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City of Angels
Technical Memorandum No. 1

Angels Creek Mixing Zone Study

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PURPOSE

The purpose of this memorandum is to present the results of the City of Angels Mixing Zone Study conducted in Angels Creek November 7 and 8, 2007. The Mixing Zone Study was implemented in accordance with the City of Angels Mixing Zone Study Work Plan (revised September 11, 2007 to reflect comments received by Regional Water Board staff).

OVERVIEW

Currently the City does not have an outfall allowing effluent from the City's tertiary treatment wastewater reclamation facility (Facility) to be discharged to Angels Creek. However, effluent discharges to Angels Creek are necessary under certain climatic situations, and as the City continues to grow. The Regional Water Board adopted Order No. R5-2007-0031 (hereinafter, Order), which allows discharge of tertiary treated effluent to Angels Creek under specific conditions. One of those conditions is that each gallon of effluent must be diluted with at least 19 gallons of creek water such that the resulting downstream creek flow does not contain more than 5 percent effluent.

Although the Order specifies a minimum amount of effluent dilution to occur in the creek, the effluent limitations in the Order do not reflect that required level of dilution, i.e., the City was given no "dilution credit" under the State Implementation Policy (SIP). To be considered for receiving dilution credits, the City needs to demonstrate via a mixing zone study that the effluent is completely-mixed into Angels Creek within two creek widths of the effluent discharge point. With this demonstration, the Regional Water Board will reopen the Order and the effluent

limitations may be changed to reflect dilution credits. The City's effluent does not comply with the "no dilution credit" effluent limitations in the current Orders; and it appears that additional treatment and source control to comply with those limitations is not feasible. The effluent would comply with effluent limitations that are based on the City receiving dilution credits.

ANGELS CREEK

Angels Creek flow originates from three sources: 1) releases from the Angels Creek Diversion Dam, 2) runoff from the unimpaired watershed of Angels Creek below the dam, and 3) releases from the Angels Powerhouse. The "base flow" of Angels Creek during the November through mid-May effluent discharge period is estimated to range from about 8 million gallons per day (Mgal/d) to 17 Mgal/d, typically, as discussed in the City's March 2007 Report of Waste Discharge. In the vicinity of the Facility this range in flow appears to remain in a fairly well defined natural channel (see Photograph 1 in Attachment B) that has a width of about 18 feet. The proposed effluent discharge point is at the end of this reach just before the stream narrows to go through a more turbulent and twisting reach. Two typical stream widths (i.e., 36 feet) downstream from the proposed effluent discharge point is still in the turbulent and twisting reach. At this point downstream, the creek has a width of about 8 feet under typical flow conditions.

MIXING ZONE STUDY TEST CONDITIONS

During the mixing zone study, Angels Creek flow was approximately 12.9 Mgal/d (after the removal of 0.65 Mgal/d to create the "surrogate effluent" for discharge into the creek, as will be discussed). The 12.9 Mgal/d flow is central to the 8 to 17 Mgal/d typical flow range of Angels Creek forecast in the Report of Waste Discharge to occur during the effluent discharge period. Therefore, the mixing zone study was conducted under typical creek flow conditions modeling the mixing of a nearly maximum permitted effluent discharge 0f 0.65 Mgal (which is slightly less than $1/19^{th}$ of the 12.0 Mgal/d creek flow). Under lower creek flows (e.g., 8 Mgal/d), lesser effluent discharge is permitted (e.g., no more than 0.42 Mgal/d of effluent can be discharged to a creek flow of 8 Mgal/d).

STUDY METHODOLOGY

Full-scale effluent discharge and mixing zone simulations were conducted in November 2007 and are described briefly below. A more detailed description is provided in the Work Plan (Attachment A).

PROPOSED EFFLUENT DISCHARGE POINT

The Angels Creek effluent discharge mixing zone study was conducted at the site of the proposed effluent discharge point using full-scale, temporary, PVC pipe models of possible effluent discharge outfall designs. The effluent discharge point was selected based on:

- Proximity to the Facility.
- Stable streambed and creek hydraulic conditions at the effluent discharge point.

- Very turbulent creek conditions immediately downstream of the effluent discharge point to facilitate mixing of the effluent into the stream.

The effluent mixing characteristics of two outfall designs were studied:

- An open-ended pipe discharging directly into the creek at a point of maximum flow concentration, maximum turbulence, and maximum water velocity (see Photograph 7 in Attachment B). This design would discharge all of the effluent at a point of natural stream mixing to disperse the effluent through a high percentage of the stream flow prior to additional mixing occurring in the subsequent turbulent reach of the creek. This design would have lower initial cost and easier maintenance because an open-end outfall is less likely to plug with stream sand (and other debris) when not in use (i.e., when storage and/or reclamation are possible) and is easier to clean if it does plug.

- A cross-stream multi-port diffuser located immediately upstream of the turbulent reach of Angels Creek (see Photograph 10 in Attachment B). This more expensive higher maintenance design mixes the effluent into the stream flow just upstream of the point of natural maximum stream turbulence so that there are three phases of effluent/creek water mixing: initial mixing via the diffuser, further mixing at the point of maximum stream turbulence, and still further mixing in the turbulent reach of stream extending two stream widths downstream from the diffuser.

Surrogate effluent was discharged to Angels Creek at these locations via these two model outfall designs in various orientations in the stream.

SURROGATE EFFLUENT

A surrogate effluent discharge was created by pumping water from a location in Angels Creek approximately 1,000 feet upstream of the proposed effluent discharge point. This was accomplished using an irrigation pump and piping system. This system was fitted with a dye injection port (dye was used to distinguish "surrogate effluent" from Angels Creek water in the study), an inline flow meter, a flow control valve, a discharge sampling port, and a flexible 8-inch diameter discharge pipe (see Attachment B, Photographs). Instantaneous Angels Creek flow was determined using the City's permanently installed electronic stream gauge. Using the flow control valve and in-line flow meter, surrogate effluent flow (i.e., creek water with dye) was adjusted to equal about five percent of the flow in Angels Creek (i.e., about 1 gallon of surrogate effluent for every 19 gallons of water left in the creek).

DYE INJECTION

Fluorescent dye (Rhodamine WT) was injected into the aforementioned dye injection port using a peristaltic pump, at a rate to provide a target fluorescence concentration in the surrogate effluent of approximately 200 parts per billion (ppb). This discharge dye concentration fully mixed with Angels Creek provides a fluorescence concentration of approximately 10 ppb that is a level visually observable, and quantifiable with a field fluorometer.

DYE MEASUREMENT

Dye measurements were obtained at three locations: background Angels Creek, surrogate effluent discharge, and cross-sectionally at a location two stream widths downstream of the discharge location. All field measurements were conducted using a calibrated Self-Contained Underwater Fluorescence Apparatus (SCUFA). The SCUFA provides temperature corrected fluorescence (TCF) readings, water temperature, and water turbidity.

SIMULATION RESULTS

In initial study trials, measurements were obtained by direct submersion of the SCUFA into the flow stream. Using this approach, the TCF reading fluctuated in the faster moving sections of the creek. The SCUFA manufacturer was contacted regarding these observations. The manufacturer stated that the SCUFA is sensitive to water velocity and any air bubbles that may be entrained in this higher velocity, more turbulent flow. The recommendation was made to collect a discrete sample from each desired location and conduct measurements from a bucket, thereby removing any potential velocity and air bubble related affects. Following the recommendations of the manufacturer, sampling procedures were modified to take individual readings from a bucket that was filled with water from the specified locations in the creek downstream from the effluent discharge point.

Multiple iterations of possible effluent outfall designs and outfall orientations in Angels Creek were conducted on November 7, 2007 and November 8, 2007. The following conditions were observed for the most successful mixing zone dye studies:

- Observation time: November 8, 2007 15:47-16:23.
- Discharge through fabricated 12 foot long, 6-inch diameter PVC model diffuser with one-inch discharge ports, one foot on center, facing upstream.
- Sampling method: Measurements obtained from discrete creek samples to reduce the effects of water velocity and air bubbles on SCUFA meter output.
- Sampling cross-section location: 36 feet downstream of discharge.
- Angels Creek flow: 12.9 Mgal/d after removal of water to create the surrogate effluent.
- Discharge flow: 0.65 Mgal/d (450 gallons per minute).
- Dilution: 19.8 parts creek flow to 1.0 part surrogate effluent.
- Approximate creek velocity at downstream monitoring location: 3-4 feet per second.
- Approximate period of diffuser operation before dye measurements began: 1 hour.

- Background creek temperature corrected fluorescence: 2.29 ppb at 3 - 4 ft/sec in the stream upstream of the diffuser and 1.79 ppb at 0 ft/sec in a discrete sample of water removed from the creek to reduce water velocity and air bubble effects.
- Temperature corrected fluorescence in surrogate effluent at 0 ft/sec: 193.4 ppb.

The results from the final, most successful simulation are presented below.

Table 1
Temperature Corrected Fluorescence (ppb) at 0 ft/sec
36 Feet Downstream of Effluent Discharge Made Via a Cross-Stream Diffuser

Distance from E. Bank of Creek (ft)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Creek Depth (in.)	**11**	**18**	**23.5**	**21**	**16**	**11.5**	**8**
2" Below Creek Water Surface	12.97	8.68	9.64	10.30	10.37	10.21	9.91
Mid Depth in Creek	9.70	9.16	12.27	10.26	10.30	10.15	13.49
2" Above Creek Bottom	12.11	11.41	8.77	10.14	10.28	10.16	10.87
Averages:	11.59	9.75	10.23	10.23	10.32	10.17	11.42

Notes on dye concentrations:

Minimum:	8.68ppb
Maximum:	13.49ppb
Median:	10.26ppb
Mean:	10.53ppb
Standard Deviation:	1.27ppb

OBSERVATIONS

Throughout the study, visual observations were made to assess conditions during the discharge of surrogate effluent into Angels Creek. A defined dye plume was observed in the creek during the discharge of dye-enriched surrogate effluent to Angels Creek. As the flow proceeded through the turbulent section of the creek, just downstream of the discharge point, significant mixing was observed. At the transect location two stream widths (36 feet) downstream of the discharge point, and beyond, the dye appeared, visually, to be completely mixed into the creek flow.

To determine the degree of mixing of the surrogate effluent with the receiving water, temperature corrected fluorescence (TCF) results and flow data were inserted into the following formula in accordance with USGS Techniques of Water Resources Investigations of the United States Geological Survey, Measurements of Discharge Using Tracers Book 3, Chapter A16, Appendix A.

$$P_m = 100 - \frac{50}{C_{av} Q} \sum_{i=1}^{N} |C_i - C_{av}| Q_i$$

Where: P_m = Percentage mixing
C_i = concentrations at points i across the section;
C_{av} = average of the plateau concentrations, C_i;
Q_i = discharges applicable to the points, i; and
Q = total stream discharge.

Percent mixing was calculated using two approaches. The first approach was to run the calculation using the mid-depth TCF measurement from each sampling location on the stream transect. This approach yields a percentage mixing result of 93.5 percent. The second approach was to run the calculation using the average of all three TCF measurements at each sampling location vertical on the stream transect. This approach yields a percentage mixing result of 97.6 percent. Both of these approaches are consistent with USGS guidance. Detailed calculation spreadsheets are included as Attachment C to this memorandum.

EDGE OF MIXING ZONE

As indicated above, complete mixing takes place at approximately two stream-widths downstream of the proposed effluent discharge to Angels Creek. The initial intent of the field aspect of this study was to gather data at multiple Angels Creek transects between the proposed discharge location and two stream widths (36 feet) downstream. However, due to the turbulent conditions upstream at the "two stream widths downstream" transect (see Photograph 8 in Attachment B) and the sensitivity limitations of the field equipment, data collection was problematic. So the determination of the exact location of the edge of the mixing zone, i.e., where percentage mixing equals exactly 95 percent, was not possible, and would not be significant because that location varies with the methods of data interpretation (93.5% to 97.6% as noted above), creek flows, creek rock location (i.e., bedload movement), etcetera. It would be misleading to state that there is repeatable precision in stream mixing analyses. The limit on significant accuracy is that approximately two stream widths downstream of the diffuser, the stream will be approximately 95 percent mixed on a long-term average basis. There is no one place in the creek that is 95 percent mixed (or any other percentage mixed) at all times, under all creek flows, and under all reasonable bedload rock configurations.

Therefore, it is reasonable to assume that two stream widths, or 36 feet, downstream of the proposed discharge location, is the appropriate edge of the mixing zone for regulatory purposes for this discharge.

SIP REQUIRED CONDITIONS

The *Policy for Implementation of Toxic Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California* (SIP), in Section 1.4.2.2, contains mixing zone conditions that must be met to allow a mixing zone. The requirement that "A mixing zone shall be as small as practicable" has been demonstrated in previous sections of this document. The following SIP requirements and explanations of how these requirements are met are provided as numbered items below.

1. A mixing zone shall not compromise the integrity of the entire water body.

   Because effluent discharge is limited to a maximum of five percent of the resulting receiving water flow, and discharge will occur though a multi-port, cross-stream diffuser at a location immediately upstream of a turbulent cascading section of Angels Creek

(which facilitates mixing), it is extremely unlikely that the integrity of the water body downstream of the proposed effluent discharge point will be compromised in any way.

2. A mixing zone shall not cause acutely toxic conditions to aquatic life passing through the mixing zone.

   Within SIP, "acutely toxic" means "acutely lethal." The effluent is tested for acute lethality (results included with February 2006 Report of Waste Discharge). Even undiluted effluent does not appear to cause acute lethality over the 4-day test period of an acute bioassay test. With the proposed diffuser design, "worst-case" 100 percent effluent conditions exist only in a very small orifice area at each diffuser port. A fish holding its position in the water column against a diffuser port for a four day period would not be killed. The risk of any acute lethality is reduced dramatically and quickly from this extreme, near nonsensical example, as a result of initial effluent dilution at the diffuser.

3. A mixing zone shall not restrict the passage of aquatic life.

   There are no obstructions that will limit the passage of aquatic life. Effluent will be discharged through a multi-port diffuser mounted on the downstream side of a low concrete stem wall to be installed in the streambed (see the figure in Attachment D). The low cascade created by the stem wall is smaller than natural cascades in the creek, and therefore should pose no significant barrier to aquatic life movement in the creek.

4. A mixing zone shall not adversely impact biologically sensitive or critical habitats, including, but not limited to, habitat of species listed under federal or State endangered species laws.

   No biologically sensitive or critical habitats are known to be located within the mixing zone. Therefore, no biologically sensitive or critical habitats will be adversely impacted within the mixing zone.

5. A mixing zone shall not produce undesirable or nuisance aquatic life.

   This mixing zone configuration, tertiary level treated effluent and a discharge rate of a maximum of 1 part effluent to 19 parts receiving water, are not expected to produce undesirable or nuisance aquatic life. The effluent discharge occurs only in winter/spring, and in an area (including the zone) that is heavily shaded. With these limits, objectionable biostimulation in the area where the effluent mixes into the creek water is not expected.

6. A mixing zone shall not result in floating debris, oil, or scum.

   Because the Facility provides tertiary level treatment, effluent is free of any floating debris, oil, or scum.

7. A mixing zone shall not produce objectionable color, odor, taste, or turbidity.

   Documented historical tertiary treated effluent water quality visual observations and data, combined with the fact that the proposed mixing zone will contain no more than 1 part effluent to 19 parts receiving water, support that the proposed mixing zone will not produce objectionable color, odor, taste, or turbidity.

8. A mixing zone shall not cause objectionable bottom deposits.

   Tertiary treated effluent contains no measurable stettleable solids to form bottom deposits. The BOD of tertiary effluent is sufficiently low to cause no objectionable bacterial biofilms downstream of the diffuser. Even with the nitrification/denitrification SBR treatment process, effluent nutrients should be sufficient to cause some biostimulation, but not to objectionable levels, particularly considering the limited discharge season and the shaded setting of the effluent diffuser and mixing zone.

9. A mixing zone shall not cause nuisance.

   The mixing zone will not cause a nuisance because the Facility provides tertiary level treatment, the discharge will make up less than five percent of the volume in the mixing zone (i.e., a maximum of 1 part effluent to 19 parts receiving water), and effluent will be discharged through a multi-port cross-stream diffuser.

10. A mixing zone shall not dominate the receiving water body or overlap a mixing zone from different outfalls.

    The mixing zone is small relative to the surrounding creek. Therefore, the mixing zone will not dominate the receiving water body. Furthermore, there are no other outfalls within the vicinity of the proposed discharge point that would result in an overlap of mixing zones.

11. A mixing zone shall not be allowed at or near any drinking water intake.

    There is no drinking water intake in the vicinity of the outfall.

CONCLUSIONS

Following two days of field dye studies, the data obtained were evaluated using a USGS mixing model to calculate the percentage mixing of a maximum surrogate effluent discharge into Angels Creek as a function of different outfall designs and orientations. The maximum percentage

mixing for an effluent discharge to Angels Creek without a diffuser was 94.2 percent at a location two stream widths downstream from the effluent discharge point. The percentage mixing resulting from a cross-stream diffuser design with the diffuser ports facing upstream (to maximize immediate mixing at the diffuser) was 93.5 percent (using only mid-depth measurements) to 97.6 percent (using depth integrated data) at a location two stream widths downstream from the proposed effluent discharge point. This degree of mixing appears to meet USGS guidance for an essentially completely mixed condition at the location (two stream widths downstream) specified in SIP. Furthermore, based on the results of this study, the proposed edge of the mixing zone is determined to be 36 feet downstream of the proposed discharge location.

RECOMMENDATIONS

This mixing zone study should be submitted to the Regional Water Board as the basis for a request to reopen the existing Order for the purpose of considering revision of the current effluent limitations to reflect dilution credits as described in the City's original Report of Waste Discharge. Any revision to the effluent limitations would take effect only after the permanent effluent diffuser has been installed and tested to produce a percentage mixing of 95 percent in two stream widths.

The cross-stream diffuser is recommended for implementation because the study results and common sense suggest that if a multi-port, cross-stream diffuser located immediately upstream of a turbulent reach of stream does not constitute complete-mixed discharge conditions, then those conditions do not exist anywhere in any realistic feasible sense. The issue of dilution credits for the people of Angels Camp is too important to be put at risk by less costly designs for discharging effluent to Angels Creek.

Attachment A

City of Angels Mixing Zone Study Work Plan

(Revised 11 September 2007 to reflect comments received from Regional Water Board staff)

Attachment B

Photographs

Photograph 1
Angels Creek Upstream of Study Area

Photograph 2
Surrogate Effluent Pump

Photograph 3
Surrogate Effluent Pipe

Photograph 4
Surrogate Effluent Flexible Discharge Pipe

Photograph 5
Surrogate Effluent Dye Injection

Photograph 6
Surrogate Effluent Dye Concentration Measurement (~200 ppm)

Photograph 7
Dye Enriched Surrogate Effluent Discharge to Angels Creek

Photograph 8
Monitoring Location Looking Upstream to Discharge Point

Photograph 9
Model Discharge Diffuser Assembly

Photograph 10
Dye Enriched Surrogate Effluent Discharged Through Model Diffuser

Photograph 11
Discrete Sample Collection

Photograph 12
Filling of Sample Measurement Bucket

Photograph 13
Discrete Sample Fluorescence Measurement

Photograph 14
Angels Creek, Downstream of Study Area View A

Photograph 15
Angels Creek, Downstream of Study Area View B

Attachment C

Diffuser TCF Concentrations

City of Angels
Angels Creek Mixing Zone Study
Diffuser - Mid depth TCF concentrations

$$P_m = 100 - \frac{50}{C_{av} Q} \sum_{i=1}^{N} |C_i - C_{av}| Q_i$$

Total Flow 8958gpm
C_{av} 8.40

Location (a)	Distance From East Bank (ft) (b)	Water Depth (in)	Estimated % Area	Dye Concentration (ppb) (l)	Stream background Reading (j)	Net Reading (k)	Estimated Incremental Flow (gpm) (l)	Product of (k) and (l)	Dye Deviation	Dye Deviation x Flow
				Ci			Q_i		$\|C_i - C_{bar}\|$	$\|C_i - C_{bar}\| Q_i$
1	1	5.5	0.1015	9.70	2.29	7.41	909	6,738	0.99	896.82
2	2	9	0.1662	9.16	2.29	6.87	1,489	10,229	1.53	2,272.48
3	3	11.75	0.2169	12.27	2.29	9.98	1,943	19,392	1.58	3,077.21
4	4	10.5	0.1938	10.26	2.29	7.97	1,736	13,837	0.43	740.12
5	5	8	0.1477	10.30	2.29	8.01	1,323	10,598	0.39	511.14
6	6	5.75	0.1062	10.15	2.29	7.86	951	7,478	0.54	510.23
7	7	4	0.0738	13.49	2.29	11.2	661	7,405	2.80	1,853.59
Totals			1				9,013	75,676		9,861.60
Averages				10.76						

Percent Mixing: **93.5 %**

Diffuser - Depth integrated TCF concentrations

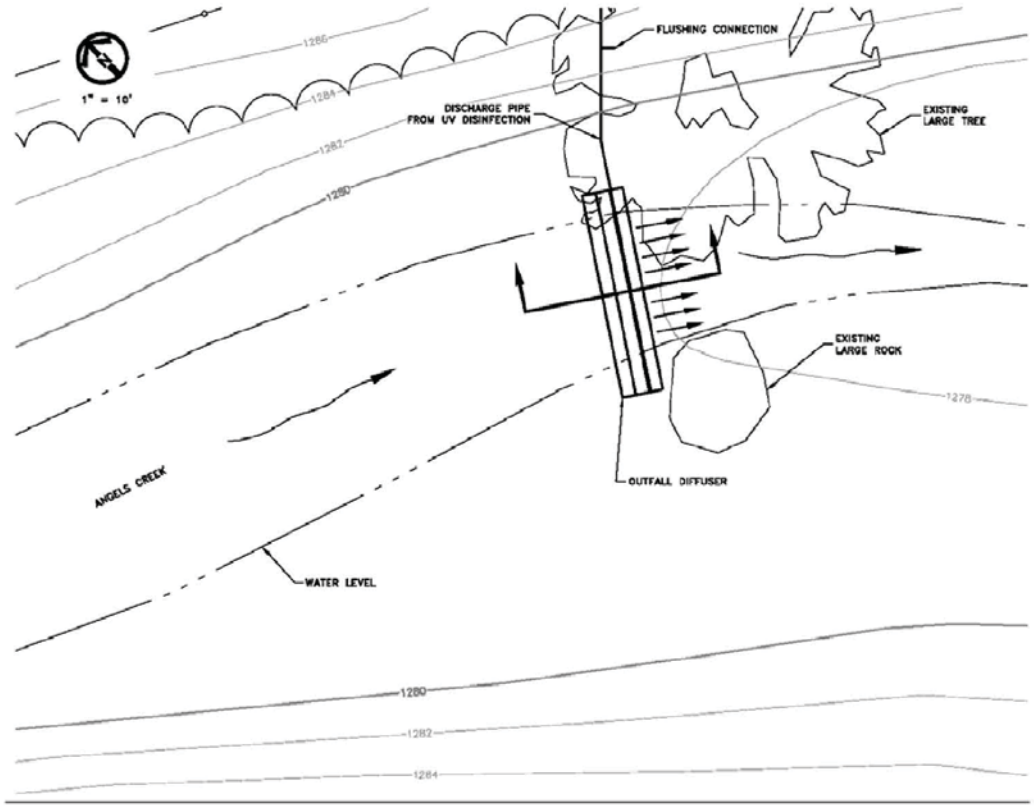
Total Flow 8958gpm
C_{av} 8.09

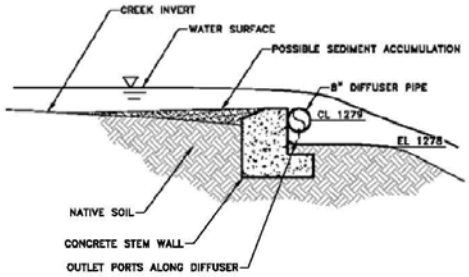
Location (a)	Distance From East Bank (ft) (b)	Water Depth (in)	Estimated % Area	Dye Concentration (ppb) (l)	Stream background Reading (j)	Net Reading (k)	Estimated Incremental Flow (gpm) (l)	Product of (k) and (l)	Dye Deviation	Dye Deviation x Flow
				Ci			Q_i		$\|C_i - C_{bar}\|$	$\|C_i - C_{bar}\| Q_i$
1	1	5.5	0.1015	11.59	2.29	9.3	909	8,456	0.90	821.70
2	2	9	0.1662	9.75	2.29	7.46	1,489	11,107	0.94	1,394.05
3	3	11.75	0.2169	10.23	2.29	7.94	1,943	15,428	0.46	886.64
4	4	10.5	0.1938	10.23	2.29	7.94	1,736	13,785	0.46	792.21
5	5	8	0.1477	10.32	2.29	8.03	1,323	10,625	0.37	484.68
6	6	5.75	0.1062	10.17	2.29	7.88	951	7,497	0.52	491.20
7	7	4	0.0738	11.42	2.29	9.13	661	6,036	0.73	485.06
Totals			1				9,013	72,934		5,355.53
Averages				10.53						

Percent Mixing: **97.6 %**

Attachment D

City of Angels Diffuser Configuration





CONCRETE STEM WALL
WITH ATTACHED
8" DIFFUSER PIPE

DIFFUSER SECTION

Attachment D
City of Angels Diffuser Configuration