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MEMORANDUM

T61-2

Date: **September 7, 1999**

To: **Paul Fendt**
Linda Logan

From: **Jim Dexter**

Subject: **Sensitivity Analysis of Mixing Zone Parameters (continued)**

cc: **Ken Ludwa**

Project Number: **55-2912-61-01**

Project Name: **Port of Seattle Stormwater Management**

Questions

The following list identifies the questions raised concerning the outcome of the stormwater mixing zone analysis:

1. Will the stormwater discharge comply with the State dissolved copper water quality criteria (WQC) if the background (ambient) concentration is zero? A correlated question is whether additional ambient sampling should be conducted to develop better data for WQC compliance calculations?
2. How sensitive are the compliance calculations for WQC to each of the parameters used?
3. How would the outcome of the water effect ratio (WER) testing effect the results of the compliance calculations?
4. Would greater control over the stormwater release rate help the Port meet the WQC?
5. Can higher hardness (at lower ambient flows) help meet WQC compliance?

Approach

I used a spreadsheet to calculate the reasonable potential to exceed WQC in an approach that can be classified as a dynamic modeling technique. This is the same spreadsheet referred to in a previous memo (August 20, 1999). You may recall that this memo discussed three methods; one of these methods used herein (in the spreadsheet) is also recommended by EPA (*Technical Support Document For Water Quality Based Toxics Control*, 1991). The method is identified in the referenced document as a Monte Carlo simulation model approach. The calculations apply to the Des Moines Creek point of compliance, which is assumed to be the outlet of the NW Ponds. The effluent is assumed to be from the SDS-3 outfall. I've changed the format of the spreadsheet to show the parameters and the range in potential values that seem reasonable to expect. I'd like to explain the basis for the calculation of the potential to exceed the WQC's a bit further before proceeding to a discussion of the results.

There are a number of parameters that effect the calculations: 1) ambient (receiving water flow), 2) effluent (stormwater) flow, 3) ambient pollutant concentrations, 4) effluent pollutant concentrations, 5) the dissolved copper water quality criterion, 6) allowable mixing volume (in the receiving water), 7) the assumed WER, and 8) the assumed effluent flow control capacity. I considered the first five parameters to be stochastic input variables. I assumed that the last three parameters could be altered by the results of new studies.

Presumably, the HSPF output which reflects future conditions, already incorporates detention affects that are the result of meeting the stormwater quantity control standards. The additional flow control capacity that is discussed in this memo is a hypothetical flow rate reduction that is assumed to be achievable by increased onsite detention in order to meet WQC compliance.

I considered (and recommend for future evaluation) using a dynamic dissolved copper criterion (for the acute zone boundary considered herein) that changes with flow rate (and hardness). A Monte Carlo modeling approach doesn't make much sense if the relationship between toxicity and water quality variables isn't varied at the same time every other onsite parameter is varied.

I evaluated the questions on page 1 two different ways: varying one input parameter at a time for each @RISK simulation case, and 2) using an @RISK add-in called TOPRANK to automatically rank the sensitivity of the exceedence value results to each variable in the spreadsheet.

Attachment 1 shows the equations used to calculate pollutant concentration, CP, based on a calculated dilution factor, DF. As explained in the earlier memo, the effluent and ambient flow magnitude-exceedence probability relationships were determined using the output from HSPF. The spreadsheet uses these probability distributions to calculate a range of possible outcomes of the exceedence of the WQC relative to varying input parameters. Attachment 1 shows the results for one combination of input values:

1. the fraction of the NW Pond receiving water volume (assumed) for dilution purposes – in this example, vol_factor = 0.1
2. additional onsite detention/flow control for WQC compliance purposes - in this example = 0
3. water effects ratio that is multiplied by the WQC to obtain a revised copper criterion based on bioavailability and aquatic organism toxicity tests- in this example WER = 3.0

The exceedence outcome of the spreadsheet (Attachment 1) for the parameter combination described above is 16.60 ug/L. In other words, the expected value of the dissolved copper concentration in the receiving water mixing zone (after effluent dilution) is 16.6 ug/L above the value calculated for the copper WQC (4.21 ug/L in the spreadsheet).

I used @RISK to simulate the exceedence values for a number of cases wherein I varied only one input parameter, but allowed the stochastic variables (ambient flow and quality, effluent flow and quality, and dissolved copper water quality criterion) to vary. The input variables that were varied in these cases are mixing volume fraction (from 0.1 to 1.0), onsite detention/flow control (from 0 to 10 cfs), and WER (from 1 to 6). The range in

WER values were based on the results of studies cited in an article shown in Attachment 2.

The TOPRANK add-in provides an automated and rigorous approach to evaluation of variable input values. It performs a multi-way random what-if analysis by using vary-function tables that describe the most likely and range over which variable that values can vary. Combinations of inputs are varied at the same time so that one variable may increase and another decrease during a single what-if calculation. The input variables are ranked then ranked by the magnitude of their effect upon the output variable results; the output variable is assumed to be the WQC exceedence. The three input variables considered are the WER, allowable mixing volume, and effluent flow control capacity. The TOPRANK feature doesn't vary the @RISK probability function values; so the TOPRANK sensitivity results use the mean value for each of the first four input variables described on the top of page 2.

Having explained how the calculations are made, I'll explain the results I obtained from the spreadsheet to the questions posed on page 1.

Results for Question 1 – Effect of Ambient Copper Concentration
If the MECB, ambient or background concentration value is assumed to equal zero, the expected value of the WQC exceedence drops to 14.48 ug/L, assuming the WER is equal to 1.0. An @RISK simulation that I performed (for the previous memo) indicated that the lowest WQC exceedence value for the range in input parameters was about 8 ug/L as shown in Attachment 3. The results are dominated by the magnitude of the effluent concentration and the poor dilution factors in the receiving water. The effluent copper concentration mean is an order of magnitude greater than the ambient copper concentration. Dilution factors are generally less than 2. In other words, WQC were always exceeded regardless of the ambient copper concentration. Increasing the WER to a value of 3 (and assuming the ambient copper concentration equals zero) increases the percent of time compliance is achieved to about 20 percent as shown in Attachment 4.

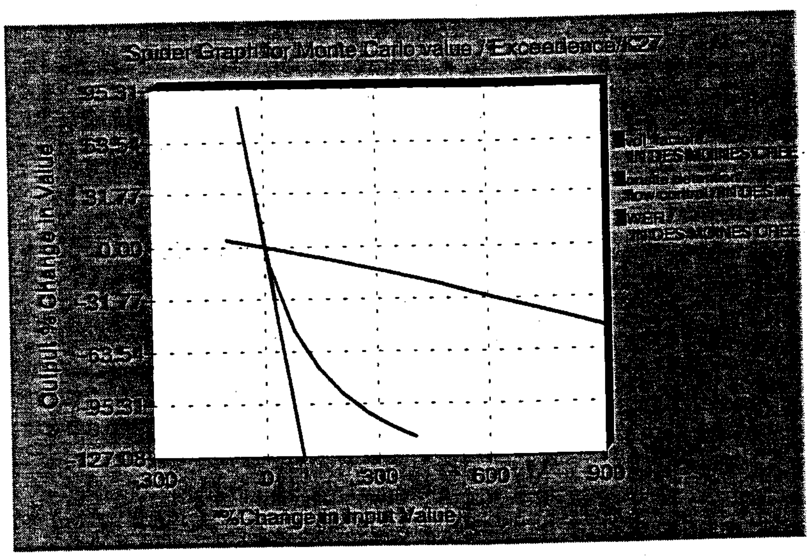
These outcomes make the utility of additional stormwater sampling for ambient water quality characterization in Des Moines Creek questionable in terms of achieving compliance solely by better monitoring; more can be achieved by researching other parameters. However, this monitoring may be warranted to verify that existing conditions do not exceed the WQC. This would make a stormwater-mixing zone difficult to establish under any conditions.

Results for Question 2 – Sensitivity of All Parameters
The following table summarizes the sensitivity of the WQC exceedence from TOPRANK:

What-If Results for STORM_wq_probdist.xls
Most Significant Inputs
(From TopRank Analysis of STORM_wq_probdist.xls- Run on 9/8/99 at 2:24:05 PM, Runs= 1, Iterations= 56)
Ranking for Monte Carlo value / Exceedence in Cell K27

Rank	Cell	Name	Output Max	When Input Value=	Output Min	When Input Value=
#1	F21	WER	18.354	1	-2.691	6
#2	F10	vol_factor	16.203	0.1	-1.535	1
#3	F19	onsite detention/fl	10.363	0	5.046	10

The following figure shows that a small percentage change in the WER has more dramatic effect upon the exceedence value than the other two variables.



The exceedence results are linearly related to the WER and onsite detention, but nonlinearly related to the allowable volume of mixing factor. The above results don't consider the variability in flow and contaminant concentrations (the probability distributions are not sampled in the TOPRANK procedure).

Results for Question 3 – Outcome of WER on Compliance

The following table summarizes the @RISK case by case results in which only one variable was changed, but the stochastic inputs were allowed to change based on the probability distributions.

SENSITIVITY RESULTS

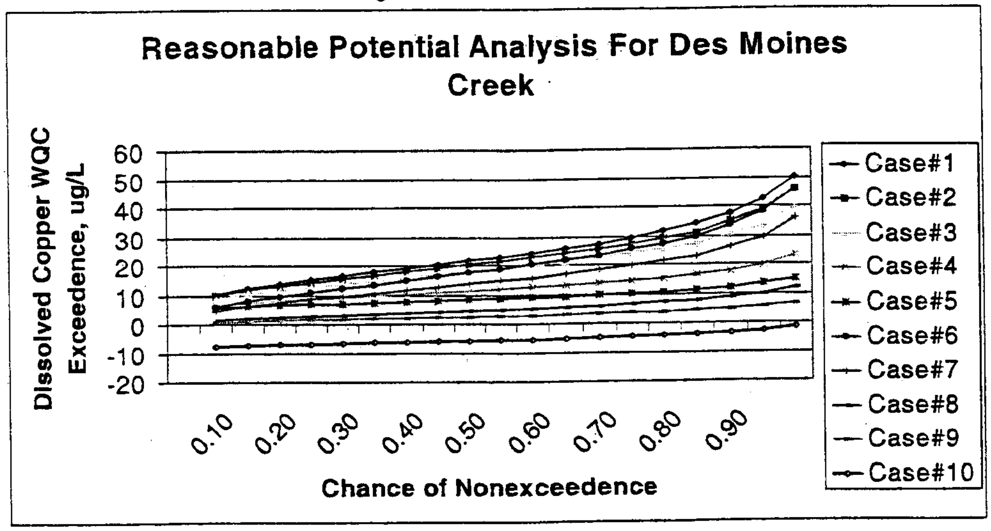
CASE #	1	2	3	4	5	6	7	8	9	10
Vd_Factor	0.1	0.1	0.1	0.5	1	0.1	0.1	0.5	1	1
Flow Detention, cfs	1	5	10	1	1	1	10	10	10	10
WER	1	1	1	1	1	2	2	2	2	4
Median WQC Exceedence, ug/L	22.85	21.34	18.71	11.83	8.67	18.54	14.59	4.77	2.74	-5.69

The above table gives some information on the sensitivity of the exceedence value to the assumed input parameter values. However, I summarized some results below to make it clearer which parameter has the greatest impact upon the result.

AR 024684

Case #	Parameter Varied	Median Exceedence,ug/L	Change From Base, ug/L
4	Base Comparison	11.83	-
5	Vol_Factor 0.5 to 1.0	8.67	3.16
7	Vol_Factor 0.5 to 1.0 Flow Det. 1 to 10 WER 1 to 2	4.77	7.06
10	Vol_Factor 0.5 to 1.0 Flow Det. 1 to 10 WER 1 to 4	-5.69	17.52

The WER is again seen to have a larger impact than other variables. The following figure shows the percent chance of nonexceedence for the indicated values that were calculated in each of the cases. These results use the @RISK probability functions to randomly sample the input variables for each simulation. One thousand events are simulated for each of the following case results.



The previous figure shows that only Case #10 resulted in all the predicted exceedence values being negative (i.e., the WQC was achieved). The assumptions in this case were: 1) a WER value of 4, 2) utilization of the full volume of in the NW Ponds for mixing, and 3) additional flow control of 10.0 cfs. The last factor contributes the least to achieving the WQC. The conclusion I have from this these simulation results is that the WER is more important than either the volume for mixing or the flow detention amount in terms of achieving WQC compliance. A WER value of 3 or greater is needed for WQC compliance.

Results for Questions 4 & 5 – Flow Control and Hardness Effects

Recall in the previous memo I showed there was a strong relationship between hardness and flow; and therefore a strong relationship between flow and the copper WQC. I used TOPRANK to evaluate the WQC exceedence if the WQC was based on a function related to ambient flow:

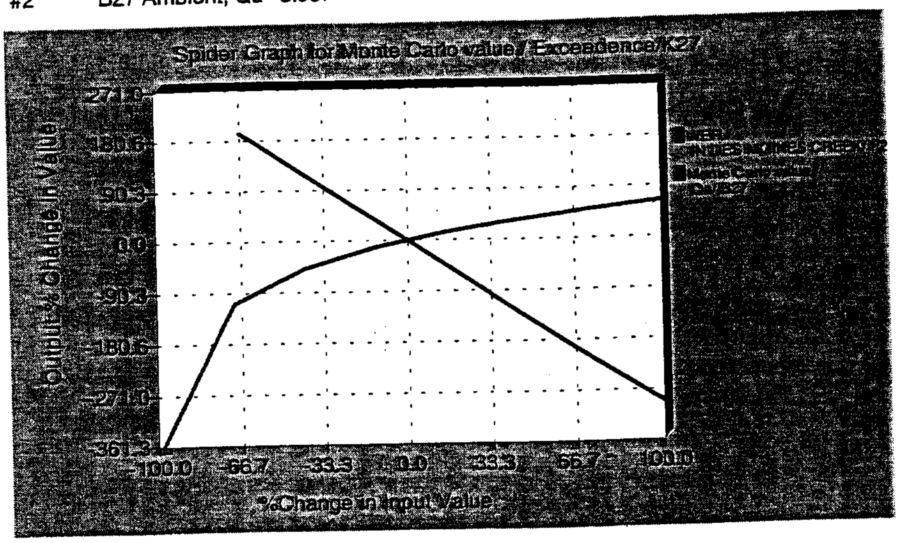
Cu WQC, ug/L = $-3.3672*(LN(Q_a))+16.056$

AR 024685

where Q_a is the ambient flow out of the NW Ponds. Ambient flow was assumed to vary between 0.1 to 10 cfs with a most likely value of 5 cfs. The WER was varied between 1 to 6, with a most likely value of 3. The relationship between WQC and flow was based on a regression evaluation of the Des Moines Creek ambient water quality data. The following table shows the range in WQC exceedence

What-If Results for STORM_wq_probdist.xls
Most Significant Inputs
(From TopRank Analysis of STORM_wq_probdist.xls- Run on 9/8/99 at 4:45:29 PM, Runs= 1, Iterations= 56)
Ranking for Monte Carlo value / Exceedence in Cell K27

Rank	Cell Name	Output Max	When Input Value=	Output Min	When Input Value=
#1	F21 WER	10.335	1	-42.849	6
#2	B27 Ambient, Qa	-3.937	10	-50.456	0.1



This figure shows that changes to the WER are more effective than changes to ambient flow conditions; but the latter has a significant effect when low flows are achieved.

Conclusions
Based on the literature Sabina has collected, I believe a strong case can be made for a WER of at least three that should be applied to the mixing zone analysis. Our own studies may confirm this; or suggest even higher values for the WER. Using this magnitude for the WER, in combination with a greater amount of allowable mixing volume in the NW Ponds will allow the Port to achieve WQC compliance in Des Moines Creek.

Suggestions
We should start thinking about the issues that will arise using the NW Ponds as a mixing zone assuming we are going to take this strategy to Ecology. I've had Sabina collect some literature related to copper accumulation in stormwater detention pond sediments. Do we have any recent information on copper concentration in the ponds' sediments? We need a defensible basis for arguing for a greater allowable volume for mixing in the ponds.

A strategy needs to be worked out and a preliminary analysis conducted for Miller Creek.

CALCULATION OF REASONABLE POTENTIAL
TO EXCEED WATER QUALITY CRITERIA (WQC)
IN DES MOINES CREEK

NOTES:

MECB based DM-1 Regression:
1.6684*(LN(Qa))+2.7268
MECB based on LN prob dist:
=RiskLognorm(C10,C11)
DF= ((Qa*vol_factor)+Nwvol
+Qe)/Qe   vol_factor 0.1   0.25   0.5   0.75   1
Varies From 0.1 to 1.0
NW pond Includes Active + Dead Storage
volume in second-foot-days of   125
CP=(MEC+(MECB*DF-1))/DF

Qa considered lognormally distributed
Qe considered lognormally distributed
Qe can be control considered to range between 0 to 10
onsite detention/flow control 0   1.5   2.5   5   10
Water Effects Ratio is multiplied by WAC WQC considered to vary between 1 to 6
WER   3   3.5   4   4.5   6

Variables	Qa	MECB	Qe	MEC	Dilution Factor	Concentrat	Hardness	WQC	WER	Exceedence
mean	33.73	5.83	21.88	42.6						
std deviation	1.53	3.69	1.48	20.8						
stochastic value	33.73	5.83	21.88	42.6						
Monte Carlo value	33.73	5.83	21.88	42.6	1.57	29.23	22.23	4.21	3	16.60

ATTACHMENT 1

ATTACHMENT 2

cal municipal conditions, for all practical purposes, no toxic copper will be present. This fact was demonstrated by H.E. Allen and D.J. Hansen at the University of Delaware in Newark in January 1994 using standard analytical techniques for quantifying binding agents of mixtures.

On the basis of more than 20 years of observations and research on metal speciation chemistry and fate of metals in receiving waters and treatment facilities, Allen, a nationally recognized expert on metals toxicity, concluded that virtually all copper in a municipal treatment plant effluent will be in the form of soluble copper complexes or sorbed to particulate material not removed from the effluent stream in the final clarifier. The effluent also will contain a finite concentration of free, ionic copper, but this low concentration will not pose a toxicity risk.

Field studies of water effect ratios, which add metal salts to effluents in an attempt to gauge potential toxicity, have repeatedly confirmed laboratory observations and validate the total detoxification of copper by biologically treated effluents (see Table 2, below. For example, in January 1991, DiToro *et al.* performed water effect ratios on the site-specific detoxification of copper in the Naugatuck River in Connecticut. Very little difference in toxicity was observed between laboratory water with minimal complexing ability and river water from pristine segments. However, where river water contained treated municipal effluents, up to a 12-fold reduction in copper toxicity was recorded. The study team concluded that the copper present in the municipal effluent was nontoxic. Moreover, the municipal effluents contained excess binding capacity that rendered bioavailable copper from upstream sources nontoxic.

A 1992 EPA-funded summary of water effect ratios for heavy metals compiled by William Brungs showed that copper is up to 26 times less toxic in water influenced by municipal effluent. To have a water effect ratio significantly above 1.0, the existing metal in the discharge must be complexed. The water effect ratio actually represents the excess binding capacity of the effluent. In general, if a water effect ratio is greater than 2 or 3, the effluent metal should be classified as nontoxic.

A number of states completed surveys of metals toxicity due to concerns that application of the metals criteria, even as dissolved metals, would misallocate state resources. The North Carolina Department of Environment, Health, and Natural Resources documented 78 cases in which total recoverable copper in effluents and in receiving waters was measured well in excess of water quality criteria without observed chronic toxicity to *Daphnia*. Instream total copper ranged up to 378 ug/L. Bioassay testing was conducted using *Daphnia magna*, one of the most sensitive species to copper. The Massachusetts Department of Environmental Protection confirmed the same results in its survey of 35 facilities.

Most recently, testing by the Connecticut Department of Environmental Protection confirmed that copper toxicity was significantly reduced in ambient river water *above* municipal discharges, with water effect ratios ranging from 3 to 5. The state agency further found that when ambient river water was mixed with treated municipal wastewater effluent, the water effect ratio typically exceeded 10 at effluent concen-

Table 2. Impact of Municipal Effluent on Reported Water Effect Ratios

River	Water effect ratio	Condition
Niagara[1]	5.5	Water effect ratio with high dilution
Cuyahoga	10	
Naugatuck	5.8	
Shayler Run[2]	26	Water effect ratio with low dilution
South Ana River Tributary[3]	64	Water effect ratio with low dilution
Rocky Creek[4]	32	Water effect ratio with low dilution
Saugatuck[5]	8.53	Water effect ratio (geometric mean) upstream of publicly owned treatment works influence
Housatonic	5.75	
Shepaug	5.19	
Salmon	3.27	
Willimantic	3.17	
Eight Mile	3.06	
Farmington	2.92	
Quinnipiac River Basin[6]	14.7	Water effect ratio with low dilution

1. Brungs, W.A., *et al.* 1992.
2. Geckler, J.R., *et al.* 1976.
3. Diamond, Jerry. 1990 *Summary Data Report for Liberty Fabrics Inc., Woolwine, Va., Biological Monitoring Inc.*
4. Diamond, Jerry. *Draft Final Report: Site-Specific Copper and Zinc Effluent Limits Study for the City of Washington, Georgia Water Pollution Control Plant, Biological Monitoring Inc.*
5. Connecticut DEP. 1996. *Derivation of a Site-Specific Copper Criteria for Selected Freshwater Streams in Connecticut.*
6. Conneticut DEP. 1996. *Effect of Streamflow on the Ability of Ambient Waters to Assimilate Acute Copper Toxicity.*

SOURCE: John C. Hall, William T. Hall, and Charles T. Simmons. June 1997. "Water Quality Criteria For Copper — A Need For Revisions To National Standards"

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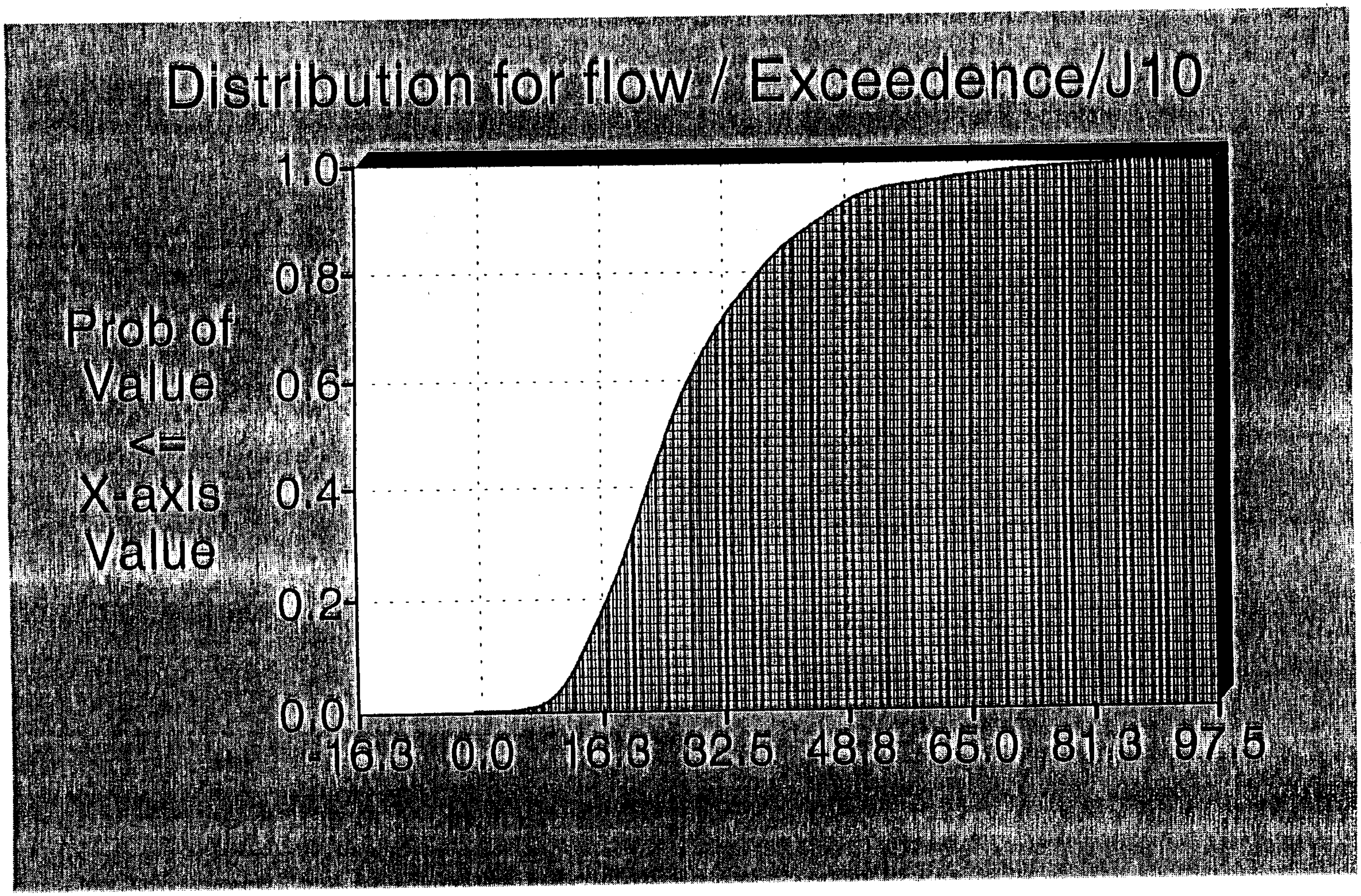
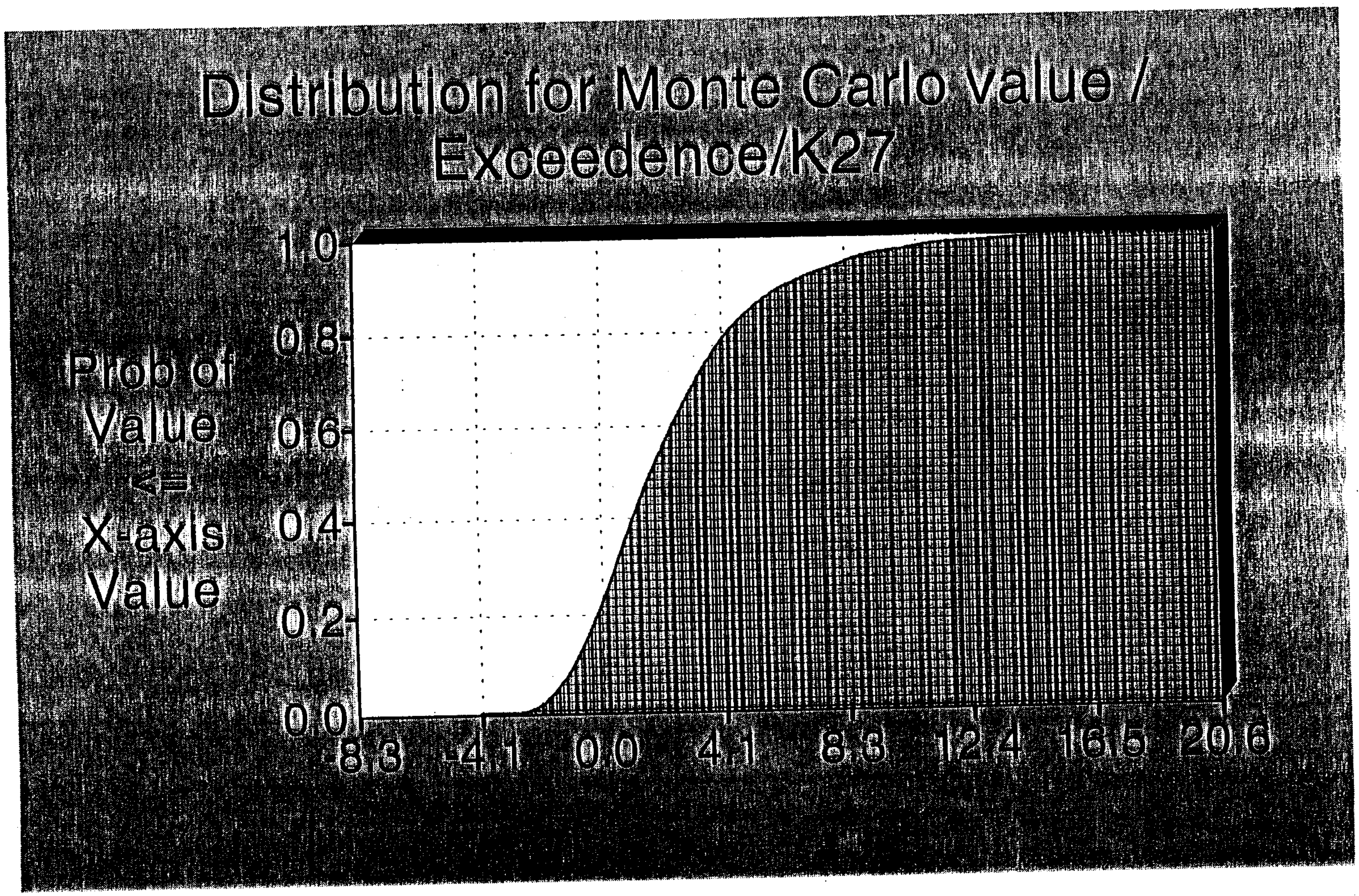
BASED ON C_U = 0 µg/L
AMBIENT WQ CONDITION



ATTACHMENT 3

VCL FACTOR = 1
WER = 3
FLOW CONTROL = 1
MECB = LOGNORMAL DIST.



ATTACHMENT 4