperature, and Resulting Mixed pH Values

Season	pH				Temperature	
	Effluent	Upstream	Mixed acute	Mixed chronic	Effluent	Upstream
Summer	7.0	8.5	7.3	7.7	24.4	28.3
Winter	6.8	8.7	7.1	7.5	11.6	12.8

Table 5. Critical pH and Temperature, and Resulting Water Quality Standards

Season	Temperature	Chronic pH	Acute pH	Acute Standard (mg NH3-N/l)	Chronic Standard (mg NH3-N/l)
Winter	12.8	7.5	7.1	21.9	2.2
Summer	28.3	7.7	7.3	6.1	0.7

Flow

The wasteload allocation modeling also requires specification of upstream Potomac River flow, as this affects the amount of available dilution. Consistent with EPA guidance, the once in ten year, one day average low flow (1Q10) was selected as the appropriate flow statistic for evaluating acute toxicity concerns, while the once in ten year, seven day average low flow (7Q10) was selected as the appropriate flow statistic for evaluating chronic toxicity concerns. Values for each of these flow statistics were calculated using EPA's DFLOW program for each of the seasons under consideration using observed Potomac River flows at Chain Bridge, with the results listed in Table 6.

Table 6. Upstream Design Flows (cfs) Used in Analysis

Season	1Q10 Flow	7Q10 Flow
Winter	1070	1290
Summer	507	607

Background/Upstream Ammonia

The wasteload allocation calculations required to define the relationship between Blue Plains effluent ammonia concentrations are resulting Potomac River ammonia concentrations also require specification of upstream ammonia concentrations. A statistical analysis was conducted using observed Potomac River data from the Naval Research Laboratory station (2005-2012) to define the 90th percentile Potomac River ammonia concentration for each of the two seasonal periods. Results of the analysis are provided in Table 7.

Table 7. Critical Upstream Ammonia Concentrations, mg NH3-N/l

Season	Upstream Concentration
Summer	0.20
Winter	0.15

Due to reversing tidal flows in the Potomac, it is recognized that "upstream" concentrations are still influenced by the Blue Plains discharge, and that changes in future effluent concentration can change the upstream concentration. This influence was addressed by conducting simulations with the Dynamic Estuary Model to define the relationship between Blue Plains effluent ammonia concentrations and the resulting "upstream" concentration. This analysis is discussed in the following section.

Wasteload Allocation

Mathematical modeling was conducted to define the ammonia concentration in the Blue Plains effluent that would result in compliance with water quality standards at the edge of the regulatory mixing zone. These calculations required five activities:

- Definition of the regulatory mixing zone
- Mixing zone modeling for the acute mixing zone
- Mixing zone modeling for the chronic mixing zone
- Calculation of background concentrations with the Dynamic Estuary Model (DEM)
- Calculation of wasteload allocation values

Definition of the Regulatory Mixing Zone

Chapter 11 of the District of Columbia Municipal Regulations (DCMRs) establish the District's Water Quality Standards and provide for the allowance of Mixing Zones, areas where concentrations may exceed the water quality standard while the effluent undergoes initial mixing with the receiving water. General guidance is given on the specification of mixing zones both for acute and chronic toxicity, and this guidance requires site-specific interpretation.

For acute toxicity, Rule 1105.7(d) of the DCMRs requires that, "the water quality within the mixing zone shall be such that the concentration of a substance in the mixing zone does not cause lethality to passing organisms, as determined by the appropriate EPA method." This requirement will be addressed by calculating the time-average dilution experienced along the centerline of the effluent plume for the first hour after the point of discharge, based upon results from the CORMIX model. This calculation of time-averaged dilution will represent the maximum possible exposure that a drifting organism could receive, as it predicts the exposure of an organism that is immediately entrained into the effluent as it is discharged to the Potomac, and drifts along the center line of the effluent plume for the entire hour.

For chronic toxicity, Rule 1105.7(f) of the DCMRs requires that, "within the estuary, the maximum cross-sectional area occupied by a mixing zone shall not exceed 10% of the numerical value of the cross-sectional area of the waterway, and the width of the mixing zone shall not occupy more than one third of the width of the waterway."

Mixing Zone Modeling for the Acute Mixing Zone

EPA's Technical Support Document for Water Quality-based Toxics Control (1991) recommends that acute toxicity considerations can be addressed by demonstrating that a drifting organism entrained in the plume would not be exposed to one-hour average concentrations exceeding the acute criterion during critical environmental conditions. The Cornell Expert System Mixing Zone Model (CORMIX Version 3.2) was applied to define the average dilution that occurs along the centerline of the plume under worst case conditions. The worst case (i.e. lowest dilution) condition for a tidal system such as the Potomac corresponds to slack tide, where there is zero ambient velocity. Because of the worst-case, zero ambient velocity assumption, this critical dilution will be essentially the same for both seasonal periods. Resulting dilutions are summarized in Table 8.

Table 8. CORMIX-Predicted Dilution Factors

Season	Acute Toxicity Dilution Factor
Summer	1.7
Winter	1.7

Mixing Zone Modeling for the Chronic Mixing Zone

Two aspects of the Blue Plains/ Potomac River discharge location were not directly amenable to CORMIX application. First, the river undergoes tidally-driven flow reversals. CORMIX is a steady-state model that assumes constant flow conditions. Second, CORMIX assumes relative constant river geometry. The Blue Plains outfall is located on a shallow flat, over which the effluent must travel before meeting the deeper navigation channel. These limitations did not significantly affect the ability of CORMIX to address acute toxicity concerns, but did make CORMIX inappropriate for addressing chronic toxicity dilution factors.

The approach used to determine chronic toxicity dilution factors was patterned after the most commonly used approach for assessing chronic mixing zones in rivers. The approach allows a fraction of the total available flow to be used for dilution, with this fraction being set equal to the fraction of the river's cross-sectional area allotted to the chronic mixing zone. For the Potomac, that fraction is 10%. Because the Potomac River near Blue Plains is tidally influenced, it is appropriate to use the total dilution flow available over a tidal cycle (rather than just the freshwater flow). The chronic toxicity dilution factor equation therefore becomes:

$$S = (Q_w + 0.10 Q_{Tid,Season}) / Q_w \qquad (4)$$

where S = Dilution factor

Q_w = Wastewater flow

$Q_{Tid,Season}$ = Tidal prism flow corresponding to 7Q10 flows for each season

Tidal dilution flows for were calculated for each of the three seasonal periods using the Dynamic Estuary model and seasonally appropriate 7Q10 upstream flows. Resulting dilution factors are shown in Table 9.

Table 9. Chronic Toxicity Dilution Factors

Season	Chronic Toxicity Dilution Factor
Summer	3.71
Winter	3.71

Calculation of Background Concentrations with the Dynamic Estuary Model (DEM)

The standard dilution equation used to calculate a wasteload allocation can be written as:

$$C_{mix} = C_w/S + ([S-1]/S)\, C_{upstream} \quad (5)$$

where C_{mix} = In-stream concentration after mixing

C_w = Wastewater concentration

S = Dilution factor, as predicted by mixing model

$C_{upstream}$ = Upstream concentration

Tidal receiving waters pose an additional complicating factor when calculating the dilution available for wasteload allocations, because the upstream concentrations used in Equation 5 are affected by effluent concentrations. As part of this study, LimnoTech conducted a series of simulations to determine the effect of Blue Plains ammonia on upstream concentrations. The response between upstream river concentration and effluent ammonia concentration was linear (assuming all other inputs are held constant). Model results for ammonia concentration at junction 129 (directly upstream of Blue Plains) were analyzed to develop the linear relationship for each permit design condition. Results of the DEM simulations were combined with observed data for effluent concentration and the observed 90th percentile upstream ammonia concentration to yield the following:

- Summer: $C_{upstream} = 0.20 + 0.0892 \times (C_{effluent} - 0.19)$
- Winter: $C_{upstream} = 0.15 + 0.186 \times (C_{effluent} - 0.61)$

The above relationships were used to adjust upstream concentrations from the observed values reported in Table 7 to account for changing effluent concentrations in the wasteload allocation calculations.

Calculation of Wasteload Allocation

The standard dilution equation shown in Equation 5 was algebraically rearranged to define the effluent concentration necessary to meet water quality standards during critical conditions. By requiring the concentration after mixing to comply with the water quality standard, Equation 5 can be re-written as:

$$C_{w,WLA} = S[C_{WQS} - ([S-1]/S)\ C_{upstream}] \quad (6)$$

where:

$C_{w,WLA}$ = Wasteload allocation effluent concentration

C_{WQS}= Water quality standard concentration

Equation 6 was applied using the water quality standards in Table 5 in conjunction with the dilution factors in Tables 8 and 9 to generate the acute and chronic wasteload allocations for each seasonal condition. These are presented in Table 10.

Table 10. Wasteload Allocation Values for Ammonia (mg NH3-N/l)

Season	Acute Toxicity	Chronic Toxicity
Winter	32.9	5.4
Summer	9.6	1.7

Permit Limit Derivation

The results of the wasteload allocation must be converted to serve two purposes before being used in the permit. The calculations are:

1. Calculation of a required Long Term Average (LTA) effluent concentration which will, when considering the variability in effluent concentrations, exceed the wasteload value and acceptably small percentage of time.
2. Calculation of average weekly and average monthly values which, if exceeded, indicate that effluent concentrations are not meeting the required long term average value.

The results of Step 2 are specified in the permit limit, and are referred to as the Average Weekly Limit (AWL) and Average Monthly Limit (AML).

Permit Equations

The procedure for calculating the LTAs and AMLs is documented in EPA's Technical Support Document for Water Quality-based Toxics Control (1991), and clarified for ammonia in EPA's revised water quality criteria (EPA, 1999). The starting point for this analysis is definition of the wasteload allocations for acute and chronic toxicity, as well as the coefficient of variation (CV) for effluent quality.

The acute long term average (LTA_a) is determined from the acute wasteload allocation (WLA_a) using the equation:

$$LTA_a = WLA_a \exp\,[0.5\sigma^2 - z\sigma] \quad (7)$$

where $\sigma^2 = \ln(CV^2 + 1)$

z = probability statistic for desired level of significance

The chronic long term average (LTA_c) is determined from the chronic wasteload allocation (WLA_c) using the equation:

$$LTA_c = WLA_a \exp [0.5\sigma_{30}^2 - z\sigma_{30}] \quad (8)$$

where $\sigma_{30}^2 = \ln (CV^2/30 + 1)$

z = probability statistic for desired level of significance

A comparison of the LTA_a and LTA_c is then performed and the minimum value is selected (LTA_{MIN}). The average monthly limit (AML) is then calculated from the LTA_{MIN} using the equation:

$$AML = LTA_{MIN} \exp [z\sigma_n - 0.5\sigma_n^2] \quad (9)$$

where $\sigma_n^2 = \ln (CV^2/n + 1)$

The value of "n" in the calculation of the AML is based on the monthly effluent monitoring frequency. Given daily monitoring frequency, n=30 for calculation of the AML. Finally, the average weekly limit (AWL) for Blue Plains is also calculated using Equation 9, but using n=7 to reflect seven samples collected per week.

Application to Blue Plains

Equations 7 through 9 were applied to the wasteload allocation results described above in Table 10. A 95% significance level was used for all calculations, corresponding to a z value of 1.645. The coefficient of variation was calculated from observed Blue Plains effluent data (FY 2013-2014), with the results as follows:

- Summer coefficient of variation: 2.3
- Winter coefficient of variation: 2.2

The monitoring frequency was set at thirty samples per month. The resulting permit calculations are shown in Table 11.

Table 11. Permit Limits for Ammonia (mg NH3-N/l)

	November 1 – April 30	May 1 - October 31
Average Monthly Limit (mg N-l)	5.4	1.7
Average Weekly Limit (mg N-l)	7.8	2.5

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