City of Winnipeg
Water and Waste Department

Combined Sewer Overflow Management Study

PHASE 3 Technical Memoranda

Appendix No. 8

AMMONIA IMPACTS

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Internal Document by:

WARDROP Engineering Inc. and TetrES CONSULTANTS INC.

In Association With:

Gore & Storrie Limited and EMA Services Inc.

TABLE OF CONTENTS

1. INTRODUCTION

Ammonia is a natural by-product of the decay of organic matter and is present in healthy ecosystems at low concentrations. Municipal wastewater often has concentrations of ammonia high enough to impact aquatic life. Ammonia is an issue in the discharge of wastewater treatment plant effluent and is being studied in a concurrent study for the City of Winnipeg. The purpose of this Appendix is to review whether ammonia is a CSO issue in the City of Winnipeg. There are three key questions which helped guide this assessment. They are:

- is ammonia a CSO issue in general, and is there any guidance in terms of wet weather effects and regulation of wet weather with respect to ammonia?
- what is the current impact of CSOs with respect to ammonia in the Red and Assiniboine rivers?
- would the selection of controls in the CSO study be affected by the degree to which they would potentially change the ammonia concentrations in the river?

An outline of this report is as follows.

- Section 2 will review the definition of chronic and acute impacts.
- Section 3 will review the river quality data and the exceedences of the Manitoba Surface Water Quality Objectives at various stations within and out of the areas of the combined sewer districts; and compare wet weather and dry weather river quality data.
- Section 4 will review the CSO ammonia discharge monitoring records to determine the impact of dilution from the wet weather flow and whether there is any sign of a first flush causing higher ammonia concentrations.
- Section 5 will discuss how the CSO system model was used to develop ammonia pollutographs and how they are screened for duration-concentration-frequency to determine whether significant impacts with respect to ammonia toxicity could be expected at the end of the pipe under current conditions.
- Section 6 will assess the impacts in the mixing zone downstream of the CSO. This will be a coarse assessment assuming some worst-case mixing conditions, again for current conditions.

2. CHRONIC AND ACUTE AMMONIA IMPACTS

The Manitoba Surface Water Quality Objectives provide an objective for ammonia which is based on a U.S. EPA document which compiled and analyzed data in order to develop criteria to protect aquatic life against chronic impacts. Chronic impacts are impacts which occur from long or frequent exposure to high concentrations of ammonia. Chronic impacts on fish include reducing their growth and possibly their ability to reproduce. Chronic impacts on fish, attributed to ammonia, were documented in a test stream in Duluth, Minnesota. In the tests on this stream, fish grew less over 18 months when exposed to a continuous dosage of ammonia than the same species of fish in a controlled parallel situation with no ammonia. There is uncertainty as to how long or how frequent exceedances of chronic concentrations need to be before they cause impacts on fisheries. Generally, chronic exposure is considered to be at least 4 days in duration and may be 1 month or up to 1 year.

Acute ammonia impacts occur at much higher concentrations than chronic impacts. They are generally considered to involve concentrations 8 to 16 times higher than chronic concentrations. Acute impacts occur over much shorter periods. They may occur in shorter periods from 1 hour up to 4 days. Most standard acute toxicity tests are 48 to 96 hours. Acute impacts are usually measured by mortality. A standard test called LC_{50} is the concentration that kills 50% of the population in 48 or 96 hours. There has been no documentation of acute impacts or acute concentrations on the Red or Assiniboine rivers in Winnipeg. Some tests have shown that wastewater treatment plant effluent can be toxic prior to dilution with river water.

Downstream of the NEWPCC ammonia concentrations have been above the MSWQO and, at one time, were similar to the concentrations which produced chronic impacts in the Duluth study. However, the fisheries in the Red River appear to be healthy. The two previous statements appear contradictory therefore the City has initiated a fish and ammonia study to clarify this issue. Some of the questions which are being asked in the study are:

- what is the extent-duration-frequency of chronic concentrations in these rivers?
- are fish inhabiting this region, and for how long?
- what fish are inhabiting this region?
- is there any evidence of chronic impacts?

- are these due to ammonia?
- what is the sensitivity of key local species?
- are there other constraints, i.e., habitat, or barriers, limiting the fisheries?

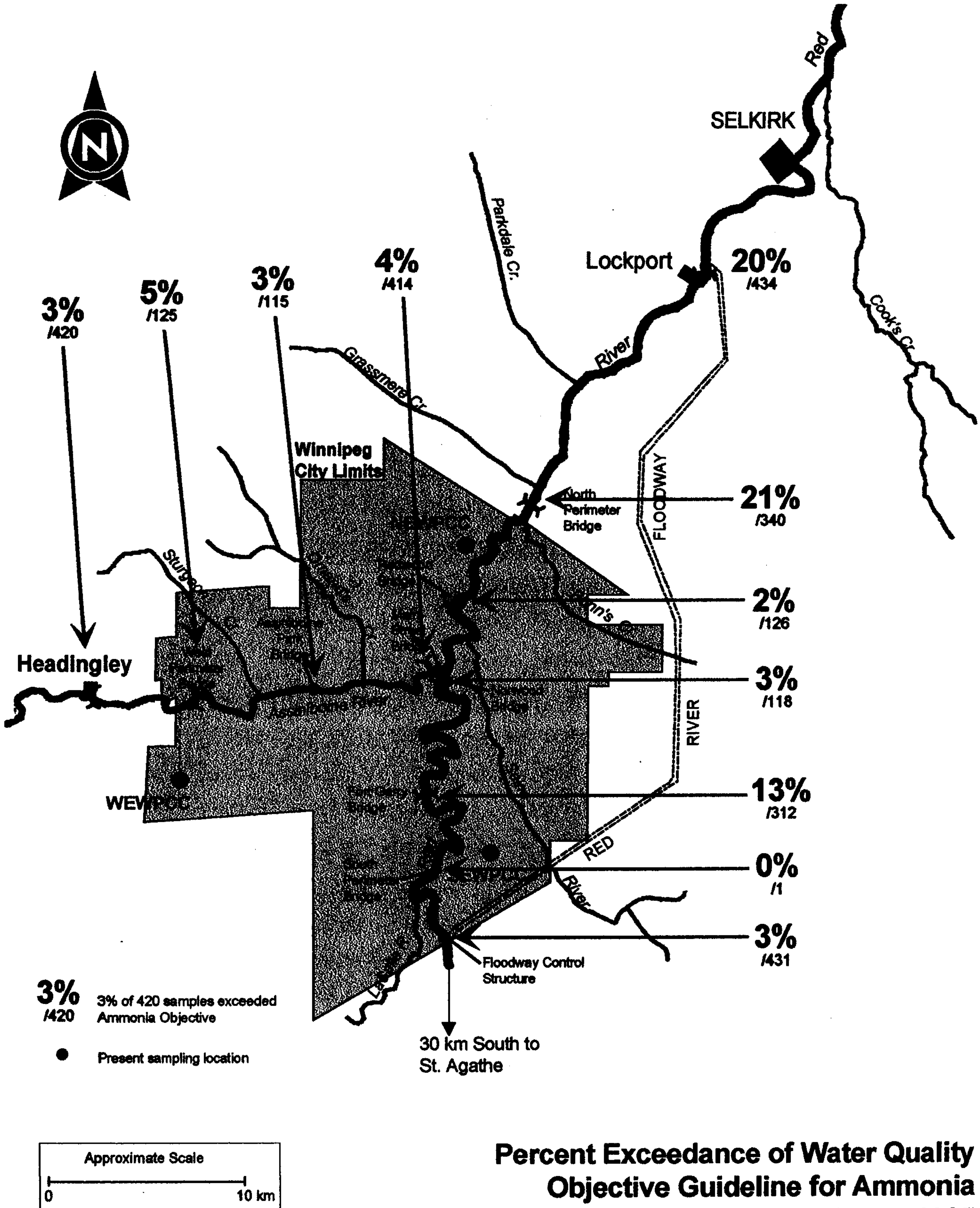
3. REVIEW OF RIVER QUALITY DATA

A review of ammonia concentrations, pH and temperature was performed on data at the monitoring stations upstream, within and downstream of the City of Winnipeg. Using this information, the un-ionized ammonia concentration was calculated for each sample and compared to the corresponding MSWQO for ammonia for the corresponding pH and temperature. A summary of the percentage of exceedances is shown in Figure 3-1. This analysis shows for varying lengths of record that the percent of exceedances varies from roughly 2% to 21% at various locations upstream, within and downstream of the City of Winnipeg. It should be noted that the percentage of exceedances significantly differ from the upstream compliance record only in sample locations located downstream of major treatment plants of the NEWPCC and SEWPCC. At locations downstream of the NEWPCC, the North Perimeter Bridge and Lockport, the percentage of exceedances is roughly 20%. Downstream of the SEWPCC, at the Fort Garry Bridge, the exceedances occur about 13% of the time.

It should be noted that in the heart of the CSO Districts, at the Main Street Bridge, exceedances occur only 4% of the time. This is very similar to the record upstream of the City at Headingley (exceedances 3% of the time) and the Floodway Control Structure (exceedances 3% of the time). At other stations with shorter records, the Norwood and Redwood Bridges, which are also located downstream of the CSOs, the compliance record is only 2 to 3% of the time being exceeded. This information seems to indicate that there is no significant impact of CSOs on ammonia in the river. The major impact appears to occur downstream of treatment plants.

A second analysis was done by partitioning data at the North Perimeter Bridge immediately downstream of the NEWPCC and all CSOs. The mass of ammonia in the river was calculated by multiplying the concentration monitored at the North Perimeter Bridge downstream of the NEWPCC and the flow in the river. The data was partitioned into two sets; one set contained only dry weather events in which there was no rain for at least the previous 5 days. The second set considered wet weather, and included data either when it had rained the day the data was collected or one of the previous two days. Both datasets considered only data during the May to October wet weather period. The results were as follows:

- for dry weather conditions the mean ammonia mass was 68 g/s ±38; and



Percent Exceedance of Water Quality Objective Guideline for Ammonia for Records from 1977 to 1995

Figure 3-1

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- for wet weather conditions the mean of 73 g/s ± 85.

The latter data set is plotted on Figure 3-2. The above analysis showed that, although the wet weather was slightly higher, there was no statistically-significant difference between the two. This information supports the hypothesis that the total ammonia discharge from the city does not change significantly during a CSO. The ammonia may discharge from a CSO rather than the NEWPCC, however the total mass is much the same. This is because the plant does not significantly treat ammonia.

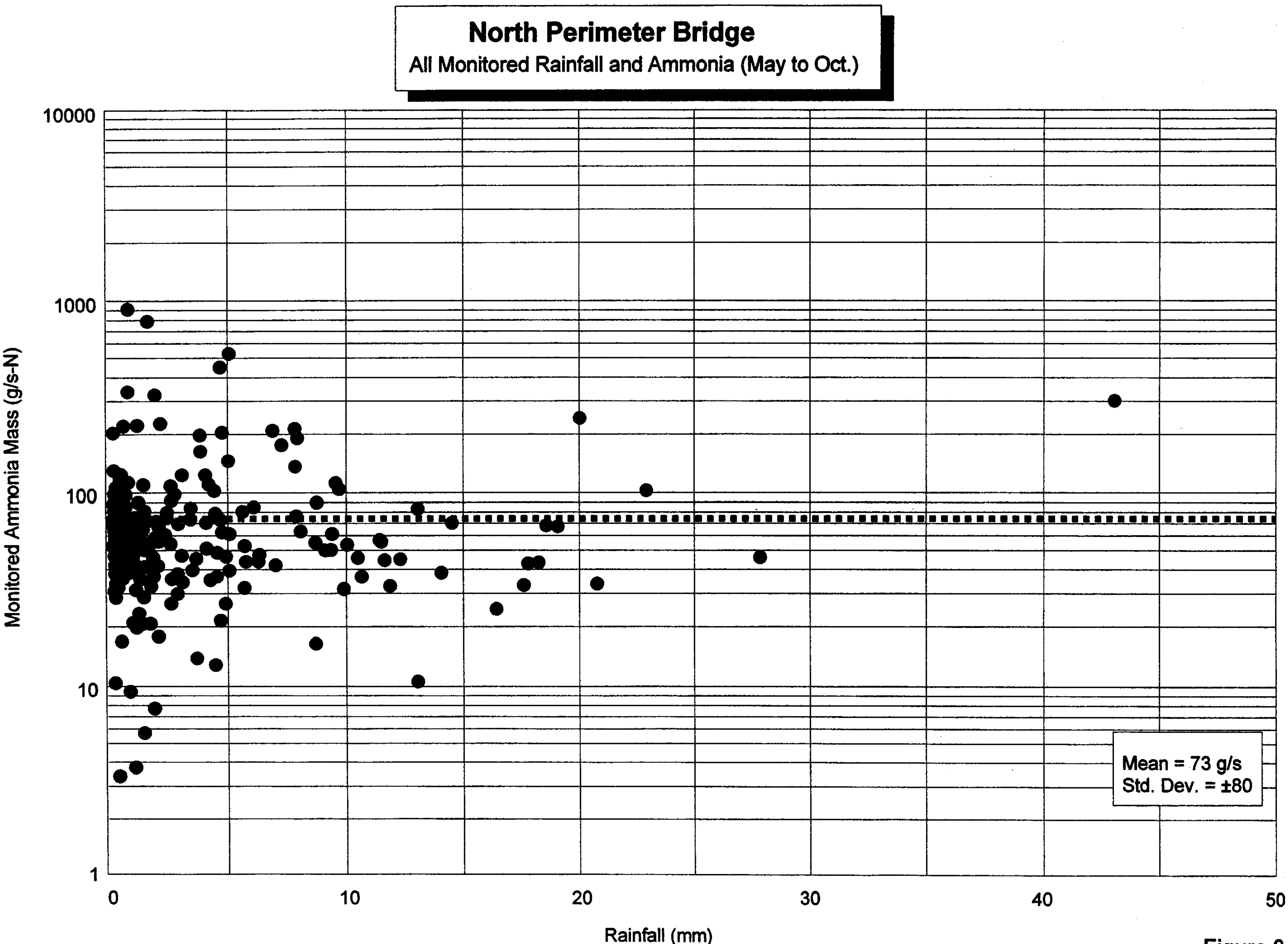

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Figure 3-2

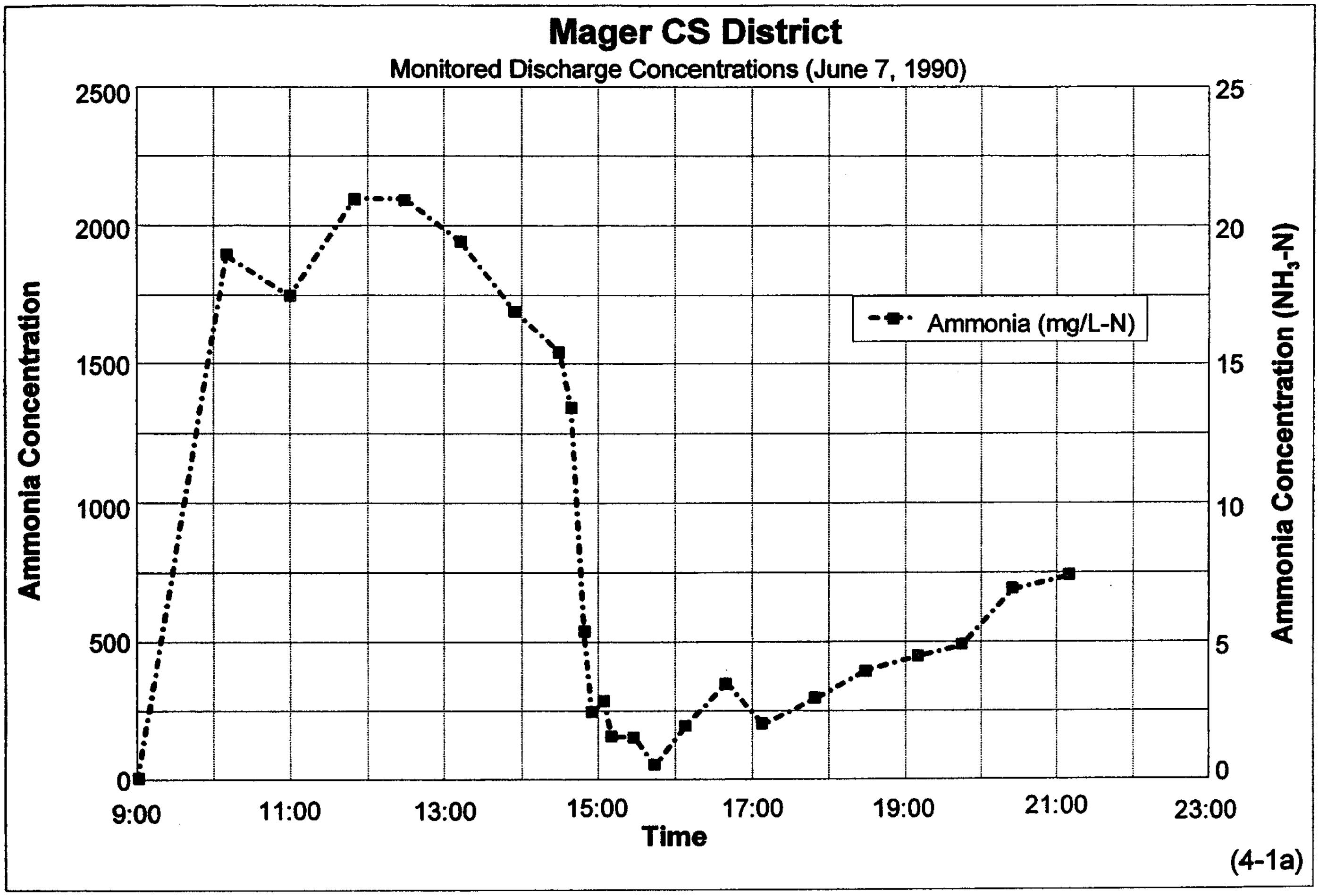
4. CSO AMMONIA DISCHARGES

Water quality data taken during CSO monitoring from 1990 to 1994 was used to assess the concentrations of ammonia found in CSOs. Figure 4-1 illustrates flow monitoring and quality monitoring at the Mager District on June 7, 1990. The ammonia concentration was taken at multiple intervals (see Figure 4-1(a)) as was the flow in cubic meters per second (see Figure 4-1(b)). The high ammonia concentration of between 15 and 20 was monitored at the Major District from 9:00 to 15:00 hours, and then after 15:00 hours the concentration dropped quickly to below 5mg per litre. At first sight, this could be thought of as a first flush phenomena, however, analysing this information along with the flow information indicates that the high concentration was due to minimal dilution due to low flows in the sewer system. Between 9:00 and 14:00 hours the flow was very low, close to 0.02 m^3/s. When the flow increased to greater than 0.4 m^3/s, the concentration of ammonia dropped dramatically to less than 5, due to dilution of the sanitary sewage by rainwater.

In order to confirm that dilution seems to be the driving factor in predicting ammonia concentrations in CSOs, a simple model was developed which assumed a raw sewage concentration of 25 mg/L and diluted the sewage according to the estimated measured flow in the sewer system. An example for Alexander District is shown in Figure 4-2: as the flow increased at the beginning of the storm, the concentration of ammonia dropped dramatically. The model shown in Figure 4-2(b) and plotted against the measured data illustrates how the drop in concentration of ammonia can be predicted by the dilution model.

A similar model was developed for Tylehurst District for June 27, 1994 and is shown in Figure 4-3. This model again illustrates that the dilution of ammonia by rainwater can be predicted, on the basis of the flow in the sewer system.

A fourth model run was done for Alexander Station on June 22, 1992 (Figure 4-4). It reconfirms that the drop in ammonia concentration can be predicted on the basis of increase in flow in the sewer system. Likewise, the subsequent increase in ammonia can be predicted as the flow in the sewer system drops.



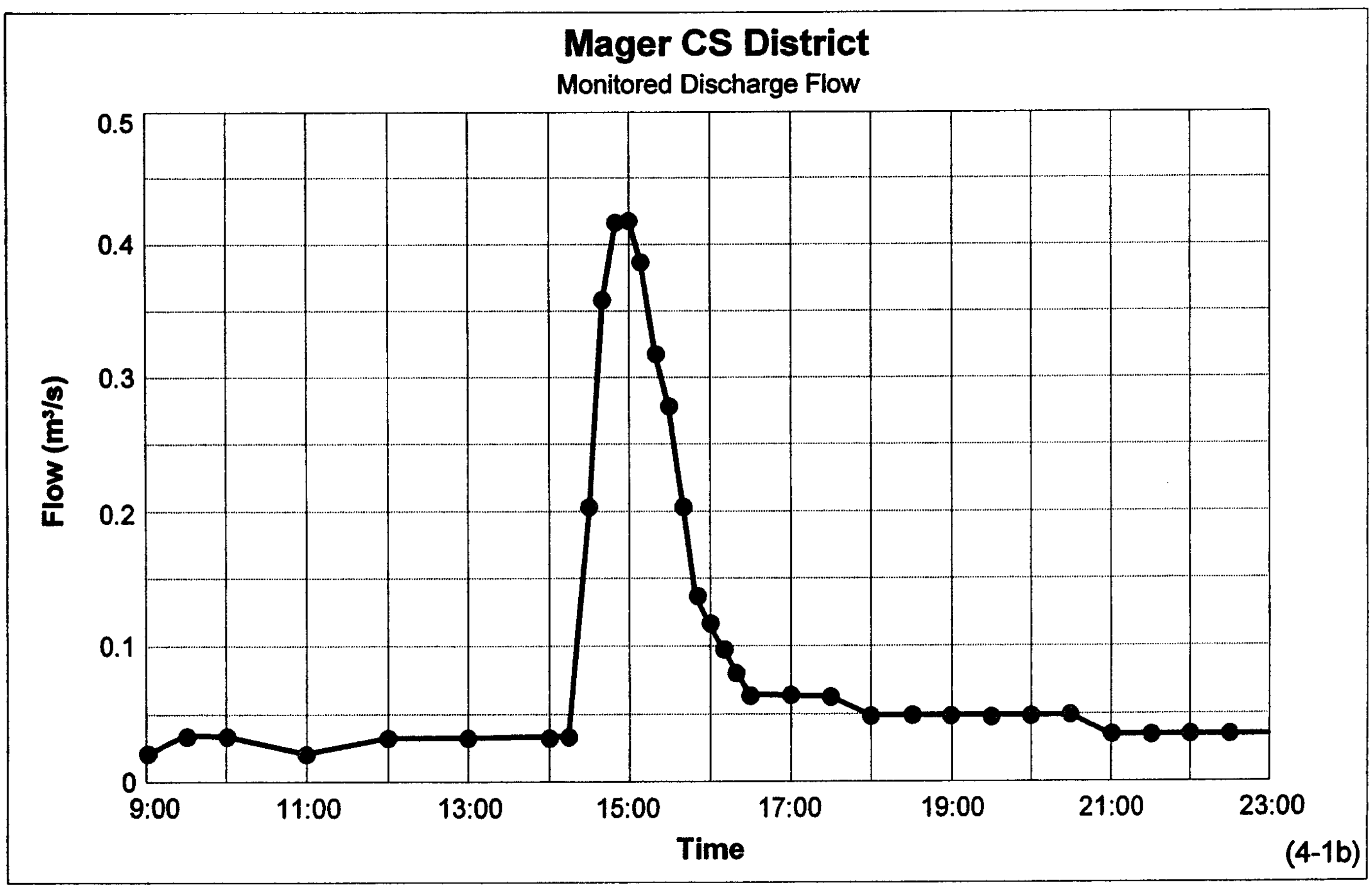
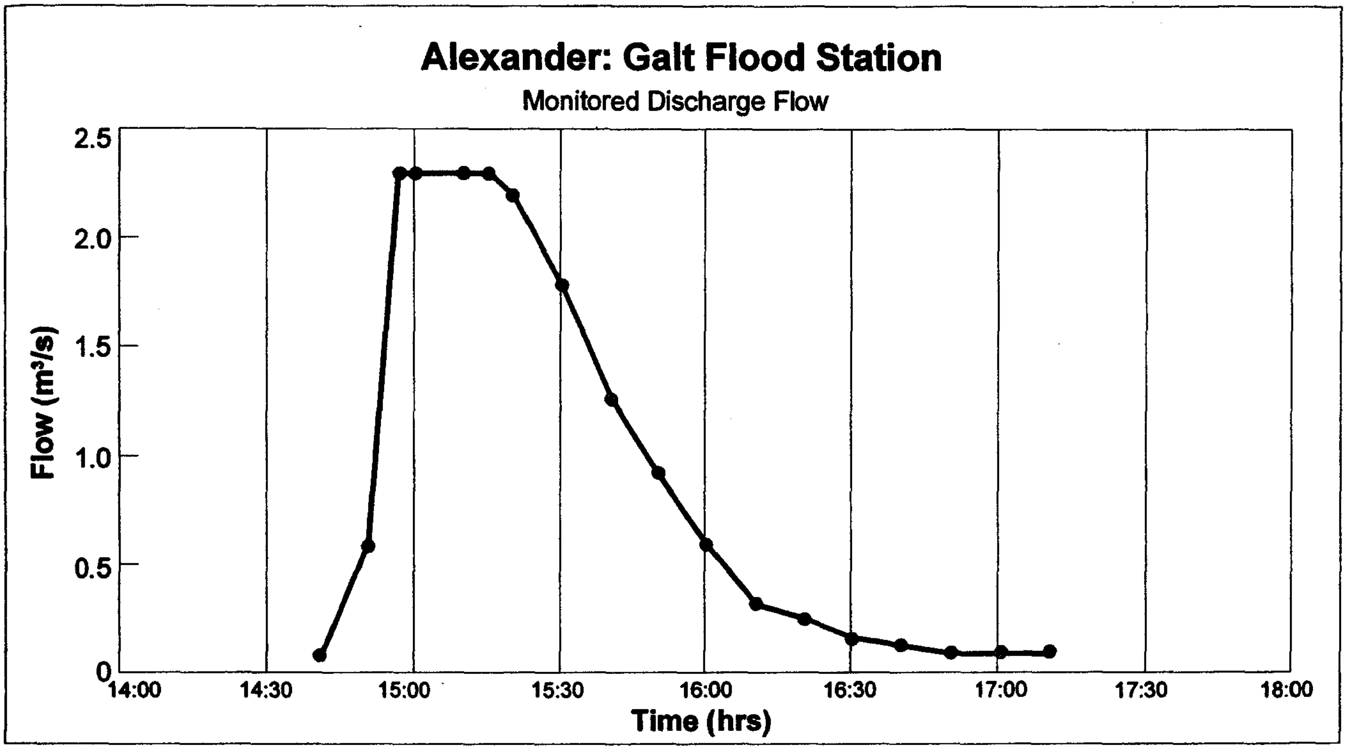


Figure 4-1

magerdist



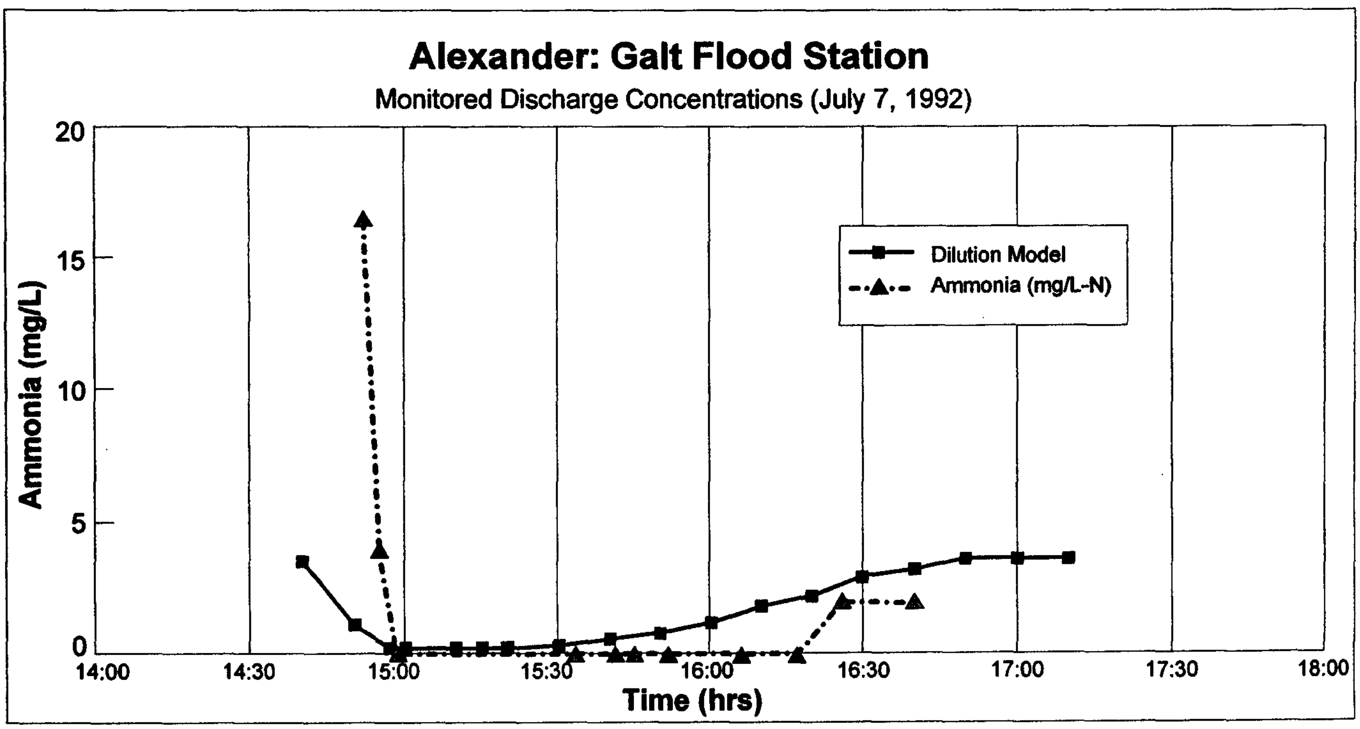


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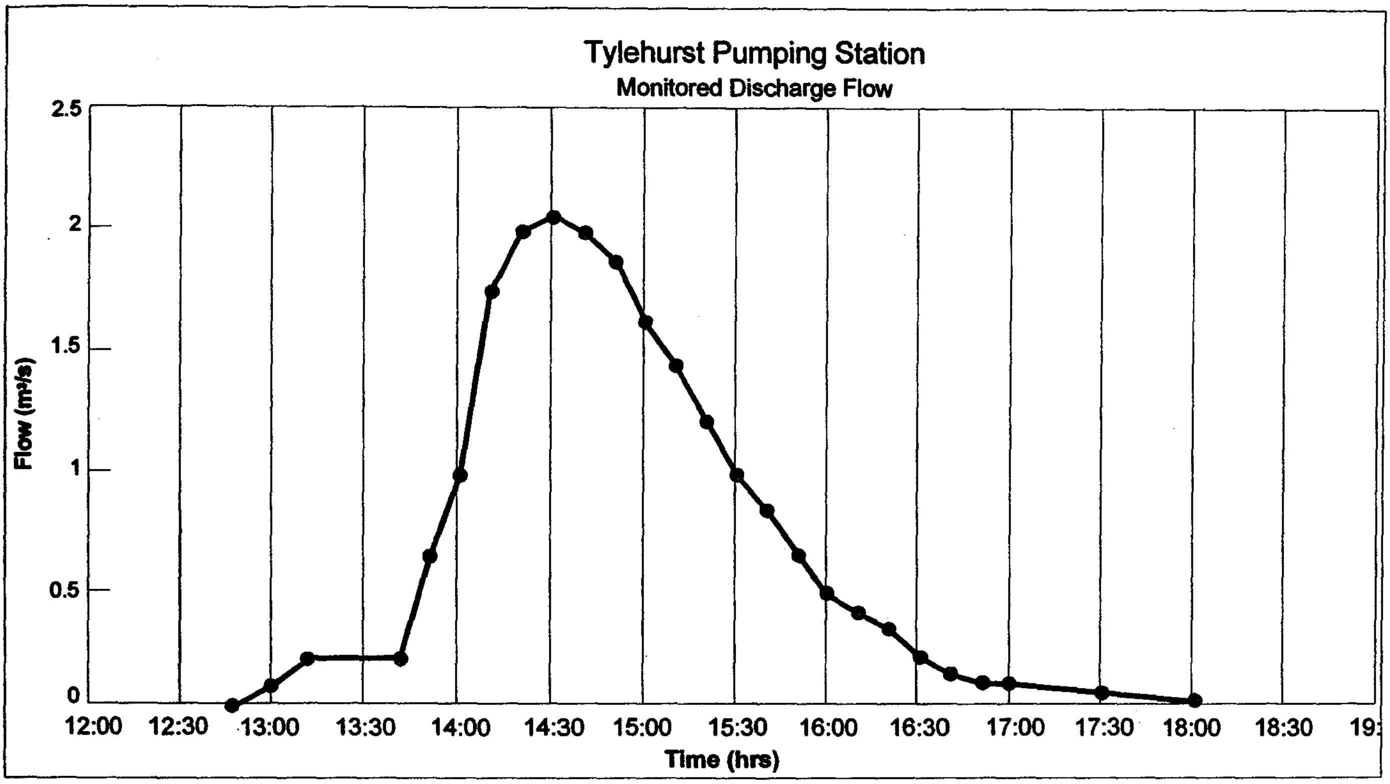
Figure 4-2



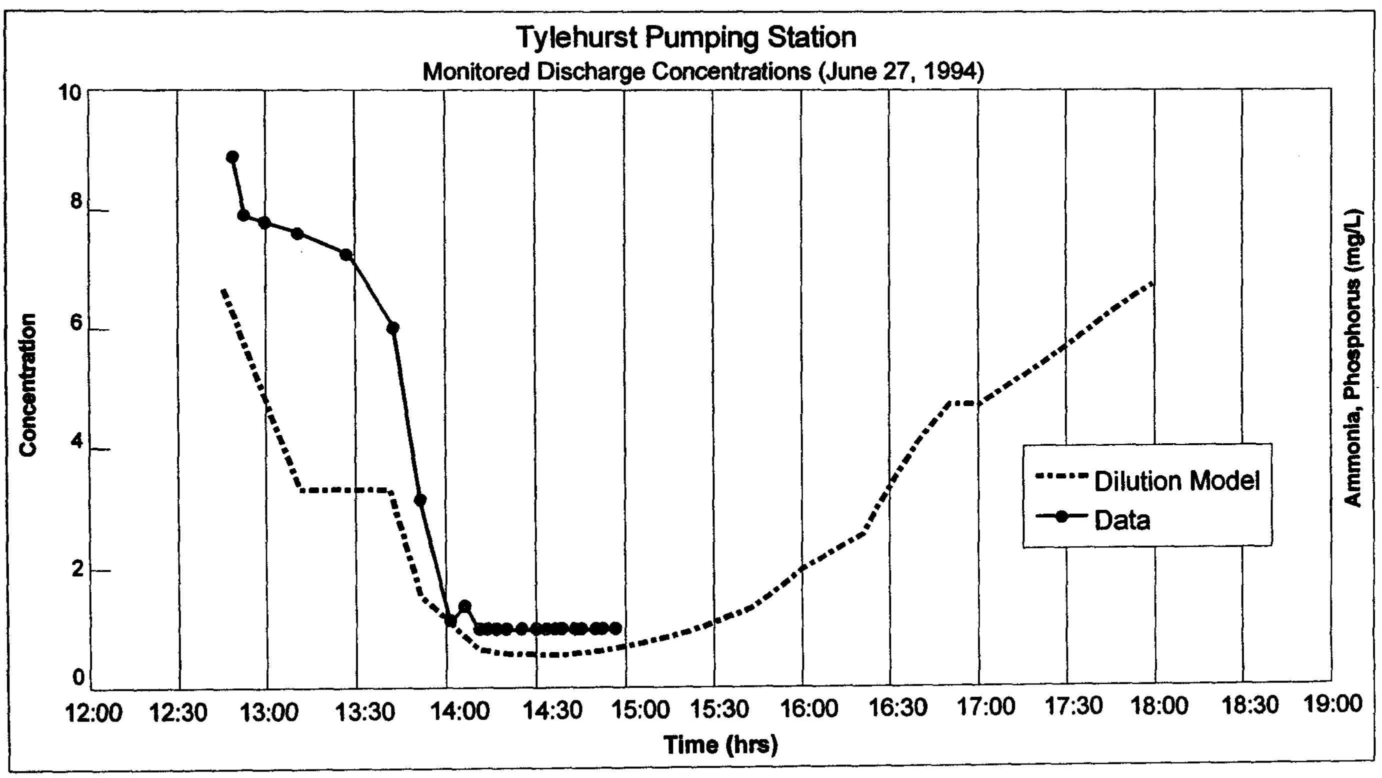


Figure 4-3

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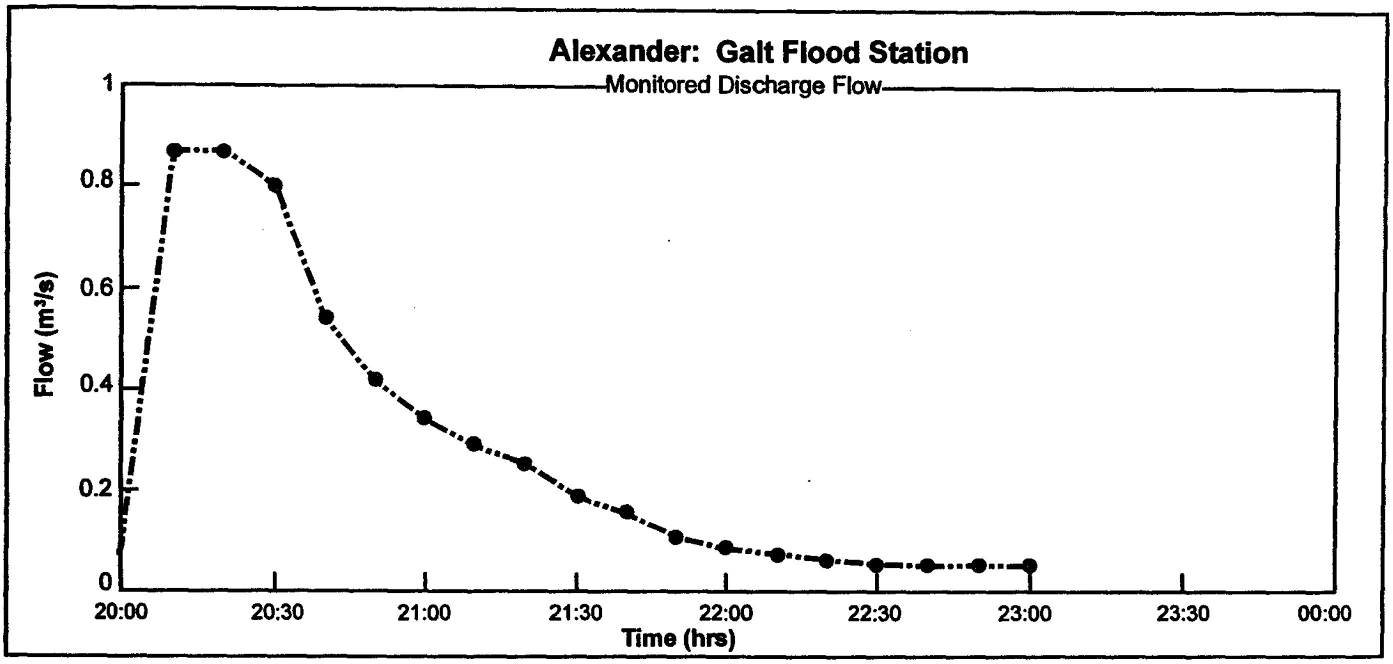

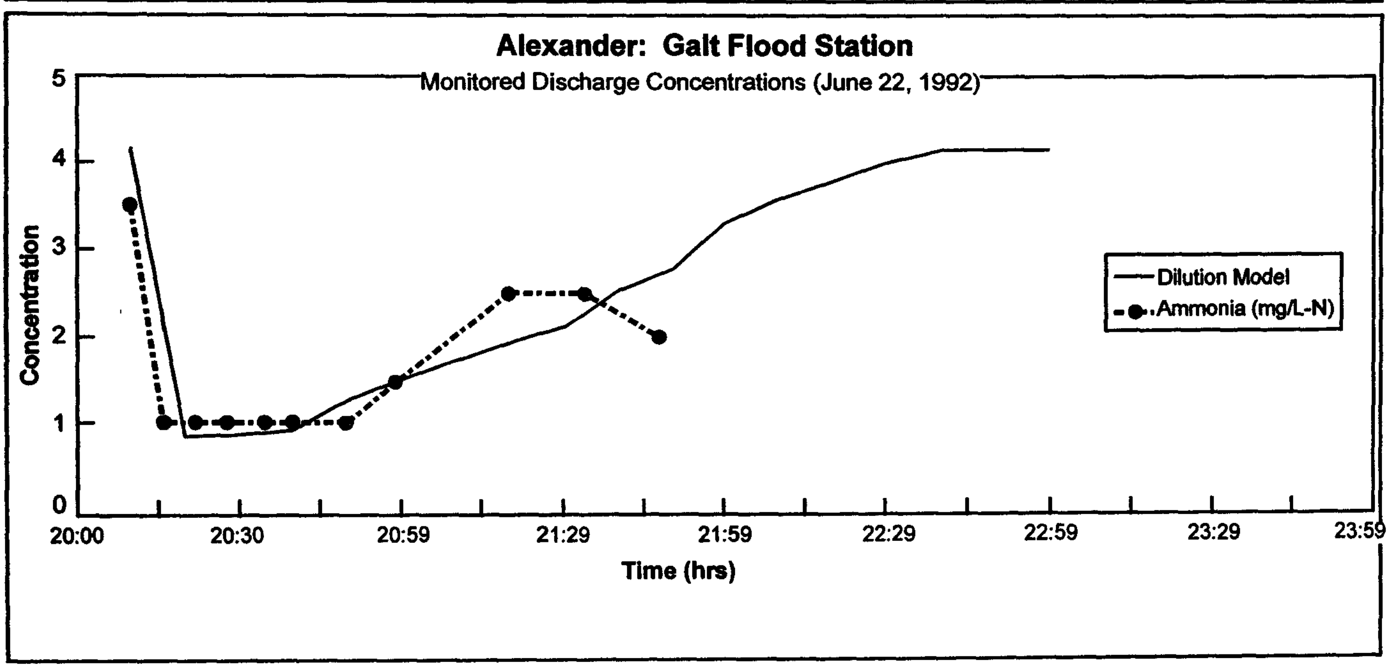

Figure 4-4

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The above analysis indicates that a first-flush phenomena which increases the concentration of ammonia does not appear to occur. Rather, dilution by rainwater appears to be the driving factor.

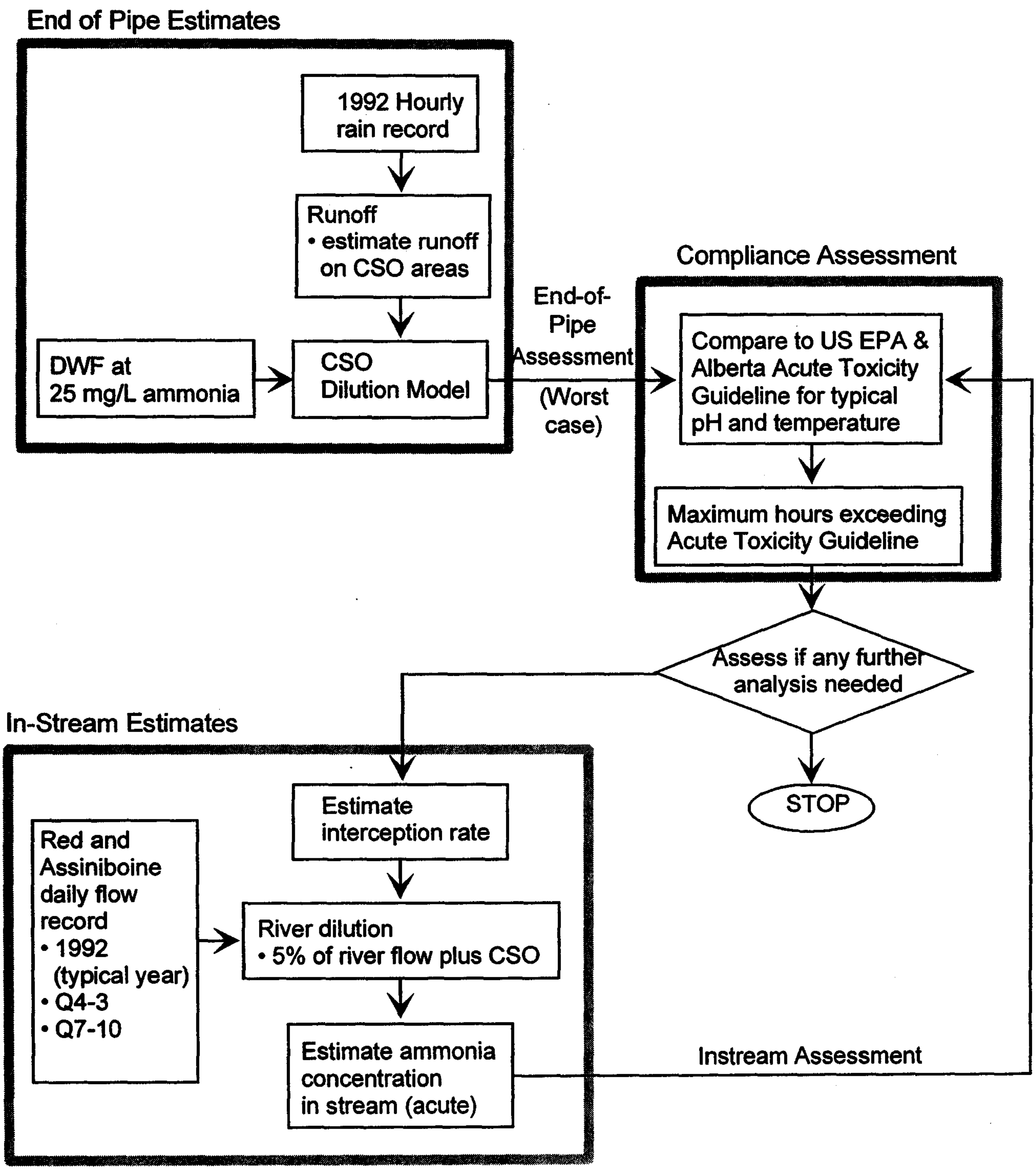
5. MODELLING OF AMMONIA CONCENTRATIONS IN CSOs

An illustration of the assessment process used, to determine whether the concentrations at the end-of-pipe comply with various guidelines, is shown in Figure 5-1. The CSO rainfall/runoff model developed in Phase 2 was used to estimate runoff and overflow for each CS district for a representative year (1992). Once the runoff for each area was estimated on an hourly basis, the concentration of ammonia for each CSO, for each hour of that year, was calculated assuming a concentration of 25 mg/L in the sewage. In a worst case type of assessment, this end-pipe concentration was compared to a typical acute guideline for pH 8, as termed by Alberta Environment (there is no similar end-of-pipe guideline in Manitoba). This concentration was determined to be about 5 mg/L. This number of hours during which this overflow concentration exceeded this acute toxicity guideline was then calculated. It was considered that, if there were any hours during this overflow that exceeded guidelines, further analysis may be needed for that district. Where further analysis was needed for some districts, an instream estimate was made as discussed in Section 6.

Figure 5-2 illustrates the process of estimating concentrations for one storm on July 3, and 4, 1992 for two districts: the Ash District and the Mager District. The hourly rainfall was used to determine flow in the sewers and subsequent dilution of the sewage. The ammonia concentration was estimated for each hour during the overflow.

Using the above approach, the average duration in which a CSO exceeded 5 mg/L of total ammonia was calculated for all CSO events at all districts for the representative year. Also calculated was the maximum duration of any exceedance of 5 mg/L of total ammonia for the entire representative year. These are shown on Figure 5-3(a) and Figure 5-3(b). Several of the districts with longer duration exceedances are labelled on the diagrams.

The figures illustrate that the hours in which the CSO exceeds 5 mg/L total ammonia is correlated to the interception rate. The higher the interception rate, the less likely there will be an exceedance because there is more dilution within the sewer prior to an overflow occurring. In a simple analysis, it could be determined that if an interception rate is five times the dry weather flow, then the concentration should be diluted by a factor of 5 before an overflow. Therefore, this concentration of 25 mg/L of total ammonia should reduce to 5 mg/L prior to



Near Field Mixing
CSO/Ammonia Joint Rainfall
River Flow Assessment
Figure 5-1

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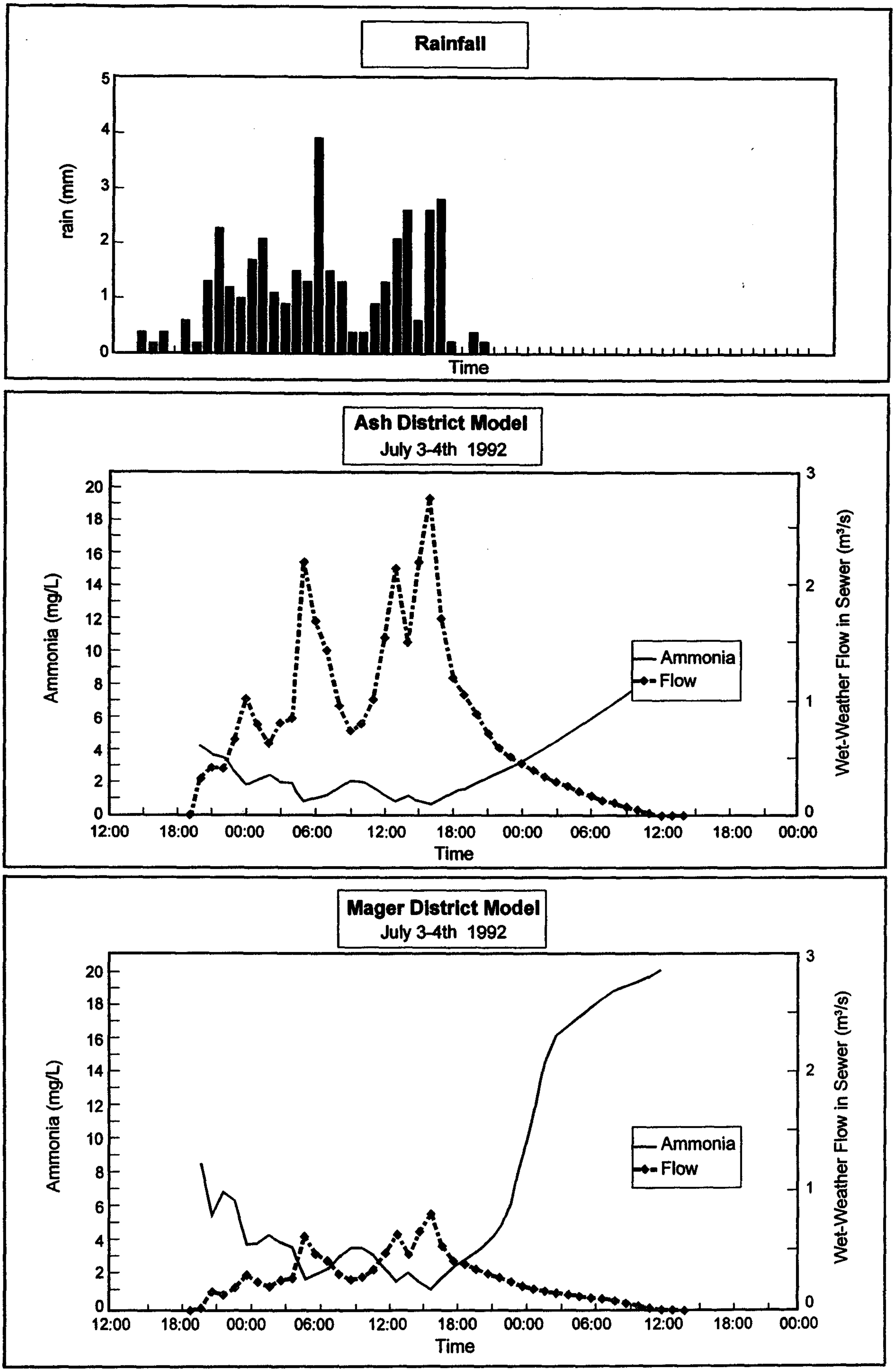

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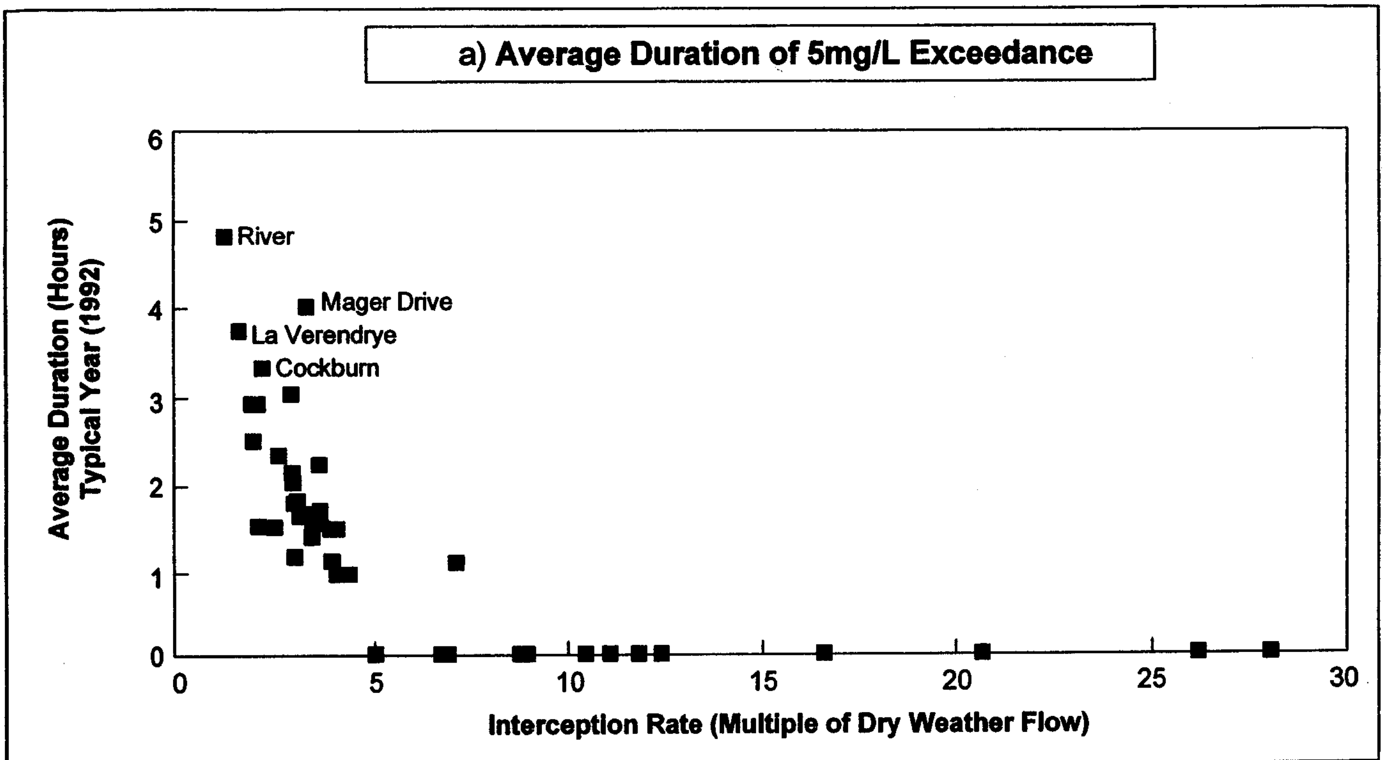
Figure 5-2



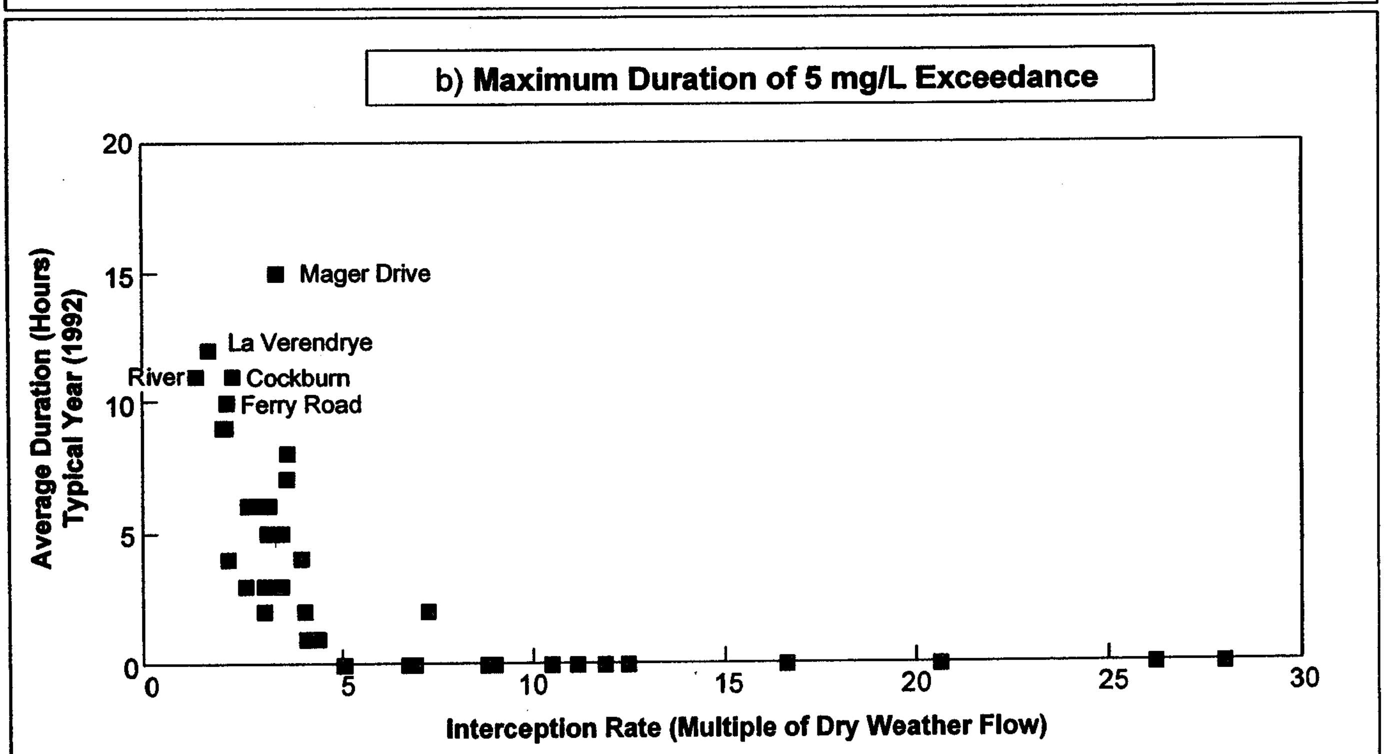


Figure 5-3

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overflow. This illustrates that even a simple measure of increasing the interception rate at each district will decrease the concentration of ammonia flowing into the river. In-line or off-line storage would also increase the dilution of sewage.

6. ASSESSMENT OF AMMONIA CONCENTRATION IN CSO MIXING ZONE

An assessment of the potential concentrations of ammonia within the receiving stream in a mixing zone downstream of a CSO was done for two of the larger districts on each of the upper Red (upstream of the Forks) and the Assiniboine rivers. The mass of ammonia entering the river for a large storm was calculated using the model described in the previous section. It was assumed that 5% of the river flow was used to dilute the ammonia. The concept is illustrated in Figure 6-1. The flow coming out of the CSO was not considered to be added to the river flow. This is a conservative way of estimating the concentration in the river which will likely over-predict the concentrations. For a large storm, a discharge mass from Ash District and from Mager District was assessed to determine the concentration of ammonia, if that mass was mixed with 5% of the flow during 1992 river conditions. The results are shown on Figure 6-2. As seen from these figures, the ammonia concentration remains below 1 mg/L in the river and well below the acute toxicity guideline (for Alberta) of 5 mg/L. This indicates there would likely be no impact on the receiving stream. The same analysis was done using a much lower flow in the river of Q_{4-3} (see Figure 6-3). The results of the analyses for both districts, for Q_{7-10}, are shown on Figure 6-4. For the Ash District the concentration was less than 3 mg/L ammonia. For the Mager District the concentration would be slightly above 5 mg/L for about 4 hours. For these conditions, the concentration in either of the rivers remained below 2 mg/L.

This analysis was done during Q_{7-10} flow (Figure 6-5) Ferry Road District on the Assiniboine River. For Ferry Road, the concentration of ammonia in the effluent would be above 5 mg/L at some time during the storm (assessed July 3 and 4, 1992). However, when the analysis was done assuming 5% of the river flow used for mixing, the concentrations never got above 2 mg/L.

The Manitoba Surface Water Quality Objectives indicate that 25% of the river width is allowed to be used for mixing. That would result in five times the flow that was used in this analysis, and therefore one-fifth the concentration of ammonia. It can therefore be stated that due to dilution of the sewage by rainwater and mixing in the river, the concentration of ammonia within the river after CSO will not be near acutely toxic concentrations at any time. If the concentrations are low enough (likely less than 2 mg/L) even in the lowest flow conditions, chronic toxicity guidelines

Mixing Zone Assessment

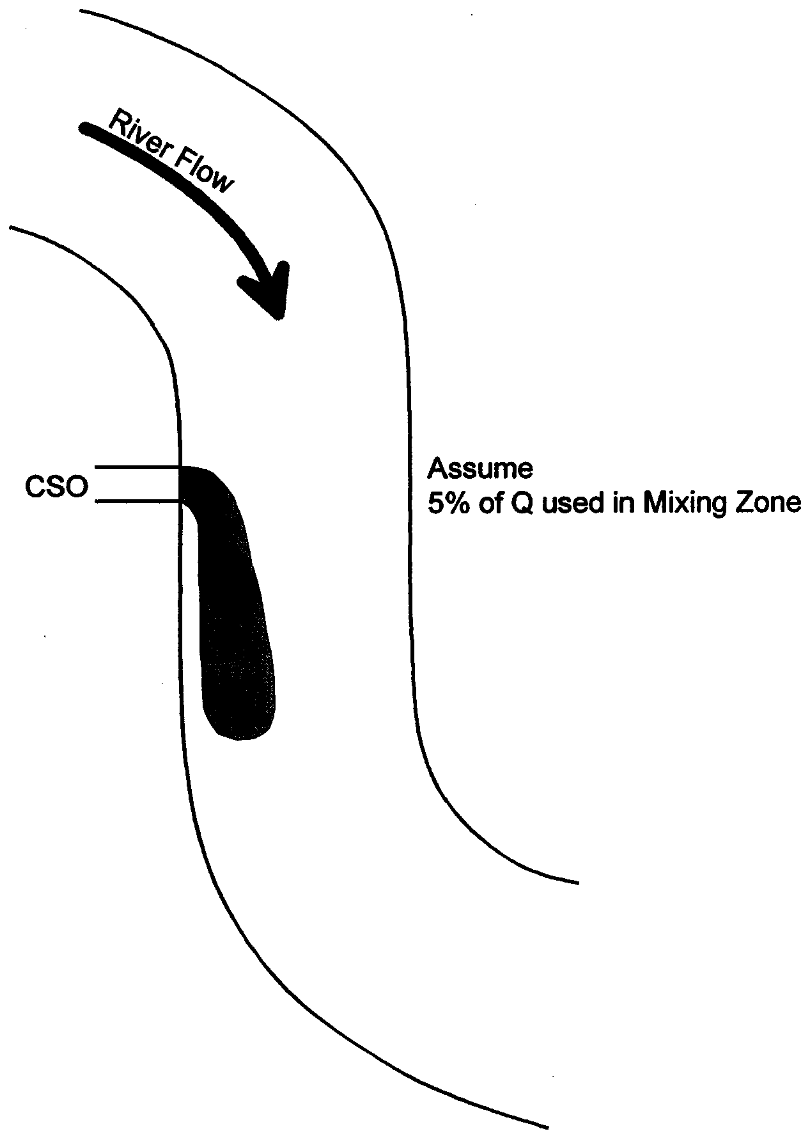

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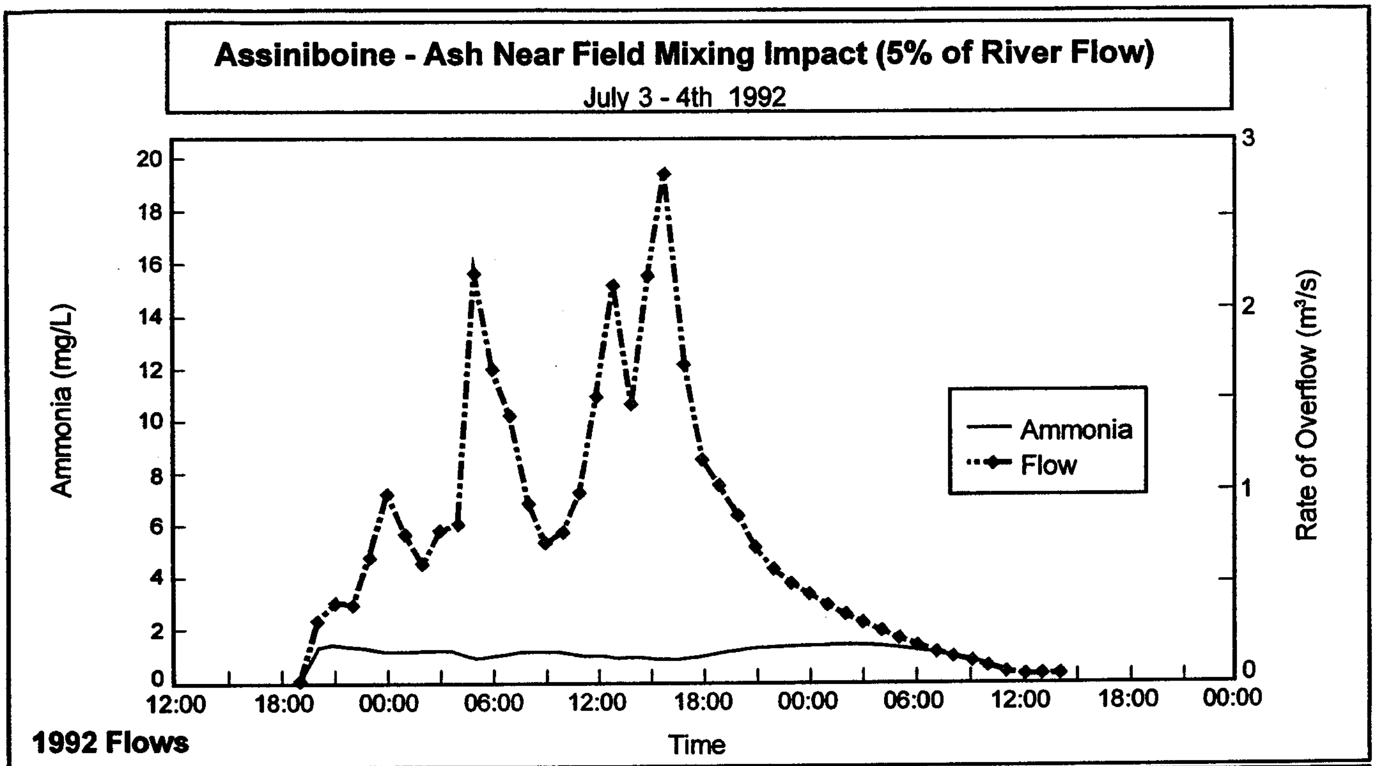
Figure 6-1



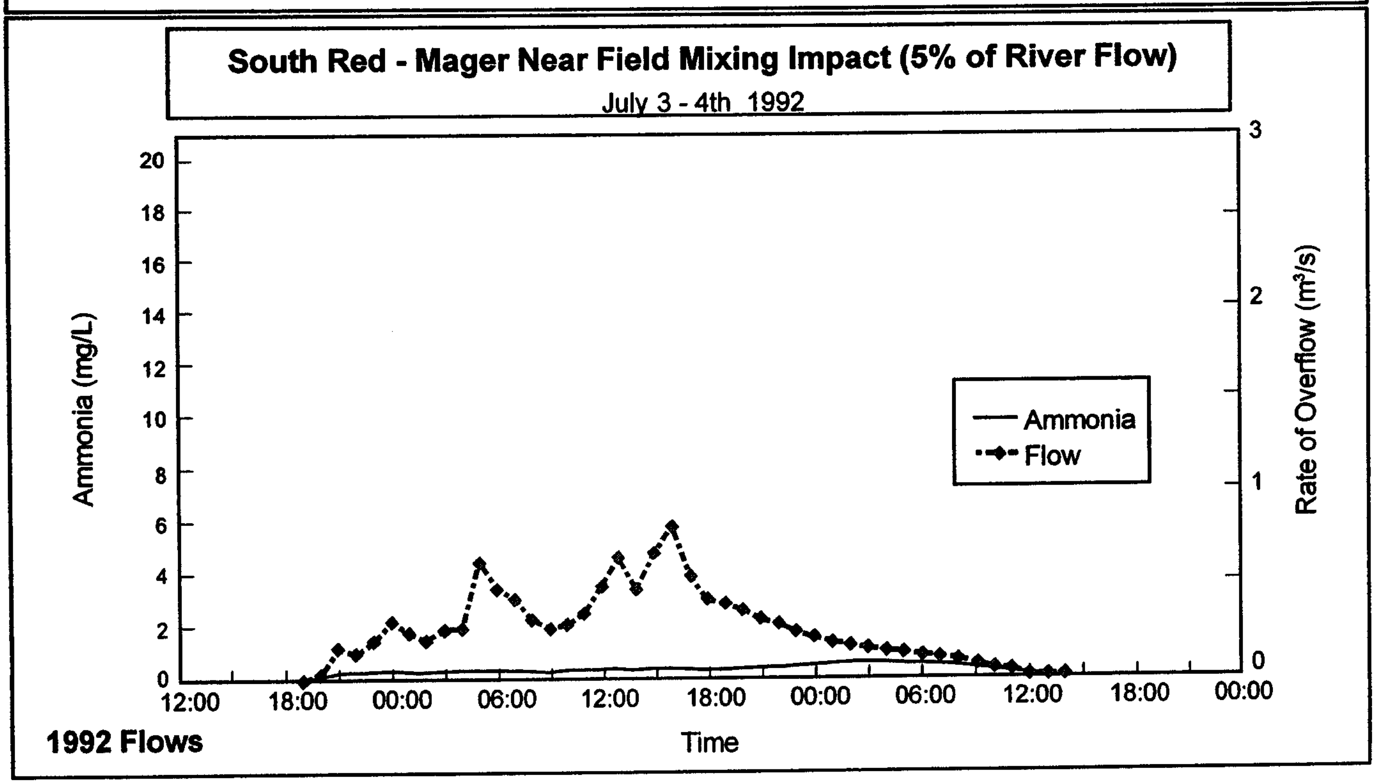


Figure 6-2

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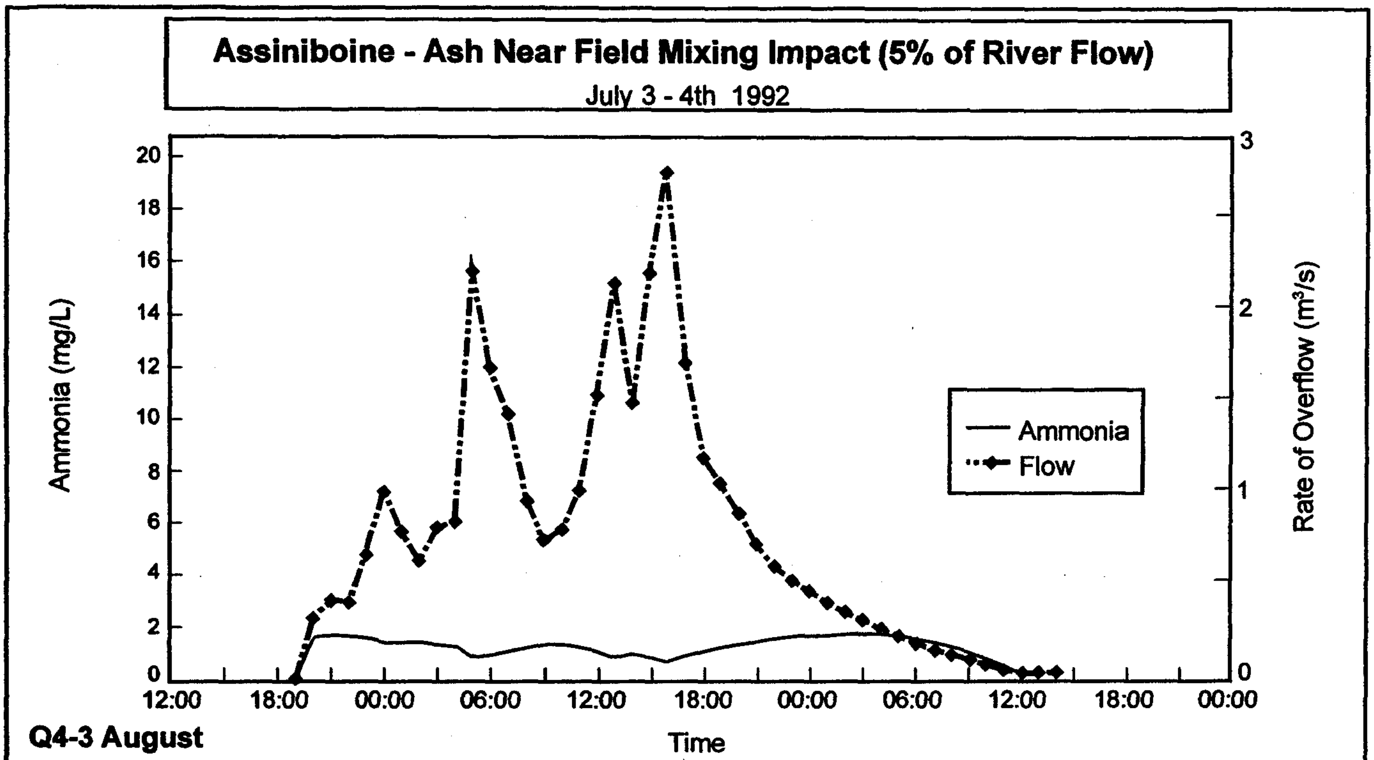

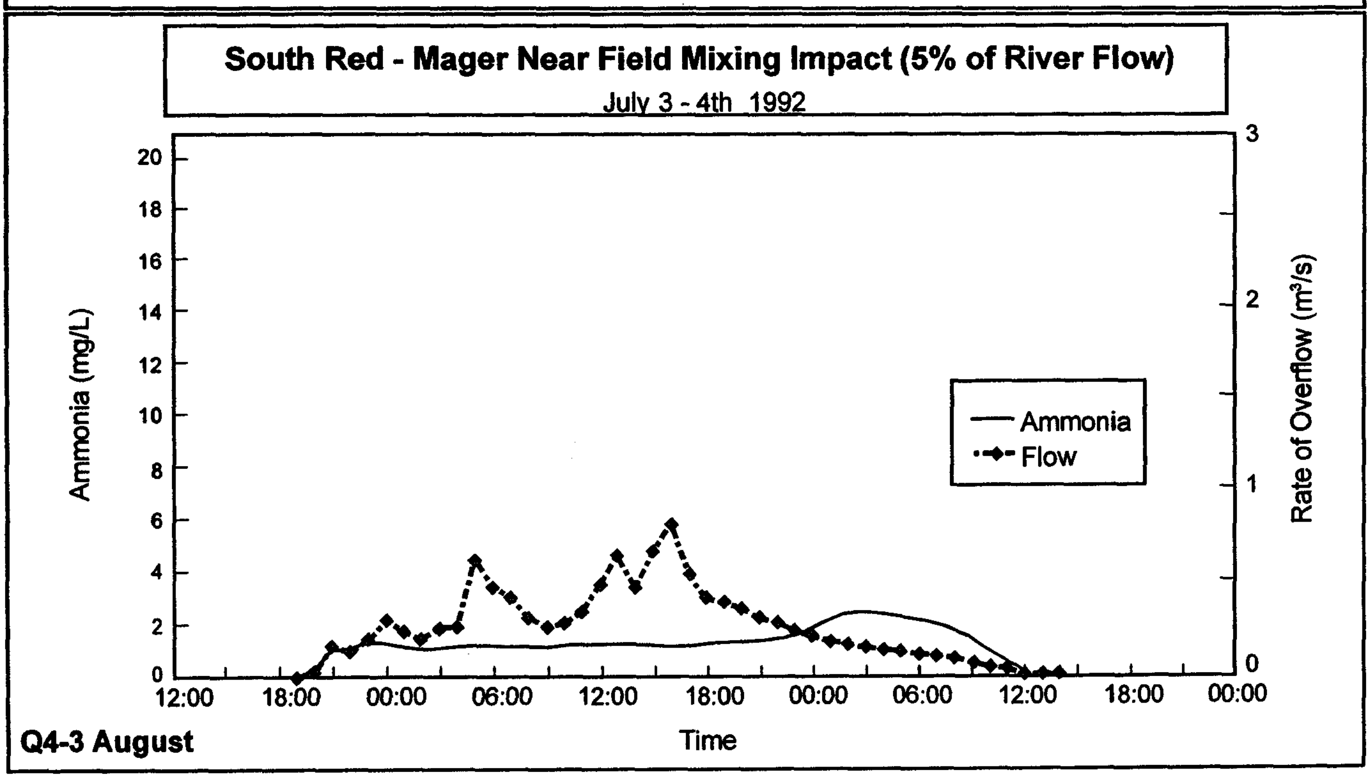

Figure 6-3

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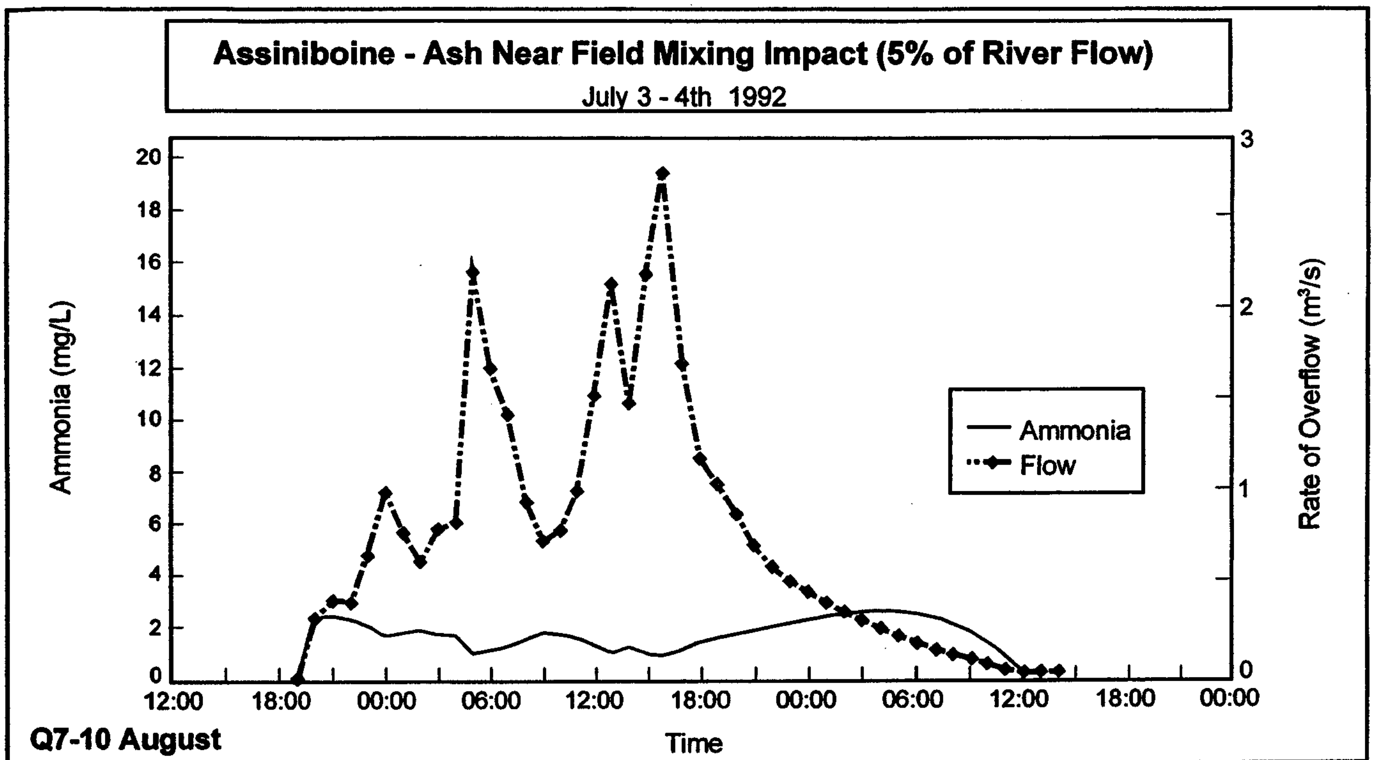

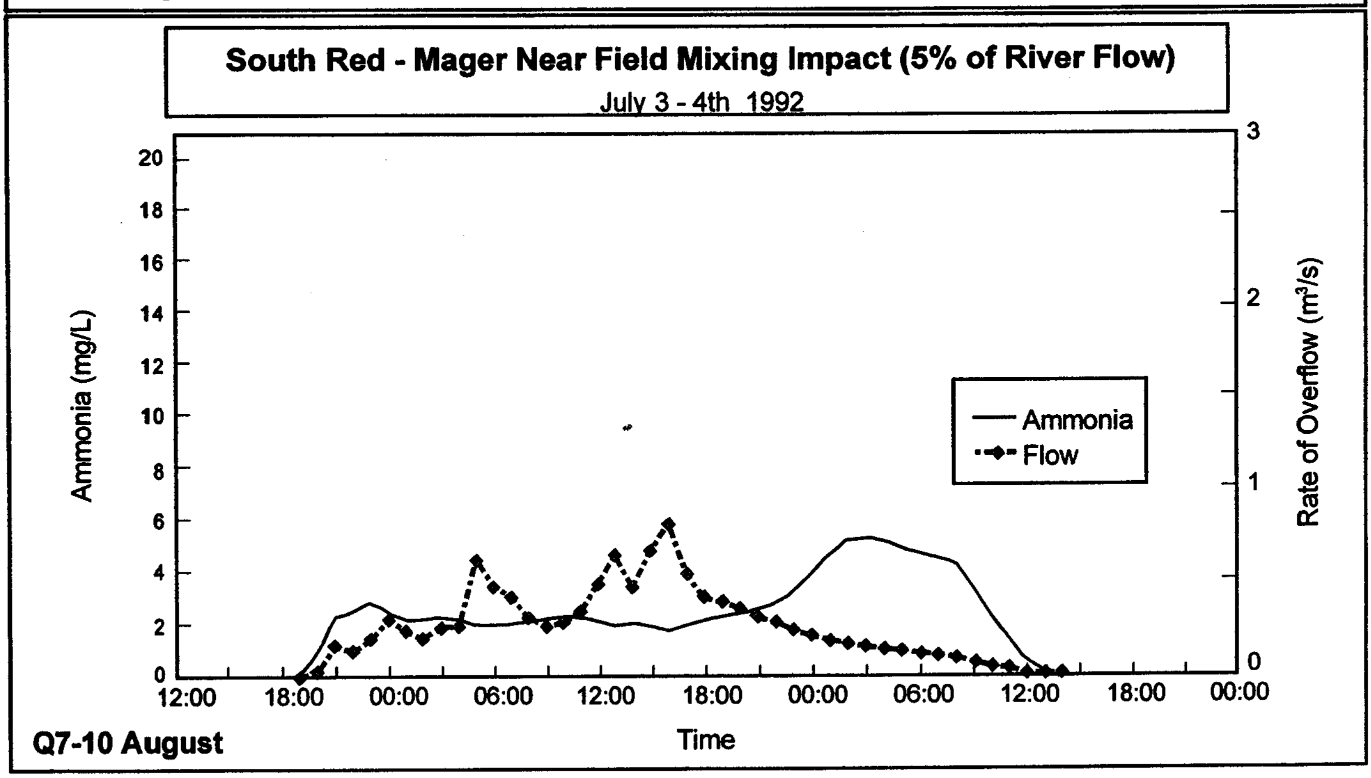

Figure 6-4

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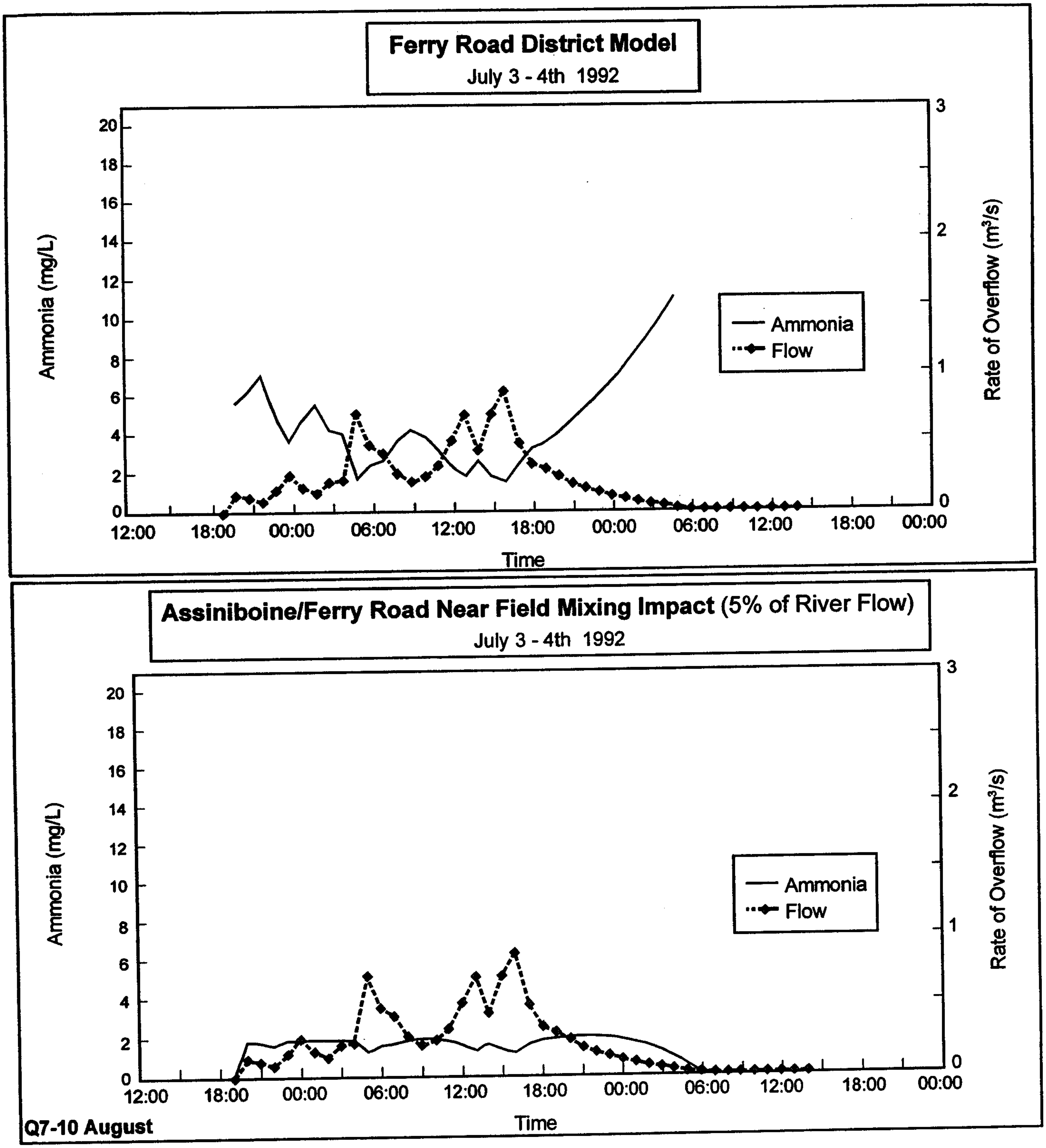

Figure 6-5

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would likely not be exceeded. If there was an exceedance the duration would be relatively short, likely less than one day.

7. SUMMARY

With the dilution of ammonia during CSO, and the short duration of CSOs (hours rather than days), it is unlikely that CSOs have any impact on fish toxicity in the river. The amount of flow available in the river, even during the lowest $Q_{7\text{-}10}$ conditions would further dilute the CSOs, reducing the concentrations in the river to low levels.

Any increase in interception rate or additional storage would further add to dilution, thereby reducing ammonia concentrations in the river. However, ammonia need not be a factor in selecting CSO controls in the river, since these overflows would have little impact on ammonia concentrations. Historic records indicate that concentrations in the heart of the CSO districts at the Main Street bridge are generally the same as upstream stations.

Ammonia is a water pollution control centre issue. It should be mainly investigated during dry weather flows, and for chronic impact assessments, or within the mixing zone of the treatment plant effluent. If the treatment plant is designed to nitrify, and thereby remove ammonia, there could be short-term increases in ammonia concentrations during wet weather flows due to the by-passing of the secondary process. The CSO storage options might increase the length of this by-pass (depending on the rate of storage dewatering), however with dilution of wet weather flows at the plant, it is unlikely that concentrations of ammonia in the river will be high enough for a sufficient length of time to have any potential of chronic impacts to aquatic life.