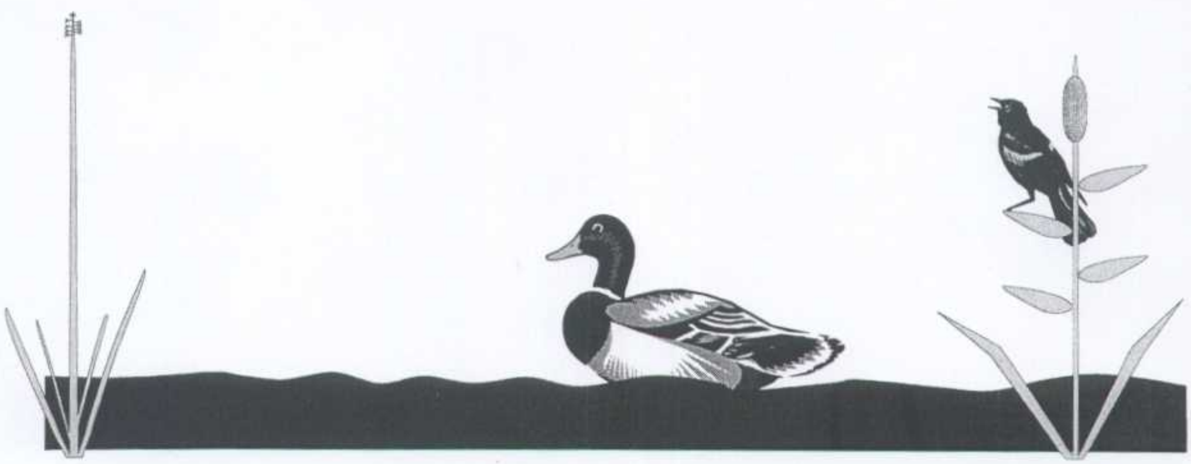
City of Winnipeg
Water and Waste Department

Combined Sewer Overflow Management Study

PHASE 2 Technical Memorandum No. 4

RECEIVING STREAM



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In Association With:

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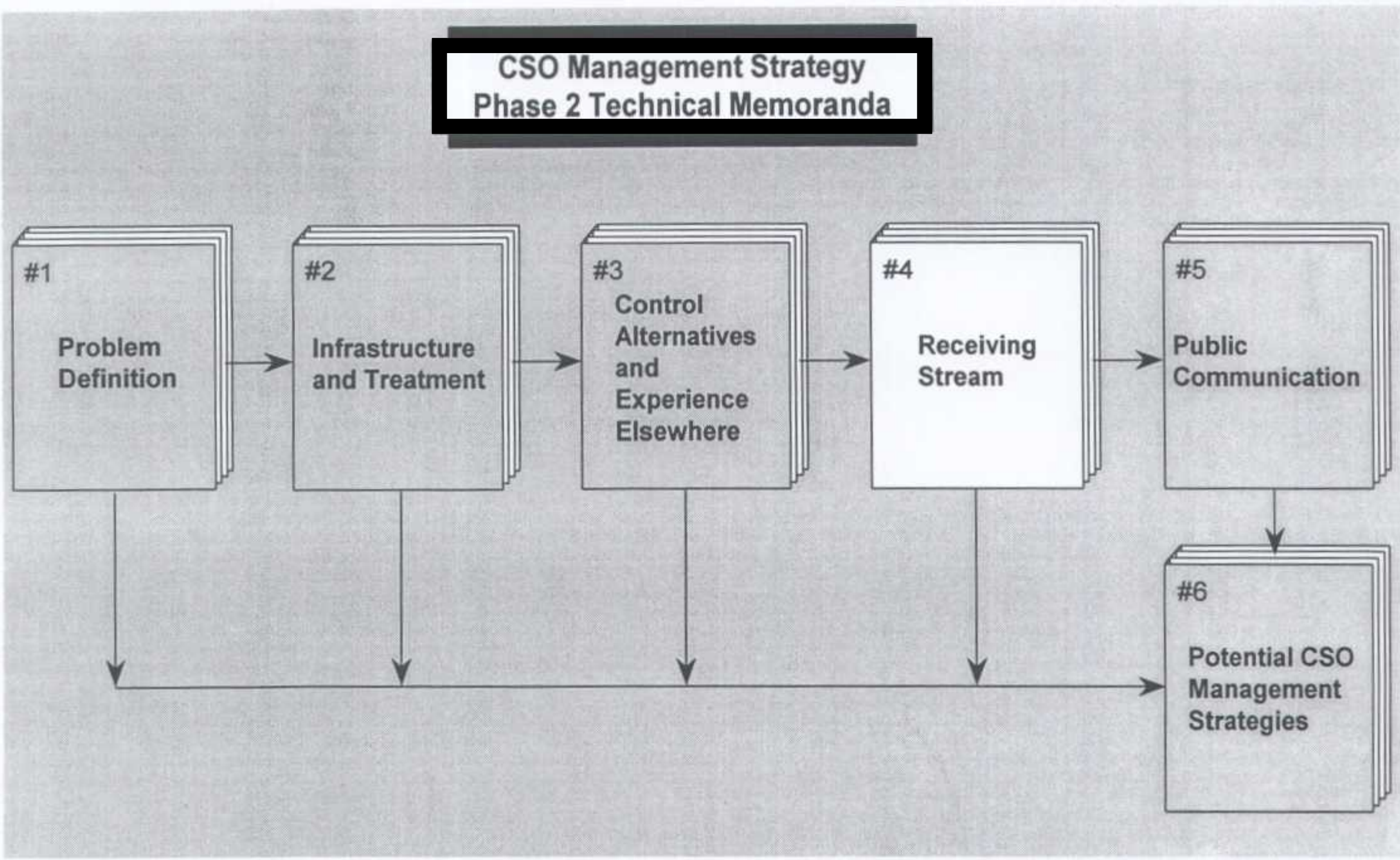
PREAMBLE

This Technical Memorandum (TM) is one of a series of TM's intended for internal discussion. It is not intended as a report representing the policy or direction of the City of Winnipeg.

This particular TM is part of a group of Phase 2 reports as shown in the schematic.



Each of the Phase 2 TMs draws on information developed in the prior Phase 1 TMs. In addition, the Phase 2 TMs document information and study analyses sequentially. Ideally, therefore, the TMs should be read in the sequence shown.

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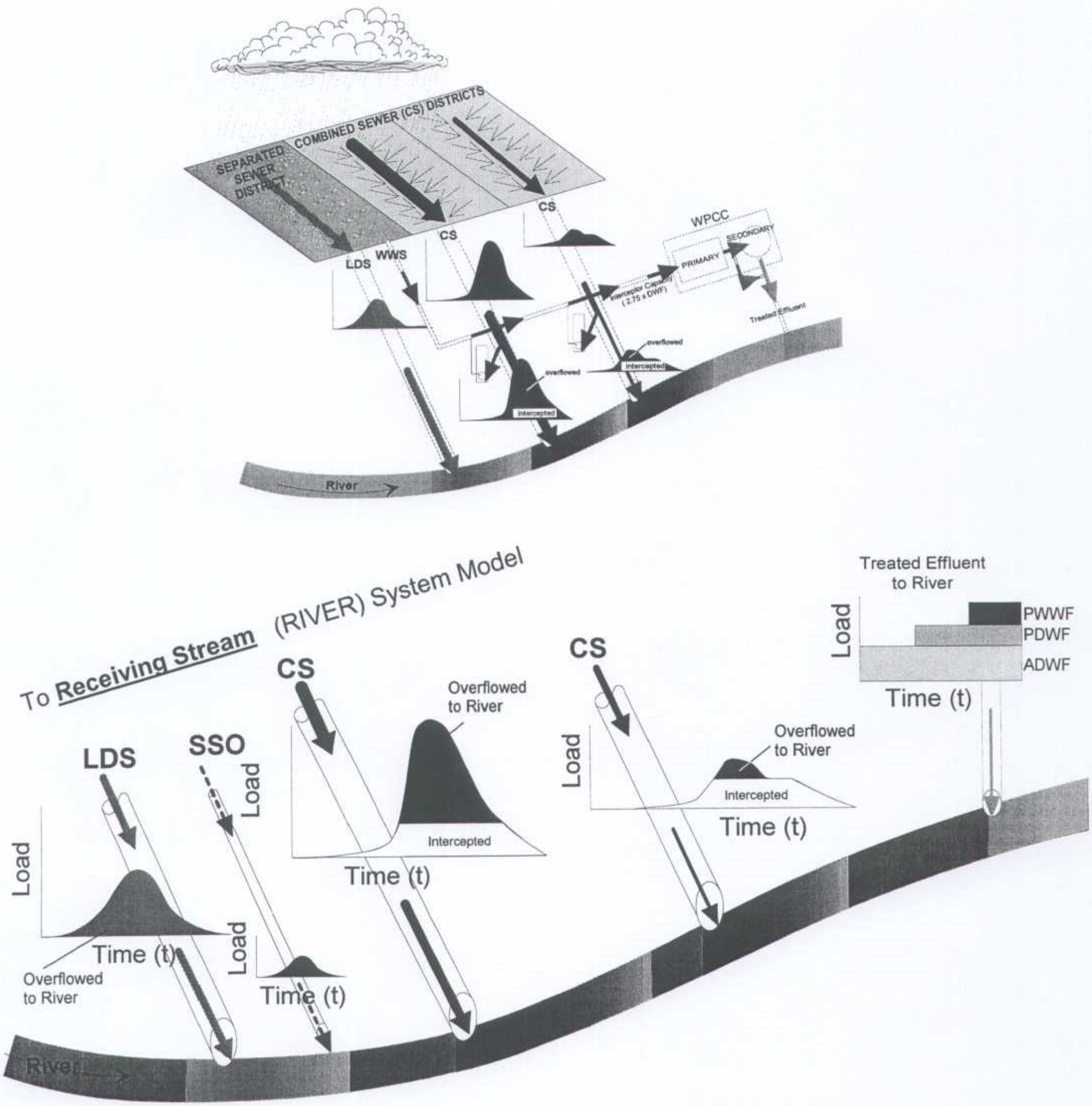
1.0 INTRODUCTION

This Technical Memoranda (TM) will cover the aspects related to water quality simulation of impacts from dry and wet weather loadings on the receiving streams. The systems modelling approach, as shown in Figure 1-1 and discussed earlier in TM #1 (Runoff Modelling) and TM #2 (Interceptor Modelling), illustrates that receiving stream modelling is the last component of the systems approach to modelling. As depicted in Figure 1-1, the receiving stream model accepts loadings from the continuous dry weather sources (treatment plant effluents) and the various intermittent wet weather sources. Model output files from both XP-SWMM Runoff (TM #1), and Controls (TM #3) were post-processed to supply the receiving stream model with the necessary input files to simulate water quality impacts and response under a range of existing conditions and potential new scenarios. Simulation results from this river modelling exercise were compiled in a database and post-processed to assess existing water quality and compliance with regulatory objectives. These conditions established a measure by which to gauge the benefits for a range of control options.

The method used to assess receiving stream quality for existing conditions and responses to possible control alternatives is conceptually illustrated in Figure 1-2.

Such an iterative approach provides the information for screening and evaluation of each of the possible control strategies involved in the modelling exercise, the identification of concerns or needs for additional data-gathering, the progressive focus on the most appropriate "solutions", and regular peer review by special advisors to ensure that model consistency and integrity are valid. The systems approach consisted of a series of integrated linked models. These included a land-use runoff model of urban areas to generate the runoff hydrographs and quality concentrations to the interceptor and possible control alternatives. Control modelling was initially used to simulate existing interception conditions (regulators, weirs, pumping capacities) and generate the quantities for overflow and estimate the flows reaching the treatment plants and later used to simulate to various control technologies and their associated capacity to reduce loadings to the rivers. The receiving stream model represented the culmination of all dry and wet weather loadings. It accepted loadings generated from various discharge sources and boundary conditions to simulate the response of the receiving streams under dry and wet weather conditions for the full duration of the recreation season.



Instream Concentrations

- Mass Balance
- Fecal Coliform Die-off Kinetics
- Compliance with MSWQO

Receiving Stream (RIVER) System Model

Figure 1-1

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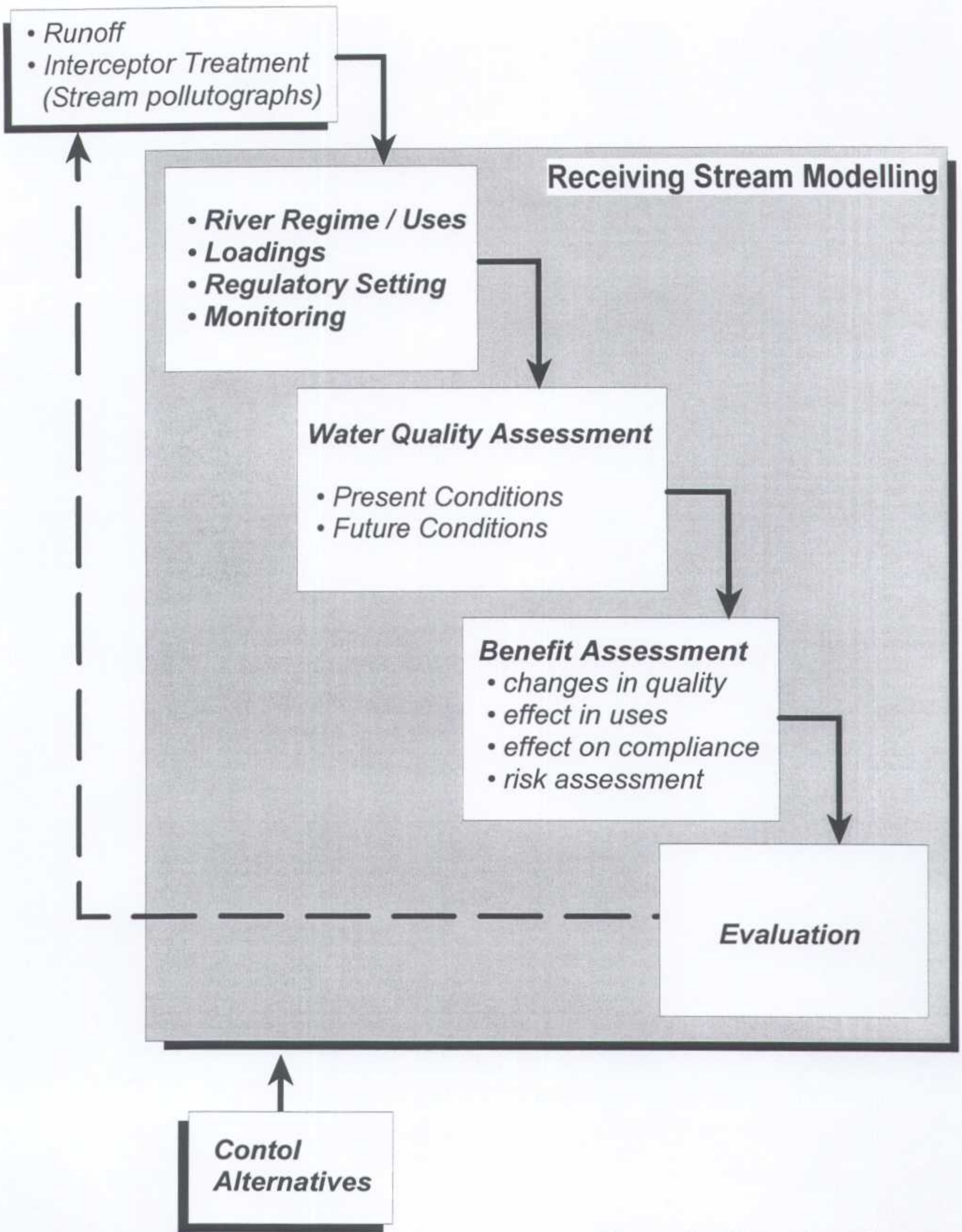

Conceptual Overview of Approach to Receiving Stream Modelling

Figure 1-2

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These considerations were used to assess model needs in terms of system requirements and provisions for model setup and development.

2.0 WATER QUALITY MODELLING CONSIDERATIONS

The Terms of Reference for the Combined Sewer Overflow (CSO) Management Strategy Study incorporate the recommendations of the 1992 CEC Hearings and has been expanded to include related concerns. Study requirements of particular importance and guidance to receiving stream modelling are:

- *"assess the relative impacts caused by various sources of pollution on the receiving waters, including a review and summary of existing documentation and information on the impacts of potential impacts on Lake Winnipeg";*

- *"estimate and recommend on the practicability of CSO abatement as an independent approach to surface water quality improvements versus abatement of other independent sources, or a combination of sources".*

From these broad objectives for water quality assessment, the main considerations which would influence the model development and application were reviewed beginning with the water quality issues, model products, and other associated technical factors.

2.1 WATER QUALITY ISSUES AND MODEL PRODUCTS

Phase 1 TM #7 (Receiving Stream) outlined the main water quality issues with the Red and Assiniboine Rivers. This information and other previous reports relating to river uses and water quality issues were re-assessed to identify the possible impacts from wet weather flows (WWF) to the receiving streams and relating to compliance requirements with Manitoba Surface Water Quality Objectives (MSWQO). River uses and related CSO issues are summarized in Table 2-1. Public health, aesthetics and regulatory policy issues are key issues. The Phase 1 Workshop also highlighted the importance of public perception and public

TABLE 2-1

RIVER WATER QUALITY ISSUES AND CSOS IN WINNIPEG

RIVER USE	CSO ISSUE
Aesthetics	Floating matter
Environmental regulation/policy/public perception	Overflow of sewage
Primary recreation	Microbiological (public health)
Secondary recreation	Microbiological (public health)
Greenhouse, irrigation	Microbiological (public health)
Aquatic life	• Sediment • Dissolved Oxygen • Toxic Substance (metals, pesticides, etc.)

education in CSO control policy. Controls will be costly and will involve policy issues and choices, therefore, an informed public is very important to a successful study.

With respect to specific water quality parameters and possible water quality modelling, the Phase 1 Workshop evaluated the particular water quality parameters and judged as to whether the parameters should be modelled or addressed in other workshops. These issues were reassessed in Phase 2 Working Session #1 (held on November 1 & 2, 1994) with the results shown in Table 2-2.

The main findings with respect to water quality modelling are:

- the key issues are microbiological quality (fecal coliforms are used as indicator bacteria and a measure of contamination), floatables, CSOs (number, duration and volume), and regulatory compliance;

- sediment loading is not likely to be a significant WWF issue since the river already carries a high sediment concentration. CSO volume was considered, with an EMC for suspended solids, to provide adequate perspective on sediment loading;

- toxic substances, such as metals, pesticides, were not considered to warrant specific modelling; sediment loading, as expressed in CSO volumes, can be used to provide perspective on mass discharged from CSOs in this respect;

- dissolved oxygen (DO) was shown (Phase 1 TM #4) to have been modestly impacted by WWF discharges and not likely to be a major CSO-related issue. Additional monitoring was considered to be a better way to address DO, if it becomes an issue, than dynamic modelling.

- floatables are virtually impossible to accurately quantify or model. It was considered that the number and volume of CSOs represent a proxy for floatable loading into the river;

Table: 2-2: Phase 1 Evaluation Matrix
Receiving Stream Issues

	Issue				Monitoring		Modeling	
	Potential CSO Issue	CSO Elsewhere	Winnipeg CSO Issue		Winnipeg CSO Study		Winnipeg CSO Study	
Parameter	⇓	⇓	⇓	**Comments**	⇓	**Comments**	⇓	**Comments**
Hydraulic							●	*Hydrodynamics*
DO - BOD	●	O	O		●	*Confirmation Information*	O	
Nutrients	●	⊙		*Unlikely as Winnipeg Issue*		*Adequate*		*Loading Perspective*
Ammonia	●	O	O	*Unlikely as Winnipeg Issue*		*Separate Study*		*Loading Perspective*
Fecal Coliforms	●	●	●			*Adequate*	●	*Dynamic*
Mixing Zone	●	O				*Some Information Available*	O	*If Required as Detail*
Toxic Substances	●	●	?		O	*Some Information Available*	●	*Overflow volume as proxy*
Sedimentation	●	O	O		O	*Possibly, if Fisheries Issue*		
Aquatic Health	●	●	O		⊙	*Benthic Studies, More ?*		
Aesthetics	●	●	●		?	*Some Limited Information*	●	*Overflow volume as proxy*

● - HIGH
⊙ - MEDIUM
O - LOW
? - UNCERTAIN

EVALMTRX.WK4

- nutrients and ammonia issues can be placed in perspective from a review of WWF and dry weather flow (DWF) loadings and do not require dynamic modelling from a CSO perspective.

The loadings to the river, (e.g., CSO, SSO, LDS, ...) are defined from Phase 2 Runoff Modelling (TM #1) and Control Assessment (TM #3), which provide number, frequency and duration of dry and wet weather loadings from major sources. Given these considerations, the water quality of model needs to provide the following products:

- predicted concentrations (hourly) of fecal coliforms at representative locations (e.g., at Redwood Bridge) for dry and wet weather conditions to illustrate the response of the rivers to rainfall events and possible benefits of different control strategies;

- representation of average conditions (geometric mean) for the recreation season along the Red and Assiniboine Rivers within and downstream of Winnipeg;

- compliance frequency with Manitoba Surface Water Quality Objectives (MSWQO) at representative locations and on a system-wide basis; and

- revised health risk assessment, to estimate the number of cases of gastrointestinal illness for existing conditions and possible avoided cases with controls in place.

2.2 MODEL SELECTION

Selection of the appropriate model and its coding/setup is strongly dependent upon the complexity and level of sophistication required to assess river water quality response to dry and wet weather loadings. Several models were considered in Phase 1 of the CSO study for use in the simulation of receiving stream water quality dynamics. These included QUALHYMO, QUAL2E, WASP, HSPF, and SWMM. Each of these models were reviewed to determine their strengths and weaknesses in terms of ability to simulate receiving stream water quality dynamics, extendability, user-friendliness, use elsewhere, and their ability to be linked for data transfer and export between models.

Several US EPA models and others were reviewed to identify the most appropriate mathematical model to describe the water quality response of the receiving streams under various loading conditions and meteorological conditions under a continuous basis for the recreation season. The dynamic Water Quality Analysis Simulation program (WASP) version 5 developed and maintained by the United States Environmental Protection Agency (US EPA) was selected based on its ability to analyze water quality dynamics under continuous simulation basis and its potential for later reuse for the simulation of water quality dynamics associated with nutrient cycles and dissolved oxygen levels.

It was found that the US EPA WASP model was the most capable and flexible model for the continuous dynamic simulation microbiological and nutrient dynamics in surface waters. It is capable of accepting loadings directly from XP-SWMM (used in the runoff and interceptor modelling). As well, WASP is capable of accepting the hydraulic description of the river flows from other hydraulic-based models to use in its water quality routines (e.g., SWMM, RIVMOD, DYNHYD). The WASP model is also flexible with respect to possible future requirements. It was uncertain during Phase 2 assessments if nutrient dynamics would need to be modelled to simulate dissolved oxygen levels in the river and assess the impacts of wet weather loadings. It is also believed that CSO impacts have an insignificant effect on dissolved oxygen budgets of the river. The WASP model could be readily adapted in the future if modelling of dissolved oxygen behaviour or ammonia dynamics in response to wet weather events should it be required.

The model is a compartmental model which separately describes hydraulic behaviour of the river system and then applies numerical routines to describe the quality behaviour of selected water quality constituents. The receiving stream is divided into representative segments that are individually tracked by the model so that water quality dynamics can be described for each segment on a continuous basis for the duration of the simulation event.

The familiarity of the study team with the WASP model on other projects (Deacon Reservoir, Teulon, Dauphin), was also an important factor in its selection. The model had been previously adapted such that output results could be viewed and readily adjusted to achieve a favourable match with observed conditions and display the results in a format that could easily be visualized.

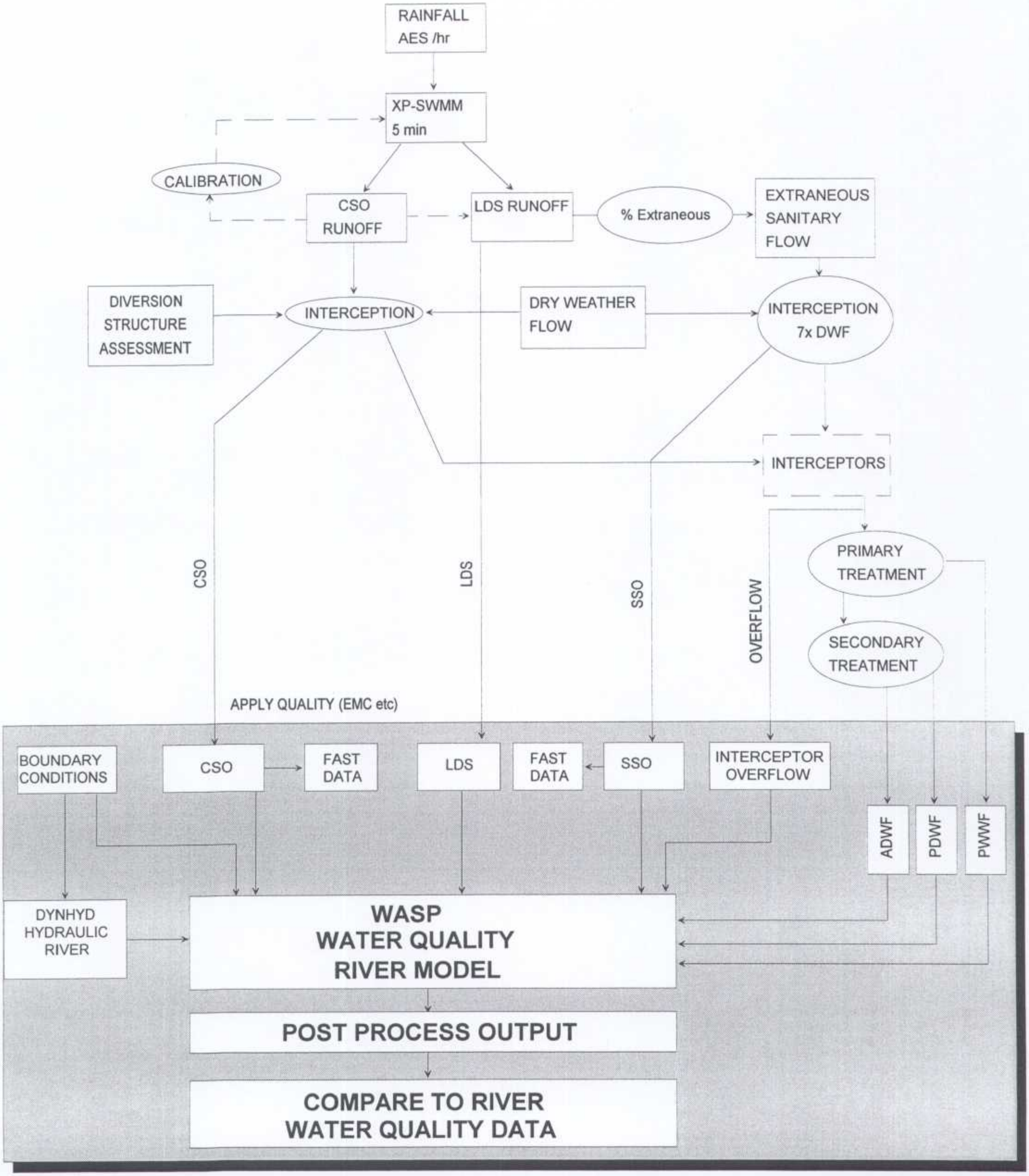
The key numerical routines used within the WASP model framework were the DYNHYD and TOXI systems. DYNHYD is the hydraulic compartmental model routine that is used within the WASP family of models to describe the hydraulic behaviour of the river systems. It is not as robust as other hydraulic models such as HEC-2 or HSPF. It was considered adequate to describe the major hydraulic aspects of the river system with sufficient accuracy for this level of receiving stream modelling. The TOXI compartmental modelling system can be used to describe the fate of specific water quality constituents that do not require detailed interactions such as algae/nutrient cycle relationships. However, TOXI can model a wide range of user-defined water quality kinetics for a wide range of parameters and complex interactions (e.g., eutrophication, algae, dissolved oxygen, PCBs, pesticides, ...) but these are not deemed necessary for assessment of fecal coliform dynamics. As well, TOXI has been optimized so that it does not have the computational overhead burden associated with the complete modelling of nutrient cycles including algal-dynamics.

The US EPA WASP model also contains the provision for a simplified description of river hydraulics. The same segmental setup as used in the DYNHYD model can be described in the simplified coding in the WASP model but does not consider the change in volumes of each of the segments associated with varying flows (i.e., cascading pools). This aspect will be discussed in greater detail in Section 3.1.

It was deemed prudent to select a model that was developed and endorsed by the US EPA (United States Environmental Protection Agency) to simulate the continuous dynamic water quality behaviour of surface waters. The US EPA has made a commitment to continually improve and upgrade their models since their initial development, to include technological advances, information transfer, software development, and error reports. The US EPA is a recognized world leader in the development and application of environmental models.

2.3 APPROACH

The approach to receiving stream water quality modelling is depicted in Figure 2-1. The approach integrates the results of urban hydrology, the representation of the sewer



Approach to Receiving Stream Modelling

Figure 2-1

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infrastructure, dry and wet weather loadings to the streams, the application of a water quality simulation model (WASP), and the assessment of output.

The key steps in receiving stream modelling are:

- system description (hydraulic and biokinetic)
- calibration (selection of coefficients)
- simulation of local conditions
- verification
- sensitivity analysis
- data requirements/monitoring
- selection of prediction scenarios
- peer review

The validity and reliability of model predictions and the forthcoming recommendations are strongly dependent on the careful application and review of the above noted steps.

The City and CSO study team are familiar with a wide range of custom developed and public domain (i.e., US EPA) computer based mathematical models to assess river water quality response. This study builds upon the modelling exercises and information performed on the Winnipeg rivers since 1979, as listed in Table 2-3. Members of the study team were involved in each of these water quality assessments. Each of the studies listed built upon the previous study and progressively developed the knowledge base for the current modelling exercise. The recent advances in public domain numerical models and program code provided the level of model complexity and sophistication required for detailed simulation of water quality response. Specifically, the detailed information on local river flows, loadings and fecal die-off kinetic rates from the previous studies were an important resource to this study.

An important aspect of any modelling exercise is that the onus is on the model user rather than its developer, if they are different, to support the conclusions or recommendations reached in response to the modelling exercise. Due to the complexity of receiving stream simulation of key water quality components, local and outside experts were sought to assist in its setup/development and critical review of model results. Special working sessions (#7

TABLE 2-3

PREVIOUS LOCAL WATER QUALITY MODELLING

1979 RVRQUAL-Custom - WWF (MacLaren 1979)
- Plug flow transport - Winnipeg as single mixing zone - First order decay for Total Coliform - Streeter-Phelps BOD-DO model - Used wet weather loads from STORM model and NEWPCC discharges - Modelled reaches downstream of City
1984-85 USEPA QUAL2E + DWF (MacLaren 1986)
- stage-discharge hydrodynamics - Finite difference transport - Red and Assiniboine discretized into 1 kilometre cells - Three plant discharges for DWF - First order decay of Fecal Coliform - Eutrophication (BOD/ALGAE CYCLE - DO) - No algae data available
1986 USEPA QUAL2E -Custom Model - WWF (MacLaren 1986)
- Disinfection and 1st Order Decay - "dynamic" fecal coliform for one month - First Order decay of Fecal Coliforms - Use model and statistical analysis of monitoring
1990-92 QUAL2E - DWF (Wardrop/Tetr*ES* 1992)
- More detail in hydraulics - Calibrate to detailed monitoring from 1988 (about Q_{7-10}) - Included algae data in calibration
1992-93 Coli-model Custom - WWF (Tetr*ES* 1993)
- Stage discharge hydrodynamics (as done in QUAL2E) - Discretized River model - Plug flow transport - Mass balance and first order decay of Fecal Coliforms - One month

and 8) were convened to solicit the input of City representatives, local, and outside experts. The following sections discuss and incorporate the advice and direction given at these working sections.

A database management system was used to compile model results and to individually develop the input files for each of the dry weather and wet weather sources. Pre-processing involved the formatting of data into a compatible structure for direct input into the WASP river quality model. Receiving stream water quality behaviour on an hourly basis at each segment for the recreation season in response to each loading source were individually modelled and then combined using the theory of super-position. The source types consisted of:

- boundary conditions;
- combined sewer overflows;
- LDS;
- SSO;
- interceptor overflow; and
- WPCC effluents.

WASP model results were compiled into a database management system and post-processed (see Figure 2-1) to develop a dynamic display of water quality behaviour along both river reaches to illustrate the spatial and temporal response to dry and wet weather events. After calibration, the WASP model output was subsequently used to assess the response of the receiving stream to dry and wet weather loadings for a representative year. Existing conditions were first assessed and used as a basis for comparison of various control alternatives to estimate the possible benefits associated with reduced fecal coliform levels in the river and compliance with Manitoba Surface Water Quality Objectives (MSWQO).

2.4 DATA REQUIREMENTS

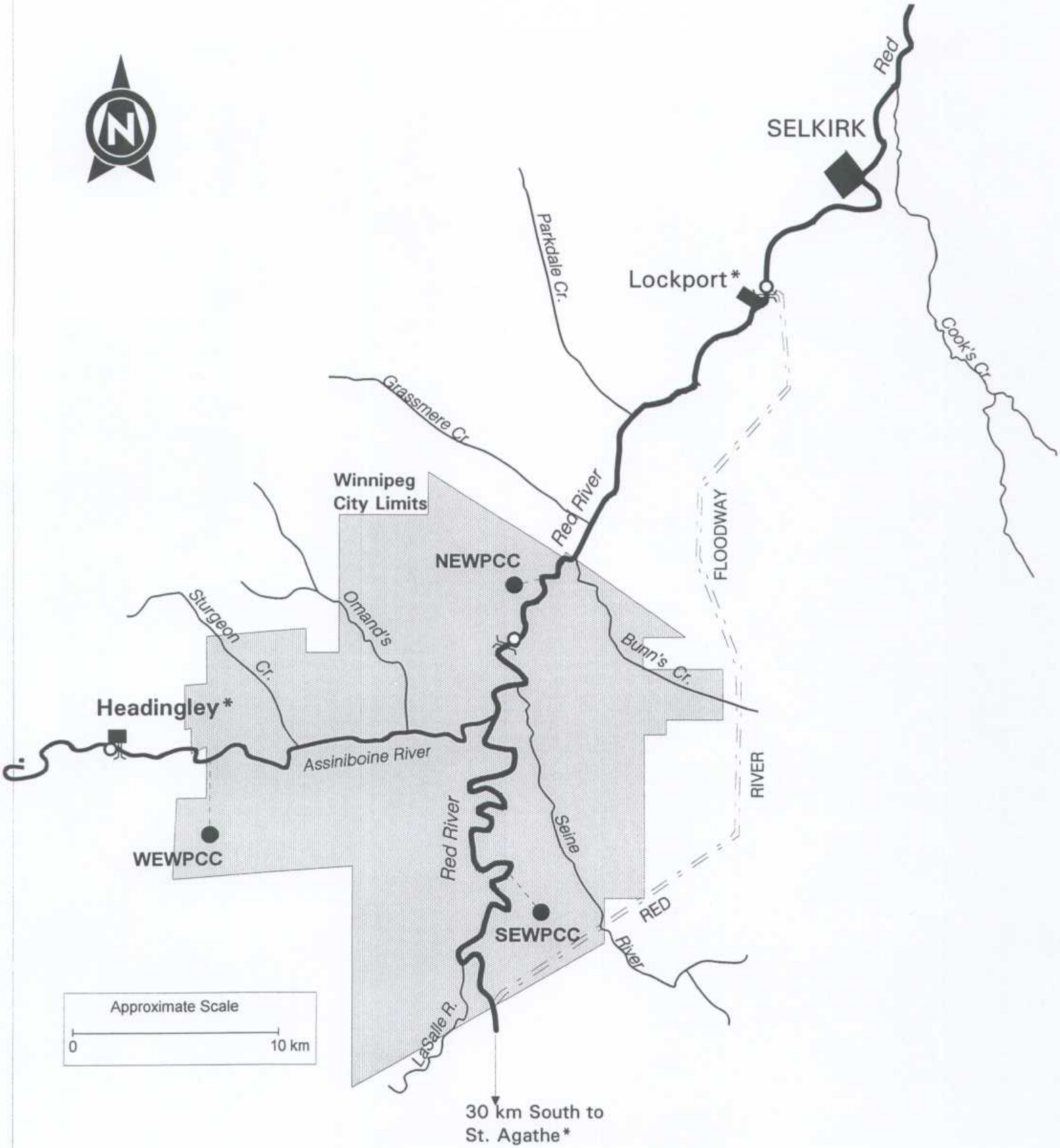
Data requirements for the WASP model consisted of hydraulics for river flows, loadings from dry and wet weather sources, seasonal water temperature, and fecal coliform die-off kinetic rates. The following sub-sections describe each of these specific requirements.

2.4.1 Hydraulics

The first step in developing a surface water quality model is the appropriate conceptualization of the river's physical hydraulic characteristics for the range of flows being modelled. The important hydro-dynamics of the rivers that are derived from the physical characteristics are segment volumes and time of travel through a segment. These key dynamics are influenced by the variable downstream boundary affects of St. Andrews Locks and Dam at Lockport, and the seasonal range of inflows on the Red and Assiniboine Rivers upstream of Winnipeg. These were all considered in the model setup. It is essential that the key hydro-dynamics be described to a sufficient degree of accuracy for subsequent water quality modelling simulations. Segmentation of the river so that adjacent segments are within 10% by volume (WASP User's Manual) are required for the proper calibration of kinetic rates used in water quality modelling. Calibration of kinetic rates are sensitive to temporal and spacial aspects of river flows (i.e., travel time through a specific river reach). Specifically, rates of transformation associated with first order die-off behaviour need to be adequately characterized to describe the response and behaviour of the receiving streams.

It is very important that the system hydraulics be reasonably well represented for the Red and Assiniboine Rivers before kinetic rates for fecal coliform die-off are calibrated to site-specific conditions. A controlling factor in nearly all water quality processes and interactions is time. Accordingly, segment size selection in terms of length and the variation of segment volume in response to changing upstream flows is an important factor used in calculating travel times and the transfer of mass between segments. It is possible to adjust kinetic rates in the WASP model to achieve a reasonable fit with the monitored conditions even if the hydraulic representation may be inaccurate. In such a case, the selected rates are considered "apparent" because they are likely skewed. Sensitivity analysis are routinely used to determine the relative importance of assumed rates, including hydraulics, with respect to their influence on model predictions. In the case of the Red and the Assiniboine Rivers, the inflow and geometry of the segment volumes are well known and hydraulically characterized.

One of the major inputs to the model are flows. Flows are monitored by Environment Canada, at headingley on the Assiniboine River and at St. Agathe and Lockport on the Red River are shown in Figure 2-2. Mainstem flows on the Red and Assiniboine Rivers entering the City at



*- denotes: Locations monitored by Environment Canada for Flows

**Key Hydraulic Features
of the Red and Assiniboine Rivers**

Figure 2-2

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the Floodway Inlet gates and Headingley, respectively, were estimated by using gauged streamflows at Headingley and Lockport. A simple time-lag model of Lockport flows minus Headingley flows was used to approximate the flows at the Floodway Inlet gate on the Red River. For modelling purposes it was assumed that the main source of flow in the rivers under summer conditions were from mainstem flows. Another modelling consideration is the range of flows that the hydraulic model will need to accurately simulate. Typically, river flows are highest in the spring and taper off throughout the remainder of the year.

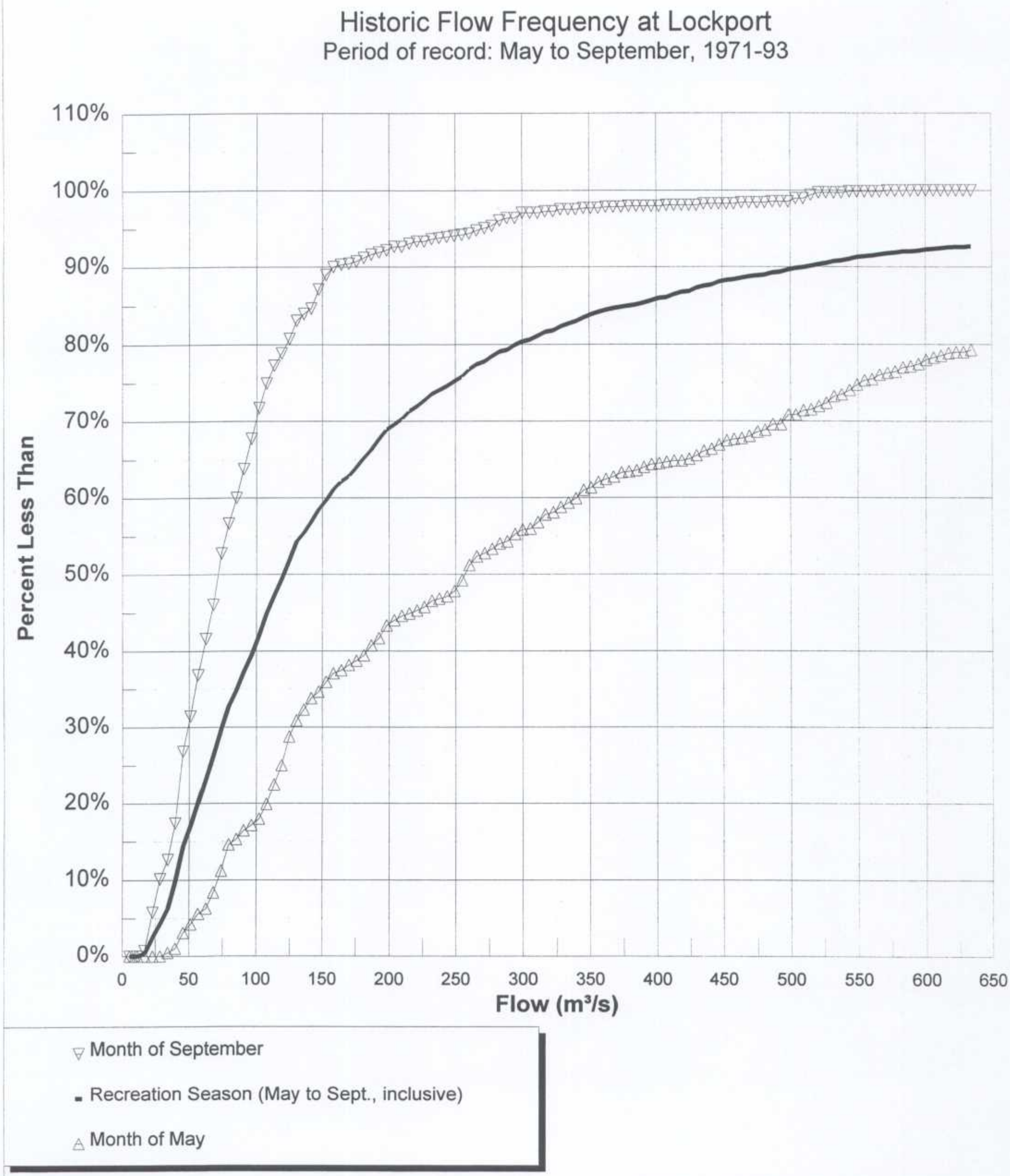
Illustrated in Figure 2-3 is a frequency analysis of flows during the recreational season (i.e., May to September). The hydraulic model was calibrated to a range of flows up to 370 m^3/s. A flow of 370 m^3/s was chosen because it represents a high flow probability (i.e., 84 percentile) and it is also the point where levels begin to rise in the centre of the City. The 370 m^3/s flow was used to estimate modelling time interval (ΔT), segment length (ΔX), and corresponding segment volumes for the dynamic routing model.

The St. Andrews Lock and Dam has a major influence on the hydraulics of the Red and Assiniboine Rivers:

- Under low flows, the backwater affect of the dam can extend as far back as Ste. Agathe (approximately 100 km upstream of Lockport on the Red River). The influence of backwater effects also impacts the Assiniboine River surface water level as far back as Omands Creek, (approximately 6 km upstream from the confluence with the Red River). Upstream of these points there is a significant rise in the river's streambed and backwater effects of Lockport have no impact on water surface profile.

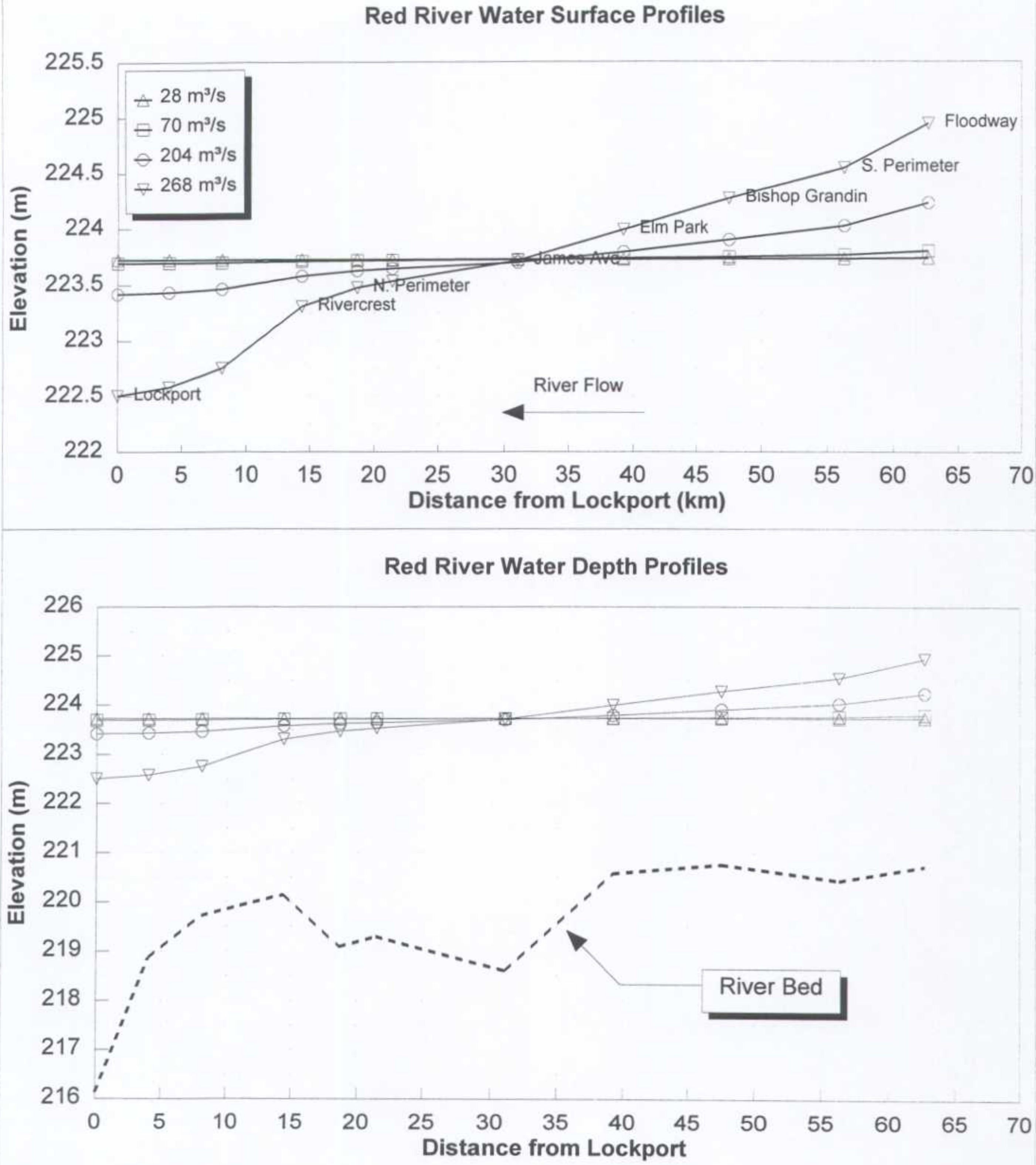
- Under higher flow conditions, up to approximately 400 m^3/s, water levels can be maintained relatively constant in the centre of the City by lowering water levels at St. Andrews Lock and Dam. This is illustrated in Figure 2-4.

- As the water surface profile changes at St. Andrews due to increased flow the size of segment volume changes. Segment volumes decrease in the Lockport area, remain relatively constant in the core of the City, and increase in the upstream area (i.e., southern part of the City).



Flow Frequency for Recreation Season Range of Flows to be Considered in Receiving Stream Model

Figure 2-3



Operation of Lockport Dam to Maintain a Constant Water Surface Elevation near the Center of the City

Figure 2-4

- Time of travel is mostly influenced by the magnitude of flow, and is moderately affected by water level profile as is the case with the Red River.

To accurately describe the influence of St. Andrews Lock and Dam requires a class of routing models that incorporates backwater in its hydraulic calculations. While HEC-2 is a backwater model, it is only used for steady-state conditions. Dynamic routing models such as EPA DYNHYD, EPA RIVMOD, and DWOPER are capable of simulating backwater effects. A hydrologic model can be confidentially applied if used within a range of flows that do not introduce significant distortion in segment volumes and affect time of travel. Accordingly, if segment volumes remain relatively constant (±10%) a simpler cascading pool model could sufficiently describe key hydro-dynamics for water-quality modelling. Examination of Figure 2-4 indicates that there is relatively flat water surface slope on the Red River from Lockport to the Floodway Inlet a distance of 60 km for flows up to 200 m^3/s, a range that would occur approximately 70% of the time according to a flow frequency assessment as shown in Figure 2-3. This indicates that a simpler cascading pool model could be applied for flows that are limited to this range. A more detailed discussion on the range of applicability of hydrologic model, i.e., a cascading pool model is found later in Section 3.1.

The key aspects to be characterized by the receiving stream model is seasonal flow variation, velocity, volume, and travel time in both the Red and Assiniboine Rivers from where they enter the City of Winnipeg, through to St. Andrews Lock and Dam (Lockport).

Various hydraulic studies have been performed on the Red and Assiniboine River. In the late 70's, the Water Resources Branch conducted flood risk mapping studies using the HEC-2 model for high flow conditions. In the mid 1980s, Environment Canada carried out dynamic routing studies (ONE-D) on the Red River between Emerson and the Floodway Inlet. One of the study members (G. Mohr) has been developing a dynamic routing model for the river to model low to moderate flow conditions (for a master's thesis). This work has further defined the hydraulic characteristic of the river. Based on this work and familiarity with the above work, the study team members have a good understanding of the hydraulic conditions of the river under a wide range of flow conditions.

Similarly, the application of the water quality model QUAL2E by local study team members in previous water quality studies of the Red and Assiniboine Rivers (MacLaren 1986; Wardrop/Tetr*ES* 1992; Tetr*ES* 1993) have enhanced our understanding of the water quality conditions for the river. The hydraulic representation of the Red and Assiniboine Rivers in the QUAL2E model provide another benchmark to compare the hydraulic characterization of the river.

2.4.2 Loadings

Response of the rivers during dry and wet weather conditions is a function of river flows and the temporal spatial discharges into the rivers. This involves the characterization of discharge sources by type (i.e., WPCC, SSO, CSO, LDS, and boundary conditions) and input locations along the extent of river to be modelled. The type of sources can be categorized as continuous (such as dry weather discharges from treatment plants) or intermittent (rainfall induced). The rate of discharge and associated water quality concentration of each discharge source needs to be quantified in terms of loading to evaluate its relative influence on the receiving stream water quality. Event mean concentrations (EMCs) as described in Technical Memoranda No. 1 - Problem Definition, were applied to the modelled discharges from each of the major sources to estimate loadings.

Major sources were considered to originate from:

- boundary conditions, quality of water just upstream of the City of Winnipeg in the Red (South Floodway Control Structure) and Assiniboine (Headingley) Rivers;

- treated effluent discharges from the three wastewater treatment plants (NEWPCC, SEWPCC, WEWPCC) under dry and wet weather conditions;

- land drainage, direct and storm retention basin (SRB) discharges;

- combined sewer overflows (CSOs), dry weather overflows and rainfall-induced discharges; and

- sanitary sewer overflows (SSOs), extraneous flows entering the sanitary wastewater system from rainfall induced events and overload the conveyance capacities of the lift stations or interceptor and result in emergency discharges to the rivers.

The key water quality constituents for receiving stream modelling were determined to be fecal coliforms and suspended solids. Fecal coliforms follow a first order die-off behaviour which is dependent on time, temperature, pH and sunlight. The response of the receiving stream to loadings from both dry and wet weather sources were considered in the receiving stream model. Suspended solids were used as a proxy for other parameters such as metals and pesticides. Both of these water quality constituents were used to estimate the relative benefits that could be achieved from a range of available control alternatives.

Dry and wet weather loadings were uniquely categorized by source type as noted earlier. Each source type was post-processed for the direct input into the receiving stream model (WASP). These included:

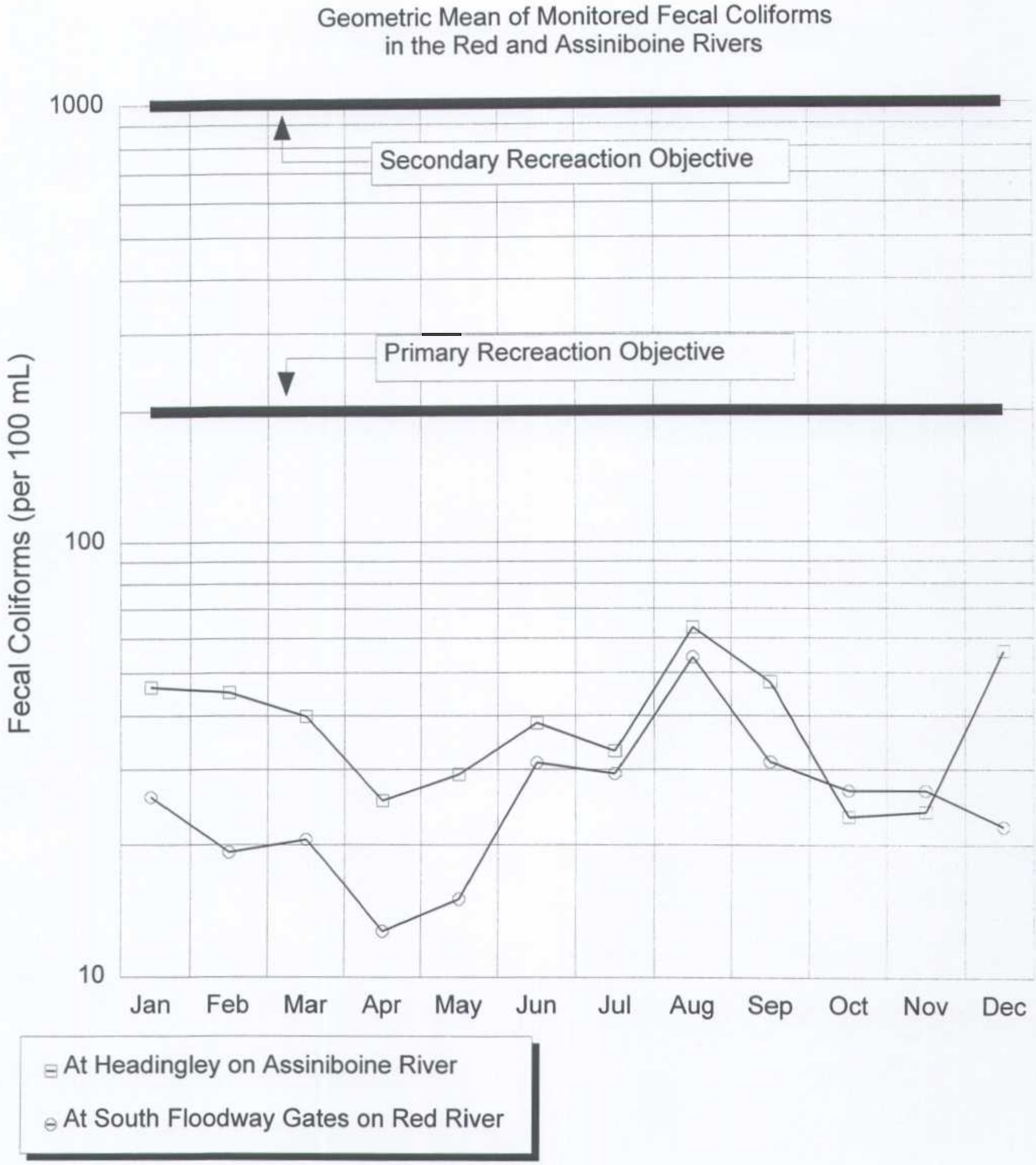
Boundary Conditions

Fecal coliforms as seasonally monitored at Headingley on the Assiniboine River and the South Floodway Inlet on the Red River were used as boundary conditions in the WASP model. The seasonal averages for both of these locations are shown in Figure 2-5.

The seasonal inputs were characterized for fecal coliforms on an average monthly basis. These values were input directly into the WASP model as the initial concentrations at the headwaters of the two rivers (Headingley and St. Agathe) and are considered to represent background levels.

Dry Weather Sources

Dry weather sources were considered to consist of average dry weather flows from the treatment plants, and dry weather overflows from combined sewers.



Seasonal Fecal Coliform Concentrations in the Red and Assiniboine Rivers Upstream of Winnipeg

Figure 2-5

Discharges from the wastewater treatment plants were considered to be a continuous source. Event mean concentrations were applied to the average dry weather discharges from the treatment plants to estimate the loadings to the rivers from each of the three plants. No attempt was made to account for the daily or seasonal fluctuations in discharges to approximate the variations in actual dry weather loadings.

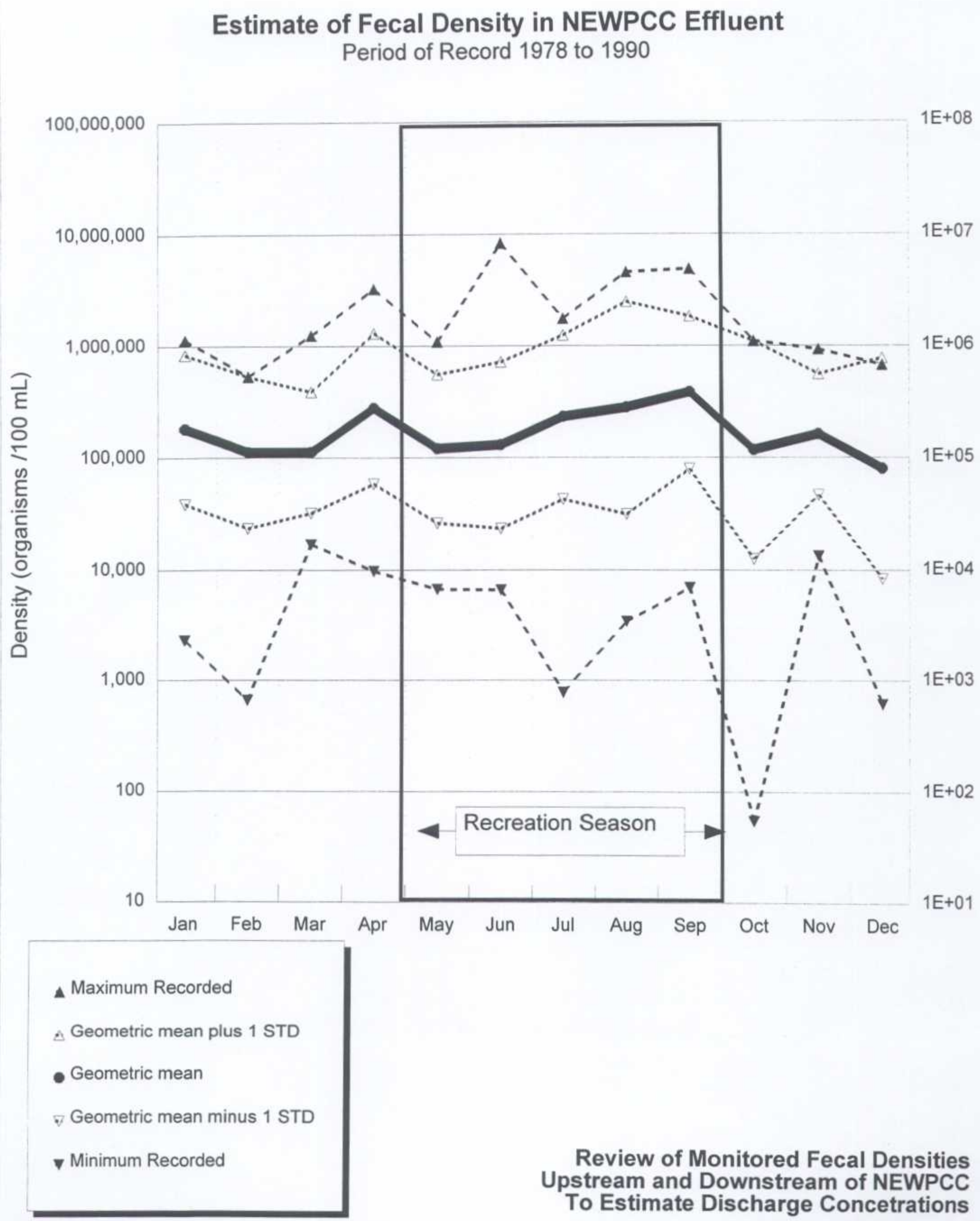
The previous studies (MacLaren 1986) estimated the final effluent fecal coliform densities to be about 400,000 organisms per 100 mL for the NEWPCC and about 250,000 organisms for the SEWPCC (MacLaren 1986).

A review of RECENT monitored river and effluent fecal coliform data was conducted to help place the current value of event mean concentrations into perspective. A recent UV disinfection study (Wardrop 1991) found fecal coliform levels in the final effluent to be:

- NEWPCC = 41,000 organisms per 100 mL;
- SEWPCC = 200,000 organisms per 100 mL; and
- WEWPCC = 20,000 organisms per 100 mL.

The significant difference in NEWPCC fecal coliform concentrations prompted a cursory analysis to be done to estimate the loading originating from the North End Water Pollution Control Centre (NEWPCC). This involved the comparison of monitored fecal coliforms as monitored upstream of the NEWPCC at the Redwood Bridge and downstream of the NEWPCC at the North Perimeter Bridge. Actual river flows and temperatures were used to estimate travel time and corresponding die-off from the fecal coliforms and the loading that would need to come from the NEWPCC to correspond with levels monitored at the North Perimeter Bridge based on upstream concentrations monitored at the Redwood Bridge. The full record of available data from 1978 to 1990 was used to estimate the statistical monthly geometric mean and its variance. It was found from this cursory analysis, as shown in Figure 2-6, that the long-term geometric mean for the recreation season is about 200,000 fecal coliforms per 100 mL. These were proposed in the EMCs for plant effluents (see Phase 2 TM #2).

The full history of fecal coliforms at established routine bi-weekly sampling locations as monitored by the City of Winnipeg for the recreation season (May 1 to September 30,



Review of Monitored Fecal Densities Upstream and Downstream of NEWPCC To Estimate Discharge Concetrations

Figure 2-6

inclusive) are shown in Table 2-4. The data was reviewed to determine if a long-term pattern was evident. The period between 1977 to 1984 was the period of record used in the MacLaren 1986 disinfection study. It was later narrowed to a smaller time period (1982 to 1984) to include the sampling done at the Fort Garry Bridge location. The geometric mean values as shown in Table 2-4 for these time periods are significantly higher than that for the 1980 to 1989 period (which was used in the 1992 CEC Hearings) and for the full period of record from 1977 to 1993. A comparison of the monitored 1992 data indicates that the values for this specific year were substantially lower than the long-term average. This trend for reducing coliform densities indicates that the treatment plant expansions, upgrades, and improvements in operations have been responsible for reducing fecal coliform concentrations in the final effluent.

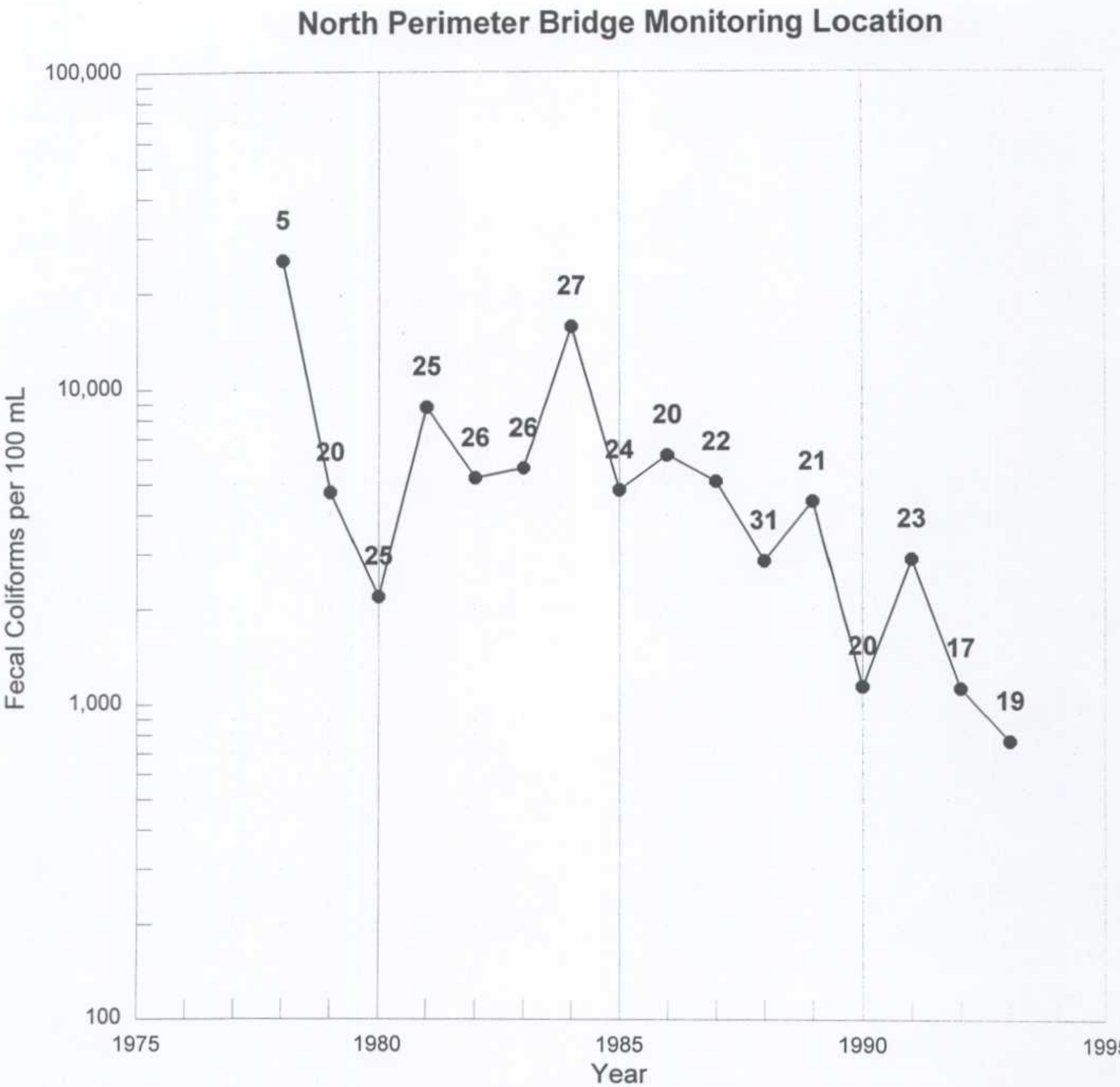
This trend is illustrated in Figure 2-7 which shows monitored fecal coliforms at the North Perimeter Bridge. Fecal coliform densities pre-1985 (before the NEWPCC secondary expansion), tended to be significantly higher than the levels monitored after the expansion. The monitored data indicates that fecal coliform levels in the final effluent in the early 1990s are at much reduced levels relative to the full history. The current lower instream fecal coliform levels can be considered as an ancillary benefit of the plant upgrades.

It was recognized that fecal coliform densities in treated effluent discharges are quite variable and would need to be taken into consideration during subsequent calibration exercises. The cursory analysis identified the likely need to adjust base loadings from these continuous sources to achieve a favourable match with monitored dry weather in stream fecal coliform concentrations. The long-term average of 200,000 fecal coliforms per 100 mL for the North End Water Pollution Control Centre (NEWPCC) was considered appropriate for initial receiving stream model development and assessment. The Disinfection Evaluation Study (MacLaren 1986) estimated the concentration to be about 200,000 fecal coliforms per 100 mL in discharge from the South End Water Pollution Control Centre (SEWPCC). The UV Pilot Study (Wardrop 1991) found the discharge concentration to be slightly higher at 250,000 fecal coliforms per 100 mL. The Disinfection Evaluation Study performed much greater effluent quality analysis to derive a statistically confident fecal coliform concentration. The UV Study confirmed that a concentration of 200,000 fecal coliforms per 100 mL is representative and remains appropriate for discharges from the SEWPCC. The West End Pollution Control Centre

TABLE 2-4

MONITOR FECAL COLIFORM CONCENTRATIONS
(ORGANISMS/100 mL)
RECREATION SEASON (MAY 1 TO SEPT 30, INCLUSIVE)

Time Period	77-84	82-84	80-89	77-93	1992
No. of Samples	n = 70	n = 30	n = 81	n = 144	n = 10
RED RIVER					
Floodway	31	43	26	30	19
Fort Garry		708	474	581	340
Norwood	676	708	542	496	151
Redwood	1122	912	924	876	373
North Perimeter	8128	8912	4016	3711	1251
Lockport	447	933	535	524	500
ASSINIBOINE RIVER					
Headingley Bridge	38	45	37	42	17
West Perimeter	72	120	100	119	88
Assiniboine Park Bridge				84	74
Main Street	1178	912	1047	1103	709



Geometric Mean of Monitored Fecal Coliform Concentrations at the North Perimeter Bridge

Figure 2-7

fecaltrd.WK4

(WEWPCC) was recently upgraded and expanded to provide full conventional secondary treatment equivalent to the SEWPCC and was considered to produce similar quality effluent. Accordingly, a concentration of 200,000 fecal coliforms per 100 mL was considered representative of long-term discharge quality from the three WPCCs and used as the EMC to estimate DWF loading from the plants.

Wet Weather Flow Sources

Wet weather flow sources were considered to be intermittent sources and the response to rainfall events. The sources considered were:

- tributary small streams;
- peak wet weather flow from WPCC;
- interceptor overflows;
- combined sewer overflows (CSOs);
- land drainage systems;
  - direct
  - storage retention basins (SRB)
- sanitary sewer overflows (SSOs).

Wet weather loadings were estimated by applying event mean concentrations as listed in Table 2-5 to estimated wet weather induced overflows as discussed in Phase 2 TM #3 - Control Alternatives.

2.5 TEMPERATURE

The simulation of many biological responses receiving stream modelling are strongly influenced by water temperature. It is therefore important to consider the thermal influences on the rate of reactions associated with the selected water quality constituents.

Table 2-5 :

Event Mean Concentrations of Fecal Coliforms

Source	Organisms/100mL
WPCCs	
- ADWF	200,000
- PDWF	200,000
- PWWF	2,400,000
Land Drainage	
- Direct	40,000
- Ponds	20,000
CSO	2,400,000
SSO	10,000,000
Interceptors	
- CSO	2,400,000
- SSO	10,000,000

The reaction rates are typically measured at standard temperature and pressure, i.e., 20°C and one atmosphere. The normal response is that cooler temperatures tend to reduce reaction rates. Temperature functions are often described by the equation listed below.

$$K = k\,\Theta^{(T-20)}$$

where
- K = decay rate per day
- k = decay constant
- Θ = temperature coefficient (1.0 to 1.08)
- 20 = standard reference temperature (°C)
- T = ambient water temperature (°C)

As can be seen by the form of the equation, the greater the difference from the reference temperature of 20°C the greater the exponential effect exerted on the decay rate. Temperature can have a profound influence on the rate of coliform die-off in the receiving stream. It is therefore important to approximate the seasonal variation water temperature in both rivers when modelling water quality dynamics on a continuous basis to account for this natural phenomena.

The City of Winnipeg routinely samples the river quality of the Red and Assiniboine Rivers every 2 weeks at several locations on a year-round basis. Information collected includes water temperature. Table 2-6 lists specific dates and corresponding water temperatures as measured in the Red and Assiniboine Rivers for 1991. These values were directly coded into the WASP model input file to approximate the change in seasonal temperatures. The WASP model uses these temperatures to adjust the kinetic rates by applying a temperature related coefficient to the rates of kinetic reactions and biological activities.

2.6 FECAL COLIFORM DIE-OFF RATES

This section will discuss the key aspects related to fecal coliform die-off. The main intent of this receiving stream water quality modelling exercise is to simulate the response of the rivers to dry and wet weather fecal coliform loadings and their corresponding transport and die-off behaviour over space and time. The WASP model was coded to accept separate input files to describe each of the loadings and rates and coefficients that were representative for the Red and Assiniboine Rivers. The general form of the equation is shown below.

TABLE 2-6

REPRESENTATIVE RIVER WATER TEMPERATURES FOR 1991

DATE	TEMPERATURE °C
May 5	9.5
May 29	21.5
June 12	22.0
June 26	24.0
July 10	24.0
July 24	25.0
August 7	22.0
August 21	24.0
September 5	20.0
September 18	13.5

$$S = S_o e^{(-Kt)}$$

where
- S = the concentration at a specific time
- S_o = the initial concentration
- e = exponential function
- K = decay rate
- t = accumulated time since S_o

To understand the sensitivity of decay rate (K), a simple sensitivity analysis was performed varying the die-off constant and temperature coefficient. The results of the analysis are shown on Figure 2-8. Figure 2-8a represents the values for die-off constant and temperature coefficient used in the Disinfection study (MacLaren 1986). The values were based on monitored river data between 1977 and 1984. The graph illustrates that cooler temperatures tend to retard the die-off of fecal coliforms over time while warmer temperature tend to accelerate the die-off behaviour. In typical summer river temperatures, the coliform essentially die-off in 2 to 3 days. Figure 2-8b illustrates the impact of holding the die-off rate constant and increasing the temperature coefficient. As seen in this graph, increasing the temperature coefficient tends to further exaggerate the spread between the family of lines. This causes reduced die-off at cooler temperatures and increased die-off for warmer temperatures. Figure 2-8c illustrates the impact of decreasing the die-off constant and holding the temperature coefficient constant. As would be expected, the family of curves shifts to the right indicating a slower die-off rate for all temperature bands.

This sensitivity analysis indicates the significance of establishing appropriate values for die-off constant and temperature coefficient in order to mimic the die-off behaviour observed in local rivers.

A cursory analysis was performed on monitored data at the North Perimeter Bridge and St. Andrews Lock and Dam (Lockport) to estimate appropriate values of die-off constant and temperature coefficient for local conditions. The North Perimeter Bridge is immediately downstream of the NEWPCC outfall, while Lockport is approximately 19 km downstream of the North Perimeter Bridge. This section of the river does not contain any other substantial dry or wet weather sources and therefore can be used to estimate the die-off constant and temperature coefficient based on monitored fecal coliform levels. The full history of data from 1977 to 1994 was used in the analysis with 1992 identified separately since it was

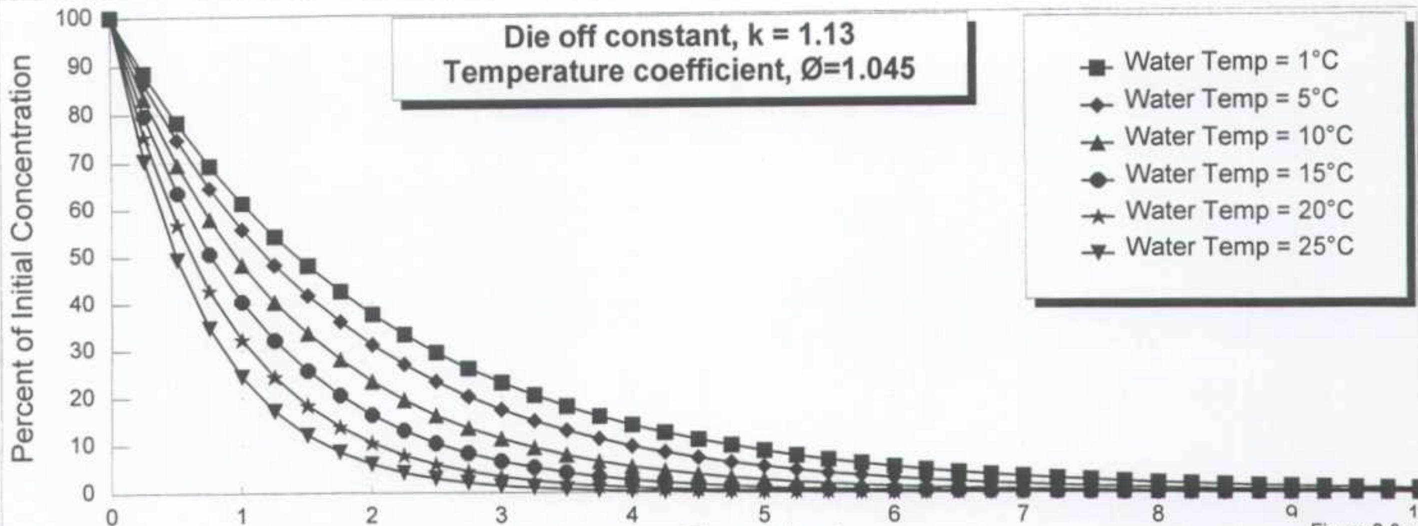


Figure 2-8a

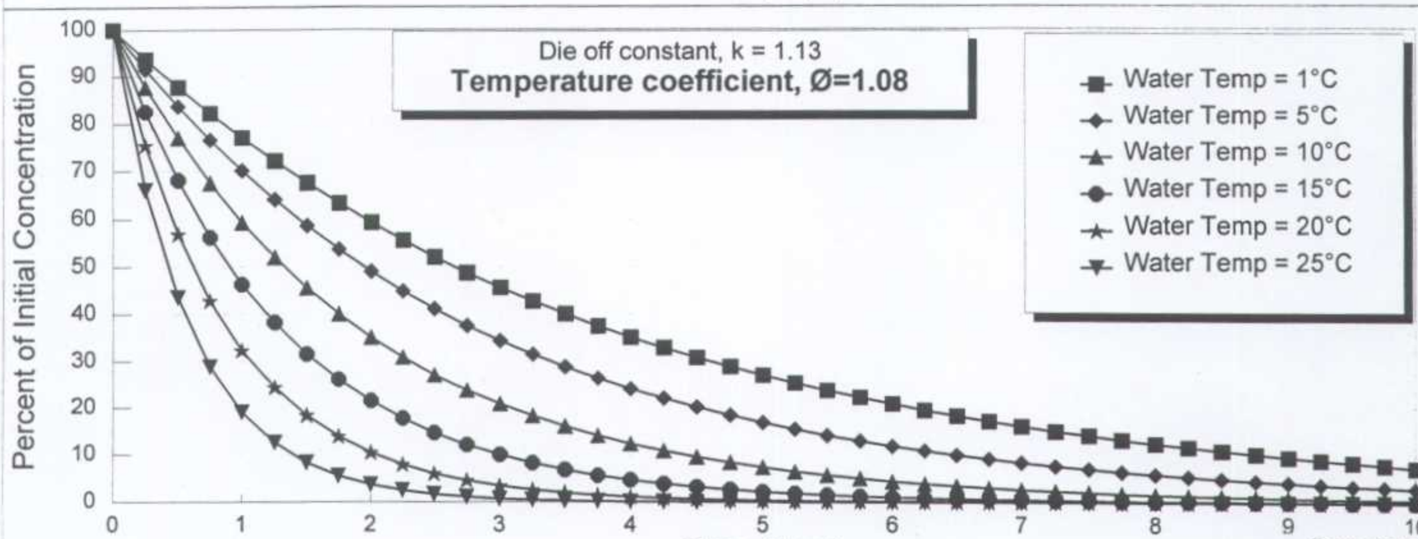


Figure 2-8b

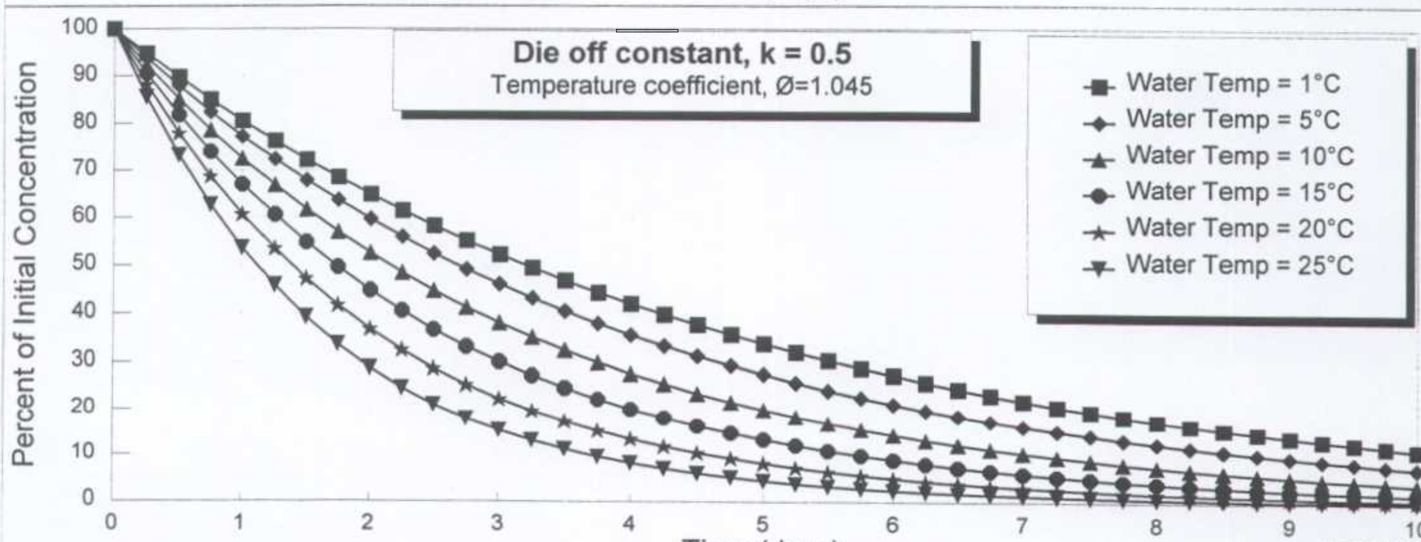


Figure 2-8c

Temporial Impact of Temperature and Decay Rate on Fecal Coliform Die-off Behaviour

Figure 2-8

considered to be representative year. The analysis involved the estimation of travel time for specific river flows from the North Perimeter Bridge to Lockport. Actual water temperatures and monitored fecal coliform levels at the North Perimeter Bridge were used to estimate the values that would best agree with monitored concentrations at Lockport. The temperature coefficient was held within the bounds of 1.0 to 1.08 and used to calculate a die-off constant that would best agree with monitored data. An objective function was created to minimize the sum of difference from predicted to that monitored to estimate the decay rate and temperature coefficient. The results are shown in Figure 2-9. It was found that a decay constant of 1.13 and temperature coefficient of 1.045 as previously assessed in the disinfection study (MacLaren 1986), remained valid for this current study.

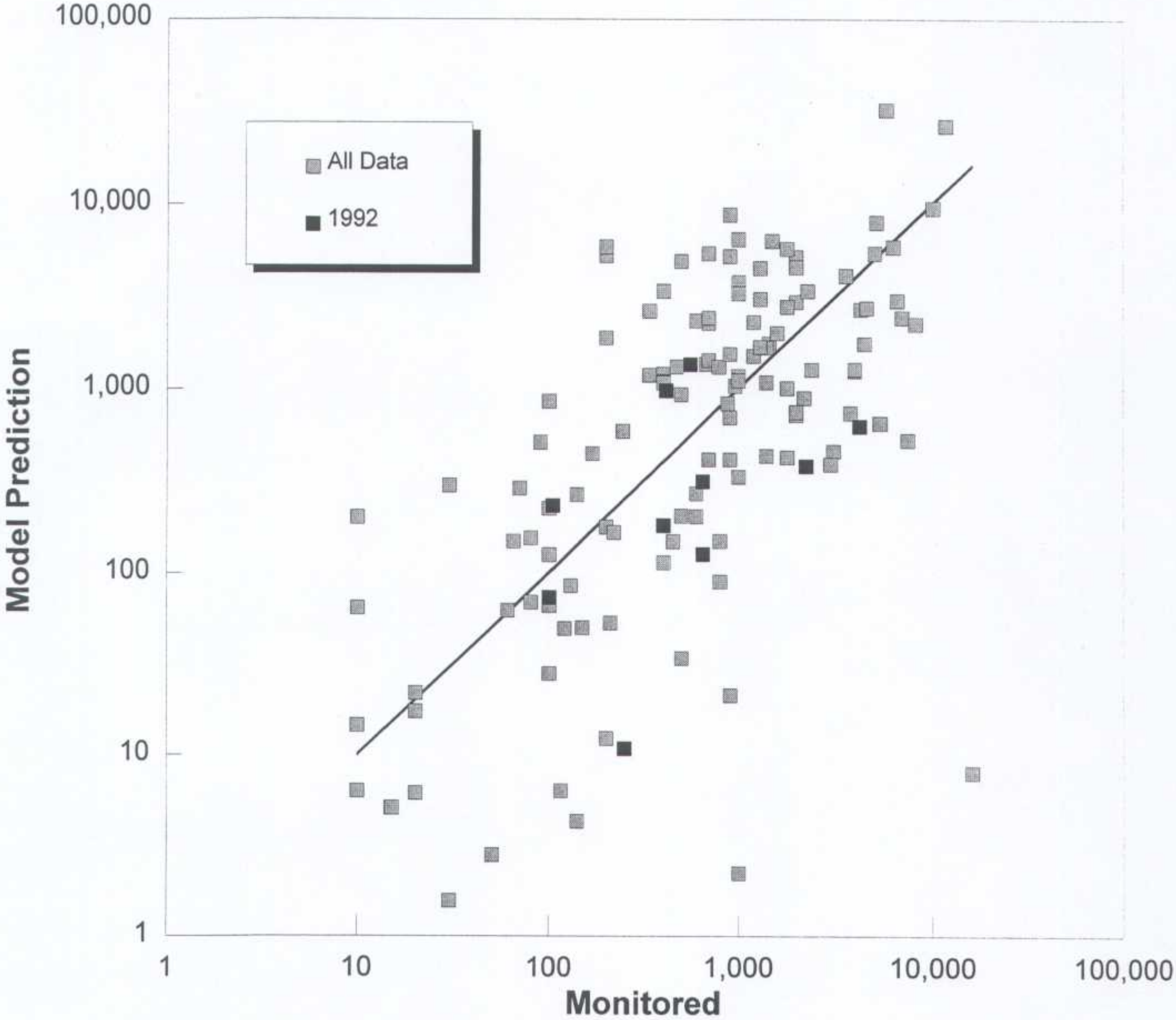
3.0 MODEL DEVELOPMENT

As part of the "quality assurance" considerations in applying a sophisticated numerical model, it was deemed prudent that its capabilities in terms of hydraulic and chemical/biological simulation routines be evaluated prior to full scale model development and application. It was important to assess the model's hydraulic representation, transport and conservation of mass for first order die-off behaviour, analytical versus numerical dispersion, and format of model output. After these conditions were satisfied, calibration and verification of receiving stream water quality (fecal coliform dynamics) was performed.

3.1 HYDRAULIC ANALYSIS

Applying a dynamic routing model, such as EPA DYNHYD, that is suitable to produce input data for later water quality modelling, involved initially applying a HEC-2 steady-state model to define the hydraulic characteristics of the river for various flow ranges. The HEC-2 model was calibrated to observed water level profiles for low to moderate flows. After calibrating the HEC-2 model, the model was used to define boundary conditions of St. Andrews Lock and Dam (Lockport). Developing boundary conditions is fundamental to applying a dynamic routing model. Several iterations were undertaken to determine the appropriate starting water surface level, for various flows to maintain a relatively constant water elevation of 223.7 m

Comparison of Fecal Coliform Concentrations
Monitored and Modelled Values



Decay Coefficient = 1.130
Temperature Coefficient = 1.045

Calibration Kinetic Rates
Associated with Fecal Coliform Die-Off

Figure 2-9

in the centre of the city. Based on this work, a stage-discharge curve was developed for Lockport.

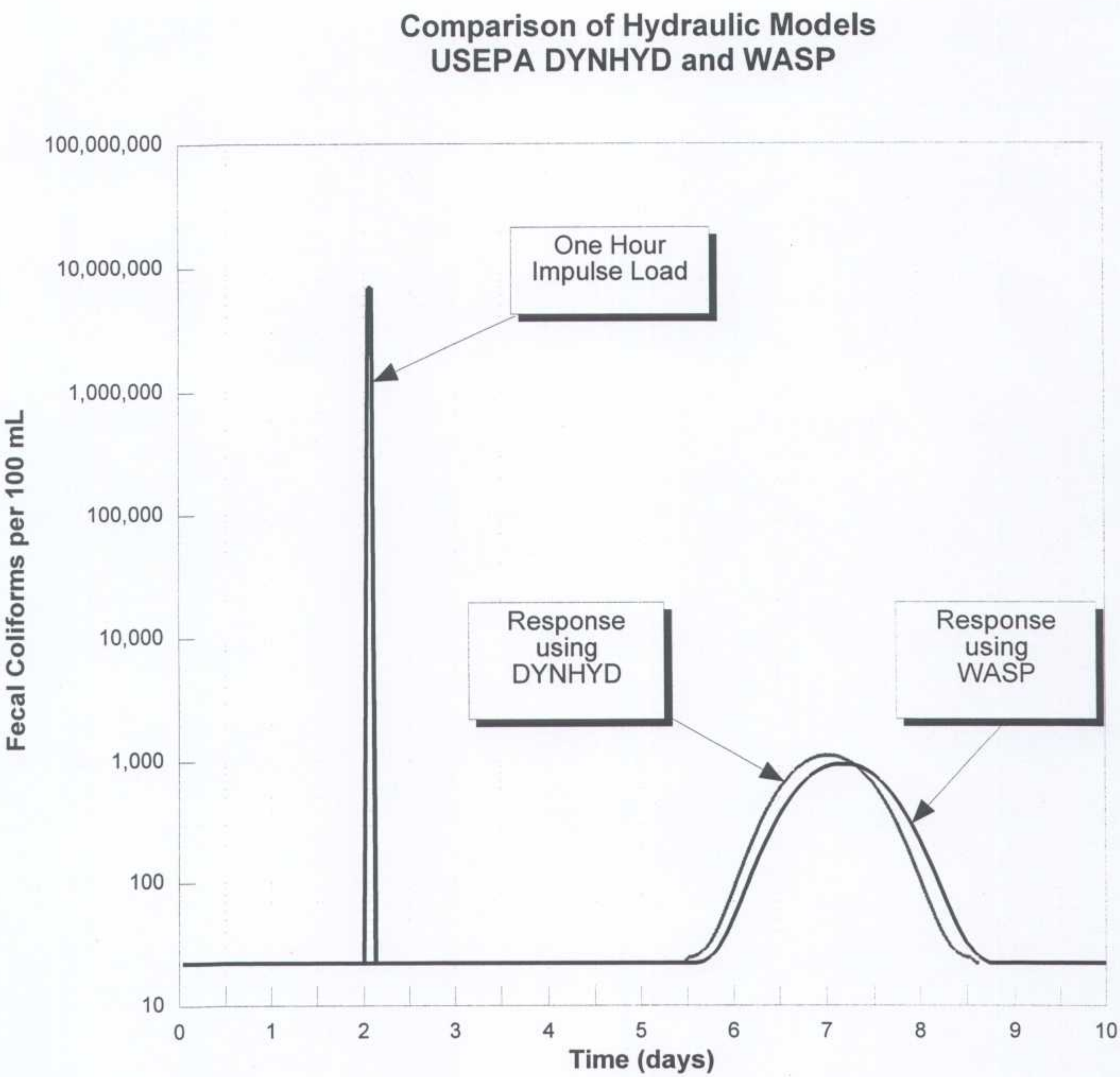
Output from HEC-2 model simulations was used to provide a cumulative calculation of volume, travel time, and distance. The South Floodway gates to Lockport on the Red River and Headingley to the confluence on the Assiniboine River, were the key stretches of the rivers used in these analyses. These analyses provided the information necessary to estimate appropriate longitudinal spacing (ΔX) and simulation time interval (ΔT) for the DYNHYD model. The Courant criteria was applied to determine specific ΔT and ΔX spacing required for the DYNHYD model. Using a design flow of 370 m^3/s for the Red River (as discussed in Section 2.4.1) and a ΔX spacing of 1 km (previously used QUAL2E studies) it was estimated that a time interval of 2 minutes or less would be needed for hydraulic calculations. Based on this estimate, cross-sections were deleted from the original HEC-2 input file to approximate the 1 km spacing. The HEC-2 output was then analyzed to assess segment volumes variation prior to inputting in the DYNHYD. From this analysis, it was determined that too much variation in segment volumes existed. The input file was then adjusted to achieve a more uniform volume distribution that resulted in a greater variation of ΔX distribution. Based on this information an input file that described the hydraulic characteristics of the river was developed for the DYNHYD model. Boundary conditions were input into the model and the model executed under steady-state conditions. Water levels from the DYNHYD runs were then compared with calibrated water levels from the HEC-2 simulations. It was observed that the DYNHYD model duplicated the HEC-2 calibrated water levels for the Red River accurately for the flow range used in the analysis.

Subsequent to the DYNHYD development a simpler hydraulic model was developed from within the WASP water quality model. Detailed hydraulic information on river stage, velocity and volume from DYNHYD was used to setup a cascading pool description within the WASP model. In a "WASP only" application, river stage dynamics (i.e., backwater) are not considered. The model uses a simple routing technique that can be described as a cascading pool model. In a cascading pool model, segment volumes are fixed and time through a segment is governed only by flow rate. Various analyses were carried out to determine the differences between the results of the two modelling techniques.

In the first test, the two hydraulic models (DYNHYD and WASP's cascading pool model) were tested using the water quality routines within the WASP model. For this test a single 1-hour point source loading was applied at the upstream end of the river, i.e., the South Perimeter Bridge and the simulation results at the downstream end at Lockport were observed. Figure 3-1 displays the response to both the DYNHYD and WASP model to a single point source hourly load at segment 64 (South Perimeter Bridge on the Red River) and the corresponding concentration at segment 1 (Lockport). The comparison of the two responses indicates a very tight representation of the key hydraulics controlling travel time and dispersion. A slight difference in magnitude and time shift is observed between the DYNHYD and WASP model. For the 10 day test case simulation, the flows were in the 80 m^3/s range. At this low flow range there is a negligible slope on the river.

In the second test, the DYNHYD model was not used. A comparison between HEC-2 and WASP (cascading pool) was made by computing volume and time of travel differences for a range of flows. For the pool model, volumes were derived from a flow of 120 m^3/s because it represents median summertime conditions and a condition where there is a negligible slope to the river. A comparison of the pool model to that of the HEC-2 model found that the maximum difference between the two models is within $\pm 5\%$ for low to median flows. As the flows increase to 244 m^3/s (upper quartile flows) the maximum difference in volume is about 10% and within the tolerance for water quality. At flows of 370 m^3/s the maximum differences increase to about $\pm 25\%$ in volume at the upstream and downstream extremes of the river. The differences approach zero at the centre of the city, as previously indicated in Figure 2-4. Because the pool model does not account for volume changes, the time of travel estimated by the pool model will be correspondingly faster in the upstream reach, the same in the centre of the City, and slower in the downstream reach than the HEC-2 estimate. The foregoing indicates that modest errors are introduced at the upstream and downstream limits for the range of flows used and satisfactory for simplified assessment of receiving stream water quality dynamics for planning level assessments.

When compared to other planning level assumptions, such as uniform rainfall across the city and EMC for fecal concentrations in overflows, the cascading pool model is sufficiently accurate to assess receiving stream response to wet weather loading and the relative benefits of different control technologies. Therefore, due to its ease of use, the cascading pool model



Impact of Choice of Hydraulic Model on Predicted Fecal Coliforms Concentrations

Figure 3-1

was used to provide flow and volume data for the WASP water quality model. Given the range of uncertainty in other assumptions it was concluded that the simplified WASP cascading pool model would adequately describe the hydraulics of the river for flows less than 400 m^3/s.

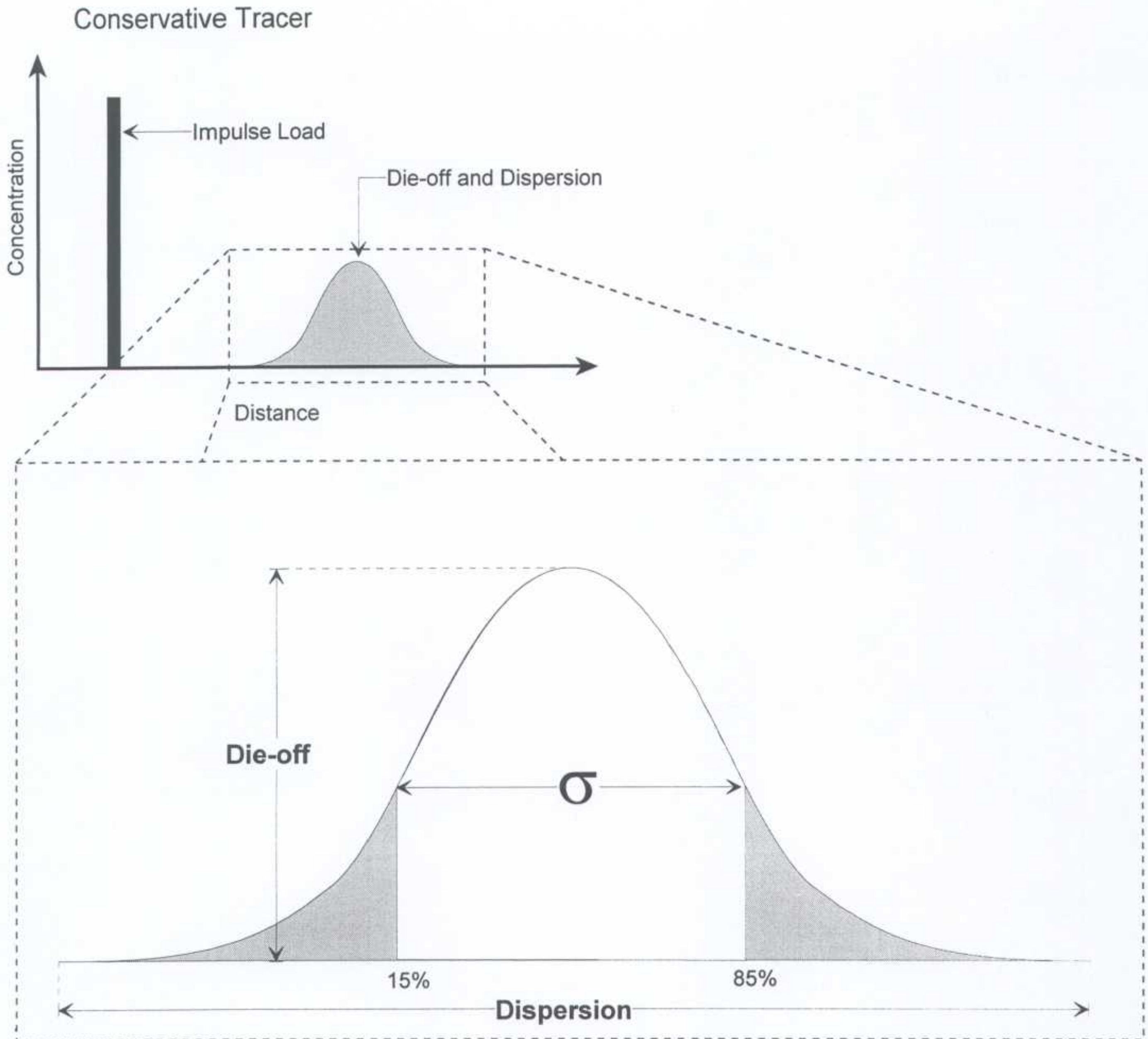
3.2 DISPERSION

It is noted that a significant amount of dispersion was exhibited by both models (DYNHYD and WASP). This aspect was subsequently reviewed to determine the extent of real dispersion that may occur in the rivers and numerical dispersion introduced by mathematical formulations/calculations.

The model routines describing die-off behaviour were evaluated to ensure that methods of transport and conservation of mass were being observed in model calculations. A spreadsheet analysis was performed to evaluate the results from the WASP model. It was found that conservation of mass was being maintained and that the transport and die-off calculations performed by the WASP model were being performed accurately.

In order to maintain a numeric stability, the WASP model calculates internally the most appropriate calculation timestep. The calculation timestep is based upon the Courant equation and varied accordingly to ensure the most stable timestep for numerical calculations. The calculation timestep is primarily a function of flows and segment volumes. A varying timestep, as calculated by the WASP model, minimizes the numerical dispersion error that could be introduced by utilizing a constant timestep for varying flows.

A comparison of the real dispersion to that which may be introduced by numerical formulation of the model was performed to assess the accuracy of model predictions and the formulation of river hydraulic representation in terms of segment size. Fischer's equation, and the McQuivey and Keefer equations (Thoman 1987) were used to estimate the actual dispersion that may be experienced in the Red and Assiniboine Rivers. The estimation of dispersion for a conservative substance is illustrated in Figure 3-2.



σ is standard deviation of the distribution of the conservative tracer (km)

$$\sigma = 2\sqrt{E_x t}$$

Solving for "E_x"

Where "E_x" is the dispersion coefficient (km²/day) and "t" is time (days)

Estimation of Numerical Dispersion Introduced by Model Calculations

c:\01_files\510a38\x4_river\FIG3-2.DRW

Figure 3-2

- Fischer *et al.* (1979) suggested the following equation to estimate dispersion coefficient in real streams.

$$E_x = 3.4 \times 10^{-5}\ U^2\ B^2\ /(HU^*)$$

$$U_* = \sqrt{gHS}$$

where

E_x = coefficient of dispersion (mi^2/day)
U = mean river velocity (ft/s)
B = mean river width (ft)
H = mean river depth (ft)
U^* = shear river velocity (ft/s)
S = river slope (ft/ft)
g = gravity (32 ft/s^2)

- McQuivey and Keefer (1974) proposed the following equation for situations where the Froude number (F) is less than 0.5:

$$Ex = 1.8 \times 10^{-4}\ Q/(S_o B)$$

where

$$F = U\sqrt{gH}$$

Q = steady state base flow (cfs)
S_o = bed slope (ft/ft)

A very favourable match was achieved between estimated dispersion based on the physical properties as described in the Fischer's equations and that introduced through WASP model computations. The analysis was done at two different river flows, a high flow in May (400 m^3/s) and a lower flow in July and August (85 m^3/s). A conservative substance was assumed to be added as an instantaneous mass load during each flow period. By measuring the standard deviation (σ) of the distribution of the mass at a specific time the dispersion coefficient (E_x) can be measured. At high flow, the dispersion coefficient was calculated to range between 46 to 54 km^2/day from WASP model results, which compares favourably to the 59 km^2/day estimated from Fischer's Equation. McQuivey and Keefer's estimate of real dispersion is much higher at 307 km^2/day. At low flows the dispersion coefficient was calculated to be between 9-12 km^2/day from WASP model predictions and were somewhat higher than the Fischer's estimate of 3 km^2/day but lower than the McQuivey and Keefer estimate of 69 km^2/day.

The results indicate that the extent of numerical dispersion introduced by WASP model computations is a good representation of that which may be experienced in the rivers.

3.3 DATA INTERPRETATION

An important aspect of modelling is the ability to interpret model output. Based on the requirements of continuous simulation and the segmentation of the river reaches, it is necessary to post-process the data in order to display the results in a meaningful fashion. The developers of the US EPA WASP (AScI) were contacted directly to assist in both the pre-processing and post-processing of model results. It was learned that the WASP model generates output data for model predictions in a format that can be readily managed by a database information management system. To prevent the misinterpretation of results, input and output units were carefully assessed so that comparison with monitored information were accurately represented. The other important parameter when considering model output is the detail and frequency at which printout of results are generated by the model. In this particular case, a 1-hour printout timestep of results was required to describe the transient response of fecal coliforms in the rivers.

The preliminary results from the WASP model for 1991 data were reviewed with special advisors at Working Session No. 7. This provided the opportunity and forum for outside advisors and City representatives to comment on model construction and results at an early enough stage to influence its detailed setup and processing of results. This working session confirmed that the approach used in the development of the receiving stream model and the analysis of its results would provide the information necessary to assess receiving stream impacts and the framework to assess benefits for various control alternatives. It was strongly emphasized that a development of the receiving stream model consider control aspects prior to its construct to efficiently utilize resources and minimize modelling effort in subsequent stages.

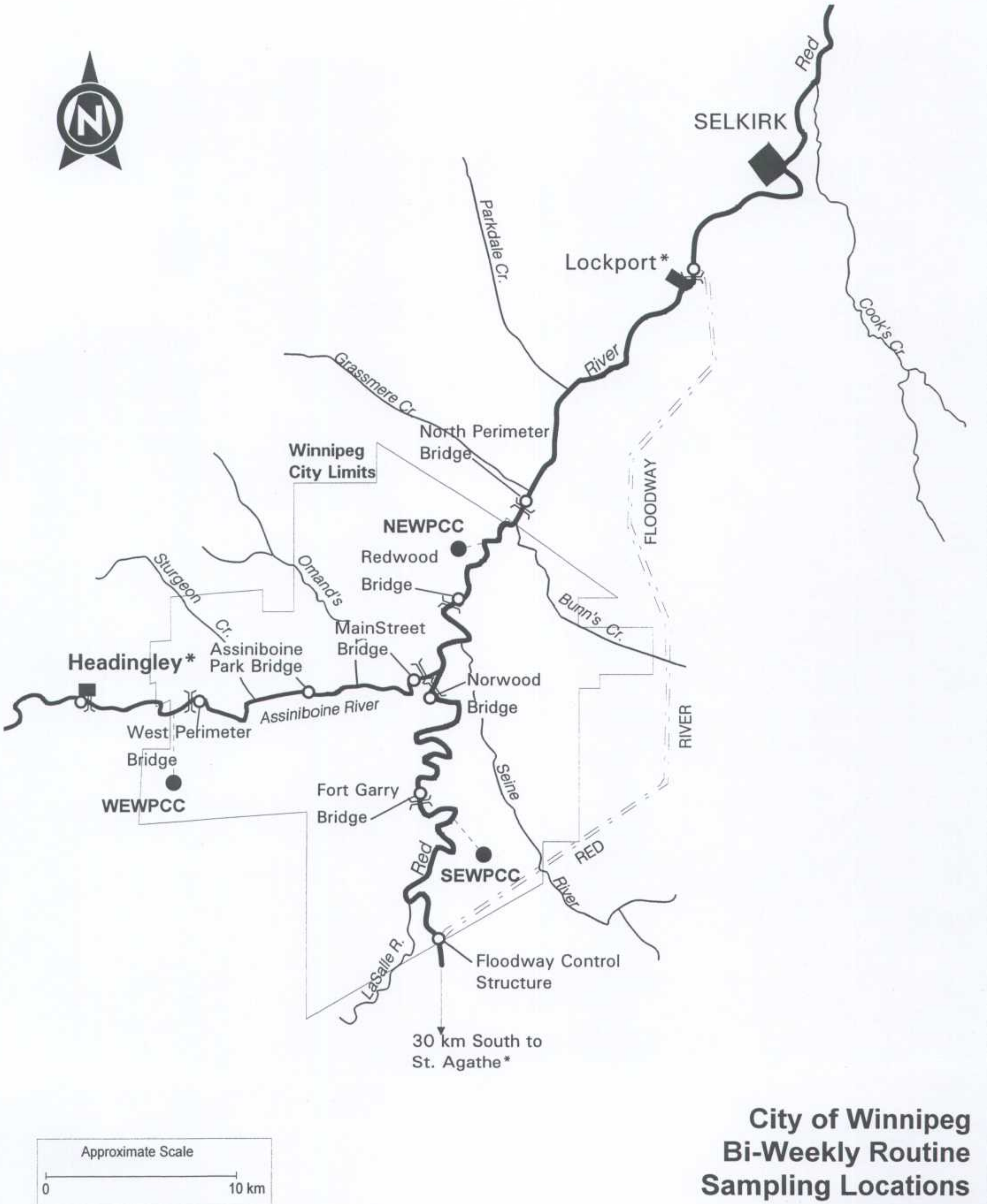
3.4 CALIBRATION

The calibration of the model involved a review of the monitored bi-weekly river quality data at locations shown in Figure 3-3 for the period 1977-93. Geometric mean and standard deviation of monitored fecal coliforms at these locations were used as the target range within which the receiving stream model should predict. Model predictions for the representative year (1992) for the Red and Assiniboine Rivers were compared with these long term monitored fecal coliform levels at specific locations along the rivers to assess the model predictions. Figure 3-4 displays geometric means and one standard deviation (STD) for both predicted and monitored fecal coliform levels.

For the Red River, the results for the representative year compared very well with the range monitor for the full history from 1977-93, except for one location. As shown on Figure 3-4, at approximately river mile 35, the monitored geometric mean and its standard deviation are above the levels predicted by the model. It is suspected this may result from a dry weather overflow occurring on the Assiniboine River or on the Red River downstream of the confluence.

For the Assiniboine River, predicted coliform densities do not correspond well with the 1977-93 monitor range in the upper reaches of the river. While the downstream ranges match reasonably well, the predicted levels are too high upstream. The loading from the WEWPCC are clearly too high and not representative of long-term conditions, as shown in Figure 3-4a. Previous studies did not have the benefit of the newly added bi-weekly monitoring location at the Assiniboine Park bridge at river kilometre 16. Previously, it was uncertain whether discharges from the WEWPCC at river kilometre 6 were responsible for the measured concentration at the Main Street Bridge on the Assiniboine River. Recent data suggests that the discharges from the WEWPCC are (and probably have been) significantly lower than the assumed 200,000 fecal coliforms per 100 mL that were used in the model to match levels monitored at the Main Street Bridge.

The inclusion of the recent monitoring location at the Assiniboine Park Bridge indicated that discharges from the WEWPCC have been significantly lower historically and that a dry weather overflow (DWO) source of loading was likely occurring downstream of the



City of Winnipeg
Bi-Weekly Routine
Sampling Locations

** - denotes: Locations monitored by Environment Canada for Flows*

Figure 3-3

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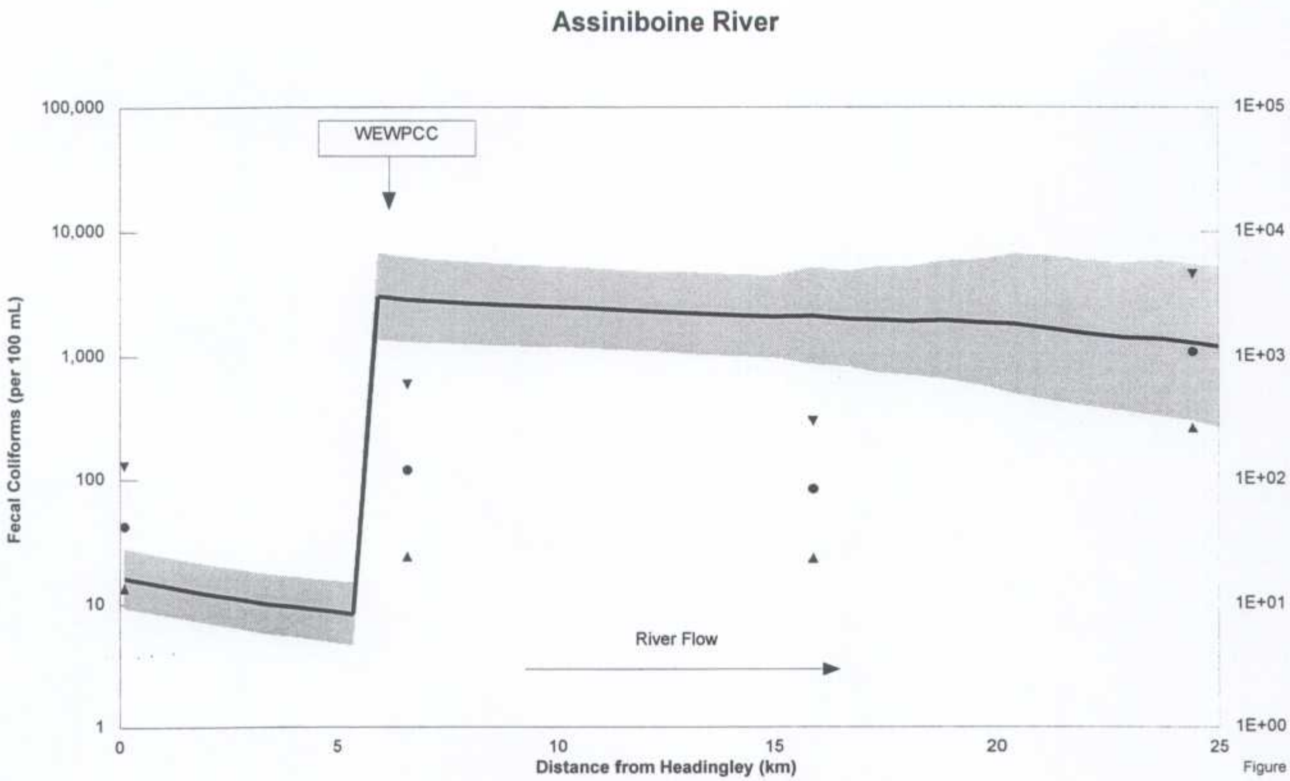


Figure 3-4a

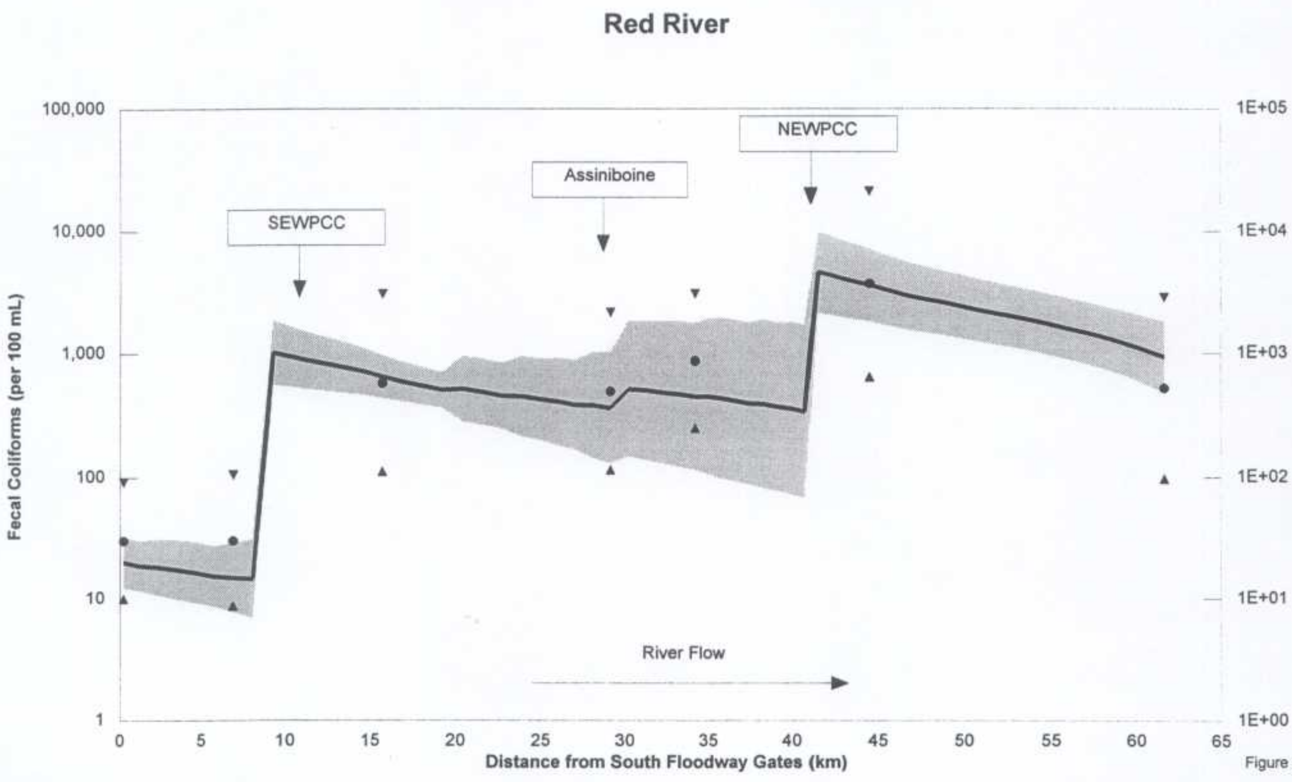


Figure 3-4b

- Modelled Geometric Mean
- Modelled Standard Deviation (STD)
- ▼ Upper STD for 1977-93 Monitored Data
- ● GeoMean for 1977-93 Monitored Data
- ▲ Lower STD for 1977-93 Monitored Data

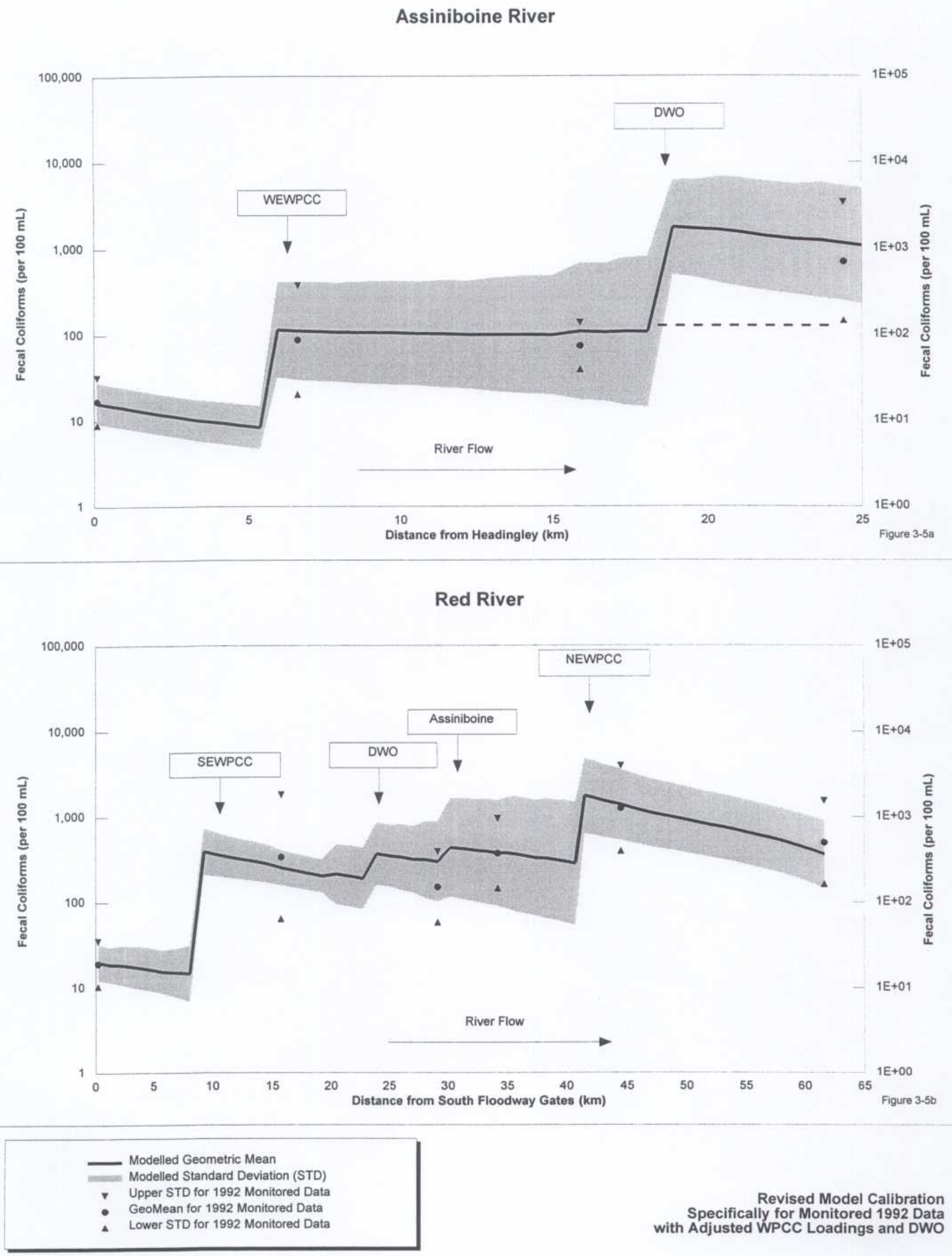
Initial Model Calibration for Monitored Long-term Data (1977-93) and Predicted Fecal Coliform Densities for Representative Year (1992)

Figure 3-4

Assiniboine Park Bridge. The increase in geometric mean concentration from that monitored at the Assiniboine Park Bridge to that monitored at the Main Street Bridge is likely in response to a dry weather overflow (DWO) source. The FAST alarm data indicates that the Tylehurst station (at about river kilometre 18) has overflowed frequently during dry weather conditions and is a highly suspect location. As well, the Cockburn combined sewer district (on the Red River) as monitored by the FAST alarm data indicates that it is also a possible source of dry weather overflows. The loadings to the Red River from the Cockburn dry weather overflow are not as identifiable as those observed on the Assiniboine River, as illustrated by the plotted data on Figure 3-4b.

A second calibration was done specifically using monitored 1992 data as shown in Figure 3-5. The comparison of the predicted and monitored fecal coliform concentrations further indicates that WPCC fecal coliform loadings for 1992 were significantly lower in concentration that the long-term average, and that a dry weather source was likely occurring on the Assiniboine River downstream of the Assiniboine Park Bridge. This is the only plausible explanation for the overall observed data. Loadings from the three treatment plants were adjusted to correspond with monitored river concentrations as shown in Table 3-1. The adjustment reflects that current loadings from the treatment plants are significantly lower than the long-term average. As discussed earlier, the observed concentrations for current conditions are an ancillary benefit from the treatment plant upgrades and enhanced operations.

The results of the receiving stream modelling for the Assiniboine River indicated the possibility of a dry weather overflow occurring downstream of the Assiniboine Park Bridge. An increase of about 900 fecal coliforms per 100 mL in the predicted values in the river would be sufficient to achieve the observed concentrations at the Main Street Bridge location. A cursory calculation was performed using Tylehurst as a representative dry weather overflow source to estimate the quantity of discharge that would be required to achieve an increase of about 900 fecal coliforms per 100 mL in the Assiniboine River. Table 3-2 illustrates the calculation of discharge and fecal coliform concentration in wastewater that would be sufficient to cause such an increase. Monitored dry weather fecal coliform concentrations in raw wastewater ranged from 4 million to 400 million fecal coliforms per 100 mL. The concentration of 100 Million per 100 mL represents the higher range of monitored concentrations while the 10 Million per 100 mL represents the estimated concentration of



Revised Model Calibration Specifically for Monitored 1992 Data with Adjusted WPCC Loadings and DWO

Figure 3-5

Table 3-1

Estimated Concentration of Fecal Coliforms in Treated Effluent (Organisms per 100 mL)

Wastewater Treatment Plant	Representative Long-term Concentration	Calibrated 1992 Conditions
NEWPCC	200,000	60,000
SEWPCC	200,000	70,000
WEWPCC	200,000	5,000

Table 3-2
Estimated Potential Loading From a Dry Weather Overflow Source
Downstream of Assiniboine Park Bridge

Calulation #1 :Tylehurst

Assume Raw Sewage =	**100,000,000 fc/100 mL**
Dry Weather Flow (DWF) =	0.022 m^3/s
Pumping Capacity =	0.177 m^3/s
River Flow =	32.6 m^3/s
Overflow Density =	12,276,786 fc/100 mL
Upstream River Density =	60 fc/100 mL
Downstream River Density (‡) =	888 fc/100 mL
Overflow Required =	0.0022 m^3/s
Equivalent multiple DWF =	**0.10**

Calulation #2 :Tylehurst

Assume Raw Sewage =	**10,000,000 fc/100 mL**
Dry Weather Flow (DWF) =	0.022 m^3/s
Pumping Capacity =	0.177 m^3/s
River Flow =	32.6 m^3/s
Overflow Density =	1,089,109 fc/100 mL
Upstream River Density =	60 fc/100 mL
Downstream River Density (‡) =	895 fc/100 mL
Overflow Required =	0.025 m^3/s
Equivalent multiple DWF =	**1.14**

‡ Note: Indicated Actual Increase in River Density is about 900 fc/100mL

sanitary sewer overflows. The intent was to estimate the range of flows required from a single discharge source with these concentrations to determine if a single dry weather source could reasonably cause such a response in the receiving stream.

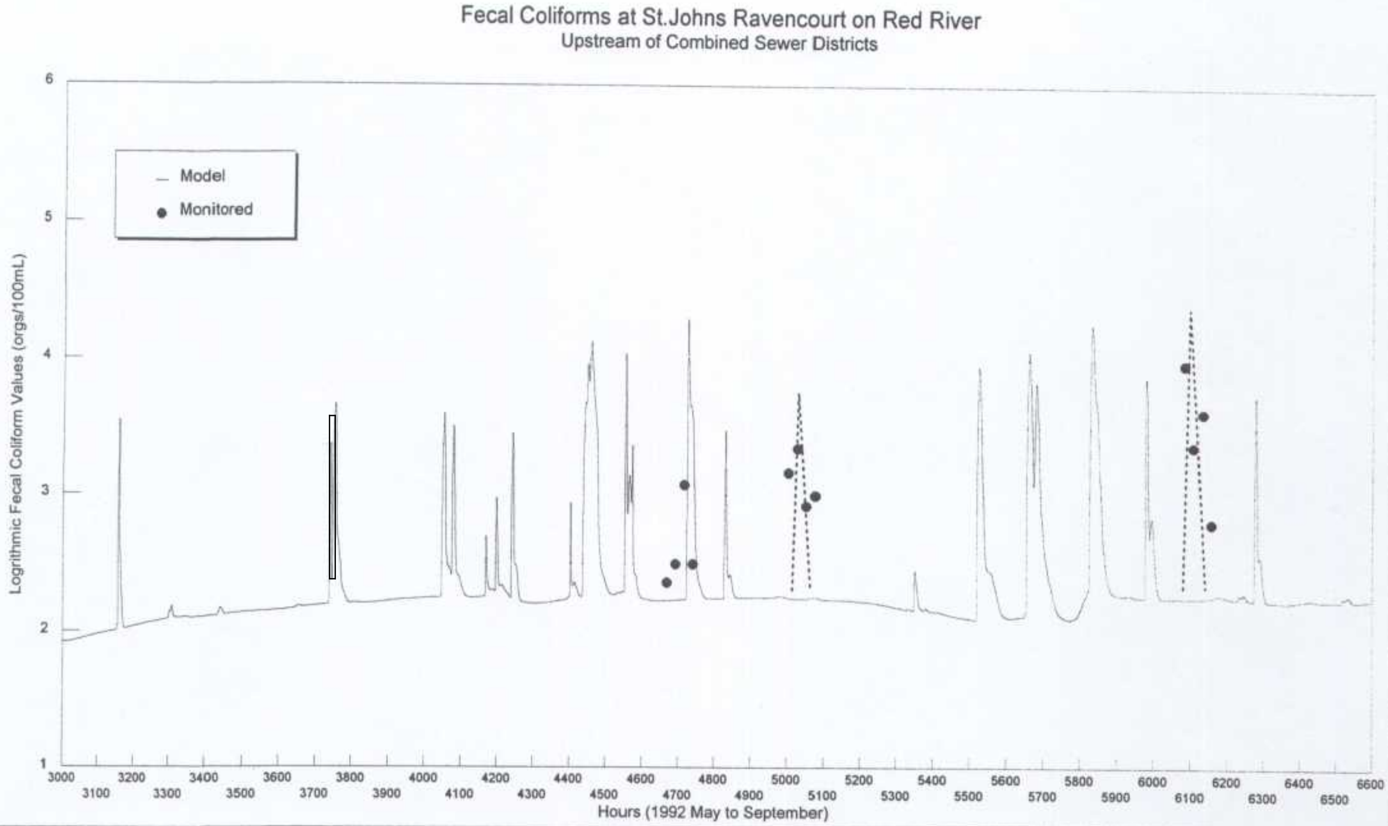
Results of the cursory calculation revealed that a discharge in the range of .1 to 1.1 times DWF would be sufficient to cause an increase in the receiving stream that would correspond to an increase of about 900 fc per 100 mL. The calculations indicated that a small amount of continuous dry weather overflow would be capable of causing such an increment in fecal coliform concentrations.

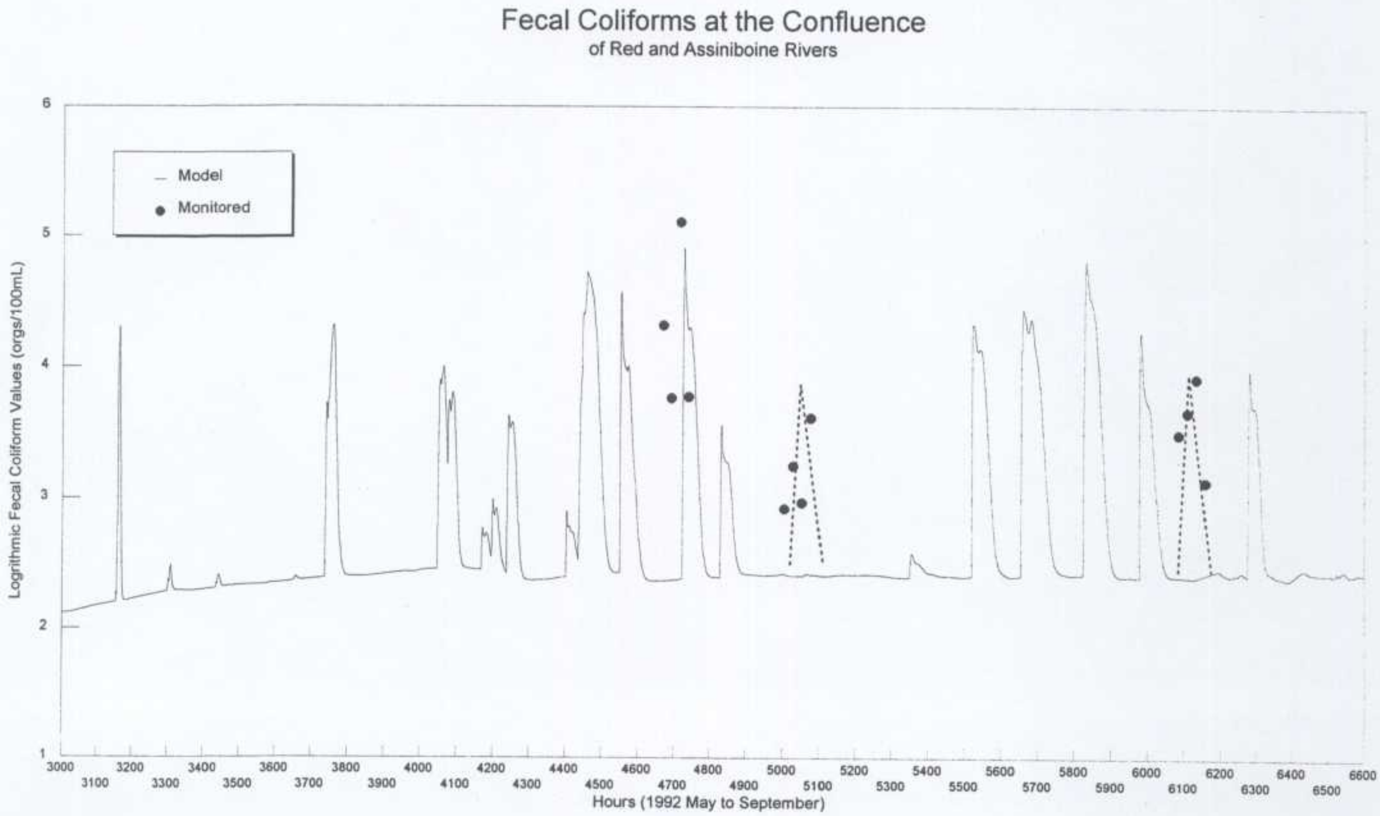
The Tylehurst location was selected to illustrate the impact of a dry weather overflow. It is not necessarily the overflow source responsible for the increase in observed fecal coliform concentrations in the river, however, the FAST alarm data strongly indicates that Tylehurst does experience dry weather overflows. Further investigation in the reach of the river downstream of the Assiniboine Park Bridge is warranted to identify other possible dry weather sources and appropriate actions to taken to identify the cause and possible controls.

The addition of dry weather overflows at Tylehurst and the use of reduced loadings from the WPCCs achieved a favourable calibration with monitored 1992 conditions as shown in Figure 3-5a. The dashed-line, for the Assiniboine River, indicates the predicted fecal coliform level if the assumed dry weather overflows were corrected. It is also noted that the fecal coliforms objective for recreation is 1000 organisms per 100 mL on the Assiniboine River and 200 organisms per 100 mL for the Red River. The preceding indicates that a favourable calibration between model prediction and monitored results was achieved for both rivers.

3.5 VERIFICATION

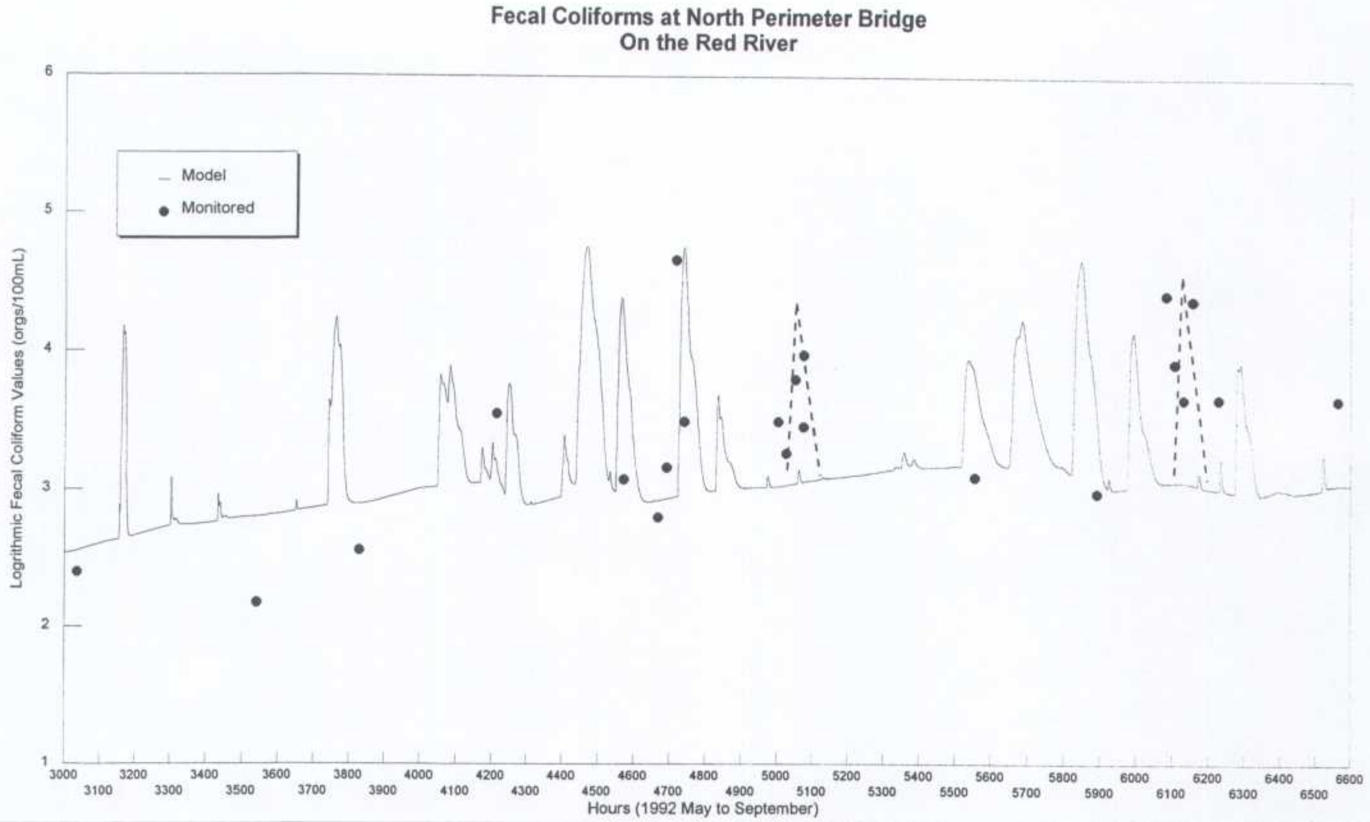
The City staff monitored water quality for several days after a CSO event. This 1992 special CSO monitoring program was used as an independent data set to verify the model predictions. A series of comparative data from the model and these monitored data at several locations are shown in Figure 3-6 and Figure 3-7. These illustrate the predicted range of fecal coliform levels in the rivers before and after rainfall events and how these relate to monitored fecal

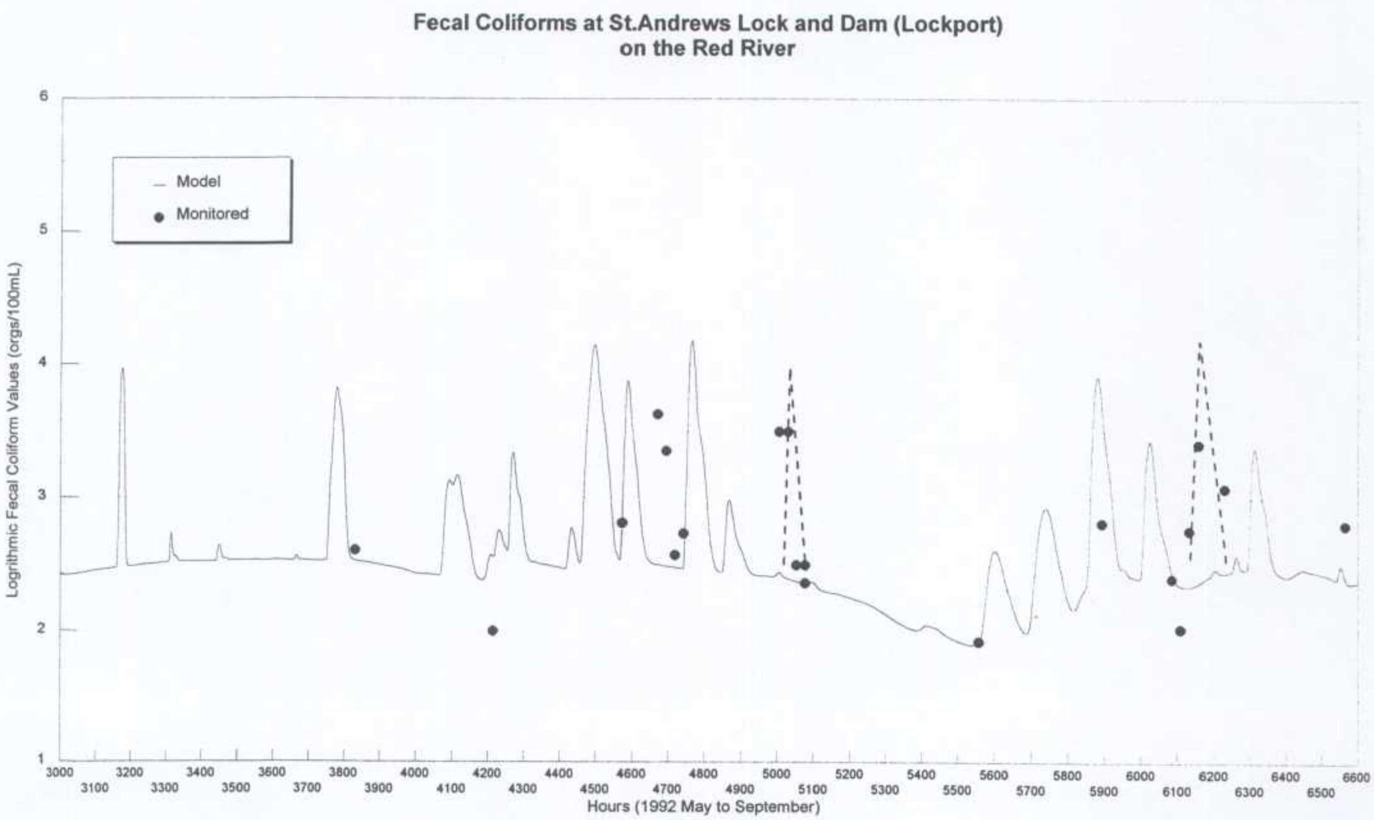




Verification Modelled Fecal Coliforms for Selected Locations Adjusted WPCC Loading and DWOs

Figure 3-6





Verification Modelled Fecal Coliforms for Selected Locations Adjusted WPCC Loading and DWOs

Figure 3-7

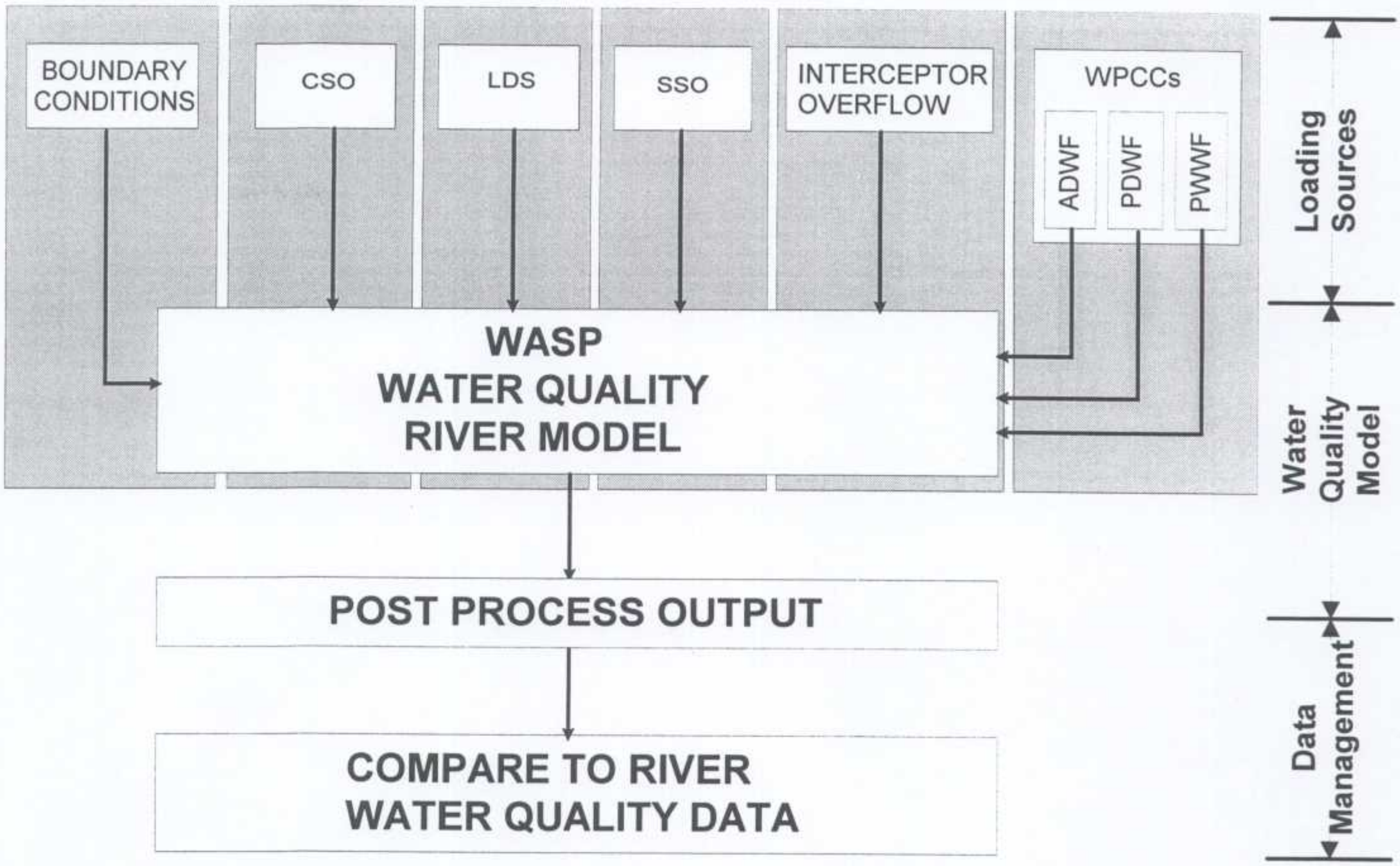
coliform concentrations. The rainfall data used for runoff predictions was based on the AES gauge at the airport. This rainfall was applied uniformly across the City of Winnipeg in the runoff modelling. While the predicted and monitored ranges coincided well, there were two monitored events where the model did not show any response.

An integrity check was performed on the AES Winnipeg International Airport rainfall data. The two data sets (hourly and daily totals) published by the AES were reviewed along with City of Winnipeg telemetry data. The AES hourly rainfall data was used in the runoff modelling. The sum of AES hourly data was compared to the reported daily totals to determine if data gaps or inconsistencies were inherent in the hourly data set. The integrity check revealed that several rainfall events in 1992, and other years, were missing from the hourly data. Specifically, two of the three 1992 CSO events monitored by the City of Winnipeg during a special monitoring program were missing from the AES hourly rainfall data set and, accordingly, were not included in the runoff modelling. This explains the lack of agreement between monitored and predicted fecal coliform levels in the rivers for these specific dates. Model predictions for rainfalls of this magnitude were estimated and are shown in dotted lines on the graphs. (Time did not permit a full re-run of the river model. This will be done early in Phase 3). These estimates show good agreement with the observed data. Given the inherent difficulties and variations in coliform assessment, it is considered that the model calibration is verified for planning purposes.

4.0 EXISTING CONDITIONS

As part of the recommendations from Working Session No. 7, a representative year (1992) was selected for use in the WASP modelling. As discussed earlier, 1992 was found to have representative river flows and rainfall and would be indicative of typical or normal conditions for screening level assessments. The representative year for calibrated 1992 conditions was considered as existing conditions and used as a baseline to assess compliance with MSWQO. Accordingly, WASP model inputs were prepared specifically for the year 1992. Figure 4-1 illustrates the major sources of loadings to be accepted by the receiving stream model and the post-processing to compare with actual monitored data. The inputs to the WASP model included:

Run WASP for Each Loading Source and Add (Superposition) Results



Receiving Stream Modelling

Figure 4-1

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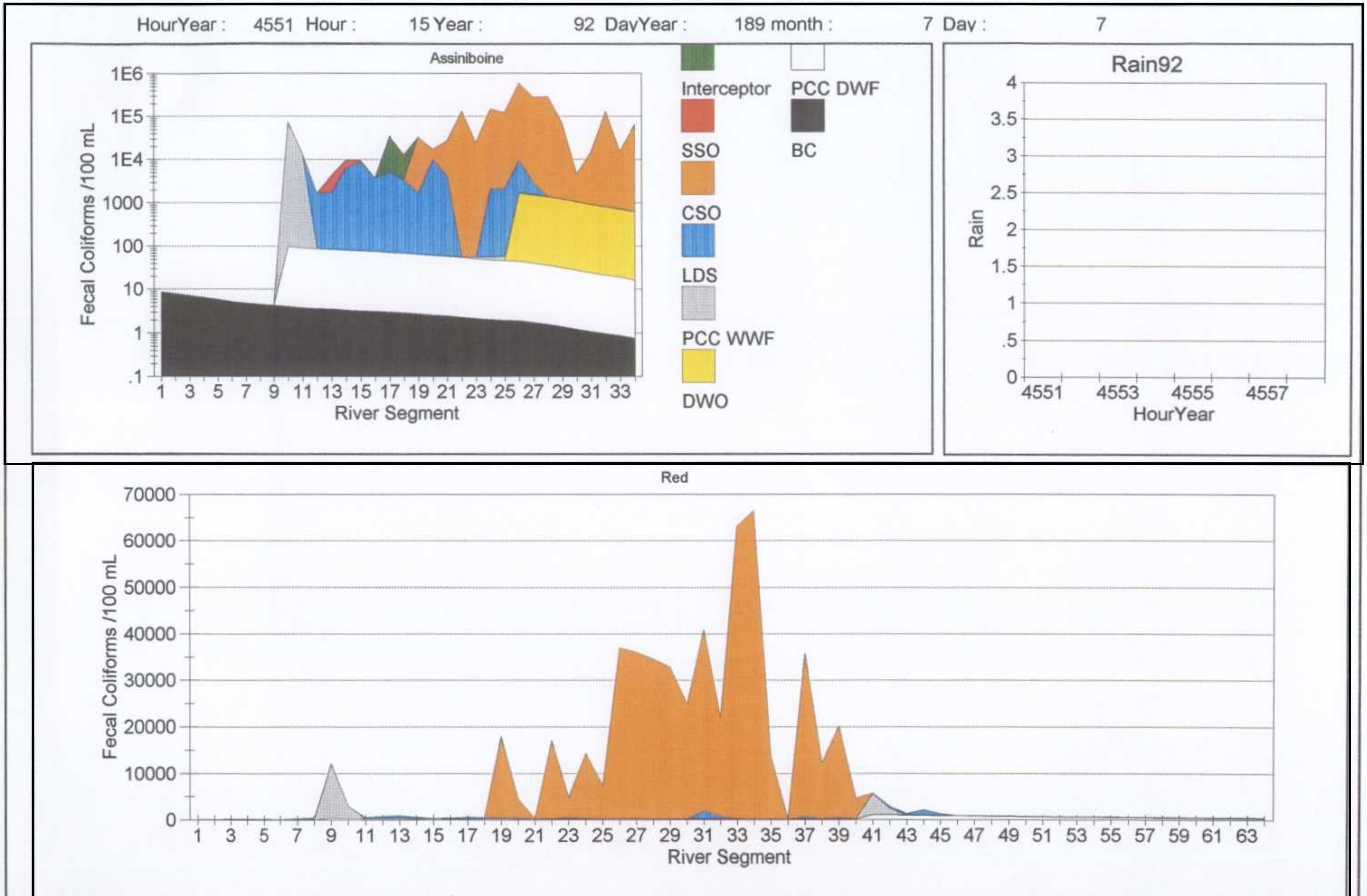
- daily river flows;
- monthly average water temperatures;
- hydraulic description of the Red and Assiniboine Rivers;
- fecal coliform die-off rate;
  - decay constant, (K = 1.13)
  - temperature coefficient, (Θ = 1.045)
- loads from various sources (see Figure 4-1)
  - boundary conditions
  - WPCC discharges for ADWF, PDWF, PWWF
  - interceptor overflows
  - combined sewer overflows
  - sanitary sewer overflows
  - direct discharge of LDSs and through SRBs.

4.1 MODEL SIMULATIONS

Individual WASP runs were performed for each of the identified loads to characterize its relative contribution to fecal load into the rivers. This approach permits the characterization of the relative contribution of the major fecal loading sources to the rivers and identification of the key sources for control. The theory of super-position was used to add the loads from the various sources, as shown in Figure 4-2, to display the relative impacts of each of the sources and the cumulative total along the reaches of the Red and Assiniboine Rivers for a specific date and time. Figure 4-2 displays the information for a specific date and time for a 1-hour display of the dynamic modelling of the whole season. The graph shown for the Assiniboine River is in logarithmic format simply to accommodate all components. The relative impacts from each of the major sources are better seen on the conventional scale on the Red River display. A dynamic presentation of the data for the full recreation period in hourly time segments was produced for the year 1992. The response of the receiving stream to rainfall events and the relative contribution of the major loading sources to the rivers was shown at Working Session #8. The results clearly indicate that combined sewer overflows are the dominant influence of fecal coliform levels in the receiving stream during wet weather events. These peaks die-off fairly rapidly as they pass through the river system. Loadings



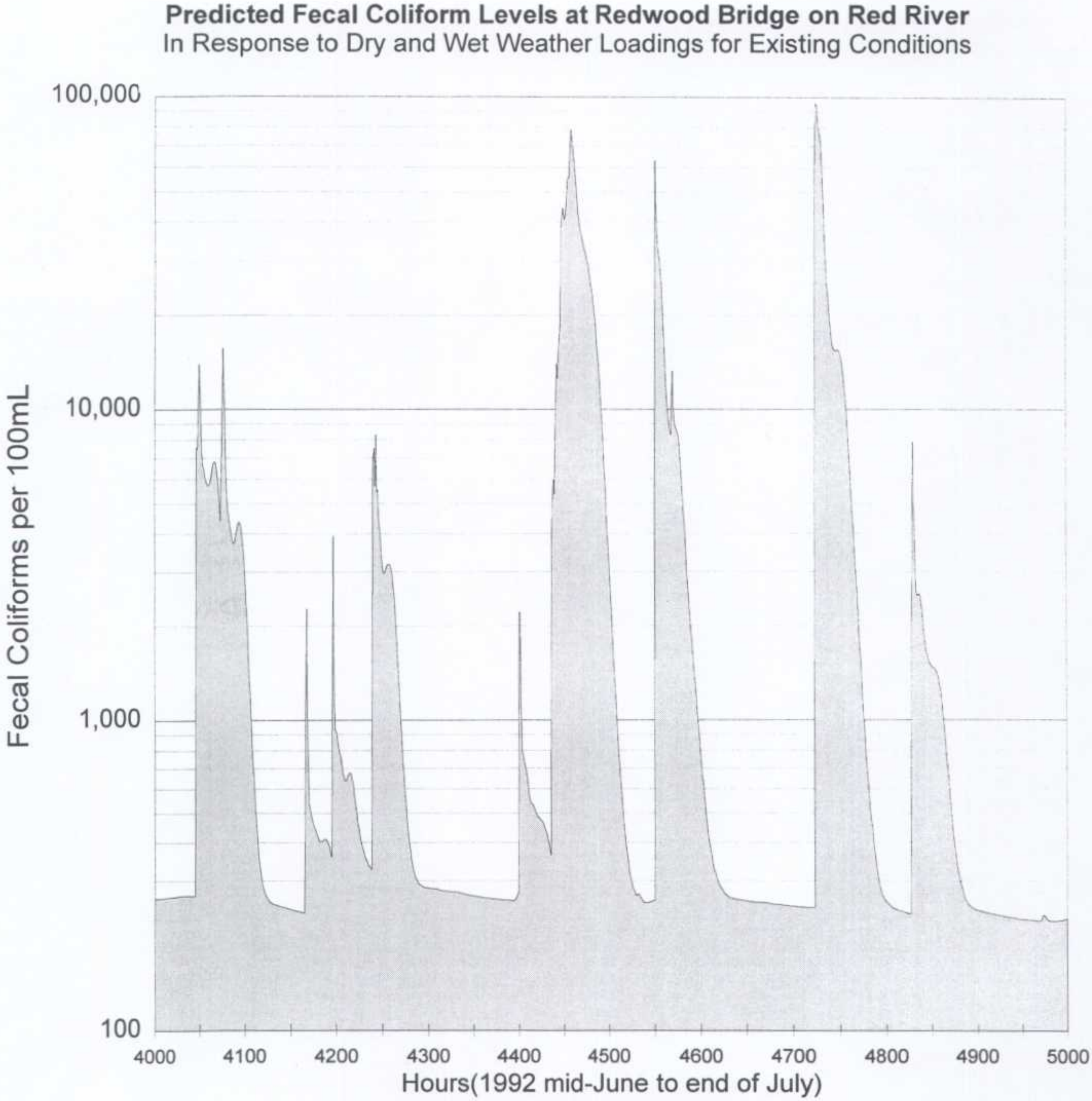
Dynamic Fecal Coliform Model

Figure 4-2

from the WPCCs are the dominant influence of fecal coliforms in the rivers during dry weather conditions.

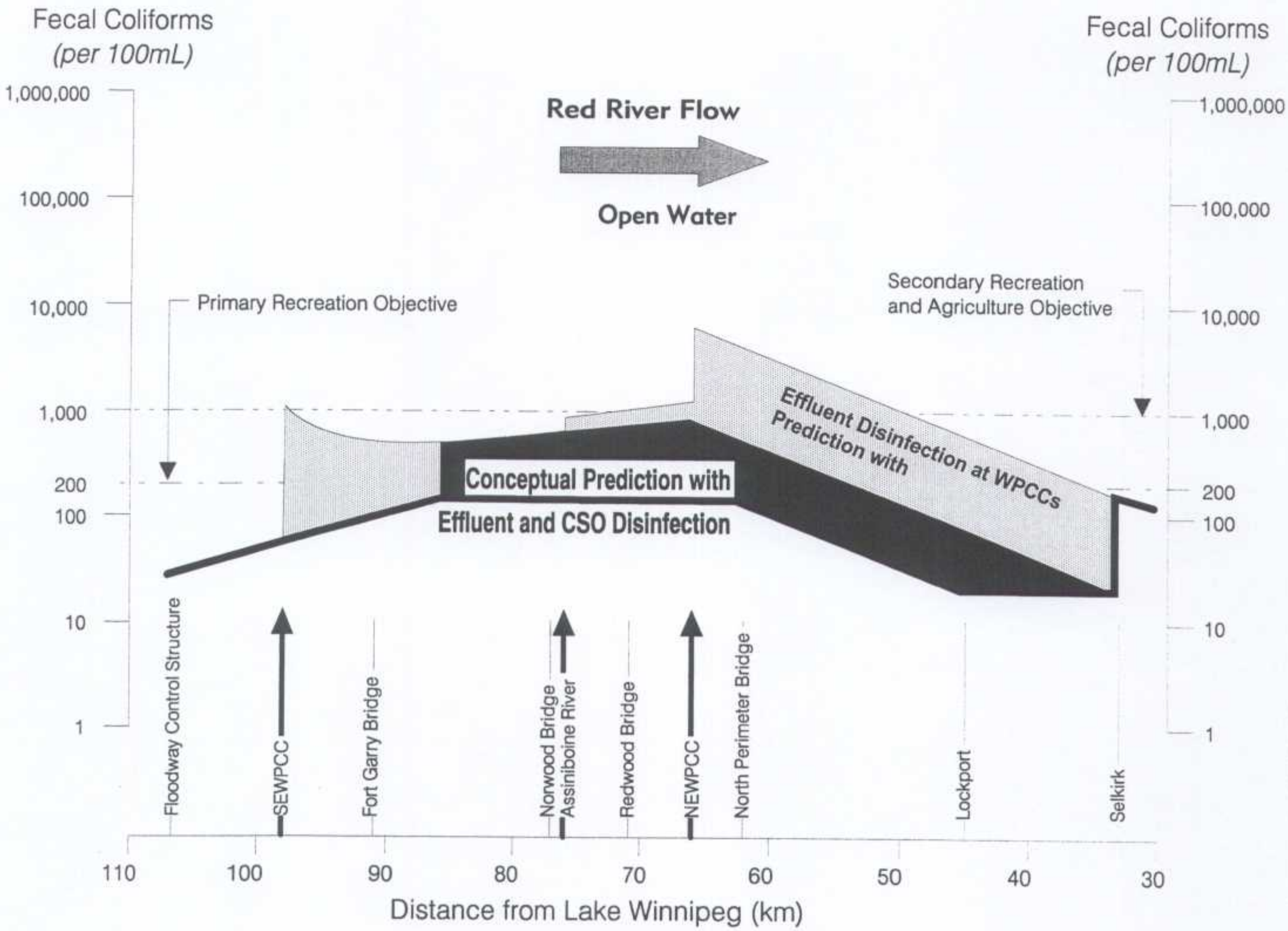
The calibrated model can now be used to assess the response of the rivers under dry and wet weather loadings for existing conditions. Understanding the existing conditions is essential for evaluation purposes. The statistical compliance and actual response at a specific location over time can be used to estimate the benefits arising from various control technologies. Figure 4-3 illustrates the response of both dry and wet weather conditions as predicted by the model at the Redwood Bridge location from mid-June to July 31, 1992. The peak concentrations are in response to wet weather loadings and the constant base of about 250 fecal coliforms per 100 mL reflect continuous discharge from the West End and South End Wastewater Treatment Plants. The data as plotted on Figure 4-3 is based on hourly printouts of the predicted fecal coliform concentrations at Redwood bridge location on the Red River. This data was used to assess the percent compliance with MSWQO microbiological objectives if 200 and 1000 fecal coliforms per 100 mL. That is, the sum of the hours less than 200 or 1000 fecal coliforms per 100 mL for the total 3600 hours associated with the recreation season (May to September, inclusive) is a measure of compliance. However, it is evident that combined sewer overflows in response to rainfall events can cause large but short-term concentrations of fecal coliforms that greatly exceed objectives. Therefore measure of compliance with MSWQO from a purely statistical perspective must be mutually considered with the actual river response to comprehensively assess the benefits of different control technologies.

The previous studies (MacLaren 1986, Wardrop/Tetr*ES* 1991) estimated the benefit of effluent disinfection, and effluent and CSO disinfection in terms of compliance with MSWQO along the Red River as shown in Figure 4-4. The representative years will be used to establish the geometric mean which forms the upper boundary of the compliance graph to establish a baseline by which to gauge the effectiveness of various controls to achieve compliance with MSWQO. The following discussions will update this graph.



Predicted Fecal Coliform Levels at Redwood Bridge on Red River for Existing Conditions

Figure 4-3



Ilustration of Seasonal Fecal Coliform Profile and Conceptual Benefits of Effluent and CSO Disinfection

Figure 4-4

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4.1.1 Statistical Compliance With Manitoba Objectives

The 1992 simulation results were interpreted to assess compliance with both the 200 and 1000 fecal coliform per 100 mL primary and secondary recreation objectives. It is noted that the modelling produces output results on an hourly basis. This produces approximately 3600 hours or equivalent data points to assess statistical compliance with the Manitoba Fecal Coliform Objectives. Shown in Table 4-1 is the estimated percent compliance in the Red and Assiniboine Rivers for the 1000 and 200 fecal coliform per 100 mL objectives for 1992 at various locations. Figure 4-5 displays the geometric mean fecal coliform concentrations along the Red and Assiniboine Rivers. Subsequent analyses of control technologies relate the benefits in terms of improved percent compliance.

4.1.2 Discharge Reduction

A second measure of benefit or compliance used by a number of regulatory authorities is the limiting of the number of combined sewer overflows and increasing the volumetric capture of combined sewage. It was estimated for 1992 rainfall that approximately 10 to 30 overflows would have occurred within the recreation season (May to September inclusive). The number and volume of overflows is discussed in TM #3 - Control Alternatives.

4.1.3 Health Risk Assessment

Previous studies, 1986 Disinfection (MacLaren 1986) and the Red and Assiniboine River Surface Water Quality Objectives (Wardrop/Tetr*ES* 1991) have estimated the health risk associated with elevated fecal coliforms in the rivers. These studies reviewed the potential health risk as measured in terms of gastrointestinal illness (GI). Cases of GI illness have symptoms similar to that of influenza, with typical symptoms of vomiting or diarrhea. It is not an infection that typically requires hospitalization and is considered to be a mild short-term illness. The information from three separate epidemiological studies of the use of surface water for recreation and the incidence of GI were reviewed to quantify the possible number of cases of GI that would likely occur per 1000 immersions. Figure 4-6 illustrates the plot of

Table 4-1
Compliance with Manitoba Fecal Coliform Objectives
For Calibrated and Verfied 1992 Model Predictions
at Representative Locations

Location	Percent Compliance	
	200 fc/100mL	1000 fc/100mL
Assiniboine River		
Headingley	100.0%	100.0%
West Perimeter Br.	89.1%	93.7%
Assiniboine Park	82.3%	87.8%
Main St. Bridge	0.0%	76.6%
Red River		
Floodway Control	100.0%	100.0%
South Perimeter Br.	99.2%	100.0%
Fort Garry Br.	21.4%	97.9%
Norwood Bridge	22.0%	89.7%
Redwood Bridge	43.7%	82.9%
North Perimeter	0.0%	37.0%
Lockport	15.4%	88.2%

the estimated cases of GI per 1000 immersions. All three studies found that the number of GI cases per 1000 immersions increased very slowly with large increases in fecal coliform densities in the water column, i.e., the risk of contracting GI is more a use-driven function than it is of the density of fecal coliforms in the water column. The American equation is the base used for estimating health risk.

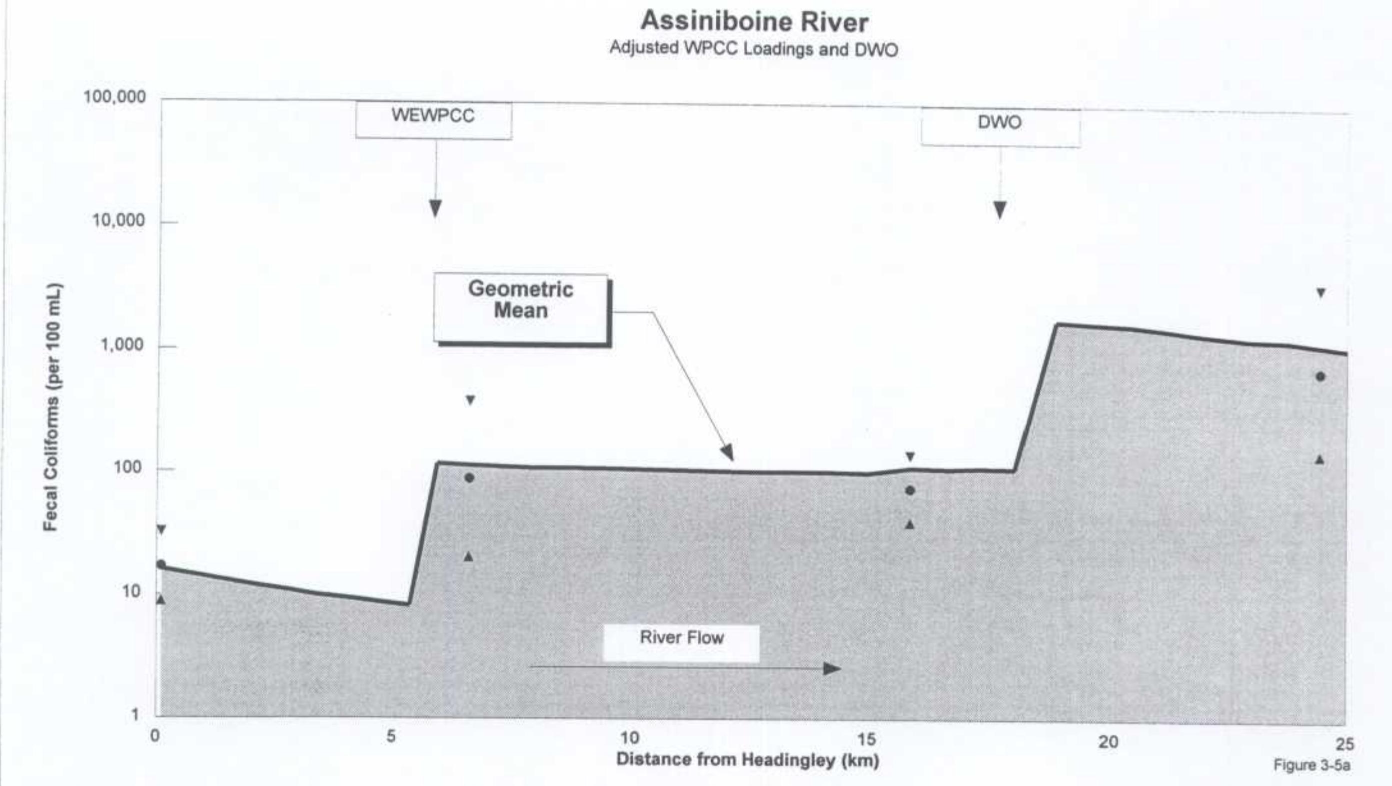
Figure 4-7 illustrates the health risk in estimated cases of GI per 1000 immersions. For existing conditions, it is estimated at 13 cases/1000 immersions. For reference, the previous studies had estimated 17 cases/1000 immersions. The Manitoba objective of 200 fecal coliforms per 100 mL is equivalent to a health risk of 10 cases/1000 immersions and deemed accepted by the Environmental Management Division (EMD) of the Province. The reduction in cases is primarily a result of ancillary benefits from the upgrading, expansion, and operation of the three WPCCs. The following sections will estimate the expected number of cases for different control technologies.

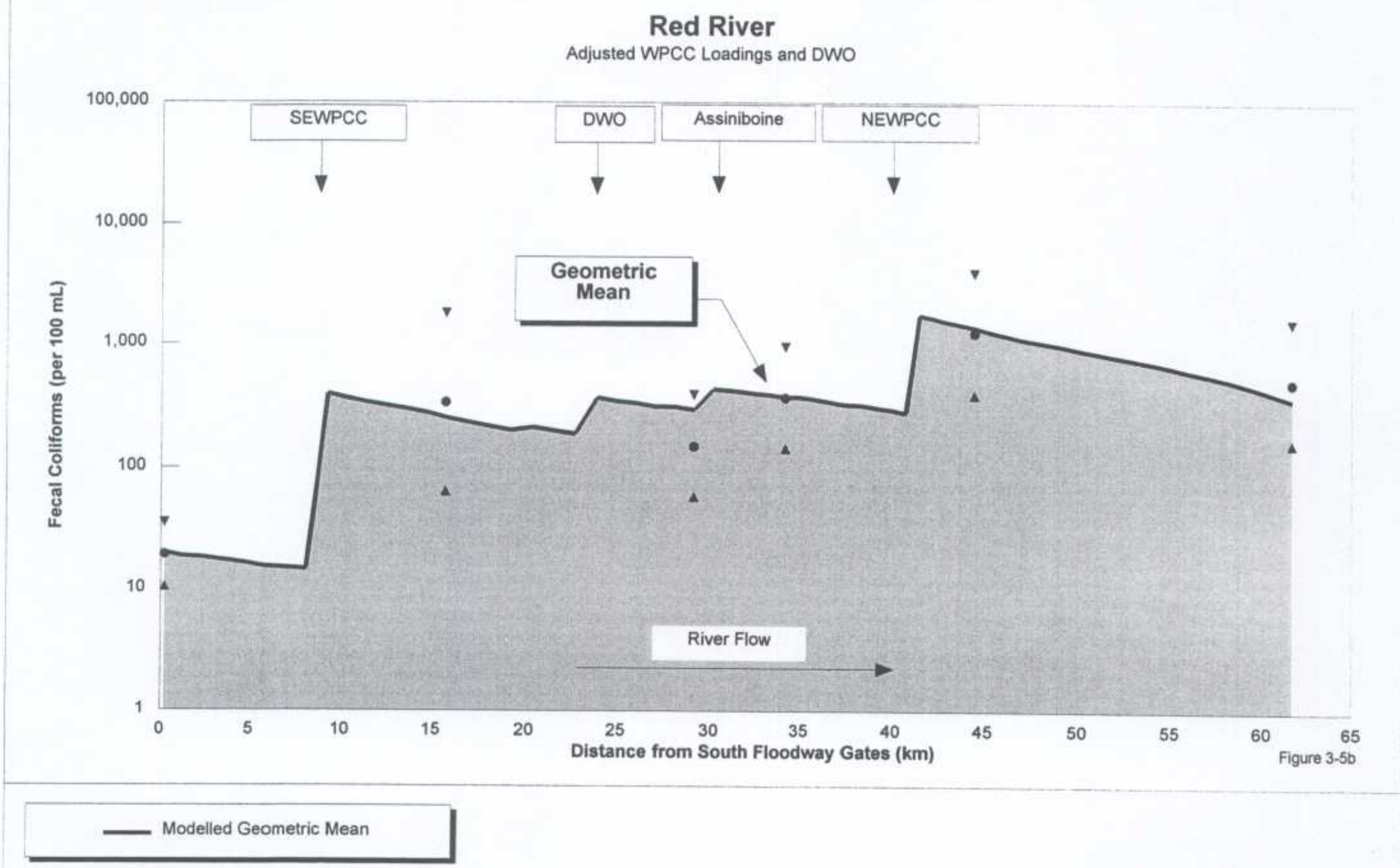
5.0 POTENTIAL FUTURE CONTROLS

Water quality modelling was used to estimate the response of the rivers to wet weather loadings with the potential implementation of various control technologies. The technologies were considered in a number of categories, i.e., addressing the existing DWF issues, existing infrastructure for WWF, and structurally intensive CSO controls such as complete separation complete separation, disinfection of all CSOs, and the elimination of all CSOs. The following subsections will discuss the modelling and related benefits of each of the control alternatives in terms of compliance with Manitoba Surface Water Quality Objectives and reduced health risk. An overall comparison of these potential control options will be presented.

5.1 ADDRESSING THE EXISTING DWF ISSUES

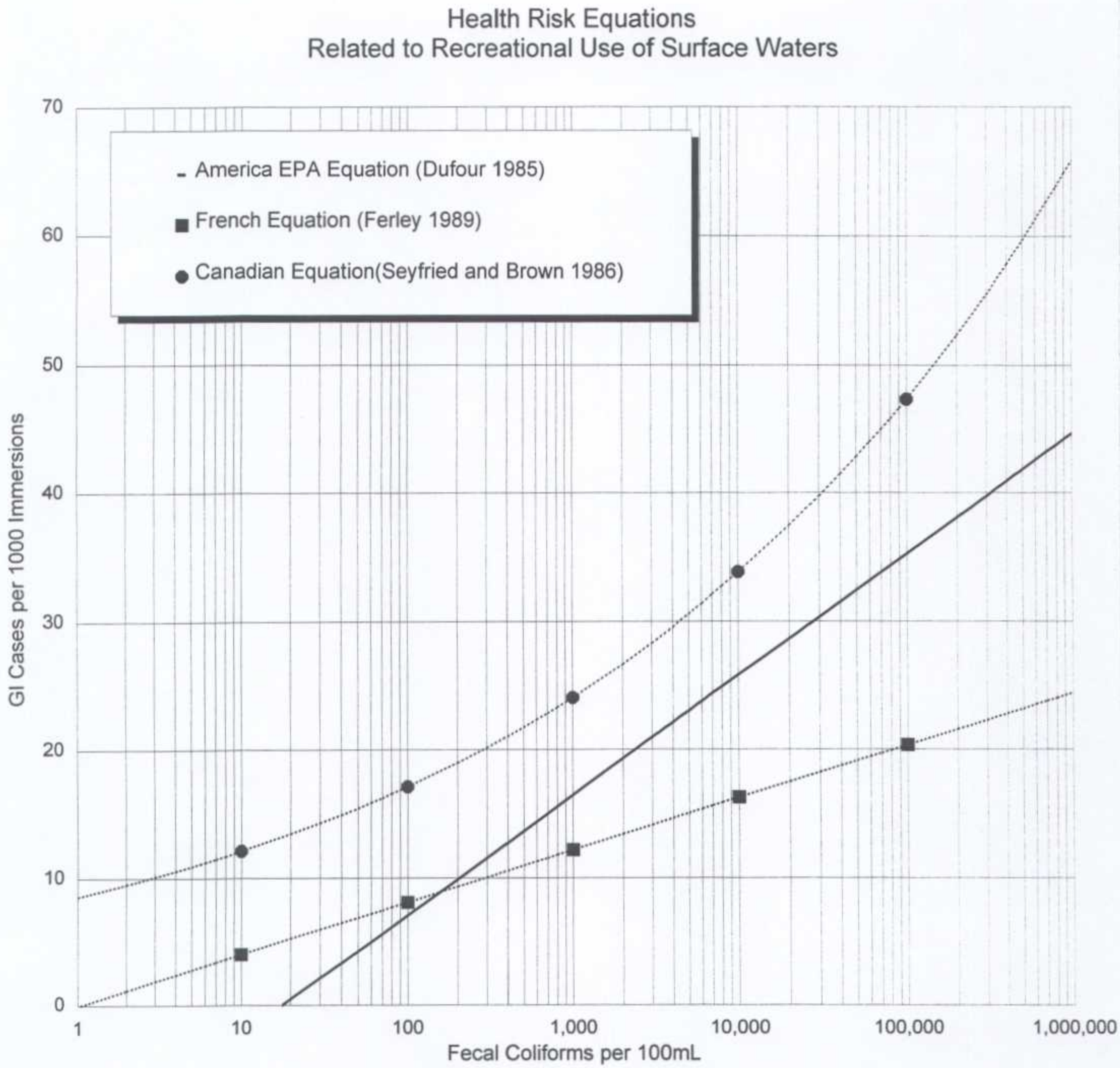
It was assumed that the first step in any program for reduction of wet weather loadings of fecal coliforms to the river would involve the correction of all dry weather overflows and the disinfection of treated effluent from the WPCCs. For modelling purposes, it was assumed that





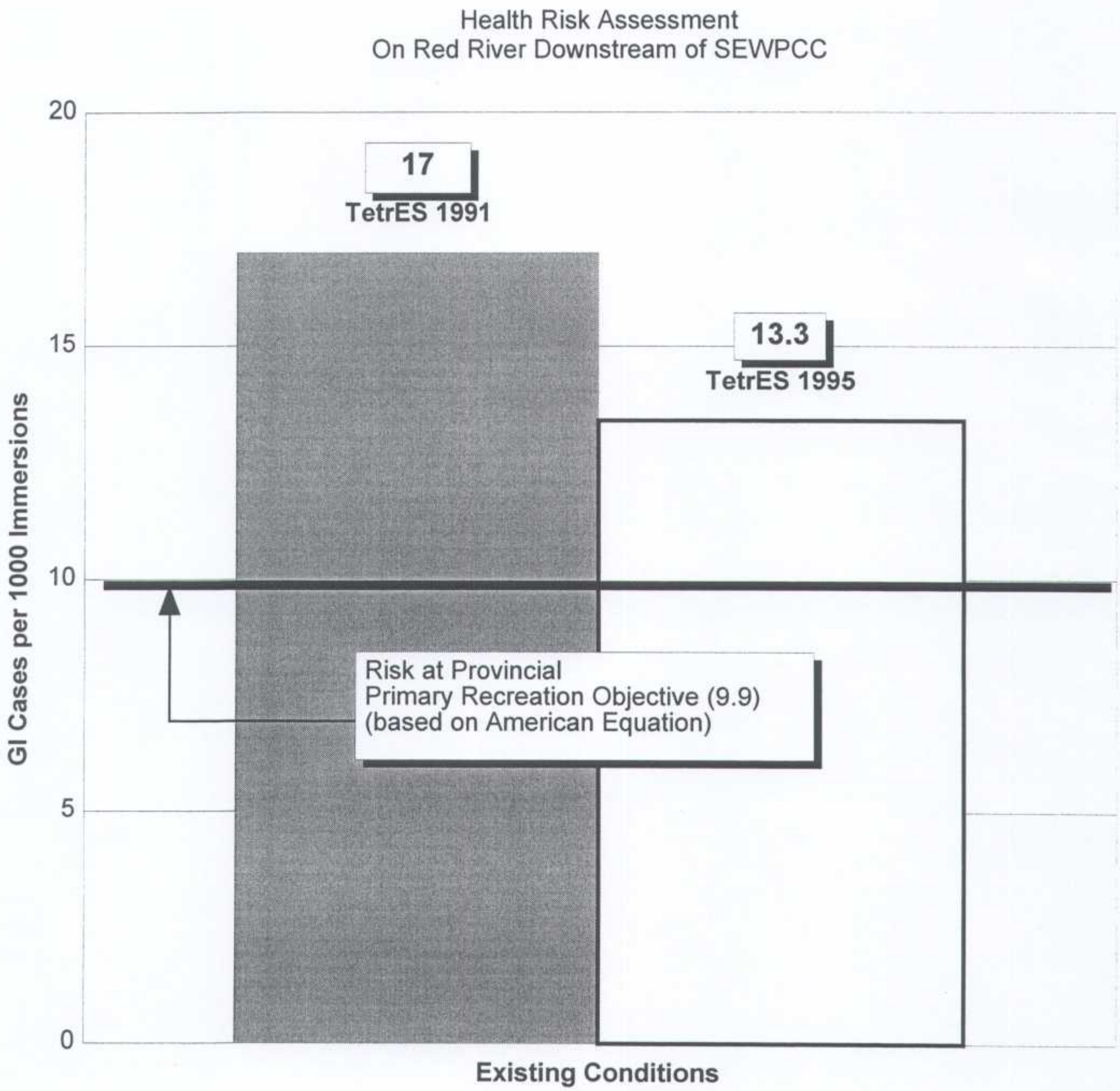
Existing Conditions
Baseline for Estimating Benefits

Figure 4-5



Estimated Cases of Gastrointestinal Illness (GI) per 1000 Immersions for Various Levels of Fecal Coliforms Concentrations in Recreational Waters

Figure 4-6



Gastrointestinal Illness (GI) Cases per 1000 Immersions Related to Recreation Downstream of the SEWPCC on the Red River

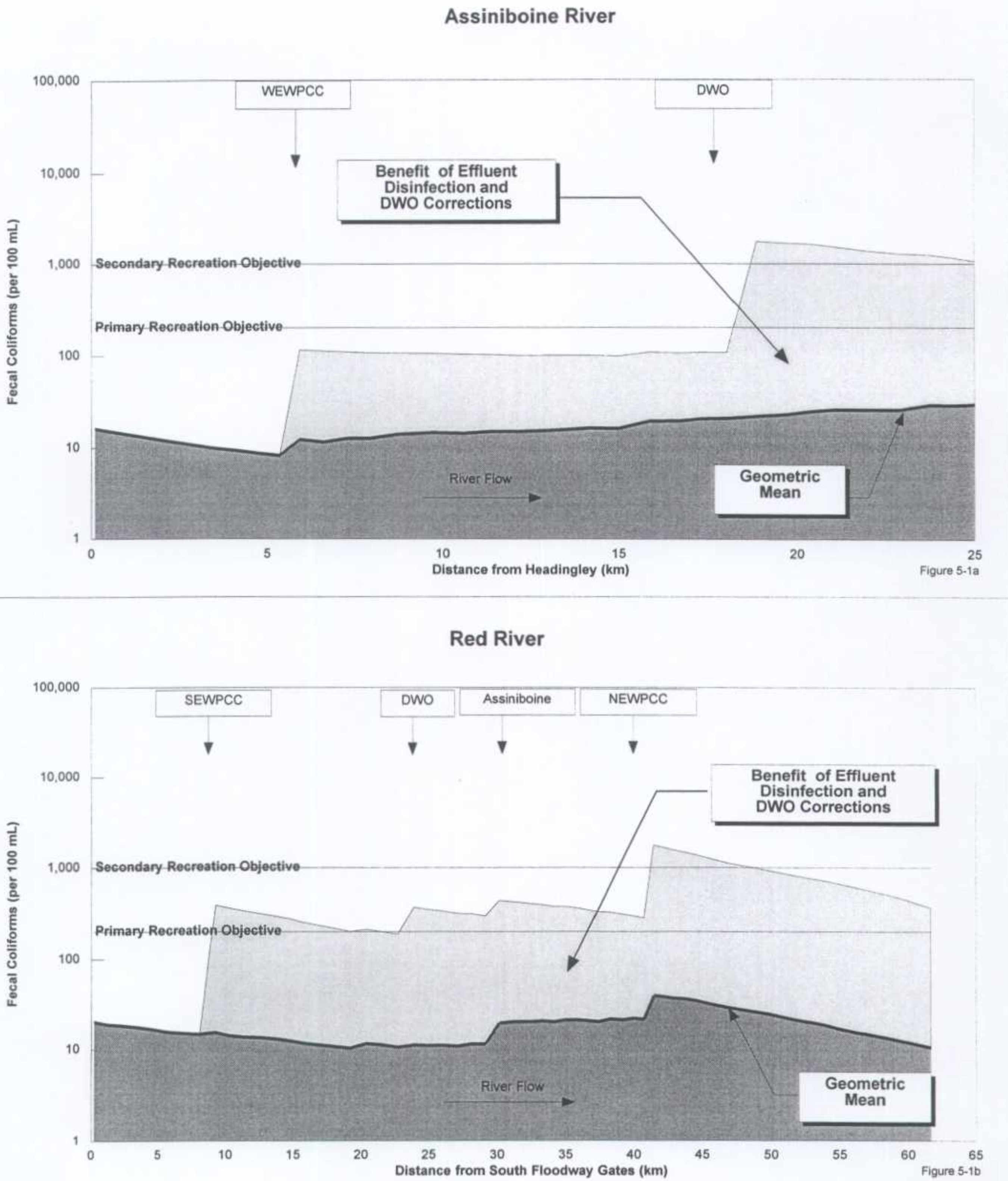
Figure 4-7

the disinfection of treated effluent would achieve 200 fecal coliforms per 100 mL under dry weather flow conditions and 2400 fecal coliform per 100 mL under wet weather flow conditions as discussed in Phase 2 TM #2. The DWO on the Assiniboine River was considered to be corrected along with WPCC effluent disinfection. The model was run for the recreation season for the representative 1992 year to simulate these conditions. Statistical representation of the predicted fecal coliform levels in the rivers for these new conditions are shown in Figure 5-1.

The result indicate a very significant reduction in average coliform levels. On a geometric mean basis, it would be possible to achieve substantial statistical compliance with Manitoba Surface Water Quality Objective for fecal coliforms for the new conditions. It is important to note that the sample size used for statistical analysis was based on the full output of hourly timesteps for the recreation period, i.e., approximately 3600 hours or to 3600 data points to assess compliance. Caution needs to be exercised in reviewing such results since it does not necessarily depict the same results as would be achieved through bi-weekly sampling. The hourly data set reflects a significantly larger database of which the dry weather data substantially outweighs the wet weather data. It should also be noted that the peak coliform densities would be largely unaffected, since the CSO discharges remain the same , as shown in Figure 5-2.

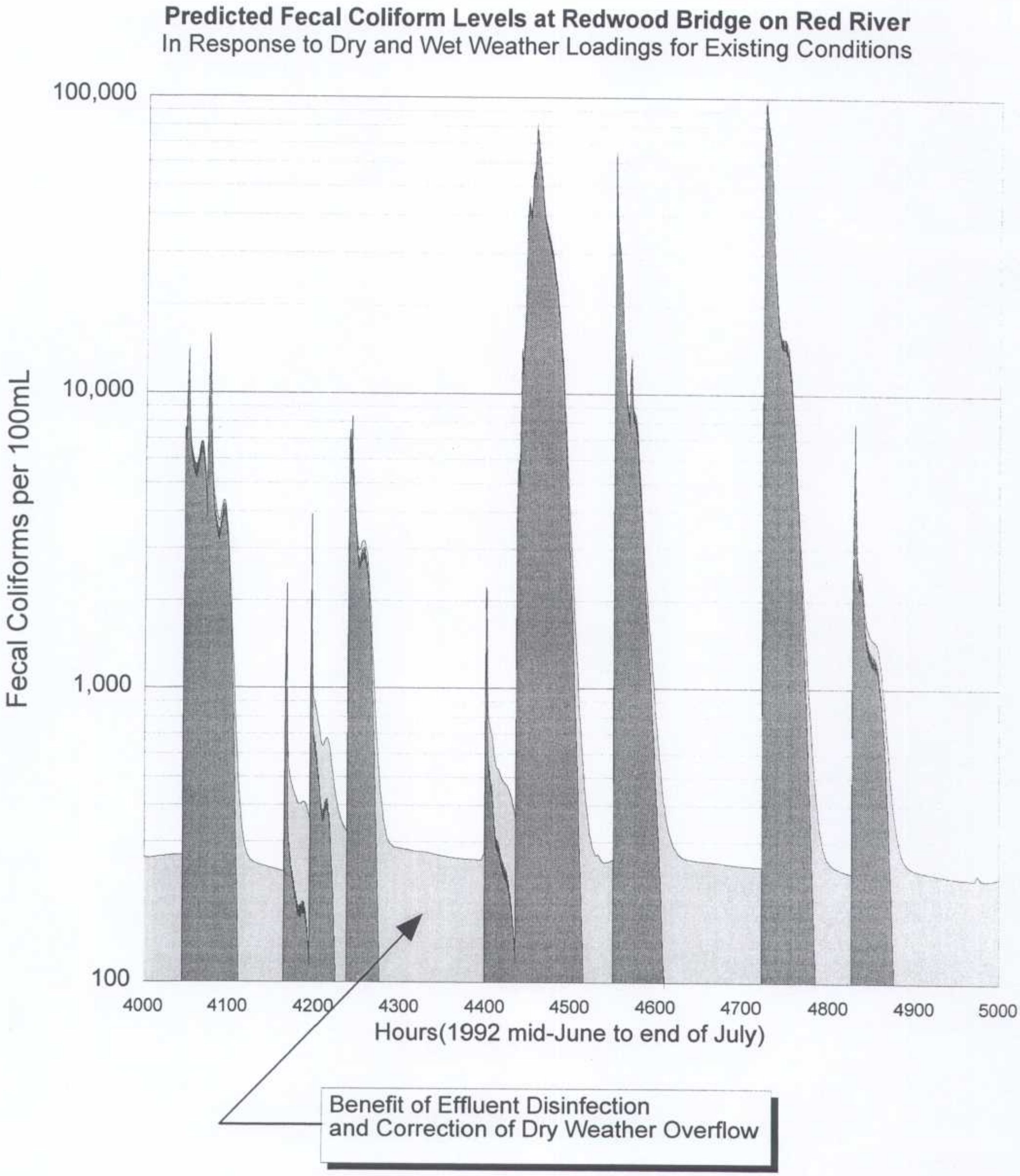
The results shown in Figure 5-1 represents the new baseline conditions for optimized DWF conditions. Future loadings due to growth of the City, would not deviate significantly from current loadings under these new baseline conditions. Specifically, the main growth in the City of Winnipeg will occur in the areas serviced by the SEWPCC and WEWPCC plants. The vast majority of these areas are serviced by separate sewer systems and would not significantly increase the loadings from those considered. Most new land drainage systems will also include storm retention basins (SRB). SRBs have proven to be quite effective in reducing fecal coliform levels and other pollutants. The NEWPCC service area will experience little growth and no further increases in combined sewers.

Another related consideration is that the City of Winnipeg is currently promoting water conservation initiatives to reduce water consumption. The program is expected to achieve



Modelled Benefit of Effluent Disinfection and Correction of Dry Weather Overflows

Figure 5-1



Benefit of Effluent Disinfection and Correction of Dry Weather Overflows Predicted at Redwood Bridge on Red River

Figure 5-2

between 5 and 10% reduction in water consumption. This could reduce average dry weather flows somewhat. It would not impact on wet weather flows.

Based on the foregoing, the conditions representing elimination of DWO and effluent disinfection will be representative of future conditions and that the new baseline will adequately represent the base condition by which to assess the benefits of WWF control alternatives.

The improved percent compliance with Manitoba Surface Water Quality Objectives are shown in Table 5-1. The model results for the new baseline conditions indicate that for both rivers, substantial compliance, (i.e., a minimum of about 75% of the time, with the 200 fecal coliform per 100 mL objectives) can be met over the recreation season, through dry weather overflow corrections and effluent disinfection. For the Assiniboine River, compliance with the 1000 fecal coliform/100 mL secondary recreation objective is achieved about at least 82% of the time. The need for disinfection of the WEWPCC could be questioned, given the effectiveness of the lagoons in reducing effluent coliform densities.

5.2 OPTIMIZING EXISTING SYSTEMS FOR WWF

The previous TMs have shown that there is potential for using the existing infrastructure to convey greater WWF. This section reviews the optimization of the interceptor system to carry five times dry weather flow (5 x DWF) and the use of available inline storage in the trunk/collection system. These measures can be considered minimum structural controls.

5.2.1 Intercept Five Times Dry Weather Flow (5 x DWF)

Evaluation of the existing infrastructure revealed that the main interceptor has the capacity to carry 5 x DWF. For details on interceptor conveyance capacity refer to Technical Memoranda No. 2 - Infrastructure/Treatment. This increased capacity would reduce the CSO loadings somewhat. Predicted instream fecal coliform concentrations were simulated by the US EPA WASP model under these conditions for the recreation season and compiled in a

Table 5-1
Improved Compliance with Manitoba Fecal Coliform Objectives

• Dry Weather Overflow Corrections and Effluent Disinfection

Location	Percent Compliance	
	200 fc/100mL	1000 fc/100mL
Assiniboine River		
Headingley	100.0%	100.0%
West Perimeter Br.	100.0%	100.0%
Assiniboine Park	86.7%	100.0%
Main St. Bridge	76.8%	82.0%
Red River		
Floodway Control	100.0%	100.0%
South Perimeter Br.	99.2%	100.0%
Fort Garry Br.	96.3%	99.8%
Norwood Bridge	87.0%	90.5%
Redwood Bridge	78.9%	83.8%
North Perimeter	74.6%	82.1%
Lockport	81.6%	91.4%

database. Model results were assessed in terms of compliance with Manitoba Objectives as listed in Table 5-2 and shown in Figures 5-3 and 5-4. A slight improvement in compliance is noted except at the Assiniboine Park Bridge. This is due to overflows at Woodhaven and Strathmillan, which currently have interception rates of 12 x DWF and 21 x DWF respectively. By reducing an interception to 5 x DWF the number of overflows has increased.

5.2.2 Inline Storage and 5 x DWF

A preliminary analysis of the available storage in the districts that have been studied found that on average 1.2 mm of equivalent rainfall could be stored in combined sewer trunks. Refer to TM #2 - Infrastructure/Treatment or TM #3 - Control Alternatives, for details.

The receiving stream model results were assessed in terms of compliance with the Manitoba Surface Water Quality Objectives for these revised loadings and are listed in Table 5-3 and Figures 5-5 and 5-6. A small but notable increase in compliance relative to the 5 x DWF option, is achieved by the inclusion of inline storage. The main benefit of inline storage is the reduction of overflows as depicted on Figure 5-6.

5.3 STRUCTURALLY INTENSIVE CSO CONTROLS

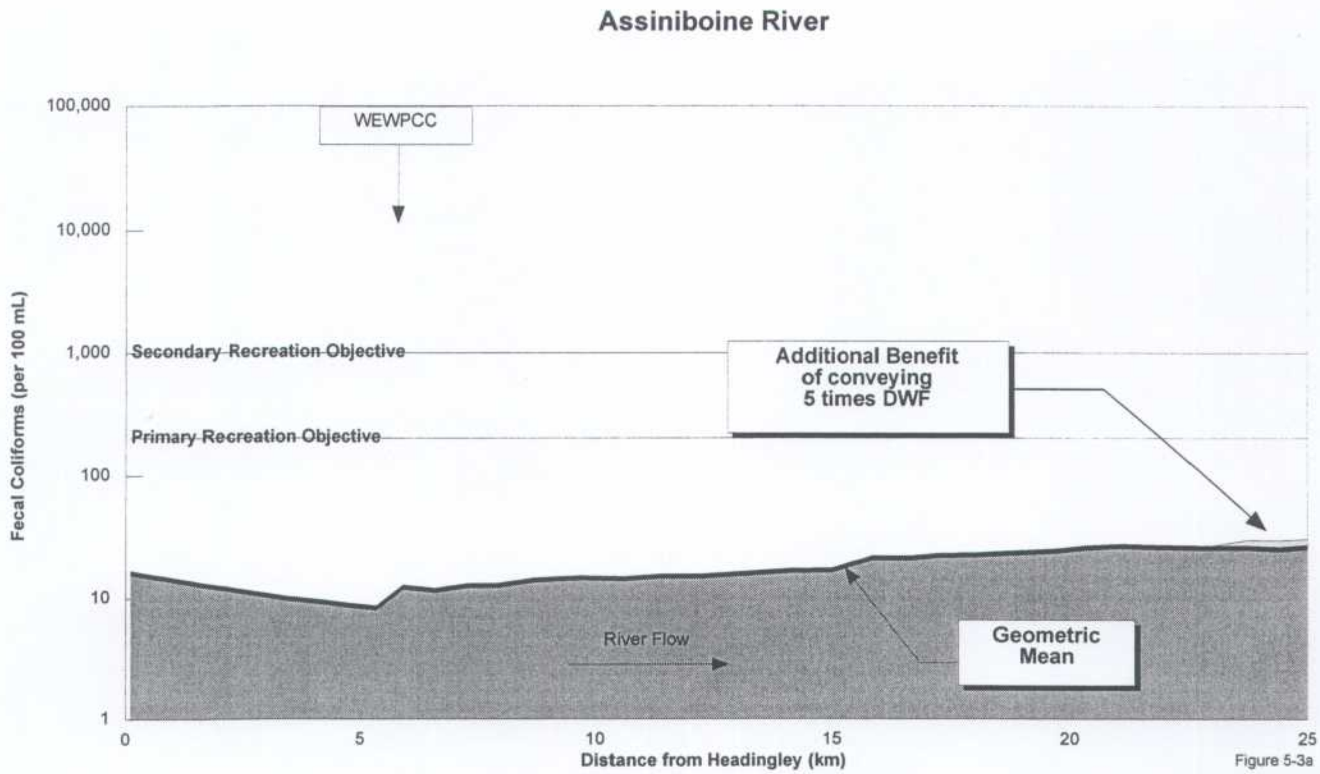
Structurally intensive controls are those techniques that require significant modification to the existing system and carry very high costs. These include complete separation, disinfection of CSOs, and elimination of all CSOs through massive regional storage. The following subsections discuss the conceptual assessment of these control options.

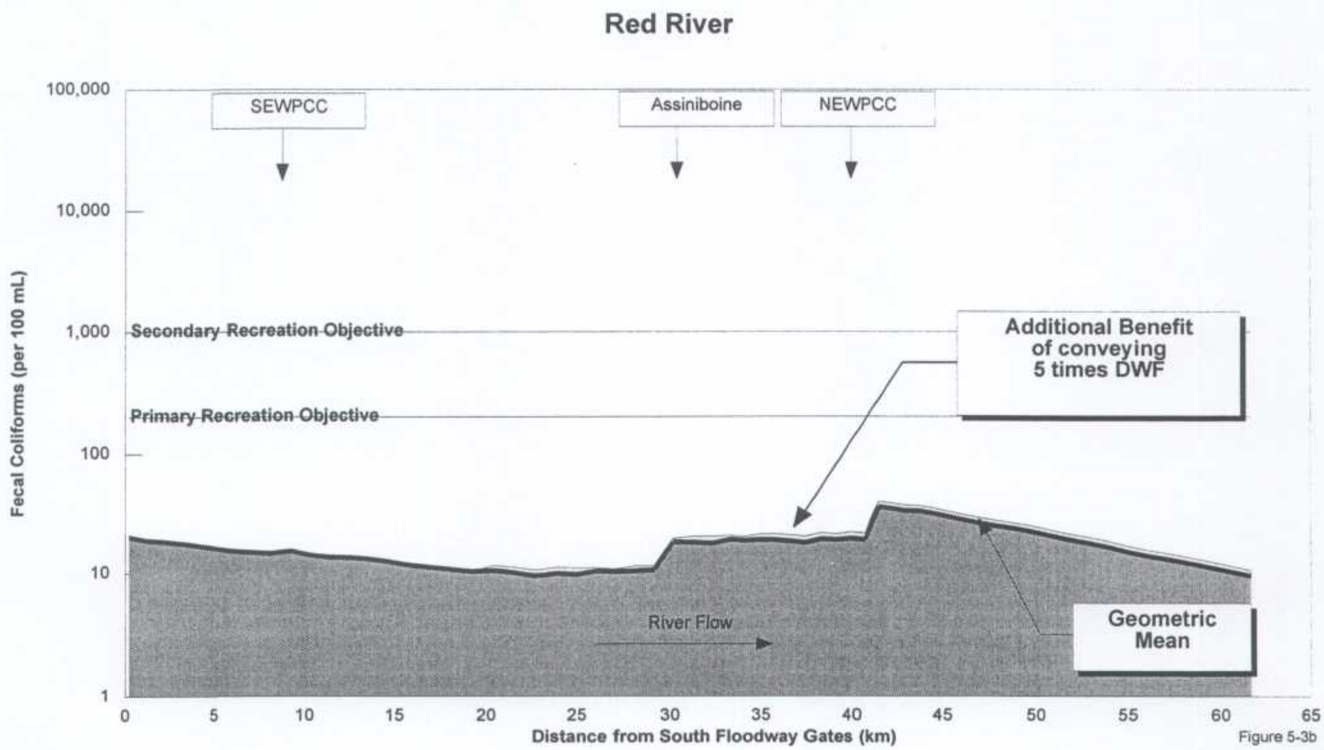
5.3.1 Separation

Complete separation would involve the retrofit conversion of all combined sewer systems into separate sanitary and land drainage systems. This has been done in selective areas as part of the ongoing sewer relief program where is was shown to be practical and cost-effective

Table 5-2
Improved Compliance with Manitoba Fecal Coliform Objectives
For Interception Capacity of 5xDWF
• *Includes New Baseline Conditions*

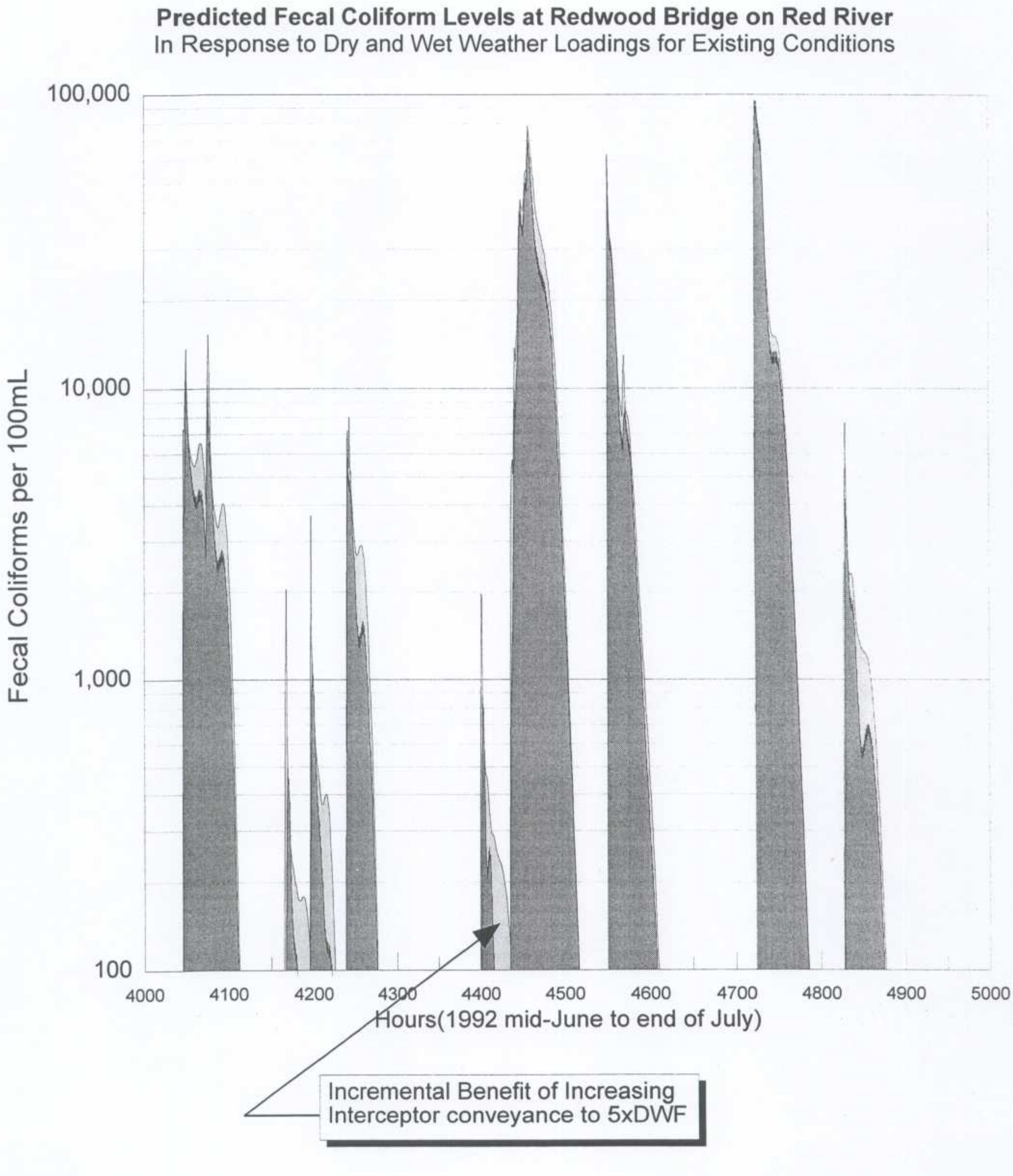
Location	Percent Exceeding	
	200 fc/100mL	1000 fc/100mL
Assiniboine River		
Headingley	100.0%	100.0%
West Perimeter Br.	100.0%	100.0%
Assiniboine Park	84.7%	90.7%
Main St. Bridge	78.9%	84.2%
Red River		
Floodway Control	100.0%	100.0%
South Perimeter Br.	99.2%	100.0%
Fort Garry Br.	96.3%	99.8%
Norwood Bridge	88.6%	92.0%
Redwood Bridge	80.0%	84.6%
North Perimeter	76.3%	83.4%
Lockport	82.7%	92.0%





Incremental Benefit of Conveying 5 times Dry Weather Flow

Figure 5-3

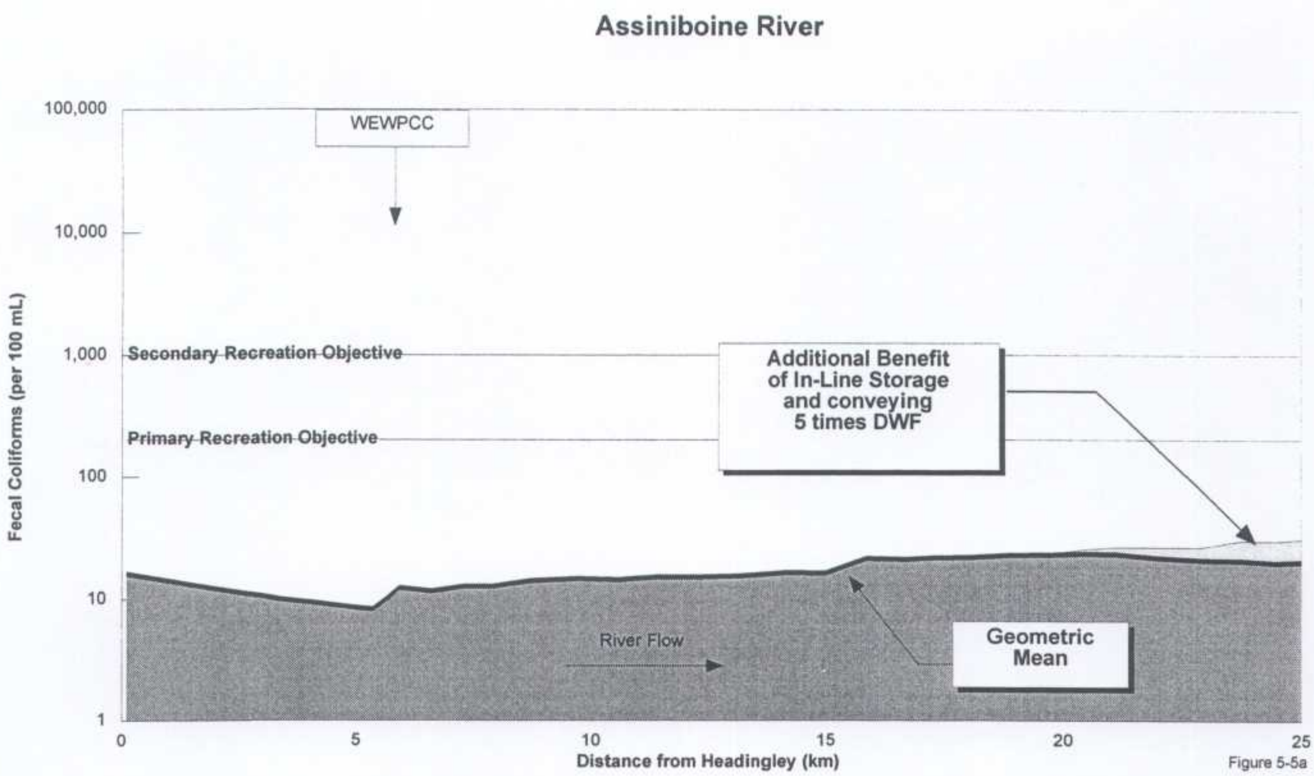


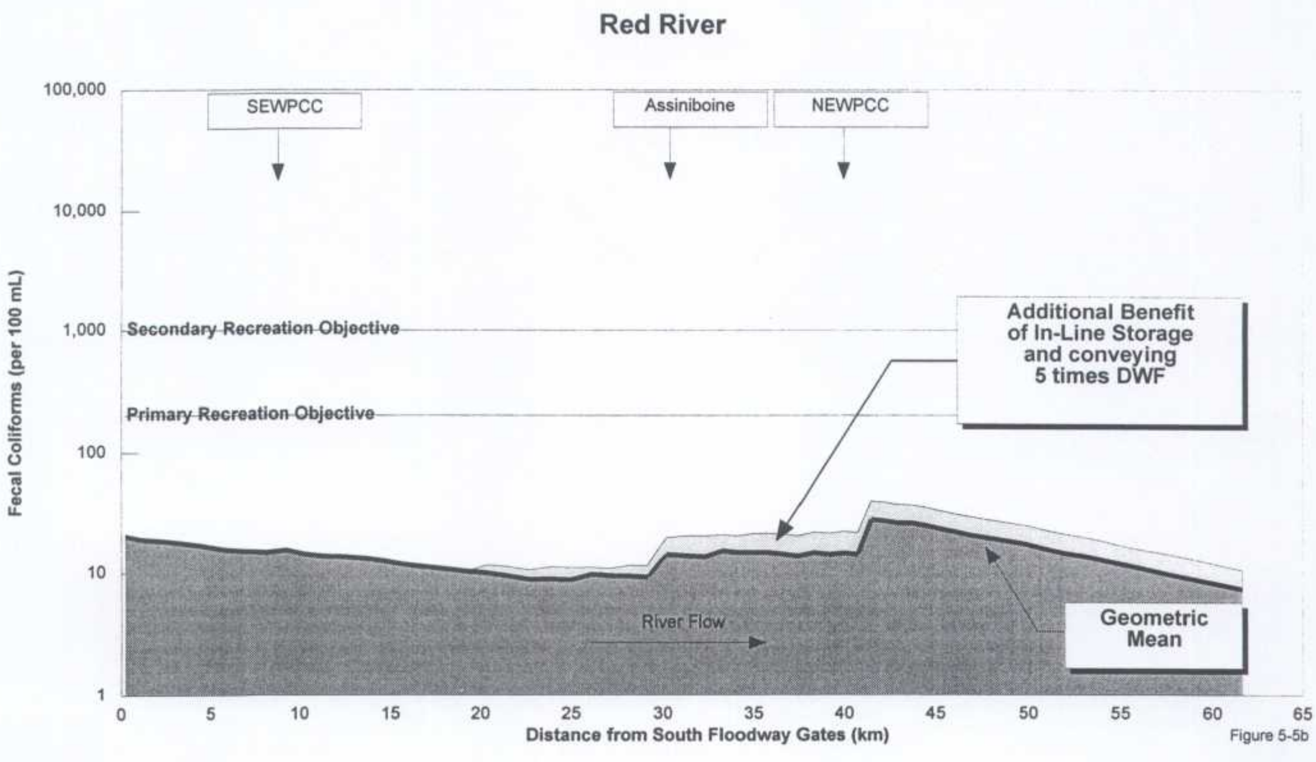
Benefit of Effluent Disinfection and Increasing Interceptor Conveyance to 5xDWF Predicted at Redwood Bridge on Red River

Figure 5-4

Table 5-3
Compliance with Manitoba Fecal Coliform Objectives
For Inline Storage and Interceptor Conveying 5xDWF
• *Includes New Baseline Conditions*

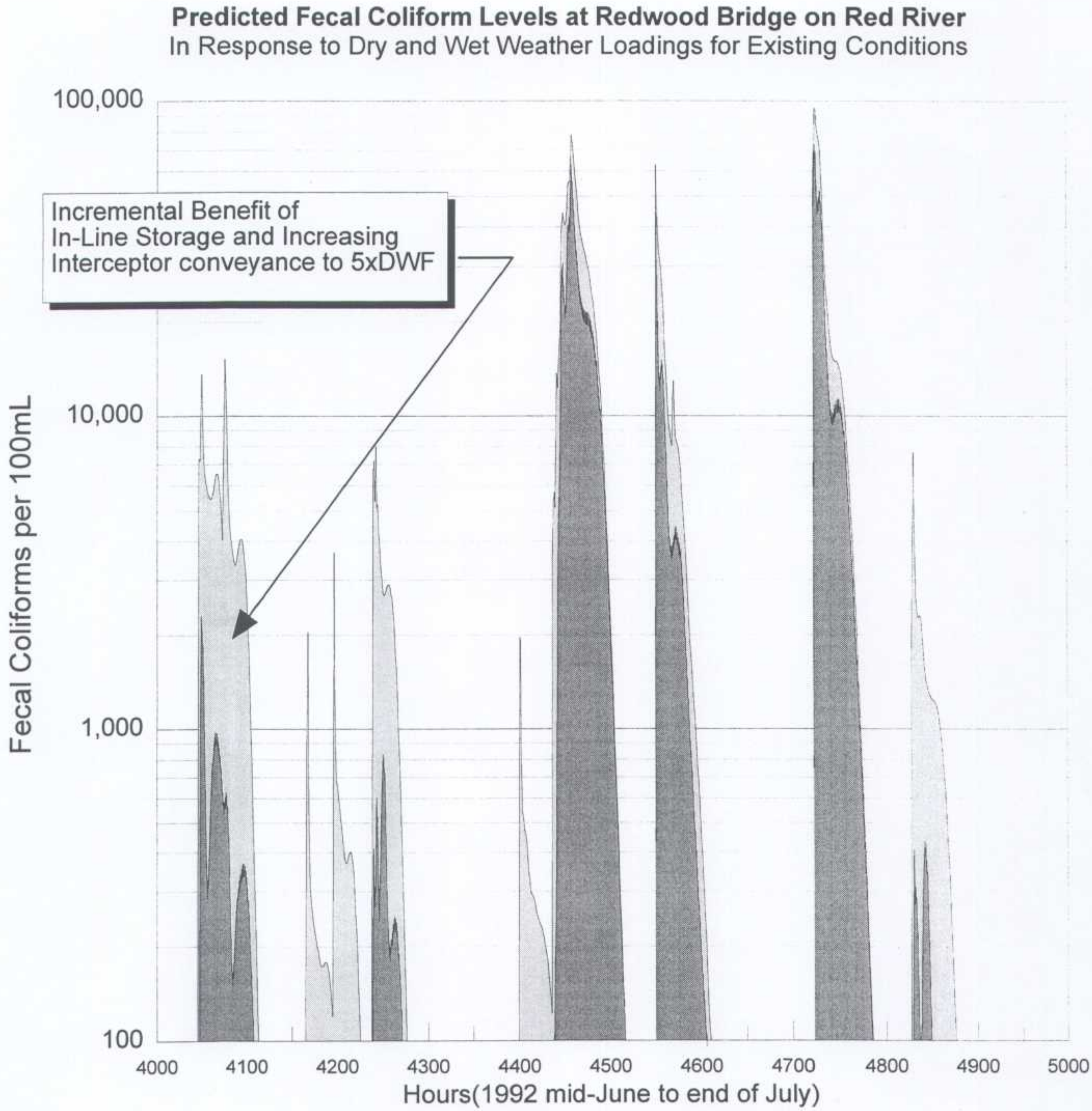
Location	Percent Exceeding	
	200 fc/100mL	1000 fc/100mL
Assiniboine River		
Headingley	100.0%	100.0%
West Perimeter Br.	100.0%	100.0%
Assiniboine Park	88.6%	91.7%
Main St. Bridge	81.9%	86.7%
Red River		
Floodway Control	100.0%	100.0%
South Perimeter Br.	99.2%	100.0%
Fort Garry Br.	96.3%	99.8%
Norwood Bridge	90.4%	92.9%
Redwood Bridge	83.1%	88.8%
North Perimeter	79.8%	88.1%
Lockport	88.7%	94.0%





Incremental Benefit of In-Line Storage and Conveying 5 times Dry Weather Flow

Figure 5-5



Benefit of Effluent Disinfection and In-Line Storage plus Increasing Interceptor Conveyance to 5xDWF Predicted at Redwood Bridge on Red River

Figure 5-6

compared to adding relief pumping. Full separation would result in essentially all wastewater flows being conveyed to the treatment plant for processing under both dry and wet weather conditions. The stormwater portion of the CSOs would be taken to the river through new LDS. These discharges would be equivalent to direct land drainage to the receiving streams under these conditions. Combined sewage was estimated to have an event mean concentration of 2.4×10^6 fecal coliforms per 100 mL. A direct land drainage discharge was estimated to have an EMC of 4×10^4 fecal coliforms per 100 mL. Separation would thus provide the equivalent of a 2-log reduction in fecal coliform loadings to the rivers. Modelling of this control alternative thus considered the existing volumetric loadings for CSOs but reduced the EMCs by 2-logs to simulate full separation of the combined sewer district.

5.3.2 Disinfection of CSO

Disinfecting all CSOs encompasses those control technologies that involve high-rate treatment such as Retention Treatment Basins (RTBs) and Vortex Solid Separators (VSS), all with the intent of providing a CSO effluent that can be disinfected. It was assumed that all discharges from combined sewer overflows could be reduced from an EMC of 2.4×10^6 by a 4-log reduction, or the equivalent of 240 fecal coliform per 100 mL. This alternative considers treatment at each outfall. A 4-log reduction is probably optimistic, even for chlorination, and probably not attainable with current UV technology. However, this simulation was done to demonstrate the best possible CSO coliform control.

5.3.3 Regional Storage of CSO

CSOs can be eliminated through massive storage in the form of either tunnel storage or distributed tank storage at strategic locations which are ultimately conveyed to a central location for treatment. This option has the potential to collect all the runoff from combined sewer areas and completely eliminate the impact of fecal coliform loading on the rivers. This represents the greatest possible improvement in CSO controls in that the stored CSO would eventually be given central treatment before discharge to the receiving streams. With full storage, there would be no loadings from combined sewers along the reaches of the Red and

Assiniboine Rivers within the City of Winnipeg. Clearly there is potential for reduced levels of storage, and acceptance of CSO under extreme rainfall. This simulation was done to demonstrate the maximum benefit that could be attained.

5.3.4 Compliance Assessment

Table 5-4 summarizes the statistical compliance with Manitoba Objectives for the conceptual extremes noted above. Figures 5-7, 5-9 and 5-11 illustrate the compliance with MSWQO and possible improvements to the Red and Assiniboine Rivers for structurally intensive CSO options. These options improve statistical compliance modestly, but rather significantly in terms of overflows as shown in Figures 5-8, 5-10 and 5-12. Full separation was found to have the lowest compliance due to the residual loading associated with land drainage discharges to the river.

5.4 COMPARISON OF BENEFITS

The modelling results for the spectrum of control options studied and their interpretation in terms of relative compliance with Manitoba Surface Water Quality Objectives is summarized in Table 5-5.

5.4.1 Compliance

The logical combinations of alternatives are shown in Table 5-6. For all combinations, the correction of DWO and the disinfection of WPCC effluent is common. For most combinations, the optimization of existing infrastructure is also a common component. Other factors, such as cost, enter into this evaluation, as discussed in Phase 2 TM #3 and #6. The incremental benefits relative to the existing condition for compliance with Manitoba Surface Water Quality Objectives for various logical combinations is summarized in Figures 5-13 and 5-14 where the options are logical combinations of control options as listed in Table 5-6. The incremental benefits are additive, as illustrated.

Table 5-4

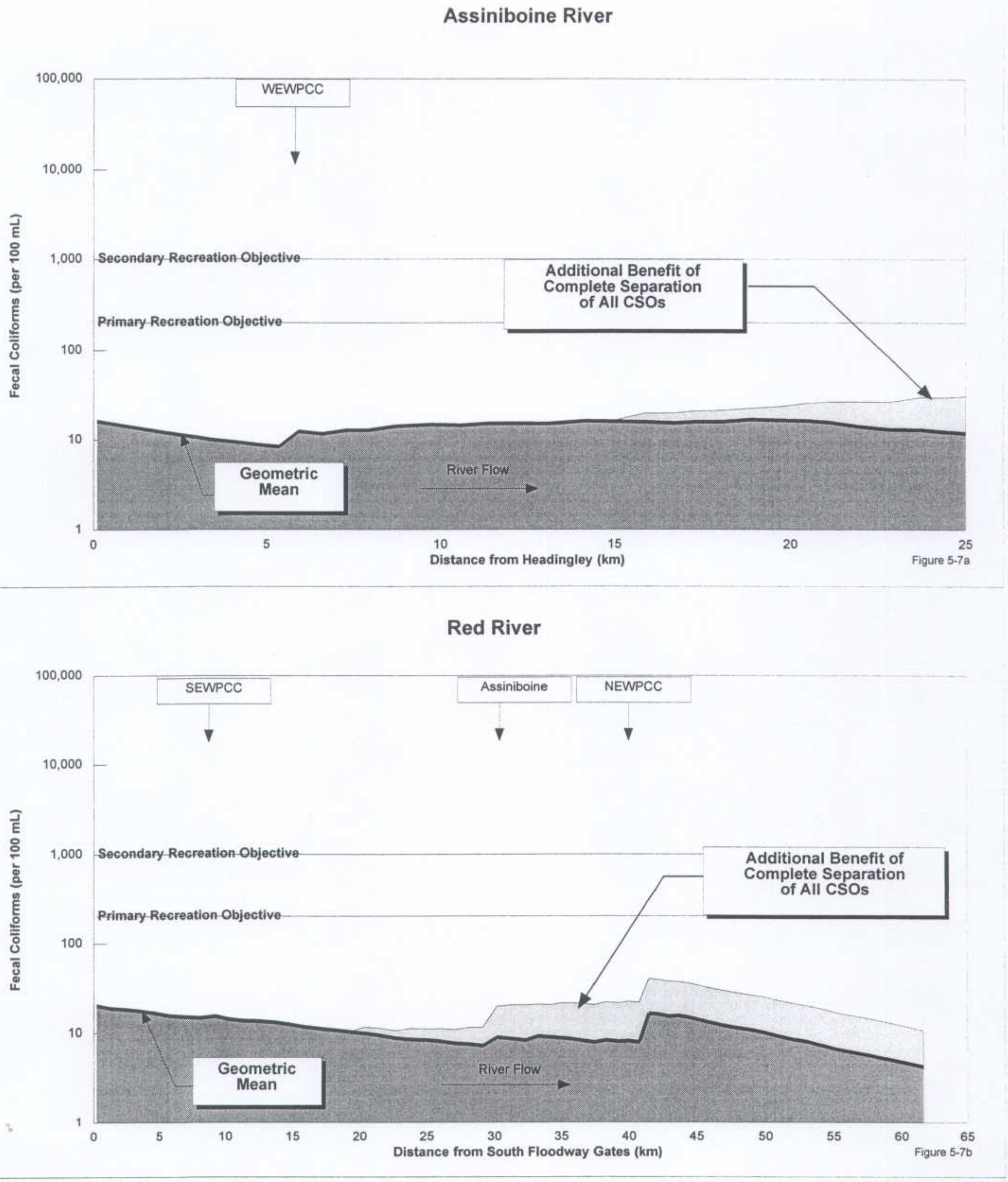
Structurally Intensive Control Options
Percent Compliance with Manitoba Microbiological Objectives
for Recreation Season (May to September, inclusive)

- **Percent Compliance with Manitoba 200 fc/100mL Objective**

	Control Option		
Location	Complete Separation	Disinfection All CSOs	Regional Storage
Assiniboine River			
Headingley	100.0%	100.0%	100.0%
West Perimeter Br.	100.0%	100.0%	100.0%
Assiniboine Park	89.4%	89.7%	89.7%
Main St. Bridge	84.4%	86.9%	86.9%
Red River			
Floodway Control	100.0%	100.0%	100.0%
South Perimeter Br.	99.2%	99.2%	99.2%
Fort Garry Br.	96.3%	96.3%	96.3%
Norwood Bridge	95.8%	97.4%	97.4%
Redwood Bridge	90.1%	91.5%	91.5%
North Perimeter	89.0%	90.9%	90.9%
Lockport	97.7%	98.8%	98.8%
Minimum Compliance	84.4%	86.9%	86.9%
Station Average	94.7%	95.5%	95.5%

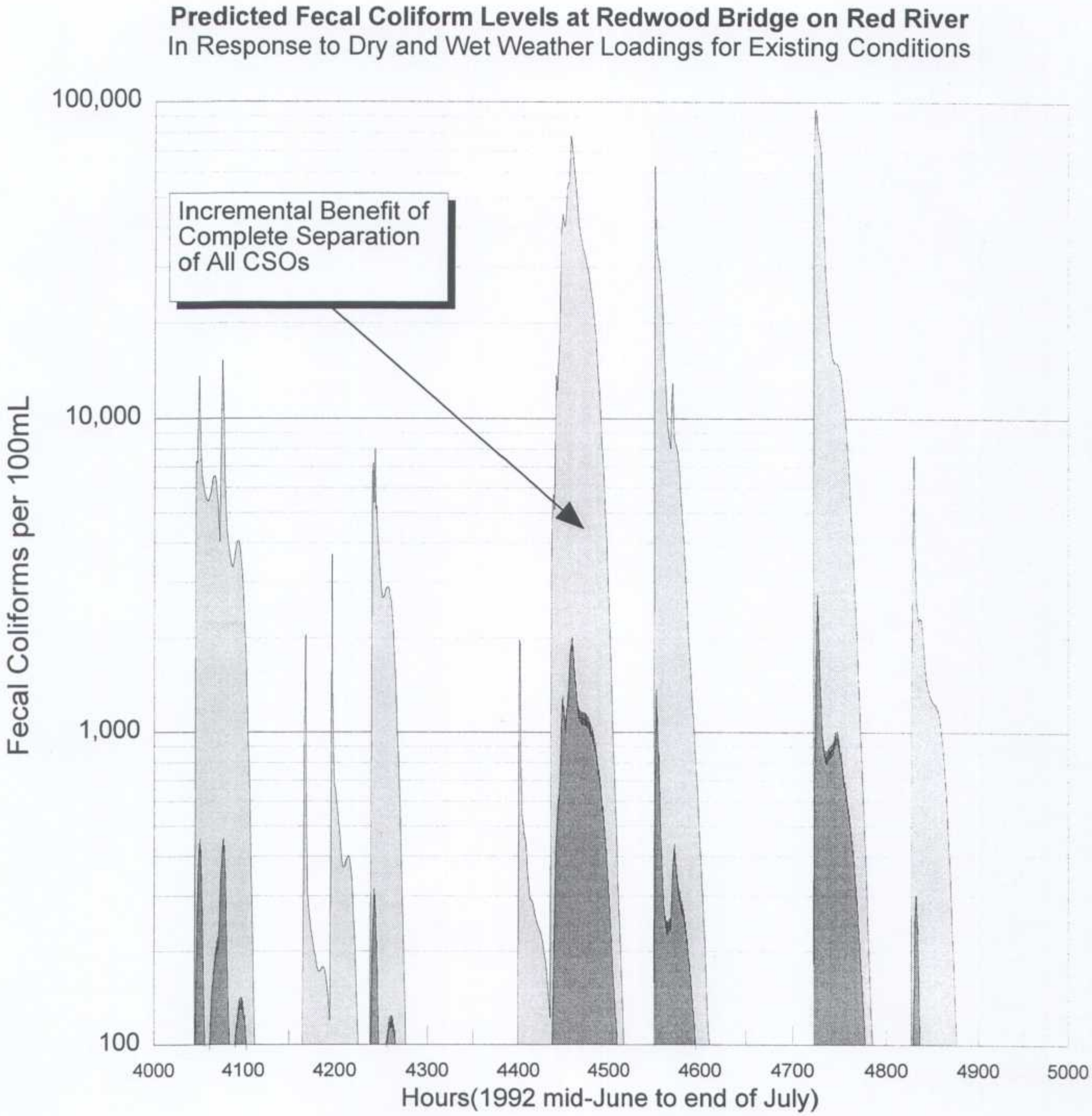
- **Percent Compliance with Manitoba 1000 fc/100mL Objective**

	Control Option		
Location	Complete Separation	Disinfection All CSOs	Regional Storage
Assiniboine River			
Headingley	100.0%	100.0%	100.0%
West Perimeter Br.	100.0%	100.0%	100.0%
Assiniboine Park	93.3%	93.5%	93.5%
Main St. Bridge	92.2%	95.2%	95.2%
Red River			
Floodway Control	100.0%	100.0%	100.0%
South Perimeter Br.	100.0%	100.0%	100.0%
Fort Garry Br.	99.8%	99.8%	99.8%
Norwood Bridge	99.7%	99.9%	99.9%
Redwood Bridge	98.2%	99.4%	99.4%
North Perimeter	98.3%	99.2%	99.2%
Lockport	100.0%	100.0%	100.0%
Minimum Compliance	92.2%	93.5%	93.5%
Station Average	98.3%	98.8%	98.8%



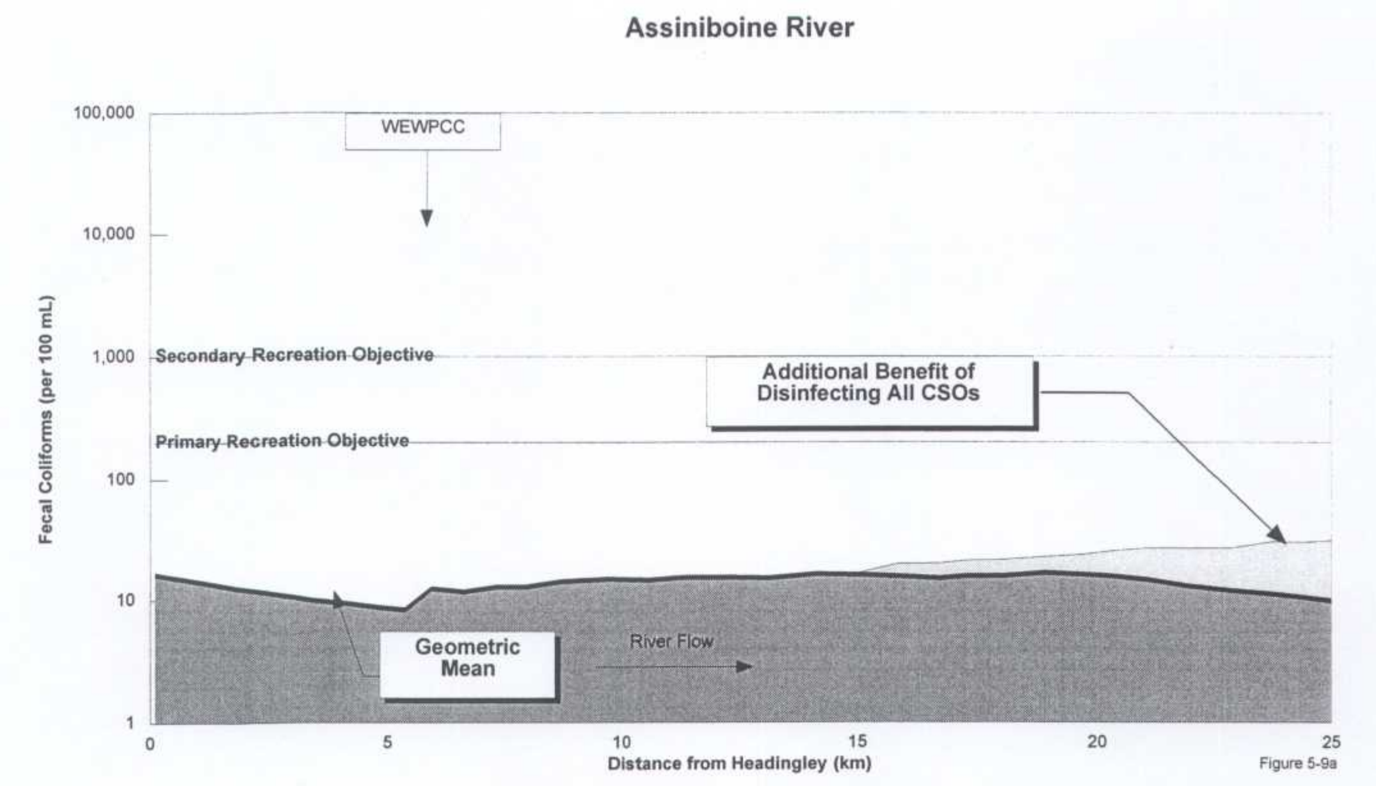
Incremental Benefit of Separating All CSOs

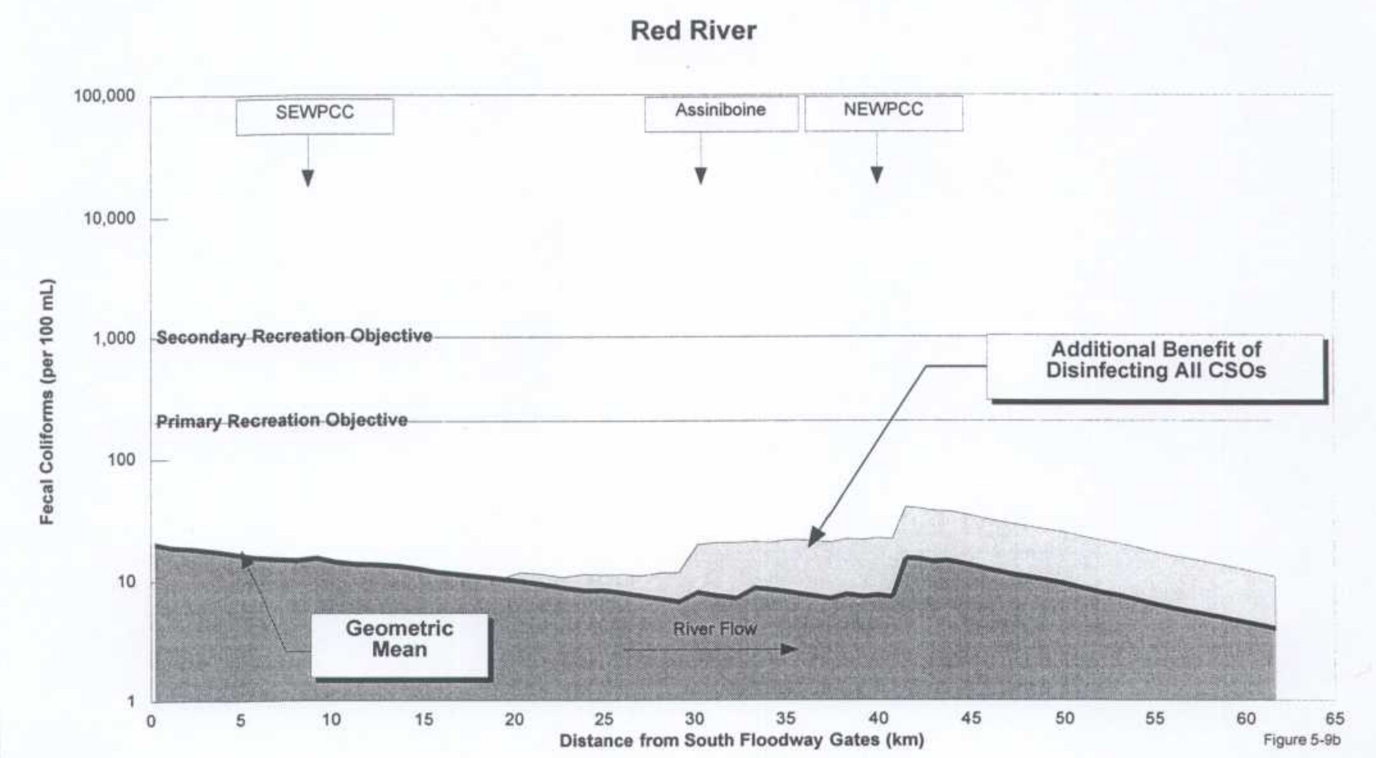
Figure 5-7



Benefit of Effluent Disinfection and Complete Separation of All CSOs Predicted at Redwood Bridge on Red River

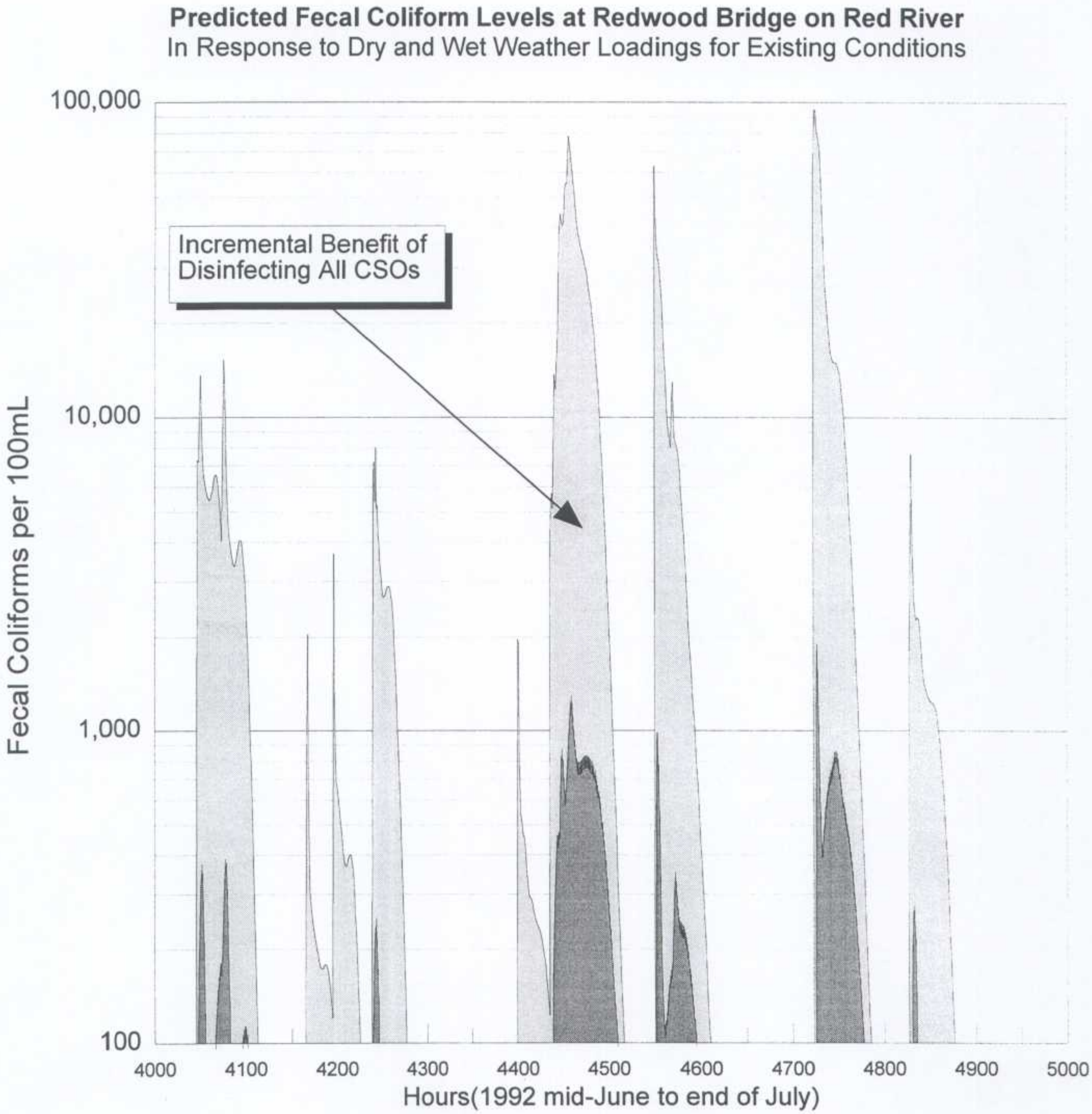
Figure 5-8





Incremental Benefit of Disinfecting All CSOs

Figure 5-9



Benefit of Effluent Disinfection and Disinfection of All CSOs Predicted at Redwood Bridge on Red River

Figure 5-10

Assiniboine River

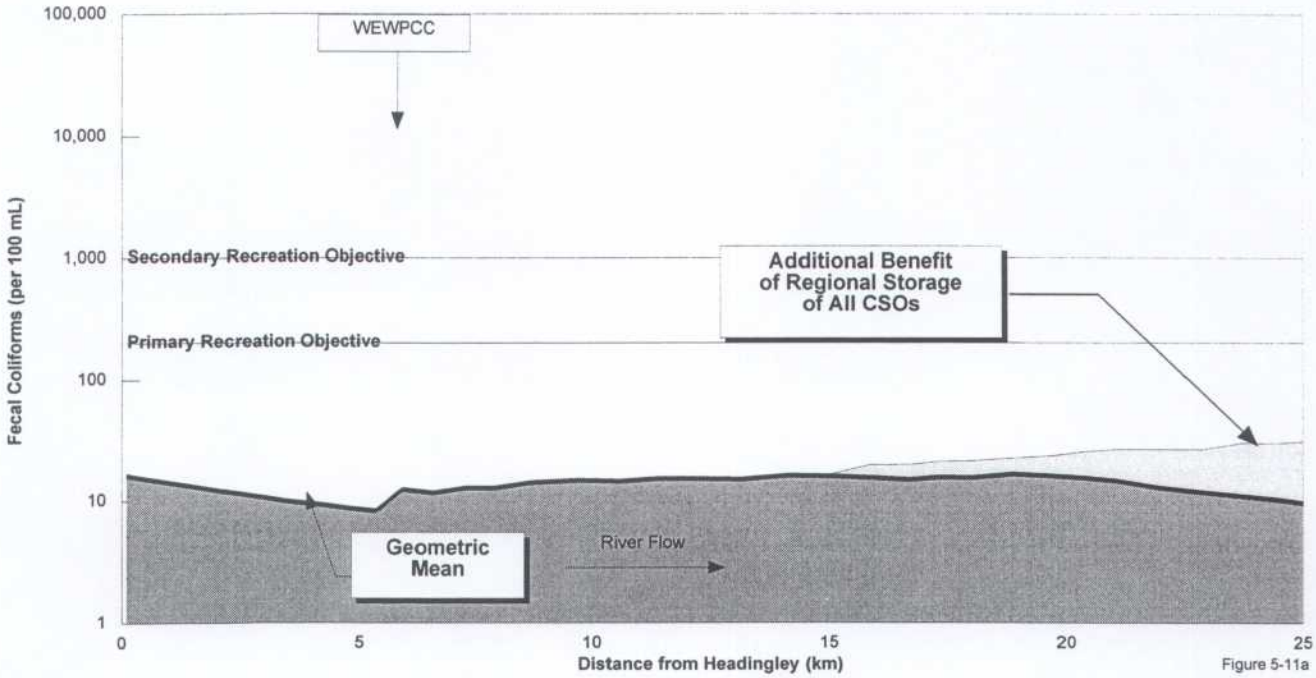


Figure 5-11a

Red River

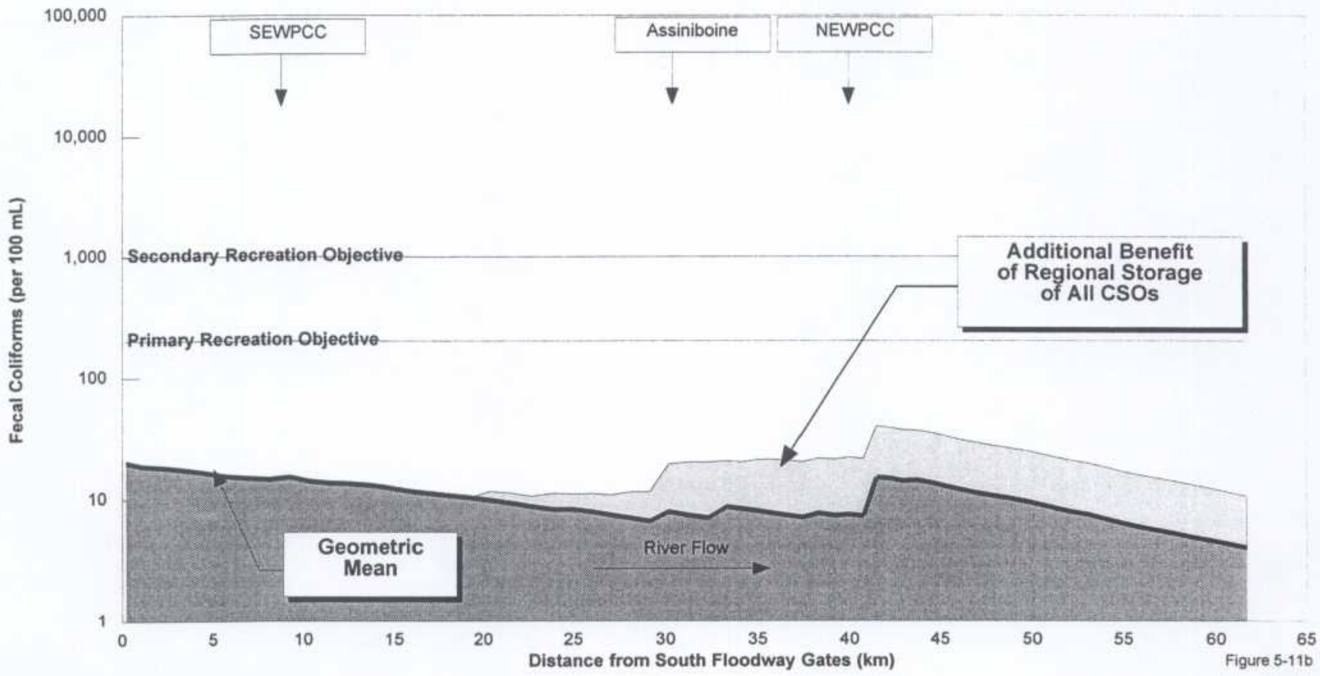
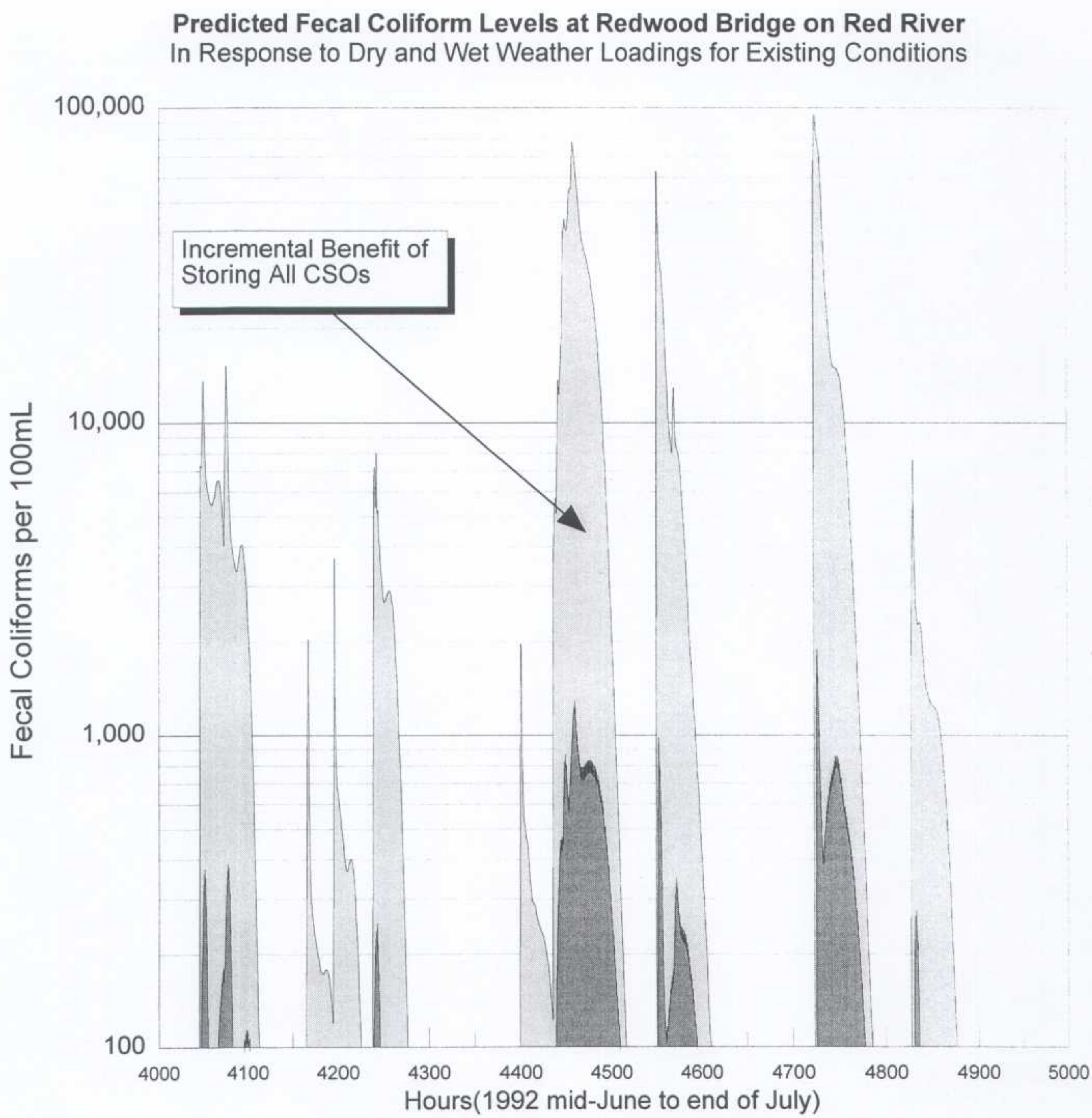


Figure 5-11b

Incremental Benefit of Regional Storage of All CSOs

Figure 5-11



Benefit of Effluent Disinfection and Regional Storage of All CSOs Predicted at Redwood Bridge on Red River

Figure 5-12

Table 5-5
Summary of Percent Compliance with Manitoba Microbiological Objectives
For Spectrum of Alternatives Considered

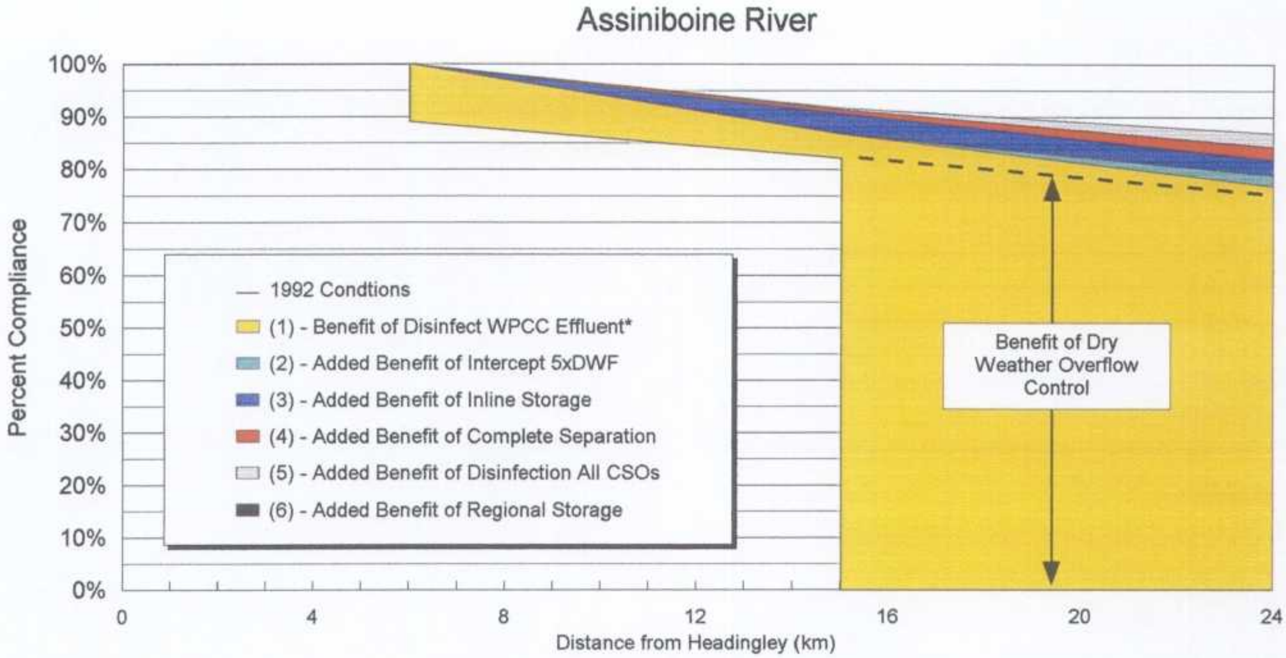
- **Percent Compliance with Manitoba 200 fc/100mL Objective**

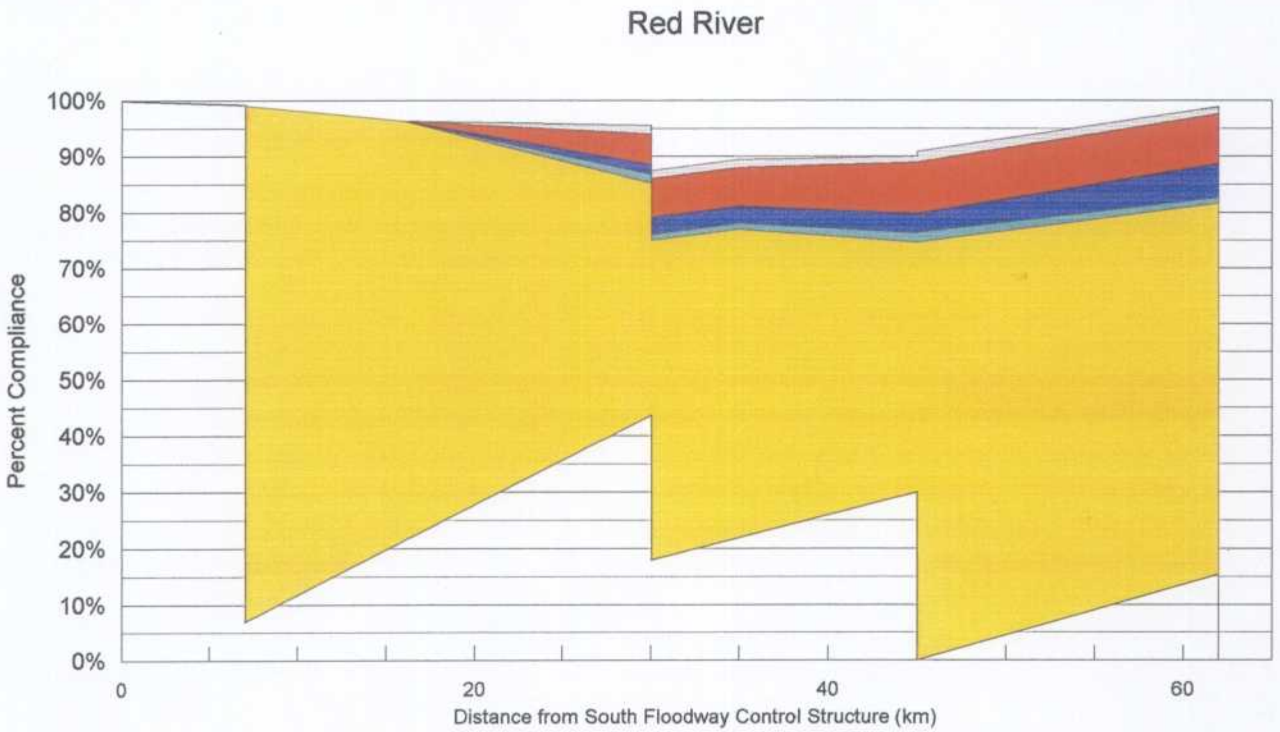
		Control Option					
Location	1992 Condtions	Disinfect WPCC Effluent*	Intercept 5xDWF	Inline Storage and 5xDWF	Complete Separation	Disinfection All CSOs	Regional Storage
Assiniboine River							
Headingley	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
West Perimeter Br.	89.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Assiniboine Park	82.3%	86.7%	84.7%	88.6%	89.4%	89.7%	89.7%
Main St. Bridge	0.0%	76.8%	78.9%	81.9%	84.4%	86.9%	86.9%
Red River							
Floodway Control	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
South Perimeter Br.	99.2%	99.2%	99.2%	99.2%	99.2%	99.2%	99.2%
Fort Garry Br.	21.4%	96.3%	96.3%	96.3%	96.3%	96.3%	96.3%
Norwood Bridge	22.0%	87.0%	88.6%	90.4%	95.8%	97.4%	97.4%
Redwood Bridge	43.7%	78.9%	80.0%	83.1%	90.1%	91.5%	91.5%
North Perimeter	0.0%	74.6%	76.3%	79.8%	89.0%	90.9%	90.9%
Lockport	15.4%	81.6%	82.7%	88.7%	97.7%	98.8%	98.8%
Minimum Compliance	0.0%	74.6%	76.3%	79.8%	84.4%	86.9%	86.9%
Station Average	52.1%	89.2%	89.7%	91.6%	94.7%	95.5%	95.5%

- **Percent Compliance with Manitoba 1000 fc/100mL Objective**

		Control Option					
Location	1992 Condtions	Disinfect WPCC Effluent*	Intercept 5xDWF	Inline Storage and 5xDWF	Complete Separation	Disinfection All CSOs	Regional Storage
Assiniboine River							
Headingley	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
West Perimeter Br.	93.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Assiniboine Park	87.8%	91.0%	90.7%	91.7%	93.3%	93.5%	93.5%
Main St. Bridge	76.6%	82.0%	84.2%	86.7%	92.2%	95.2%	95.2%
Red River							
Floodway Control	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
South Perimeter Br.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Fort Garry Br.	97.9%	99.8%	99.8%	99.8%	99.8%	99.8%	99.8%
Norwood Bridge	89.7%	90.5%	92.0%	92.9%	99.7%	99.9%	99.9%
Redwood Bridge	82.9%	83.8%	84.6%	88.8%	98.2%	99.4%	99.4%
North Perimeter	37.0%	82.1%	83.4%	88.1%	98.3%	99.2%	99.2%
Lockport	88.2%	91.4%	92.0%	94.0%	100.0%	100.0%	100.0%
Minimum Compliance	37.0%	82.0%	83.4%	86.7%	92.2%	93.5%	93.5%
Station Average	86.7%	92.8%	93.3%	94.7%	98.3%	98.8%	98.8%

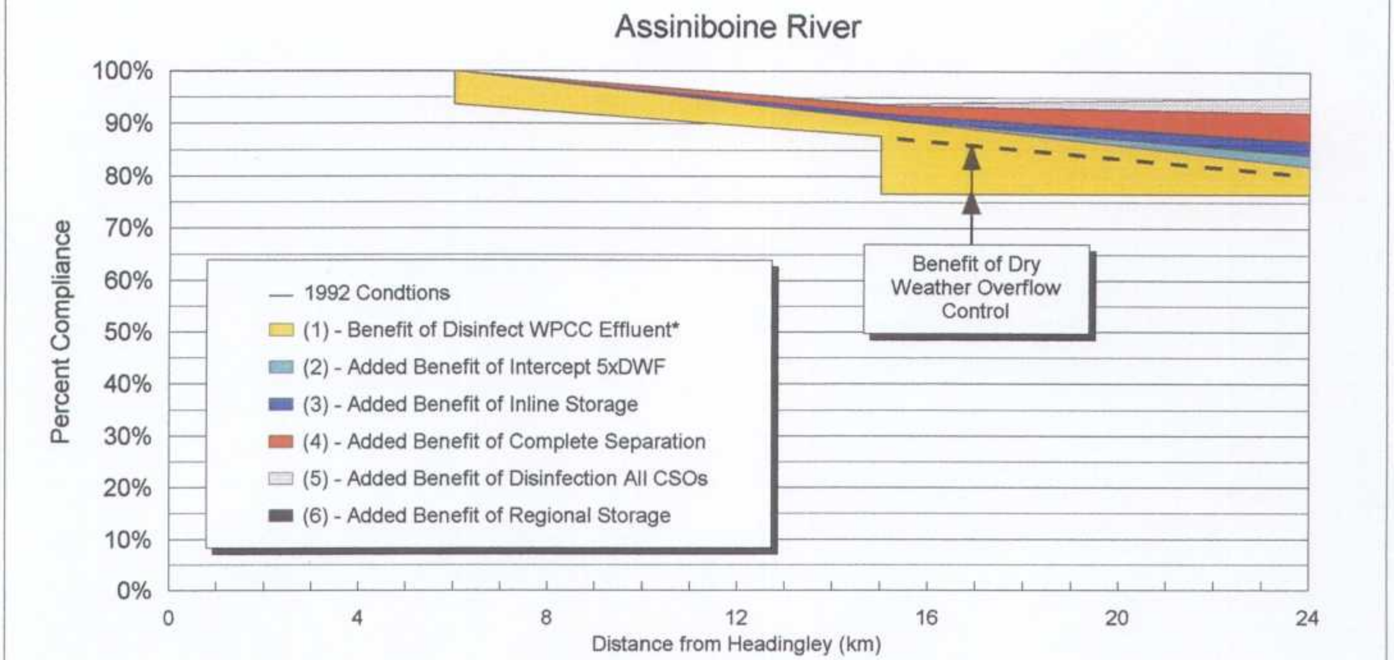
** - Denotes: Assumes Dry Weather Overflows (DWO) have been corrected*

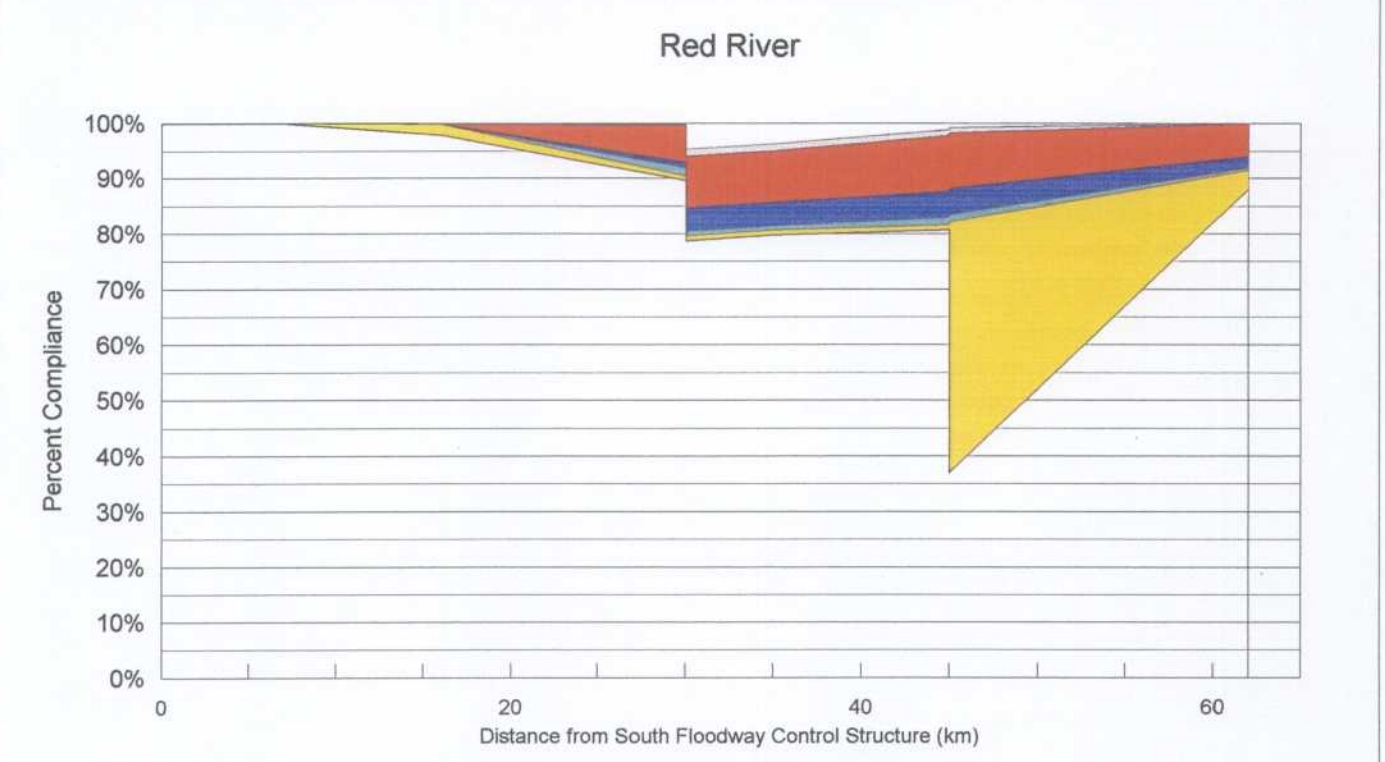




Percent Compliance With
Manitoba 200 Fecal Coliforms per 100mL Objective
For Spectrum of Control Alternatives

Figure 5-13





Percent Compliance With Manitoba 1000 Fecal Coliforms per 100mL Objective For Spectrum of Control Alternatives

Figure 5-14

TABLE 5-6

POTENTIAL COMBINATIONS OF CSO TECHNOLOGIES

CONCEPTUAL OPTIONS	
(1)	Disinfect WPCC effluent and DWO corrections
(2)	Intercept 5 x DWF
(3)	Inline storage + (2)
(4)	Full CSO separation
(5)	Full CSO disinfection
(6)	Eliminate CSO (storage)
LOGICAL COMBINATIONS	
A = (1)	
B = (1) + (2)	
C = (1) + (3)	
D = (1) + (4)	
E = (1) + (3) + (5)	
F = (1) + (3) + (6)	

Correction of dry weather overflows and disinfection of plant effluent will achieve the greatest improvement in terms of statistical compliance with both 200 and 1000 fecal coliforms per 100/mL objectives. Complete 100% compliance cannot be attained due to the residual impacts of land drainage on the rivers.

5.4.2 Reduced Health risk

Disinfection of municipal wastewater effluents (or, in the case of CSOs, other means of reducing coliform levels in the rivers) is intended to reduce the risk to human health arising from the use of surface waters. Disease transmission depends on exposure to the pathogens in the water. This is related to the type and frequency of water use. The benefits of wastewater disinfection arising from a reduction to human health risk can be quantified through risk assessment methods. The methods draw upon concentrations of indicator bacteria, under present conditions and for conditions if disinfection were applied, known levels of use, and disease dose-response (health risk) relationships from the literature. In this way, estimates of the potential number of disease cases contracted with and without control alternatives can be compared.

Quantitative risk assessment was an important component of prior river water quality studies 1986 Disinfection Evaluation (MacLaren 1986), Red and Assiniboine Surface Water Quality Objectives (Tetr*ES* 1991). The risk assessment focused on the incidence of gastrointestinal illness (GI) based on epidemiological equations accepted by regulatory agencies, including Manitoba Environment. This section provides an updated risk assessment. Appendix A to this TM provides relevant background information from the 1991 Report.

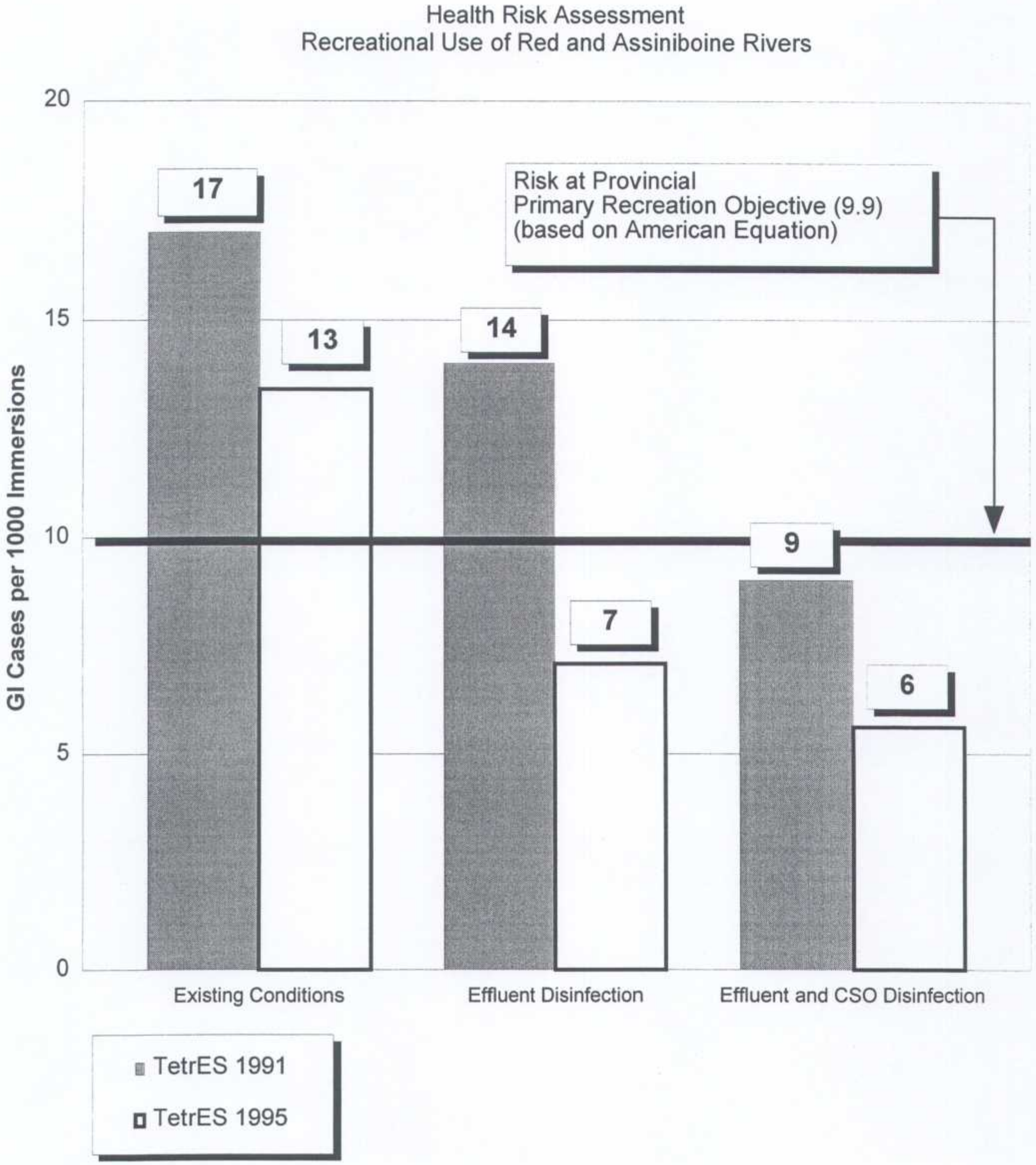
The benefit of disinfection of discharges (or reduced coliform levels) relates chiefly to reducing the health risk from the recreational use of the water. The coliform levels are not a factor in the use of the rivers as a source of raw water for domestic use in that complete treatment is required in any case. Prior studies showed that the probable health risk associated with greenhouse or crop irrigation with river water was so low as to be non-quantifiable. The health risk assessment therefore deals only with recreational use of the rivers.

The use of surface water for recreation is not risk-free. Manitoba Environment acknowledges the concept of acceptable risk in such use of surface waters. The Department estimates that immersion in waters with fecal coliform levels of 200/100 mL (the Provincial Objective) will result in a risk of about 10 cases of GI per 1000 immersions (Rationale Document, Williamson 1988).

Using the American epidemiological equation, the standard by which the US EPA estimates the number of probable GI cases per 1000 immersions, the health risk was estimated under existing conditions for the recreation season on a system-wide basis. While the coliform densities vary throughout the City, the average density of all monitoring locations was used on the premise that primary recreation was just as likely at one location as another.

As previously discussed in Section 4.1.3, the current assessment indicates that the health risk for existing conditions (no effluent disinfection) is about 13 cases per 1000 immersions. With effluent disinfection, the health risk would reduce to about 7 cases/1000 immersions, and to about 6 with CSO disinfection (or elimination of overflows). These last two conditions reflect average fecal coliform densities in the rivers of 100/100 mL for effluent disinfection and 70/100 mL with the addition of CSO disinfection. An estimated number of immersions per year is 5,700 (waterskiers and swimmers), which is expected to cause about 70 cases of GI per year (Phase 1 - TM - Receiving Stream). The estimated benefit in avoided GI cases with effluent disinfection is about 30 per year with an increment of another 6 avoided cases/year with CSO disinfection. The background level of GI cases in Winnipeg has been estimated to be about 300,000 to 700,000 per year (Water Quality Objectives, 1991).

The health risk assessments in previous studies are also shown on Figure 5-15 for comparative purposes. The difference in estimated levels of risks between the studies are attributed to two factors. Firstly, the average coliform densities in the rivers are lower than in previous years due to better quality effluent from the WPCCs. Secondly, the effect of dry weather overflows was not recognized in prior studies and these DWOs are now believed to exert a fairly persistent burden on the river, which was previously attributed to residual effects of CSOs. The increment of benefit for disinfecting WPCC effluents (including the elimination of DWOs) is therefore larger than in previous studies. The current estimates of avoided GI cases are very similar to prior studies.



Estimated Reduction in Gastrointestinal Illness (GI) Cases in the Winnipeg Area for Various Disinfection Options

Figure 5-15

5.4.3 Evaluation

The implementations of the above measures of benefit (compliance and health risk) are discussed in an overall evalution provide in Phase 2 - TM #6.

6.0 MONITORING REQUIREMENTS

Phase 2 has provided planning level modelling of water quality assessments for the purpose of understanding the existing conditions and provide future improvements. This section will identify analyses, monitoring and follow-up studies required to better characterize key characteristics of the receiving stream for improved understanding for informed decision-making. Monitoring programs and laboratory analysis would focus on data-gathering to fill gaps, build databases, and improve or validate receiving stream modelling for Phase 3 of the study.

Three major areas that require further follow-up are:

- the isolation of dry weather overflow sources;
- the characteristic of fecal coliforms in treated effluent discharges; and
- the identification of specific river reaches for special monitoring programs.

Each of these major items are discussed in the following sections.

6.1 ISOLATE DRY WEATHER OVERFLOW SOURCES

The current receiving stream modelling exercise identified that dry weather overflows (DWO) may be frequently occurring on the Red and Assiniboine Rivers. The City of Winnipeg FAST alarm data (TM #3) has confirmed that specific locations are susceptible to dry weather overflows. The City's bi-weekly monitoring data on fecal coliforms in the rivers were used to calibrate The receiving stream model. The calibrated model results strongly indicate that dry weather overflows are likely occurring on the Assiniboine River. This was not as evident on the Red River from monitored data. However, a FAST alarm data indicates that DWO may also be occurring on the Red River and also requires follow-up study, investigation and appropriate action(s). The issue of DWO needs to be addressed promptly and effectively.

Suspected locations of DWO on the Assiniboine River are downstream of the Assiniboine Park Bridge. FAST alarm data indicates that the Tylehurst Station frequently experiences incipient dry weather overflows and needs to be investigated with appropriate corrective studies and actions implemented to prevent dry weather overflows. A suspected second source could be the Aubrey combined sewer outfall. The Aubrey outfall was identified at a public open house held at The Forks on October 1/2, 1994 where concerned citizens stated that ice cover on the river at this location was open in the winter. Security fencing warning signs were erected by the City to identify this area as a potentially dangerous site due to the thin ice conditions. It was also brought to the attention of the study team that the storm relief's outfall sewer near the Donald Street Bridge has a cross-connection to the sanitary sewer system and could act as a combined sewer during both dry weather and wet weather conditions.

It is uncertain if other dry weather overflow sources exist along the Assiniboine River. FAST alarm data needs to be reviewed to identify locations with a previous history of incipient dry weather overflows.

The Cockburn combined sewer outfall was identified by the FAST alarm data as a site that has historically experienced incipient dry weather overflows. This combined sewer system is part of the area serviced by the South End Wastewater Treatment Plant. It should be targeted along with the Tylehurst outfall as two primary candidates for detailed study and appropriate corrections.

A first step in assessing DWO is to initiate flow measurement in the sewers to confirm that these excess flows are occurring and, if possible, to identify the sources of these excess flows. An Inflow and Infiltration (I&I) detection program needs to be defined to reduce these flows at the source, where practical.

Another step in identifying sources of dry weather overflows would involve increased frequency and locations of monitoring on the Assiniboine River. Increasing the number of locations and frequency at which water samples are collected for later analyses would help identify the reaches where DWO sources may be occurring. This could be accomplished by either using selected bridge locations downstream of the Assiniboine Park Bridge and increasing the frequency at which samples are taken or conducting an intensive sampling program by boat at fixed reference locations. Such a program would likely involve the targeting of a specific month, such as August, and samples be taken once per day five days per week at each location for the full month. The cost and logistics of such an exercise would need to be coordinated with the City of Winnipeg laboratory staff before defining the specifics of such a program. It is uncertain whether the Red River needs to be monitored to the same level or detail at this time. It would be reviewed subsequent to the results of the Assiniboine River and assessed whether it is required based on the results of the Assiniboine River monitoring program.

The proposed programs and studies would be used to isolate suspected locations of dry weather sources and improve/expand the database available for refinement of the receiving stream model. The information gathered would be used in Phase 3 of the study to help identify activities that may need to be undertaken as part of the wet weather control implementation strategy.

Historic information from the FAST alarm system should be compiled into a user-friendly information management system and critically assessed to identify outfall for detailed investigation. This FAST alarm system represents a valuable monitoring resource and the data needs to be made available for routine surveillance and interpretation. The data can contribute to identifying "trouble" areas. Suspected locations should be monitored separately through the use of level alarms such as Manning dippers and visual inspections year-round to determine if overflow are occurring and their seasonal behaviour.

6.2 FECAL COLIFORM CONCENTRATIONS IN WPCC EFFLUENTS

Review of loading data used in the receiving stream model indicated that measurements of fecal coliform concentrations in treated effluent were sparse. Discharges from the treatment plants are a significant contributor of fecal coliforms to the rivers during dry weather conditions and to the question of compliance with MSWQO. Values used in previous modelling exercises, including this study, estimated the concentration in the effluent based on monitored river concentrations. The 1991 UV disinfection study (Wardrop 1991) indicated that fecal coliform concentrations in the treated effluent were lower than those previously assumed. It was recommended, during the course of Phase 2 of this study, that the wastewater entering the treatment plant, by-pass from secondary treatment, and the combined discharge to the receiving stream be monitored and quantified to more accurately characterize the density of coliforms in the effluent discharges during DWF and WWF.

The City of Winnipeg initiated the sampling and characterization of wastewater effluent in May of 1995. Table 6-1 contains the City of Winnipeg laboratory summary for effluent quality monitoring at the NEWPCC, SEWPCC and WEWPCC in July of 1995. The fecal coliform densities from all 3 WPCCs are much lower than the 200,000 organisms per 100 mL as indicated from long-term data. Recent monitoring tends to confirm substantially lower levels, and warrants ongoing monitoring and follow-up study.

The WPCC effluents are important contributors of fecal coliform and a reasonable data set on these effluents is important. An adequate characterization is necessary.

6.3 SPECIAL PROGRAMS

Several special programs that could contribute to better characterization of specific characteristics of the river and thus allow for an improved understanding of its behaviour and Phase 3 receiving stream modelling are discussed in the following sub-sections.

6.3.1 Dry Weather Conditions

Increased monitoring during dry weather conditions from the headwaters where the Red and Assiniboine Rivers enter the City of Winnipeg downstream to Lockport would provide the information necessary to categorize baseline water quality and fecal coliform die-off more accurately. The City of Winnipeg routinely monitors a water quality of the Red and

Table 6-1
Treatment Plants Coliform Monthly Summary: July 1995

	NEWPCC Final Effluent			SEWPCC Final Effluent			WEWPCC Effluents		
Date	Sample	Fecal (/100mL)	E. coli (/100mL)	Sample	Fecal (/100mL)	E. coli (/100mL)	Sample	Fecal (/100mL)	E. coli (/100mL)
07/06/95	N1	9310	4300	S1	3900	930	FE	21000	9300
	N2	4300	4300	S2	9300	750	C5	930	990
	N3*	43000	23000	S3	4300	2300	C4	4	4
	G.M.	***12000***	***8000***	**G.M.**	**5400**	**1200**	**C3**	**0**	**0**
07/13/95	N1	9300	4300	S1*	150000	93000	FE	230000	83000
	N2*	21000	15000	S2	93000	93000	C5	930	430
	N3	4300	4300	S3	93000	93000	C4	0	0
	G.M.	***9000***	***7000***	**G.M.**	***110000***	**93000**	**C3**	**0**	**0**
07/20/95	N1	24000	9300	S1	39000	23000	FE	46000	9300
	N2*	9300	9300	S2	39000	93000	C5	15	9
	N3	15000	9300	S3	93000	21000	C4	9	9
	G.M.	***12000***	**9300**	**G.M.**	**70000**	**35000**	**C3**	**0**	**0**
07/27/95	N1	43000	43000	S1*	150000	150000	FE	43000	23000
	N2	43000	43000	S2	43000	23000	C5	43	15
	N3	23000	23000	S3	93000	43000	C4	750	750
	G.M.	**35000**	**35000**	**G.M.**	***80000***	***50000***	**C3**	**93**	**43**

Note: NEWPCC and SEWPCC are sampled in triplicate once per week.

* represents suspect values. Environmental Sciences Center advises that these values may be a result of variation in analytical techniques/interpretation of dilution tubes. Underlined and Italic indicate suspect values. WEWPCC sample C# represents effluent leaving cell C#3 on way to cell C#4. G.M. = Geometric mean.

Assiniboine Rivers at 13 established bridge locations within the City of Winnipeg. The samples are collected every two weeks (i.e., a mix of dry weather and wet weather influences) and analyzed for a range of water quality parameters. Consideration should be given to establishing a more detailed monitoring program from all bridge locations on a more frequent basis to better characterize the response and behaviour of the receiving stream during dry weather conditions.

It is envisioned that such a program would consist of monitoring twice per week for a complete month (say August) at all bridge locations located within the City of Winnipeg. The collected water samples would be analyzed for a better characterization of the fecal coliform die-off behaviour in the river systems. It is uncertain that if the upstream portions of both the Red and Assiniboine Rivers have similar die-off characteristics and the combined influence downstream of the confluence. Collected data would be analyzed to more accurately define the die-off constant (k) and temperature coefficient theta (Θ) used in the first order die-off equation. Sensitivity analysis done as part of the receiving stream modelling indicated several combinations of die-off constant and temperature coefficient could fit the monitored data. The benefit of such information would relate to the specific characterization of river reaches in terms of fecal die-off behaviour. As well, from a modelling perspective, it would more confidently establish appropriate local site values for first order die-off behaviour of fecal coliforms.

Previous river monitoring and modelling indicated that the dissolved oxygen (DO) resources on the river during dry weather conditions were adequate to support healthy aquatic life and fully comply with Manitoba Surface Water Quality Objectives. It is important to continue to collect supporting data to confirm that the wet weather influences do not cause an unacceptable DO suppression. Previous modelling exercises indicated that the greatest impact on DO levels during dry weather flow conditions would be observed downstream of the NEWPCC. This location would be most vulnerable to any suppression of DO resulting from CSO. A convenient monitoring point on the river which minimum DOs are predicted to occur does not exist. The location of the DO sag is dependent upon river flows and will accordingly vary in location in response to changes in flow. A better characterization of the DO profile along the stretch of river downstream of the NEWPCC would characterize its fragility and its susceptibility in response to low river flows, increased plant discharges, and possible influences of wet weather loadings and allow for focussed monitoring. It is recommended that monitoring be conducted by boat at several locations downstream of the NEWPCC to Lockport to better characterize DO levels in this stretch of the Red River. The program would require frequent monitoring, approximately 2 days per week for a month (say August) to collect the data necessary to accurately define DO levels to confirm it satisfies MSWQO and for possible use in dynamic DO modelling should it be necessary. Consideration should be given to installing a fixed DO probe to collect continuous DO readings in this stretch of the River.

6.3.2 Wet Weather Response

The City of Winnipeg has conducted numerous special CSO monitoring programs since 1990 to collect sufficient data to better characterize the water quality response in terms of:

- fecal coliform concentrations;
- dissolved oxygen;
- nutrients and algae;
- toxic substances; and
- mixing zones.

Additional monitoring of fecal coliform levels and dissolved oxygen levels, especially downstream of the NEWPCC is required to better characterize the rivers under wet weather conditions. The City of Winnipeg should continue to selectively conduct these special monitoring programs and piggy-back them with other river quality monitoring programs. The program would likely involve the collection of water samples on a daily basis for a complete month (that is 5 days per week) analyzed for fecal coliforms, BOD, and ammonia. This information would continue to build the database of information necessary to assess response and behaviour of the receiving stream under dry and wet weather conditions. This information would help characterize the response of the rivers to wet weather loadings and the corresponding levels of fecal coliforms and possible impacts on the DO resources of the receiving streams. Monitoring would likely be performed from a boat at established locations along the river systems. The collected data would then be processed into a database, critically analyzed, and used to assess the behaviour of fecal coliform response/die-off, dissolved oxygen dynamics, and validate or refine model predictions.

6.3.3 Sediment Deposition

The impacts of discharges from the land drainage and combined sewers on the rivers need to be better understood to assess riverbed impacts. Specifically, wet weather discharges may cause a buildup of sediments or a scouring of the river bed at outfall locations. A cursory program was conducted to map the river bottom at selected outfalls and establish a baseline to determine if such impacts were occurring. This involved a special river monitoring program utilizing a sonar unit to map the river bottom. Results of this program are included in Appendix B. This information served as an initial attempt to characterize key locations and also assess whether or not spring high flows would wash out or fill in any potential impacts of sediment buildup or scouring from wet weather discharges. It was found that sediment appeared to be accumulating at the Jefferson outfall. A follow-up bank inspection was attempted in the fall to visually assess the impacts of discharge at this location. Due to high flows, snow fall and freezing conditions, it was not possible to gain any further knowledge from a visual inspection.

It is recommended that this program be repeated and sediment samples be taken to determine if hydraulic discharges are influencing the river bed and whether or not toxic substances are accumulating at outfall locations.

7.0 PHASE 3 MODELLING

The receiving stream modelling exercise conducted in Phase 2 of the CSO study was performed on a first level screening basis. It was intended that the modelling would help assess the relative impacts of the sources of discharges and screen the range of control alternatives to identify their effect on water quality and thus form the basis of benefits assessment. This initial screening helped place the key water quality influences into perspective and identify the most promising control alternatives (refer to TM #5 - Control

Alternatives). The focus of activities associated with Phase 3 receiving stream modelling will be to simulate combinations of different control technologies in an attempt to achieve a least cost solution for a given level of benefit. Phase 3 modelling will also be used to identify the response of different control strategies to protect key river reaches.

The reduction of fecal coliform concentrations used in disinfection of combined sewer overflows and treatment plant discharges were based on representative values to screen alternatives and identify the most promising technologies. Phase 3 will review the practicable levels of disinfection for various control technologies as well as the possible processes (e.g., chemical versus UV). The analysis will involve the review of satellite end-of-pipe treatment technologies such as VSS and RTVs and the levels of disinfection that could be realistically achieved. A similar analysis will be conducted to identify the possible centralization of regional distributed storage and treatment facilities which would service a number of districts. Each of these refinements would be tested to assess their significance in terms of receiving stream response and help place achievable benefits into perspective.

Disinfection of WPCC effluents will be reviewed in more detail to determine the optimal configuration to achieve the maximum fecal coliform reduction under various modes of dry and wet weather operation. This will involve the modelling of various disinfection processes:

- dry weather disinfection only;
- dry weather disinfection train and separate wet weather disinfection train;
- all flows disinfected at a single point of discharge;
- disinfection at SEWPCC, WEWPCC, NEWPCC (alone or in combination); and
- other possible combinations.

A more elaborate benefits assessment would be conducted on receiving stream impacts to better quantify the merits and associated costs of selected technologies. This could involve the establishing of a framework such as protecting key river reaches based on either recreational use, edification in highly-sensitive areas, improved compliance with Manitoba Surface Water Quality Objectives, or reduction in number of overflows in volume to evaluate alternatives.

APPENDIX A

HEALTH RISK

This Appendix provides the health risk equations, the immersion events estimated from primary and secondary recreation activities on the Red river, and the calculated health risk (Gastrointestinal Illness, GI) that may occur for normal and extreme conditions from Winnipeg to Selkirk.

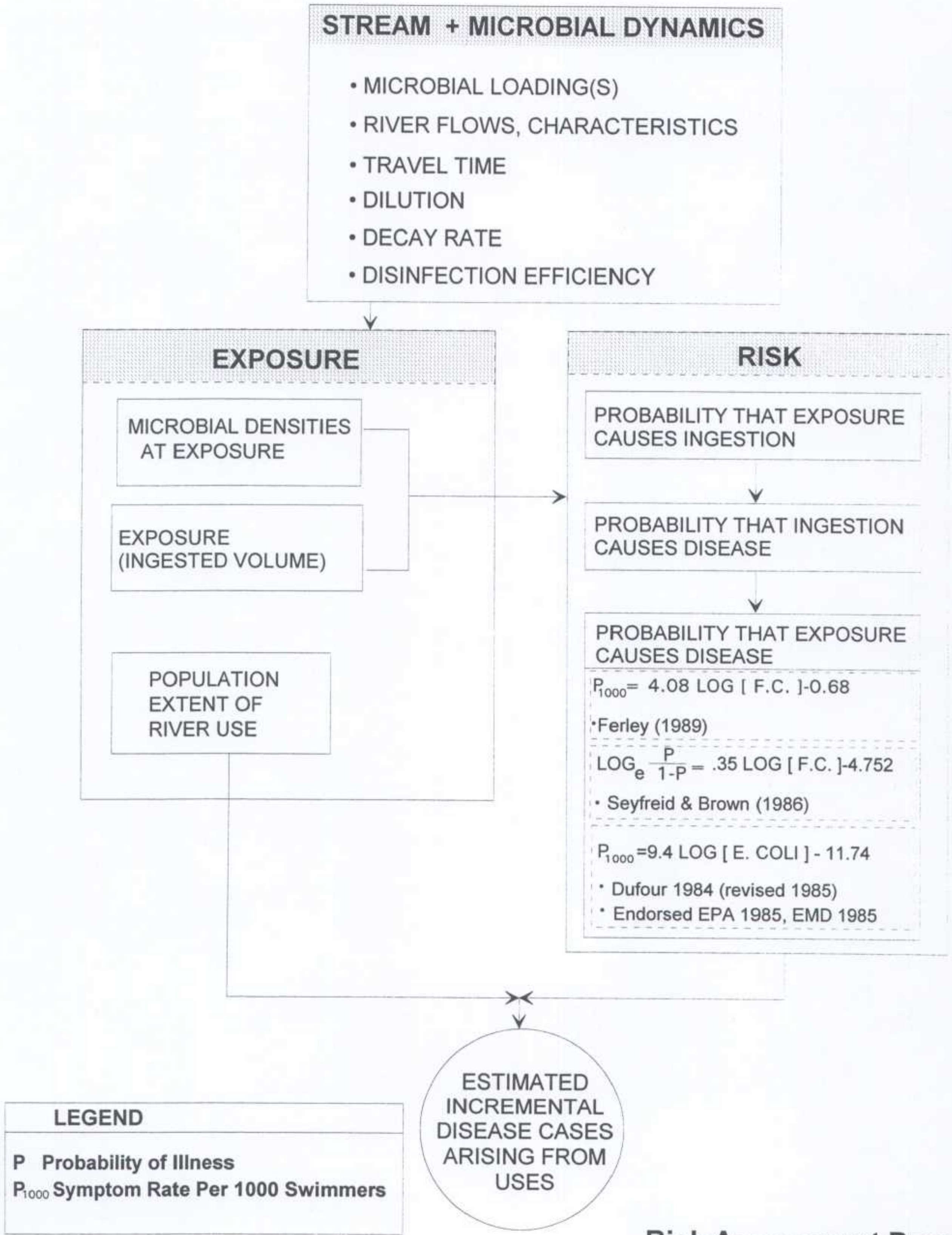
Health Risk With Recreation

The objective of the risk assessment is to estimate annual cases of GI which may be associated with recreational use of the river, as well as the number of GI cases which can potentially be avoided through disinfection. The risk assessment process is illustrated in Figure A-1. The principles of health risk through use of surface water is shown. The epidemiological relationships have been expressed in mathematical formulations.

Overview of Trends in Disease Incidence

Most records or research into recreation-associated disease incidence have been for primary contact, especially swimming, where full immersion is likely and intentional. (In fact, very few agencies have microbiological objectives for secondary recreation.) Very few instances of gastrointestinal disease have been documented. Single outbreaks only of hepatitis, Coxsackie A and Coxsackie B virus infections have been associated with recreational waters. The best documented case of enteric disease associated with swimming was an outbreak of Shigellosis (bacillary dysentery) in the Mississippi River (Hubly *et al.* 1985)[1]. No known deaths anywhere have been attributed to gastrointestinal disease from recreational water use (Dutka *pers. comm.* 1986)[2].

The most frequently reported illnesses associated with primary contact recreation are infections of ears, eyes, skin and upper respiratory tract (Health and Welfare Canada 1984)[3]. Otitis externa caused by *Pseudomonas aeruginosa* is probably the most common infection reported, although there is little definitive data to indicate whether the source of the organisms is the water or the auditory canals of the bathers (e.g., Calderon and Mood 1982)[4]. There have been about a dozen cases of wound infections caused by *Aeromonas hydrophila* associated with swimming in ponds and lakes. One of the most commonly



Risk Assessment Process

riskases
cso1

Figure A-1

reported skin diseases associated with swimming is swimmer's itch, the causative agent of which is carried by birds (Health and Welfare Canada 1984).

Four epidemiological studies of swimming-associated disease incidence have been conducted in North America. All focused on gastrointestinal disease. In the 1950s, several recreational areas in the United States were surveyed and found that regardless of water quality, swimmers had a relatively higher illness rate than non-swimmers (Stevenson 1953)[5]. However, a significant difference was only observed at a few locations when total coliform count was greater than 2,300 organisms/100 mL. These studies were later used to develop water quality criteria by the USEPA.

A review of the USEPA criteria prompted two recent epidemiological studies on marine (Cabelli *et al.* 1983)[6] and freshwater beaches (Dufour 1984)[7]. These studies found an increased risk of illness from swimming in water contaminated with treated sewage and quantitative relationships between indicator organism concentrations and symptom rate were developed. These equations are referenced in the MSWQO.

A similar type of epidemiological study has been conducted for bathing beaches in Ontario (Seyfreid *et al.* 1985a, 1985b)[8]. Symptom rates for all types of illnesses were 69.6 per 1,000 swimmers compared to 29.5 per 1,000 non-swimmers, with respiratory and gastrointestinal ailments being those most frequently experienced. This study also derived a mathematical expression for relating fecal coliform, river use, and incidence of GI cases.

The above reports were considered in the 1986 Disinfection Study. A recent French study (Ferley *et al.* 1989)[9] provides the only additional epidemiological research since the studies of Dufour and Seyfreid. Although following a similar methodology to the earlier studies, the French research differed in two important ways. The work was conducted in a river while the earlier studies considered lakeshore beaches and the new study encountered much higher indicator bacteria concentrations. Fairly similar results were found. Compared to non-swimmers, swimmers ran a higher risk for all, GI when fecal coliform concentrations exceed 270 fc/100 mL; for GI with vomiting and diarrhea above 800 fc/100 mL; and for skin diseases above 120 fc/100 mL.

Risk Assessment Methods

To conduct a risk assessment, data on several variables are required for both "no-disinfection" and "disinfection" scenarios:

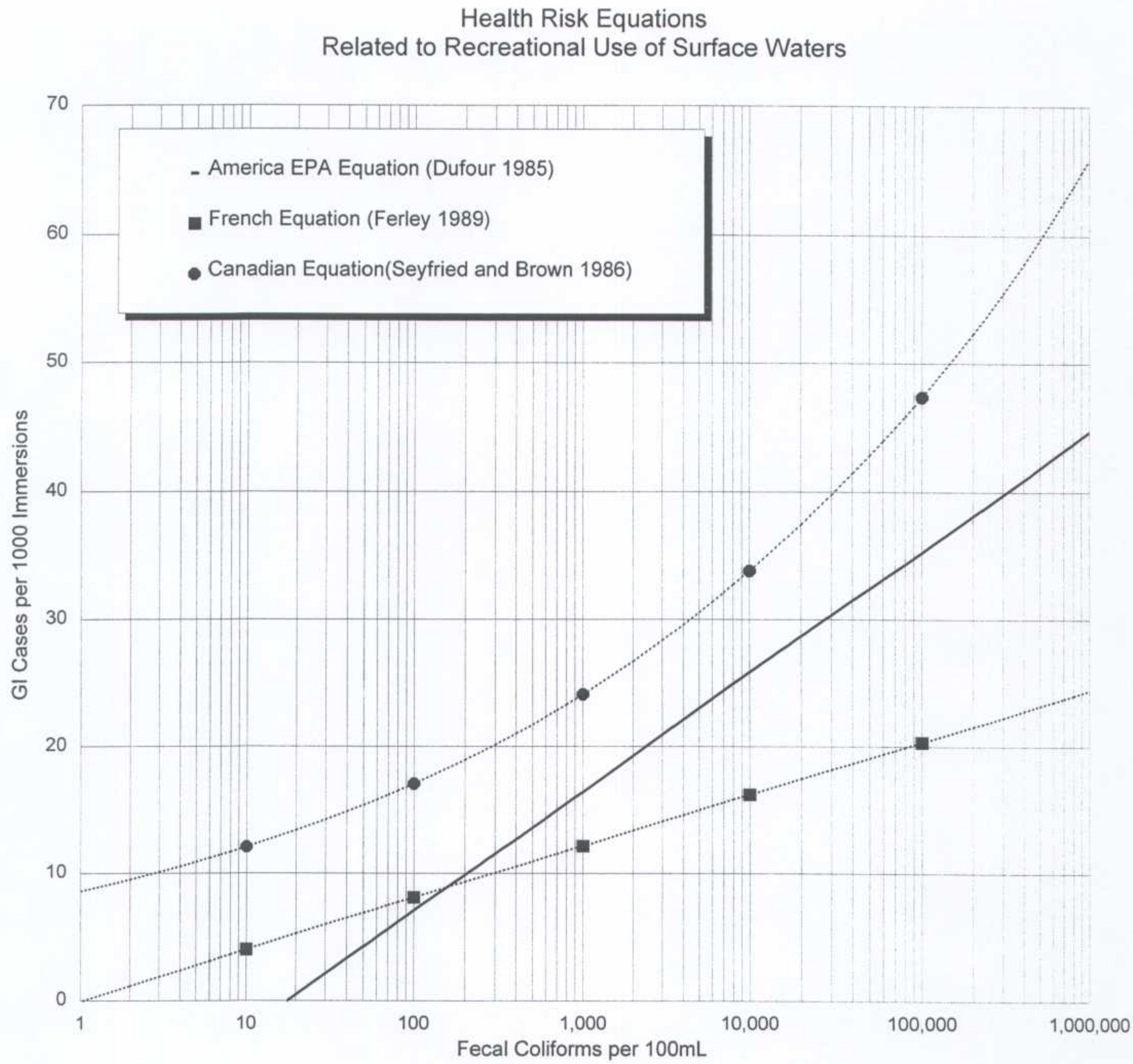
- Microbial loadings: These are derived from current measurements and from known efficiencies of the technology. Disinfection was assumed to remove 99% of the indicator organisms (MacLaren 1986)[10];

- Stream dynamics: The importance of river flow on the concentrations of microorganisms in the river, considering dry weather and wet weather factors. The "no-disinfection" scenario used actual data from 1980-1989 and predicted river concentrations were used for the disinfection scenarios (Wardrop/Tetr*ES* 1991)[11];

- River uses: The number of immersion events for primary and secondary recreation in the Winnipeg and Selkirk areas were derived in the Red and Assiniboine SWQO (Wardrop/Tetr*ES* 1991);

- Dose-response rates: These are the quantifiable relations between concentrations of indicator organisms and the frequency that gastrointestinal disease symptoms occur. This information was drawn from the American, Canadian and French epidemiological studies discussed above.

Epidemiological studies have been undertaken in various countries which correlate bather-related gastrointestinal illness (GI) to the density of indicator organisms, often fecal coliforms. These studies have derived health risk equations. The USEPA adapted the work of Dufour and Cabelli to develop criteria for US recreational waters. Manitoba Environment has also used this work to support the Manitoba Objectives. Three health risk equations, American (Dufour, 1984-USEPA endorsed), Canadian (Seyfreid *et al.* 1985a, 1985b) and French (Ferley *et al.* 1989), were applied to local river use estimates to calculate the number of potential cases of GI for the current condition (no disinfection), plant effluent disinfection, and combined sewer overflow (CSO) and plant effluent disinfection. Figure A-2 is a plot of the symptom rate derived from these equations in terms of estimated cases of GI based on a given fecal coliform



Estimated Cases of Gastrointestinal Illness (GI) per 1000 Immersions for Various Levels of Fecal Coliforms Concentrations in Recreational Waters

Figure A-2

density. The logarithmic scale for the fecal coliform density indicates that a large increase in fecal coliform density results in a small increase in GI cases per 1000 immersions. This relationship indicates that the total number of GI cases resulting from surface water recreation will be largely attributable to the intensity of use or the number of immersions.

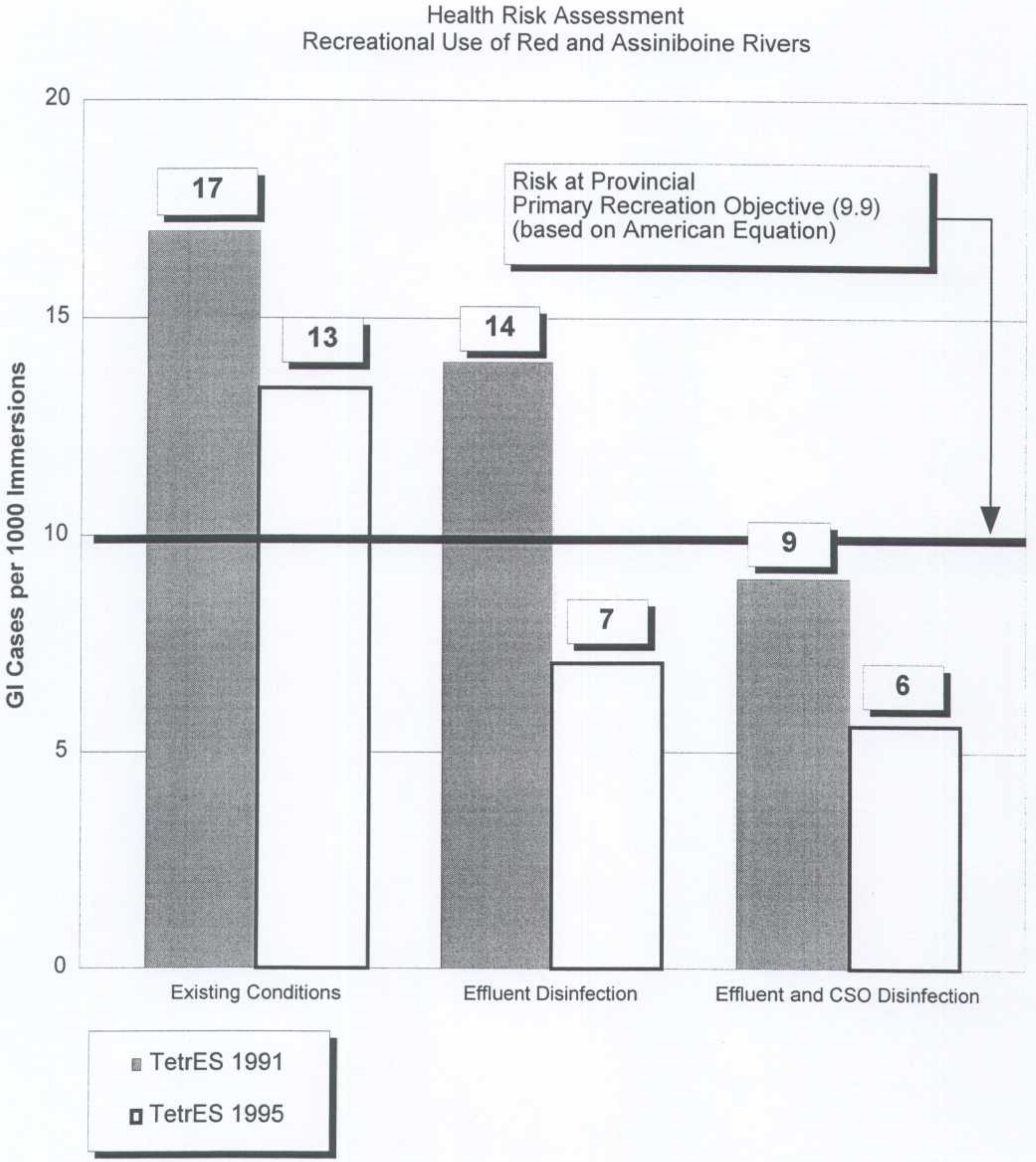
The key factor in assessing the public health risk associated with recreational use is to estimate the total number of immersions. A summary of the extent of use and annual immersion events for river recreation in the study are was done in the Red and Assiniboine Surface Water quality Objectives Study, Wardrop/Tetr*ES* (1991). The total estimated number of immersions per year is about 5,700 in the Winnipeg area and about 6,500 when Selkirk is included.

Detailed Calculations

The number of GI cases were calculated for a range of coliform densities and disinfection scenarios, i.e., current conditions (no disinfection), plant effluent disinfection, and CSO and effluent disinfection. An estimated symptom rate and the number of predicted GI cases are shown in Figure A-3 and Table A-1, respectively. The normal indicator density for current conditions (no disinfection) was based on the geometric mean of the fecal coliform data for the representative year 1992.

Using the equation from the American study which has been the basis for the Manitoba Objectives, the predicted incremental GI rate in Winnipeg from primary and secondary recreation without disinfection is about 78 cases per year. Disinfection of plant effluents is likely to reduce the number to about 40 cases, giving a disinfection benefit of about 36 avoided recreation-related cases in Winnipeg.

If both CSO control and wastewater treatment plant effluent disinfection were implemented, about 44 GI cases would be avoided annually based on normal conditions. Thus, the incremental benefit of CSO disinfection is about 8 avoided GI cases. Nonetheless, even after implementation of both strategies, GI cases will continue to occur in association with river recreation. This annual case load will likely be about 32 cases.



Estimated Reduction in Gastrointestinal Illness (GI) Cases in the Winnipeg Area for Various Disinfection Options

Figure A-3

TABLE A-1

HEALTH RISK ASSESSMENT SUMMARY REGARDING CSO CONTROL NUMBER OF CASES AND BENEFITS (FOR NORMAL CONDITIONS)

RED RIVER - WINNIPEG
(Sum of Primary and Secondary Recreation)

DISINFECTION CONTROL OPTIONS		AMERICAN
1.	Existing Conditions	76
2.	Disinfection at Palnts only	40
	Avoided Cases	**36**
3.	Disinfection at Plants and CSO Control	32
	Additional Avoided Cases Benefit of CSO Control	8
	Total Avoided Cases	**44**

Observations

The following comments place the estimated number of annually avoided cases in context, and explain several implications of the epidemiological equations used.

An important observation gained by applying the epidemiological study approach to the Red River, is that the Manitoba Surface Water Quality Objective of 200 fc/100 mL is not risk-free for recreational use. This has been recognized in derivation of the MSWQO (Williamson 1986)[12]. The American epidemiological equation indicates that exposures to waters with fecal coliform concentration at this objective could cause about 10 cases per 1000 immersions. If the Canadian predictive equation is applied, then the currently accepted risk is 19 cases per 1000 immersions. For the French equation, the accepted risk is 9 cases per 1000 immersions. In essence, this means that people choosing to use surface waters for recreation implicitly accept a degree of health risk from exposure to these surface waters. The GI risks for the primary objective and for potential conditions in the Red River are shown in Figure A-3.

The estimated avoided cases represent the total number of cases directly attributable to recreation on the Red River. The number of cases actually reported to doctors or health officials would be much lower. In the Ontario epidemiological study, the reporting rate was 1 to 3% (Seyfreid *pers. comm.* 1986). If this ratio is applied to the estimated Winnipeg incremental case load, the difference in reported gastrointestinal cases attributable to implementing disinfection is not measurable. A higher reporting ratio of 1 in 10 cases may be probable for most diseases in Manitoba (Ronald *pers. comm.* 1986)[13]. This ratio suggests that disinfection could reduce the annual number of reported recreation-related GI cases by up to nine cases from the Winnipeg area. In relation to the total number of reported cases of illness, this benefit of disinfection would be difficult to detect. The disinfection-related reduction of reported GI cases in Selkirk using any reporting ratio would not be measurable.

The number of total recreational-related cases and of avoided cases is very small when compared to the estimated background GI case load for Winnipeg. This background value is extremely difficult to determine, because of problems in determining the causative agents, low reporting rates, etc. The 1986 Disinfection Evaluation study (MacLaren 1986) estimated by two methods, the base case load between 288,000 and 720,000 cases annually.

It is important to note that the risk assessment estimates do not indicate the severity of the disease. In general the symptoms are likely to be mild and of short duration (Seyfreid *pers. comm.* 1986). Only a small proportion of cases are likely severe enough to cause hospitalization.

Recreation Health Risk from Other Pathogens

Dose-response relationships are presently unavailable for the following organisms: total coliforms, *Staphyloccus aureus, Candida albicans* and protozoans (e.g., *Giardia lamblia*). although quantified relationships have been determined for enterococci, fecal streptococci, *Pseudomonas aeroginosa*, and *Shigellae*, insufficient Red River data are available to apply these. (Note that *enterococci* data has been collected by the City since February 1988).

Two of the above species are implicated in non-gastrointestinal illness. *Staphyloccus aureus* is potentially a very debilitating disease expressed in infected wounds or dermatitis. However, since the major route of waterborne infection is likely physical proximity to other bathers shedding the pathogen (Seyfreid *pers. comm.* 1986), this organism should not be of major concern for the Red River, given the lack of beaches or organized bathing. Studies have also shown that its presence cannot be correlated with indicator densities (Williamson 1985).

Pseudomonas aeruginosa can cause ear infections, which may re-occur particularly in children. Although a probability of illness has been calculated for this species, the relationship is not very strong. Age has been predicted to be more important than pathogen density in the relationship (Seyfreid and Brown 1985)[14]. Several researchers believe that swimming and the presence of water in the ear reduces an individual's resistance and there are no definitive data to indicate whether the source of the pathogen was the water or the auditory canals of the bathers themselves (Health and Welfare Canada 1984). A review article suggested that *Pseudomonas aeruginosa* are naturally present in freshwater and not amenable to quantifiable dose-response relationships (Cabelli 1984). It is difficult to quantify further the hazard for users of the Red River. The Guidelines for Canadian Recreational Water Quality suggest monitoring concentrations in conjunction with epidemiological data for recreationally used beach areas. The scattered and low levels of use for the Red River would make this difficult. In addition, while disinfection may reduce *P. aeruginosa* concentrations, infections may still be associated with recreational use of the Red River if the pathogen were already present in the ears of bathers.

Summary

The assessment of public health risks associated with recreation has provided the following insights:

1. Disinfection of the plant effluents will likely reduce, on average, gastrointestinal illness in the Winnipeg area by about 36 cases annually for total recreation.

2. Control of combined sewer overflows will further reduce recreation-related GI cases by about 8 annually.

3. The number of cases of gastrointestinal illness associated with water recreation represent a very small percentage of the background gastrointestinal loads. Given the low reporting ratio, there would likely be no detectable difference in health risk arising as a benefit of disinfection;

4. A sensitivity analysis indicates that microbial concentration is not the most important factor in determining recreation-related health risks. The case load is primarily use-driven. If significantly greater recreation (especially primary) occurs following effluent disinfection, more cases of illness will likely result from increased exposure;

5. Compliance with Manitoba Surface Water Quality Objectives for primary recreation will not provide disease-risk-free recreation.

Seasonal Use of Rivers for Irrigation

A total of 58 greenhouse operations were identified to be within the study area, but only 40 of these were found to be applicable to the microbiological objectives for irrigation. The greenhouse microbiological objective is intended to protect humans from the potentially adverse effects of accumulated substances on market produce that may not be cleaned prior to consumption. The objective also includes protection of staff that may come in direct contact with irrigation waters. The objectives are:

- maximum geometric mean of 1000 fecal coliforms/100 mL for field crops; and
- maximum geometric mean of 200 fecal coliforms/100 mL for workers in direct contact with irrigation water.

A survey was conducted by Tetr*ES* is 1992 confirmed that the Red and Assiniboine Rivers are very limited in their use as a year-round or season source of irrigation water for greenhouse operations. Virtually all (38) were primarily involved in the production of bedding plants, except for two greenhouse operations that grow a variety of crops for agricultural research purposes as shown in Table A-2. Seven of these 40 operations were found to use the rivers within the study area for a portion of their operating season. Of these, four operations were upstream of the WPCCs, one used the Seine River, leaving only two greenhouse operations, both on the Red River (Riverside Greenhouses #4 and Petal Place #5), that might benefit from the disinfection of treated effluent discharges, as shown on Figure A-4.

The use of the Red River by these two greenhouse operations are summarized as follows:

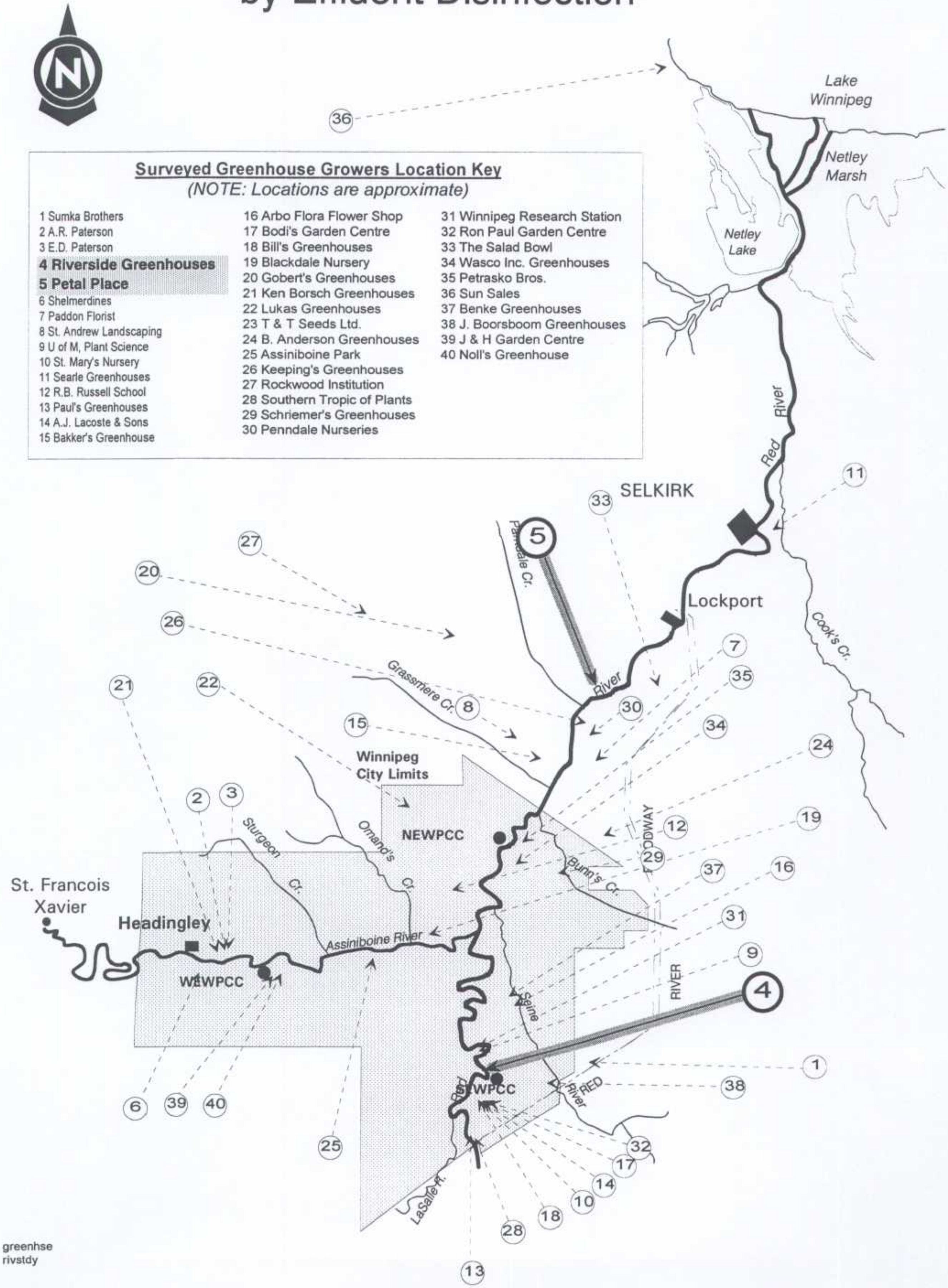
- Riverside Greenhouses, downstream of SEWPCC, withdraws water from the Red River after the river is ice free in the spring until freeze-up in the fall, approximately seven months of the year. This greenhouse operation is downstream of the SEWPCC plant and is not influenced by treated effluent discharges from the WEWPCC or NEWPCC. The periods of possible concern would therefore be a small time in the spring (April to May) and a small time in the fall (October to November) if the City effect effluent disinfection at the WPCCs for the recreation season (May 1 to September 30). As previously discussed, instream fecal coliform levels are at their lowest in the spring and

TABLE A-2

SUMMARY OF PATTERN AND NATURE OF GREENHOUSE OPERATIONS

	BEDDING PLANTS	FIELD CROPS	EDIBLE CROPS	TOTAL
Seasonal	21	0	0	21
Year-Round	17	2	0	19
Total	**38**	**2**	**0**	**40**

Greenhouse Operations Potentially Benefited by Effluent Disinfection



greenhse
rivstdy

Figure A-4

on average comply with MSWQO. Conversely, instream fecal coliform levels tend to reach their maximum levels in August and remain close to these levels until spring thaw. Year-round disinfection is not warranted at any or all of the three WPCCs based on this greenhouse operation since it only draws from the Red River for a maximum of seven months.

- Petal Place, a seasonal greenhouse operation (mid-February to late-June), is downstream of Winnipeg and draws water from the Red River opportunistically after spring thaw until late June. The open water season this user relies upon will vary from one year to the next as a result of meterological and climatic conditions. Typically, the open water season, as defined by the Water Resources Branch of the Province of Manitoba, is from April 1 to October 31. The ice on the rivers will break-up during spring thaw and the rivers will not be "ice free" for possibly 2 to 3 weeks afterwards. Operators of this greenhouse operation wait until the river is "ice-free" before installing their intake lines and operating pumps to protect their equipment from possible damage or loss. The earliest this greenhouse grower will have their river intakes operating would be April. It is expected disinfection of treated effluent from all three WPCCs may be required during the recreation period (May 1 to September 30). The possible period of concern would therefore be a small period in time between April to the beginning of May. Based on historic water quality data, namely fecal coliform counts, instream levels are at their lowest during this period and on average comply with the microbiological objectives for greenhouse irrigation within city limits. Based on the opportunistic seasonal withdrawal practices of this user and low instream fecal coliform levels during peak spring river, year-round disinfection at any or all of the 3 WPCCs is not warranted.

The method used by Shelmerdines, aerated holding pond, demonstrates how a greenhouse irrigator can use river water and exercise control over water quality on-site. If microbiology was a concern, disinfection could be easily done on-site as well. This approach to on-site disinfection is a cost effect alternative to effluent disinfection at the WPCCs if space permits.

In addition, concerns were raised regarding river water quality with respect to pH, pesticide and herbicide residue, etc. by many of the Greenhouse Growers. These concerns would not be alleviated by disinfection of treated effluent discharges from the three WPCCs.

The survey confirms that the use of the river water for greenhouse irrigation purposes is limited. This limited use exists irrespective of the treated effluent discharges. The seasonal opportunistic withdraw characteristics of these two operations would indicate that the maximum disinfection period for treated effluent from any of the three WPCCs would be April to November, approximately seven months of the year. Since the use of the rivers is a function of open water season, it will likely remain valid for potential new greenhouse operations that are contemplating use of river water in their irrigation practices.

CSO - MONITORING

Objective

To determine if a detectable amount of sediment accumulation occurs at C.S. and L.D. outfalls

Methods

- Three C.S. and three L.D. outfalls examined with a Lowrance X-15 SONAR

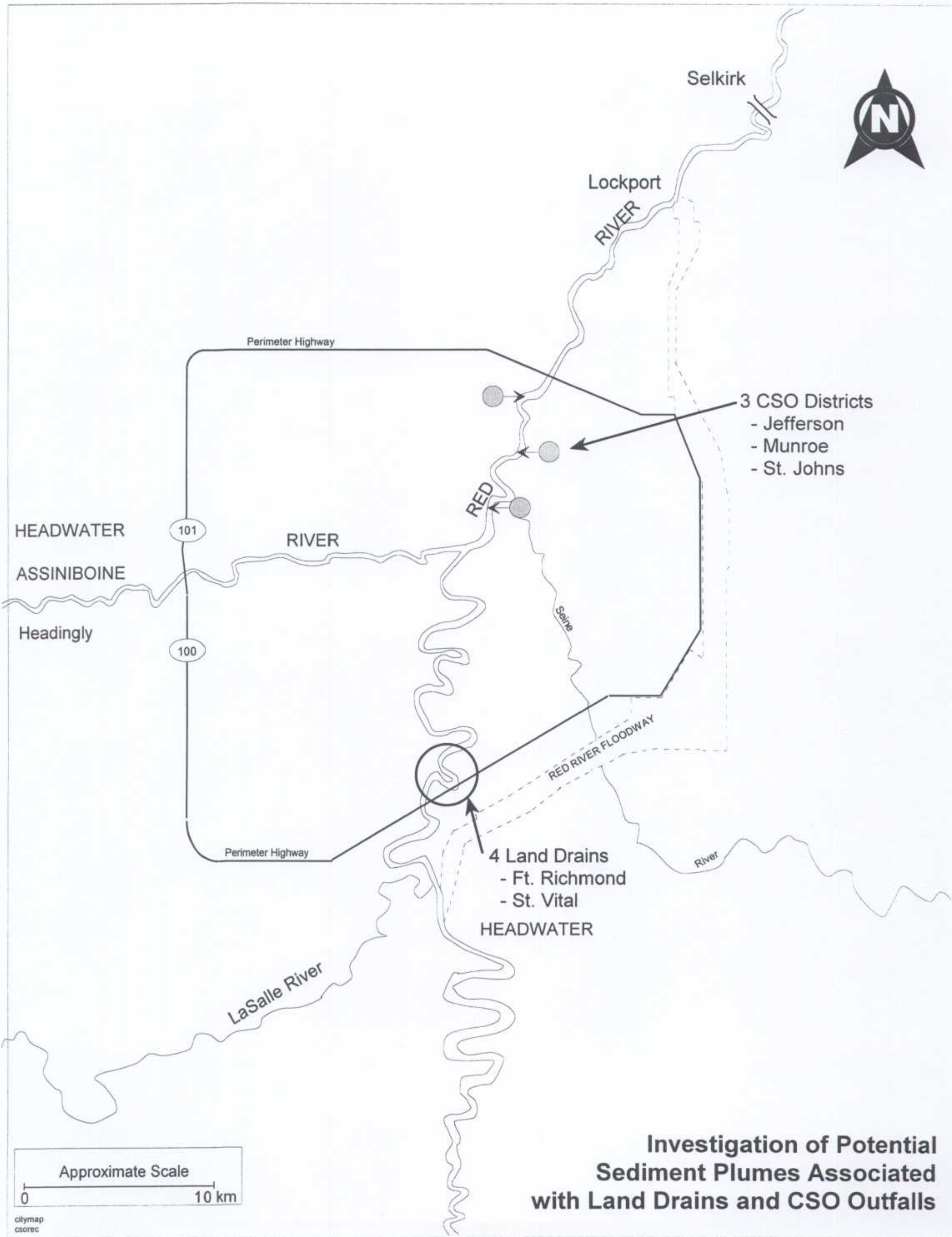
- C.S. outfall districts examined were:

  - Jefferson
  - Munroe
  - St. John

- L.D. outfalls examined were:

  - three in Fort Richmond
  - South St. Vital

- 3 transects (5, 10 and 15 m from shore) were done at each outfall



Investigation of Potential Sediment Plumes Associated with Land Drains and CSO Outfalls

CSO - MONITORING (CONT'D)

Results

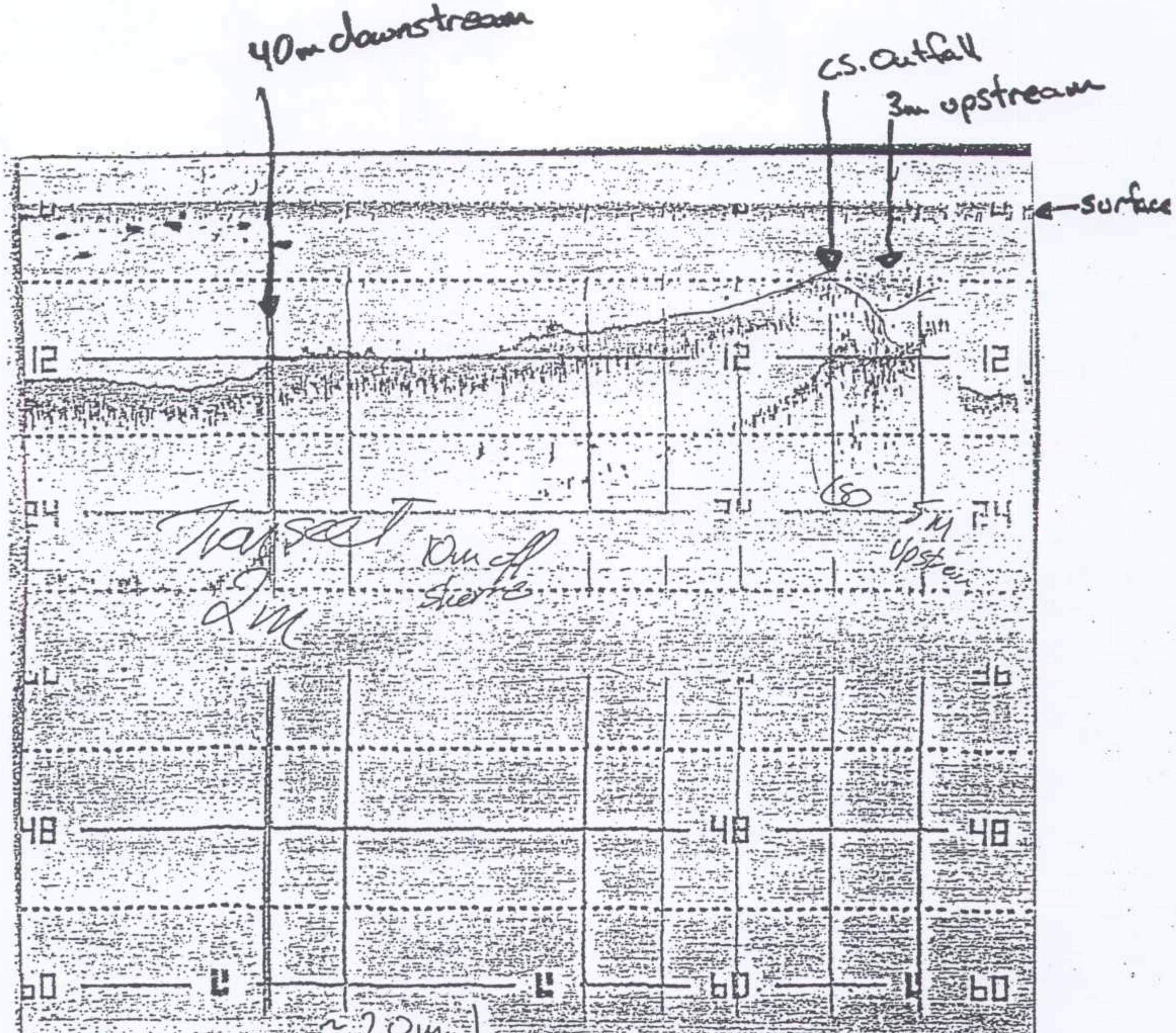
- Accumulation of sediment observed at the Jefferson outfall

- No accumulation of sediment detected at St. John or Munroe

  - evidence that discharges at the St. John C.S. outfall were scouring a channel in the bottom

- No accumulation of sediment observed at any of the L.D. outfalls

  - located adjacent to the South St. Vital and Kings Drive (Fort Richmond) L.D. outfalls are "deep holes" in the river with depths of 7.3 m and 6.7 m respectively



SONAR Trace 10m
Offshore at the
Jefferson C.S. Outfall

CSO - MONITORING (CONT'D)

Recommendations

- After the fall Red River drawdown, examine exposed sediment at the Jefferson C.S. outfall to determine
  - if sediment is still present
  - if the material present is indicative of material known to originate from CSO events
- After spring breakup, examine the Jefferson C.S. outfall to determine if the build-up of material is still evident:
  - depositional material not detected in the spring would indicate that this is a seasonal (annual) occurrence
  - depositional material detected in the spring would suggest that the build-up of sediment observed was the result of long-term accumulation