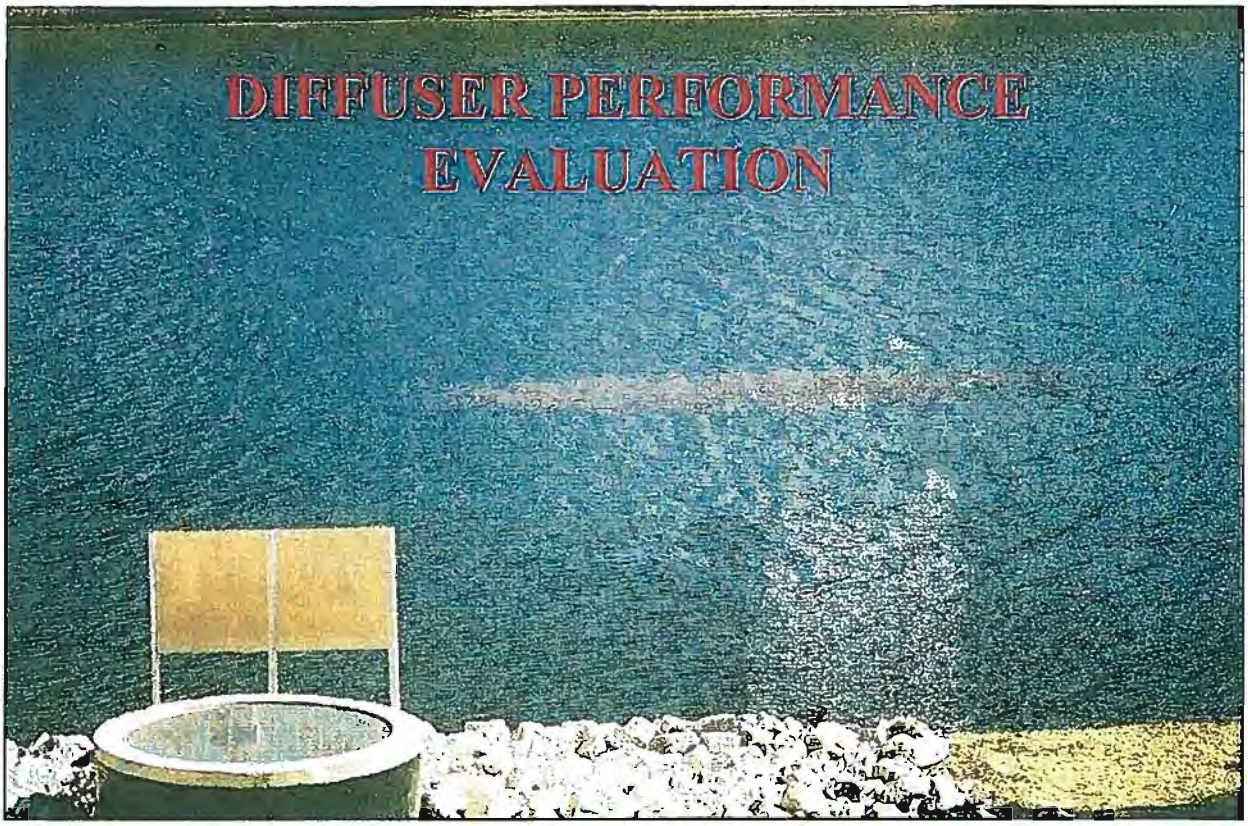
Exhibit 4



ILLINOIS RIVER
HENRY, ILLINOIS

noveon
The Specialty Chemicals Innovator™

AquAeTer

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DECEMBER 2005

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DIFFUSER PERFORMANCE EVALUATION

ILLINOIS RIVER NEAR HENRY, ILLINOIS

FOR:

NOVEON, INC.

AND

HORNER & SHIFRIN, INC.

AND

MASSMAN CONSTRUCTION COMPANY

PREPARED BY:

JOHN MICHAEL CORN, E.I.T.
MICHAEL R. CORN, P.E.

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DECEMBER 2005

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2	Joint Application Form and Acceptance Correspondence
3	Fluorometer Calibration Curves
4	Field Notes and Data

EXECUTIVE SUMMARY

A diffuser performance study was conducted on October 25, 2005 for the new multiport diffuser installed for Noveon, Inc. The average river flow during the study was 4,155 cfs, which is below the harmonic mean standard of 9,870 cfs. A GPS unit was utilized with a fluorometer to measure the dye plume in real time. Additionally, stationary locations were measured within the dye plume.

The water quality standard for total dissolved solids and the acute standard for total ammonia were met in less than 20 feet from the diffuser. The chronic standard for ammonia was projected to be met at less than 300 feet from the diffuser. The flux average dispersion at 553 feet downstream from the diffuser was 239.2:1. The flux average dispersion at 1,000 feet downstream from the diffuser was 299.9:1. The plume achieved full vertical mixing within 90 feet from the diffuser. No significant restratification due to total dissolved solids (negative buoyancy) or temperature (positive buoyancy) was encountered. A plan view of the plume in the River is presented in Figure E-1.

The diffuser is performing as it was designed. All water quality standards are met at less than 300 feet from the diffuser under the maximum ammonia discharge limit. The mixing zone is very narrow. The flux average plume width ranged from approximately 10 feet at the diffuser to 54 feet at 273 feet downstream from the diffuser.

A comparison between the measured dispersion and the CORMIX predicted dispersion is presented in Table E-1. The flux average dispersions and the flux average plume widths measured during the October field study are presented in Table E-2.

TABLE E-1. CORMIX COMPARISON

DISTANCE DOWNSTREAM (ft)	CORMIX PREDICTED DISPERSION (_:1)	AVERAGE FAD MEASUREMENT DISPERSION	
		ACROSS PLUME (_:1)	IN WATER COLUMN (_:1)
20		39.7	66.0
30	45.2		
37		39.8	53.3
78	52.2		
92		47.9	47.9
102	55.1		
553		151.5	151.5
558	146.2		
1087	430.9		
1090		299.9	299.9

TABLE E-2. FAD

TRANSECT	DISTANCE DOWNSTREAM (ft)	FAD WIDTH (ft)	AVG FAD (__:1)
Stationary	20	-	39.8
Stationary	37	-	39.9
Lat 3	60	52	
Stationary	92	-	47.1
Lat 4	97	-	
Lat 5	151	48	
Lat 6	193	-	
Lat 7	273	54	
Lat 8	354	66	
Lat 9	463	70	
Lat 10	508	54	
Stationary	553		239
Lat 11	658	70	
Lat 2	1,058	-	
Stationary	1090		577
Stationary	1094		415
Stationary	~1,090		300
Lat 1	1,146	112	

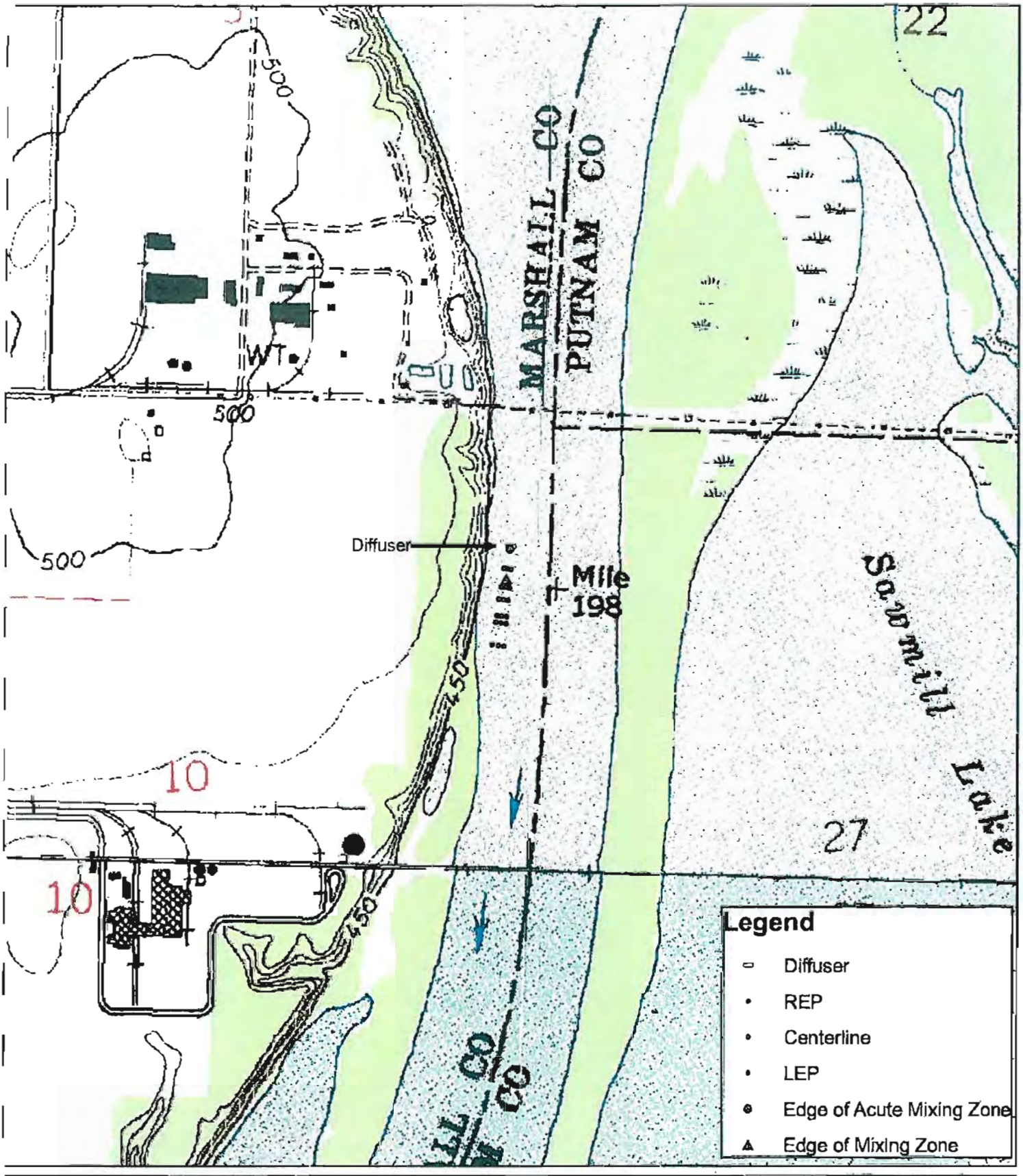

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Figure E-1
Plan View of Plume in River
Henry, Illinois

N W E S

0 250 500 1,000 1,500 2,000 Feet

1:10,000

Topographic map provided by

SECTION 1

INTRODUCTION

Noveon, Inc. (Noveon) has recently installed a multiport diffuser to discharge its treated effluent into the Illinois River. Historically, Noveon discharged their effluent through a single port diffuser located approximately 38 feet offshore at a water surface elevation of 442 feet above the National Geodetic Vertical Datum of 1929 (ft NGVD 1929).

The Illinois Pollution Control Board (IPCB) granted Noveon an Adjusted Ammonia Standard on November 4, 2004 and also ruled that Noveon is providing the Best Degree of Treatment, which would allow them to apply for a mixing zone under the Illinois Environmental Protection Agency (IEPA). The IEPA subsequently granted Noveon a mixing zone. In order to meet the requirements of the Adjusted Ammonia standard set by the IPCB and the mixing zone requirements, Noveon installed a multiport diffuser.

SITE LOCATION

Noveon owns and operates a manufacturing facility located in Henry, Illinois, as presented in Figures 1-1 and 1-2, which produces specialty chemicals for the rubber industry. This location employs approximately 120 people. In addition to the Noveon manufacturing facilities, PolyOne operates a PVC manufacturing facility at the site. Process wastewaters from both plants are treated in the on-site industrial wastewater treatment systems, and the effluent is discharged to the Illinois River at approximately Illinois River mile (IRM) 198. PolyOne operates a pretreatment system that pretreats some of its wastewater prior to sending it to Noveon's treatment facility. Noveon owns and manages the treatment facilities, including pretreatment and equalization at the site. The City of Henry Publicly Owned Treatment Works (POTW) discharges its treated effluent to the Noveon river control structure, where it mixes with Noveon's treated effluent prior to being discharged to the multiport diffuser. Prior to the installation of the multiport diffuser, both effluents were discharged through a single port diffuser. The

N

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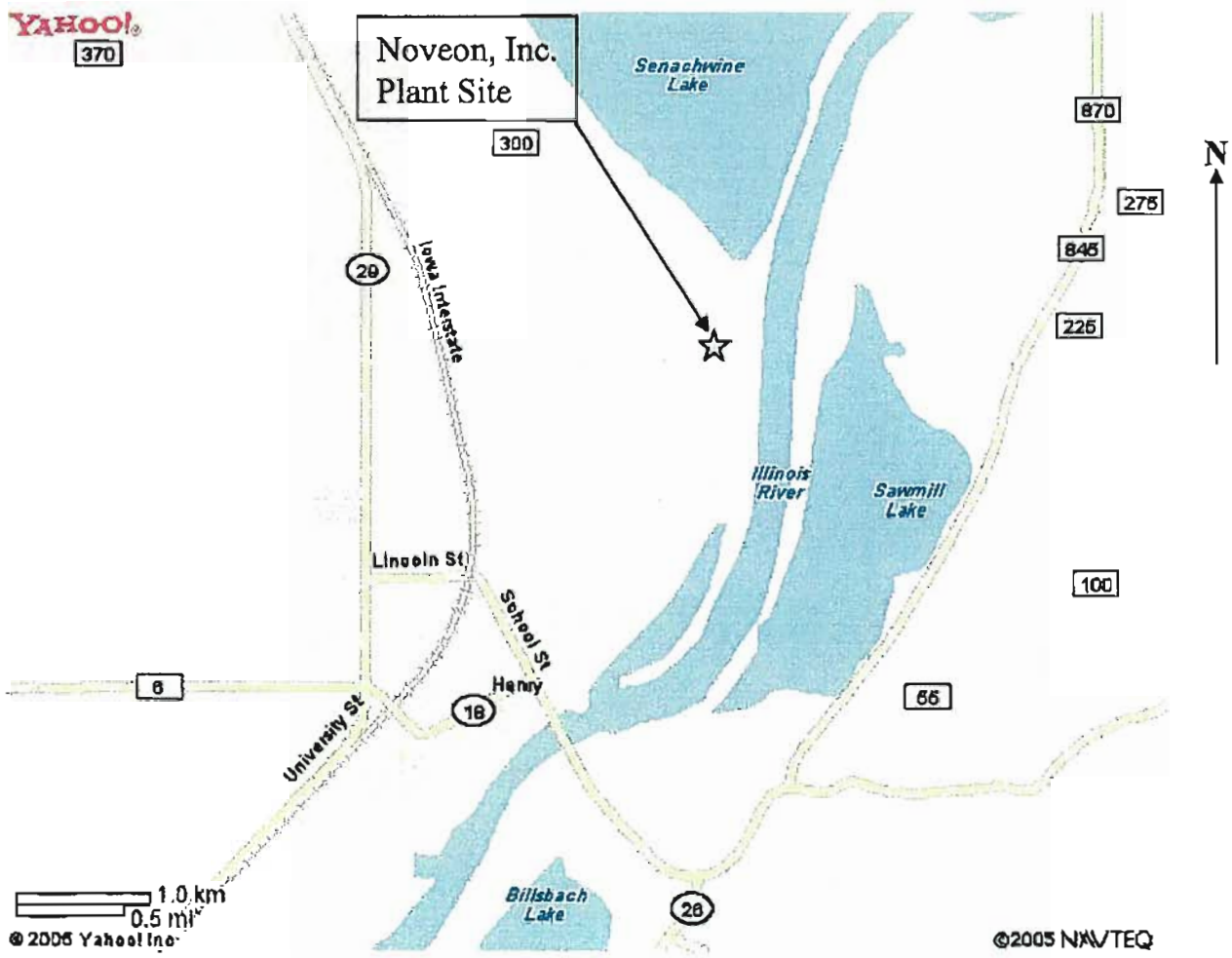
CLIENT: Noveon, Inc.
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

FIGURE 1-1

LOCATION MAP

NOVEON – HENRY, ILLINOIS

CITY OF HENRY, ILLINOIS



CLIENT: Noveon, Inc.	**FIGURE 1-2**
LOCATION: Henry, Illinois	**AREA MAP**
PROJECT/FILE: 051415	**NOVEON – HENRY, ILLINOIS**

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single port diffuser was retained as an emergency overflow in order to handle excessive stormwater flow from both the City of Henry POTW discharge and the Noveon discharge.

RIVER DESCRIPTION

The Illinois River is formed at the junction of the Kankakee and Des Plaines Rivers near Joliet, Illinois and runs 273 miles west, southwest and south to the Mississippi River near Grafton, Illinois, a few miles upstream from St. Louis. The Noveon plant site is located on the right edge of water (REW – when looking downstream) between IRM 198 and 199, as shown previously in Figure 1-2.

The Illinois River at Henry, Illinois has a drainage area of approximately 13,543 square miles. The United States Geological Survey (USGS) has operated a gaging station at Henry since October 1981. The gage is located on the U.S. Highway 18 Bridge, downstream from the Noveon plant site. The harmonic mean flow has been provided by the IEPA as 9,870 cfs (Mosher, 2005).

Background Conditions

AquAeTer previously reported (**AquAeTer**, 1994) the temperature and ammonia based on the nearest upstream gage, which is at Hennepin. Temperature values were split into two seasons, ranked, and the 75th-percentile ranked value was chosen. The summer and winter temperature values selected are 26 °C and 6.5 °C, respectively. Likewise, total ammonia was ranked seasonally, and the long term average (LTA) computed as a mathematical average of the data points. The summer and winter background total ammonia concentrations are 0.297 mg/L and 0.8 mg/L, respectively.

AquAeTer also reported on the appropriate pH to use as a background (**AquAeTer**, 1994). The value that was reported was 7.77 standard units (S.U.) for the summer time period and 7.63 S.U. for the winter time period.

AquAeTer collected two background samples for total dissolved solids (TDS) analysis. One sample was collected during the previous study in December 2004 and the

second was collected during this study on October 25, 2005. A concentration of 420 milligrams per liter (mg/L) was measured in December 2004. A concentration of 480 mg/L was measured in October 2005.

DIFFUSER DESCRIPTION

The diffuser is 21 feet in length and has six ports spaced 3.0 feet apart. The diffuser was designed to allow more future growth by either of the dischargers. Currently, four ports are open and two ports are closed. The length of the diffuser that is currently in operation is 15 feet. The port inside diameter is 3.0 inches for each port and the ports are at a 45° angle to the horizontal. The number of ports and port diameters were sized to give a velocity of close to 10 feet per second (ft/sec) exit velocity at an effluent flow rate of 1.3 million gallons per day (mgd). The overflow, which flows through the single port diffuser, is designed so that the maximum velocity out of the multiport diffuser is 18 ft/sec. This velocity is equivalent to a discharge flow rate of 2.28 mgd.

During the diffuser performance study, the daily effluent flow rate from the POTW averaged 263 gallons per minute (gpm), or 0.379 mgd, and the daily average flow rate from Noveon was 635.9 gpm, or 0.916 mgd. The combined effluent flow rate was 898.9 gpm, or 1.29 mgd. At the time of the study, a small amount of splash over from the POTW's discharge was flowing through the overflow to the single port diffuser. The flow that was diverted was visually estimated at 3 to 5 gpm. The splash over problem has since been eliminated, so that all of the flow from the POTW flows through the multiport diffuser during normal conditions. The first open port is approximately 125 ft offshore (from REW) and the last port is at about 140 ft offshore. The diffuser is anchored to the bottom and the bottom of the header pipe is approximately 1 ft above the bottom. The end of each port is approximately 2 ft 8 inches from the river bed, depending on the variability in the river bed.

WATER QUALITY STANDARDS

Total Dissolved Solids Standard

Noveon's effluent must meet standards for TDS. The standard for TDS can be found in Illinois Administrative Code (IAC) Title 35, Subtitle C, Chapter II, Part 302, Section 302.208. The standard required at the edge of the mixing zone for TDS is 1,000 mg/L. A 24-hour composite of Noveon's effluent was collected by Noveon's employees as part of their normal sample routine and sent to PDC Laboratories to be analyzed. The concentration of the TDS in the effluent for October 25, 2005 was measured as 5,200 mg/L.

Total Ammonia Standards

The standards for total ammonia can be found in Section 302.212 in the same part listed for TDS. Total ammonia concentrations must not exceed 15 mg/L at any time outside of the zone of initial dilution (ZID). In addition to this requirement, there are acute and chronic standards that must also be met.

The acute standard is the concentration that must be met at the edge of the ZID. The acute standard is independent of temperature or time of year. The acute standard (AS) can be calculated using the following equation:

$$AS = \frac{0.411}{1+10^{7.204-pH}} + \frac{58.4}{1+10^{pH-7.204}} \qquad (1)$$

The acute standard that must be met is based on the background pH value reported above of 7.77. The acute standard is then calculated by plugging a pH of 7.77 into Equation 1.

$$AS = \frac{0.411}{1+10^{7.204-7.77}} + \frac{58.4}{1+10^{7.77-7.204}}$$
$$AS = \frac{0.411}{1+0.272} + \frac{58.4}{1+3.681}$$
$$AS = 0.323 + 12.476$$
$$AS = 12.80\ mg/L$$

The chronic standard (CS) is the concentration that must be met at the edge of the mixing zone. The chronic standard is dependent on the time of the year and on the temperature. The IAC defines the Early Life Stage Present as occurring from March through October. All other times are defined as Early Life Stage Absent. However, if early life stages are present at times outside of the March through October time period, the more stringent standard of Early Life Stage Present is applicable. There are two equations for calculating the chronic standard for the Early Life Stage Present period. They are as follows:

For conditions when the water temperature is less than or equal to 14.51 °C:

$$CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} * 2.85 \qquad (2)$$

For conditions when water temperature is above 14.51 °C:

$$CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} * \left(1.45 * 10^{0.028*(25-T)} \right) \qquad (3)$$

The summer temperature is 26 °C and the pH is 7.77 S.U. The chronic standard for the early life stage present is then calculated by plugging these values into Equation 3 as presented below:

$$CS = \left\{ \frac{0.0577}{1+10^{7.688-7.77}} + \frac{2.487}{1+10^{7.77-7.688}} \right\} * \left(1.45 * 10^{0.028*(25-26)} \right)$$

$$CS = \left\{ \frac{0.0577}{1+0.973} + \frac{2.487}{1+1.208} \right\} * (1.45 * 0.938)$$

$$CS = \{0.029 + 1.126\} * (1.360)$$

$$CS = 1.57\, mg/L$$

DISPERSION REQUIRED

A more detailed description of mixing zone theory is provided in Appendix 1. The amount of dispersion required is dependent upon the standard that is required. The dispersion for all standards can be calculated using the following equation:

$$(S-1)*C_{river}+(1)*C_{effluent}=(S)*C_{Total} \quad (4)$$

where:
- S = dispersion required (__:1, dimensionless);
- C_{river} = background concentration in river (mg/L, or mass/volume);
- $C_{effluent}$ = effluent concentration (mg/L, or mass/volume); and
- C_{Total} = desired concentration (mg/L, or mass/volume).

By solving for S, and rearranging, Equation 4 becomes:

$$S=\frac{C_{effluent}-C_{river}}{C_{Total}-C_{river}} \quad (5)$$

By plugging in the TDS values given above into Equation 5, the dispersion can be calculated as:

$$(S-1)*480+(1)*5{,}200=(S)*1{,}000$$
$$S=8.1$$
$$\therefore \textit{Dispersion of } 8.1:1$$

Achieving a dispersion of 9:1 in the mixing zone will meet the standard for TDS of 1,000 mg/L.

The total ammonia concentration from the Noveon Plant is 155 mg/L at a flow of 1 mgd. The total ammonia concentration from the City of Henry POTW is estimated at 30 mg/L at a flow of 0.3 mgd. The total ammonia concentration in the combined effluent can be calculated using the following equation:

$$Q_{Noveon}*C_{Noveon}+Q_{POTW}*C_{POTW}=(Q_{Noveon}+Q_{POTW})*C_{Total} \quad (6)$$

Inserting the values given above and rearranging Equation 6 to solve for C_{Total} gives the following:

$$C_{Total}=\frac{1*155+0.3*30}{1+0.3}$$
$$C_{Total}=126\ ppm$$

The dispersion required for the total ammonia acute standard is calculated by inserting the values into Equation 5.

$$(S-1)*0.297+(1)*126=(S)*12.80$$
$$S=10.1$$
$$\therefore \textit{Dispersion of } 10.1:1$$

Achieving a dispersion of 11:1 in the ZID will meet the acute standard of 12.8 mg/L.

The dispersion required for the total ammonia chronic standard is calculated by inserting the values into Equation 5.

$$(S-1)*0.297+(1)*126=(S)*1.57$$
$$S=98.7$$
$$\therefore \textit{Dispersion of } 98.7:1$$

Achieving a dispersion of 99:1 in the total mixing zone will meet the chronic standard of 1.57 mg/L for that pH.

STUDY OBJECTIVE

Several discharge designs (single-port diffuser and multiport diffuser) were previously investigated to determine the best engineering technology for dispersion of the combined effluent into the Illinois River. Ambient River characteristics, including flow analyses, bathymetry, water velocities, and background and effluent densities, were gathered during a field study conducted in December 2004. Following the completion of the field work and the subsequent predictive modeling efforts, a Joint Application Permit was submitted to the United States Army Corps of Engineers (USACE), the IEPA, and the Illinois Department of Natural Resources (IDNR). A copy of the permit is provided in Appendix 2. **AquAeTer, Inc. (AquAeTer)** provided the conceptual diffuser design to Horner & Shifrin, Inc. (Horner & Shifrin), located in St. Louis, Missouri. Horner & Shifrin designed the diffuser and Massman Construction Company (Massman), located in St. Louis, Missouri, installed the multiport diffuser. The new discharge structure was commissioned in October 2005, and treated effluents were discharged directly to the Illinois River through the new multiport diffuser at that time.

AquAeTer of Brentwood, Tennessee, was contracted to delineate the effluent/River mixing zone downstream from the diffuser during a condition at or below harmonic mean River flow, and thereby evaluate the performance of the diffuser. The harmonic mean flow for the Illinois River at the USGS Henry gage (#05558300) is 9,870 cfs (Mosher, 2005). The specific objectives of the present study were to: 1) define the in-stream location of the discharge plume center line; and 2) measure the degree of vertical and lateral effluent dispersion in the Illinois River. The study objectives were accomplished by injecting a fluorescent dye into the effluent, and subsequently determining dye concentrations in the Illinois River mixing zone area. The degree of dye concentration reduction in the River provided a direct measure of diffuser and ambient River dispersive forces.

SECTION 2

STUDY METHODOLOGY

STUDY PERIOD AND AREA

The IEPA requires that a dye dispersion study be performed when River flow is at, or below, the harmonic mean flow. Acceptable flow conditions for the study were defined by the IEPA as 9,870 cfs or less for the Illinois River at Henry, Illinois. The USGS has reported the average flow for the month of October as 9,144 cfs, based on 23 years of record. The flows on the river were monitored for two weeks prior to the study and the study was scheduled for the week of October 24, 2005. The dye dispersion study was conducted from 0714 hrs to 1549 hrs on October 25, 2005 and the average flow during this time was 4,155 cfs, with a range from 3,120 cfs to 5,600 cfs.

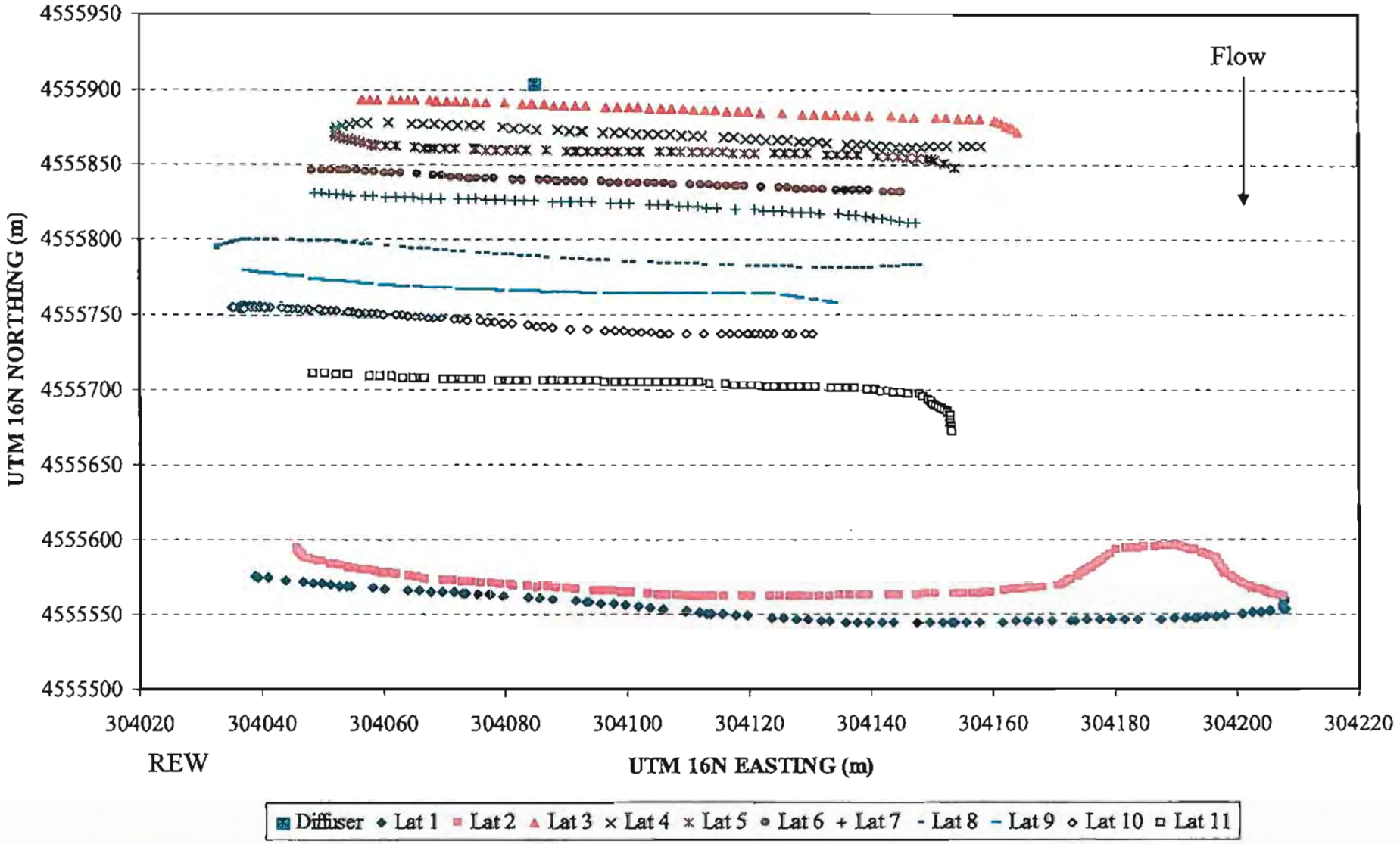
Background dye readings were measured approximately 30 feet upstream from the diffuser. A Global positioning satellite (GPS) device was utilized to record the position of all measurements made. Following this, eleven lateral transects were made that ranged from 60 feet downstream to approximately 1,000 feet downstream from the diffuser, as shown in Figure 2-1. Additionally, seven runs were made longitudinally, as shown in Figure 2-2. All points were recorded with a dye concentration and position coordinates.

FIELD PROCEDURES

Dye Injection

During the study period, a $2x10^8$ µg/L Rhodamine WT dye solution (20% solution) was continuously injected into the Noveon effluent at the final practical access point (after Noveon's Outfall 001 weir, prior to flowing into the pipe to the river control structure). The effluent travels approximately 1,300 feet through the pipeline prior to flowing into the river control structure, where it is joined by the POTW's effluent prior to flowing out to the diffuser for discharge into the Illinois River, resulting in complete mixing of the dye with the effluents. The dye was pumped into the effluent with a

Location of Dye Concentration Measurements



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LOCATION: HENRY, ILLINOIS
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FIGURE 2-1 LATERAL TRANSECTS

Location of Dye Concentration Measurements

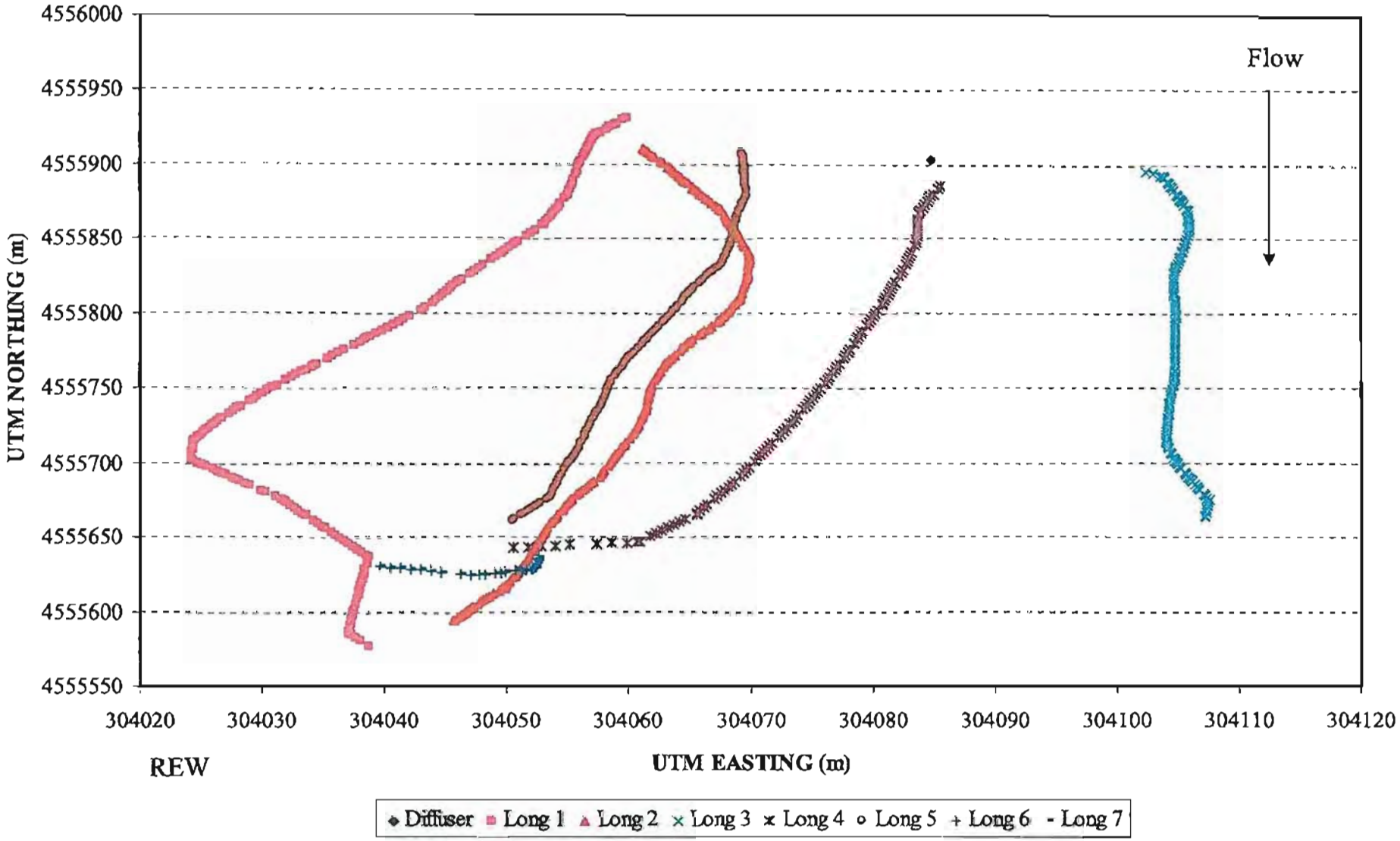

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FIGURE 2-2

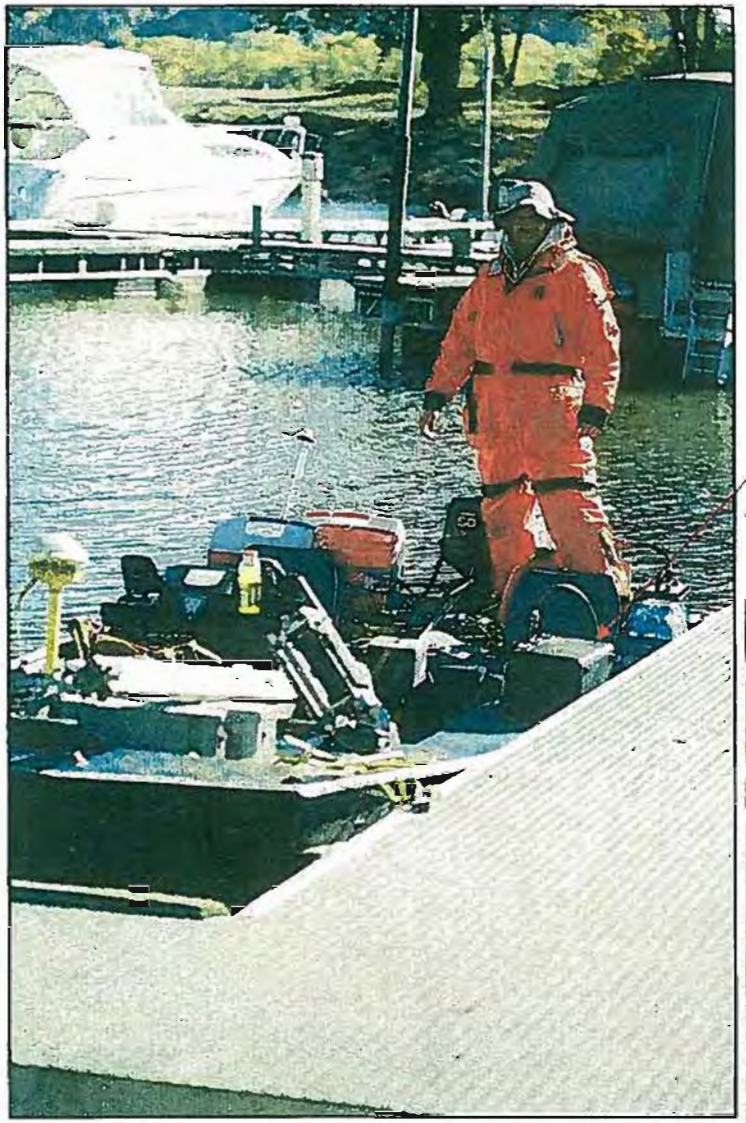
LONGITUDINAL TRANSECTS

Masterflex console drive 6-600 revolutions per minute (rpm) peristaltic pump. The dye injection was initially begun at 0528 hrs, but was turned off following equipment problems with the GPS unit on the boat. The computer was utilized to interface with the GPS unit to get a usable output, which fixed the equipment problem. The dye was restarted at 0713 hrs. The dye was turned off at 1532 hrs. A total of 11 pounds of Rhodamine WT dye was pumped through the diffuser during the study at a flow rate of 10 mL/min. The dye pump rate was calibrated by determining the flow following one minute of pumping. The pump rate was calibrated at **AquAeTer**'s office in Brentwood, Tennessee prior to the study, then checked following setup of the pump on Monday, October 24, and finally it was checked at startup of the dye injection and midway through the dye injection. The dye flow rate was computed such that a concentration at the edge of the zone of initial dispersion would be 25 parts per billion (ppb), based on theoretical dispersion.

Fluorometric Procedures

A Turner Designs Model 10AU Fluorometer was used with a flow-through cell. The fluorometer was linked to the computer with a GPS receiver. The equipment set-up is presented in Figure 2-3. Two different pumps were used depending upon the method. An in-line centrifugal pump was utilized while motoring around the river. A submersible pump was used at stationary locations. Fluorometer calibration curves were made prior to the study in order to convert fluorometer readings into dye concentrations. The calibration data and the resultant linear relationships which correlate fluorometer reading with dye concentration are contained in Appendix 3.

The fluorometer was blanked upstream from the diffuser. An in-line centrifugal pump was used to pump water from approximately 1 foot below the water surface. While the pump was in operation, the boat was driven across the river in lateral transects and up and down the river in longitudinal runs. While motoring the boat, the computer recorded GPS position and fluorometer reading approximately each second, although the output from the fluorometer is an integrated 3 second interval (i.e., average of previous 3 seconds). A total of 11 lateral transects and 7 longitudinal runs were completed.



GPS Antenna is the Yellow Pole with the White Dome

Fluorometer

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LOCATION: HENRY, ILLINOIS
PROJECT/FILE: 051415

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FIGURE 2-3

EQUIPMENT SETUP

The second method involved a spotter on-shore directing the boat via cell-phone to the visible dye cloud. Rhodamine WT is normally visible at around 20 ppb Once anchored at the location of maximum visible concentration, a submersible pump was lowered and fluorometer readings were made at 1 foot increments down to the depth measured by the depth finder on the boat. Three locations were chosen based on the visible dye plume. Two additional locations were chosen downstream based on driving through the plume until it was located.

Water Quality Measurements

In situ water quality measurements were collected as "secondary", or surrogate, parameters to assist in effluent dispersion and field plume location determination. River temperature, pH, specific conductance, and dissolved oxygen (DO) were measured at various locations including each stationary location. A Hydrolab Quanta (Quanta) was lowered to measure parameters at two foot increments starting at 1 foot below water surface. The Quanta was calibrated the night before the study and again the day after the study was completed. Specific conductance was calibrated using 1,413 μΩ/cm standard solution. The pH was calibrated using standard pH buffers of 7.0 S.U. and 10.0 S.U. DO was calibrated using an air calibration method.

A sample of the Noveon effluent was shipped to **AquAeTer**'s Brentwood laboratory for testing of compatibility of the dye with the effluent. At that time, a density was also measured using a National Bureau of Standards (NBS) calibrated hydrometer. While conducting the study, a river water sample was collected for a total dissolved solids (TDS) analysis that was sent in by Noveon. The remaining water that was collected was brought back to **AquAeTer**'s Brentwood laboratory for a density measurement using a NBS calibrated hydrometer. The density measurements provide an indication of plume buoyancy; that is, whether the plume can be expected to demonstrate negative buoyancy (sink), positive buoyancy (float), or neutral buoyancy.

Water Velocity Measurements

Water velocity measurements at various stations were made in accordance with USGS discharge measurement techniques (Buchanan and Somers, 1969; Smoot and

Novak, 1968), using a Scientific American Price AA Current Meter and reel mounted on a bridge board. The meter was suspended in the current with a 35-pound bomb connected to the reel with a steel cable. At each station, measurements were made at 0.2, 0.6, and 0.8 total depth representing maximum, average, and minimum velocities, respectively.

SECTION 3

RESULTS

FLOW CONDITIONS

The Illinois River flow, as measured at the USGS gage at Henry, ranged from 3,120 cfs to 5,600 cfs during the study, with an average flow of 4,155 cfs. This flow rate was in the acceptable range for the IEPA flow requirements of less than or equal to 9,870 cfs at the Henry gage for conducting the study. The average daily flows and stage at the Henry gage prior to the study, during the study, and following the study are presented in Table 3-1. The stage, flow, and velocity for the Henry gage that was recorded during the study are presented in Table 3-2. The velocities measured by **AquAeTer** are presented in Table 3-3. All field measurements made by **AquAeTer** presented in Appendix 4.

TABLE 3-1. GAGE MEASUREMENTS AT HENRY

DATE	STAGE (ft NGVD)*	AVERAGE DAILY FLOW (cfs)
Thursday, October 20, 2005	440.51	3,728
Friday, October 21, 2005	440.45	3,423
Saturday, October 22, 2005	440.31	4,196
Sunday, October 23, 2005	440.18	4,178
Monday, October 24, 2005	440.15	4,803
Tuesday, October 25, 2005	440.20	4,665
Wednesday, October 26, 2005	440.23	3,769
Thursday, October 27, 2005	440.25	4,395

* Gage 0 = 425.88 feet above the National Geodetic Vertical Datum of 1929 (ft NGVD)

TABLE 3-2. GAGE MEASUREMENTS AT HENRY DURING STUDY

DATE & TIME	VELOCITY (ft/sec)	STAGE (ft NGVD)*	FLOW (cfs)
10/25/2005 5:00	0.573	440.20	4,690
10/25/2005 6:00	0.735	440.18	6,000
10/25/2005 7:00	0.624	440.20	5,110
10/25/2005 8:00	0.684	440.21	5,600
10/25/2005 9:00	0.684	440.22	5,600
10/25/2005 10:00	0.582	440.19	4,750
10/25/2005 11:00	0.429	440.13	3,480
10/25/2005 12:00	0.386	440.08	3,120
10/25/2005 13:00	0.429	440.08	3,470
10/25/2005 14:00	0.437	440.14	3,560
10/25/2005 15:00	0.412	440.16	3,350
10/25/2005 16:00	0.429	440.20	3,510

* Gage 0 = 425.88 feet above the National Geodetic Vertical Datum of 1929 (ft NGVD)

The daily average flow rate for Noveon was 635.9 gpm. The average flow rate for the POTW was 262 gpm in the afternoon and 264 gpm in the morning. **AquAeTer** assumed an average flow rate of 263 gpm from the POTW. The combined flow rate of both effluents is 898.9 gpm. During the study, splashing from the POTW discharge was spilling into the overflow. **AquAeTer** has estimated this flow to be approximately 3 to 5 gpm or negligible compared to the overall flow rate, based upon video documentation.

FIELD AND LABORATORY DATA

Dye Data

All fluorometer readings were measured and recorded in the field using a Turner Designs Model 10AU Field Fluorometer with a flow-through cell. Fluorometer readings were converted to ppb units based on calibration relationships developed previously in the laboratory and based on background measurements. Calibration data and the resulting calibration computations for the fluorometer are presented in Appendix 3.

TABLE 3-3. VELOCITIES MEASURED ON ILLINOIS RIVER

DATE	TIME (CDT)	LOCATION	INSTRUMENT	TOTAL DEPTH (ft)	READ DEPTH (ft)	TIME INTERVAL (sec)	REVOLUTIONS (count)	VELOCITY (ft/sec)	VELOCITY (cm/sec)
10/25/2005	7:51	Upstream	Price AA	9.7	7.76	44.25	9	0.46	14.12
10/25/2005		Upstream	Price AA	9.7	6.8	43.5	10	0.52	15.88
10/25/2005	7:56	Upstream	Price AA	9.7	2.94	42.1	11	0.59	17.97
10/25/2005	8:20	DS11A	Price AA	8.8	7.04	41.75	8	0.44	13.34
10/25/2005		DS11A	Price AA	8.8	5.28	41.31	8	0.44	13.48
10/25/2005		DS11A	Price AA	8.8	1.76	43.13	10	0.53	16.02
10/25/2005	8:35	DS11B	Price AA	16.2	12.96	41.66	7	0.39	11.77
10/25/2005		DS11B	Price AA	16.2	9.72	40.41	7	0.40	12.12
10/25/2005		DS11B	Price AA	16.2	3.24	42.34	10	0.53	16.30
10/25/2005	8:47	DS11C	Price AA	11.1	8.88	41.85	8	0.44	13.31
10/25/2005			Price AA	11.1	6.66	43.78	7	0.37	11.23
10/25/2005	8:50	DS11D	Price AA	11.1	2.22	42.75	11	0.58	17.71
10/25/2005	9:14	DS50A	Price AA	8.8	7.04	42.47	16	0.84	25.64
10/25/2005		DS50A	Price AA	8.8	5.28	42.31	11	0.59	17.88
10/25/2005		DS50A	Price AA	8.8	1.76	42.78	11	0.58	17.69
10/25/2005	14:52	DS500	Price AA	11.7	9.36	42.13	4	0.23	6.92
10/25/2005		DS500	Price AA	11.7	7.02	44.09	7	0.37	11.16
10/25/2005		DS500	Price AA	11.7	2.34	41.19	7	0.39	11.90

Note: 0.6 of Depth measurment represents average velocity in vertical water column

The Rhodamine WT dye was introduced into the effluent at a rate of 10 mL/min using a Masterflex pump. Using the estimated effluent flow rate of 898.9 gpm (~3,402,336.5 mL/min), and assuming complete mixing of the dye and effluent by the end of the pipeline, the dye concentration is calculated as follows:

$$C_{eff+dye} = \frac{C_{eff} * Q_{eff} + C_{dye} * Q_{dye}}{Q_{eff} + Q_{dye}} \quad (7)$$

where: $C_{eff+dye}$ = dye concentration in effluent discharged to the Illinois River (ppb)
C_{eff} = background dye concentration in effluent (ppb)
C_{dye} = concentration of dye (ppb)
Q_{dye} = dye flow rate (mL/min)
Q_{eff} = effluent flow rate (mL/min)

then:
$$C_{eff+dye} = \frac{0\,ppb * 3{,}402{,}336.5\,mL/min + 2x10^{8}\,ppb * 10\,mL/min}{3{,}402{,}336.5\,mL/min + 10\,mL/min}$$
$$C_{eff+dye} = 587\,ppb$$

The fluorometer readings are presented in Appendix 4. The maximum and average concentrations with depth at the stationary locations are presented in Table 3-4. The average concentrations were calculated by averaging the concentration measured within the plume height. The plume was mixed top to bottom by the time it had reached 92 feet, so the average would be across the entire vertical water column. At the first two stations downstream from the diffuser, the plume occupied the top 5 feet and 8 feet of the water column, respectively. Including the concentrations measured outside of the plume artificially minimizes the average plume concentration, which in turn inflates the dispersion achieved. The plume surfaced at approximately 20.5 feet from the diffuser. At that location, the plume was spread from the surface to 5 feet below water surface. At the next station downstream, 37.3 feet from the diffuser, the plume was spread from 1 to 8 feet below water surface, with some traces of the plume at 9 and 10 feet below water surface. At 92.3 feet from the diffuser, the plume was mixed top to bottom.

TABLE 3-4. STATIONARY LOCATION DYE MEASUREMENTS

DATE	TIME	DISTANCE FROM DIFFUSER (ft)	DEPTH* (ft)	DYE CONCENTRATION	
				MAX (ppb)	AVERAGE (ppb)
10/25/2005	13:19	20.5	2	19.77	19.73
10/25/2005	12:37	37.3	3	19.72	19.68
10/25/2005	14:03	92.3	1	19.74	16.37
10/25/2005	14:40	553	8	4.90	3.10
10/25/2005	15:19	1,090	8	2.84	1.29
10/25/2005	15:37	1,094	8	3.29	1.79
10/25/2005	15:49	~1,090	9	3.81	2.48

Note: * Depth represents the depth at which the maximum dye concentration was measured. Average is calculated by the average concentration over the plume depth, not total water depth.

The plume was very narrow in the water column. At one point, the **AquAeTer** field crew was anchored above the diffuser, and no dye was detected at this location. At 20.5 feet from the diffuser, any movement of the boat in the current caused variation in the fluorometer reading. When this happened, a minimum and maximum were recorded. The maximum concentrations measured were used for all calculations. The measurement at 92 ft best represents the ZID concentration.

Bulk Dispersion

Steady-state conditions are assumed in river analyses. Therefore, flow, mass, or concentration can be used in place of volume in this definition of dispersion. The mixing that occurs in the JMZ (near-field) can be crudely estimated by a bulk dispersion analysis of a one-second snap-shot of the system. During the one-second interval being studied, the effluent mixes with only the volume of water that passes over the discharge with no jet entrainment included in the calculation. Dispersion, S, is defined as:

$$S = \frac{\textit{total volume of the sample}}{\textit{volume of effluent in sample}} \qquad (8)$$

Substituting values from the data collected into Equation 8 yields an estimate of dispersion in the JMZ, given by the following equation:

$$S = \frac{Q_{riv} + Q_{eff}}{Q_{eff}} \tag{9}$$

where: Q_{riv} = river flow (ft^3/sec, or volume/time); and
Q_{eff} = effluent flow (ft^3/sec, or volume/time).

The river flow in the area of the diffuser is calculated by the following equation:

$$Q_{riv} = L_D * D * u \tag{10}$$

where: L_D = effective length of the diffuser (ft, or distance);
D = river depth, (ft, or height); and
u = river velocity (ft/sec, or length/time).

The effective length of the diffuser is defined as the number of ports times the port spacing plus one-half port spacing on each end. The diffuser effective length is 15 feet. The depth of the river in the area of the diffuser during the study was 11 feet. The average velocity measured at 0.6 of depth, which the USGS defines as the average river velocity, was 0.47 feet per second. Plugging these values into Equation 11 gives the following:

$$Q_{riv} = 15 * 11 * 0.47$$
$$Q_{riv} = 77.55\ cfs$$

The effluent flow during the study was 1.29 mgd, or 2.00 cfs. Plugging these values into Equation 10 yields:

$$S = \frac{77.55 + 2.00}{2.00}$$
$$S = 39.78$$
$$\therefore Dispersion\ of\ 39.7:1$$

The dispersion, S, in this calculation is a theoretical maximum dispersion if the full depth of the river is used. This analysis assumes complete mixing and ignores entrainment of water from the side and from behind the diffuser.

The bulk dispersion analysis presented above is an oversimplification of a quite complex plume development and mixing process. However, it is a "back of the envelope" method to estimate the order of magnitude of achievable dispersion. Actually, diffuser effluent flow-induced entrainment of additional waters can typically increase dispersion, dependent on river velocity, by 10% to 30%, or more, over the dispersion available due to river water passing directly over the diffuser.

Flux Average Dispersion

For a more detailed explanation of dispersion, refer to Appendix 1. The flux average dispersion is defined as the average dispersion across the plume face. This is defined in the jet momentum zone (JMZ) as 74.81% of the maximum concentration. The FAD for each stationary location is presented in Table 3-5.

The maximum concentration measured at the stationary locations presented previously in Table 3-4 represent the location of minimum dispersion, as presented in Table 3-6. The FAD is also presented. Based on the fluorometer readings measured at the stationary locations during the study, the chronic standard of 1.57 mg/L was met between 92 feet and 553 feet downstream. The acute standard of 12.8 mg/L was met within 20 feet from the diffuser.

Lateral Transects

All of the lateral transects showed a well defined Gaussian plume. The lateral transects showed good agreement with the stationary locations in the far-field. The transects that were closer to the diffuser do not show very good agreement with the stationary measurements, even though their plume profile looks good. The reason for this is the way the fluorometer outputs a value. The fluorometer averages its readings over a three second period. Because the boat is moving about 5 to 6 feet per second, this means that anywhere from 15 to 18 feet pass over the course of one reading. At distances farther downstream, where the plume is >100 feet wide, this error is minimized. However, as one gets closer to the diffuser, the plume becomes narrower. At narrower parts of the plume, the plume peak (maximum concentration) or even the plume itself can pass through the fluorometer and be averaged out with background values or plume edge

TABLE 3-5. STATIONARY LOCATION DYE MEASUREMENTS

DATE	TIME	DISTANCE FROM DIFFUSER (ft)	DYE CONCENTRATION		
			MAX (ppb)	AVERAGE (ppb)	AVG. FAD (ppb)
10/25/2005	13:19	20.5	19.77	19.73	14.76
10/25/2005	12:37	37.3	19.72	19.68	14.72
10/25/2005	14:03	92.3	19.74	16.37	12.25
10/25/2005	14:40	553	4.90	3.10	2.45
10/25/2005	15:19	1,090	2.84	1.29	1.02
10/25/2005	15:37	1,094	3.29	1.79	1.41
10/25/2005	15:49	~1,090	3.81	2.48	1.96

Note: Average represents average concentration over plume height.
Maximum concentration represents maximum dye concentration in vertical water column.

TABLE 3-6. STATIONARY LOCATION DYE MEASUREMENTS

DATE	TIME	DISTANCE FROM DIFFUSER (ft)	DYE CONCENTRATION				DISPERSION (__:1)				
			MAX (ppb)	MAX FAD (ppb)	AVERAGE (ppb)	AVG. FAD (ppb)	MIN	MIN FAD	AVG	AVG FAD IN PLUME	AVG FAD IN WATER COLUMN
10/25/2005	13:19	20.5	19.77	14.8	19.73	14.76	29.7	39.7	29.7	39.8	66.0
10/25/2005	12:37	37.3	19.72	14.75	19.68	14.72	29.8	39.8	29.8	39.9	53.3
10/25/2005	14:03	92.3	19.74	14.77	16.37	12.25	29.7	39.7	35.9	47.9	47.9
10/25/2005	14:40	553	4.90	3.88	3.10	2.45	119.8	151.5	189.2	239.2	239.2
10/25/2005	15:19	1,090	2.84	2.25	1.29	1.02	206.7	261.3	456.0	576.5	576.5
10/25/2005	15:37	1,094	3.29	2.60	1.79	1.41	178.4	225.6	328.2	414.9	414.9
10/25/2005	15:49	~1,090	3.81	3.01	2.48	1.96	154.1	194.8	237.2	299.9	299.9

concentrations. Adjustments were made based on the stationary locations to the concentrations for the lateral transects closer to the diffuser. The plume measured during the lateral transects is shown in Figure 3-1.

The plume widths measured by the lateral transects are presented in Table 3-7. The total plume widths are provided, as well as the flux average plume widths. A plan view of the plume is presented in Figure 3-2. The plume dimensions are measured from the lateral transects. The lateral transects were adjusted to account for the lag time in the measurements. A plan view of the plume as it occurs in the river is presented in Figure 3-3.

Water Quality

The water quality measurements collected during the field study are provided in Appendix 4. The measurements with depth showed that the river was completely mixed from top to bottom.

TABLE 3-7. PLUME DIMENSIONS MEASURED BY LATERAL

TRANSECT	DISTANCE DOWNSTREAM (ft)	PLUME WIDTH (ft)	PLUME HALF-WIDTH (ft)	FAD WIDTH (ft)
Lat 3 *	60	95	-	52
Lat 4 *	97	-	45	-
Lat 5	151	90	-	48
Lat 6	193	-	38	-
Lat 7 **	273	161	-	54
Lat 8	354	136	-	66
Lat 9	463	131	-	70
Lat 10	508	129	-	54
Lat 11	658	181	-	70
Lat 2	1,058	-	105	-
Lat 1	1,146	239	-	112

* - Acute Standards Met

** - Chronic Standards Met

Maximum Concentration versus Distance Downstream

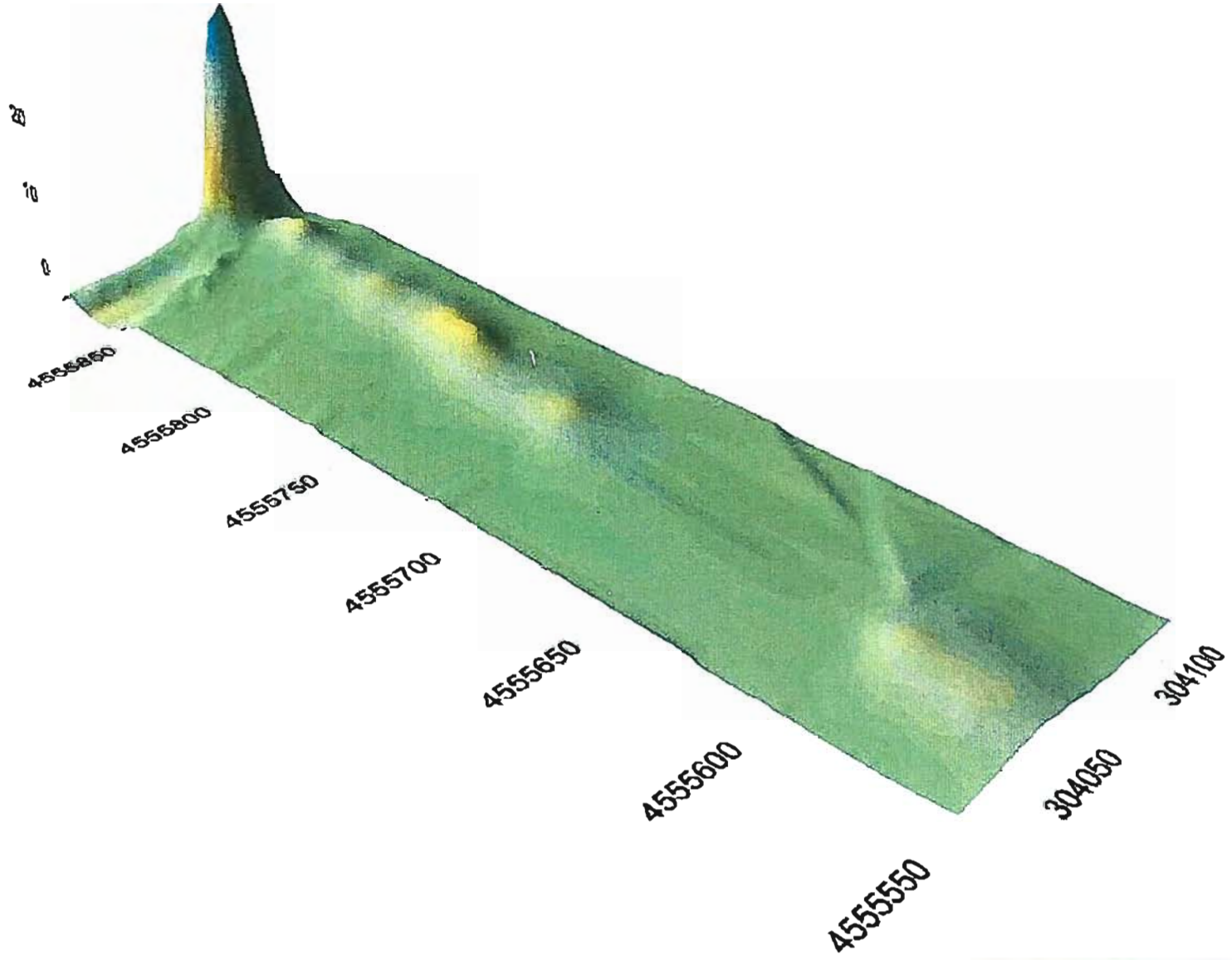

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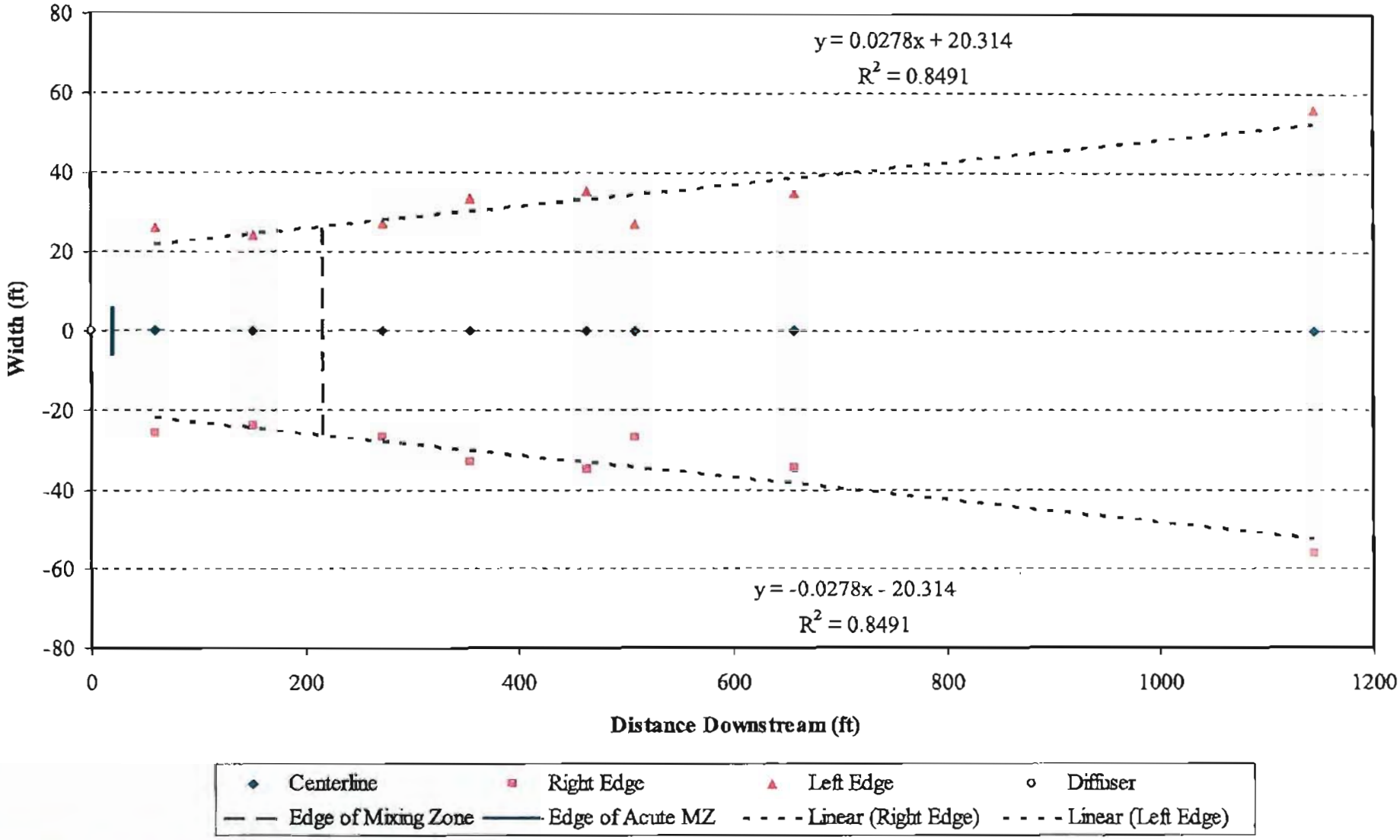
FIGURE 3-1 PEAK CONCENTRATIONS WITH DISTANCE DOWNSTREAM

FAD Plume Dimensions



CLIENT: NOVEON, INC.
LOCATION: HENRY, ILLINOIS
PROJECT/FILE: 051415

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FIGURE 3-2 PLAN VIEW OF PLUME

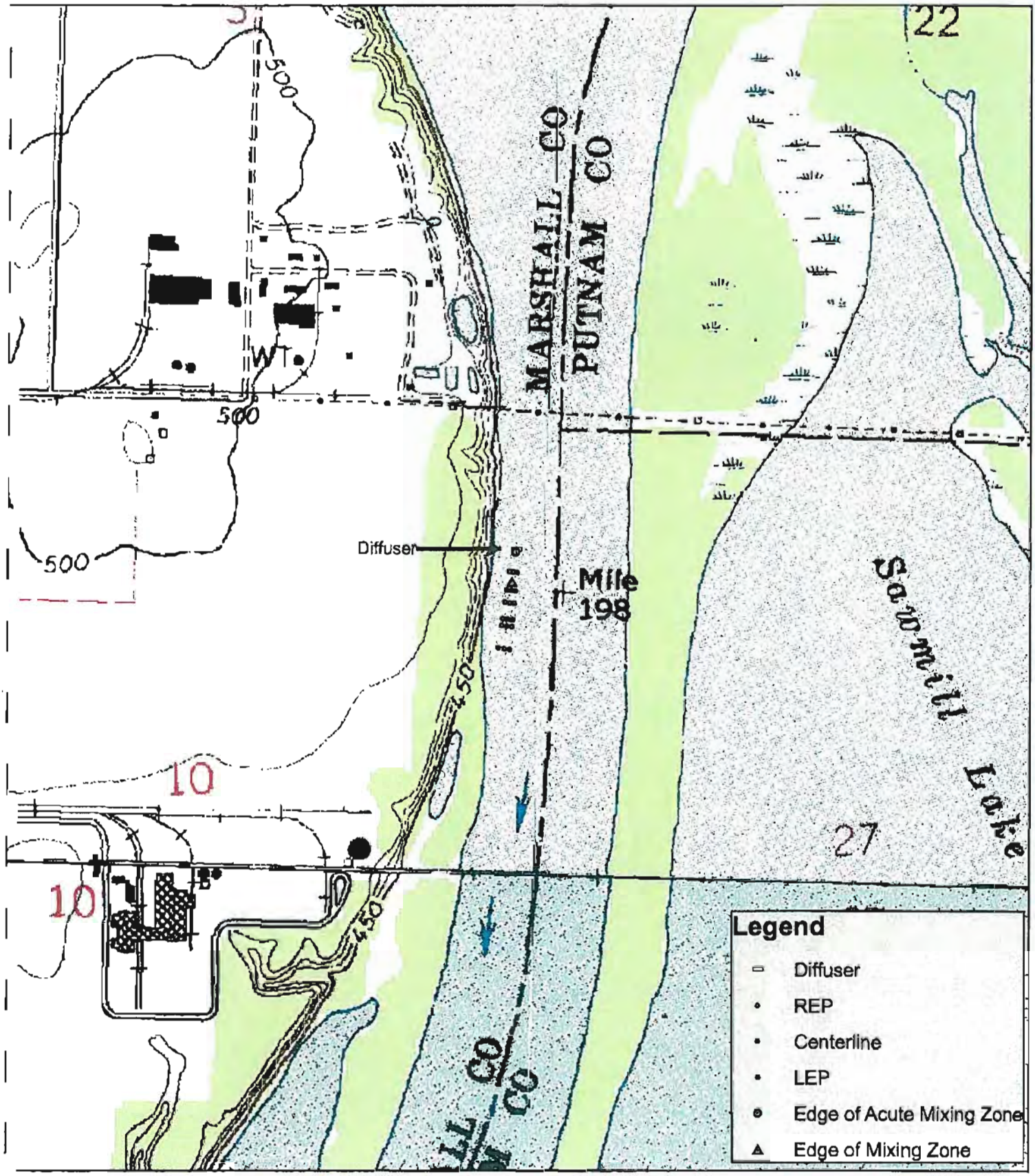

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Figure 3-3
Plan View of Plume in River
Henry, Illinois

N
W E
S

0 250 500 1,000 1,500 2,000 Feet

1:10,000

Topographic map provided by

PREDICTIVE MODELING

Initial modeling of the Noveon diffuser was based on an effluent flow rate of 1.3 mgd and an Illinois River 7Q10 low flow. The diffuser performance evaluation was conducted when the combined effluent flow was at 898.9 gpm (1.3 mgd), and the Mississippi River flow varied from a low of 3,120 cfs to a maximum of 5,200 cfs. The computer models were updated to account for these conditions, and new dispersion projections were developed. A comparison of the measured dispersions as compared to the CORMIX predicted dispersions is presented in Table 3-9.

Overall, the CORMIX predicted dispersion is in general agreement with the dispersion measured during the field study.

TABLE 3-8. CORMIX COMPARISON

DISTANCE DOWNSTREAM (ft)	CORMIX PREDICTED DISPERSION (_:1)	AVERAGE FAD MEASUREMENT DISPERSION	
		ACROSS PLUME (_:1)	IN WATER COLUMN (_:1)
20		39.7	66.0
30	45.2		
37		39.8	53.3
78	52.2		
92		47.9	47.9
102	55.1		
553		151.5	151.5
558	146.2		
1087	430.9		
1090		299.9	299.9

APPENDIX 1

MIXING ZONE AND DISPERSION THEORY

MIXING ZONE THEORY

Regardless of how an effluent is discharged, the effluent will be mixed with the receiving stream in several distinct hydraulic mixing zones, as illustrated in Figure A1-1. These zones can be described as follows:

1. Jet Momentum or Entrainment Zone (JMZ) – mixing occurs almost exclusively due to the energy or initial momentum of the effluent discharge;

1A. Restratification Zone – the plume restratisfies due to residual density differences (seldom occurs);

2. Buoyant or Density Spreading Zone (BSZ) – transition zone where mixing occurs due to residual excess effluent energy (momentum), density gradient between the effluent and the river, and ambient river diffusion; and

3. Far-Field Zone – longitudinal, lateral, and vertical mixing due to ambient river diffusion alone.

1. Jet Momentum Zone

In regulatory language, the JMZ is commonly referred to as the Zone of Initial Dilution (ZID), or the zone of rapid and immediate mixing. The ZID, or JMZ, is where the maximum reduction in effluent concentration occurs. The size of the JMZ is directly related to the difference between the initial effluent velocity and the ambient river velocity (in the discharge area), the geometry of the discharge structure, the initial densimetric Froude number, and the initial density gradient between the effluent and the river. Lee and Jirka (1980) define this near-field mixing zone as occurring within a

distance described by them as "of order of the diffuser length" (i.e., meaning within ½ to 1½ diffuser length) downstream from the discharge structure, for low to stagnant ambient currents. Higher ambient velocities can extend the near-field mixing zone to distances greater than one diffuser length.

1A. Restratification Zone

Once the effluent plume has lost its jet momentum into the receiving stream, the remaining density differences between the plume and the river can cause the plume to restratisfy or form a density wedge. This can occur for strongly positively or negatively buoyant plumes, but generally not for plumes that are essentially neutral in density following the JMZ. The effect of restratification is to restrict the exchange of new water with the plume through physical density gradients.

2. Buoyant Spreading Zone

Dispersion processes in the BSZ arise due to the buoyant forces caused by the density difference of the mixed flow relative to the ambient density (Fickian diffusion). Buoyant spreading, defined as "the horizontally transverse spreading of the mixed effluent flow while it is being advected downstream by the ambient current" (Doneker and Jirka, 1990), will normally not occur in the cases of weakly-buoyant or non-buoyant plumes. The buoyant spreading region occurs between the JMZ or restratification zone and the far-field zone, and is a difficult to define zone of transition.

3. Far-field Zone

Far-field dispersion is totally dependent upon, and driven by, ambient river diffusion. Parameters such as river velocity, morphology, and lateral and vertical dispersion coefficients, determine the rate and extent of ambient diffusion. Eventually, the effluent will become completely mixed laterally and vertically across the river by the far-field dispersive forces. The distance to total mixing with the river is usually measured in miles, rather than in feet. The total regulatory mixing zone encompasses a portion of the total far-field mixing zone. Based on this study, the Noveon *regulatory* total mixing zone extends somewhere between 553 feet and 1,090 feet downstream from the diffuser.

ANALYTICAL APPROACHES TO MIXING ZONE THEORY PROJECTIONS OF PLUME DISPERSION

In general, there are two broad approaches to analyzing diffuser dispersion performance: 1) Independent Analysis of each zone, calibrating against field data, and applying best engineering judgment, theory, and experience on a case-by-case basis; or 2) employing an "Expert System" approach, such as CORMIX 2. The analytical processes of both approaches are illustrated in Figures A1-2 and A1-3.

In the "Independent Analysis" approach, presented in Figure A1-2, well established theoretical and experimental hydraulic principles are used to evaluate the impacts on dispersion of each zone (where applicable). This approach permits correlation of theory with "the real world," by allowing calibration of modules to site-specific field conditions. Essentially, if theory predicts "oranges," but one observes "apples" in the field, then allowance must be made for the impacts of field conditions on the predictions. Models and theory are functions of idealized conditions, and cannot account for all possible actual conditions. Calibration and interpretation, using experience and engineering judgement, become necessary at each step in the analytical process.

Using the Expert System approach, as in Figure A1-3, appears to simplify the process considerably. Unfortunately, all calculations and theory are locked inside the model, and calibration to field conditions is made virtually impossible. If situations approaching ideal conditions are encountered, the expert system can be a reliable tool. However, the further a site departs from "ideal" conditions, then the less reliable and accurate the results obtained from the Expert System approach will be.

In the following pages, the approaches to analyzing diffuser performance illustrated in Figures A1-2 and A1-3 are explored in greater detail and evaluated for the appropriateness for the Noveon site. An approach is selected and then used for model calibration and model projections at a critical condition.

INDEPENDENT ANALYSIS APPROACH

Near-Field Bulk Dispersion Estimate

The near-field bulk dispersion estimate provides a reality check to compare with results from various other analyses, such as the "Expert System" approach.

Dispersion, S, also called mixing, is defined as:

$$S = \frac{\textit{total volume of the sample}}{\textit{volume of effluent in sample}} \qquad \text{(A1-1)}$$

Steady-state conditions are assumed in river analyses, hence flow, mass, or concentration can be used in place of volume in this definition of dispersion. The mixing that occurs in the JMZ (near-field) can be crudely estimated by a bulk dispersion analysis of a one-second snap-shot of the system, as shown in Figure A1-4. During the one-second interval being studied, the effluent mixes with the volume of water that passes over the discharge. Changing Equation A6-1 into a usable format with variables yields the following equation:

$$S = \frac{Q_{eff} + Q_{riv}}{Q_{eff}} \qquad \text{(A1-2)}$$

where: S = Dispersion (__:1, dimensionless)
Q_{riv} = river flow (ft^3/sec, or volume/time)
Q_{eff} = effluent flow (ft^3/sec, or volume/time.)

By plugging values measured in the field into equation A1-2, an estimated bulk dispersion in the JMZ can be calculated.

$$S = \frac{(Diffuser\ length)(River\ Height)(River\ Velocity) + 1.29mgd * 1.547\frac{cfs}{mgd}}{1.29mgd * 1.547\frac{cfs}{mgd}}$$

$$S = \frac{(12\ ft)(11\ ft)(0.45\ ft/sec) + 1.9956cfs}{1.9956cf}$$

$$S = \frac{59.4cfs + 1.9956cfs}{1.9956cfs}$$

$$S = 30.77$$

$$\therefore S = 30.8:1$$

This analysis assumes complete mixing and ignores entrainment of water from the side and from behind the diffuser. In actuality, the relatively high velocity of the effluent exiting the diffuser (compared to ambient velocity) creates a "vacuum" and entrains, or pulls, water into the plume from bordering waters, as illustrated in Figure A1-5. This entrained water has the effect of increasing dispersion, as more water is made available for the effluent to mix with.

The bulk dispersion analysis presented above is an oversimplification of a quite complex plume development and mixing process. However, it is a "back of the envelope" method to estimate the order of magnitude of achievable dispersion. Actually, diffuser effluent flow induced entrainment of additional waters can typically increase dispersion 10% to 30%, or more, over the dispersion available due to river water passing directly over the diffuser. The initial plume behavior, and hence the resultant JMZ dispersion, is dependent upon the stability of the plume in the receiving body of water. Two general methods of solving for dispersion (that account for entrainment) exist for a multiport diffuser with a flowing ambient current:

1. Unstable discharge domain (shallow-water conditions) where flow recirculation and breakdown occur; and

2. Stable discharge domain (deep-water conditions).

In order to determine whether an unstable plume analysis or a stable plume analysis technique is appropriate for determining effluent dispersion, the plume stability must first be determined.

Plume Stability Analyses

Discharge flow patterns in the immediate diffuser vicinity are strongly dependent upon a combination of ambient conditions, discharge characteristics, and diffuser geometry. The purpose of plume stability analysis is to predict under what combination of conditions the effluent plume will exhibit stable or unstable characteristics. The stability classification, when compared to observed field plume behavior, can give credence to, or disqualify from application, the various predictive dispersion equations or computer models available.

The definitions of stability and instability given by Jirka (1982) illustrate two broad classes of expected flow behavior, depending on the combination of factors as mentioned above:

> A *stable* near field is defined as one in which a buoyant surface layer is formed which does not communicate with the initial buoyant jet zone...The near field is defined as *unstable* whenever the layered flow structure breaks down in the discharge vicinity, resulting in recirculating zones or mixing over the entire water depth..."

In simple terms, a stable plume is one which propagates downstream in a well-defined conical fashion, growing in size until the effluent is mixed top-to-bottom over the entire water column. A stable plume is typically described by a Gaussian profile, as illustrated in Figure A1-6. An unstable plume, on the other hand, will demonstrate a turbulent, and sometimes oscillatory, centerline trajectory with a tendency to mix top-to-bottom within a very short distance (on the order of one diffuser length) downstream from the diffuser. An unstable plume may appear as in Figure A1-6. Vlachos has used the analogy of a garden hose discharging into a swimming pool (stable plume, slowly mixing), or into a one-gallon bucket (unstable plume, rapid and turbulent complete mixing) to illustrate the concept of plume stability. The various mathematical equations that have been proposed to calculate bulk dispersion rely on knowledge of plume stability. The Adams (1982) equation for bulk dispersion, for instance, is valid for shallow water plumes which are mixed top-to-bottom. By extension to the definition of stability, the Adams bulk dispersion analysis is applicable only to unstable plume situations. CORMIX2 incorporates a rigorous flow classification scheme, categorizing

the flow into one of 31 classes, depending on plume momentum and buoyancy as well as ambient velocity and depth. If the plume is stable, dispersion is calculated by simulating the plume as a two-dimensional wall jet (plane source). If the plume is unstable (and the diffuser is unidirectionally co-flowing), CORMIX2 calculates bulk dispersion based on the equations developed by Adams (1982). DKHW always assumes a stable plume, and approximates a Gaussian distribution for projecting the effluent dispersion.

Holley and Jirka have described a stable plume as presented in Figure A1-7. The longitudinal cross-section that is presented in Figure A1-7 is fairly representative of the plume from Noveon's diffuser. The plume during the field study was fully mixed in the water column at the end of the jet mixing/buoyant spreading zone before the far field mixing zone.

Early work in dispersion modeling dealt primarily with positively buoyant plumes, such as those emanating from cooling water discharges. A stability criterion reported by Jirka (1982) during this early work, and still widely used is:

$$\frac{m_o}{p_o^{2/3} * H} + \frac{m_a + m_o * \cos\theta_o}{p_o^{2/3} * H} = 0.54 \qquad \text{(A1-3)}$$

where:
- m_o = discharge momentum flux
- m_a = ambient momentum flux
- p_o = buoyancy flux
- H = water depth
- θ_o = discharge angle

If the left hand side (LHS) of equation A1-3 is greater than or equal to 0.54, then the plume is said to be unstable. A closer examination of Equation A1-3 shows that both the discharge momentum flux and any ambient momentum flux act as destabilizing agents. The tendency to instability is further increased if the discharge momentum also has a horizontal component ($m_o * \cos \Theta_o$).

A slightly different form of Equation A1-3 is used by Adams (1982) and Jirka (1973, 1982).

$$\frac{m_o * \left(1+\cos^2\theta_o\right)+m_a}{p_o^{2/3} * H} = 0.54 \qquad \text{(A1-4)}$$

Again, the criterion for instability is if the LHS of Equation A1-4 is greater than or equal to 0.54.

The CORMIX2 computer model, developed by Akar and Jirka (1991), uses modified forms of Equation A1-4 in their rigorous flow classification scheme, depending on plume buoyancy. As stated previously, most early work dealt only with positively buoyant plumes. In the case of positively buoyant plumes, an ambient current momentum flux (m_a) will tend to accelerate the spreading of the plume, and promote rapid top-to-bottom mixing. In this sense, ambient momentum flux does play a destabilizing role, and thus m_a is added to the LHS of Equations A1-3 and A1-4. In the case of negatively buoyant plumes, however, an ambient current will act more in a stabilizing role; that is, an ambient current will moderate the tendency of the jet plume to oscillate and mix rapidly top-to-bottom. The following stability criterion from CORMIX2 accounts for the difference in plume and ambient densities, as well as the height of the diffuser from the water body floor:

POSITIVE:
$$\frac{m_o * \left(1+\cos^2\theta_o\right)^2 + m_a - 0.1 * h_o * \frac{m_a}{m^o} * p_o^{2/3}}{p_o^{2/3} * H} = 0.54 \qquad \text{(A1-5)}$$

NEGATIVE:
$$\frac{m_o * \left(1+\cos^2\theta_o\right)^2 - m_a}{\left|p_o^{2/3}\right| * H} = 0.54 \qquad \text{(A1-6)}$$

where: h_o = elevation of discharge port above bottom

The significant difference between Equation A1-4 and Equations A1-5 and A1-6 is the role played by the ambient momentum flux (m_a): that is, whether m_a is stabilizing ($+m_a$) or destabilizing ($-m_a$).

It is instructional to determine the theoretical stability of the Noveon plume, as it existed during the October field study. The effluent plume did not immediately mix top-to-bottom, as would have been expected if the plume had been unstable. Rather, dispersion was accomplished gradually, with the effluent plume surfacing approximately

20 feet downstream from the diffuser. The plume was mixed top to bottom within 100 feet downstream of the diffuser, however. The plume appears to have been stable, especially if one considers the ambient water depth, the river current and the discharge exit velocity. It is interesting to compare this intuitive plume classification to the theoretical classification computed by Equation A1-6.

$$\frac{m_o * \left(1 + \cos^2 \theta_o\right)^2 - m_a}{\left|p_o^{2/3}\right| * H} \Rightarrow < 0.54 = \textit{unstable}, \geq 0.54 = \textit{stable}$$

where:

m_a = ambient momentum flux
$= u_a^2 H$
$= (0.45 \text{ ft/sec})^2 * (11 \text{ ft})$
$= 2.2275 \text{ ft}^3/\text{sec}^2$

u_a = ambient current velocity

H = water depth

g_o' = initial buoyant acceleration
$= g(\rho_a - \rho_o)/ \rho_a$
$= 32.2 \text{ ft/sec}^2 * (62.36\text{-}62.77)/ 62.36$
$= -0.212 \text{ ft/sec}^2$

ρ_a, ρ_o = ambient, discharge density

q_o = volume flux
$= Q_o/L_D$
$= (2.00 \text{ ft}^3/\text{sec})(15 \text{ ft})$
$= 0.133 \text{ ft}^2/\text{sec}$

L_D = diffuser length

Q_o = total discharge flow

g = acceleration of gravity

m_o = discharge momentum flux
$= q_o u_o$
$= (0.133) * (10.24)$
$= 1.36 \text{ ft}^3/\text{sec}^2$

p_o = buoyancy flux
$= q_o g_o'$
$= (0.133) * (-0.212)$
$= -0.028 \text{ ft}^3/\text{sec}^2$

q_o = discharge port exit velocity, ft/sec

therefore:

$$\frac{1.36 * \left(1 + \cos^2 45\right)^2 - 2.2275}{\left|-0.028^{2/3}\right| * 11} \Rightarrow < 0.54 = \textit{stable}, \geq 0.54 = \textit{unstable}$$

$$\frac{1.36 * \left(1 + \cos^2 45\right)^2 - 2.2275}{\left|-0.028^{2/3}\right| * 11} = \frac{1.36 * (1 + 0.5)^2 - 2.2275}{\left|-0.092\right| * 11}$$

$$\frac{1.36 * \left(1 + \cos^2 45\right)^2 - 2.2275}{\left|-0.028^{2/3}\right| * 11} = \frac{0.8325}{1.012}$$

$$\frac{1.36 * \left(1 + \cos^2 45\right)^2 - 2.2275}{\left|-0.028^{2/3}\right| * 11} = 0.82$$

$0.82 \geq 0.54$

$\therefore$ *Plume is unstable*

Since the LHS of Equation A1-6 is greater than the criterion of 0.54, theory predicts that the plume is unstable. However, the field measurements showed that the plume had more of a stable plume geometry at the first two stations downstream, 20 and 37 feet. The discrepancy with the theoretical calculation is in part because the LHS of Equation A1-6, although greater than 0.54, was on the same order of magnitude as 0.54. Real world plumes behave more like the theoretical calculation when the numbers are orders of magnitude apart. Additionally, the effects of ambient and effluent temperatures have not been accounted for here which would tend to bring the effluent and River densities closer.

JMZ Stable Plume Analysis

Adams (1982), Jirka (1982), and Holley and Jirka (1986) present analyses based on Adams's (1982) work, that takes the simple bulk dispersion a step further by accounting for back entrainment. The Holley and Jirka equation is:

$$S = \frac{1}{2}V + \frac{1}{2}\left(V^2 + \frac{2m_o H}{q_o^2}\cos\theta_o\right)^{0.5} \qquad \text{(A1-7)}$$

where:
- S = bulk dispersion (__:1, dimensionless);
- V = volume flux ratio, or ambient mixing due to ambient current; $= u_a H/q_o$
- H = water depth (ft);
- q_o = discharge flux per unit length (ft^2/sec^2); $= u_o a_o/L$;
- m_o = momentum flux (ft^3/sec^2); $= u_o^2 a_o/L$;
- L = port spacing (ft);
- a_o = port area;
- u_o = port exit velocity (ft/sec); and
- θ_o = port discharge angle.

It should be noted that Adams calculates the discharge momentum flux as a function of the total diffuser length, whereas Holley and Jirka define this discharge momentum flux as a function of port spacing. For long diffusers, these two methods give similar results. The Noveon diffuser is not a long diffuser, however, so care should be taken when calculating with this equation. The port spacing is 3 feet, and the effective

diffuser length is 12 feet. The dispersion predicted by this equation during the study is calculated by plugging values into Equation A1-7.

$$S = \frac{1}{2}V + \frac{1}{2}\left(V^2 + \frac{2m_o H}{q_o^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\frac{u_a * H}{q_o} + \frac{1}{2}\left(\left(\frac{u_a * H}{q_o}\right)^2 + \frac{2\frac{u_o^2 a_o}{L}H}{q_o^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\frac{u_a * H}{\frac{u_o a_o}{L}} + \frac{1}{2}\left(\left(\frac{u_a * H}{\frac{u_o a_o}{L}}\right)^2 + \frac{2\frac{u_o^2 a_o}{L}H}{\left(\frac{u_o a_o}{L}\right)^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\frac{0.45 * 11}{\frac{10.165 * 0.049}{3}} + \frac{1}{2}\left(\left(\frac{0.45 * 11}{\frac{10.165 * 0.049}{3}}\right)^2 + \frac{2\frac{10.165^2 * 0.049}{3}11}{\left(\frac{10.165 * 0.049}{3}\right)^2}\cos 45\right)^{0.5}$$

$$S = \frac{1}{2}\frac{0.45 * 11}{\frac{10.165 * 0.049}{3}} + \frac{1}{2}\left(\left(\frac{0.45 * 11}{\frac{10.165 * 0.049}{3}}\right)^2 + \frac{2\frac{10.165^2 * 0.049}{3}11}{\left(\frac{10.165 * 0.049}{3}\right)^2}\cos 45\right)^{0.5}$$

$$S = \frac{1}{2}\frac{4.95}{0.166} + \frac{1}{2}\left(\left(\frac{4.95}{0.166}\right)^2 + \frac{2 * 1.6877 * 11}{(0.166)^2}\cos 45\right)^{0.5}$$

$$S = 14.91 + 0.5(889.189 + 1347.4\cos 45)^{0.5}$$

$$S = 14.91 + 0.5(1841.94)^{0.5}$$

$$S = 14.91 + 0.5 * 42.92$$

$$S = 36.37$$

The actual dispersion achieved during the diffuser performance study was 39.8:1, which is an increase of approximately a 9% increase over the dispersion predicted by Equation A1-7. This slight increase over the predicted dispersion is in keeping with previous diffuser performance studies.

The Equation that was developed by Adams, which is not included here, results in a dispersion of 36.31. Thus, according to the Holley and Jirka model, a dispersion of 36.37 could have been achieved within about the first 12 to 18 ft (1 to 1.5 diffuser lengths) downstream from the diffuser. This dispersion is approximately a 15% increase

in the dispersion predicted by Equation A1-2. The 15% increase in dispersion is the result of entrainment of additional water by the plume. As ambient river velocity decreases, the effect of entrainment is magnified, and can approach 100% of the dispersion at zero river velocities. The measured values showed a dispersion of 39.8 was achieved at 20.5 feet downstream from the diffuser. This is approximately a 9% increase over the value predicted by Equation A1-7. This is a result of more water being entrained than is predicted by this model. Reducing ambient flow to zero in Equation A1-7 reduces the volume flux ratio, V, also to zero. Thus, the dispersion that occurs at this condition is entirely dependent upon entrainment, as shown by the following equation:

$$S = \frac{1}{2}\left(\frac{2m_o H}{q_o^2}\cos\theta_o\right)^{0.5} \qquad \text{(A1-8)}$$

$$S = \frac{1}{2}\left(\frac{2m_o H}{q_o^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\left(\frac{2\frac{u_o^2 a_o}{L} H}{q_o^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\left(\frac{2\frac{u_o^2 a_o}{L} H}{\left(\frac{u_o a_o}{L}\right)^2}\cos\theta_o\right)^{0.5}$$

$$S = \frac{1}{2}\left(\frac{2\frac{10.165^2 * 0.049}{3} 11}{\left(\frac{10.165 * 0.049}{3}\right)^2}\cos 45\right)^{0.5}$$

$$S = \frac{1}{2}\left(\frac{2 * 1.688 * 11}{0.166^2}\cos 45\right)^{0.5}$$

$$S = \frac{1}{2}(1347.66\cos 45)^{0.5}$$

$$S = \frac{1}{2}(952.94)^{0.5}$$

$$S = \frac{1}{2} * 30.87$$

$$S = 15.44$$

The unstable plume analysis for high ambient currents gives results close to the simple bulk dispersion analysis because entrainment becomes a minor percentage of the water in the JMZ, in comparison to the total volume of water crossing directly over the diffuser.

JMZ Stable Plume Dispersion Analysis

There are two separate computer models that can be used to predict stable plume dispersion: 1) DKHW (Frick, et al., 199); and 2) CORMIX2. DKHW projects the stable plume as increasing Gaussian cones until plumes merge, whence it reverts to a power profile analysis. CORMIX2 projects the plumes as a series of merged rectangular area source that widens vertically through the entire water depth.

DKHW computes a plume centerline maximum concentration as well as a flux average dispersion (FAD). In the JMZ, the FAD is the average dispersion across the plume face. The plume face can be defined as the width of the diffuser plus one water depth, at the distance where plume height equals water depth. Shirazi and Davis (1974) and Prych (1977) suggested that the average concentration across a Gaussian plume can be estimated using $(2)^{1/2}\sigma$ (1.41σ) for plume boundaries (i.e., plume extending 1.41 standard deviations). This is equivalent to approximately 84% of the plume area (mass) in the JMZ (near-field). Once the plume has established its approximate Gaussian profile, the FAD computed by DKHW is approximately 75% of the centerline concentration where plume height equals water depth. Prior to this point, the centerline concentration in DKHW can be 200% to 400% less than the FAD. Therefore, the use of 1.41σ provides a very conservative estimate for converting the observed centerline concentration to FAD concentrations for comparison with DKHW results.

A normal Gaussian distribution is illustrated in Figure A1-8, and is mathematically defined by the following expression:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \qquad \text{A1-9}$$

where: f(x) = value of the normal distribution at any point;
σ = standard deviation;
x =
μ = mean.

Transforming the equation yields:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(z)^2} \qquad \text{A1-10}$$

An example of a normal distribution with a mean of 0 and a variance of 1 is presented in Figure A1-8. The maximum value of f(z) occurs at z = 0, or at the centerline. This corresponds with the peak plume concentration:

$$z = 0 \quad f(z) = \frac{1}{\sqrt{2\pi}} e^{0}$$
$$f(0) = 0.3989$$

This value thus represents 100% of the maximum value of f(z). As stated earlier, several researchers have defined the Gaussian effluent plume in the JMZ as extending to $\sqrt{2}\sigma$ ($z = \pm 1.41$, or at 1.41 standard deviations):

$$z = 1.41 \quad f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(1.41)^2}{2}}$$
$$f(1.41) = 0.1476$$

The value of the normal distribution at the edge of plume is at f(1.41), which represents 37% of the maximum value as calculated by:

$$\frac{f(1.41)}{f(0)} = \frac{0.1476}{0.3989} = 0.37$$

The FAD is calculated by recognizing that the area under the curve for $z = \pm 1.41$ accounts for 84.14% of the total area of the standard normal distribution f(z) (from standard normal distribution tables). Therefore, the normal distribution mass (area under the curve) represented by the area of $\pm 1.41\sigma$ can be approximated as a rectangular of equivalent area, with a width of $\pm 1.41\sigma$ and a height calculated as follows:

$$Height = \frac{Area}{Width} = FAD$$

where: Area = defined from normal distribution tables for 2σ; and
Width = 2σ (i.e., 2 * 1.41)

$$FAD = \frac{0.8414}{2(1.41)} = 0.2984$$

Consequently, in this case the FAD corresponds to the average height of f(z) between $z = \pm 1.41$.

The concept of FAD and "equivalent area" and "average box height" are illustrated in Figure A1-9.

The FAD represents 74.81% of the maximum centerline value (0.2984 / 0.3989 = 0.7481). Therefore, the maximum centerline concentration (or minimum centerline dispersion) divided by 0.7481 gives the FAD across the plume face. The dispersion at the edge of the plume is calculated as the minimum centerline dispersion divided by 0.37. This analysis allows translation between observed maximum centerline concentrations to finite edge of plume limits and to a flux average concentration in the main body of the plume.

Restratification

Once the effluent plume has lost its jet momentum into the receiving stream, the remaining density differences between the plume and the river can cause the plume to restratify, which would cause slower dispersion in the field. This could occur for strongly positively or negatively buoyant plumes. Holley and Jirka (1986) and Akar and Jirka (1991) give equations for determining if restratification will occur. From Holley and Jirka, restratification will occur if the densimetric Froude number is less than a critical value as follows:

$$\frac{u_o}{\sqrt{|g'|H}} < 0.6 \text{ to } 0.7 \qquad \text{(A1-11)}$$

where:

u_a	=	ambient velocity (ft/sec);
$\|g'\|$	=	buoyant acceleration (ft/sec^2);
	=	$\|g \Delta \rho / \rho_a\|$;
$\Delta \rho$	=	$\| \rho_a - \rho \| / S$
ρ_a	=	ambient density;
g	=	acceleration due to gravity (ft/sec^2)
	=	32.2 ft/sec^2;
S	=	dispersion at the end of the JMZ, adjusted by FAD;
S	=	$S_{JMZ}/0.7481$
H	=	water depth (ft).

Hence, for Equation A1-11:

$$LHS = \frac{u_a}{\sqrt{|g'|H}}$$

$$LHS = \frac{u_a}{\sqrt{|g * \Delta\rho / \rho_a|H}}$$

$$LHS = \frac{u_a}{\sqrt{|g * ((\rho_a - \rho)/S)/\rho_a|H}}$$

$$LHS = \frac{0.45}{\sqrt{|32.2 * ((0.999 - 1.0055)/(36.37/0.7481))/0.999|11}}$$

$$LHS = \frac{0.45}{\sqrt{|32.2 * (-1.338 * 10^{-4})|11}}$$

$$LHS = \frac{0.45}{\sqrt{0.00431 * 11}}$$

$$LHS = \frac{0.45}{0.218}$$

$$LHS = 2.06$$

$$2.06 > 0.6$$

$\therefore$ *No restratification*

Since the densimetric Froude number is greater than the criterion, no restratification is expected and none was observed during the study. Because the plume comes to the surface before beginning to fall, this ensures adequate mixing top-to-bottom within the water column, which helps minimize the chance of restratification.

Buoyant Spreading Zone or Transition Zone

Once the plume has lost the majority of its jet momentum (outside the near-field mixing zone), the residual buoyancy outside the near-field mixing zone can induce lateral

spreading perpendicular to the ambient flow. Adams (1982) and Lee and Jirka (1980) discuss the shape of the plume at the end of the JMZ. At low to stagnant currents, the effluent plume will contract due to side entrainment of the receiving water into the plume, as shown previously in Figure A1-5, to a width equivalent to about one-half the diffuser length. At higher ambient velocities, this entrainment becomes negligible and the plume width at the end of the JMZ is on the order of one diffuser length.

At the end of the JMZ, the plume maintains some excess velocity over the ambient river velocity. In this intermediate zone, the excess velocity and the slight buoyancy differences between the plume and the ambient waters cause the plume to spread laterally. As the plume slows to ambient velocities (e.g., due to boundary friction with the bottom), passive ambient diffusion or far-field mixing becomes the dominant mixing force. Lee and Jirka (1980) developed an analysis to compute buoyant spreading in this transition zone between the JMZ and the far-field.

The residual plume velocity at the end of the JMZ can be calculated by the following equation:

$$u_i = \frac{2S_i Q_e}{L_D H} \qquad \text{(A1-12)}$$

where: u_i = plume velocity at the end of the JMZ (ft/sec);
S_i = Dispersion at the end of the jet momentum zone;
Q_e = Effluent flow in (ft^3/sec);
L_D = Diffuser length (ft);
H = Local water depth (ft).

Thus, the plume velocity at the end of the JMZ during the October field study can be calculated using the following conditions:

S_i = 36.37/0.7481 = 48.62;
Q_e = 1.29 mgd = 2.00 cfs
L_D = 15 ft;
H = 11 ft.

$$u_i = \frac{2 * 48.62 * 2.00}{15 * 11}$$
$$u_i = 1.179\ ft/sec$$

For comparison, the ambient current was 0.45 ft/sec and the port exit velocity was 10.165 ft/sec. Thus, the plume had slowed from its exit velocity to about 1.179 ft/sec at the edge of the JMZ. CORMIX2 predicts that the edge of the JMZ is 6 feet downstream from the diffuser (i.e., arbitrarily set at ½ diffuser length).

The Lee and Jirka equations are for low to stagnant ambient velocities, which can be considered as around 0.25 ft/sec to 0.30 ft/sec (typical lower range for measuring velocity using a pygmy or Price AA current meter). Calculations from these equations for river conditions with greater ambient velocities are considered an approximation, but the results are consistent with the intermediate zone decreasing in aerial extent or not existing at higher ambient velocities (river turbulence becomes more of a dominant factor.) For the conditions existing during the October field study, a buoyant spreading region would be expected, since the ambient velocity in the area is approaching the minimum velocity. The plume velocity, plume width, and plume dispersion can be calculated according to the Lee and Jirka equations.

Intermediate zone mixing is driven by excess plume velocity and frictional interaction. A realistic means of defining the end of the intermediate zone is to determine the distance at which the plume velocity has been reduced to approximately the ambient velocity. A value of within ±5% of the ambient velocity, based on USGS discharge measurement techniques, is used to define the end of this intermediate zone. That is, velocity measurements and subsequent flow calculations using a Price AA current meter can be made to ±2% to 10% accuracy with 5% being typical. For instance, the average ambient velocity on October 25 was about 0.45 ft/sec, and therefore the end of the intermediate zone has been set at the distance where the plume velocity is 1.05 * 0.45 ft/sec, or 0.47 ft/sec.

The following equation is used to determine the plume velocity at the end of the buoyant spreading regions:

$$u = u_i e^{-\phi(x-x_i)}\left[1 + \beta\left[1 - e^{-\phi(x-x_i)}\right]\right]^{-0.5} \qquad \text{(A1-13)}$$

where: u = velocity at the end of the BSZ (ft/sec);
u_i = velocity at the end of the JMZ (ft/sec);
ϕ = $f_o / (8H)$;
f_o = Moody friction factor = 0.035;
H = Local water depth;
ϕ = $0.035 / (8 * 11)$;
ϕ = $0.0003977\ ft^{-1}$;
x = distance downstream from x_i;
x_i = distance at end of JMZ (ft);
β = $2a_2 / (I_i b_i \phi)$;
a_2 = entrainment coefficient = 0.068;
I_i = $\sqrt{\pi} / 2$;
b_i = $0.5\ L_D$;
L_D = diffuser length = 15 ft.

The objective is to determine the distance x when u is within 5% of the ambient river velocity. Equation A1-13 was implemented on an Excel® spreadsheet, and through an iterative process, x was found to be 222 feet downstream from the edge of the JMZ, or 228 feet downstream from the diffuser.

The plume width at the end of an intermediate zone are calculated according to the following equation:

$$b = b_i\left[e^{-\phi(x-x_i)} * (1+\beta) - \beta\right] \qquad \text{(A1-14)}$$

where: b = plume width at end of BSZ(ft);
b_i = plume width at the end of the JMZ (ft).

The dispersion at the end of the BSZ can be calculated using the following equation:

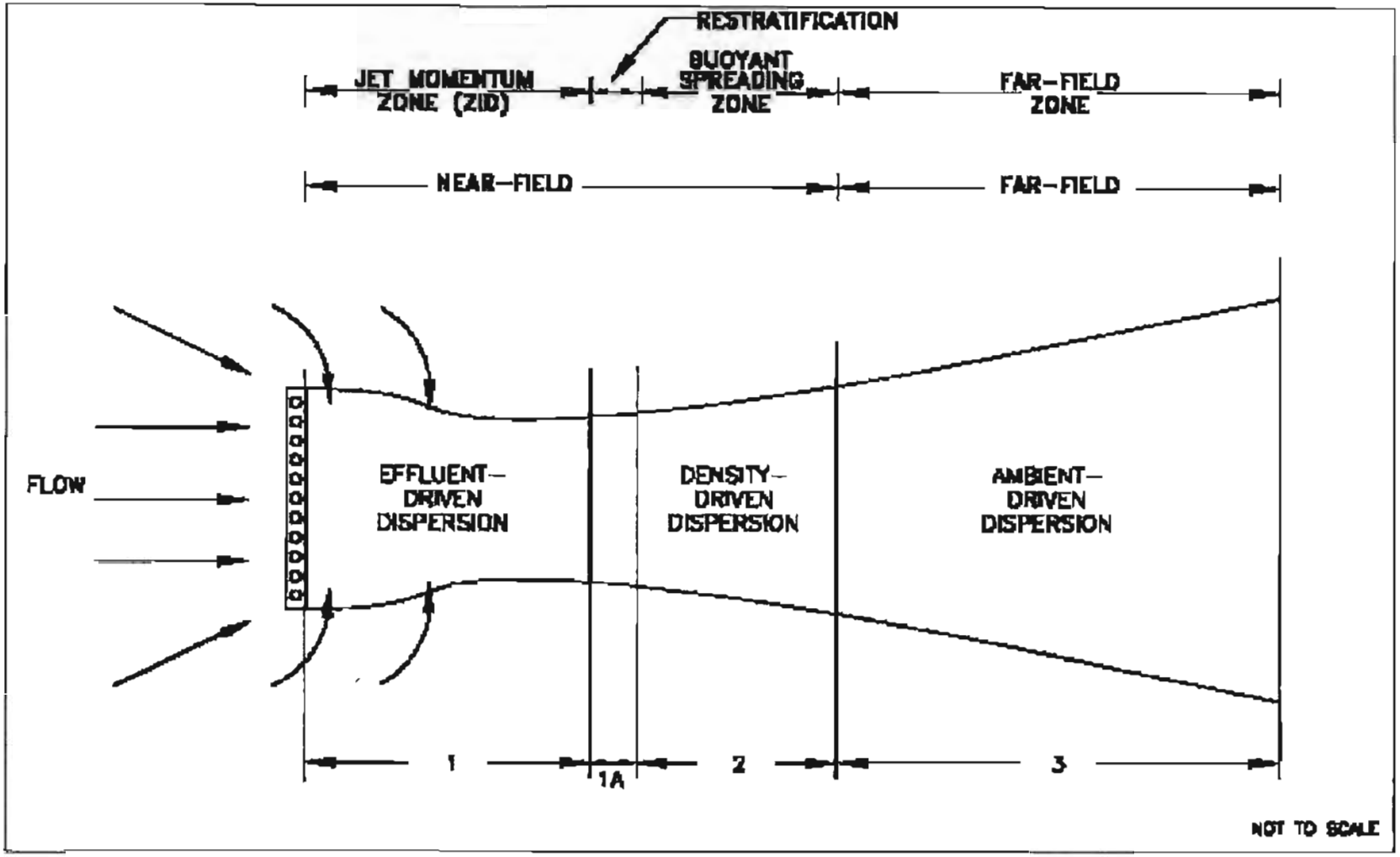
$$S = S_i\left[1 + \beta\left(1 - e^{-\phi(x-x_i)}\right)\right]^{0.5} \qquad \text{(A1-15)}$$

where: S = dispersion at end of BSZ;
b_i = dispersion at the end of the JMZ.

CORMIX2 predicted a plume width of 9.777 feet at the end of the JMZ. Substituting this into Equation A1-14, yields a plume width at the end of the BSZ of 45 feet. Using the calculated FAD at the end of the JMZ of 48.62 in Equation A1-15 yields a dispersion of 100:1 at the end of the BSZ, 228 feet downstream from the JMZ.

The dispersion required within the mixing zone was 99:1, which is shown to be reached at the end of the buoyant spreading zone by this equation.

HYDRAULIC MIXING ZONES

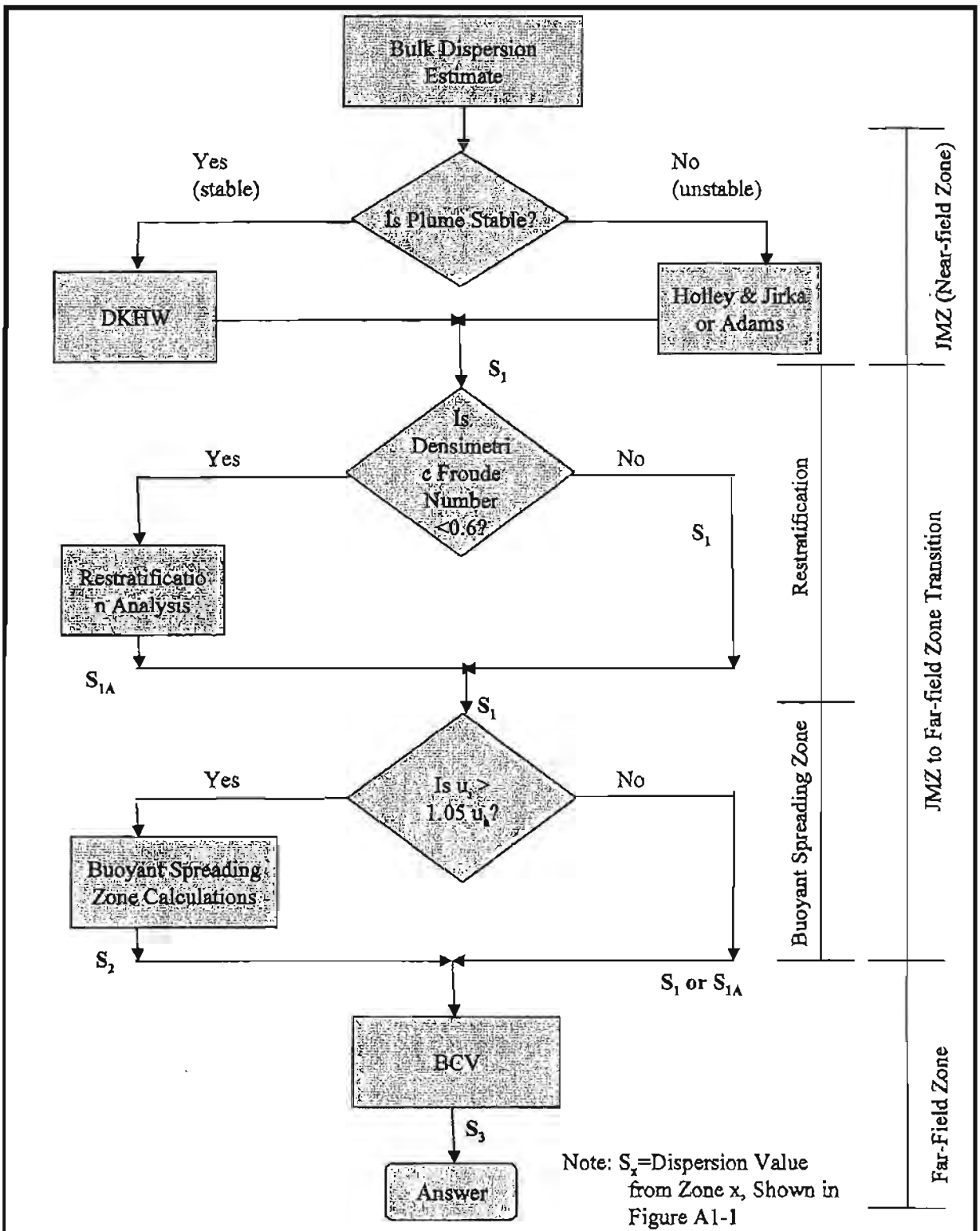


AquAeTer

CLIENT: Noveon
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

optimizing environmental resources | water, air, earth

FIGURE A1-1 - HYDRAULIC MIXING ZONES



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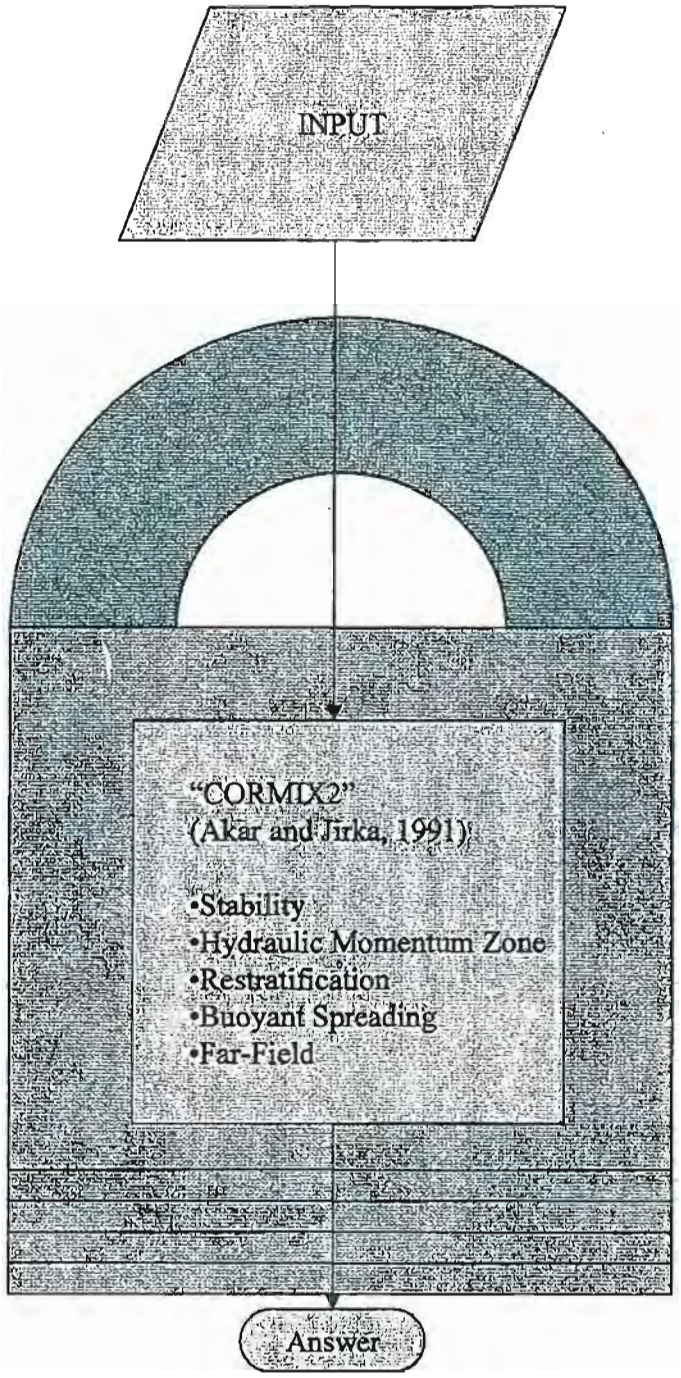
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

FIGURE A1-2

INDEPENDENT ANALYSIS PATHWAY



CLIENT: Noveon, Inc.	**FIGURE A1-3**
LOCATION: Henry, Illinois	**"EXPERT SYSTEM" APPROACH**
PROJECT/FILE: 051415	

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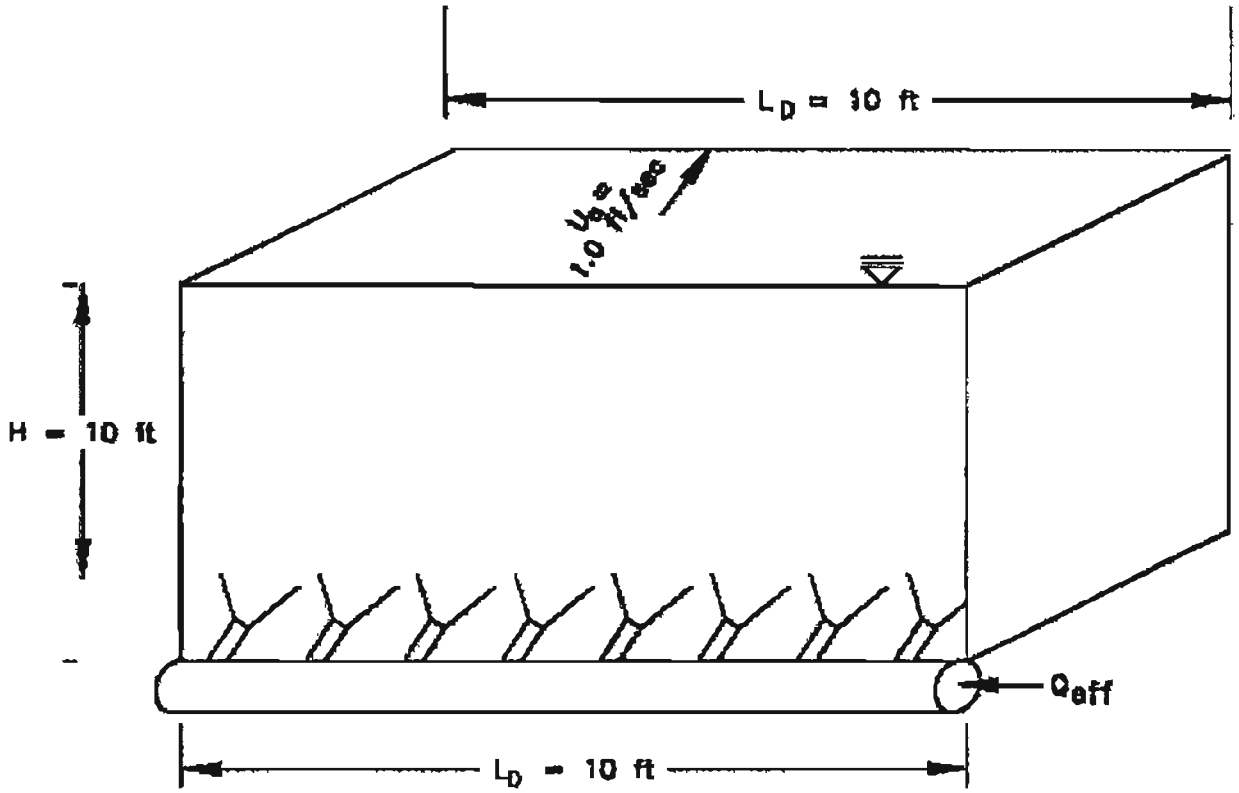

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CLIENT: Nuveco
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

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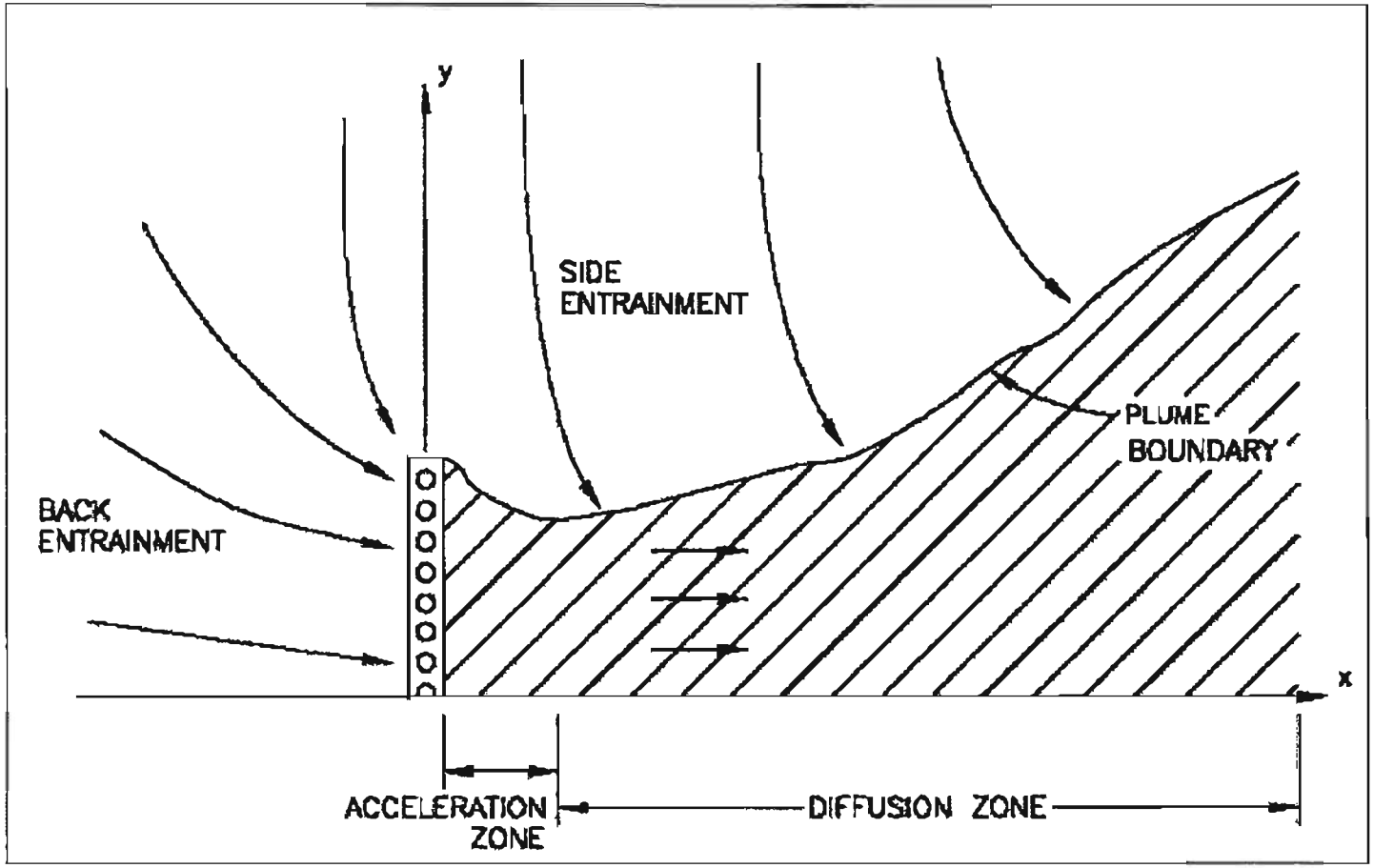
FIGURE A1-4 – BULK DISPERSION ANALYSIS



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CLIENT: Noveon
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

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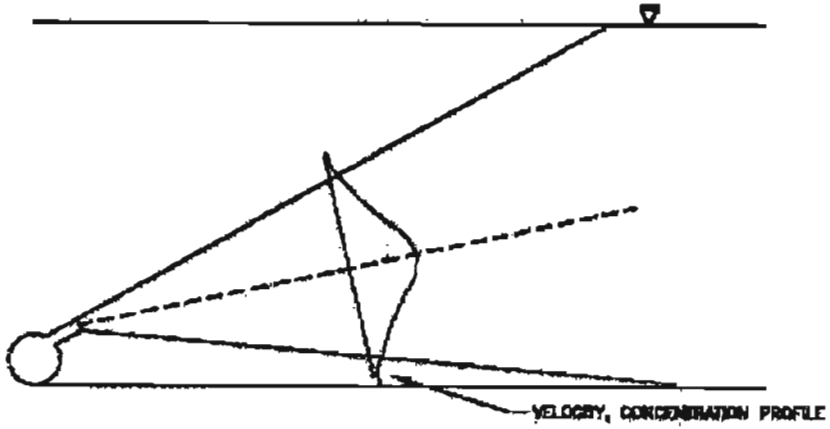
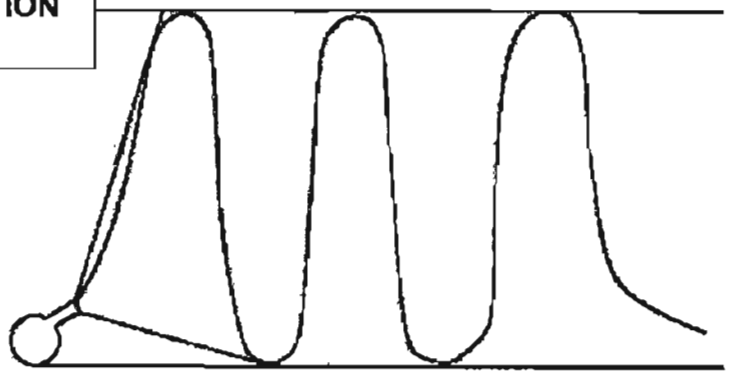
FIGURE A1-5 – ENTRAINMENT OF WATER (1/2 PLUME)

STABLE (GAUSSIAN) PLUME



VELOCITY
CONCENTRATION
PROFILE

UNSTABLE PLUME



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CLIENT: Noreon
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

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FIGURE A1-6 – PLUME STABILITY ANALYSIS

LONGITUDINAL CROSS-SECTION OF A STABLE PLUME THEORIZED BY HOLLEY & JIRKA

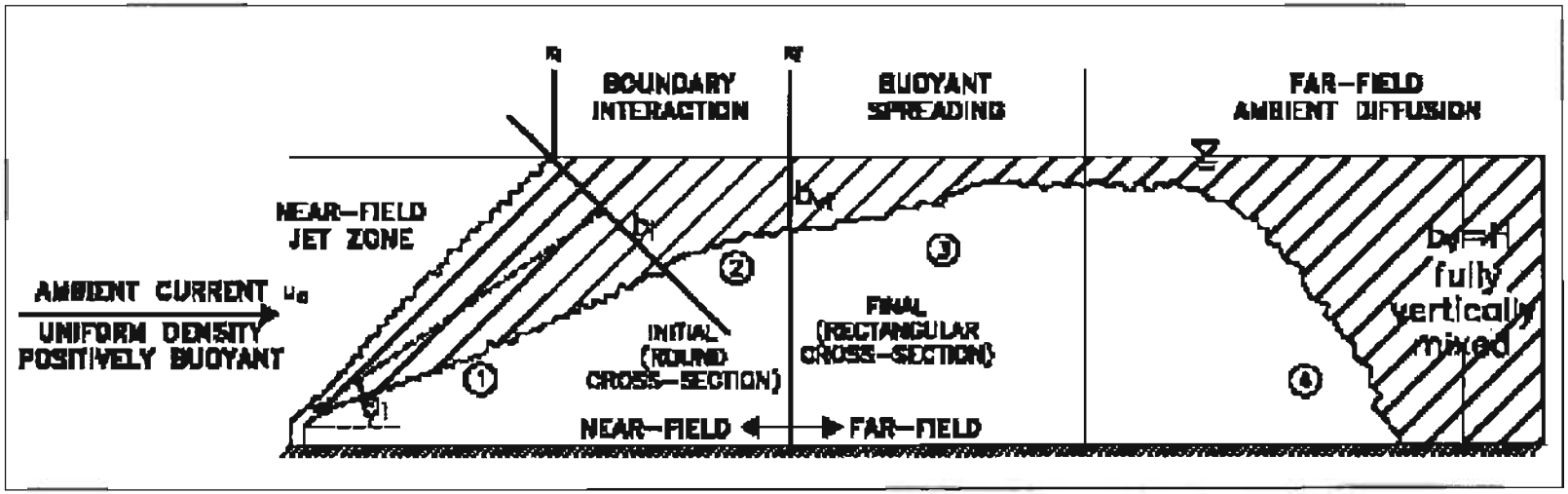

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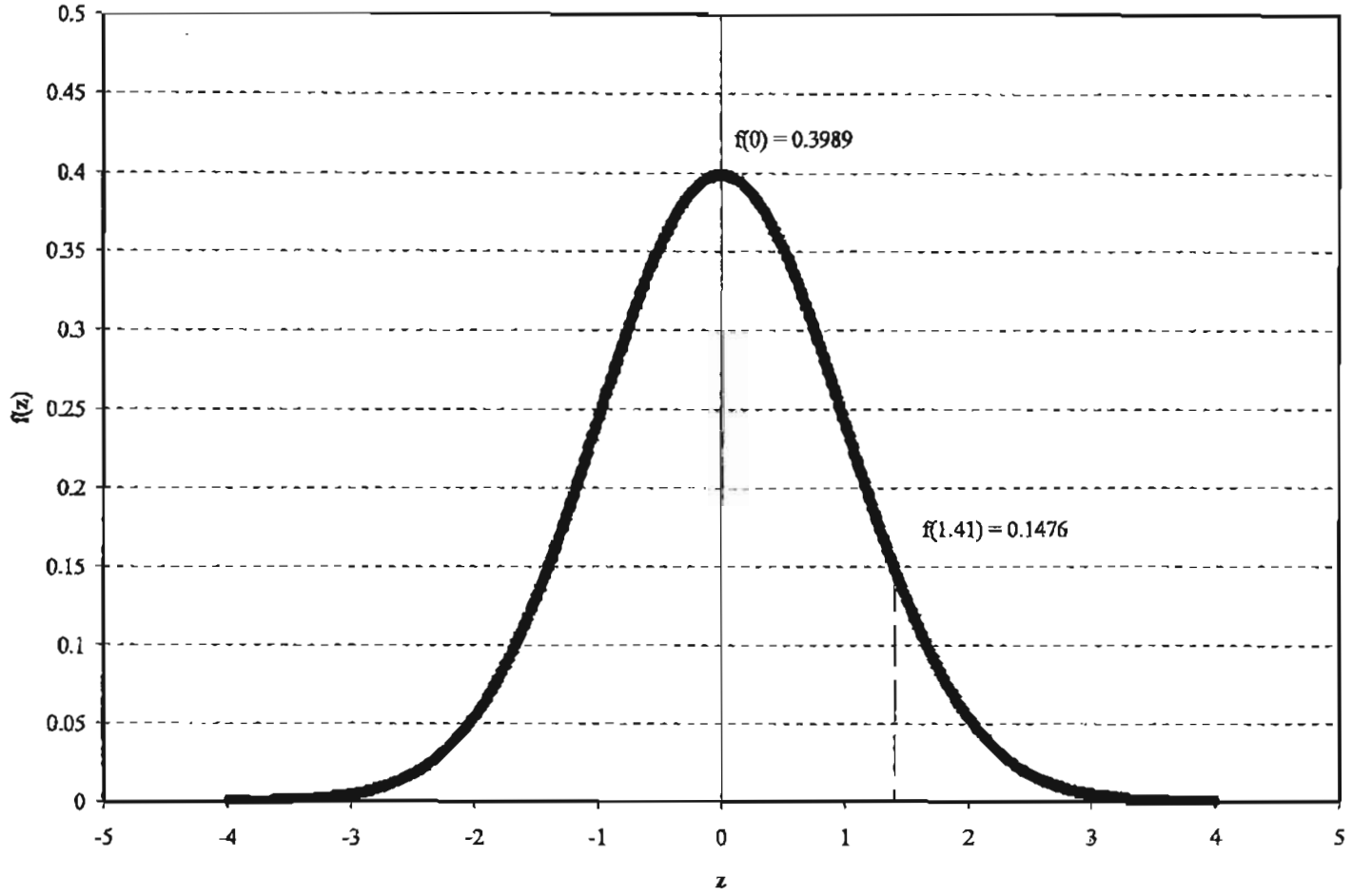
FIGURE A1-7 – LONGITUDINAL CROSS-SECTION

Normal Gaussian Distribution
(mean = 0, variance = 1)



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LOCATION: Henry, Illinois
PROJECT/FILE: 051415

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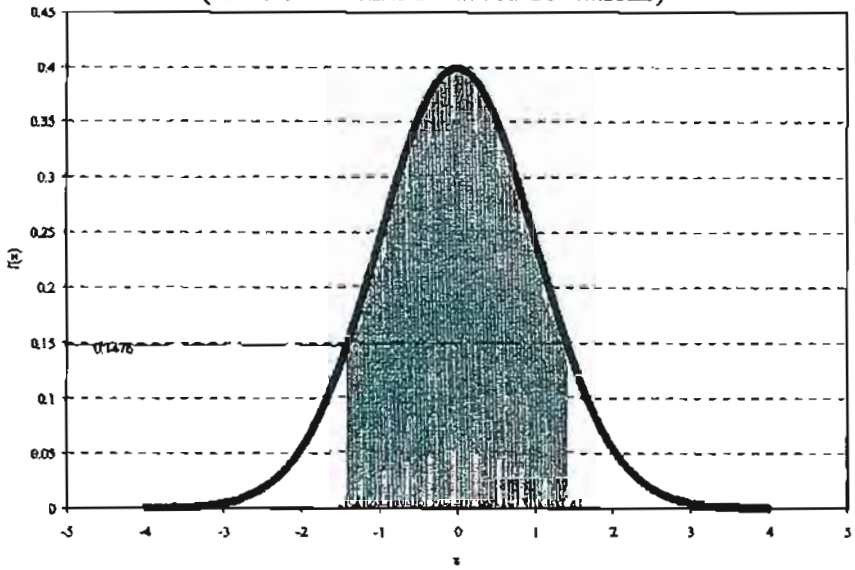
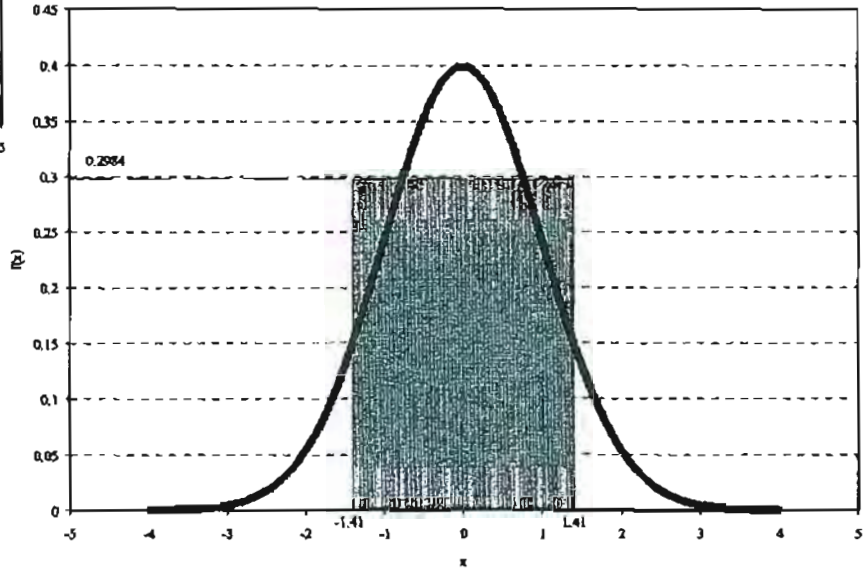
FIGURE A1-8 – NORMAL GAUSSIAN DISTRIBUTION

Normal Gaussian Distribution
(mass between 2 standard deviations)



Normal Gaussian Distribution
(equivalent area)



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CLIENT: Novozu
LOCATION: Henry, Illinois
PROJECT/FILE: 051415

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FIGURE A1-9 – NORMAL GAUSSIAN DISTRIBUTION AND EQUIVALENT AREA

Exhibit 5

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215 Jamestown Park, Suite 100 › Brentwood, TN 37027 › Phone (615) 373-8532 › Fax (615) 373-8512

June 20, 2006 051415

Dave Giffin
Emerald Performance Materials LLC
1550 County Road 1450N
Henry, Illinois 61537-9706

RE: Quarterly Monitoring for Nitrogen

Dear Mr. Giffin:

On June 15, 2006, Mr. Mike Corn of **AquAeTer** contacted Mr. Bob Mosher of the Illinois EPA in regards to quarterly sampling for nitrogen. The current ruling by the Illinois Pollution Control Board (IPCB) states "Noveon must monitor ammonia nitrogen in the Illinois River on a quarterly basis to demonstrate compliance with the applicable ammonia water quality standards...".

Mr. Mosher has agreed that a serial dilution of the discharge with the background river water from the Illinois River will be acceptable for the quarterly monitoring. A sample of the combined effluent should be taken from the outfall structure at the River prior to its discharge to the diffuser. Additionally, a sample of river water from upstream from the discharge point should be collected. Both samples should be chilled to 4 °C and shipped to the testing laboratory the same day it is sampled. Both samples should be analyzed for ammonia and total dissolved solids concentrations. The testing laboratory will need to filter the background river water to ensure that there is no interference from biota in the water column. The testing laboratory will tell you how much water they need in order to perform the test. For instance, more effluent will be needed if the test is required to run for 96-hours.

The diffuser performance testing showed that where the plume was fully mixed at the edge of the ZID, a dispersion of 47.9:1 was achieved (~2% effluent). A dispersion of 299.9:1 (0.3%) was shown at the edge of the mixing zone.

The toxicity test procedure calls for at least five serial dilutions, with a recommended dilution factor of ≥0.5 effluent. One of the serial dilutions needs to be equivalent to the dilution at the edge of the ZID. That means that one dilution needs to be at 2% combined effluent. A suggestion for the serial dilutions would be 64% combined effluent, 32% combined effluent, 16% combined effluent, 8% combined effluent, 4% combined effluent, 2% combined effluent, 1% combined effluent, and 0% combined effluent (all river water). If the toxicity test shows no effects visible at 1% or greater, then there is no need to add additional dilutions for the chronic

value. If the dilution at 1% shows some effects, then an additional dilution should be added of 0.3% combined effluent.

In short, here are your directions:

1. Collect a sample of river water from upstream of your discharge point (your lab will tell you how much you need to provide);
2. Collect a sample at your combined effluent from the outfall structure at the River (your lab will tell you how much you need to provide);
3. Submit both samples to the testing laboratory for the following procedures:
    a. Toxicity testing;
    b. Analytical analysis on the background River water and the combined effluent for:
        i. Ammonia;
        ii. TDS;
4. The laboratory should run both the acute and chronic toxicity testing at the following serial dilutions:
    a. 100% Effluent;
    b. 64% Effluent, 36% River Water;
    c. 32% Effluent, 68% River Water;
    d. 8% Effluent, 92% River Water;
    e. 2% Effluent, 98% River Water;
        i. This number shows compliance at the edge of the ZID;
    f. 0.5% Effluent, 99.5% River Water; and
    g. 0% Effluent, 100% River Water (Control)
5. If there is an effect at the 0.5% effluent, then at least one additional serial dilution should be added at 0.3% Effluent, 90.7% River water (for compliance at the edge of the mixing zone).

Samples should be submitted on a quarterly basis, as per your permit requirements.

If you have questions or comments pertaining to this letter, please contact us by telephone at (615) 373-8532, by FAX at (615) 373-8512, or by e-mail at jmcorn@aquaeter.com or mcorn@aquaeter.com. We appreciate the opportunity to assist you on this project.

Sincerely,

AquAeTer, Inc.

John Michael Corn, E.I.T.
Project Engineer

Michael R. Corn, P.E. (IL)
President

REVISION 1

QUARTERLY MIXING ZONE SAMPLING GUIDANCE MANUAL TO MEET NPDES PERMIT NO. IL0001392 SPECIAL CONDITION 18

ILLINOIS RIVER NEAR HENRY, ILLINOIS

FOR:

EMERALD PERFORMANCE MATERIALS, INC.
HENRY, ILLINOIS

PREPARED BY:

JOHN MICHAEL CORN, P.E.
MICHAEL R. CORN, P.E. (IL)

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APRIL 2007

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6.2 Temperature Measurement 5
6.3 pH Measurement 5

SAMPLING PROCEDURES FOR QUARTERLY SAMPLING

1. PURPOSE

This document contains the procedure for collecting *in situ* samples for the analysis of ammonia at the edge of the zone of initial dilution (ZID) in order to meet the requirements set forth in NPDES Permit No. IL0001392 (Permit). This procedure also presents operational, calibration, and maintenance procedures for on-site parameter measurements of pH and temperature of aqueous samples.

2. APPLICABILITY

This procedure should be followed whenever quarterly samples are collected to demonstrate compliance with the ammonia water quality standard. An ammonia sample will be collected and sent to a certified laboratory for analysis. Measurements of pH, temperature, and conductivity will be collected and recorded in the field.

3. REQUIREMENTS

As specified in the Permit, samples are to be collected in March, June, September, and December and reported annually. The sampling equipment should be operated and calibrated according to manufacturer specifications. Calibration should be performed prior to use, after use, and according to the manufacturers' suggested frequency. Calibration should also be performed if the instrument begins to respond erratically.

4. SAFETY

A Health and Safety Plan should be prepared and followed for the sampling effort. There will be no sampling if the River is iced over or if there are ice flows due to endangerment of the sampling crew. There will be no sampling during periods of high river flow that pose safety concerns to the crew. River flow information can be obtained from the USGS gage at Henry, IL. Proper safety precautions should be followed while on-board the sampling boat. Proper safety precautions should be followed to ensure that

unnecessary exposure to calibration fluids is avoided. Furthermore, none of the equipment should be used in a manner other than its specified purpose.

5. EQUIPMENT AND MATERIALS

The following equipment is required to collect a sample and to measure pH, conductivity, and temperature in the field.

- Marine Equipment:
  - Boat with capacity to hold 2 – 3 people plus equipment;
  - Fire Extinguishers;
  - Personal flotation devices (PFD), one of the following types for each person present on the boat:
    - Type I, sometimes called an offshore life jacket;
    - Type II, sometimes called a near-shore buoyant vests
    - Type III, sometimes called flotation aids;
    - Type V, or special use devices (necessary for working in cold weather conditions);
  - Throwable flotation devices, coast guard rated Type IV PFD;
  - Sound producing devices capable of a four second blast;
  - Visual distress signals;
  - Paddle(s);
  - Anchors, two will be required;
  - Rope;
  - Tools and Spare Parts should be on-board;
- Sampling Equipment for collecting ammonia sample:
  - GPS with real-time DGPS capable of sub-meter accuracy;
  - Nitrile (or equivalent) gloves for handling the sample bottle while collecting the samples;
  - Sample items:
    - Bottle(s) provided by the laboratory;

- Chain of custody, should be provided by the laboratory;
- Cooler with ice for sample storage;

- Field measuring equipment:
  - pH meter;
  - Clean glass or plastic container;
  - thermometer, should be included with the pH meter previously listed;
  - Back-up batteries for the instrument;
- Calibration standards
  - National Institute of Standards and Technology – Standard Reference Materials (NIST-SRMs) certificate of traceability, standard solutions for pH calibration, such as pH values of 4.0, 7.0, or 10.0;
- Distilled or de-ionized water;
- Clean polypropylene or glass container(s), large enough to fill the ammonia sample with enough left over to adequately cover the pH probe;
- Field book.

All sampling equipment and materials must be properly decontaminated as described in the decontamination section of this document. Sampling equipment will not require decontamination if provided in the original packaging from the manufacturer and certified to be free of contaminants.

6. PROCEDURE

6.1 Sample Location and Collection

6.1.1 Calculation of Sample Location

The Permit specifies that the sample should be collected from the Illinois River. The sample location will be chosen to be approximately 22 feet downstream from the center of the diffuser. This procedure specifies sampling at a location 22 feet perpendicularly downstream from the center of the diffuser and within the sub-meter accuracy of the GPS device (±3.28 feet). An as-built survey was not performed, so construction coordinates for the diffuser will be used. The center of the outfall structure

is given co-ordinates of N 1626919.53, E 2525716.45. The end of the diffuser is given coordinates of N 1626919.53, E 2525948.45. Both of these coordinates are in the Illinois State Plane West Zone. For navigation purposes using a GPS unit, the coordinates must be in either UTM or latitude/longitude. The multiport diffuser was designed to be 10 feet long, so the center of the diffuser should be 5 feet from the end of the diffuser structure. The UTM Zone 16N coordinates for the center of the diffuser are 304081.68E and 4555903.15N, both in meters. The river runs almost directly south at the diffuser location. The sample location is 22 feet downstream from the center of the diffuser. Therefore, the coordinates of the sample location are 304081.68E and 4555896.40N.

6.1.2 Method for Maneuvering to the Sample Location

Due to the current of the river, maneuvering to the exact specifications set forth by the Permit must be done very carefully. The sample should be collected while the boat is being maneuvered to stay at the coordinates listed above. Anchoring may be possible at lower flows, but the potential for an anchor to damage the multiport diffuser is not worth the risk. At higher river flows, anchoring is unlikely to be successful due to the current of the river. In order to do this, the following steps, illustrated in Figure 1, should be followed:

1. Starting downstream from the diffuser, orient the boat on the approximate easting specified so that it is facing upstream on a perpendicular line to the diffuser;

2. Motor upstream until the specified northing is reached;

NOTE: Care should be taken in the event of other boat traffic on the river. It is suggested that the sampling crew do their best to avoid sampling when the wake from a passing boat or barge is rolling the boat. In other words, it is much safer for the sampling crew to sample from the river when the river is calm.

6.1.3 Suggested Sample Equipment Setup

The GPS receiver (antenna) should be positioned directly above the location on the water from which the sample will be collected. The sampler can hold the receiver above the water until the sample locale is reached. Then, bringing the receiver back onto the boat, the sampler can use his/her other hand to collect the sample from the River. The sampler should take care so that his/her body is not overextended over the river.

6.1.4 Sample Collection

The sample will be collected in the following manner:

1. Identify the sample location;
2. Collect one liter of water from the surface in a clean glass or plastic (nalgene) container;
3. The ammonia sample will be collected from this sample as soon as possible;
4. After the ammonia sample is collected, a measurement of pH and temperature shall be made from the sample remaining in the glass or plastic container; and
5. The remaining sample can then be discarded.

6.2 Temperature Measurement

Temperature readings are made by a NIST-traceable thermometer or an electronic temperature meter. The meter's temperature probe attachment is plugged into the input socket, if not already attached, and the probe is placed into the sample. The digital reading displays temperature in degrees Celsius or degrees Fahrenheit. The value and units will be recorded on the sampling record.

6.3 pH Measurement

The pH measurement device will generally be a stand-alone device, although a multi-probe instrument may also be used. The manufacturer's instructions will be followed for the use and care of the pH measurement device. Check the calibration prior

to each day of use with two known standards. Record the date and time of calibration in the permanent sampling record or field book.

6.3.1 Operation

Standalone instruments are generally powered by 9-volt dry cell batteries, while multi-probe instruments are powered by multiple dry cell batteries. To use the instrument, connect the cell to the input socket on the instrument, if not already attached, and place the cell in the sample. The pH of a sample is determined by measuring the current between a pH reference potential electrode and a glass electrode in the sample. The display reading is the pH value of the solution. After the reading has stabilized, record the meter type, reading, and standard units (SU) of measurement on the sampling form.

6.3.2 Calibration

Calibration should be done in a controlled environment prior to use in the field. This procedure assumes that the instrument being used requires a two-point calibration. Refer to the instrument manual for calibration procedures if questions arise during instrument calibration. Standard buffer solutions of pH 4.0, 7.0, or 10.0 will be used for instrument calibration. Based upon USGS measurements at the Henry gage and two gages upstream, the river is on average slightly basic, so the two point calibration will use pH 7.0 and pH 10.0 buffer solutions. Connect the cell to the input socket on the side of the instrument, if not already attached, and place it in a buffer standard solution of 7.0 SU. The pH 7.00 standard solution is poured into a small beaker to a sufficient depth to cover the cell. Allow the reading to stabilize; then, using the cell constant adjustment, set the reading to the value of the calibration solution. The instrument should now prompt the user for the second solution. Discard the first buffer solution and rinse the cell with distilled water. If another clean glass or polypropylene container is available, pour the pH 10.00 buffer solution into it. If there is not a clean glass or polypropylene container, rinse the container used for the first buffer solution with distilled water three to four times before pouring the second buffer solution into the container to a depth that will cover the cell. Place the cell in the pH 10.00 buffer solution and complete the instrument

calibration. Remove the cell, rinse with distilled water, and discard the used buffer solution. Record the initial and final readings for each of the buffer solutions in the field notes.

6.3.3 Sample Measurement

After the ammonia sample is collected, pour a portion of the collected sample into the laboratory provided sample bottle for ammonia. If the remaining sample does not provide an adequate depth to cover the pH probe, pour the remaining sample into a smaller container that will allow the sample volume to cover the pH probe. Measure and record the pH of the ammonia sample collected.

6.3.4 Maintenance

The cell will be rinsed with distilled water after measuring each sample and gently cleaned with distilled water at the end of the day. If the meter starts giving inconsistent readings and this problem is not eliminated by recalibration, the manual will be consulted or the manufacturer will be contacted for further instructions.

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215 Jamestown Park, Suite 100 › Brentwood, TN 37027 › Phone (615) 373-8532 › Fax (615) 373-8512

June 20, 2006 051415

Dave Giffin
Emerald Performance Materials LLC
1550 County Road 1450N
Henry, Illinois 61537-9706

RE: Quarterly Monitoring for Nitrogen

Dear Mr. Giffin:

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Samples should be submitted on a quarterly basis, as per your permit requirements.

If you have questions or comments pertaining to this letter, please contact us by telephone at (615) 373-8532, by FAX at (615) 373-8512, or by e-mail at jmcorn@aquaeter.com or mcorn@aquaeter.com. We appreciate the opportunity to assist you on this project.

Sincerely,

AquAeTer, Inc.

John Michael Corn, E.I.T.
Project Engineer

Michael R. Corn, P.E. (IL)
President

REVISION 1

QUARTERLY MIXING ZONE SAMPLING GUIDANCE MANUAL TO MEET NPDES PERMIT NO. IL0001392 SPECIAL CONDITION 18

ILLINOIS RIVER NEAR HENRY, ILLINOIS

FOR:

EMERALD PERFORMANCE MATERIALS, INC.
HENRY, ILLINOIS

PREPARED BY:

JOHN MICHAEL CORN, P.E.
MICHAEL R. CORN, P.E. (IL)

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APRIL 2007

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SAMPLING PROCEDURES FOR QUARTERLY SAMPLING

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- Marine Equipment:
  - Boat with capacity to hold 2 – 3 people plus equipment;
  - Fire Extinguishers;
  - Personal flotation devices (PFD), one of the following types for each person present on the boat:
    - Type I, sometimes called an offshore life jacket;
    - Type II, sometimes called a near-shore buoyant vests
    - Type III, sometimes called flotation aids;
    - Type V, or special use devices (necessary for working in cold weather conditions);
  - Throwable flotation devices, coast guard rated Type IV PFD;
  - Sound producing devices capable of a four second blast;
  - Visual distress signals;
  - Paddle(s);
  - Anchors, two will be required;
  - Rope;
  - Tools and Spare Parts should be on-board;
- Sampling Equipment for collecting ammonia sample:
  - GPS with real-time DGPS capable of sub-meter accuracy;
  - Nitrile (or equivalent) gloves for handling the sample bottle while collecting the samples;
  - Sample items:
    - Bottle(s) provided by the laboratory;

- Chain of custody, should be provided by the laboratory;
- Cooler with ice for sample storage;

- Field measuring equipment:
  - pH meter;
  - Clean glass or plastic container;
  - thermometer, should be included with the pH meter previously listed;
  - Back-up batteries for the instrument;
- Calibration standards
  - National Institute of Standards and Technology – Standard Reference Materials (NIST-SRMs) certificate of traceability, standard solutions for pH calibration, such as pH values of 4.0, 7.0, or 10.0;
- Distilled or de-ionized water;
- Clean polypropylene or glass container(s), large enough to fill the ammonia sample with enough left over to adequately cover the pH probe;
- Field book.

All sampling equipment and materials must be properly decontaminated as described in the decontamination section of this document. Sampling equipment will not require decontamination if provided in the original packaging from the manufacturer and certified to be free of contaminants.

6. PROCEDURE

6.1 Sample Location and Collection

6.1.1 Calculation of Sample Location

The Permit specifies that the sample should be collected from the Illinois River. The sample location will be chosen to be approximately 22 feet downstream from the center of the diffuser. This procedure specifies sampling at a location 22 feet perpendicularly downstream from the center of the diffuser and within the sub-meter accuracy of the GPS device (±3.28 feet). An as-built survey was not performed, so construction coordinates for the diffuser will be used. The center of the outfall structure

is given co-ordinates of N 1626919.53, E 2525716.45. The end of the diffuser is given coordinates of N 1626919.53, E 2525948.45. Both of these coordinates are in the Illinois State Plane West Zone. For navigation purposes using a GPS unit, the coordinates must be in either UTM or latitude/longitude. The multiport diffuser was designed to be 10 feet long, so the center of the diffuser should be 5 feet from the end of the diffuser structure. The UTM Zone 16N coordinates for the center of the diffuser are 304081.68E and 4555903.15N, both in meters. The river runs almost directly south at the diffuser location. The sample location is 22 feet downstream from the center of the diffuser. Therefore, the coordinates of the sample location are 304081.68E and 4555896.40N.

6.1.2 Method for Maneuvering to the Sample Location

Due to the current of the river, maneuvering to the exact specifications set forth by the Permit must be done very carefully. The sample should be collected while the boat is being maneuvered to stay at the coordinates listed above. Anchoring may be possible at lower flows, but the potential for an anchor to damage the multiport diffuser is not worth the risk. At higher river flows, anchoring is unlikely to be successful due to the current of the river. In order to do this, the following steps, illustrated in Figure 1, should be followed:

1. Starting downstream from the diffuser, orient the boat on the approximate easting specified so that it is facing upstream on a perpendicular line to the diffuser;

2. Motor upstream until the specified northing is reached;

NOTE: Care should be taken in the event of other boat traffic on the river. It is suggested that the sampling crew do their best to avoid sampling when the wake from a passing boat or barge is rolling the boat. In other words, it is much safer for the sampling crew to sample from the river when the river is calm.

6.1.3 Suggested Sample Equipment Setup

The GPS receiver (antenna) should be positioned directly above the location on the water from which the sample will be collected. The sampler can hold the receiver above the water until the sample locale is reached. Then, bringing the receiver back onto the boat, the sampler can use his/her other hand to collect the sample from the River. The sampler should take care so that his/her body is not overextended over the river.

6.1.4 Sample Collection

The sample will be collected in the following manner:

1. Identify the sample location;
2. Collect one liter of water from the surface in a clean glass or plastic (nalgene) container;
3. The ammonia sample will be collected from this sample as soon as possible;
4. After the ammonia sample is collected, a measurement of pH and temperature shall be made from the sample remaining in the glass or plastic container; and
5. The remaining sample can then be discarded.

6.2 Temperature Measurement

Temperature readings are made by a NIST-traceable thermometer or an electronic temperature meter. The meter's temperature probe attachment is plugged into the input socket, if not already attached, and the probe is placed into the sample. The digital reading displays temperature in degrees Celsius or degrees Fahrenheit. The value and units will be recorded on the sampling record.

6.3 pH Measurement

The pH measurement device will generally be a stand-alone device, although a multi-probe instrument may also be used. The manufacturer's instructions will be followed for the use and care of the pH measurement device. Check the calibration prior

to each day of use with two known standards. Record the date and time of calibration in the permanent sampling record or field book.

6.3.1 Operation

Standalone instruments are generally powered by 9-volt dry cell batteries, while multi-probe instruments are powered by multiple dry cell batteries. To use the instrument, connect the cell to the input socket on the instrument, if not already attached, and place the cell in the sample. The pH of a sample is determined by measuring the current between a pH reference potential electrode and a glass electrode in the sample. The display reading is the pH value of the solution. After the reading has stabilized, record the meter type, reading, and standard units (SU) of measurement on the sampling form.

6.3.2 Calibration

Calibration should be done in a controlled environment prior to use in the field. This procedure assumes that the instrument being used requires a two-point calibration. Refer to the instrument manual for calibration procedures if questions arise during instrument calibration. Standard buffer solutions of pH 4.0, 7.0, or 10.0 will be used for instrument calibration. Based upon USGS measurements at the Henry gage and two gages upstream, the river is on average slightly basic, so the two point calibration will use pH 7.0 and pH 10.0 buffer solutions. Connect the cell to the input socket on the side of the instrument, if not already attached, and place it in a buffer standard solution of 7.0 SU. The pH 7.00 standard solution is poured into a small beaker to a sufficient depth to cover the cell. Allow the reading to stabilize; then, using the cell constant adjustment, set the reading to the value of the calibration solution. The instrument should now prompt the user for the second solution. Discard the first buffer solution and rinse the cell with distilled water. If another clean glass or polypropylene container is available, pour the pH 10.00 buffer solution into it. If there is not a clean glass or polypropylene container, rinse the container used for the first buffer solution with distilled water three to four times before pouring the second buffer solution into the container to a depth that will cover the cell. Place the cell in the pH 10.00 buffer solution and complete the instrument

calibration. Remove the cell, rinse with distilled water, and discard the used buffer solution. Record the initial and final readings for each of the buffer solutions in the field notes.

6.3.3 Sample Measurement

After the ammonia sample is collected, pour a portion of the collected sample into the laboratory provided sample bottle for ammonia. If the remaining sample does not provide an adequate depth to cover the pH probe, pour the remaining sample into a smaller container that will allow the sample volume to cover the pH probe. Measure and record the pH of the ammonia sample collected.

6.3.4 Maintenance

The cell will be rinsed with distilled water after measuring each sample and gently cleaned with distilled water at the end of the day. If the meter starts giving inconsistent readings and this problem is not eliminated by recalibration, the manual will be consulted or the manufacturer will be contacted for further instructions.

SUMMARY OF AMMONIA

MONITORING RESUTLS

Exhibit 6

Emerald Performance Materials

Emerald Performance Materials
1550 County Road 1450 N
Henry, Illinois 61537
309-364-2311

Illinois EPA
Division of Water Pollution Control
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

Re: NPDES Annual Summary Report - NPDES Permit No. IL0001392

12/18/06

Dear Sirs:

Emerald Performance Materials is submitting its 2006 NPDES Annual Summary Report as required by the PCB Order of AS 02-5.

1. The Henry Plant completed the installation of a 21 foot high-rate, multi-port diffuser into the Illinois River on 10/4/05. AquAeTer Inc. performed a dispersion study on 10/25/05 and issued a report on the efficacy of the diffuser December 2005. This report was submitted to the Regional (Jim Kammueller) and State (Bob Mosher) IEPA offices 12/21/05.
2. The Henry Plant is currently working with the permit section to complete the final drafting of a modified NPDES permit which includes the PCB Order of AS 02-5.
3. Monthly DMR's have been submitted to the IEPA throughout the year with ammonia monitoring results conducted 5 times per week.
4. An annual inspection of the facility was completed on December 13, 2005 by James Kammueller. Diffuser installation was reviewed along with the plant's Waste Treatment Access Database system.
5. The plant participated in the Pollution Prevention Program in 2006 by supporting a P2 intern. Additionally, the plant participated in a joint IEPA-USEPA P2 conference by presenting P2 project that have been conducted and completed at the plant.
6. Key P2 projects that the plant is currently working on which have the potential to reduce ammonia generation at the waste treatment system include the following:
    a. BBTS Dust Collector System
    b. Improved acetonitrile column efficiency to meet the Miscellaneous Organic NESHAP's (MON) standard.

In the event additional information is needed, please contact me either by phone (309)364-9411 or by email dave.giffin@emeraldmaterials.com.

Sincerely,

cc: Emerald: Jeff Brenner, Kevin Jones, Brian Denison
IEPA: James Kammueller, Region Office.

Emerald Performance Materials

Emerald Performance Materials
1550 County Road 1450 N
Henry, Illinois 61537
309-364-2311

CERTIFIED MAIL:
Illinois EPA
Division of Water Pollution Control
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

CERTIFIED MAIL:
Mr. Jim Kammueller
IEPA
Regional Office
5415 N.University
Peroia, IL 61614

Re: NPDES Annual Summary Report - NPDES Permit No. IL0001392

12/24/07

Dear Sirs:

Emerald Performance Materials is submitting its 2007 NPDES Annual Summary Report as was required by the PCB Order of AS 02-5 and now by its NPDES permit.

1. The IEPA issued Emerald Performance Material's its Final NPDES Permit on February 9, 2007 to be effective May 1, 2007 which included the conditions outlined in the PCB Order of AS 02-5.
2. The Henry Plant continues to use the 21 foot high-rate, multi-port diffuser that was installed on 10/4/05 into the Illinois River. Quarterly samples of the Illinois River for Ammonia Nitrogen are listed below:
    a. 3/28/07: 0.23 mg/l
    b. 9/28/07: 0.20 mg/l
    c. 12/21/07: Results pending analysis
3. Monthly DMR's have been submitted to the IEPA throughout the year with ammonia monitoring results conducted 5 times per week.
4. An annual inspection of the facility was completed on September 11, 2007 by James Kammueller. Diffuser installation was reviewed along with the plant's Waste Treatment Access Database system.
5. The plant participated in the Pollution Prevention Program in 2007 by supporting a P2 intern.
6. One major project that was completed during the year was the removal of the BBTS scrubber which was replaced with a dust collector. This improved overall process efficiencies by preventing loss of finished BBTS product to the waste water.
7. Key projects that the plant continued to work on during 2007 which have the potential to reduce ammonia generation at the waste treatment system include the following:
    a. Investigation of a sintered filter media for the BHS filters that would not be prone to tearing and loss of BBTS product to the waste water.
    b. Continued efforts to improve acetonitrile column efficiency to meet the Miscellaneous Organic NESHAP's (MON) standard.

c. Investigation of a new process in the Netherlands called the Anammox (anaerobic ammonia oxidation) process. This is a relatively new method of treating high concentrations of ammonia anaerobically. The first commercial process was installed 2002 and was featured in the January 2007 issue of Chemical Engineering. Based on Brown and Caldwell Environmental Consultants, the bacteria cultured in this system are very slow growing and sensitive. The inhibitors in the Emerald waste stream would render the process performance unstable.

In the event additional information is needed, please contact me either by phone (309)364-9411 or by email dave.giffin@emeraldmaterials.com.

Sincerely,

David E. Giffin
HSE Manager

cc: Emerald: Jeff Branner, Brian Denison
IEPA: James Kaminueller, Region Office

Emerald Performance Materials

Emerald Performance Materials
1550 County Road 1450 N
Henry, Illinois 61537
309-364-2311

Illinois EPA
Division of Water Pollution Control
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

Re: NPDES Annual Summary Report - NPDES Permit No. IL0001392

05/20/2010

Dear Sirs:

Emerald Performance Materials is submitting its 2008 NPDES Annual Summary Report as was required by its NPDES permit.

1. The IEPA issued Emerald Performance Material's its Final NPDES Permit on February 9, 2007 to be effective May 1, 2007 which included the conditions outlined in the PCB Order of AS 02-5.
2. The Henry Plant continues to use the 21 foot high-rate, multi-port diffuser that was installed on 10/4/05 into the Illinois River. Quarterly samples of the Illinois River for Ammonia Nitrogen are listed below:
    a. 3/14/08: 0.27 mg/l
    b. 6/19/08 <0.10 mg/l
    c. 9/28/08: <0.20 mg/l
    d. 12/13/08 < 0.20 mg/l
3. Monthly DMR's have been submitted to the IEPA throughout the year with ammonia monitoring results conducted 5 times per week.
4. An annual inspection of the facility was completed on September 29, 2008 by James Kammueller.
5. Key projects that the plant continued to work on during 2008 which have the potential to reduce ammonia generation at the waste treatment system include the following:
    a. Brown and Caldwell conducted training in August with waste water treatment operators to optimize the WWT system.
    b. Initiated study on the effects of Carbon Dioxide for ph buffering.
    c. Conducted Fed Batch Reactor testing to quantify any bio-inhibitions present in the system.

In the event additional information is needed, please contact me either by phone (309)364-9411 or by email mike.strabley@emeraldmaterials.com

Sincerely,

Mike Strabley
HSE Manager

cc: Emerald: Jeff Leech, Brian Denison

Emerald Performance Materials

Emerald Performance Materials
1550 County Road 1450 N
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Post Office Box 19276
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CERTIFIED MAIL:
Mr. Jim Kammueller
IEPA
Regional Office
5415 N.University
Peoria, IL 61614

Re: NPDES Annual Summary Report - NPDES Permit No. IL0001392

12/22/09

Dear Sirs:

Emerald Performance Materials is submitting its 2009 NPDES Annual Summary Report as was required by its NPDES permit.

1. The IEPA issued Emerald Performance Material's its Final NPDES Permit on February 9, 2007 to be effective May 1, 2007 which included the conditions outlined in the PCB Order of AS 02-5.
2. The Henry Plant continues to use the 21 foot high-rate, multi-port diffuser that was installed on 10/4/05 into the Illinois River. Quarterly samples of the Illinois River for Ammonia Nitrogen are listed below:
    a. 3/26/09: <0.20 mg/l
    b. 6/18/09 <0.20 mg/l
    c. 9/28/09: <0.10 mg/l
    d. 11/20/09 < 0.20 mg/l
3. Monthly DMR's have been submitted to the IEPA throughout the year with ammonia monitoring results conducted 5 times per week.
4. An annual inspection of the facility was completed on September 22, 2009 by James Kammueller.
5. Key projects that the plant continued to work on during 2009 which have the potential to reduce ammonia generation at the waste treatment system include the following:
    a. Improvements to the Tertiary Butyl Amine column increasing the recovery of TBA resulting in less amine to the sewer.
    b. Utilization of carbon dioxide for pH adjustment reducing overall loading on the biotreaters. The use of CO_2 reduces the slug feeding of caustic to the system at the primary clarifier adding stability throughout the system.

In the event additional information is needed, please contact me either by phone (309)364-9411 or by email mike.strabley@emeraldmaterials.com

Sincerely,

Mike Strabley
HSE Manager

cc: Emerald: Jeff Brenner, Brian Denison
IEPA: James Kammueller, Region Office.

Emerald Performance Materials

Emerald Performance Materials
1550 County Road 1450 N
Henry, Illinois 61537
309-364-2311

CERTIFIED MAIL:
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1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

CERTIFIED MAIL:
Mr. Todd Hyson
IEPA-Regional Office
5415 N.University
Peoria, IL 61614

Re: NPDES Annual Summary Report - NPDES Permit No. IL0001392

1/14/10

Dear Sirs:

Emerald Performance Materials is submitting its 2010 NPDES Annual Summary Report as was required by its NPDES permit.

1. The IEPA issued Emerald Performance Material's its Final NPDES Permit on February 9, 2007 to be effective May 1, 2007 which included the conditions outlined in the PCB Order of AS 02-5.
2. NPDES permit was modified on April 27, 2010 listing PolyOne Corporation as a co-permitee.
3. The Henry Plant continues to use the 21 foot high-rate, multi-port diffuser that was installed on 10/4/05 into the Illinois River. Quarterly samples of the Illinois River for Ammonia Nitrogen are listed below:
    a. 3/31/10: <0.20 mg/l
    b. 6/30/10 <0.20 mg/l
    c. 9/23/10: <0.20 mg/l
    d. Unable to sample in December due to the amount of ice on the river.
4. Monthly DMR's have been submitted to the IEPA throughout the year with ammonia monitoring results conducted 5 times per week.
5. An annual inspection of the facility was completed on September 23, 2010 by James Kammueller.
6. Key projects that the plant continued to work on during 2010 which have the potential to reduce ammonia generation at the waste treatment system include the following:
    a. Incorporate ammonia reduction as a metric in the employee gain sharing plan.
    b. Conduct additional testing to further determine sources of ammonia within the facility.

In the event additional information is needed, please contact me either by phone (309)364-9411 or by email mike.strabley@emeraldmaterials.com

Sincerely,

Mike Strabley
HSE Manager

cc: Emerald: Jeff Leech, Brian Denison, John McKinley

IEPA: James Kammueller, Region Office.

Emerald Performance Materials

CERTIFIED MAIL: 7010 3090 0003 0728 0105

December 20, 2011

Illinois Environmental Protection Agency
P. O. Box 19276
Springfield IL 62794-9276

Attn: Division of Water Pollution Control
Compliance Assurance Section, Mail Code #19

Re: NPDES Permit No. IL0001392 – Annual Ammonia Report

Gentlemen:

Special Condition 17 of NPDES permit No. IL0001392, requires that Emerald Performance Materials' Henry IL facility submit an annual report summarizing the activities and results of investigations required by Special Conditions 15, 16 and 18 of the permit.

Special Condition 15 requires Emerald to investigate production methods and technologies which reduce ammonia concentration in effluent from the facility's WasteWater Treatment Plant (WWTP). One source of ammonia to the WWTP is the bottoms stream from the acetonitrile recovery column in the 3114 process. It has been determined that the recovery efficiency of the column is sensitive to absolute pressure at the bottom of the column. A project was defined during the fourth quarter of 2011 to upgrade the instrumentation around the column in order to more effectively control absolute pressure. These upgrades will be implemented in 2012.

Special Condition 16 requires that Emerald evaluate any new technology or economically reasonable production methods which may reduce ammonia concentration in effluent from the WWTP. Emerald did not become aware in 2011 of any new or alternative technology that can be integrated into the facility's manufacturing processes or economically replace existing processes.

Special Condition 18 requires that Emerald quarterly monitor ammonia concentration in the Illinois River in order to demonstrate compliance with 35 IAC 302.212 and that Emerald report those results in the annual report. The results of those samples are shown below.

Sample Date	**Concentration**
31 March 2011	< 0.10 mg/L
30 June 2011	< 0.10 mg/L
23 September 2011	< 0.10 mg/L
15 December 2011	< 0.10 mg/L

If you have any questions, please e-mail me at **harold.crouch@emeraldmaterials.com** or call me at **309-364-9472.**

Harold Crouch

Harold Crouch, P.E.
Environmental Engineer

Emerald Polymer Additives, LLC

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