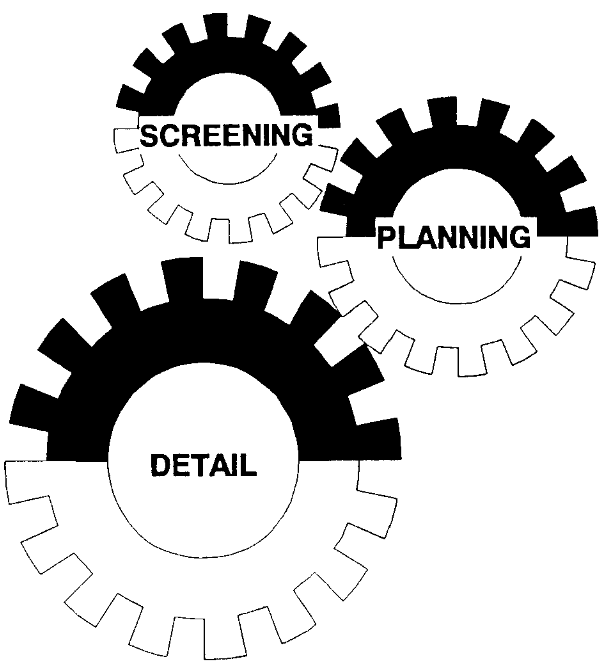
City of Winnipeg
Waterwork, Waste
and Disposal Department

Phase 1 Technical Memorandum for

Combined Sewer Overflow Management Study

TECHNICAL FRAMEWORK

Technical Memorandum No. 7



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1.0 INTRODUCTION

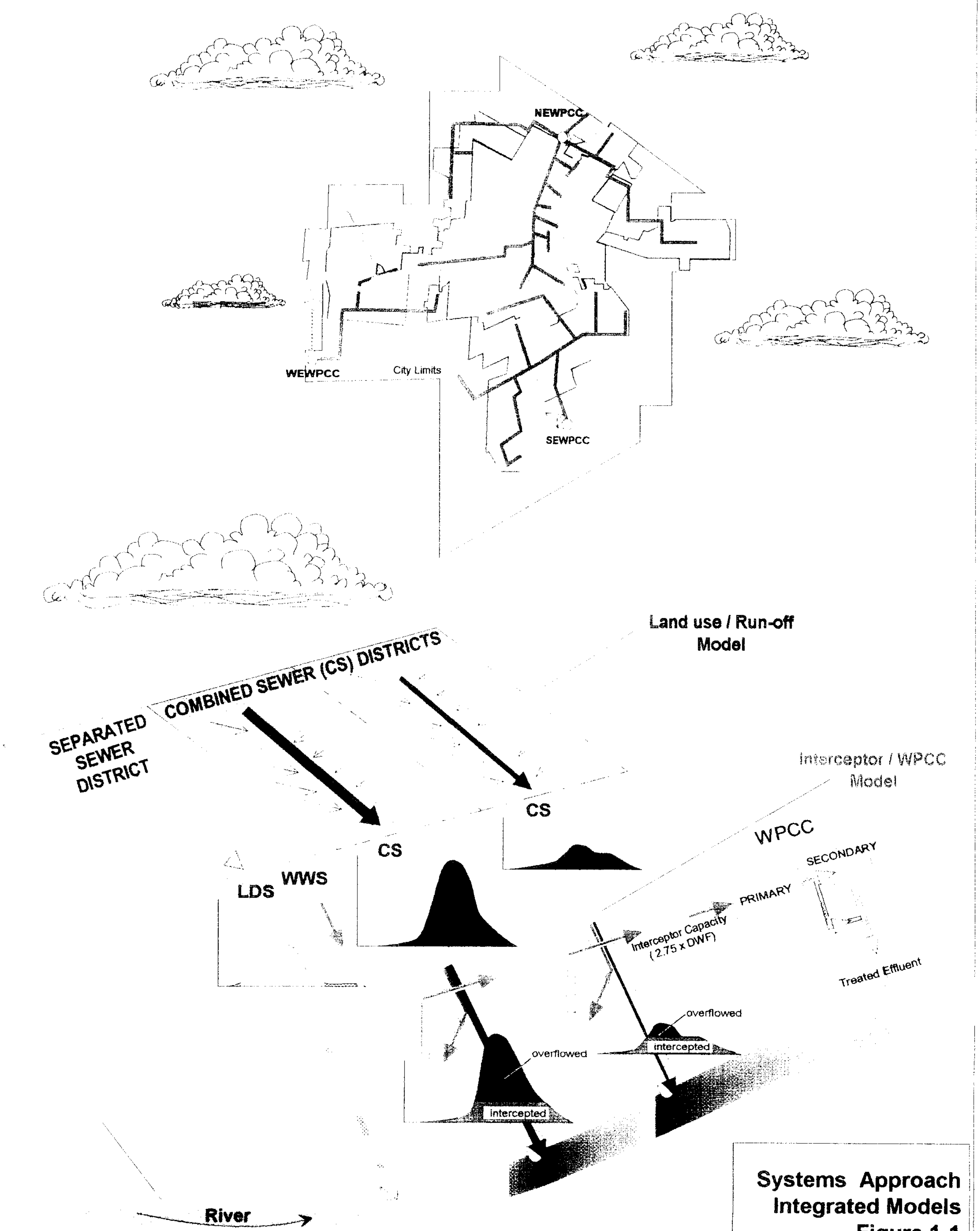
A technical framework is required to describe the behaviour of the entire system (i.e., urban drainage, interceptor system, treatment plants, and receiving stream) for current and future conditions with various control systems in place.

A series of integrated mathematical computer models will be required to simulate system hydrology, pollutant loads, conveyance hydraulics, and control options. A single computer model of adequate sophistication does not exist. Therefore it is necessary to develop a technical framework which integrates a series of models to simulate systems behaviour.

Conceptually, the model requirements were divided into three main systems, as shown in Figure 1-1.

- A land use/runoff model of the urban developments of Winnipeg which will consider existing land developments and topography along with actual periods of rainfall and their areal distribution. This model will generate hydrographs and pollutographs that will be captured by the interceptor, to its maximum interception capacity, via the diversion structures and the remainder overflowed to the river.

- An interceptor/wastewater treatment model which will be used to simulate the interception of urban runoff and its conveyance, interaction with various existing and proposed control devices, and the response of treatment plant capacities and bypasses. It will accept the hydrographs and pollutographs from the land-use/runoff model and simulate the hydraulic response of the interceptor conveyance system and treatment plants to wet weather events. It will also generate a series of overflow hydrographs and pollutographs to the receiving stream in response to existing and proposed control alternatives. This information will be used to assess the volume and mass loading reductions to the rivers and hydraulic requirements of the conveyance system.



Systems Approach Integrated Models Figure 1-1

sysapp
csorec/f

- A river water quality model capable of accepting the overflow hydrographs and pollutographs generated from the land-use and interceptor/treatment models on a continuous dynamic basis will be used to assess the response of the receiving stream for key water quality constituents considered. Model simulations will be used to access improvement in river water quality to various control alternatives and compliance with applicable Manitoba Surface Water Quality Objectives (MSWQO).

1.1 RELATED TECHNICAL MEMORANDA

Separate Technical Memoranda (TM) have been prepared for the three workstreams which outline the background information for the model systems discussed above.

1.2 WORKING SESSION

A working session was held on April 25 and 26, 1994 in Winnipeg to evaluate the background information and to develop a Technical Framework for system assessment, including the appropriate selection of computer-based mathematical models. Specialist consultants Dr. C. Rowney and D. Weatherbe, along with local key study team members G. Rempel, Dr. D. Morgan, N. Szoke, R. Gladding, and G. Steiss were requested to attend and contribute to the evaluation. Presentations were given by local study team members to familiarize the group with local conditions and essential background information. This technical memorandum summarizes the discussions, findings, and preliminary recommendations reached at the working session.

2.0 GENERAL APPROACH

Characterization of the Winnipeg situation is a complicated process that warrants careful consideration of the effects of Wet Weather Flow (WWF) on the receiving stream and its potential impairment of beneficial river uses. In order to properly characterize the Winnipeg situation and evaluate the numerous combinations of control alternatives, a phased study approach was developed.

2.1 PHASED STUDY APPROACH

A phased approach permits progressive direction, screening and refinement of options for improved decision-making and efficient utilization of resources, as illustrated in Figure 2-1. Accordingly, a hierarchy of models is needed to evaluate the factors influencing system behaviour and to progressively increase the level of detail, thereby improving the accuracy of predictions and the requirements of control alternatives.

2.2 CSO ISSUES

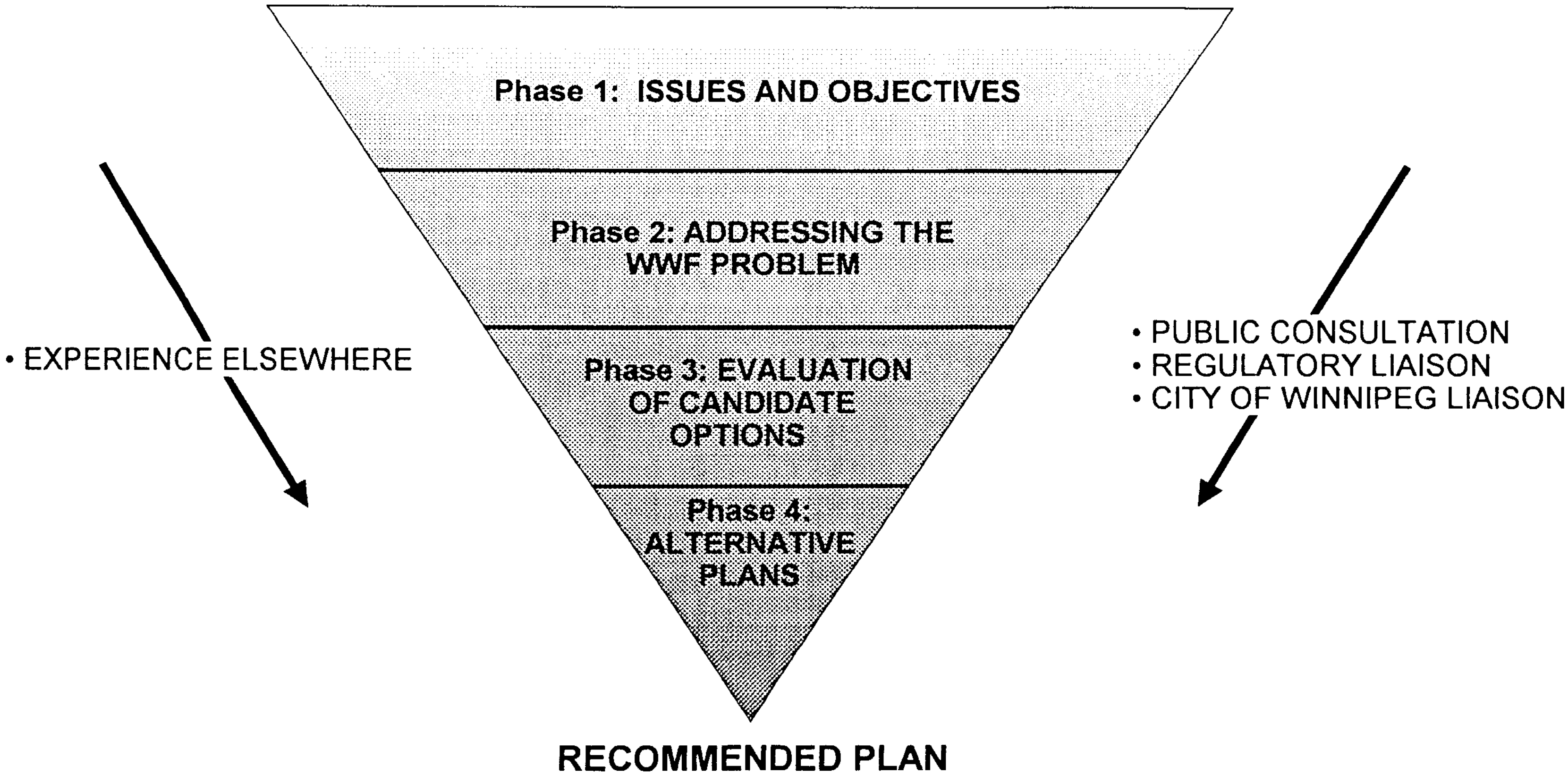
A solid understanding and definition of the core issues relevant to the study need to be identified to determine the objectives of the modelling and their influence on the structure of the technical framework for system assessment.

In late 1991 and 1992, the Clean Environment Commission (CEC) held public hearings and subsequently provided a report and recommendations concerning water quality objectives for the Red and Assiniboine rivers (and relevant tributaries) within and downstream of the City of Winnipeg. The CEC recommended that site specific studies ("Fecal Coliform Study") be undertaken to determine water quality impacts as well as the formulation of remedial measures, with special attention to fecal coliform levels (frequency and duration) all leading to recommendations to be available before July 1997.

The Clean Environment Commission's report was prepared for consideration by the Minister of Environment. In a letter to the City of Winnipeg, dated November 19, 1993, the Minister accepted the CEC recommendations, including the completion of the Combined Sewer Overflow (CSO) study by 1997.

The City of Winnipeg's Terms of Reference for the Management Strategy incorporates the requirements of the recent Clean Environment Commission recommendations and has been expanded to include related concerns. Of particular importance are:

STRATEGIC MANAGEMENT PLAN



- PROGRESSIVE SHAPING OF FOCUS ON OBJECTIVES, ISSUES, COSTS / BENEFITS
- MAXIMIZE USE OF PRIOR STUDIES AND EXPERIENCE ELSEWHERE
- ALLOW FOR ONGOING CITY, PUBLIC, REGULATORY INPUT

stratpln
csorec

Figure 2-1

- "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 and potential impacts on Lake Winnipeg".

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

2.2.1 Water Quality Issues

The chief water quality issue relating to CSOs and compliance with the MSWQO is fecal coliform levels. All of these uses relate to public health protection. The factors motivating compliance with this core issue are river uses specific to:

- *primary recreation* (body contact, full immersion in river water and high possibility of ingestion of river water);
- *secondary recreation* (accidental immersion due to mishap and ingestion of river water);
- *irrigation* (contact with river water during normal operations by workers).

Improvement of the *aesthetic quality* of the receiving stream by minimizing debris from CSOs is also an important motivating factor. While the physical effect of CSOs are not easily quantified, the evidence of combined sewage discharge is an issue of environmental ethics or policy to the public and to regulatory agencies.

Fecal coliform densities in the river are influenced by the number, frequency, and duration of both dry and wet weather discharges. Continuous dynamic modelling will be required to differentiate the loadings from combined sewer systems, separated sewer systems, and wastewater treatment plants. This information is essential to the assessment of the effectiveness of various control technologies and needed to place the potential benefits into relative perspective.

A potential conflict exists between the need to improve basement flooding protection without increasing WWF impacts on the receiving stream. A fundamental concern to home owners in combined sewer districts is the protection of their homes against *basement flooding* that can occur during rainfall events. Combined sewers have a long history of being vulnerable to flooding from intense summer rainstorms. The City has been actively improving the hydraulic capabilities of the combined sewer systems by increasing the hydraulic conveyance capacity by the addition of relief sewers and partial separation, on a selective basis. Basement flooding protection is a primary issue associated with combined sewer systems which warrants careful consideration when assessing the effectiveness of a control technology to reduce overflows to the river.

2.2.2 Associated Issues

Aside from the primary CSO issues outline above, the discharges to the river from both combined and separated sewer systems during wet weather events need to be considered from a broader perspective to address associated issues relevant to the receiving stream environment. These relate to:

- dissolved oxygen/BOD;
- ammonia;
- nutrients;
- sedimentation;
- persistent toxic substances; and
- mixing zones.

The technical framework must consider the analytical requirements of these issues and the complexity of model requirements associated with these water quality parameters.

2.2.3 Hierarchy of Models

The assessment of water quality issues and control options in subsequent study phases requires a hierarchal approach to the selection of models to progressively increase the level of detail and accuracy of analyses.

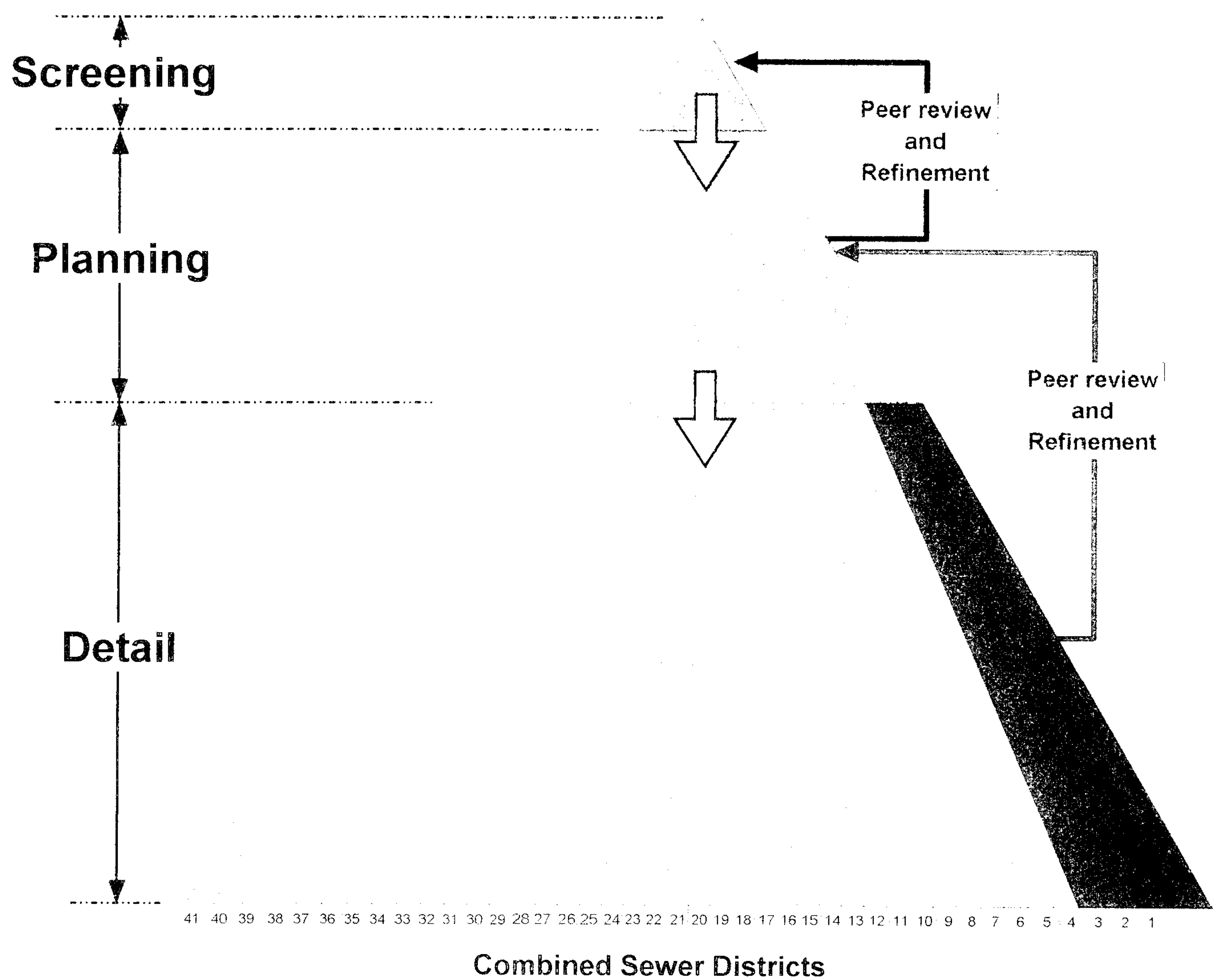
A numerical model is a structured set of equations used to mathematically describe system response and behaviour to a particular set of conditions. The complexity of the model will vary with the degree of precision required. The degree of detail and accuracy required dictates the complexity of the model structure needed for its intended purpose. As such, models are typically classified as screening level, planning level, design level, or operational level depending on its intended purpose and application. In a phased study such as the CSO study, a range of models may be required. Figure 2-2 schematically illustrates the hierarchy of screening, planning and detailed models throughout a study. In this case, screening models provide "1st cut" analyses which focus the direction of planning models which, in turn, provide direction to detailed models for a "micro" area and these results are translated to the required systems.

An important aspect of the progressive use of more detailed and sophisticated models is a feedback mechanisms, displayed here as peer review and refinement, to check previous assumptions and validate the significance of factors influencing model results. In addition to the initial calibration, verification, and sensitivity analysis at each model level the hierarchal framework provides:

- the opportunity to use the results of the current modelling to focus the data and modelling requirements of the next level of modelling;
- a built-in set of "back checks" and "reality checks" along with critical peer review as a quality assurance of model predictions and direction; and
- a feedback mechanism to help refine the previous level of modelling and improve the focus of current modelling.

Screening Level Models

Screening models are used as an initial filter, on a gross scale, to place controlling factors or alternatives into perspective. This "first-cut" preliminary evaluation approach is used to estimate the orders of magnitude associated with control alternatives and their approximate costs to reduce the list of available alternatives to potentially applicable options. As such, the use of screening level models can effectively eliminate non-competitive alternatives and reduce the range of control options to be considered. This approach minimizes the investment



Hierarchy of Models in Technical Framework

Figure: 2-2

of time and resources required to define locally applicable WWF management strategies. Data requirements and level of effort required to use screening level models are typically minimal.

Planning Level Models

Planning models typically build on the preliminary assessments performed in a screen level exercise to provide a more detailed analysis of overall system behaviour and costs associated with specific control strategies. This permits control strategies to be comparatively assessed against each other to evaluate the merits or drawbacks of the strategies considered in monetary of non-monetary terms. Data requirements and the number of system components simulated by the model are increased to provide a higher level of detail and prediction accuracy needed to evaluate system performance. Specific events are used to calibrate the model prior to its use for continuous long-term simulations.

Design Level Models

Design models typically build on the level of detail contained in the planning model to provide detailed simulation of a specific portion of the overall system. It is normally not possible to simulate the entire system because of size limitations of the numerical network the model is capable of simulating at this detail. As shown on Figure 2-2, it is not intended to model the entire combined sewer system in this study. System description for the portion of the entire system analyzed is increased to the point where the specific behaviour of major individual components are evaluated. This information is used to:

- define the specific requirements of control technologies;
- assess their specific effect on the system response;
- evaluate their effectiveness to meet control objectives; and
- assist in determining the most cost-effective solutions.

Data and modelling requirements can be quite extensive depending on the level of detail required.

Operational Level Models

Operational models, often adapted to real time control systems, typically build on information contained within design level models. Information is relayed from key locations within the actual sewerage system along with real-time rainfall information from telemetry stations to a central computer system for processing. System operators view the response of the system in real time and have the ability to accept predefined control decisions or override and make their own decisions.

Operational models are highly sophisticated, usually are custom-developed, and require the system to be extremely well-described and monitored.

3.0 MODEL CONSIDERATIONS

The selection of computer-based mathematical models relevant to the CSO study must carefully consider the CSO issues as well as model setup and application costs. To determine the most appropriate combination of models, it is necessary to start at the receiving stream and identify the parameters that may need to be considered and characterized in order to assess the costs and benefits of various control strategies. This information will help focus the details and data requirements of the interceptor/treatment model and subsequently the urban runoff model. As well, this process will define the synchronization requirements of information between system models.

This section will outline the key water quality parameters, the model requirements, evaluation criteria for models, the ranking of models and the selection of the recommended models for this study.

3.1 PARAMETERS

The parameters and variables to be considered in the models must be broad enough and capable of accurately describing the core CSO issues along with provision to address associated issues to the extent possible. Parameters associated with wet weather discharges and, including those related to CSOs are:

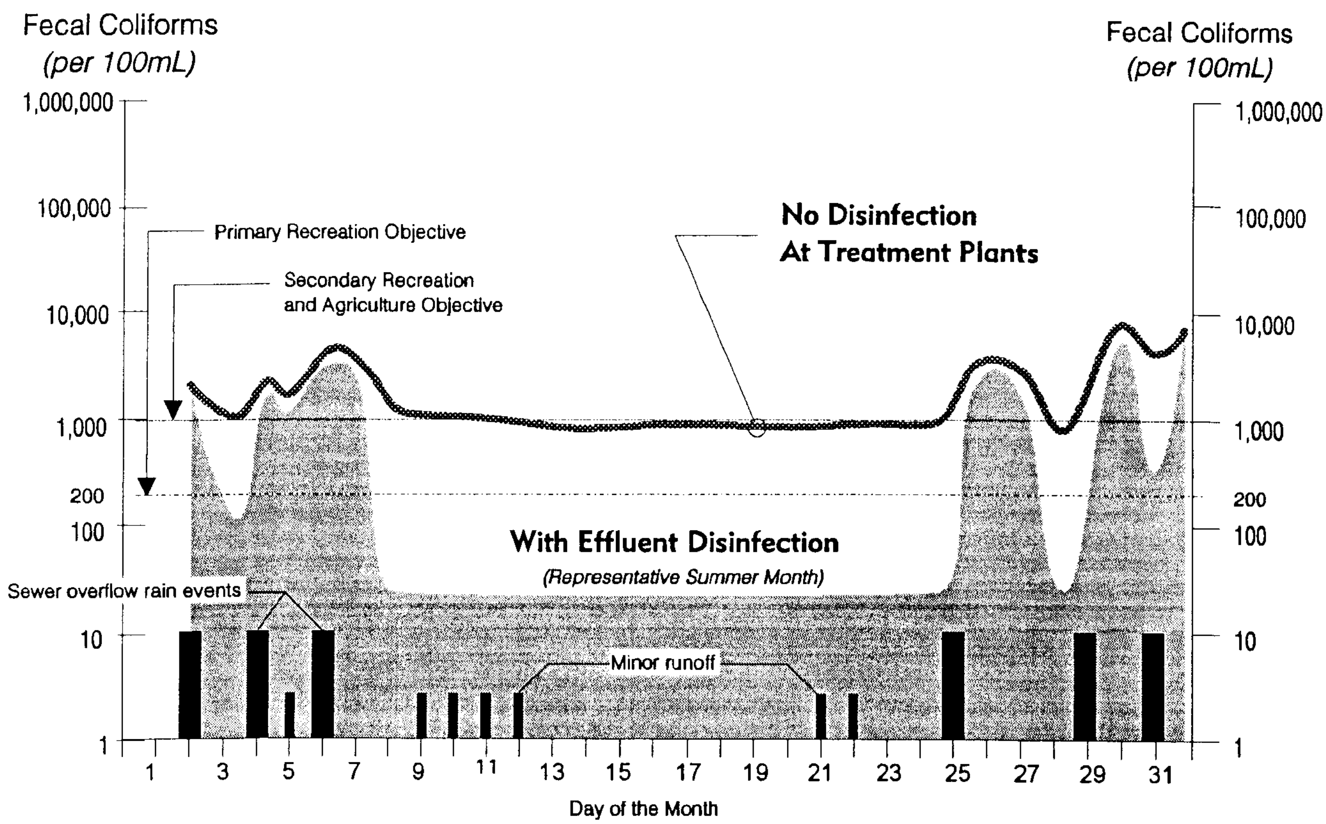
- fecal coliforms (microbiological/health)
- basement flooding relief (hydraulic)
- aesthetics (not explicitly considered in models)
- dissolved oxygen (BOD)
- ammonia (toxicity)
- nutrients (eutrophication - Lake Winnipeg and Rivers)
- persistent toxic substances (metals, pesticides, etc.)
- sediments (aquatic/benthic)
- mixing zones (chemical or physical barriers)

3.1.1 Fecal Coliforms

Fecal coliforms are an indicator organism used to estimate the quantity of disease causing microorganisms (pathogens) associated with warm blood animal excrements.

Limits of fecal coliform density of 200 and 1,000 organisms per 100 mL of river water have been established as objectives by Manitoba Environment (ref) to protect river uses relating to recreation and irrigation. Receiving streams are not a hospitable environment for these microorganisms and result in a steady decline in their densities to normal background levels in 3 to 5 days after a wet weather event during the open water season (April 1 to October 31), as illustrated in Figure 3-1. The rate of die-off is strongly influenced by receiving stream water temperature and can vary accordingly (i.e., the colder the water the longer the die-off period). The increase in fecal coliform densities in the rivers in response to wet weather events are transient and affect a localized stretch of the rivers after a rain event.

The receiving stream model must be capable of accurately simulating the hydraulics and water temperature to simulating the transient die-off behaviour of fecal coliforms along the rivers for a predefined time period on a continuous basis. This will require an accurate representation of the river flow, hydraulics (i.e., travel time), and seasonal water temperature variations to correctly formulate and calibrate instream fecal coliform die-off behaviour and concentrations



**Predicted Fecal Coliform Density
at Redwood Bridge
with Effluent Disinfection**

redwddis
csorec/f

Figure 3-1

in the rivers. Accurate geometric characterization of the Red and Assiniboine Rivers exists and can be readily interpreted to describe the hydro-dynamics over a specific time period. Dry and wet weather loads can be added as point sources to estimate the fully-mixed instream concentrations. Travel times can be used to estimate the spatial and temporal fecal coliform concentrations in response to fecal coliform die-off. This information will be fundamental to the evaluation of effectiveness of various technologies, costs, and their strategic placement to assess and differentiate the ability of control technologies to reduce fecal coliform concentrations under wet weather conditions.

3.1.2 Basement Flooding Relief

The City of Winnipeg has been actively improving hydraulic relief of combined sewers to minimize the damage to property (and potential health impacts) resulting from diluted wastewater entering public and private dwellings.

Basement flooding relief projects have been implemented by the City to minimize or prevent surcharge levels from reaching basement flood levels in combined sewer areas by improving system conveyance capacity.

These relief efforts are designed to convey surface runoff more directly to the receiving stream and to minimize surcharge levels that may threaten basement flooding. Accordingly, control technologies selected to reduce the wet weather loading on the receiving stream should not increase the risk of basement flooding. As such, the selection process of control technologies to reduce wet weather loadings to the river must consider the hydraulic implications on the combined sewer systems and potential basement flooding.

The basement flooding issue is primarily a runoff/transport consideration when reviewing model requirements. The urban runoff and interceptor/treatment model must be capable, of assessing the hydraulic implication of various control technologies on the combined sewer system in the detail design stage of modelling. This will require a direct linkage of the runoff and interceptor/treatment models on a district scale to assess hydraulic performance of the control technology and its hydraulic suitability relative to basement flood protection.

3.1.3 Aesthetics

Wet weather impacts on the aesthetics of the rivers are important but not easily quantified or modelled.

Wet weather discharges to the rivers contain undesirable physical constituents that do not solely originate from CSOs. The portion of the floating debris easily identified in the rivers following a rain event is often related to litter than has accumulated on city streets. Source control of litter is a widely accepted approach to minimizing debris that could wash off into the rivers during a rain event or be wind blown into the river during dry weather conditions. CSOs are however, diluted raw sewage and are an aesthetic issues. Control devices must consider this factor, even though it is not modelled.

3.1.4 Dissolved Oxygen

It does not appear that wet weather discharges cause a significant impact on the dissolved oxygen resources of the rivers following a rain event.

The Assiniboine River is a quick flowing shallow river that has good aeration characteristics. The WEWPCC discharges treated effluent on a continual basis to this river near the upstream city boundary. Dry and wet weather discharges to the Assiniboine River, within Winnipeg, are quickly transported by river flow to the confluence with the Red River. Dissolved oxygen suppression as a result of low oxygen levels in the discharges or oxygen demands associated with chemical processes (e.g., BOD, nutrient cycles) are not likely to present any concern on this river. Historical river monitoring and QUAL2E modelling supports this conclusion.

The Red River is a wide, slow moving river of moderate depth. The water level in this river is controlled by St. Andrew's Lock and Dam. This structure is downstream of Winnipeg and its backwater effect on the Red River extends upstream of the city limits, as well as up the Assiniboine River for approximately 6 km from its confluence with the Red River. Two wastewater treatment plants, SEWPCC and NEWPCC, discharge treated effluent to this river. The SEWPCC discharge location is near the upstream city boundary and the NEWPCC near the downstream city boundary on the Red River. The NEWPCC services the largest portion of Winnipeg, which contains most of the combined sewer districts, and discharges the greatest amount of treated effluent to the Red River. The effluent discharge ratio from the NEWPCC to SEWPCC to WEWPCC is about 7.3:1.6:1.0 for current conditions and estimated at 9.4:2.6:1.0 for projected 2011 conditions. This illustrates that the NEWPCC discharge is many times larger than the other plants and will impose a greater demand on the oxygen resources of the river downstream of the outfall. Since the NEWPCC outfall is the most downstream discharge location in the City of Winnipeg, it is also potentially the most susceptible stretch of river to the compounding influence of dissolved oxygen suppression from wet weather discharges.

Recent wet weather monitoring programs performed by the City in 1992 and 1993 revealed that the dissolved oxygen concentration in the Red River does suppress following a rainfall. The amount of suppression varied with the amount of rainfall recorded to a maximum dissolved oxygen drop of approximately 1.5 mg/L. A review of all historical biweekly information collected by the City since 1977 and partition within 3 days of a rainfall found that river dissolved oxygen levels were consistently well above the minimum MSWQO dissolved oxygen limit, (i.e., 47% of saturation) for the critical summer months. The data tends to indicate that rainfall induced overflows will cause a minor dissolved oxygen suppression in the river resources but not to the point where it might cause a concern with MSWQO compliance. The most vulnerable stretch of the rivers is downstream of the NEWPCC and may warrant a specific monitoring program or stationary probe to be established. Such a program will gather the data necessary to accurately assess the dissolved oxygen behaviour of the river along this critical reach. The receiving stream technical memorandum discusses river DO levels in more detail.

QUAL2E modelling (Wardrop/Tetr*ES* 1991) for projected 2011 conventional plant treated effluent discharges under $Q_{7\text{-}10}$ low flows during critical summer months predicted that DO levels would fully comply with MSWQO. Review of historic dissolved oxygen levels collected since 1977 as part of the City bi-weekly monitoring program found no evidence that wet weather events caused non-compliance with dissolved oxygen objectives. Accordingly, DO concerns should not be CSO issue.

To model the dissolved oxygen dynamics of the Red and Assiniboine Rivers on a continuous dynamic basis requires a sophisticated BOD/nutrient model and greatly exceeds the requirements for modelling first order decay of fecal coliforms. Data requirements for model setup and calibration can be very extensive depending on the water quality constituents to be considered. The complexity and data requirements increase in parallel with the constituents to be included in the model as shown in Table 3-1. At this stage it does not appear that DO will need to be modelled.

3.1.5 Ammonia

Ammonia is a natural compound occurring in nature and an important part in the nitrogen cycle. It can be introduced into the river system from a number of dry or wet weather sources. Ammonia in high concentration and certain temperature and pH conditions can be toxic to aquatic life. The study of the Red and Assiniboine Rivers Surface Water Quality Objectives (Wardrop/Tetr*ES* 1991) identified that the current un-ionized objective for Manitoba is questionable and requires site-specific studies to establish locally applicable un-ionized ammonia objectives.

Human excrements contain urea that breakdown to ammonia. During dry weather conditions, all wastewater that is generated in Winnipeg is collected and concentrated at the treatment plant.

Conventional secondary wastewater treatment plants, such as those in Winnipeg, do not appreciably reduce the influent concentrations of ammonia through their treatment processes. The treated effluent and influent concentrations are therefore about the same. The fully mixed instream concentration at the WPCC outfalls, river temperature and pH influence the toxicity level of the un-ionized fraction of ammonia. Current discharges of treated effluent from the WPCCs do not comply with un-ionized ammonia objectives at the point of discharge. The concentration of un-ionized ammonia decrease downstream of the outfalls in response to transformation of nitrogen into other forms and the uptake by aquatic plants and algae. The rate of decline of ammonia downstream of the outfalls increase with warmer water temperatures and metabolic plant and algae activity. The potential impacts of un-ionized ammonia in the treated effluent discharge from Winnipeg WPCCs are localized and diminish downstream of the outfalls.

TABLE 3-1

SYSTEMS AND COMPLEXITY LEVELS

SYSTEM NUMBER	SYSTEM SYMBOL	NAME	COMPLEXITY LEVEL					
			1	2	3	4	5	6
1	NH3	Ammonia nitrogen		X	X	X	X	X
2	NO3	Nitrate nitrogen			X	X	X	X
3	PO4	Inorganic phosphorous				X	X	X
4	CHL	Phytoplankton carbon				X	X	X
5	CBOD	Carbonaceous BOD	X	X	X	X	X	X
6	DO	Dissolved oxygen	X	X	X	X	X	X
7	ON	Organic nitrogen			X	X	X	X
8	OP	Organic phosphorous				X	X	X

COMPLEXITY LEVEL	EXPLANATION
1	"Streeter-Phelps" BOD-DO with SOD
2	"Modified Streeter-Phelps" with NBOD
3	Linear DO balance with nitrification
4	Simple eutrophication
5	Intermediate eutrophication
6	Intermediate eutrophication with benthos

Source: US EPA WASP5 Users Manual, 1991.

During wet weather conditions, combined sewer systems are burdened with the extra hydraulic load of urban runoff that may cause exceedence of the system's conveyance capacity and result in overflows directly to the rivers. Combined sewer overflows occur at several locations along the Red and Assiniboine rivers and distribute diluted wastewater over a greater stretch of the rivers. This results in a less concentrated loading of ammonia which is more evenly distributed over a larger area. This greatly diminishes the potential toxicity of un-ionized ammonia on aquatic life.

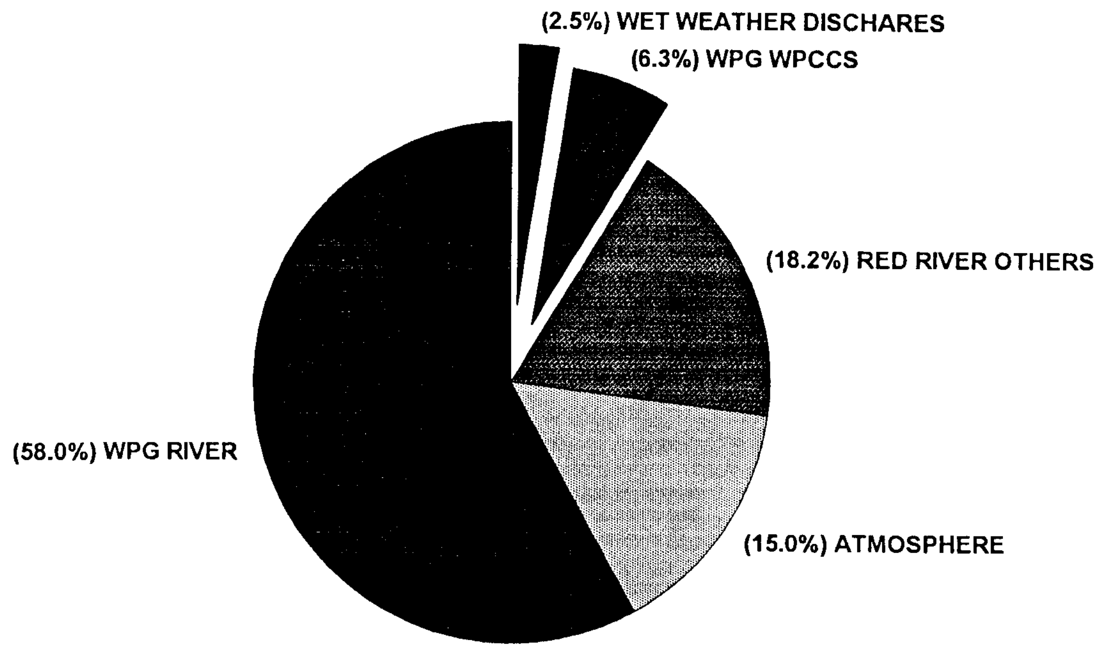
Computer modelling of ammonia is not considered to be required for the evaluation of un-ionized ammonia toxicity impacts. Instream un-ionized ammonia concentration can be calculated directly from overflow loadings and river flows, temperature and pH to determine if a potential concern exists. It is considered that the impact of rainfall induced overflows and its distribution over a broader area will have less of an impact than that associated with discharges from the WPCCs. If continuous dynamic modelling of dissolved oxygen dynamics is required, the influence of nitrogen transformations and algal dynamics/nutrient uptake will be considered and can provide a more detailed perspective of the temporal and spatial variation of several water quality constituents including ammonia.

3.1.6 Nutrients

The introduction of excessive amounts of nutrients, specifically nitrogen and phosphorous, can result in nuisance levels of aquatic plant and algae growth and lead to eutrophication of the receiving waters. The primary concern with nutrient loading from dry and wet weather discharges is the portion of nutrient enrichment (eutrophication) on Lake Winnipeg that can be attributed to the City of Winnipeg. Figure 3-2 illustrates the estimates of nutrient loading on Lake Winnipeg south basin from major sources.

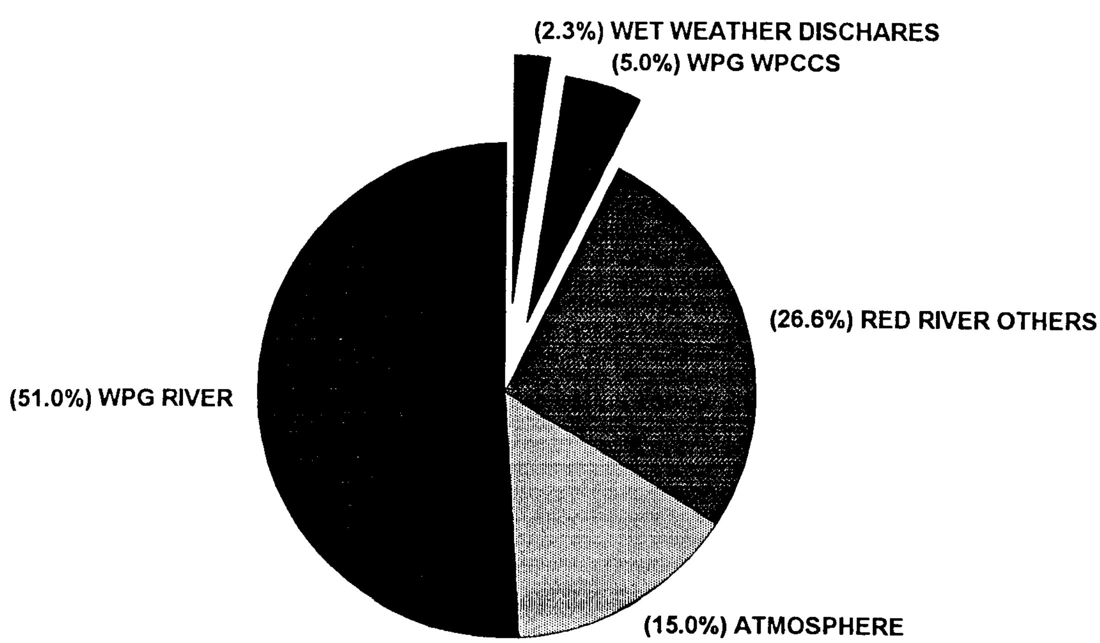
It is uncertain if wet weather discharges substantially influence the stimulation of algal or plant growth in the rivers following a rain event. Wet weather events do increase the mass loading of nutrients to the rivers and possibly influence the amount of nutrients reaching Lake Winnipeg. Lake Winnipeg is located approximately 60 km downstream of Winnipeg on the Red River. It is possible that other nutrient sources enter the system in this stretch of the river and add to the nutrient enrichment of Lake Winnipeg.

TOTAL NITROGEN LOADING
LAKE WINNIPEG SOUTH BASIN



TOTAL ANNUAL LOAD = 47 800 tonnes/yr

TOTAL PHOSPHORUS LOADING
LAKE WINNIPEG SOUTH BASIN



TOTAL ANNUAL LOAD = 5280 tonnes/yr

Lake Winnipeg
Nutrient Loading

Figure:3-2

The relative influence of nutrient enrichment on the rivers and Lake Winnipeg from dry and wet weather discharges originating from Winnipeg need to be considered in the urban runoff and interceptor/treatment models and not the receiving stream model. Modelling of urban runoff and treatment plant discharges will help quantify the annual, seasonal or event specific loading from all sources and estimate the mass of nutrients originating from Winnipeg with and without wet weather control devices. This will help place the relative loadings from dry weather and wet weather into perspective and the fraction that Winnipeg contributes to lake Winnipeg's south basin.

3.1.7 Persistent Toxic Substances

Persistent toxic substances are compounds that do not breakdown or deteriorate substantially in the water column or sediment and include substances as heavy metals and pesticides. Estimation of the amount of toxic substances entering the river system and their removal will need to be performed as part of the urban runoff and interceptor/treatment modelling.

3.1.8 Sediments

Wet weather discharges result in a high concentration of solids being discharged to the rivers. Discharges from the WPCCs under dry weather conditions are much lower in solids concentration than the natural sediment load of the rivers. Dry weather discharges from the WPCCs are not a potential issue with respect to sediments.

However, wet weather discharges contain high concentrations of sediments and can cause instream total suspended solids concentration to rise significantly and accumulate over the open water season. These high concentrations have the potential to negatively impact on the aquatic life in the water column or in the sediments. The concern with increased solids concentration in the water column during and immediately following rain events is the possible adverse affect on the ability of fish to respire. A longer term, and possibly season concern, is the build-up of sediments at or downstream of outfalls over the open water season. The accumulation of sediment deposition can cause a change in fish and benthic habitat that can result in denial of spawning grounds, nursery areas, forage locations, etc. It is uncertain if seasonal deposition of wet weather sediments is a concern and its interrelation with spring "wash-out" flows in the rivers.

Sediments and sediment deposition is not likely to be necessary to model since field monitoring can provide essential information. The implementation of various wet weather overflow control technologies such as retention basins and swirl concentrations can substantially reduce the solids load to the rivers. Modelling of such control devices will require a special adjunct to the urban runoff and interceptor/treatment models. Modelling of sediment loading and transport of sediments in the receiving stream are not required since their reduction can be estimated at the point of discharge.

3.1.9 Mixing Zones

The MSWQO requires that discharges to the receiving streams not cause a barrier to fish movements by providing a zone of safe passage. Analysis of mixing zones in the Red and Assiniboine rivers require specialized models to predict plume behaviour. The U.S. EPA has developed a set of CORMIX models to characterize the likely shape and extent of the plume in the receiving body from point source discharges.

The composition and concentrations of the dry and wet weather discharges need to be assessed to determine if a physical or chemical barrier to fish movement may exist. It is already known that dry weather treated effluent discharges from the NEWPCC fully mix at the point of discharge. Modelling of mixing zones will be performed if a demonstrated need can be established relating to dry and wet weather discharges.

3.2 MODEL REQUIREMENTS

To assess model requirements, it is necessary to define receiving stream model requirements and then translate these requirements into outputs the interceptor/treatment and urban runoff models must generate.

3.2.1 Receiving Stream Model

A matrix of parameters and categories relevant to the CSO study was developed for review and evaluation by specialist consultants and key local staff. The layout of the matrix was refined and filled-out in response to team discussions. Table 3-2 displays and summarizes the group input. Candidate receiving stream models must at a minimum be capable of simulating river hydraulics, point source loadings, and first order fecal coliform decay. The model must be capable of accepting hydrographs and "pollutographs" at explicit reaches of the river and be able to differentiate the flow inputs as to the source (i.e., CSO, land drainage or WPCCs). A secondary consideration of the model is its ability to be expanded, if required, to simulate the dynamic behaviour of other water quality constituents such as dissolved oxygen (DO) or ammonia (NH_3).

The river model will need to predict instream fecal coliform levels on a continuous basis along the reaches of the Red and Assiniboine rivers within and downstream of Winnipeg. This should be done for a number of "open water" seasons in response to actual rainfall events in order to predict present water quality profiles (time and distance along the river). The predicted levels will be used to assess the effectiveness of control alternatives to reduce elevated levels in the rivers following a rain event and test compliance with microbiological objectives. The resulting quality profiles will assist in assigning benefits to the various control options considered.

The previous river quality modelling performed by Wardrop/Tetr*ES* in 1991 using the QUAL2E model contains an excellent hydraulic description of the Red and Assiniboine rivers and a valuable resource to this study.

3.2.2 Interceptor/Treatment Model

The interceptor/treatment model must be capable of accurately simulating the hydrographs and pollutographs conveyed by the collection system and interceptor for transport to the WPCCs during dry weather conditions and the wet weather discharges to the rivers from land drainage and combined sewer systems. Model results will need to be on a continuous time basis (i.e., one hour time steps) over a specific calendar period (e.g., March to October,

Table: 3-2
Receiving Stream

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

● - HIGH

⊙ - MEDIUM

○ - LOW

? - UNCERTAIN

EVALMTRX.WK4

inclusive) to supply the receiving stream model with the source-specific data necessary to predict instream fecal coliform levels. The interceptor/treatment model relies on hydrographs and pollutographs generated by the urban runoff model for rainfall events.

The interceptor/treatment model will capture and convey wastewater flow combined with urban runoff at the designated interception rate to the WPCCs. Existing interception control structures need to be accurately characterized along with the main interceptor sewer capacity to determine how the system interacts under wet weather conditions. Normal summer water level of the Red River is also an influencing factor. A high degree of uncertainty exists in the hydraulic behaviour between the interceptor and interception points due to limited knowledge of system performance. This interaction is of vital importance to estimating the amount of combined sewage conveyed to the WPCCs and the residual split to the rivers during and following a rainfall event. The treatment component of the model will need to differentiate between WWF flows being given primary treatment (typically all flows received at the WPCCs) and secondary treatment (peak DWF).

To fully synchronize the interceptor/treatment model with the runoff model, it may be necessary to include a portion of the combined sewer trunk system in the interceptor model. This aspect will need to be more fully investigated to determine the extent of hydraulic continuity required (i.e., influence of backwater or surcharge levels in the interceptor and at the interception point) to link the models.

The interceptor/treatment model will need to interface with adjunct models such as HIRATE, used to simulate "end-of-pipe" treatment, to estimate the reduction of WWF discharges to the rivers and additional return flows to the interceptor. These adjunct models will provide the performance treatment information needed by the receiving stream model, in terms of reduced loading, to predict river response and improvement.

3.2.3 Urban Runoff Model

The urban runoff model will provide the interceptor/treatment model with dry weather flows and area-distributed wet weather inflows from rainfall. Rainstorm patterns, surface characteristics (area, percentage pervious/impervious), service system, water consumption to wastewater, land use (industrial, commercial, residential, green space, undeveloped, etc.), dust and dirt accumulation, etc. will all be considered to generate the hydrographs and pollutographs before interception. The actual area-distribution of rainfall may be important and must be considered.

Essentially, the urban runoff model will need to provide runoff hydrographs, specific to the rainfall distribution and the sewer system, over a number of years of actual rainfall events. In contrast to flood relief studies, the major attention will be towards routine rainfall events, as these lead to routine CSOs. The resulting hydrographs can be converted to "pollutographs" very readily, especially if the focus is fecal coliforms, as these are not likely to exhibit a "first-flush" phenomenon.

Synchronization of the runoff model with the interceptor model will involve the selection of an appropriate time step to adequately discretize the inflow hydrographs from the runoff model for meaningful hydraulic analysis by the interceptor/treatment model. Too large a time step may introduce numerical instability or unreal hydraulic description of system behaviour. Too small a time step can result in long computational times and no substantial increase in accuracy. It will be necessary to test this synchronization on a small scale between the interceptor/treatment and runoff model to determine the appropriate protocol to satisfy hydraulic continuity and stability.

3.3 POTENTIALLY APPLICABLE MODELS

Several state-of-the-art mathematical computer models were reviewed and narrowed to those identified in Table 3-3 and briefly discussed below.

Custom Screening Models

Screening models are custom developed through the use of readily available third party software application (e.g., Lotus 1-2-3, dBase 3 plus) or programming languages (e.g., BASIC, FORTRAN, C) to describe broad system behaviour. The systems will be viewed from a city-wide scale to evaluate the governing factors and whether a more detailed model analysis will provide a clearer selection of control alternatives. The formulation of these models are based

TABLE 3-3

POTENTIAL APPLICABLE MODELS

MODELS CONSIDERED	APPLICATION			
	RUNOFF	INTERCEPTOR	TREATMENT	RIVER
CUSTOM SCREENING MODELS	●	●	●	●
QUALHYMO (RMCC)	●	●	●	●
STORM (US ARMY)	●		●	
HSPF (EPA)	●	●	●	●
SWMM-EXTRAN (EPA AND XP)	●	●	●	●
RUNSTDY (RCPL)	●	●	●	●
HIRATE (W_2O)			●	
QUAL2E (EPA)				●
WASP (EPA)				●
GRSM (ONTARIO MOE)				●
CORMIX (EPA)				●

● - Denotes "Area of possible use"

on key equations that describe the main mechanisms of the system considered. These models are easily constructed, adapted and refined to test or determine the factors that most significantly influence system behaviour.

It is proposed that custom screening models be used on all systems initially to filter through the available control technologies and select the most cost-effective candidate options on a city-wide scale.

QUALHYMO

QUALHYMO was originally developed in 1983, and is considered to be a planning level model that is capable of simulating all systems to a greater or lesser degree of detail. It was deemed to be most applicable to the runoff and receiving stream systems. QUALHYMO can be applied to the other systems (i.e., interceptor and treatment) but not ranked as highly as some of the other models considered for these systems.

Additions to the model resulted from research funded in part by the Ontario Ministry of the Environment, the Rideau Valley and Metropolitan Toronto and Region Conservation Authorities and the Canada Mortgage and Housing Corporation. The development of the model proceeded under the direction of A.C. Rowney and C.R. Macrae within the department of Civil Engineering at the Royal Military College of Canada (RMCC) in Kingston, Ontario. Although development is presently underway to expand the scope of the model, in response to user demands, the present version of the model remains primarily a planning tool.

STORM

The original version of STORM (Storage, Treatment, Overflow and Runoff Model) was completed in January 1973 by Water Resources Engineers, Inc. (WRE). It has been extensively used in North America including the City of Winnipeg.

STORM is a long-term simulation model which facilitates the examination of the relationships between rainfall and runoff quantity and pollutant accumulation and removal over periods of up to several years. This program provides a means for analysis of the quantity and quality of runoff from urban or non-urban watersheds. For a particular simulation period, STORM can be used to investigate the effectiveness of overflow pollution control measures such as storage or treatment as well as various surface and "in-system" controls. STORM operates at a 1-hour time step which is consistent with the requirements of a planning study. The two main types of output are statistical information on quantity and quality of washoff and overflow and pollutographs for selected individual events. The purpose of the analysis is to aid in the sizing of storage and treatment facilities to control the quantity and quality of stormwater runoff and land surface erosion. For the STORM simulations it is necessary to provide input data describing major land uses and hourly precipitation totals. Land uses are categorized into single or multiple family residential, commercial, industrial and open space.

STORM is the basis of many of the next generation models developed for analysis and control of urban runoff and pollution abatement (treatment). It is at best a coarse screening model and an aging planning level model with limited capabilities. Since its original development in the early 1970s it has not been substantially improved to include many of the new and recent advances in control technologies. The STORM model is still extensively used in many urban pollution control studies but is not considered to have the degree of sophistication required to adequately model runoff or treatment alternatives relative to other models available.

HSPF

The Hydrological Simulation Program - FORTRAN (HSPF) is a planning level model that can be used to simulate the hydrologic processes of pervious and impervious land surfaces, and associated water quality in the receiving streams and well-mixed impoundments on a watershed-wide scale. The model was originally developed by Hydrocomp, Inc., under the sponsorship of the U.S. Environmental Protection Agency in 1980.

HSPF is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants.

HSPF produces a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed. Data needs for HSPF can be extensive. HSPF is a continuous simulation program and requires continuous data to drive the simulations.

Although HSPF is considered to be planning level model capable of simulating all systems to various degrees of sophistication, it is considered too complex a model to be readily and efficiently applied to this study. D. Weatherbe indicated from his experience with Ontario Ministry of Environment that the model required extensive amounts of data, substantial resources and budget (greater than $0.3 million) to setup and calibrate (Humber River Study 1988[1]).

SWMM - EPA

The Storm Water Management Model (SWMM) Version 1.0 was originally developed for the EPA in 1969 and was the first comprehensive model of its type for quantity and quality problems associated with urban runoff. Continuous maintenance and improvements since then has led to several revisions since then, the latest being Version 4.3 of SWMM released in November 1993.

SWMM is a comprehensive mathematical simulation model. The inputs to the model include a rainfall intensity distribution in time (hyetograph) and data describing the idealized catchment, transport and receiving water systems. The principle objective of the model is the complete characterization of the temporal and spatial effects of a rainfall event. To achieve this, the flow and associated pollutional aspects are represented as continuous curves referred to as hydrographs and pollutographs.

SWMM has been used extensively in North America, Europe, Australia and elsewhere. The model has been used for very complex hydraulic analysis for combined sewer overflow mitigation as well as for many stormwater management planning studies and pollution abatement projects. The model is designed for use by engineers and scientists experienced in urban hydrological and water quality processes. Because it is a public domain model, users have provided extensive feedback on needed corrections and enhancements. Correspondingly, the U.S. EPA has continuously updated the model to incorporate these needs and enhancements.

EPA Nationwide Urban Runoff Program data are often used as starting values for quality computations. Quality routing in subsequent blocks (except for Extran) requires few additional data, except for the Storage/Treatment Block in which several removal processes can be simulated.

Depending upon the simulation objective, input data requirements can be minimal to extensive. The model is best suited for simulation of urbanized areas with impervious drainage.

The biggest impediment to model usage is the user interface, with its lack of menus and graphical output. The model is still run in a batch mode, unless third-party software is used for pre- and post-processing.

SWMM is considered to be both a planning level and design level model best suited to the analyses of urban runoff and conveyance system hydraulics (i.e., interceptor). It is capable of simulating some treatment control options and receiving stream water quality behaviour. SWMM is not capable of simulating the hydraulics (underflow) and treatment performance of swirl concentrators. An adjunct model, such as HIRATE, can be used for such analyses. The receiving stream quality routines are limited and not considered well-suited for the analyses required by this CSO study. The developers of SWMM have considered and specifically designed the numerical output of SWMM to be directly read by EPA WASP, a sophisticated continuous dynamic water quality model.

SWMM-XP

The computational procedures used in XP-SWMM are based on the U.S. EPA's Storm Water Management Model (SWMM), Version 4.2 with enhancements and extensions. Accordingly, it is considered to be well-suited for both planning and design level analysis of urban runoff and interceptor hydraulics. The key advantages of XP-SWMM over EPA SWMM are:

- Graphical user interface
    - pull down menus
    - selection of options
    - graphical building of system descriptions
    - automatic generation of input files
    - error trapping routines

- graphical display of results, user modifiable
- output to other software packages for post-process analysis
- direct output to printer or plotter

- Improvements to the model code to improve speed and stability of calculations.

- The expansion of all blocks (RUNOFF, TRANSPORT, and EXTRAN) to allow a larger number of components or flexibility in their description.

The enhancement and improvements are intended to reduce the setup and runtime of model simulations by assisting the user in quickly and accurately defining the system.

XP-SWMM is an improvement over EPA-SWMM but has some potential drawbacks. These are:

- The model code is compiled (i.e., closed architecture) and does not permit the user to modify the code to service their unique needs.

- The developer, XP-Software, continually upgrades the model to keep pace with recent improvements with EPA-SWMM. New XP-SWMM files are made available at an upgrade cost when they are available.

- The cost of XP-SWMM can be substantial depending on the number of conduits that need to be modelled (i.e., $1,000 to $5,000 U.S.).

<u>RUNSTDY</u>

RUNSTDY (pronounced "run-steady") is a proprietary design and operational level model developed by Dr. Z. Vitasovic to simulate urban runoff and complex conveyance hydraulics of looped pipe systems.

RUNSTDY is based on the same St. Venant equations used to describe the conservation of flow and momentum in the U.S. EPA SWMM model. The solution used to solve gradually-varied unsteady flows in EPA SWMM was reformulated from explicit to implicit numeric solution to permit the use of variable time steps which are not restricted by the Courant criterion. This permits larger time steps (10 minutes or greater) to be used during dry weather conditions and smaller time steps (15 seconds or less) to be used during wet weather conditions while maintaining stability and accuracy of results. The primary advantage of a variable time step is the reduction in computation time associated with long-term seasonal simulations while maintaining simulation accuracy.

A further numerical improvement was added to RUNSTDY model to increase the speed of computations associated with the solution of the St. Venant equations. A commercial sparse-matric solver (Harwell MA28) is employed to rapidly solve the linearized set of equations generated from the St. Venant equations.

RUNSTDY is a new model specifically developed to build on design-level model information for operational level use. Such models are usually custom-tailored for real-time control (RTC) applications associated with conveyance systems. It is the only model of those considered capable of performing these analyses, should they be required.

The main concerns with the use of RUNSTDY are:

- This is a sophisticated model which is not appropriate to the first phases of a planning study. Its use is better suited to more detailed analyses.

- It is a first generation model that is relatively unproven. It requires model results to be verified through frequent back-checks to ensure that simulations are mimicking reality.

- The model is proprietary and preferred to be operated by its developers. Only the developer is allowed to modify the source code to add or correct any erroneous statements. This places a heavy reliance on support from a third party to provide assistance on modelling and de-bugging, all to fit within restricted timeframes.

A model of this type is highly sophisticated and will require further research and "hands-on" evaluation to determine its potential use in subsequent study phases. Its most likely use would be in real time control (RTC) related to the interceptor and CSO trunks to optimize weather control strategies.

HIRATE

HIRATE is a proprietary treatment model developed by Dr. W. Pisano and G. Zukovs. It is capable of being used in both planning and design level analysis. HIRATE is a simulation model specially developed for the analysis of wet weather storage-treatment facilities. HIRATE can be used for the evaluation of facilities designed to manage combined sewer overflow (CSO), stormwater and wet weather bypass at treatment plants. The model is capable of evaluating the removal of a wide range of quality parameters using physical-chemical treatment and disinfection technologies. HIRATE can be used in an evaluation mode to analyze the performance of existing storage-treatment facilities or in a design mode to examine alternative storage-treatment flowsheets and to determine unit process sizing needed to meet a specific control target(s). A costing module has been recently added to HIRATE to enable assessment of capital and operating costs and to facilitate the design process. The costing module also allows the ready development of cost effectiveness curves. Refer to Appendix A for more detail on Model Algorithms, inputs and outputs.

The model can simulate a number of wet weather control devices such as retention treatment basins (RTBs) and vortex solids separators (VSSs). It has been written to accept output hydrographs and pollutographs from STORM, QUALHYMO and SWMM. The HIRATE model is capable of simulating storage requirements and return underflow from CSO control devices to the interceptor. It requires specific information on the settleability of the sediment fractions in the water column and the flow rates to estimate removal efficiency. An important consideration in such an adjunct model is its ability to simulate the return underflow rate from the overflow control device to the interceptor. This rate will influence both the retention size of the device and the additional return hydraulic loading on the interceptor conveyance system. An adjunct model of this type will be used to estimate the reductions in wet weather flow solids loading to the rivers and the corresponding chemical requirements for disinfection.

As with RUNSTDY, HIRATE presents some concerns relating to:

- It is a proprietary model and preferred to be operated by its developers.

- Only the developers are allowed to modify the source code to add or correct program code.

- Model output from the runoff model is required by the HIRATE model to simulate overflow treatment and return underflow to the interceptor. This information is then input into the interceptor and receiving stream models.

Information transfer will require special considerations and coordination to ensure modelling is not disjointed or delayed.

QUAL2E

QUAL2E is a steady-state water quality simulation model typically used in planning level analysis to assist management in identifying improvements that may be required in effluent quality to ensure that the receiving stream remains healthy. It is a planning level receiving stream model.

QUAL2E is a U.S. EPA model that is in the public domain and continuously upgraded by the U.S. EPA. It is well-suited to the assessment of receiving stream and potential impacts from continuous source waste load discharges under low river flow design conditions. It is applicable to well-mixed branching river systems. River system hydraulics and water quality behaviour need to be well-understood and characterized to properly calibrate the model for confident model predictions.

In its present state, QUAL2E requires some degree of modelling sophistication and expertise on the part of a user. The user must supply more than 100 individual inputs, some of which require considerable judgment to estimate.

The QUAL2E model has been used extensively in Winnipeg to better understand and predict the water quality response of the Red and Assiniboine river systems for present and projected future conditions. The City of Winnipeg has built a large water quality database on the Red and Assiniboine rivers. The City has routinely collected water samples every two weeks at some thirteen fixed sampling locations since 1977. As well, the City has conducted several specific water quality monitoring programs, most notably the 3-day intensive collection program conducted in August 1988. This information was used to improve the understanding of water quality dynamics and refine the previous QUAL2E model calibration and verification (Wardrop/Tetr*ES* 1991[2]). An excellent match between observed and simulated conditions was achieved for both calibration and verification indicating that the model could be confidently used to forecast water quality response for a variety of projected future conditions. The main water quality constituents of interest were DO and NH_3. Model simulations for current and projected 2011 wastewater treatment plant discharges under low river flow conditions revealed that river dissolved oxygen levels would remain healthy and in full compliance with MSWQO. These results were presented at the 1991/92 Stage 1 CEC Hearings on the Red and Assiniboine Rivers Surface Water Quality Objectives. The CEC ruled on the information presented at these hearings and accepted the model predictions without challenge.

The calibration of the hydro-dynamic and biokinetic rates of the water quality constituents used in the QUAL2E model for the Red and Assiniboine rivers is a valuable resource to the CSO study. Although the QUAL2E model is a steady-state model and not well-suited for continuous dynamic simulations of the rivers, the models formulation and rates can be directly re-used in continuous dynamic models such as WASP and to a limited extent, the receiving stream routines in QUALHYMO.

WASP

Water Quality Analysis Simulation Program, WASP5 is a generalized framework for modelling contaminant fate and transport in surface waters. It is a sophisticated continuous dynamic water quality model developed by the U.S. EPA which was specifically developed to simulate the complex interactions of several water quality constituents and predict their behaviour under a diverse set of conditions. The model has been formulated to permit time variable inputs that the user can define or accept directly from companion analysis programs such as SWMM. WASP5 is the most recent version of WASP programs to date. Based on the flexible compartment modelling approach, WASP can be applied in one, two, or three dimensions. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using the WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.

WASP5 linkages to other stand-alone models using formatted ASCII files have been provided to increase its flexibility and use with other companion models. Similarly, files from SWMM4 model simulations can be reformatted and directly used by WASP5. A menu-driven user interface is provided, along with an interactive graphical post-processor that can create tables and output files in a format that are readily imported into third-party spreadsheet programs.

The body of water to be simulated must be divided into a series of computational elements or segments. Segment volumes, connectivity, and type (surface water, subsurface water, surface benthic, subsurface benthic) must be specified. Data requirements can be extensive depending on the complexity level of the system to be modelled. For each state variable, the user must specify loads, boundary concentrations, and initial concentrations. A set of boundary conditions are required to describe simulation control of model computations and includes:

- number of segments and state variables;
- time step;
- start and stop time
- print interval; and
- runtime display information.

Applying WASP5 requires both modelling sophistication and appropriate scientific and engineering judgment.

The WASP model has been applied to two separate studies performed by Tetr*ES* (Teulon Wastewater Ponds and Deacon Reservoir) to assess the water quality response of receiving bodies for current conditions and to predict their behaviour under projected future conditions. It was found that moderate effort was required to accurately code the model to simulate the water quality cycles of interest. Once this was accomplished, it was possible, through an interface developed in Lotus 1-2-3, to quickly review and present model results. Increasing the number of parameters to be used in the model resulted in a moderate increase in computational time. That is, modelling a single first-order decay of a single water quality constituent is quick, (i.e., less than 1 minute). The addition of inter-related parameters and their exchange behaviour (e.g., nutrients, algae, water column and benthos exchange) was found to cause a noticeable but acceptable increase in computational time (i.e., greater than 5 minutes). In perspective, these are still relatively short computational times for the systems considered. The application to the Red and Assiniboine rivers for continuous dynamic modelling is very feasible based on local experience with the WASP model and a detailed understanding of river hydro-dynamics and biokinetics as provided through QUAL2E modelling of the same rivers.

The WASP model is a sophisticated receiving stream model capable of detailed analysis of several water quality constituents on a continuous dynamic basis. It can be readily applied to the local rivers based on the experience of local study team members with the model and strong understanding of hydro-dynamics and biokinetics. The need to better describe dissolved oxygen and ammonia fluctuations in response to rainfall events could be readily incorporated should that level of analysis be required. It can directly accept output hydrographs and pollutographs from SWMM-EXTRAN and be used to assess the temporal and spatial behaviour of the rivers under long-term continuous dynamic simulations. The modest level of effort and cost-associated with WASP model development must be carefully weighed against the use of less sophisticated receiving stream models such as QUALHYMO to model the key parameter(s) of interest, namely fecal coliform die-off with the possibility of extending it to DO and NH_3 analyses.

Grand River Simulation Model - GRSM

GRSM is a continuous water quality simulation model, developed by the Ontario Ministry of the Environment for use in the Grand River Basin Water Management Study (1982). It is a generalized model in that it can be set up for any geometry of rivers and point source inputs. Parameters modelled include dissolved oxygen, carbonaceous and nitrogenous oxygen demand, bacteria, and user specified conservative or decaying (first order) parameters such as fecal coliforms. The model accounts for plug flow channel routing of contaminants, with Muskingum routing of flows. The dissolved oxygen component includes weir aeration, sediment oxygen demand, and photosynthesis and respiration of up to three types of attached algae and plants. Continuous inputs from point sources are generated by a flow regression model along with a randomly selected values of contaminants from a probability distribution for each source. Urban drainage inputs were generated using the STORM model. Continuous outputs are generated, which were then compared to statistical criteria.

The model is coded in FORTRAN and has recently been converted for use on an IBM PC by Ray Dewey of Gore and Storrie. GRSM is actively being used by Gore and Storrie to review wastewater discharge options for the Regional Municipality of Waterloo. The model is in public domain and available from the Grand river conservation Authority, or Gore and Storrie. Documentation is available in draft, however it has not been updated.

Although GRSM is a generalized receiving stream model capable of planning level analysis, it was not considered to be as highly ranked as QUALHYMO or WASP in its ability to assess continuous dynamic water quality behaviour of the receiving stream.

<u>CORMIX</u>

The U.S. EPA Cornell Mixing Zone Expert System (CORMIX) is a mixing zone model that may be used to analyze, predict, and design outfalls and diffusors into diverse water systems. Its major emphasis is on the prediction of plume geometry and dilution characteristics within a receiving water's initial mixing zone so that compliance with regulatory constraints may be judged. The system also predicts discharge plume behavior at larger distances.

The latest release of CORMIX, Version 2.10, combines CORMIX1 - for submerged single point discharges; CORMIX2 - for submerged multiport diffuser discharges; and CORMIX3 - for buoyant surface discharges, into a single comprehensive system for modelling diverse types of aquatic pollutant discharge into all types of receiving water bodies. It allows for non-conservative pollutant types with first-order reaction processes and/or surface heat loss, calculates plume travel times, and considers the effect of wind on plume mixing.

CORMIX requires that the actual cross-section of the water body be described as a rectangular channel that may be bounded laterally or unbounded. The ambient velocity is assumed to be uniform across the channel. All subsystems assume steady-state ambient and discharge conditions.

It is uncertain if the use of a mixing zone model, such as CORMIX is required in the initial screening or planning stage to assess plume behaviour at outfalls. It may need to be considered in the design stage if it can be demonstrated that discharges to the river are not fully mixing across the river and influencing model results, or the near-field influence may result in a barrier to fish migration or denial of important habitat. The need for mixing zone models will be determined later in the study, possibly during the design analysis stages.

3.4 SELECTION OF MODELS

It is clear that a heirachy of models i.e., a spectrum of screening level models to detailed design level models will be required in this study.

The development and application of screening models for each system was deemed a necessary and prudent approach to evaluate control alternatives on a gross scale. It was agreed by all representatives at the working session that the use of screening models prior to the use of planning models and then detailed models will help focus the model needs and the selection of appropriate control technologies.

The main advantages of screening models are:

- they are easy to develop, use, and extend;
- they can efficiently and cost-effectively assess major trade-offs in control strategies on a city-wide scale;
- they can quickly place the costs and benefits of various control strategies into relative perspective (i.e., order of magnitude); and
- that preliminary city-wide analyses will directly assist in focussing of the setup and application of planning level models.

The foregoing discussion formed the basis on which the study members attending the working session used to classify the model capabilities in terms of the applicability to the systems to be modelled and their associated modelling level (i.e., planning or design level). Screening models will be custom-developed to the needs of this project and were accordingly not evaluated. Table 3-4 summarizes the model capabilities.

TABLE 3-4

COMPARISON OF MODEL CAPABILITIES AND MODEL LEVEL APPLICATION

MODELS CONSIDER	APPLICATION							
	RUNOFF		INTERCEPTOR		TREATMENT		RIVER	
	P	D	P	D	P	D	P	D
QUALHYMO	●	○	○	---	○	---	○	---
STORM	○	---	○	---	○	---	---	---
HSPF	●	○	○	---	○	---	●	○
SWMM (EPA and XP)	●	●	●	●	○	---	○	---
RUNSTDY[1]	●	●	●	●	○	---	○	---
HIRATE	---	---	---	---	●	●	---	---
QUAL2E	---	---	---	---	---	---	○	---
WASP	---	---	---	---	---	---	●	○
GRSM	○	---	---	---	---	---	○	---
CORMIX	---	---	---	---	---	---	○	○

"P" Denotes Planning Level
"D" Denotes Design Level
● Denotes full capability
○ Denotes partial capability
--- Denotes not capable
1 Denotes proprietary and capable of real time control simulations

3.4.1 Ranking of Models

The candidate models (planning and detailed) for the systems to be modelled, that is, urban runoff, interceptor conveyance, treatment/control options, and receiving stream were evaluated on technical and non-technical merits and as well as project needs.

Technical merit was measured as the ability of a model to perform the analysis required to satisfactorily answer technical questions relating to core CSO issues and its potential capability to be expanded to deal with associated issues. The initial selection of models for each system category was based on this prime condition. The experience of Dr. C. Rowney, D. Weatherbe, Dr. D. Morgan, N. Szoke and G. Steiss were used to assess comparative model strengths.

It was important to consider non-technical merits of the models to assess its ease of use relative to the modelling capabilities of local study team members. Non-technical model considerations:

- reliable and used extensively elsewhere
- local experience
- well-documented and continuously upgraded
- easy to use, flexible, setup/calibrate, and extend
- open (model code modifiable)
- able to link with other models
- in the public domain (non-proprietary)
- cost-effective

A key aspect in the selection of models is the experience of the modeller with specific models. A skilled and experienced modeller can adapt a particular model to many different circumstances, based on their unique knowledge and understanding of the specific model's numerical structure and program code. A highly sophisticated model may be ranked differently in terms of ease of use and setup by different modellers based on their experience level with the given model. In such a case, two modellers may put forward different models to perform the same task with nearly identical results. To introduce a new model to a modeller, and expect the modeller to be capable of using it as effectively as another modeller who is experienced with it, requires a significant investment of time and effort. It would be more appropriate in such a case to use the familiar model, even though it may be more sophisticated, than to expend limited resources and time to apply the new model.

A highly significant consideration in the selection of models is their ease of integration and seamless transfer of information between models for computational reasons, and their direct re-use in subsequent study phases (i.e., used as a planning model and extended to a detail level model). The use of too many different models increases the difficulty of synchronization of models. This relates mainly to the transfer of output files of one system simulation as the input files to another system simulation (i.e., urban runoff to interceptor/treatment to receiving streams). A seamless transfer of information between models is a fundamental requirement to ensure that data is being transferred correctly between models and resources are being most effectively utilized.

Receiving Stream Models

QUALHYMO is a generalized planning model capable of performing simple receiving stream dynamics (i.e., first-order decay and Streeter-Phelps DO/BOD) and is well suited to assess the major CSO issue of fecal coliforms but is not well known by local modellers. WASP5 is a sophisticated continuous dynamic water quality model developed and endorsed by the USEPA. It is capable of performing both simple and complex receiving stream dynamics. Based on discussions at the working session, QUALHYMO was ranked higher than WASP5 because it was considered more appropriate for the analysis of simple fecal coliform decay. The basis of this ranking was founded on the premise that QUALHYMO was easier to use and setup than WASP5. Subsequent to the working session a copy of the QUALHYMO program and manuals were received to evaluate its capabilities, ease of setup and application. The review of QUALHYMO found that:

- its structure is similar to that of QUAL2E or WASP and does not provide the user with any greater ease of use or setup than these models;

- several errors in both the test files and manuals were encountered that required support from its developers to resolve;

- the manuals were adequately laid out but did not provide the same level of refinement or deal typically found in US EPA model manuals.

The local modellers are familiar with WASP. It can readily incorporate the river hydrodynamics identified in QUAL2E and can readily perform simple first-order fecal coliform die-off behaviour related to core CSO issues. Further, it provides the capability to extend to varying levels of complexity (see Table 3-1) to address associated CSO issues; such as DO in a dynamic mode. Accordingly, since local modelling experience is greater in the use of WASP5 than QUALHYMO, is EPA endorsed, and can be extended to associated CSO issues, it was subsequently ranked higher than QUALHYMO for the assessment of receiving stream impacts.

Runoff and Interceptor Models

QUALHYMO and EPA SWMM are both equally capable of performing urban runoff simulations. However, EPA SWMM has been specifically designed to directly accept the output files from its RUNOFF block into its EXTRAN block to perform the hydraulic analysis of conveyance systems (i.e., interceptor). Again, it is possible to adapt the urban runoff output files from QUALHYMO for the EXTRAN block but requires a sound understanding of QUALHYMO's numerical structure and program coding. As well, the EXTRAN block of EPA SWMM has been specifically designed to transfer its output files directly to WASP5 for detailed assessment of water quality dynamics. Once more, it is possible to adapt the output file from EXTRAN for QUALHYMO to be used in receiving stream dynamics but requires reworking of the program code. It is preferable to use the same family of models to perform systems analyses if they are capable of providing the information required rather than the use of several unrelated models because of potential synchronization concerns and additional effort to rework program codes. In this case it may be preferable to use the EPA endorsed models of SWMM and WASP because of their specific design to be used in accord, unless benefits of the use of other models can be clearly demonstrated.

The results of the assessment are shown in Figure 3-3 and illustrates the ranking of model sophistication and ease of use. As well, the transition from screening models to planning models to design level models is also depicted in Figure 3-4. Increased levels of model sophistication typically results in more difficulty in use and setup because of the inherent

Appropriate Levels of Model Sophistication and Ease of Use

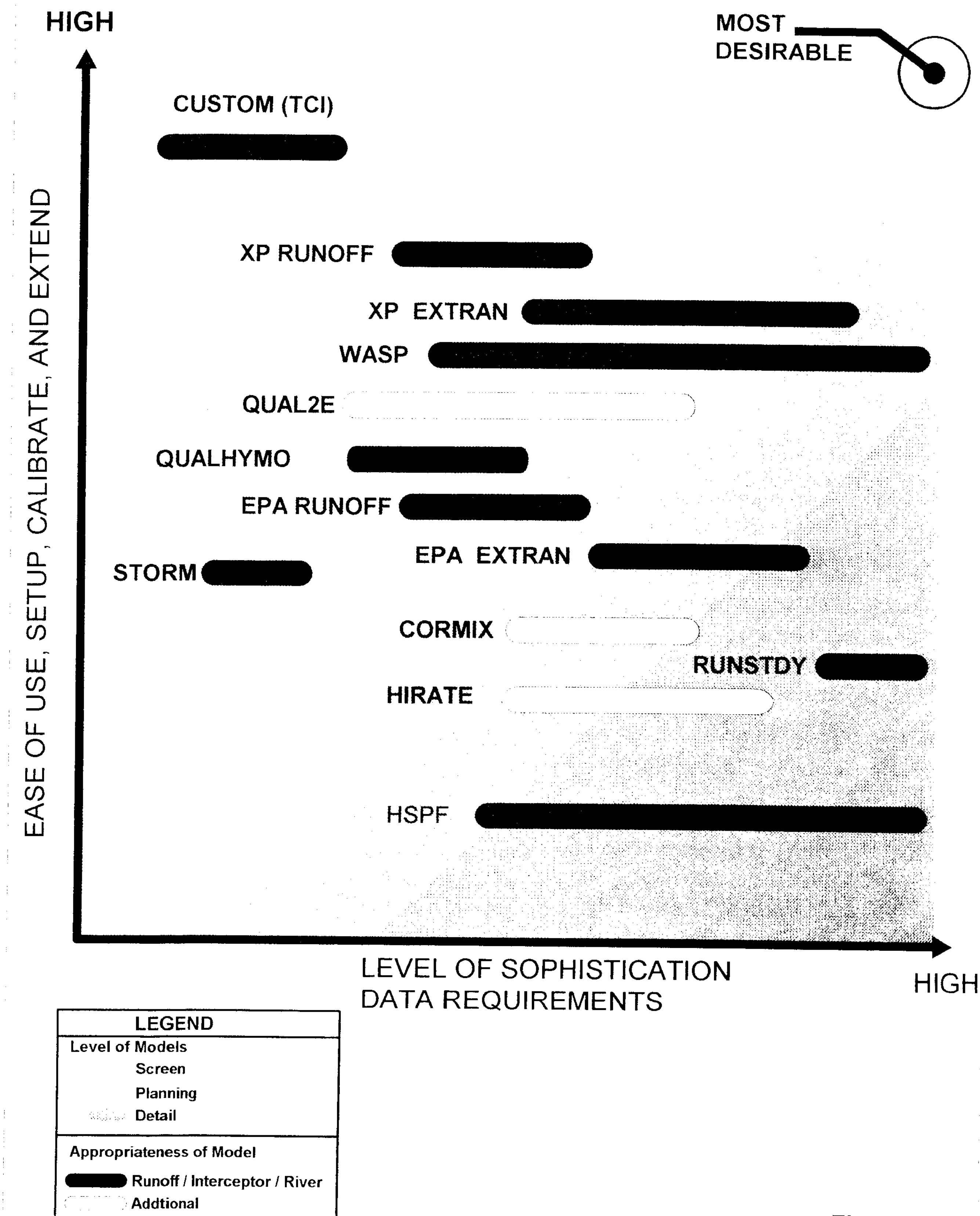
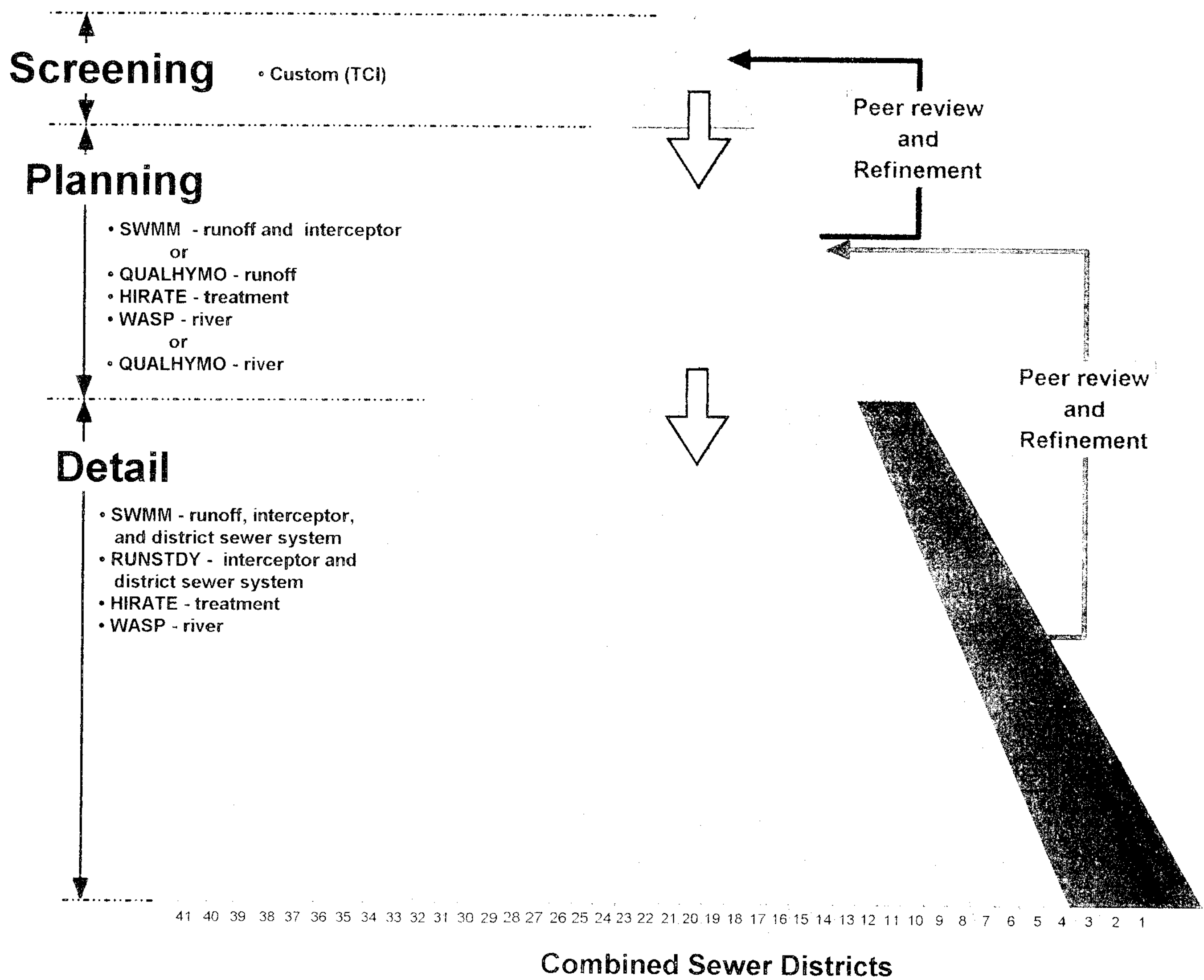


Figure 3-3



Hierarchy of Candidate Models in Technical Framework

Figure: 3-4

requirement to deal with more detailed description of system components and larger volumes of data. It can be generalized that increasing model sophistication results in a decline in ease of model use and an increase in model setup requirements, although the additional effort may be appropriate, depending on the level of detail required for the phase of study. Together, Figure 3-3 and Figure 3-4 show the progression of detail required for this study through the various phases and the candidate models appropriate for the various study phases.

The ranking tends to indicate that the primary models to consider for the various systems are:

Screening Level Models

- Custom developed for:
    - Runoff
    - Interceptor
    - Treatment
    - Receiving Stream

Planning Level Models

- EPA or XP SWMM for:
    - Runoff
    - Interceptor
- HIRATE for:
    - Treatment
- WASP5 for:
    - Receiving Stream (DO and NH_3 can be added if required)

or

- QUALHYMO for:
    - Runoff
    - Receiving Stream

Design Detail Level Models

- EPA or XP SWMM for

  - Runoff
  - Interceptor
- HIRATE for:
  - Treatment
- WASP5 for
  - Receiving Stream (DO and NH_3 can be added if required)

or

- RUNSTDY for
  - Interceptor or district collector systems if real-time control are needed.

3.4.2 Initial Selection

Models will be employed in a progressive manner through the study phases. Table 3-5 summarizes the hierarchy of models and their tentative use for specific systems. This progression will allow the refinement of detail and modelling focus as the level of model sophistication increases. Modelling results will be subject to peer review and "reality checks". This information will be used to refine the previous level of modelling and to provide a feedback mechanism to check earlier model indications. Table 3-5 illustrates the proposed hierarchial use of models for subsequent study phases as model requirements progress from screening to detail design.

It is important to note that detailed modelling will not be performed on all of the combined sewer districts. It is planed that detailed modelling will be performed on some representative micro-districts, say 3 districts, and the results of this detailed modelling effort will be translated to the overall region.

The group of candidate models initially selected will be further tested to verify their suitability and ranking. Each of the models (except RUNSTDY) will be evaluated on representative test cases to assess their technical and non-technical merits as well as their ability to adequately deal with CSO issues specific to Winnipeg. The results of these test cases will be used to assess the most effective and efficient blend of models. This will narrow the selection to specific choices of models to be used in the planning and design level analyses of the systems during the subsequent phases of the study.

TABLE 3-5

HIERARCHY OF MODEL APPLICATION

MODEL SYSTEM	SCREENING LEVEL (PHASE 2)	PLANNING LEVEL (PHASE 2 AND 3)	DETAIL LEVEL (PHASE 3 AND 4)
RUNOFF	• <u>custom developed</u>	• <u>SWMM (EPA or XP)</u> or • *QUALHYMO*	• <u>SWMM (EPA or XP)</u>
INTECEPTOR	• <u>custom developed</u>	• <u>SWMM (EPA or XP)</u>	• <u>SWMM (EPA or XP)</u> or • *RUNSTDY*
TREATMENT	• <u>custom developed</u>	• <u>HIRATE</u>	• <u>HIRATE</u>
RIVER	• <u>custom developed</u>	• <u>WASP5</u> or • *QUALHYMO*	• <u>WASP</u>

3.5 DATA AND MONITORING NEEDS

The City of Winnipeg has gathered extensive amounts of data to characterize the impacts of dry and wet weather discharges to the receiving stream.

3.5.1 Receiving Stream

Extensive amounts of river quality data has been compiled from both routine bi-weekly monitoring locations and special intensive sampling campaigns. This information has been used to describe river quality dynamics and assess dry weather flow impacts as indicated by QUAL2E model predictions (MacLaren 1986, Wardrop/Tetr*ES* 1991)[3]. Monitoring and modelling indicated that the stretch of river downstream of the NEWPCC plant is most prone to dissolved oxygen depression in response to treated effluent discharges. This stretch of the river is the most downstream point along the rivers' flow path and would be most susceptible to the potential compound dissolved oxygen suppression impacts associated with wet weather discharges. Additional monitoring in this stretch of river is required to assess whether dissolved oxygen suppression from wet weather discharges is a valid concern. A special monitoring program on a very frequent basis, two to three times per week, or continuous metering in this reach using a multi-level DO probe will assist in gathering the data needed to assess DO variation and specifically address this potential concern and the need to go to a more complex river model.

3.5.2 WWF "Pollutographs"

Wet and dry weather overflow quantity and quality data has been gathered more intensively and in greater detail since 1991 on. Data prior to this time frame exists and is also a valuable resource. Sampling was performed on dry weather CSO quality (i.e., no overflow), and wet weather stormwater and combined sewer overflows. The parameters analyzed consisted of:

- $CBOD_5$
- Total and Fecal coliforms
- pH
- Total Organic Carbon (T.O.C.)
- Chloride
- Ammonia
- Nitrate
- Total Kjeldahl Nitrogen (TKN)
- Total Phosphorus
- Total Solids
- Suspended Solids
- Conductivity
- Turbidity
- Sulphate
- Flow (synchronized with time)
- Zinc
- Lead
- Chromium

An important wet weather overflow parameter that needs to be quantified for local conditions is settleability of sediment fractions. No data currently exists specific to this parameter. A protocol for the sampling and analysis of this parameter will be given to the City for their review. This information is required to assess the performance of specific wet weather control technologies (RTBs and VSSs) and to determine potential benefits relating to receiving stream water quality improvement.

3.5.3 Interception Panels

The data collected was reviewed to determine if any gaps existed in the data collected relative to land-use. This task involved the review of the land-use sectors in terms of residential, commercial, and industrial. It was found that no one district was a unique land-use sector but a combination of sectors to varying degrees. On this basis it was determined that a primarily commercial combined sewer district should be monitored on a continuous basis. It was also found that sparse data exists on the quality of discharges from land drainage systems with and without stormwater detention basins. It was recommended that the City of Winnipeg:

- install an automated sampler in the Tylehurst combined sewer to monitor wet weather overflow loading from a primarily commercial area on a year-round continuous basis; and

- install an automatic sampler upstream and downstream of a stormwater retention basin to characterize load characteristics pre- and post of a retention basin.

- together with the study team, inspect the interception points on the main interceptor.

Inadequate information exists on the interceptor, interception points and data at the WPCCs during wet weather conditions to accurately describe the hydraulic behaviour of the system. Specific programs have been advanced from Phase 2 activities of the study to gather specific system information required to develop a coarse hydraulic model of the interceptor system and treatment plants. These programs include inspection of the interception control structures to assess their condition, weir elevation, pump or gravity interception capacity. As well, wet well levels and the pumped flow rates of the raw sewage pumps are to be recorded on at minimum intervals of one-hour for the purpose of assessing the hydraulic gradeline in the interceptor. Arrangements have been made with the City to begin collecting this data.

This information will help fill wet weather loading data gaps and improve the characterization of urban runoff and potential impacts on the receiving streams.

3.5.4 Rainfall Distribution

The spatial and temporal impacts of rain events is considered to be a key factor in the assessment of urban runoff behaviour due to its variability on a city-wide scale and its possible influence on wet weather control strategies. The City has installed 21 fixed rain gauge telemetry stations across the City of Winnipeg. As well, the City has 3 additional portable units that are relocated on a needs basis to gather district specific rainfall information for study purposes. These stations have been in use since 1988.

Rain data that has been collected accurately describes the time variability of the rainfall intensity and duration over the course of events. The City has collected a large database of continuous rainfall records for several stations located within Winnipeg. Statistical analysis of temporal variability of rainfall and its areal distribution will be used to assess the spatial significance of these events on the whole system.

In summary, the City has collected significant amounts of data that can be used to adequately characterize urban runoff and receiving stream water quality dynamics. A minor uncertainty exists regarding the dissolved oxygen levels downstream of the NEWPCC specifically after a rainfall event and may warrant a specific monitoring program. The major short-coming is the lack of adequate information to accurately describe the function and hydraulic behaviour of the interception control points, interceptor conveyance, and WPCC pumping operation and surge well levels during wet well events. Specific programs have been put forward to collect data necessary for hydraulic analysis of the interceptor system.

4.0 WORKSHOP

The Phase I workshop will provide an opportunity for specialist consultants to review the model choices, data requirements/gaps, and provide additional information that can be used to guide subsequent study phases.

APPENDIX A1: HIRATE

- MODEL ALGORITHMS
- MODEL INPUTS
- MODEL OUTPUTS

APPENDIX A: HIRATE MODEL ALGORITHMS

HIRATE incorporates mass and volume balances for each unit process as well as the whole storage-treatment flowsheet. The model includes the mass and volume balance calculations for intercepted flows and underflows taken to a central treatment facility. Removal efficiency at the central facility is also considered. Typical HIRATE flowsheets are shown in Figure A1.

HIRATE can simulate removals of solid and associated pollutants in hydrodynamic separators and sedimentation basins with and without coagulation addition. Separator analyses are based upon removal efficiencies which were determined by laboratory experimentation and which are scaled using Froude similitude. The distribution of particulate solids (settling velocities) is used as input to the separator sub-model.

The sedimentation basin sub-model uses the Camp-Dobbins formulation as modified by Chen. A bottom scour term has been added. The effect of coagulant addition was also incorporated into the model using data from full scale studies undertaken by Harleman.

When clarifiers are used in series with separators, HIRATE accounts for the changes in particle size distribution through each unit process.

Removal of parameters other than particulate solids is modelled either directly from data developed during process studies (e.g., total P removal from jar testing) or by developing pollutant concentrations ratios ($C_{pollutant}/C_{ratios}$).

Disinfection by chlorination is modelled using dose-response (CT) characteristics determined through process studies. Disinfection by ultraviolet light is modelled using the Point Source Summation Method to estimate reactor light intensities and dose-response data from process studies.

MODEL INPUTS

The primary inputs to the model are continuous (long term) flow hydrographs (one hour time step) for overflow and intercepted flow. Other model inputs include:

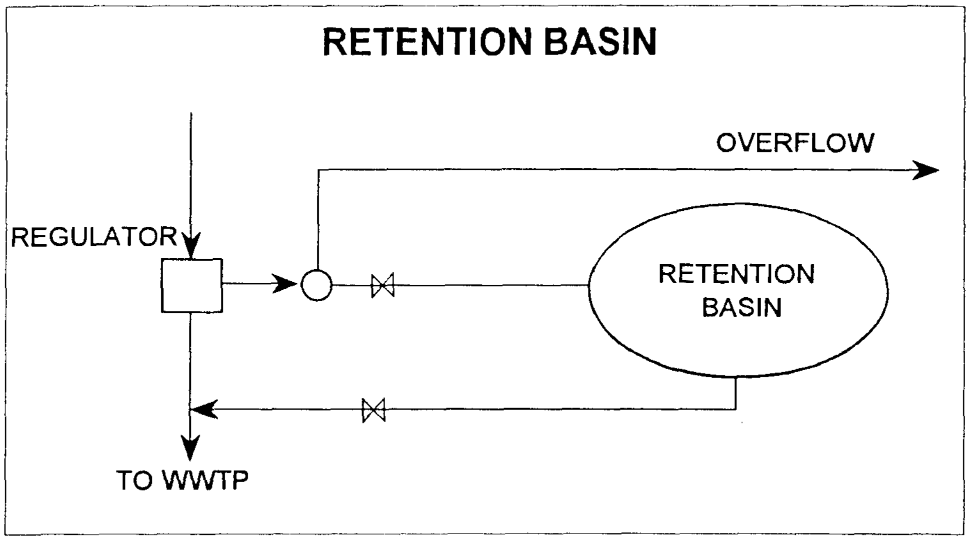
- Flowsheet description
- Regulator capacity (intercepted flow)
- Tank volumes (retention storage, vortex separator, sedimentation tank, underflow tank, U.V. reactor, chlorine contact tank)
- Coagulant addition flag
- Chlorine dosage and demand

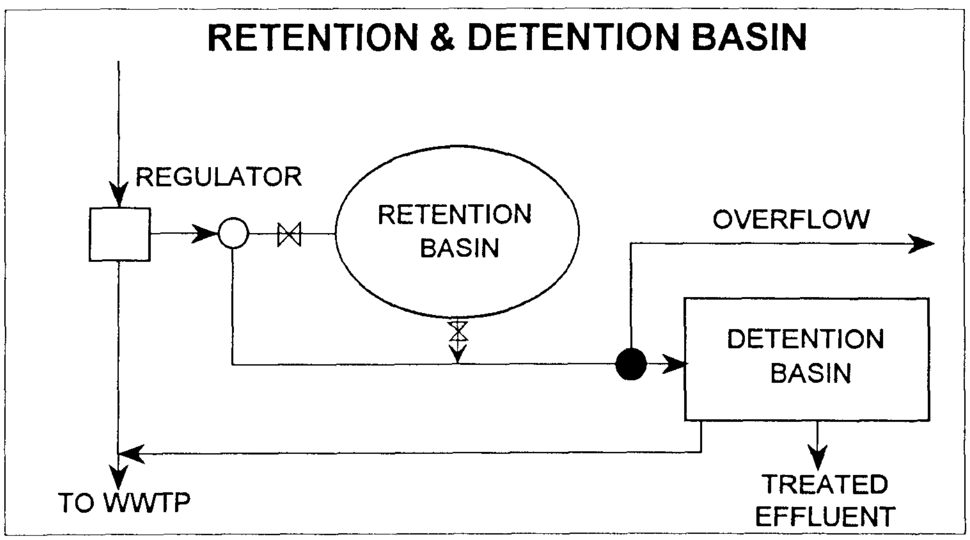
- Water quality data (TSS concentration, FC concentration, solids distribution, U.V. absorbance)
- Central treatment removal efficiencies
- Unit costs for labour, utilities and chemicals
- Current price index

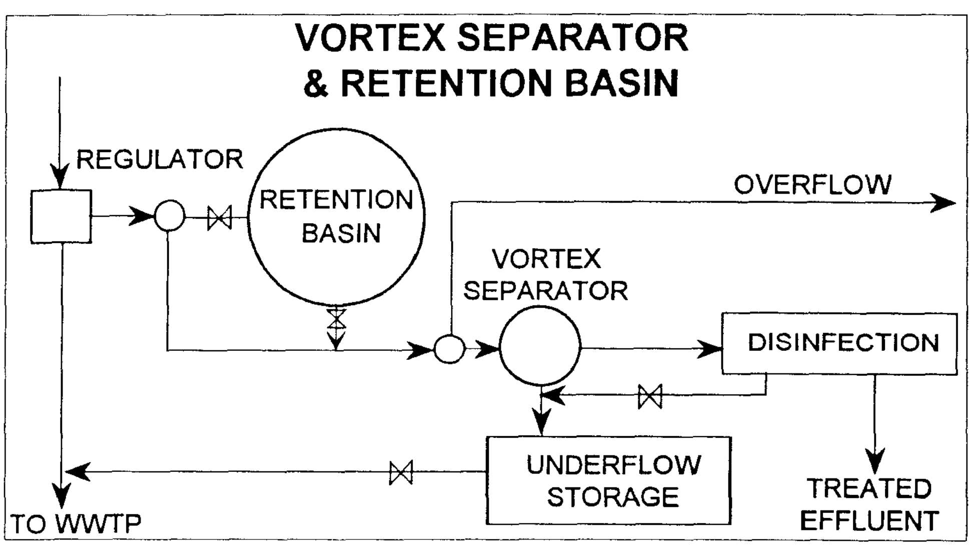
MODEL OUTPUT

Model output includes:

- Flows, mass loads and pollutant concentrations of all flow streams entering and leaving the storage treatment facility.
- Flows, mass loads and pollutant concentrations of all flow streams within the storage treatment facility.
- Summary statistics (number of events, hours of occurrence) of all flow streams within the storage treatment facility.
- Summary statistics (number of events, hours of occurrence, volumetric control, pollutant control) of the load to receiving waters from the storage treatment facility.
- Summary statistics of the pollutant load to receiving waters from the central treatment facility (central treatment of flows from the local overflow area only).
- Capital and operating cost for a designated flowsheet.







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cso1

Example HIRATE
Alternative Flowsheets
Figure A1