Assessing the Effects of Hydraulic Load Reductions on Wastewater Treatment Plant Performance

A Comprehensive Study

FINAL REPORT
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NOTE

The purpose of this report was to study the long term effects of hydraulic load reduction on wastewater treatment plant performance. To achieve this objective, Hamilton Woodward WPCP and its tributary area were chosen **for demonstration purposes.** The plans contained herein are not intended to be immediately integrated with plans developed as part of the Hamilton-Wentworth Pollution Control Plan (PCP) nor the Hamilton Harbour Remedial Action Plan (RAP).

EXECUTIVE SUMMARY

INTRODUCTION

The purpose of this study is to examine the effects of hydraulic load reduction on long term wastewater treatment plant performance. Specifically, the main objectives of the study were to:

1. Develop a comprehensive method of analysis of wastewater treatment plant flows. This involved the development of a flow disaggregation model designed to extract the various dynamic flow components (i.e., sanitary flow, dry weather infiltration, rainfall derived infiltration, and stormwater inflow) entering a wastewater treatment plant.
2. Study the effects of flow reduction and flow management programs on long term wastewater treatment plant performance.
3. Conduct an economic analysis to assess the benefits and impacts of a comprehensive flow reduction and management program.

To achieve the study objectives, the Hamilton Woodward Water Pollution Control Plant (WPCP) and its associate tributary area was chosen. **The Hamilton Woodward WPCP and its tributary area was selected for demonstration purposes only.** The Hamilton Harbour Remedial Action Plan (RAP) currently under development provides a comprehensive analysis of pollutant loading to the harbour, and also outlines a comprehensive program for reducing these loads. While some effort was made in this project to determine the interaction between the RAP and water conservation, the focus of this study remains as a general study of the effects of hydraulic load reduction on long term wastewater treatment plant performance.

BACKGROUND

It is fair to state that most wastewater treatment plants are hydraulically driven, that is, the hydraulic load to a treatment plant plays an important role in the overall performance of the plant. In fact, many treatment processes are particularly sensitive to the magnitude and variations of the hydraulic load. Water management strategies designed to reduce the hydraulic load to a plant should have a definite positive impact on wastewater treatment plant performance.

A major problem in assessing the effect of hydraulic load reduction on wastewater treatment plant performance is that the influent flow to a wastewater treatment plant usually consists of four major time-varying components:

$$Q(t) = Q_{SF}(t) + Q_{DWI}(t) + Q_{RDI}(t) + Q_{SWI}(t)$$

where:

$Q(t)$ - total WPCP influent flow;
$Q_{SF}(t)$ - diurnal sanitary flow component ;
$Q_{DWI}(t)$ - dry-weather infiltration component ;
$Q_{RDI}(t)$ - rainfall derived infiltration component; and
$Q_{SWI}(t)$ - stormwater inflow component.

These flow components are depicted in Figure 1. The purpose of the first phase of the study was to develop a comprehensive methodology for flow decomposition and analysis, allowing us to disaggregate the total flow entering a plant into the four (4) basic components.

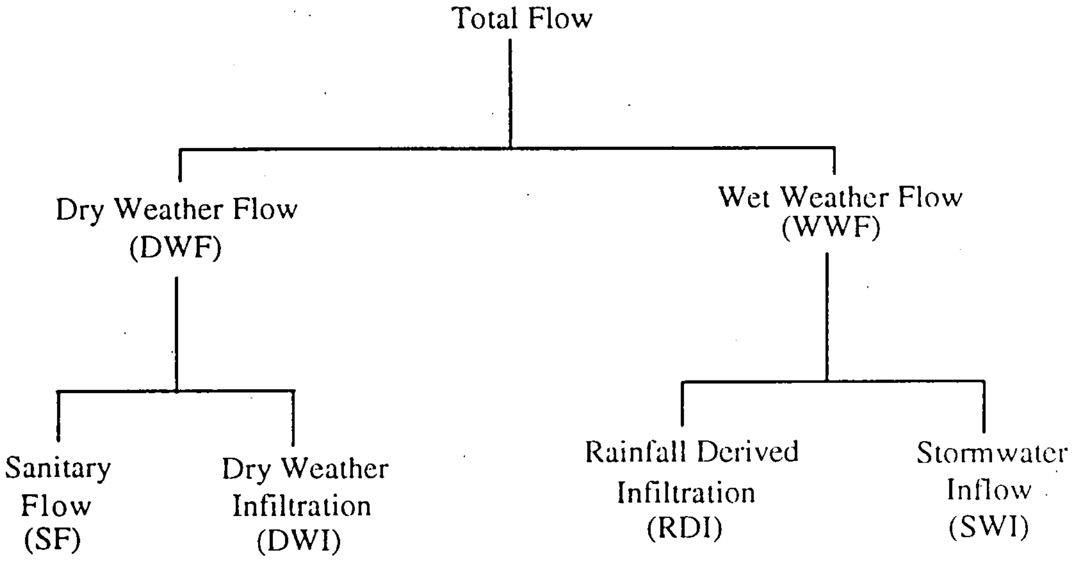

Figure 1 - Flow components.

Sanitary flow is the wastewater generated and discharged to the sewer by residential, commercial, and industrial users and is directly related to water consumption. Sanitary flow varies during the day and may vary on a weekly or yearly basis. The annual variation can be quite significant if seasonal activities are present. Water demand management programs aimed at water use reduction through conservation programs or pricing policies, directly impact the sanitary flow component.

The infiltration (dry-weather and rainfall derived infiltration) components are associated with extraneous ground water flow unintentionally entering the collection system through cracks, defective pipe joints, and other defects. This flow component may have strong seasonal frequencies reflecting the elevation of the ground water table. In addition, following a storm, the elevation of the ground water table is likely to increase slowly causing a slight increase in the ground water infiltration entering the collection system.

Finally, the inflow component is associated with extraneous flow directly entering the collection system in response to rainfall. Inflow is typically the result of a constructed combined sewer system. Even in a separate sewer system, inflow may originate from: cross-connections between the storm and sanitary sewer system; illegally connected catch basins to the sanitary sewer system; pseudo-separate system where eaves troughs and foundation drains are connected directly into the sanitary sewers system; etc.

The total flow can then enter the receiving water through several possible methods including:

1. Overflow from the collection system;
2. Untreated WPCP bypass (basically an overflow);
3. Partially treated WPCP effluent (e.g., primary treatment with disinfection); and
4. WPCP treated effluent.

In addition, nonpoint sources such as stormwater runoff directly enters the receiving water and can add significant pollutant loading to the receiving water. This pathway is of special interest since inflow reduction techniques, such as sewer separation, may actually increase the total pollutant load entering a receiving water, by increasing the volume of stormwater runoff entering the receiving water.

All four flow components described above contribute to the pollutant load entering a wastewater treatment facility. Typical pollutant concentrations entering a WPCP (BOD_5, TSS, and TKN) are shown in Table 1 for sanitary flow, infiltration, and inflow.

When developing flow reduction strategies, it is necessary to carefully consider the effect of the flow reductions on the pollutant load to the WPCP. Water demand management decreases the hydraulic load by reducing sanitary flow but does not cause a proportional reduction in the sanitary pollutant load (i.e., pollutant concentration increases as hydraulic load is reduced). Inflow and infiltration control, however, will decrease the influent load since the pollutant load is diverted away from the treatment facility.

Table 1 - Typical unit loads.

Flow Component	**BOD_5 (mg/L)**	**TSS (mg/L)**	**TKN as N (mg/L)**
Sanitary Flow	100 - 400	100 - 350	5 - 35
Infiltration	1 - 15	5 - 25	0.1 - 3.5
Stormwater Inflow	5 - 15	50 - 300	0.5 - 3.5

Sources:
Metcalf and Eddy (1991); Paul Theil Associates Ltd. and Beak Consultants Ltd. (1991); Canviro Consultants (1989); CH2M HILL Engineering Ltd. (1991); Novotny (1990); Novotny (1991).

Water demand management programs aimed at water use reduction, impacts the sanitary flow component. By reducing this component, water consumption reduction impacts both the water supply system (water treatment plant and distribution system) and the wastewater treatment system (collection system and wastewater treatment plant). Some of these impacts include:

1. Reduced operation and maintenance costs;
2. Longer time span between capacity upgrades;
3. Reduced long term pollutant load from the WPCP and collection system; and
4. Reduce frequency of high loads discharged to the receiving water from collection system overflow and WPCP bypass.

Tate (1990) describes three general methods for water demand management:

1. Structural and operational techniques (e.g., metering, retrofitting, controlling flow, recycling). Water conservation through structural and operational techniques include: metering; retrofitting (e.g., residential low flow devices); dual systems (i.e., greywater systems); infrastructure repair; improving sprinkling requirements; leakage detection; and water use restrictions. A comparison of interior residential water use with and without conservation devices is presented in Metcalf and Eddy (1991). According to Metcalf and Eddy (1991), the interior residential water use can be reduced from 287 L/cap-d to 223 L/cap-d, a reduction of 22%, through the use of low flow devices.
2. Economic techniques (e.g., water pricing, penalties, fines, rebates, tax credits) since water price increases can also reduce water use. Realistic water pricing policies would be based on full cost recovery, including water distribution, storage, and treatment costs. Water demand (use) is particularly ***inelastic***, meaning that an increase in the price of water leads to a less than proportional change in water demand. Flack (1981) reports the residential water price elasticities shown in Table 2. More recently, Gambrell Urban in association with Brown and Caldwell (1987) examined the effect of price increase on sewer flows. Their study revealed that for the City of Seattle, a 5-12% decrease in residential water demand could be expected due to higher water prices. It should be noted that the actual impact of a specific pricing policy is quite complex and depends on a number of factors, including the current water consumption rate, current pricing policy, geography, meteorological factors, water quality, etc.
3. Socio-political techniques (e.g., public awareness, building codes) designed to influence water conservation which include: promotion of sound water pricing practices; promotion of research and development; public education; and investigation of the advantages and disadvantages of water system privatization. The socio-political technique focused on in this report is public education. Tate (1990) attributes Robinson (1980) with the suggestion that "education programs alone could account for a decreased water use of up to 10% of pre-program levels."

Table 2 - Residential water elasticities.

Water Use	**Elasticity**
Residential	-0.225
Domestic	-0.26
Lawn Watering	-0.703
Average Day	-0.395
Maximum Day	-0.388

Source: Flack (1981)

A comprehensive assessment of flow reduction programs on WPCP performance requires that particular attention be given to **all** flow components, including infiltration and inflow components. The infiltration/inflow (I/I) fraction of the flow reaching a wastewater treatment facility is frequently as important, and sometimes more important, than the sanitary flow component. As part of a comprehensive flow management program, proper consideration needs to be given to the impact of infiltration/inflow reduction programs on wastewater treatment plant performance.

Infiltration/Inflow can be reduced through the replacement and/or repair of sewers, manholes and laterals. More specifically, I/I reduction measures include:

1. Sewer rehabilitation;
2. Lateral (house connection) rehabilitation;
3. Manhole rehabilitation;
4. Elimination of direct discharges by disconnecting storm drains, roof leaders, foundation drains; and
5. Sump pump installation.

When assessing the operational benefits of an I/I reduction program on WPCP performance, the effect of redirecting inflow directly to a receiving water must be considered. When sewer separation schemes are introduced, it must be recognized that a larger volume of untreated stormwater is directed to the receiving water, where previously, a limited volume of WPCP bypass or overflow may have occurred during a rainfall event.

One crucial aspect of I/I is that it greatly contributes to combined sewer overflow. Pollution control planning studies typically recommend the installation of storage facilities to reduce the volume and frequency of untreated overflows. A recent study of the Hamilton collection system (Paul Theil Associates Ltd. et al., 1991) suggested 418,000 m^3 of storage facilities are required to reduce the frequency of overflow to four events per year, while 697,000 m^3 would be required to reduce the frequency of overflow to one event per year.

The effects of flow reduction on wastewater treatment plant are many, including:

1. Reduce the frequency of high effluent concentration events, due to overflow or bypass that can cause acute water pollution problems (e.g., high bacterial counts);
2. Reduce the long term pollutant load to receiving water that can cause chronic water pollution problems (e.g., eutrophication due to high nutrient levels);
3. Reduce pumping and WPCP operating and maintenance costs;
4. Reduce need for WPCP upgrade (deferred capital expenditure); and
5. Reduce basement flooding problems.

CASE STUDY- HAMILTON

To achieve the study objectives, the Hamilton Woodward WPCP and its associated tributary area, were chosen. The WPCP and collection system was analysed for the rainfall years 1990 (wet year) and 1991 (dry year), to produce a range of results which illustrate the reaction of a combined system under extreme annual rainfall cases.

The collection system upstream of the Hamilton Woodward WPCP services a developed area of 11,600 ha, of which 5,400 ha is serviced by combined sewers and 6,200 ha is serviced by a separate sewer system (Paul Theil Associates Ltd. et al., 1991), with a tributary population of approximately 380,000.

The collection system includes 100 flow regulators, of which 35 are deemed to have significant overflow which includes the WPCP bypass, which accounts for slightly less than 11% of annual overflow volume. Simulation results show bypass during the a typical year to be 470,000 m^3 which ranges from 300,000 m^3 during a dry year to 800,000 m^3 during a wet year (Paul Theil Associates Ltd. et al., 1991)

The Hamilton Woodward Water Pollution Control Plant is a major wastewater treatment plant that includes primary, biological, advanced and anaerobic processes. The Hamilton WPCP is designed to treat an average combined sewer flow of 410 ML/d . The plant is also able to cope with an approximately 600 ML/d short term peak flow, which occurs quite frequently given that the plant services a combined sewer system. However, above 600 ML/d the plant is hydraulically overloaded and partial bypass of the whole plant is needed, resulting in the discharge of untreated sewage to Hamilton Harbour.

METHOD OF ANALYSIS

The method of analysis is summarized in Figure 2.

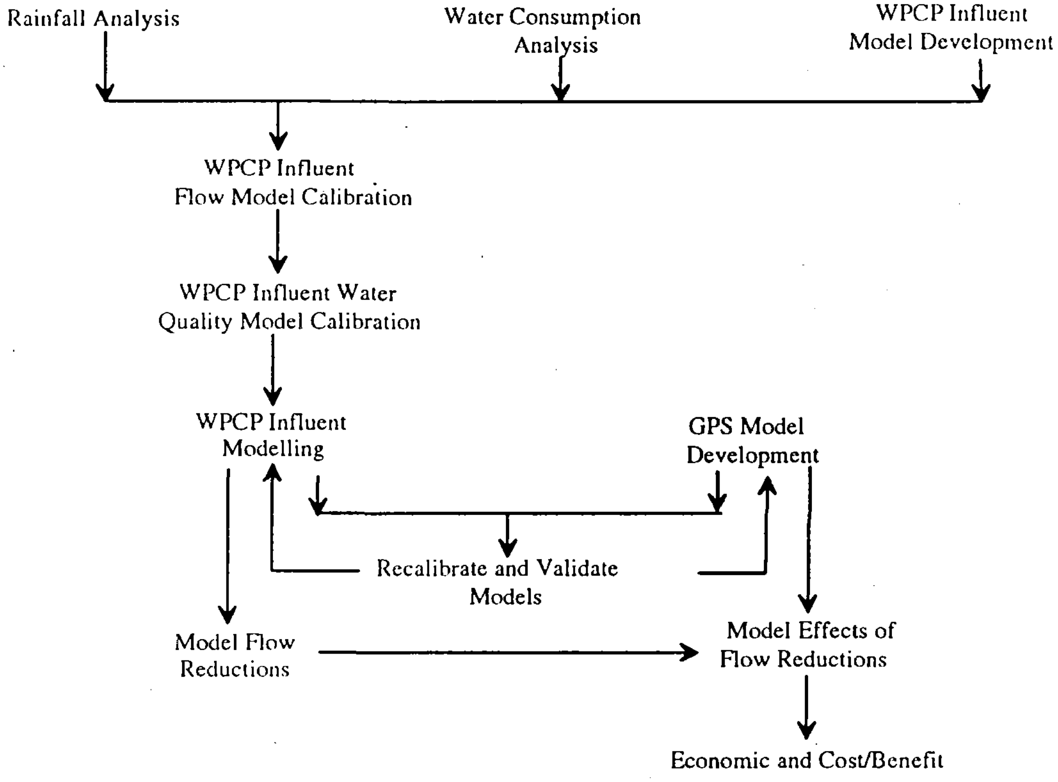

Figure 2 - Method of analysis schematic.

The analysis was carried out with a custom influent flow analysis model (WFAN) and a comprehensive wastewater treatment plant computer model (GPS-X). The levels of flow reduction used in WPCP simulations are shown in Table 3.

Table 3 - Percent reductions of flow components used in WPCP simulations.

Case	SF	DWI	SWI	RDI	Interval
Baseline Case	0%	0%	0%	0%	single case
Water Conservation	5-30%	0%	0%	0%	5%
Infiltration Control	0%	10-50%	0%	50%	10%
Inflow Control	0%	0%	10-50%	0%	10%
I/I Control	0%	10-50%	10-50%	10-50%	10%
Comprehensive Flow Control	15, 30%	25, 50%	25, 50%	25, 50%	two cases
Storage	30%	0%	0%	0%	30%

Notes:

1. SF - Sanitary Flow
2. DWI - Dry Weather Infiltration
3. SWI - Stormwater Inflow
4. RDI - Rainfall Derived Infiltration
5. Storage volume to control plant bypass/overflow to one event per year.

Two water quality parameters were examined for each case: 5 day carbonaceous Biological Oxygen Demand (BOD_5) and Total Suspended Solids (TSS).

Long term dynamic simulation were conducted over a one year period. Each run tracked the treated effluent stream from the plant, partially treated effluent stream (secondary bypass) and plant bypass stream. In addition, the three streams were combined together to allow the statistics of the total discharge to the receiving water (Hamilton Harbour) to be analyzed. Using the calibrated version of the **GPS-X** model of the Hamilton Woodward plant, a comprehensive analysis of the long term plant response to the various combinations of flow reduction and management programmes was developed.

The economic impacts of a several flow reduction programs was analysed. Cost data gathered from the literature and the Regional Municipality of Hamilton-Wentworth was used to assess the economic implications of flow reduction programs. The cost-benefit analysis was not restricted to dry-weather flow reduction programmes but also includes an economic assessment of flow reduction programmes aimed at reducing and controlling infiltration and inflow components.

RESULTS OF WPCP INFLUENT ANALYSIS AND MODELLING

Based on water consumption data for the time period under investigation, the sanitary flow to the Hamilton Woodward WPCP was estimated at 200 ML/d. The flow analysis provided the results listed in Table 4 for 1990 and in Table 5 for 1991

Table 4 - 1990 flow analysis summary.

Month	DWF (ML/d)	DWI (=DWF-SF) (ML/d)	Total Cv (%)	Direct Cv (%)	Mean Model Flow (ML/d)	Actual Mean Flow (ML/d)
January	334.7	134.7	40	12	376.7	395.6
February	339.5	139.5	10	3	358.8	386.4
March	337.8	137.8	40	10	372	359.2
April	312.8	112.8	25	18	353.8	353.7
May	343.3	143.3	8	3	379.8	376.1
June	307.8	107.1	15	3	336	328.8
July	295.8	92.9	8	3	314.4	311.6
August	279.8	79.8	5	0	308.7	302.2
September	277.2	77.2	15	3	304.1	300.2
October	269.3	69.3	15	3	314.7	315.2
November	262.9	62.9	10	3	285.9	283.8
December	282.8	82.8	8	1	311.2	302.2
Average	303.64	103.34	N.A.	N.A.	334.68	334.58

Table 5 - 1991 flow analysis summary.

Month	DWF (ML/d)	DWI (=DWF-SF) (ML/d)	Total Cv (%)	Direct Cv (%)	Mean Model Flow (ML/d)	Actual Mean Flow (ML/d)
January	318	118	45	8	329.9	334
February	292.1	92.1	15	5	293.5	312.9
March	312.5	112.5	15	5	352.7	365.7
April	317.3	117.3	20	1	386.1	374.9
May	309.6	109.6	16	4	345.7	346.2
June	292.7	92.4	12	6	300.7	303.9
July	314.2	114.2	8	4	345.8	342.2
August	268.5	68.5	20	5	296.1	300.7
September	278.7	78.7	7	2	285.1	278
October	270.5	70.5	7	3	289.6	288.8
November	270.2	70.2	10	3	288.7	284.8
December	279	79	40	5	316.3	315.3
Average	293.61	93.58	N.A.	N.A.	319.18	320.62

Results of the water quality analysis are shown in Table 6. These were derived from 1990 data and applied to the 1990 and 1991 WPCP analysis.

Table 6- 1990 WPCP influent water quality summary.

Flow Component	TSS (mg/L)	TKN (mg/L)	BOD (mg/L)
Sanitary Flow	275	39	151
Dry Weather Infiltration	137	7.7	50
Rainfall Derived Infiltration	146	4	5
Stormwater Inflow	128	4	91

WPCP MODEL CALIBRATION

The Hamilton Woodward WPCP model used in this study is an extension of the model developed by Takács et al. (1989) as part of the Hamilton-Wentworth Pollution Control Plan. For the purpose of this project, several changes and enhancements were made to the previously developed plant model. These include:

1. Conversion of the ACSL code from ACSL Version 9 to ACSL Version 10;
2. Minor changes to plant layout to include influent equalization storage, and improved bypass modelling;
3. Application of simple rules to mimic plant operations during a storm event;
4. Updated calibration.

The calibration described by Takács et al. (1989) was event -based. For this study, it was important to adjust the calibration for a long term (1 year) dynamic calibration., therefore the goal of the calibration is to simulate:

1. Long term trends;
2. Approximate frequency distribution; and
3. The relative effect of flow on final effluent.

To help match long term trends, the following changes to the model were made:

1. Functions were used that set settling parameters based on Sludge Volume Index (SVI). Daily SVI data from the plant were entered into a database used by the model.
2. Sludge Retention Time (SRT) set points were based on actual daily SRT values measured at the plant. The plant is SRT controlled, however, there were variations in plant SRT from day to day.

EFFECTS OF FLOW REDUCTION ON WASTEWATER TREATMENT AND RECEIVING WATER LOADING

Four major aspects of flow reduction are investigated:

1. Plant design life and effects on CSO storage requirements;
2. Hydraulic load to receiving water and plant bypass volumes;
3. WPCP effluent concentration; and
4. Total pollutant load (TSS and BOD) to receiving water.

To clarify the description of simulation results, the following definitions are provided:

Throughflow - flow that receives full treatment at the Woodward WPCP;
Secondary Bypass - flow that enters the Woodward WPCP and receives partial treatment, but is bypassed around the secondary treatment processes;
Plant Bypass - flow that receives no treatment at the Woodward WPCP. Note that this does not account for overflows upstream of the WPCP;
Total Outfall - the summation of throughflow, secondary bypass, and plant bypass;
Diverted - stormwater inflow that has been diverted away from the Woodward WPCP and directed into a receiving water due to sewer separation.
TOTAL - the summation of total outfall and diverted.

Paul Theil and Associates et al. (1991) provide a prediction of future wastewater flows due to population growth in the Hamilton Woodward WPCP sewershed. The population in 2025 is estimated to be 500,000 people which leads to the flow forecasts provided in Table 7. In Table 7, average flow is defined as annual average daily flow. The estimate of average flow in 2025 does not include the effects of CSO and plant bypass control.

Table 7 - Forecasted flow at Woodward WPCP.

Year	Average Annual Flow (MLD)	Dry Weather Flow (MLD)	Notes
1989	315	-	From plant records as reported in Paul Theil Associates Ltd., et al. (1991)
1990	335	304	From plant records.
1991	320	294	From plant records.
2006	383	-	Forecast in Paul Theil Associates Ltd., et al. (1991)
2025	430	420	Forecast in Paul Theil Associates Ltd., et al. (1991)

Upgrades currently under review for the Hamilton Woodward WPCP, are recommended in the Pollution Control Plan to "...handle dry weather flows from a population of 500,000 people..." (Paul Theil Associates Ltd. et al., 1991), which is forecasted to occur in the year 2025. It was assumed in this study that a future upgrade of the Hamilton Woodward WPCP will be required in the year 2025. This is a preliminary estimate only of plant upgrades only, as a better understanding of upgrades to the Hamilton Woodward WPCP will be available after the current Facility Plan study (CH2M HILL ENGINEERING LTD., 1991) is completed.

There are two ways to look at the effects of hydraulic load reduction on capital upgrade requirements:

1. Extend the design life of currently planned upgrades by increasing the time until the plant exceeds new design flows.
2. Reduce current investment by reducing the current level of expansion required to meet a specific design life.

If a water conservation program is implemented, the dry weather flow predicted for 2025 will be delayed, which will allow a delay in capital expenditure to upgrade the treatment plant. These delay times are shown in Table 8.

Table 8 - Delay of capital upgrade due to water conservation.

Water Conservation Program	Year of Capital Upgrade	Number of Years
No water conservation	2025	0
10% sanitary flow reduction	2040	14
20% sanitary flow reduction	2055	30
30% sanitary flow reduction	2080	55

The estimates in Table 8 are based on the forecasted flows in the Hamilton PCP (Paul Theil Associates Ltd. et al., 1991). Caution must be exercised in interpreting the results in Table 7.2 however, since the following assumptions were made:

1. Flow increases between 1991 and 2006 and between 2006 and 2025 were linearly interpolated.
2. Flow estimates after 2025 assumes the growth between 2006 and 2025 can be linearly projected past the year 2080. This does not account for any factors which may limit urban growth in the Hamilton Woodward WPCP tributary area.
3. The expected wet weather flow does not appreciably change from the year 2025 to 2080 and dry weather infiltration rates do not increase.
4. All forecasted flow increases are due to increases in sanitary flow and inflow and infiltration will remain constant at current levels.

Instead of extending the expected design life of the upgraded WPCP, hydraulic load reductions can be used to reduce capital investment in the proposed upgrades by reducing the required flow capacity. Essentially, water conservation can be used to offset expected flow increases due to population growth and development. Paul Theil Associates Ltd. et al. (1991) give an average flow of 315 ML/d for 1989, which is expected increase to 430 ML/d in the year 2025, which is a 115 ML/d increase. Assuming the base flow projected in Paul Theil Associates Ltd. et al. (1991) and a design period until 2025, the average flow in the year 2025 can be significantly reduced as shown in Table 9

Table 9 - Design flow reduction due to water conservation for plant design life to the year 2025.

Case	Annual Average Flow (ML/d)	Design Flow Reduction (ML/d)
0% Sanitary flow reduction	430	0
10% Sanitary flow reduction	399	31
20% Sanitary flow reduction	370	60
30% Sanitary flow reduction	341	89

By reducing the flow expected in the "design year", currently proposed capital upgrades can be designed for lower flows which will provide capital cost savings.

The purpose of these estimates are simply to illustrate the effects of water conservation on future flows to the Hamilton Woodward WPCP. It does not account for the many other factors that will affect population growth in the future.

One further aspect of hydraulic load reduction is the effect of hydraulic load reductions on storage volumes required to control combined sewer overflows. The model used in this project did not model collection system CSOs but did provide a reasonable estimate of WPCP bypass. Therefore the effects of hydraulic load reduction on overflow volume at various levels of storage was tested for controlling plant bypass. These results are shown in Figure 3.

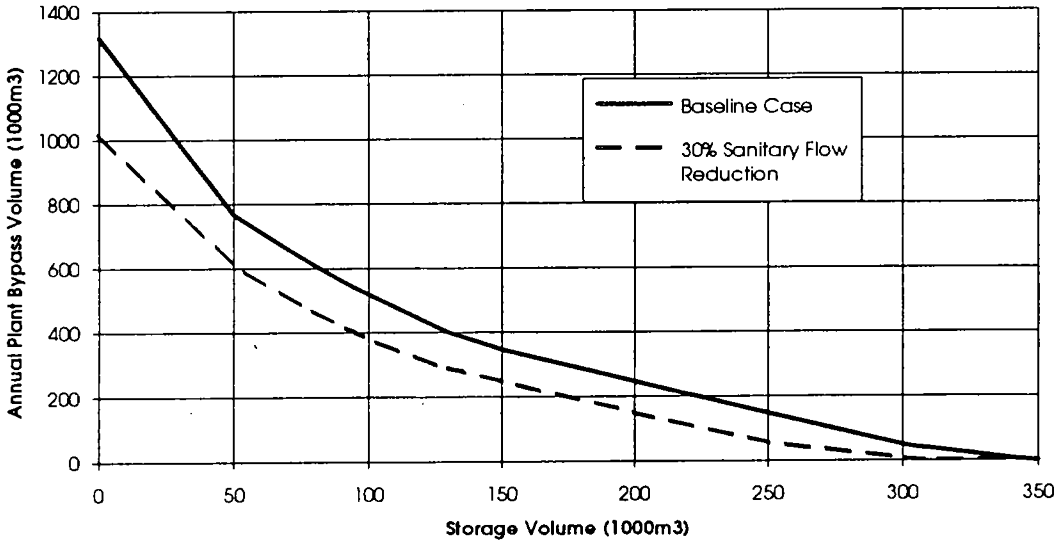

Figure 3 - Effect of hydraulic load reduction on annual WPCP plant bypass volumes versus storage volumes using 1990 rainfall year.

Table 10 shows the hydraulic loads for the baseline case for 1990 and 1991, which are the wet and dry years respectively.

Table 10 - Hydraulic load comparison of baseline cases for 1990 and 1991.

Year	Throughflow (10^6 m^3/yr)	Secondary Bypass (10^6 m^3/yr)	Plant Bypass (10^6 m^3/yr)	Total Outfall (10^6 m^3/yr)
1990	121.6 (333 ML/d)	0.11	1.33	123.0 (337 ML/d)
1991	115.9 (318 ML/d)	0.02	0.47	116.4 (319 ML/d)

Definitions:

1. *Throughflow* - flow that receives full treatment at the Woodward WPCP;
2. *Secondary Bypass* - flow that enters the Woodward WPCP and receives partial treatment, but is bypassed around the secondary treatment processes;
3. *Plant Bypass* - flow that receives no treatment at the Woodward WPCP. Note that this does not account for overflows upstream of the WPCP; and
4. *Total Outfall* - the summation of throughflow, secondary bypass, and plant bypass.

Although collection system CSOs were not modelled, the plant bypass was modelled in both this study and the Hamilton PCP. A comparison of plant bypass estimates are provided in Table 11. Note that plant bypass volumes are not measured at the plant

Table 11 - Comparison of plant bypass estimates.

Case	Paul Theil Associates Ltd. (1991)(a)	Paul Theil Associates Ltd. (1991)(c) Annually Adjusted	This Study
Dry Year			
Year	1971(b)	1971	1991
Plant Bypass	300,000	400,000	470,000 m^3
Typical Year			
Year	1989(b)	1989	not run
Plant Bypass	470,000 m^3	634,000 m^3	
Wet Year			
Year	1981(b)	1981	1990
Plant Bypass	850,000	1,110,000 m^3	1,330,000 m^3

Notes:

(a) Wet and dry year bypass volumes read from a graph in Paul Theil Associates Ltd. (1991)

(b) Year in Paul Theil Associates Ltd. (1991) defined as May 1 to October 31.

(c) Modified by dividing overflow volume by fraction of annual rainfall that occurred between May 1 to October 31. For 1989 this fraction .741 and for 1981 the fraction was .766. Insufficient data was available for 1971, so a fraction of 0.75 was used.

Hydraulic load is defined as the volume of water entering the receiving water from the following sources:

1. WPCP treated effluent;
2. WPCP partially treated effluent (secondary bypass);
3. WPCP bypass; and
4. Stormwater diverted from the combined collection system directly to the receiving water through sewer separation.

A summary of hydraulic load reductions for several cases is provided in Table 12 and a summary of average daily effluent concentrations for several cases is provided in Table 13

Table 12 - Summary of hydraulic loads reductions.

Case	% Hydraulic Load Reduction to the Receiving Water
10% Sanitary Flow Reduction	6%
30% Sanitary Flow Reduction	18%
50% Infiltration Reduction	19%
50% Stormwater Inflow Reduction	0%
50% I/I Reduction	19%
Maximum Reduction [(a)]	37%

Note: (a) Maximum flow reduction assumes 30% sanitary flow reduction and 50% I/I reduction.

Table 13 - Summary of average daily effluent concentrations.

Case	% TSS Concentration Reduction from Baseline Case	% BOD Concentration Reduction from Baseline Case
10% Sanitary Flow Reduction	11.9%	5.8%
30% Sanitary Flow Reduction	25.6%	10.5%
50% Infiltration Reduction	32.3%	12.8%
50% Stormwater Inflow Reduction	5.5%	4.7%
50% I/I Reduction	37.2%	17.4%
Maximum Reduction	53.7%	24.4%
RAP-based upgrades	87.2%	76.7%

As shown in Table 12 and Table 13, flow reductions reduce both the hydraulic load to the receiving water and effluent concentration from the WPCP. Since receiving water load is the product of flow and concentration, reducing both components will have a synergistic effect and produce even greater pollutant load reductions. A summary of pollutant load reductions is shown in Table 14.

Table 14 - Pollutant load reductions as a percent reduction from the baseline case.

Case	% TSS Load Reduction from Baseline Case	% BOD Load Reduction from Baseline Case
10% Sanitary Flow Reduction	15.6%	11.5%
30% Sanitary Flow Reduction	36.8%	25.6%
50% Infiltration Reduction	44.1%	29.5%
50% Stormwater Inflow Reduction	0.9%	-4.0%(a)
50% I/I Reduction	41.6%	23.0%
Maximum Reduction	61.4%	57.3%
RAP-based upgrades	88.5%	79.0%

Note: (a) Negative value indicates the pollutant load is increased by the given percentage.

ECONOMIC ANALYSIS OF FLOW REDUCTION

This analysis focuses on the various costs and benefits associated with the implementation of a water conservation program. Costs are incurred in the development and execution of a water conservation program. Cost reductions can be gained by:

1. Reducing operation and maintenance costs of water treatment and distribution, and wastewater collection and treatment;
2. Delaying future capital works, thereby reducing the present value of the capital expenditure; and
3. Reducing the extent of current capital works.

Key elements that can be used in developing flow reduction programs are shown in Table 15.

Table 15 - Elements of water conservation and flow reduction programs.

Flow Component	Program Element	Code #
Sanitary Flow Reduction	Pricing policy (magnitude and structure)	1
	Residential water reduction devices.	2
	Public Education	3
	Industrial/Commercial Liaison	4
I/I Reduction Program	Infrastructure needs study	5
	Sewer rehabilitation and repair	6
	Home roof disconnection	7
	Sewer separation	8
Combined Program	Database development	9
	Conservation and I/I monitoring	10
	Conservation and I/I enforcement	11

In Table 15, it was assumed that sanitary flow reduction will be achieved through water conservation techniques. This report does not investigate water distribution leakage repair since it does not significantly impact WPCP influent flows.

Table 16 defines several possible flow reduction programs that are composed of some of the program elements defined in Table 15. Although the table shows approximate flow reductions that may be achieved with each program, it is difficult to directly link, at this point, flow reductions to program effort and costs. The development of a municipality specific flow reduction program will require considerable study and likely involve the use of pilot programs to test proposed flow reduction programs.

Table 16 - Water conservation and flow reduction programs investigated.

Program	Program Elements	Approximate Flow Reductions
New pricing policy only	1	5% SF reduction
Residential water use reduction (includes meters)[(a)]	1, 2, 3	10% SF reduction
Comprehensive water conservation[(a)]	1, 2, 3, 4	30% SF reduction
Intensive I/I reduction	5, 6, 7	50% I/I reduction
Water conservation and low I/I reduction	1, 2, 3, 4, 9, 10, 11	30% SF and 10% I/I
Water conservation and high I/I reduction	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	30% SF and 50% I/I

Definitions:
SF - sanitary flow
I/I - stormwater inflow, rainfall derived infiltration and dry weather infiltration
Note: (a) - Both programs are essentially the same but examine high and low sanitary flow reductions.

A water conservation program can be pursued through a number of initiatives. These can include indirect economic techniques such as:

1. Increase the price of water and sewer use.
2. Changes to water rate structures that promote conservation.

Other effective programs include:

1. Installation of water meters.
2. Public education program.
3. Residential audits which include the distribution of water conservation kits (low flow faucets and showerheads, toilet dams). An additional aspect of the audit could be home inflow/infiltration inspection.
4. Monitoring of water use and water conservation through a database of water users.
5. Development and enforcement of tougher water use and sewer use guidelines.
6. Industrial/commercial water use program.

The total present value of the cost during the first 6 years of the programs in Table 16 is roughly $30 to $45 million. After 6 years, a monitoring and enforcement program may cost roughly $500,000 per year (in $1993 dollars). The Hamilton Harbour RAP report shows an estimate of $14 to $18 million in capital and development costs, with an annual operating cost of $500,000 to $700,000 per year. A significant part of these costs is the installation of approximately 50,000 water meters. To illustrate the importance of water metering, the following policy statement is quoted from the American Water Works Association (1992):

> **"AWWA recommends that every water utility meter all water taken into its system and all water distributed from its system to its users.**
>
> Metering of all water services is an effective means of improving and maintaining the close control of water system operations necessitated by the increasing difficulty in obtaining adequate water supplies and the increasing costs of providing water services to consumers
>
> Charging for water service on the basis of metered consumption provides a means of assessing users equitably for water service. Metering also provides a data base for system performance studies and *aids in the evaluation of conservation measures* (emphasis added). It improves accountability for water delivered through the system and, therefore, facilitates management decisions.
>
> Continual and periodic testing of meters is an essential part of a universal metering program."

Several methods are available to reduce the inflow and infiltration into the wastewater collection system. These include:

1. Separation of combined collection system by building storm sewers specifically for transporting rainfall runoff directly to a receiving water.
2. Repair or rehabilitation of sewers, laterals, and manholes.
3. Elimination of direct discharges to the sanitary system by storm drains, roof leaders, cellar drains, weeper drains.
4. Sump pump installation

Sewer separation costs are estimated to be in the order of $1 billion to separate the combined portion of the City of Hamilton sewer system. The cost will vary, depending if:

1. A shallow storm sewer is built to collect road drainage only, or
2. A deep storm sewer is built, and all laterals checked for inflow sources and reconnected as necessary.

Sewer separation will not provide 100% inflow and infiltration reduction. Although massive I/I reductions were modelled with respect to WPCP hydraulic load reductions (for demonstration purposes), the cost of sewer separation has not been pursued further in this study. This is justified by comparing the costs of sewer separation with the estimated $285 to $366 million required in the Hamilton-Wentworth area to restore Hamilton Harbour. Complete sewer separation would cost far more than all RAP projects combined in the Hamilton-Wentworth area, and would not provide the pollutant load reduction provided by the proposed RAP projects. Finally, it must be recognized that although sewer separation will reduce WPCP effluent load, and collection system CSO loading, it will direct huge volumes of rainfall runoff directly into natural watercourses. Urban runoff is often highly polluted, and complete sewer separation "generally provides only a marginal reduction in pollutant loading" and "in some cases the loading of some water quality parameters" may increase. (Paul Theil Associates Ltd., et al., 1991) as shown the simulation results presented earlier. Therefore a costly sewer separation program would likely need to be followed with a stormwater treatment program.

Other options for pursuing partial I/I reduction include:
1. Roof downspout disconnection,
2. Structurally based sewer repair and rehabilitation,
3. Selected sewer separation projects for redirecting of flows due to capacity restrictions.

Inflow and infiltration may also be reduced through a focused sewer repair and rehabilitation study. The primary purpose of these structural changes is not flow reduction, but for structural reasons and capacity restrictions. The magnitude, cost, and effect of these projects has not been estimated for this project since they would require an Infrastructure Needs Study (INS). An INS study would likely cost in the order of $500,000 - $1,000,000 for a city the size of Hamilton and would include:
1. Flow monitoring;
2. Smoke and dye testing; and
3. Videotaping of sewers.

Generally, O&M costs were divided into:
1. Fixed costs;
2. Flow dependent variable costs;
3. Influent pollutant load dependent variable costs (for wastewater treatment only).

Variable costs are primarily due to energy (electrical) and chemicals, with some variability due equipment repair and replacement. Influent pollutant load dependent variable costs are due to residuals (sludge) handling.

If flow changes, but the influent pollutant load remains constant (i.e., sanitary flow reduction), then wastewater treatment variable O&M costs are approximately:

$$\Delta\$_{WPCP} = 4821 \times \Delta Q_{WPCP}$$

If flow changes, and influent pollutant load changes proportionately to flow (i.e., I/I reduction), then wastewater treatment variable O&M costs are approximately:

$$\Delta\$_{WPCP} = 8471 \times \Delta Q_{WPCP}$$

where:

$\Delta\$_{WPCP}$ - change in annual WPCP operating cost

ΔQ_{WPCP} - change in annual average WPCP flow rate expressed in ML/d

Change in annual O&M cost as a function of change in average daily flow for the water treatment plant is:

$$\Delta\$_{WTP} = 12,236 \times \Delta Q_{WTP}$$

where:

$\Delta\$_{WTP}$ - change in annual WTP operating cost
ΔQ_{WTP} - change in annual average WTP flow rate expressed in ML/d

Note that the water treatment plant is currently operated in the evenings to avoid peak hydro-electric charges. As water use increases, or non-peak hydro hours decreases (as recently occurred), the marginal cost of electrical energy may increase significantly.

Table 17 illustrates the cost savings associated with various levels of flow reduction

Table 17 - Example annual operation and maintenance cost savings due to flow reductions.

Average Annual Flow Reduction (ML/d)	Anuual WPCP Flow Variable Savings	Annual WPCP Flow and Load Variable Savings	Annual WTP Flow Varaible Savings
10	$48,210	$84,710	$122,360
20	$96,420	$169,420	$244,720
30	$144,630	$254,130	$367,080
40	$192,840	$338,840	$489,440
50	$241,050	$423,550	$611,800
60	$289,260	$508,260	$734,160
70	$337,470	$592,970	$856,520
80	$385,680	$677,680	$978,880
90	$433,890	$762,390	$1,101,240

Notes:

1. A given flow reduction scenario does not necessarily mean equal flow reductions at the WTP and WPCP.
2. Flow reductions shown are for illustrative purposes only.
3. Flow variable savings are associated with sanitary flow reduction.
4. Flow and load variable savings are associated with I/I reduction.

An additional complication is the effect RAP based upgrades will have on annual O&M costs. The RAP report provides an estimate of $2 to $6 million per year in operating costs for collection system combined sewer overflow and primary expansion at the Woodward WPCP. The report estimates a further $1-2 million in annual operating costs due to effluent filtration at Woodward. For this study, an estimate of variable costs for CSO control is:

$$\Delta\$_{CSO} = 6250 \times \Delta Q_{WPCP}$$

and for WPCP effluent filtration:

$$\Delta\$_{filtration} = 1563 \times \Delta Q_{WPCP}$$

Combined Sewer Overflow (CSO) variable control costs assume $2 million per year in variable costs for an average annual flow of 320 ML/d while WPCP effluent filtration assumes an annual variable cost of $500,000 for an annual average flow of 320 ML/d.

By reducing flows, capital cost savings can also be realized. These include:

1. Extending the time until the next required capacity upgrade; or
2. Reduce the costs of RAP and PCP based CSO and WPCP control upgrades.

Capital costs savings were not considered for the WTP since it has appears to have sufficient capacity for the foreseeable future.

Assuming annual flow increases as predicted in the Hamilton PCP (Paul Theil Associates Ltd. et al., 1991), currently proposed plant upgrades will be effective until the year 2025, which indicates a plant capacity upgrade will be required at that time. If the flow growth rate is constant for the foreseeable future, flow reduction measures could extend the current plant life an additional 10 to 50 years, which has a signicant value.

Additional capital cost can be saved in the near future by reducing the RAP based plant and CSO upgrades based on reduced flows due to water conservation. However, the effects of any RAP-based upgrades on future capital expansions must be estimated. A better estimate of these future upgrades and RAP-based upgrades and controls will be possible after the current Woodward WPCP Facility Planning project is completed. Also note that the capacity upgrade term is an important aspect of the cost-benefit analysis, but that it will also vary extensively for each facility in any given municipality.

In addition to the costs of implementing a water conservation program, and cost reductions due to water conservation, there are several qualitative benefits associated with a water conservation and flow reduction program. These include:

1. Reduction of pollutant loading to receiving water;
2. Introduces, or reinforces, an awareness (and habits) of conservation in the community. This can then be applied to energy use and other consumptive practices;
3. Can provide employment (short and long term) to initiate and maintain water conservation, and inflow and infiltration reductions; and
4. Frees up capacity for future development (a value can be placed on this).

Specific examples of pay-back periods and flow reduction programs are shown in Tables 18 to 20 which are based on an analysis of annual cost changes for various flow reduction programs. Cost changes are defined as O&M cost decreases due to water conservation, costs of implementing water conservation, and the savings associated with delaying capital works. An additional column is included which shows the change in revenues expected due to specified billing increase, which can be used to promote conservation.

The cost benefit program shown here assumes a five year water conservation program that costs approximately $6million annually (in 1993 dollars). This can reduced by approximately 50% by assuming the installation, and therefore cost, of water meters are not part of the water conservation program. This may be feasible since water metering has uses in addition to water conservation as outlined in the previous quote from the American Water Works Association (1992, see page ES-17). As stated earlier, the program and costs used here are only an example of a one possible water conservation program.

The billing increases used in Tables 18 to 20 are based on the assumed need for increased revenues to pay for RAP-based capital works and the ensuing increased operation and maintenance costs. Table 21 shows a comparison of the "new revenues" with the cost estimates of the proposed RAP plan for projects within the jurisdiction of Hamilton-Wentworth Region. The RAP costs shown are a 10 year annualized cost and are estimated at $37 to $54 million per year, which includes $9 to $17 million in annual operating costs (Hamilton Harbour RAP Stakeholders, 1991b). Additional price increases may be justified based on the "user pay" concept, that is, if it is decided to implement a more equitable system of water billing (this aspect was not investigated for this project).

Table 18 - Cost-benefit analysis of several example flow reduction programs with a 50% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue[a]
New pricing policy only	5% SF	$273,000	0	$20.4 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$16.8 million	> 40 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$2.4 million	32 years	13
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$2.4 million	32 years	13
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$2.4 million	32 years	13

Definition:

N.A. - not applicable
SF - sanitary flow
I/I - inflow and infiltration

Note: (a) Assumes a delayed capital works in the future which provides a present value of $5 million to $15 million.

Table 19 - Cost-benefit analysis of several example flow reduction programs with a 100% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue
New pricing policy only	5% SF	$273,000	0	$43.2 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$38.4 million	> 40 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$19.2 million	32 years	immediate
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$19.2 million	32 years	immediate
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$19.2 million	32 years	immediate

Table 20 - Cost-benefit analysis of several example flow reduction programs with a 200% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue
New pricing policy only	5% SF	$273,000	0	$88.8 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$81.6 million	> 50 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$52.8 million	32 years	immediate
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$52.8 million	32 years	immediate
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$52.8 million	32 years	immediate

Table 21 - Comparison of annual new revenues at various levels of price increase to estimated annualized RAP costs.

Flow Reduction	Annualized RAP Cost ($1990)[a][b]	New Revenues[c] from a 50% Price Increase	New Revenues[c] from a 100% Price Increase	New Revenues[c] from a 200% Price Increase
5% sanitary flow reduction	$37 to 54 million	$20.4 million	$43.2 million	$88.8 million
10% sanitary flow reduction	$37 to 54 million	$16.8 million	$38.4 million	$81.6 million
30% sanitary flow reduction	$37 to 54 million	$2.4 million	$19.2 million	$52.8 million

Notes:

(a) Annualized RAP costs do not include possible cost reductions due to flow reductions.
(b) Annualized RAP costs include capital costs and operation and maintenance costs.
(c) New revenues based on 1992 revenues from water and sewer use charges.

The flow reduction programs summarized in Tables 16 to 20 are only several examples of cost/benefit analyses for the described water conservation and flow reduction programs. Revisions can be made including:

1. Program element costs;
2. Estimated flow reduction due to flow reduction programs;
3. Estimated capital costs of future capacity upgrade;
4. Pumping station, WPCP, and WTP, O&M cost reduction rates;
5. Estimated RAP variable operating costs; and
6. Inflation and interest rates.

Water conservation program costs in Tables 18 to 20 all include water meter installation which is estimated to cost $2.5 to $3.8 million per year for 5 years. This estimate is based on the installation of 50,000 meters over 5 years, or 10,000 meters per year at a cost of $250 per meter (including parts and labour). The total cost range shown is due to assumed overhead costs of up to 50% that is not accounted for in the $250 installation fee.

Tables 18 to 20 are based on assumed price increases of 50%, 100% and 200%. Table 22 shows the effect of these, and other price increases, on a customer currently paying $100/year in sewer and water use charges.

Table 22 - Example of the effect of residential water use reduction and price increases on a typical water bill.

Percent Water Use Reduction	Annual Bill at Current Prices	Annual Bill at 25% Price Increase	Annual Bill at 50% Price Increase	Annual Bill at 100% Price Increase	Annual Bill at 200% Price Increase
0%	*$100* (a)	$125	$150	$200	$300
5%	$95	$119	$142	$190	$285
10%	$90	$113	$135	$180	$270
30%	$70	$88	$105	$140	$210
50%	$50	$63	$75	$100	$150

Note: (a) Baseline case of $100/year chosen for demonstration purposes only.

Table 22 is for demonstration purposes only and the following factors must be taken into account when interpreting this table:

1. Actual billing in Hamilton-Wentworth is based on a flat rate for the first block, then a constant rate for remaining water use;
2. Flat rate block depends on the size of the water meter;
3. Price increases are assumed to affect the average price of water (i.e., both the initial flat rate block and subsequent constant rate block are increased proportionately).
4. Flat rate block means that there is a minimum water bill which the consumer cannot further reduce through reducing water use.
5. A 50% residential water use reduction is unlikely to be achieved as a community average, although some individual consumers may achieve such reductions.

CONCLUSIONS

The purpose of this study was to examine the effects of hydraulic load reduction on long term wastewater treatment plant performance. The intent of this report is not to provide a hydraulic load reduction program for Hamilton per se. Instead, the Hamilton Woodward WPCP and its tributary area was selected to demonstrate the potential effects of various flow reduction scenarios on wastewater treatment plant performance. In addition, the methods used in this study should be useful for dealing with hydraulic load reduction in a systematic fashion.

After disaggregating the flow into its various components (sanitary flow, dry weather infiltration, rainfall derived infiltration, and stormwater inflow), different flow reduction scenarios were examined to demonstrate their effects on WPCP effluent pollutant concentration and on total pollutant load entering the receiving water. From the analysis of the Hamilton Woodward WPCP performance under various flow reduction scenarios, the following conclusions were reached:

1. Significant reductions in TSS and BOD effluent concentrations were obtained with sanitary flow reduction and dry weather infiltration reductions;
2. Stormwater inflow reduction had only a marginal effect on WPCP effluent concentration reduction;
3. Significant pollutant loading reductions were obtained with sanitary flow reduction and infiltration reductions. This is due to the reduced hydraulic load to the receiving water coupled with the reduced WPCP effluent concentrations; and
4. The TSS loading to the receiving water decreased marginally (< 1.0%) with a 50% stormwater inflow reduction and BOD effluent loading actually increased with stormwater inflow reduction. This was because reducing stormwater inflow from the combined collection system implies that the same flow volume is directly diverted to the receiving water.

Hydraulic load reduction alone cannot be used at Hamilton Woodward WPCP to meet RAP specified pollutant loading requirements from the WPCP. It can, however, play a significant role in the design and expected life of currently planned collection and treatment system upgrades, including:

1. Increased expected design life of plant facilities including currently planned facility upgrades. For example a 10% sanitary flow reduction can extend the design life (based on flow) of currently planned upgrades by 10 to 15 years assuming no increases in infiltration and inflow are experienced over that time; or
2. Expected decreases in predicted future flow due to flow reduction can be used to reduce the cost of currently proposed capital works. This would include reducing the size of CSO control storage facilities and tertiary treatment at the Hamilton Woodward WPCP. By carefully staging proposed capital works and co-ordinating their design with a water conservation program, significant capital savings can be realized.

Although hydraulic load reduction did not achieve the pollutant load reductions of the RAP-based upgrades for Hamilton, it can provide significant pollutant loading reductions. Therefore, hydraulic load reduction through water conservation or infiltration control may be sufficient for WPCPs that do not require tertiary treatment but are experiencing, or are expected to experience, capacity limiting problems.

Many options are available for reducing hydraulic loads at a wastewater treatment facility and it is important to examine the economics of various flow reduction techniques. There are three aspects that need to be explored when investigating the cost and benefits of hydraulic load reduction through water conservation and infiltration/inflow control. These aspects include:

1. Cost of implementing the flow reduction program;
2. Cost savings due the effects of reducing flows; and
3. Change in revenues due to changes in pricing policy.

Cost savings can be realized through:

1. Reduced operation and maintenance (O&M) costs: and
2. Reduced capital cost requirements or through the delay of future capital expansions.

It is important to apply the O&M and capital cost savings calculations to:

1. Water treatment facility;
2. Water distribution system;
3. Wastewater collection system (including pumping stations and CSO control); and
4. Wastewater treatment facilities.

One often discussed option is the use of increased water price to promote water conservation. Theoretically, increases in water price produce a reduction in municipal water use. Increased water price alone, however attractive, is not likely to be a sufficient measure. Problems with attempting to promote water conservation through a price increase only include:

1. Water use reduction due to price increases are often temporary and eventually resume to, or near to, former levels;
2. Consumers need to be made aware of the billing increases and of methods for reducing water use (i.e., billing increases need to be accompanied by some form of public education program); and
3. Case studies show that huge billing increases are usually required to provide significant reductions in water. Using a domestic water elasticity of -0.26 (Flack, 1981), a 50% price increase would produce a 10% reduction in water consumption. It is likely that

ratepayers/taxpayers would not appreciate this burden since the large increase in revenues in this scenario (a 35% revenue increase which combines the effect of increased water cost and decreased water use) are being used to provide much smaller decreases in water and wastewater costs. In the Hamilton example, this scenario (50% price increase, 10% sanitary flow reduction) would increase revenues by approximately $17 million per year (assuming the price increase is applied to water use and sewer use) while saving only $300,000 in annual O&M costs. It is not reasonable to exert a large increase in water and sewer billing on ratepayers to achieve a marginal savings in water and wastewater costs. However, if the rate increases are justified based on the concept of user-pay and the need to pay for major capital upgrades, such as those recommended in the RAP reports, the price increase can be used inconjunction with a comprehensive water reduction program to reduce water consumption.

A comprehensive water reduction program provides a balanced program of price increases, public education, residential water use reduction programs, and commercial/industrial water use reduction programs. In addition, this can be coupled with a infrastructure rehabilitation program to reduce extraneous flows entering the collection system. In this case required price increases may also be used as an incentive and to help defray short term revenue shortages due to water use reduction. This may prove necessary since a significant proportion of water and wastewater O&M cost are fixed, that is not dependent on flow rates. If billing rates are strictly a function of flow, and are not increased during a water conservation program, revenue decreases will be higher than O&M cost decreases, thereby creating a revenue shortage.

Specific programs that could be used to reduce water use and wastewater production include:

1. Pricing increases;
2. Residential audits that would include installation of low flow devices, arranging for water meter installation, and roof leader disconnection;
3. Public education program;
4. Industrial/commercial water use reduction program;
5. Infrastructure needs study and infrastructure rehabilitation and repair. This could be applied to both the public side of the collection system (sewers, pumping stations, manholes) and the private side (laterals);
6. Focused sewer separation programs; and
7. Enforcement and monitoring of I/I and water use reduction including the development and use of a database to track the municipal water budget.

Various programs could be tested as part of a pilot project in limited area of the municipality. A comprehensive program consisting of many of the above programs could cost in the order of $30 to $45 million (which includes ~$12.5 to $19 million for residential water meter installation) over the next six years with an annual cost of up to $500,000 after the six year program is complete. It could produce sanitary flow reduction of 10-30% and similar reductions in infiltration (infiltration reductions are hard to predict). The RAP report provides an estimate of a water conservation that includes an initial capital cost of $14 to $18 million and an annual cost $500,000 to $700,000 per year.

Annual operation and maintenance costs reductions would be in the range of $500,000 to $2.1 million per year. The capital cost savings, which play an important factor in whether the program is feasible from a strictly economical point of view, is very hard to predict a this time. A rough estimate in the order of $5 to $15 million was made for this report based on the delay of an upgrade which would today cost $50 million.

There are other benefits that cannot be easily explained in terms of a cost/benefit analysis. Some of these qualitative benefits include:

1. Providing short term employment (1 to 5 years) during start-up and implementation, and long term employment for program monitoring and maintenance; and
2. Instilling a conservationist way of thinking, and lifestyle, on the general population. This is beneficial not only in reducing water use and wastewater generation, but also with respect to other utilities (e.g., gas, electricity) as well as solid waste generation.

Summary

These conclusions can be summarized as follows:

1. A hydraulic load reduction program, particularly through water conservation and infiltration reduction, can create significant reductions in receiving water pollutant loading. This study showed TSS and BOD annual pollutant load reductions of 10% to 45% for various cases of hydraulic load reduction.
2. For the Hamilton Woodward WPCP, hydraulic load reductions alone are not sufficient to achieve effluent pollutant loads that will be achieved by RAP based upgrades.
3. RAP based increases in water and sewer use rates can be used as an incentive for water conservation.
4. Annual operation and maintenance cost savings associated with reduced hydraulic load reduction, while significant, are lower than the projected costs of a comprehensive flow reduction program. Therefore, from a strictly economic cost-benefit point of view, the savings in capital expenditure due to flow reduction will determine if a hydraulic load reduction program is economically viable.
5. Expected decreases in predicted future flow due to flow reduction can be used to reduce the cost of currently proposed capital works. This would include reducing the size of CSO control storage facilities and tertiary treatment at the Hamilton Woodward WPCP. By carefully staging proposed capital works, and co-ordinating their design with a water conservation program, significant capital savings may be realized.
6. A better estimate of the effects of hydraulic load reduction on capital expenditures will be attainable after the completion of the Hamilton Woodward facility plan currently under development. It may be desirable to integrate the development of a water conservation plan with the staging and design of the treatment plant upgrades.

Section 1
INTRODUCTION

1.1 STUDY OBJECTIVES

The purpose of this study is to examine the effects of hydraulic load reduction on long term wastewater treatment plant performance. More specifically, the main objectives of the study were to:

1. Develop a comprehensive method of analysis of wastewater treatment plant flows. This involved the development of a flow disaggregation model designed to extract the various dynamic flow components (i.e., sanitary flow, dry weather infiltration, rainfall derived infiltration, and stormwater inflow) entering a wastewater treatment plant.
2. Study the effects of flow reduction and flow management programs on long term wastewater treatment plant performance.
3. Conduct an economic analysis to assess the benefits and impacts of a comprehensive flow reduction and management program.

To achieve the study objectives, the Hamilton Woodward Water Pollution Control Plant (WPCP) and its associate tributary area was chosen. The Hamilton Woodward WPCP treats flow from a collection system that has 47% of the sewershed serviced by combined sewers and 53% by a separate sewer system. The analysis was performed for the years 1990 and 1991, which represent the wettest year (1990) and the driest year (1991) in the past decade.

The Hamilton Woodward WPCP and its tributary area was selected for demonstration purposes only. The Hamilton Harbour Remedial Action Plan (RAP) currently under development provides a comprehensive analysis of pollutant loading to the harbour, and also outlines a comprehensive program for reducing these loads. While some effort was made in this project to determine the interaction between the RAP and water conservation, the focus of this study remains as a general study of the effects of hydraulic load reduction on long term wastewater treatment plant performance.

The influent flow analysis used a flow decomposition technique that identified the magnitude and significance of the various flow components. The impact of flow reduction and management strategies on wastewater treatment performance was investigated using the General Purpose Simulator (**GPS-X**) (Patry and Takács, 1989). **GPS-X** is a comprehensive model used to simulate the dynamics of large scale wastewater treatment plants. The **GPS-X** was used to assess the short and long term performance of the plant to specific flow reduction and management programs. A number of flow reduction and management programs were investigated:

1. Pricing policies;
2. Residential water conservation devices; and
3. Inflow and infiltration reduction programs.

A number of key reports were used in the preparation of this study. These included:

1. *Regional Municipality of Hamilton-Wentworth Pollution Control Plan* (Paul Theil Associates Ltd. et al., 1991);
2. *Remedial Action Plan for Hamilton Harbour - Stage 1 Report: Environmental Conditions and Problem Definition* (Ontario Ministry of the Environment et al., 1992); and
3. *Remedial Action Plan (RAP) for Hamilton Harbour* (Hamilton Harbour RAP Stakeholders, 1991).

1.2 STRUCTURE OF THE REPORT

This report is divided into ten (10) sections. Section 2 provides a background review of treatment plant influent loads, water consumption, inflow and infiltration, and the effects of influent loading on WPCPs. Section 3 offers a description of the Hamilton collection and treatment systems. Section 4 gives details on the methods of analysis of influent load, WPCP process modelling, and flow reduction management. The description of method is followed by discussion of the results of flow modelling (Section 5), WPCP calibration (Section 6), WPCP performance (Section 7), and economic analysis (Section 8). Finally, Section 9 summarises the findings of the report.

References are listed in Section 10, while a number of appendices provide the necessary support material for a thorough understanding of the report:

Appendix A	-	Simulation as a Tool for Process Optimization and Operation
Appendix B	-	WPCP Flow Analysis Program
Appendix C	-	Simulation Results
Appendix D	-	Water Conservation Program Description, Costs, and Cost Benefits

Section 2
BACKGROUND

This section contains a description of the loads that enter a typical municipal wastewater treatment plant, methods for reducing these loads, and a qualitative description of the impacts associated with hydraulic load reduction on municipal infrastructure and the environment.

2.1 WPCP INFLUENT LOADING - FLOW AND WATER QUALITY

Wastewater treatment plants consist of a network of interdependent biological, physical, and chemical processes operating under time-varying hydraulic and pollutant load conditions. While treatment plants are usually designed under steady-state conditions, the performance of these facilities is sensitive to both the time-varying loads they receive as well as to a number of environmental factors, both of which are usually beyond the control of the operators.

The focus of this report is on the time-varying loads to wastewater treatment plants. A description of hydraulic loads and pollutant loads to wastewater treatment plants is provided in the following subsections.

2.1.1 WPCP Influent Hydraulic Load

It is fair to state that most wastewater treatment plants are hydraulically driven, that is, the hydraulic load to a treatment plant plays an important role in the overall performance of the plant. In fact, many treatment processes are particularly sensitive to the magnitude and variations of the hydraulic load. Water management strategies designed to reduce the hydraulic load to a plant should have a definite positive impact on wastewater treatment plant performance.

A major problem in assessing the effect of hydraulic load reduction on wastewater treatment plant performance is that the influent flow to a wastewater treatment plant usually consists of four major time-varying components:

$$Q(t) = Q_{SF}(t) + Q_{DWI}(t) + Q_{RDI}(t) + Q_{SWI}(t)$$

where:

$Q(t)$ - total WPCP influent flow;
$Q_{SF}(t)$ - diurnal sanitary flow component ;
$Q_{DWI}(t)$ - dry-weather infiltration component ;
$Q_{RDI}(t)$ - rainfall derived infiltration component; and
$Q_{SWI}(t)$ - stormwater inflow component.

These flow components are depicted in Figures 2.1 and 2.2. The purpose of the first phase of the study was to develop a comprehensive methodology for flow decomposition and analysis, allowing us to disaggregate the total flow entering a plant into the four (4) basic components.

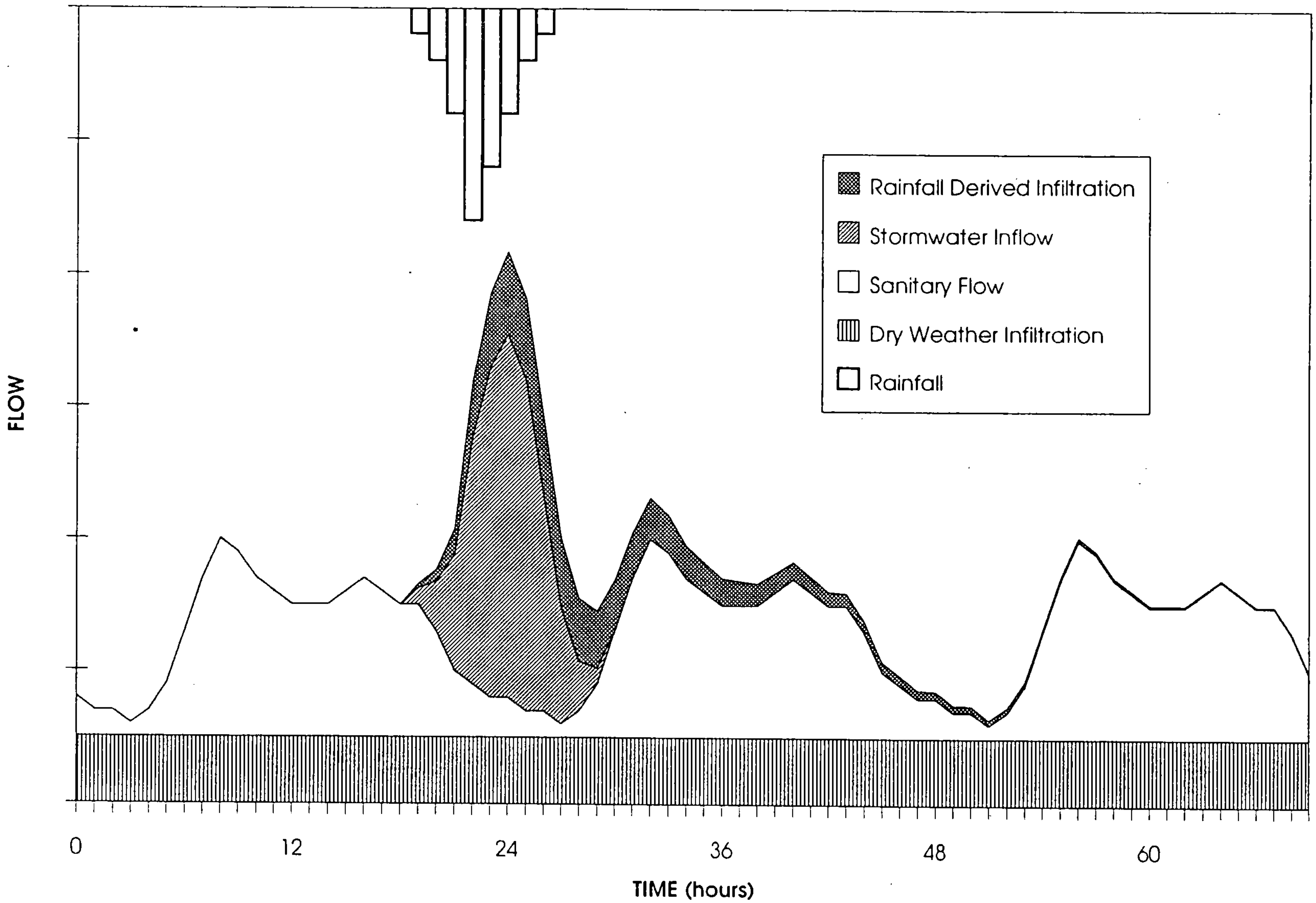

Figure 2.1 - Flow components entering a sanitary sewer system.

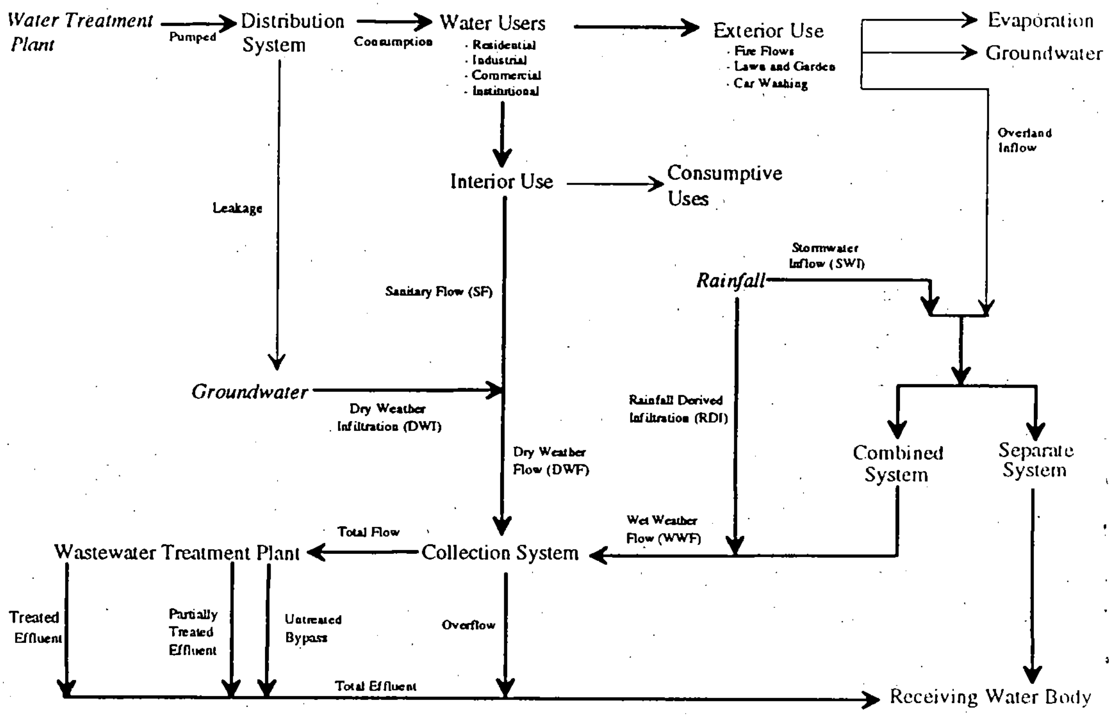

Figure 2.2 - Municipal water budget.

The combination of sanitary flow (SF) and dry weather infiltration (DWI) are usually referred to as dry weather flow (DWF), while the combination of rainfall derived infiltration (RDI) and stormwater inflow (SWI) are referred to as wet weather flow (WWF). This concept is illustrated in Figure 2.3.

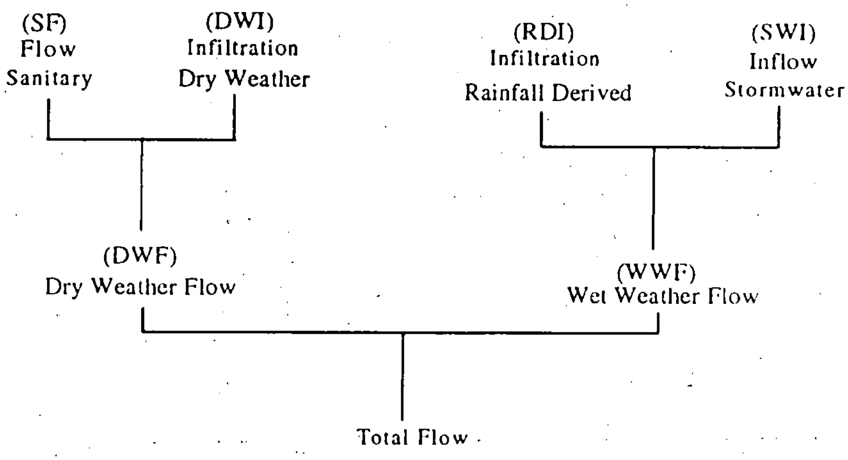

Figure 2.3 - Flow components.

Sanitary flow is the wastewater generated and discharged to the sewer by residential, commercial, and industrial users and is directly related to water consumption. Sanitary flow varies during the day and may vary on a weekly or yearly basis. The annual variation can be quite significant if seasonal activities are present. Water demand management programs aimed at water use reduction through conservation programs or pricing policies, directly impact the sanitary flow component.

The infiltration (dry-weather and rainfall derived infiltration) components are associated with extraneous ground water flow unintentionally entering the collection system through cracks, defective pipe joints, and other defects as shown in Figure 2.4. This flow component may have strong seasonal frequencies reflecting the elevation of the ground water table. In addition, following a storm, the elevation of the ground water table is likely to increase slowly causing a slight increase in the ground water infiltration entering the collection system.

Finally, the inflow component is associated with extraneous flow directly entering the collection system in response to rainfall. Inflow is typically the result of a purposely constructed combined sewer system. Even in a separate sewer system, inflow may originate from cross-connections between the storm and sanitary sewer system, illegally connected catch basins to the sanitary sewer system, pseudo-separate system where eaves troughs and foundation drains are connected directly into the sanitary sewers system, etc.

The details on how these four flow components are generated is shown in Figure 2.1, which is a simplified illustration of a municipal water budget. Of special note in this diagram is the make up of the total flow discharged from point sources to the receiving water body (RWB), which include:

1. Overflow from the collection system;
2. Untreated WPCP bypass (basically an overflow);
3. Partially treated WPCP effluent (e.g., primary treatment with disinfection); and
4. WPCP treated effluent.

In addition, nonpoint sources such as stormwater runoff directly enters the receiving water and can add significant pollutant loading to the receiving water. This pathway is of special interest since inflow reduction techniques, such as sewer separation, may actually increase the total pollutant load entering a receiving water, by increasing the volume of stormwater runoff entering the receiving water.

An understanding of these pathways is important in this study since we should determine the change in total pollutant load to the receiving water, not just the change in the treated WPCP effluent load.

2.1.2 WPCP Influent Pollutant Load

All four flow components described in Section 2.1.1 contribute to the pollutant load entering a wastewater treatment facility. Modelling the time-varying nature of the influent load is usually accompanied by a high degree of uncertainty. For the purpose of this project, simple time

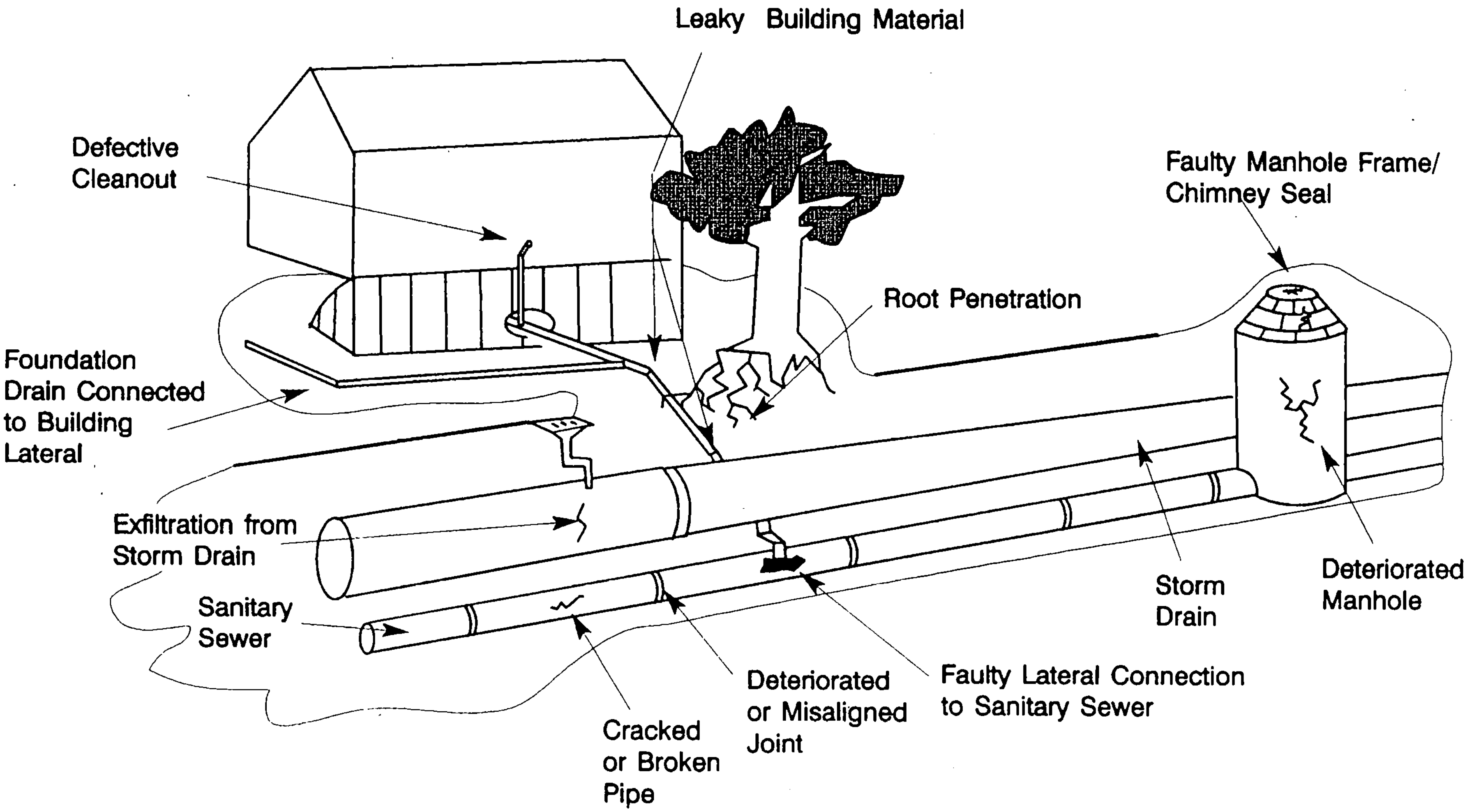

Figure 2.4 - Typical infiltration entry points.

independent unit loads (concentrations) were used for each flow component. While this model can duplicate the mean concentration of the influent load, it is not intended to model the noise about the mean. However, as stated previously, Water Pollution Control Plants are usually hydraulically driven, and the hourly variations in influent water quality do not usually have a significant effect on the long term performance of the WPCP.

When developing flow reduction strategies, it is necessary to carefully consider the effect of the flow reductions on the pollutant load to the WPCP. Water demand management decreases the hydraulic load by reducing sanitary flow but does not cause a proportional reduction in the sanitary pollutant load (i.e., pollutant concentration increases as hydraulic load is reduced). Inflow and infiltration control, however, will decrease the influent load since the pollutant load is diverted away from the treatment facility.

Typical pollutant concentrations entering a WPCP (BOD_5 , TSS, and TKN) are shown in Table 2.1 for sanitary flow, infiltration, and inflow.

Table 2.1 - Typical unit loads.

Flow Component	**BOD_5 (mg/L)**	**TSS (mg/L)**	**TKN as N (mg/L)**
Sanitary Flow	100 - 400	100 - 350	5 - 35
Infiltration	1 - 15	5 - 25	0.1 - 3.5
Stormwater Inflow	5 - 15	50 - 300	0.5 - 3.5

Sources:
Canviro Consultants (1989); CH2M HILL Engineering Ltd. (1991); Metcalf and Eddy (1991); Novotny (1991); Novotny (1992); Paul Theil Associates Ltd. et al., (1991).

The large range of sanitary flow concentrations is due to the uncertainty of the effect of industrial and commercial sources on water quality. Inflow variability is due to effects of pollutant accumulation on surfaces in the catchment between rainfall events. In addition, high runoff rate events can scour the collection system resulting in particularly high pollutant concentrations.

2.2 REDUCTION OF WATER CONSUMPTION

Water demand management programs aimed at water use reduction, impacts the sanitary flow component. By reducing this component, water consumption reduction impacts both the water supply system (water treatment plant and distribution system) and the wastewater treatment system (collection system and wastewater treatment plant). Some of these impacts include:

1. Reduced operation and maintenance costs;
2. Longer time span between capacity upgrades;
3. Reduced long term pollutant load from the WPCP and collection system; and
4. Reduce frequency of high loads discharged to the receiving water from collection system overflow and WPCP bypass.

Tate (1990) describes three general methods for water demand management:

1. Structural and operational techniques (e.g., metering, retrofitting, controlling flow, recycling);
2. Economic techniques (e.g., water pricing, penalties, fines, rebates, tax credits); and
3. Socio-political techniques (e.g., public awareness, building codes).

These techniques are interrelated (Tate, 1990). For example, an increase in the price of water will lower water consumption by encouraging consumers to apply various structural and operational techniques.

Another important issue is the difference between interior water use and exterior water use. Major residential exterior water uses such as lawn and garden watering are viewed by the consumer as less essential (Tate, 1990). Therefore, when water conservation becomes desirable, it is these less essential uses that are likely to be targeted by the consumer first. This means that when the effects of water conservation on wastewater flows are examined, it is assumed that initial conservation efforts will focus on the exterior uses. Although exterior water use reduction will not significantly impact wastewater systems, they can have a major impact on water treatment and supply operations.

2.2.1 Water Conservation Through Structural and Operational Techniques

Water conservation through structural and operational techniques include:

1. Metering;
2. Retrofitting (e.g., residential low flow devices);
3. Dual systems (i.e., greywater systems);
4. Infrastructure repair;
5. Improving sprinkling requirements;
6. Leakage detection; and
7. Water use restrictions.

A comparison of interior residential water use with and without conservation devices is presented in Metcalf and Eddy (1991). According to Metcalf and Eddy (1991), the interior residential water use can be reduced from 287 L/cap-d to 223 L/cap-d, a reduction of 22%, through the use of low flow devices. Low flow devices which impact interior residential water include:

1. Faucet aerators;
2. Flow limiting shower heads;
3. Low-flush toilets;
4. Pressure reducing valve;
5. Retrofit kits for bathroom fixtures;
6. Toilet dam;
7. Toilet leak detectors;
8. Water-efficient dishwasher; and
9. Water-efficient clothes washer.

The reduction of industrial flow through water conservation is far less predictable and will not be addressed as part of this investigation.

2.2.2 Water Demand Management Through Water Pricing Strategies

There is no question that water use is a demand that can be influenced by pricing policies. In fact, Canada has a long history of subsidizing the true cost of water, including its distribution, storage and treatment. Tate (1990) has collected some interesting statistics on the consumption and cost of water (Table 2.2) throughout the world. The 1986 Canadian water costs are particularly low, while the per capita consumption is relatively high.

Table 2.2 - Cost and consumption of water throughout the world.

Country	1986 Cost $/1000 L	1986 Consumption Litres/capita-day
United States	$ 0.53	425
Canada	$ 0.25	360
France	$ 0.75	150
Belgium	$ 0.70	-
U.K.	$ 0.50	200
Sweden	$ 0.50	200
Australia	$ 1.65	-
Germany	$ 0.99	150
Italy	$ 0.17	-
Israel	-	150

Source: Tate (1990)

In fact, the 1986 residential water prices (including water and sewage) in Canada varied from a low of $0.23/1000 L (Newfoundland) to a high of $0.94/1000 L (Northwest Territories) (Anon., 1989). The Ontario mean monthly water price (water and sewage) was $0.50/1000 L. On the other hand, the marginal price of water, or the price of the next unit of water, varied from a low of $0.14/1000 L to a high $0.81/1000 L, with a Canadian average of $0.31/1000 L (again this includes the price of water and sewage). Many actions can be taken to lower water demand without changing significantly the socio-economic activities. Realistic water pricing policies would be based on full cost recovery, including water distribution, storage, and treatment costs.

Water demand (use) is particularly ***inelastic***, meaning that an increase in the price of water leads to a less than proportional change in water demand. Flack (1981) reports the following residential water price elasticities (Table 2.3).

Table 2.3 - Residential water elasticities.

Water Use	Elasticity
Residential	-0.225
Domestic	-0.26
Lawn Watering	-0.703
Average Day	-0.395
Maximum Day	-0.388

Source: Flack (1981)

More recently, Gambrell Urban in association with Brown and Caldwell (1987) examined the effect of price increase on sewer flows. Their study revealed that for the City of Seattle, a 5-12% decrease in residential water demand could be expected due to higher water prices. It should be noted that the actual impact of a specific pricing policy is quite complex and depends on a number of factors, including the current water consumption rate, current pricing policy, geography, meteorological factors, water quality, etc. However, based on the data presented in Tate (1990) it is suggested that municipal water demand and its impacts on wastewater treatment plant performance, should be examined more thoroughly.

When applying this information, care must be taken to differentiate between the **cost** of water and the **price** of water. While changing pricing strategies may have some effect on demand, consideration of the effect of reduced demand on cost must also be considered.

Other issues include the need to isolate the difference in elasticity between residential, commercial, and industrial water users, and the effect of pricing strategies on interior water use (versus exterior or non-returned water use). Lyman (1992) concludes "that peak (summer) demand is significantly more elastic than off-peak (winter) demand". This does not likely indicate a difference in seasonal interior water use elasticities. Since the summer elasticity is greater, this probably indicates consumer reductions in exterior water uses such as lawn and garden watering and car washing.

2.2.3 Water Conservation Through Socio-political Techniques

Tate (1990) lists four socio-political techniques designed to influence water conservation:

1. Promotion of sound water pricing practices;
2. Promotion of research and development;
3. Public education; and
4. Investigation of the advantages and disadvantages of water system privatization.

The socio-political technique focused on in this report is public education. Tate (1990) attributes Robinson (1980) with the suggestion that "education programs alone could account for a decreased water use of up to 10% of pre-program levels."

2.3 INFILTRATION AND INFLOW CONTROL

A comprehensive assessment of flow reduction programs on WPCP performance requires that particular attention be given to **all** flow components, including infiltration and inflow components. The infiltration/inflow (I/I) fraction of the flow reaching a wastewater treatment facility is frequently as important, and sometimes more important, than the sanitary flow component. As part of a comprehensive flow management program, proper consideration needs to be given to the impact of infiltration/inflow reduction programs on wastewater treatment plant performance.

Infiltration/Inflow can be reduced through the replacement and/or repair of sewers, manholes and laterals. More specifically, I/I reduction measures include:

1. Sewer rehabilitation;
2. Lateral (house connection) rehabilitation;
3. Manhole rehabilitation;
4. Elimination of direct discharges by disconnecting storm drains, roof leaders, foundation drains; and
5. Sump pump installation.

When assessing the operational benefits of an I/I reduction program on WPCP performance, the effect of redirecting inflow directly to a receiving water must be considered. When sewer separation schemes are introduced, it must be recognized that a larger volume of untreated stormwater is directed to the receiving water, where previously, a limited volume of WPCP bypass or overflow may have occurred during a rainfall event.

One crucial aspect of I/I is that it greatly contributes to combined sewer overflow. Pollution control planning studies typically recommend the installation of storage facilities to reduce the volume and frequency of untreated overflows. A recent study of the Hamilton collection system (Paul Theil Associates Ltd. et al., 1991) suggested 418,000 m^3 of storage facilities are required to reduce the frequency of overflow to four events per year, while 697,000 m^3 would be required to reduce the frequency of overflow to one event per year.

2.4 EFFECTS OF WPCP INFLUENT LOADING REDUCTIONS

The effects of flow reduction on wastewater treatment plant are many, including

- reduce the frequency of high effluent concentration events, due to overflow or bypass that can cause acute water pollution problems (e.g., high bacterial counts);
- reduce the long term pollutant load to receiving water that can cause chronic water pollution problems (e.g., eutrophication due to high nutrient levels);
- reduce pumping and WPCP operating and maintenance costs;
- reduce need for WPCP upgrade (deferred capital expenditure); and
- reduce basement flooding problems.

Patry and Takács (1990) investigated the effects of hydraulic load reduction at the Saint-Hyacinth plant, located 50km north of Montreal. The study tested total flow reductions of

10-40% while keeping the pollutant load the same for all simulations. The results showed that hydraulic load reductions produced small reductions in long term effluent load but produced a significant reduction in the frequency and magnitude of water quality violations under short term conditions.

Two aspects of Patry and Takács (1990) will be changed in the methodology of this study:

1. Flow reduction will not be applied to the total flow but to individual flow components, that is sanitary flow, dry weather and rainfall derived infiltration, and stormwater inflow.
2. Pollutant load reductions will be simulated when infiltration or stormwater inflow reductions are modelled.

Section 3
CASE STUDY- HAMILTON

To achieve the study objectives, the Hamilton Woodward WPCP and its associated tributary area, were chosen. The location of the treatment plant along with the Atmospheric Environment Service (A.E.S.) rainfall gauges, are shown in Figure 3.1. The WPCP and collection system was analysed for the rainfall years 1990 (wet year) and 1991 (dry year), to produce a range of results which illustrate the reaction of a combined system under extreme annual rainfall cases. The rainfall data is discussed in more detail in Section 4.

3.1 HAMILTON COLLECTION SYSTEM

The collection system upstream of the Hamilton Woodward WPCP services a developed area of 11,600 ha, of which 5,400 ha is serviced by combined sewers and 6,200 ha is serviced by a separate sewer system (Paul Theil Associates Ltd. et al., 1991), with a tributary population of approximately 380,000.

The collection system includes 100 flow regulators, of which 35 are deemed to have significant overflow. The Hamilton-Wentworth Pollution Control Plan (Paul Theil Associates Ltd. et al., 1991) reports an annual overflow volume of 4.4 million cubic metres for a typical year (1989), with a range from 2.4 million cubic metres in a dry year (1971) to 9.7 million cubic metres in a wet year (1981). These results were based on simulations conducted with the Runoff and Transport blocks of the Stormwater Management Model (SWMM4) with a year defined as the period from May 1 to October 31.

The overflow statistics includes the WPCP bypass, which accounts for slightly less than 11% of annual overflow volume. Simulation results show bypass during the a typical year to be 470,000 m^3 which ranges from 300,000 m^3 during a dry year to 800,000 m^3 during a wet year (Paul Theil Associates Ltd. et al., 1991). Wet weather response at the Woodward WPCP was typically 11 ML/d (hourly rate) per millimetre of rainfall for 12 hours following the rainfall event (Paul Theil Associates Ltd. et al., 1991). This can be roughly translated to a runoff coefficient of 4.7%, which ranges from 1.7% to 10.8%.

The pollutant loading to Hamilton Harbour due to overflow and bypass are shown in Table 3.1. These will be used later to evaluate the results of our collection system modelling.

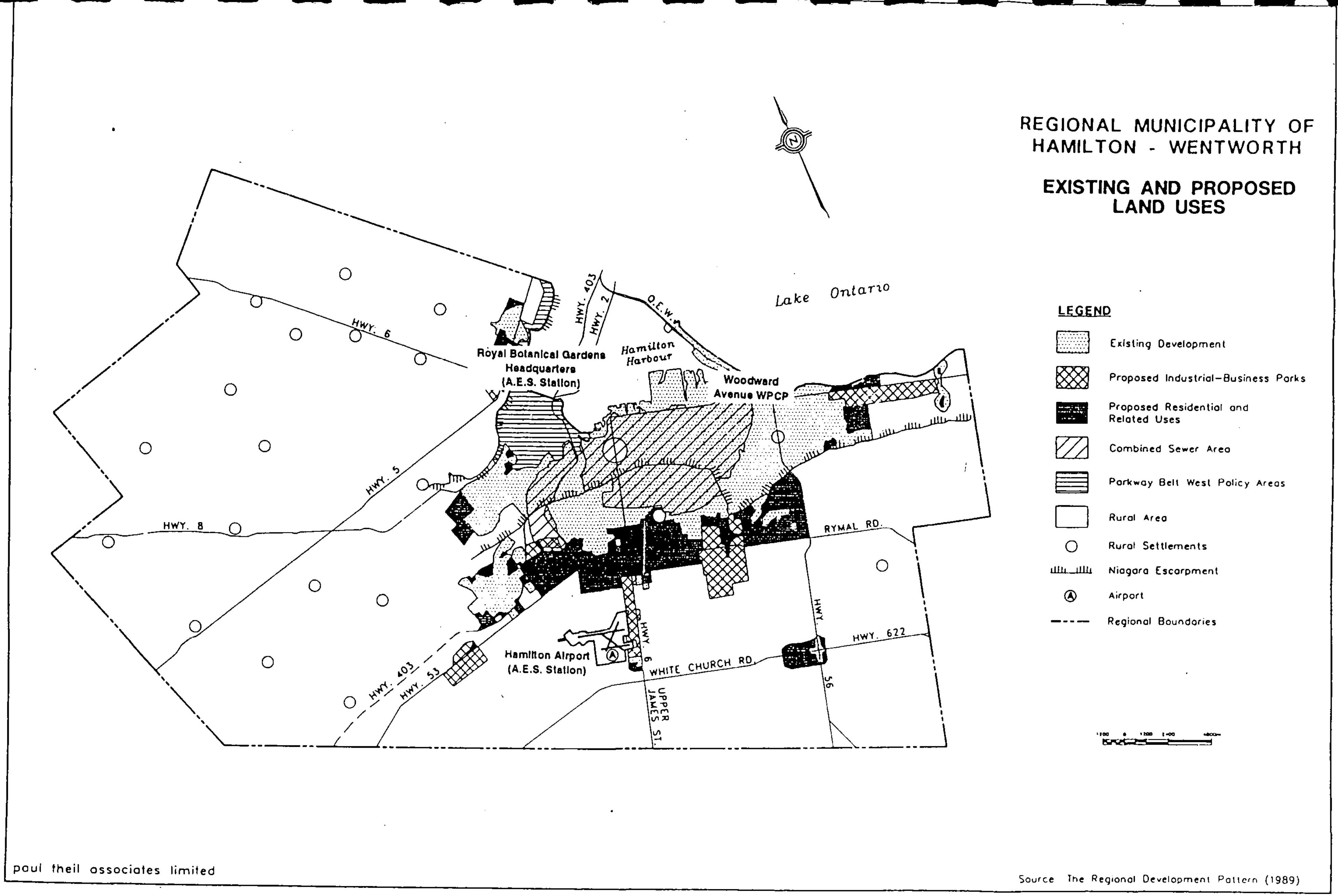

Figure 3.1 - Study area (Paul Theil Associates Ltd. et al., 1991).

Table 3.1 - Annual average pollutant loading to Hamilton Harbour due to Woodward WPCP bypass and Hamilton collection system overflows (kg/d).

Parameter	Dry Year (1971)	Typical Year (1989)	Wet Year (1981)
SS	1,475	2,715	5,985
TP	9.2	17	38
TKN	41	76	168
BOD_5	220	405	893

Source: Paul Theil Associates Ltd. et al., 1991 (note definition of a year is May 1 to October 31)

3.2 HAMILTON WOODWARD WATER POLLUTION CONTROL PLANT

The Hamilton Woodward Water Pollution Control Plant is a major wastewater treatment plant that includes primary, biological, advanced and anaerobic processes. The flow sheet of the plant is shown in Figure 3.2 while plant specifications are summarized in Table 3.2

Table 3.2 - Hamilton Woodward WPCP plant specifications.

Unit	Volume (m^3)	Depth (m)	Surface Area (m^2)
Wet Well	1,220	-	-
Detritors	335	0.75	440
Primary Settlers	25,080	3.3	7,600
Aeration (north)	75,500	4.7	-
Final Settlers (north)	32,100	3	10,700
Aeration (south)	22,000	4.9	-
Final Settlers (south)	18,000	3.7	4,860

The Hamilton WPCP is designed to treat an average combined sewer flow of 410 ML/d . The plant is also able to cope with an approximately 600 ML/d short term peak flow, which occurs quite frequently given that the plant services a combined sewer system. However, above 600 ML/d the plant is hydraulically overloaded and partial bypass of the whole plant is needed, resulting in the discharge of untreated sewage to Hamilton Harbour.

Even below 600 ML/d, increased suspended solids concentration is washed out mostly from the old part of the treatment plant due to the failure of the secondary settlers. In the first 9 months of 1989 the biological stage was bypassed to prevent loss of biomass about 8 % of the time. The primary settlers have to be bypassed even sooner (at lower hydraulic load), so bypassing the secondary treatment with the effluent from a partially bypassed primary treatment is similar to some extent to a complete plant bypass.

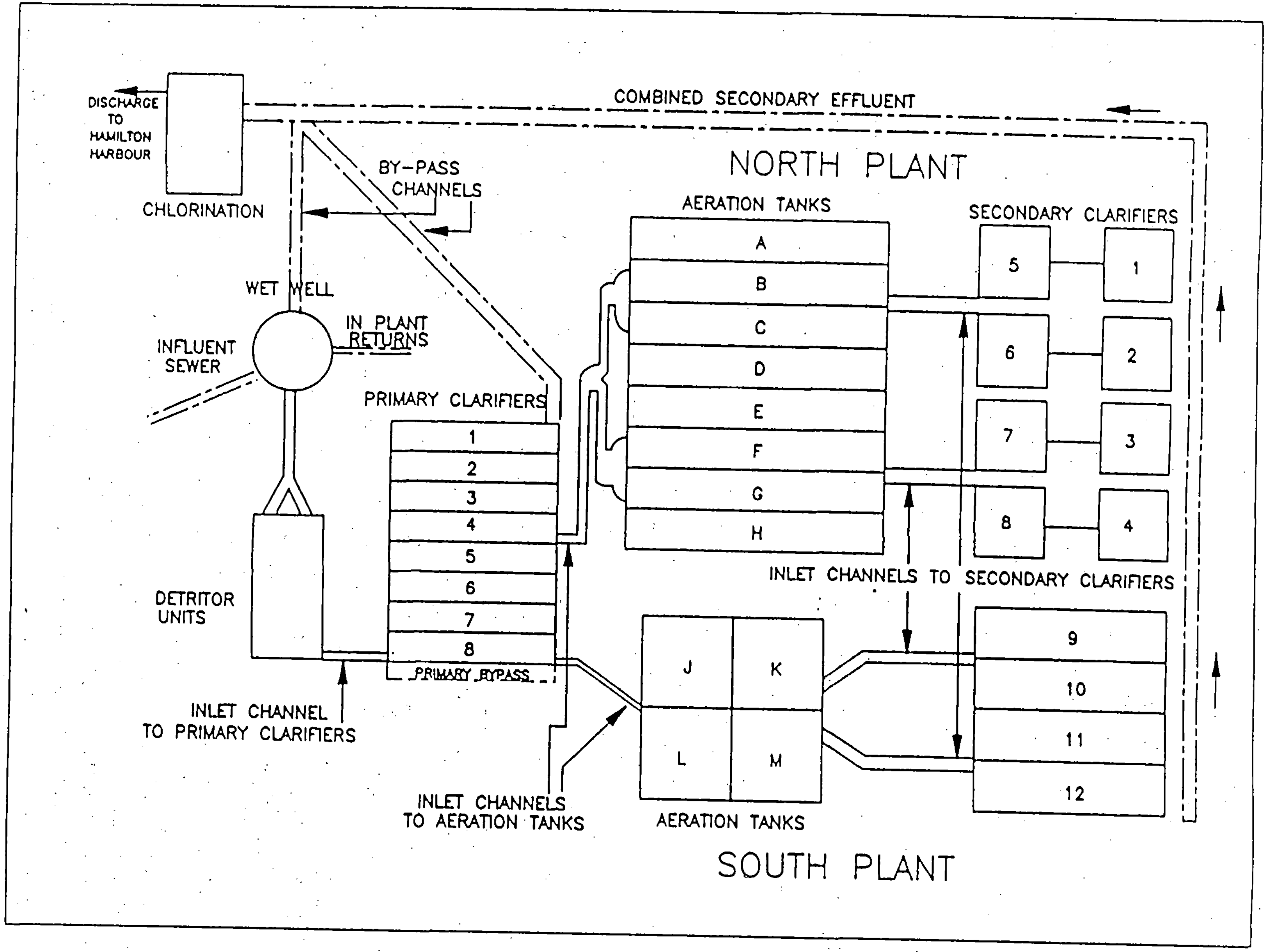

Figure 3.2 - Woodward Avenue Water Pollution Control Plant (Enviromega, 1992).

In 1991, ENVIROMEGA LTD. studied the effects of step feed operation on plant performance during storm flows (Georgousis, Z., et al., 1992). Step feed has since been adopted by plant operators as standard procedure during storm flow.

Plant data used in this study included hourly flows, and daily influent and effluent water quality concentration (BOD_5, TKN, and TSS). There was some data missing in all seven time series. Flow data was collected from operator log sheets, while water quality data is based on time composite samples of plant influent and effluent. One problem with influent water quality data was that the sampling point is downstream of the secondary wastage return, which means that reported influent quality is a function of plant operation.

The average effluent load to the Hamilton Harbour from the Woodward WPCP is shown in Table 3.3.

Table 3.3 - Hamilton Woodward WPCP effluent load to Hamilton Harbour (kg/d).

Parameter	PCP	RAP (1989)	% Total Load to Harbour
SS	6,950	4,800	10.7%
TP	140	130	38%
TKN	3,058	2,900	66%
BOD_5	2,780	-	-

Section 4
METHOD OF ANALYSIS

4.1 Overview of Methodology

An overview of the method of analysis used to assess the effect of hydraulic load reduction on the Hamilton Woodward WPCP is shown in Figure 4.1. The analysis at each site covered two years of data (1990 and 1991). The wettest year in the past decade occurred in 1990, while 1991 was the driest year in the past decade.

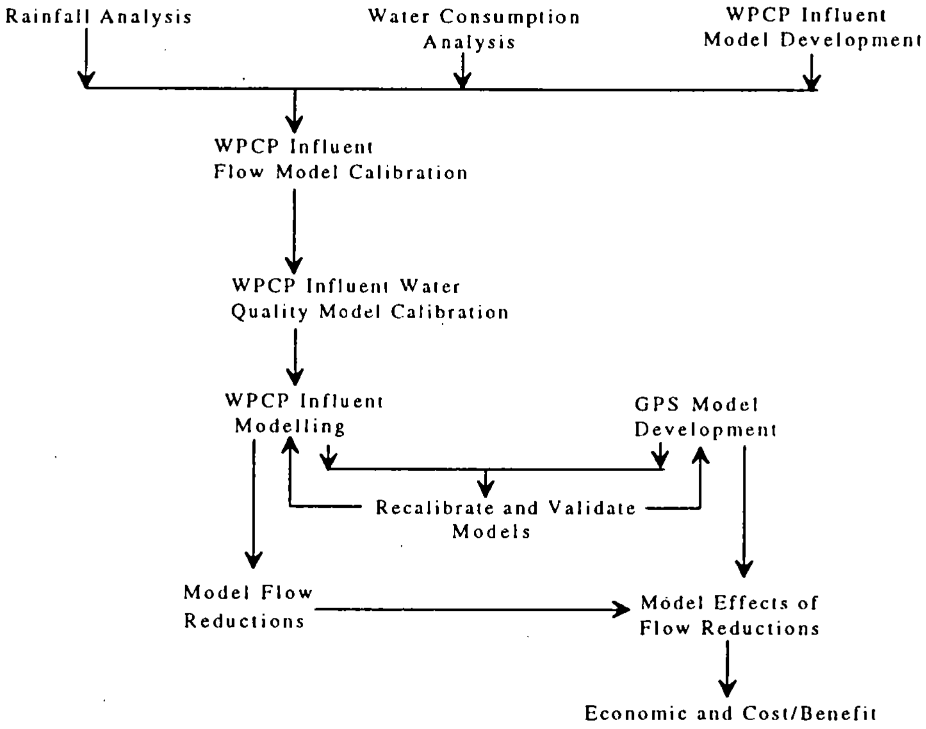

Figure 4.1 - Method of analysis.

4.2 WPCP Influent Analysis and Modelling

Most of the influent flow analysis and modelling (except the water consumption analysis and the rainfall analysis) were done with a customized model called WFAN (Wastewater Flow ANalysis). WFAN was written in MS Visual Basic and runs in a MS Windows 3.1 environment. Details of WFAN are provided in Appendix B.

4.2.1 Water Consumption Analysis

An analysis of the water consumption data for the sewershed is required to estimate the sanitary flow component.

The Hamilton sewershed analysis was based on 1991 water pumping records and an estimate of water use (residential, industrial, commercial) by Region of Hamilton-Wentworth staff. By comparing the volume of water pumped with the volume of water used, an estimate of system leakage was calculated. This leakage rate is then applied to the volume of water pumped from the water treatment plant in the winter months.

$$R_{leak} = (Q_{pumped} - Q_{used}) / Q_{pumped}$$

$$Q_{SF} = \text{Winter } Q_{pumped} \times (1.0 - R_{leak})$$

where: R_{leak} = System leakage rate (annual water lost divided by water pumped)
Q_{pumped} = Average daily pump rate from WTP to distribution system
Q_{used} = Average daily water use.
Q_{SF} = Sanitary flow
Winter Q_{pumped} = Average daily pump rate during winter months

These equations assume :

1. The rate of leakage is a constant fraction of the total volume of water pumped
2. Winter water use includes only internal water use.

4.2.2 Rainfall Analysis

Wet weather flows at treatment plants are the result of a spatially distributed rainfall, while rainfall data is gathered at a point on or near the sewershed. Rainfall data used in this study included:

1. Hamilton Royal Botanical Gardens (hourly data, typically spring to fall);
2. Hamilton Airport (hourly data, all year); and
3. Hamilton Municipal Lab (daily, all year).

The locations of these sites are shown in Figure 3.1 (previous section). The Hamilton Municipal Lab is located at the Woodward WPCP.

Rainfall data analysis included a comparison of annual total rainfall and monthly average rainfall at each site (1981-1991).

4.2.3 WPCP Influent Flow Analysis and Model Calibration

Hamilton Woodward WPCP hourly flow data were available on data sheets filled out by WPCP operators. Therefore, the first step in the analysis was to digitize the raw influent flow data. Data entry forms were constructed with MS-Visual Basic (Microsoft, 1992) to simplify the data entry process. After flow data were input, missing points were interpolated before the data is saved to an ASCII file. After all interpolations are complete, the data is automatically checked to remove days of data were too many interpolations have been made. This is necessary since a day with too many interpolated points may invalidate the flow analysis results.

The next step of the analysis is to disaggregate the total flow entering a plant into its basic components discussed in Section 2.

Dry Weather Flow (DWF)

The first step in disaggregating the flows is to identify dry weather flow days. This is done by calculating average daily flows and converting these values into a frequency histogram. The histogram bound with the most frequent occurrence is considered dry weather flow, since it is likely that the most frequent daily flow value is the dry weather flow value.

Any day which is selected as a dry weather flow day is then used to calculate the typical daily dry weather flow pattern. This is done by using the hourly flow data from each dry weather flow day. This daily dry weather flow pattern is then checked graphically against the actual data, and is manually adjusted if necessary.

Dry weather flow analysis is performed with one month worth of data at a time.

Sanitary Flow (SF)

Sanitary flow was calculated from the water consumption data as explained in Section 4.2.1. Sanitary flow is assumed to be constant throughout the year.

Dry Weather Infiltration (DWI)

The DWI is then calculated by subtracting the average daily SF from the average daily DWF:

$$Q_{DWI} = Q_{DWF} - Q_{SF}$$

Since DWF is calculated on a monthly basis, and SF is assumed constant for the year, monthly DWF variation is therefore reflected as a monthly variation in DWI.

Wet Weather Flow (WWF)

A WWF time series is then calculated by subtracting the daily DWF pattern from the total flow:

$$Q_{WWF} = Q_{total} - Q_{DWF}$$

Stormwater Inflow (SWI) and Rainfall Derived Infiltration (RDI)

The next step is to calibrate the wet weather flow model to the wet weather flow time series. The wet weather flow model consists of a stormwater runoff model and a rainfall derived infiltration model. For both models, the rainfall hyetograph is first transformed using the time of concentration (T_c) of the catchment, for example:

```
If  5 mm of rainfall falls in one hour
And the time of concentration (Tc) is 4 hours
Then rainfall is transformed into 1.25mm/hr lasting 4 hours.
```

Stormwater runoff is calculated by using a volumetric stormwater runoff coefficient (Cv_{dir}) :

```
If transformed rainfall is 1.25 mm/hr
And Cvdir is 20%, or 0.20
Then the runoff is 1.25 * 0.20 or .25mm/hr
```

The latter is then converted to a flow rate by multiplying it by the catchment area.

Rainfall derived infiltration is calculated by using an volumetric infiltration coefficient (Cv_{indir}) similar to the stormwater runoff calculation except that the infiltration flow is then routed through a linear reservoir model.

Model coefficients for SWI and RDI were first determined theoretically from catchment data and then refined using an interactive, trial and error, graphical calibration procedure. Finally, the results are tested by running the WPCP simulation model with both the actual plant data and the modelled data and comparing the simulation results.

4.2.4 WPCP Influent Water Quality Analysis and Model Calibration

Hamilton Woodward WPCP daily quality data were available typed data sheets. Therefore, the first step of the water quality analysis was to enter the daily influent and effluent water quality data into ASCII files. Once again this is facilitated through the use of customized data entry forms created with MS Visual Basic. For this study, three influent water quality parameters were required:

1. Total Suspended Solids (TSS)
2. Total 5 day Biological Oxygen Demand ($TBOD_5$)
3. Total Kjeldahl Nitrogen (TKN as N)

Since water quality plant records are limited to daily averages from composite samples, the flow time series for each flow component was converted to daily flow averages. A multiple linear regression is then conducted to determine the concentrations of each flow component for the water quality parameter of interest. A time plot of the plant data was then overlaid with a time series plot calculated from the regressed concentrations. The computer program allows the user to adjust the concentrations, if desired, until an appropriate fit is obtained.

4.2.5 WPCP Influent Modelling

Once the influent flow and influent quality models were calibrated to the plant records, influent flow time series could be generated for any desired level of flow reduction resulting from various water management programs. A form for generating these time series was created with MS Visual Basic. This form allows the user to enter the reduction of each flow component. When flow reductions are specified, rules are called which make the appropriate changes to water quality concentrations. The default rules are:

1. If sanitary flow is reduced, then proportionately increase the sanitary flow concentrations. This assumes that sanitary pollutant load does not decrease with sanitary flow (i.e., sanitary pollutant load is constant); and
2. If infiltration or inflow is reduced, the concentration does not change and the load is therefore reduced.

These rules can be changed by the user, or, new water quality concentrations can be directly entered by the user.

In addition, if inflow is reduced, the program calculates the pollutant loads that have been diverted from the collection and treatment system and are likely being directly discharged to a receiving water.

These new time series are then used as input to the WPCP simulation. Other features of the influent model include:

1. Option to select default water quality parameters;
2. Summary statistics of WPCP flow time series, model flow times series, and new time series generated for the WPCP simulation; and
3. Plant bypass statistics.

4.3 WPCP PROCESS MODELLING

The Hamilton Woodward WPCP modelling is based on an extensions of the work by Takács et al. (1989).

Dynamic mathematical modelling was chosen to facilitate analysis of existing data through calibration of a detailed mathematical model. The calibrated and verified model was used to provide estimates of operating conditions (i.e., flow reductions) which cannot be easily tried on the real plant.

The model was written in ACSL (Mitchell and Gauthier Associates, 1986) based on a library of dynamic mathematical models developed at McMaster University (Patry and Takács, 1990).

4.3.1 General Purpose Simulator

Simulations were conducted using the General Purpose Simulator (**GPS-X**) developed by Hydromantis, Inc. for the analysis of large-scale wastewater treatment plants. The **GPS-X** provides a graphical programming environment for the specification, analysis, and control of wastewater treatment plant simulations. A comprehensive library of wastewater treatment processes has been developed for use with **GPS-X**. Details of the program are provided in Appendix A.

In order to keep the mathematical model executable within reasonable CPU time some simplifications have to be applied to the complex layout of the real plant. One of the most obvious possibilities to simplify the model is to simulate parallel technological units as one unit, with the combined volume and surface of the individual units. This approach is tenable as far as there is reasonable evidence that the loading of the parallel units does not differ extensively from each other. In this case, this means that probably the primary clarifiers and the parallel aerators, settlers within one process line can be modelled as single units, while the North and South process line have to be dealt with separately, due to the different loading they receive.

Another attempt to simplify the modelled plant layout was to omit all the technological processes not directly associated with the performance of the activated sludge process (anaerobic digestion, incineration, etc.). Some of these processes have an impact on the activated sludge process by contributing to the load of the plant (digester supernatant, sludge filtrate, scrubber water), but the load will be incorporated to the influent of the plant.

The layout of the simplified plant generated by the **GPS-X** is shown in Fig 8.

4.3.2 Activated Sludge Model

A modified version of the IAWPRC task group model was used to describe the carbonaceous degradation and nitrification/denitrification processes occurring in the activated sludge process at the Gold Bar wastewater treatment plant.. The original model developed by the task group makes use of 8 processes and 13 components to describe carbon oxidation, nitrification, and denitrification. The original structure of the model is presented in matrix form in Table 4.1.

The original structure of the IAWPRC model was modified. Nitrate uptake by the heterotrophic biomass is used to replace ammonium as a nitrogen source (Dold, 1990), leading to the introduction of two new processes which are switched off in the presence of ammonium, and become operational only when the ammonium concentration is very low, and there exist an ample source of nitrogen in oxidized form. The new process is essentially a duplication of the IAWPRC aerobic and anoxic growth (processes no. 1 and 2) coupled with a new switching function. This new switching function will activate ammonium uptake (as in the original IAWPRC model) or NO_3^- uptake depending on the form of nitrogen available.

In addition to the usual IAWPRC state variables (e.g., soluble and particulate substrate, soluble and particulate organic nitrogen) a number of conventional water quality parameters were also simulated, including BOD_5, $BOD_{ultimate}$, total Kjeldahl nitrogen (TKN), etc. Stoichiometric relationships were used to relate conventional water quality parameters to those simulated in the IAWPRC activated sludge model. The interested reader is referred to the IAWPRC activated sludge model report for a more detail description of the basic model (Henze *et al.*, 1987).

4.3.3 Solids/Liquid Separation Model

In modelling of large-scale wastewater treatment plants, it is particularly important to implement a realistic description of the solids/liquid separation processes for both the primary and secondary clarification units. While the biological reactor might be considered as the central unit of the treatment plant, because of the role that it plays in transforming organic matter into CO_2, H_2O and biomass, the ultimate success of the process relies on our ability to separate the biomass and other solids from the effluent liquid stream. For the purpose of this investigation, we have made use of a comprehensive layered solids-flux settler model for both the primary and secondary clarifiers.

The layered solids-flux settler model that was used as part of this study makes use of a double exponential settling velocity equation (Takács *et al.*, 1991):

$$v_s = v_0 e^{-r_h X^*} - v_0 e^{-r_p X^*}$$

where:

v_s=settling velocity of the solids particles (m/d)
v_0=maximum settling velocity (m/d)
r_h=settling parameter characteristic of the hindered settling zone (m^3/g)
r_p=settling parameter characteristic of low solids concentration (m^3/g)

and: $X^* = X - X_{min}$,
where:

X=suspended solids concentration
X_{min}=minimum attainable suspended solids concentration

and: $X_{min} = f_{ns} X_{in}$
where:

f_{ns}=non-settleable fraction
X_{in}=mixed liquor suspended solids entering the clarifier.

In addition, the settling velocity model is bounded at V_{bnd}. Details of the model can be found in Takács *et al.* (1991) and Patry and Takács (1992).

The settler model also includes a number of additional parameters used to control the distribution of solids to the various layers of the clarifier based on pre-specified maximum (V_{uma}) and minimum (V_{umi}) upflow velocities. These upflow velocity limits are usually specified by the user based on the performance of the clarifiers. For upflow velocities less than the minimum (V_{umi}), the influent solids enter the designated feed layer. For upflow velocities greater than the maximum limit (V_{uma}), the influent solids are distributed to the bottom layer of the clarifier. For upflow velocities less than V_{uav} (where V_{uav} is the average between V_{uma} and V_{umi}), the influent solids are unevenly distributed in the layers below the feed layer with the maximum solids entering near the feed layer. Finally, for upflow velocities greater than V_{uav}, the influent solids are distributed in the layers below the feed layer, with most of the solids entering the lower layers of the settler.

4.3.4 Computer Program

The mathematical model of the WPCPs were generated by the General Purpose Simulator, based on the flow sheets presented in Figure 3.2 (see Section 3). The core computer program for the Woodward plant is presented in Appendix B.

4.4. ANALYSIS OF FLOW REDUCTION MANAGEMENT

The effects of flow reduction programs were investigated by first testing the effects of various levels of flow reduction on treatment plant performance. The second step was to determine the costs and feasibility of achieving the modelled levels of hydraulic load reduction.

4.4.1 Flow Reduction Cases

The levels of flow reduction used in WPCP simulations are shown in Table 4.2

Table 4.2 - Percent reductions of flow components used in WPCP simulations.

Case	SF	DWI	SWI	RDI	Interval
Baseline Case	0%	0%	0%	0%	single case
Water Conservation	5-30%	0%	0%	0%	5%
Infiltration Control	0%	10-50%	0%	50%	10%
Inflow Control	0%	0%	10-50%	0%	10%
I/I Control	0%	10-50%	10-50%	10-50%	10%
Comprehensive Flow Control	15, 30%	25, 50%	25, 50%	25, 50%	two cases
Storage	30%	0%	0%	0%	30%

Notes for Table 4.2:

1. SF - Sanitary Flow
2. DWI - Dry Weather Infiltration
3. SWI - Stormwater Inflow
4. RDI - Rainfall Derived Infiltration
5. Storage volume to control plant bypass/overflow to one event per year.

Two water quality parameters were examined for each case: 5 day carbonaceous Biological Oxygen Demand (BOD_5) and Total Suspended Solids (TSS). The analysis was conducted for 1990 and 1991 to compare results for a wet year (1990) and a dry year (1991).

Long term dynamic simulation were conducted over a one year period. Each run tracked the treated effluent stream from the plant, partially treated effluent stream (secondary bypass) and plant bypass stream. In addition, the three streams were combined together to allow the statistics of the total discharge to the receiving water (Hamilton Harbour) to be analyzed.

4.4.2 Impacts of Flow Reduction on WPCP Operation and Effluent Load

Using the calibrated version of the **GPS-X** model of the Hamilton Woodward plant, a comprehensive analysis of the long term plant response to the various combinations of flow reduction and management programmes was developed. Plant responses are recorded in two ways:

1. Total annual load (TSS and BOD) entering the receiving water; and
2. WPCP effluent concentration (TSS and BOD).

Total annual load is used to illustrate the effect of flow reduction programs on the total annual pollutant load entering Hamilton Harbour. Total load is defined as the pollutant load entering the receiving water from treated WPCP effluent, partially treated WPCP effluent (from the secondary bypass), and WPCP bypass. *WPCP effluent concentrations plots* are used to illustrate the range of effluent water quality concentrations.

4.4.3 Economic Analysis of Flow Reduction

The economic impacts of a several flow reduction programs was analysed. Cost data gathered from the literature and the Regional Municipality of Hamilton-Wentworth was used to assess the economic implications of flow reduction programs. The cost-benefit analysis was not restricted to dry-weather flow reduction programmes but also includes an economic assessment of flow reduction programmes aimed at reducing and controlling infiltration and inflow components.

Section 5
RESULTS OF WPCP INFLUENT ANALYSIS AND MODELLING

5.1 WATER CONSUMPTION ANALYSIS

Based on water consumption data for the time period under investigation, the sanitary flow to the Hamilton Woodward WPCP was estimated at 200 ML/d. Winter water consumption during early 1991 was 250 ML/d for all of Hamilton (inclusive of Waterdown and Dundas). Subtracting Dundas and Waterdown water use (typically 20 ML/d) and losses from the distribution system (leakage, water not returned) which approximately 30 ML/d annually, yields the following sanitary flow:

$$\begin{aligned} Q_{SF} &= (250 - 20) - 30 \\ &= 200 \text{ ML/d} \end{aligned}$$

5.2 RAINFALL ANALYSIS

Rainfall data used included:

1. Hamilton Airport (12 months per year of hourly data, 12 months per year of daily totals)
2. Royal Botanical Gardens (~7months per year of hourly data, 12 months per year of daily totals)
3. Hamilton Municipal Labs (no hourly data, 12 months per year of daily totals)

An analysis of the rainfall data showed:

1. Hamilton airport recorded rainfall depth was consistently the highest (recorded 6.4% more rainfall than RBG from 1981 to 1992, 8% more than Municipal labs in 1990).
2. Average annual rainfall depth at Hamilton Airport from 1981 to 1991 was 967 mm/year.
3. 1990 was the second wettest year with 1090 mm/year (1983 was 1091 mm/year, but practical considerations in modelling the Woodward WPCP dictate the use of 1990 as "the wet year").
4. 1991 was the driest year with 744 mm/year.

The Hamilton Airport data was used since it alone provided 12 months of rainfall data, and also based on the quote from the Hamilton PCP Report where Hamilton Airport data "has been found by other researchers to be more representative of rainfall patterns in the Hamilton area than the Royal Botanical Gardens rainfall gauge (Robinson, 1989)" (from Paul Theil Associates et al., 1991)

At the time of this report, the Hamilton Airport hourly rainfall data for October to December of 1991 was not available. To provide an suitable analysis for 1991 (dry year), this data was recreated using the daily rainfall data and other information available in the appropriate monthly meteorological summaries for Hamilton Airport, as well as known flow data at the plant. This was deemed acceptable since:

1. The 1991 analysis was a secondary analysis done to provide a gross comparison to the 1990 based (wet year) analysis.
2. Total rainfall volumes in the months October to December of 1991 were relatively low.

5.3 HISTORICAL WPCP INFLUENT FLOW ANALYSIS

Using the estimated sanitary flow (SF) of 200 ML/d and a time of concentration of 4 hours [1], the flow analysis provided the results listed in Table 5.1 for 1990 and in Table 5.2 for 1991. The tables show the estimated DWF for each month and the calculated DWI which is calculated by subtracting SF from DWF. The Cv's are based on an estimate by the program WFAN, and are then tuned using the interactive WWF modelling interface. The total Cv's are very high in winter months due to snowmelt. Only rainfall was used in the Cv calculation, therefore the large magnitude of precipitation represented as snowfall was not included. Using only rainfall works well in recreating the flows since rainfall days are often the high snowmelt days. These days are also most likely the winter days with measurable inflow.

Table 5.1 - 1990 influent flow analysis summary.

Month	DWF (ML/d)	DWI (=DWF-SF) (ML/d)	Total Cv (%)	Direct Cv (%)	Mean Model Flow (ML/d)	Actual Mean Flow (ML/d)
January	334.7	134.7	40	12	376.7	395.6
February	339.5	139.5	10	3	358.8	386.4
March	337.8	137.8	40	10	372	359.2
April	312.8	112.8	25	18	353.8	353.7
May	343.3	143.3	8	3	379.8	376.1
June	307.8	107.1	15	3	336	328.8
July	295.8	92.9	8	3	314.4	311.6
August	279.8	79.8	5	0	308.7	302.2
September	277.2	77.2	15	3	304.1	300.2
October	269.3	69.3	15	3	314.7	315.2
November	262.9	62.9	10	3	285.9	283.8
December	282.8	82.8	8	1	311.2	302.2
Average	303.64	103.34	N.A.	N.A.	334.68	334.58

Figure 5.1 is a probability plot of the modelled and recorded hourly flow data, while Figure 5.2 is a probability plot of modelled and recorded daily flow data entering the Hamilton Woodward WPCP.

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[1] Using a catchment length of approximately 17 km,:
If a sewage flow velocity of 1m/s is assumed, then Tc = 4.7 hr
If a sewage flow velocity of 2m/s is assumed, then Tc = 2.4 hrs

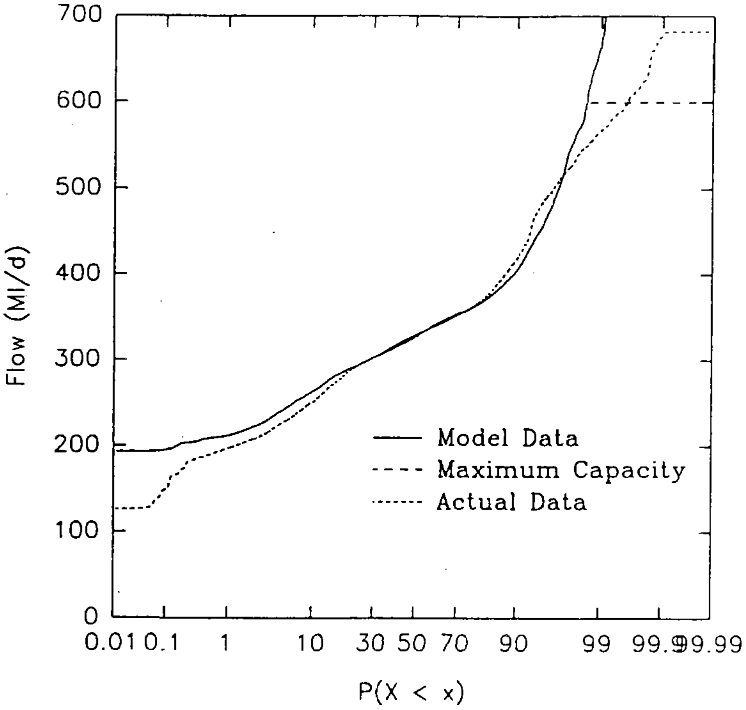

Figure 5.1 - Probability plot of modelled hourly flow versus actual hourly flow data from Hamilton Woodward WPCP.

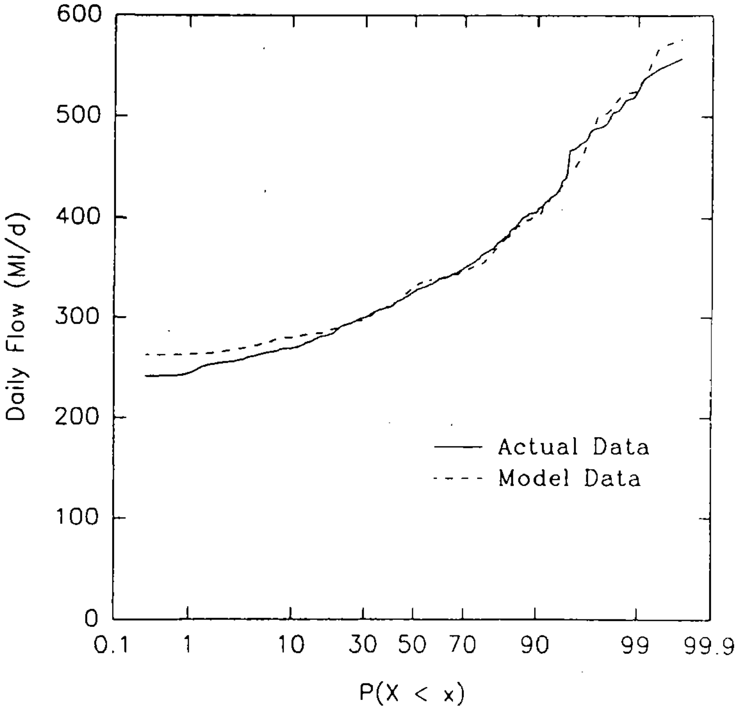

Figure 5.2 - Probability plot of modelled daily flow versus actual daily flow data from Hamilton Woodward WPCP.

Table 5.2 - 1991 influent flow analysis summary.

Month	DWF (ML/d)	DWI (=DWF-SF) (ML/d)	Total Cv (%)	Direct Cv (%)	Mean Model Flow (ML/d)	Actual Mean Flow (ML/d)
January	318	118	45	8	329.9	334
February	292.1	92.1	15	5	293.5	312.9
March	312.5	112.5	15	5	352.7	365.7
April	317.3	117.3	20	1	386.1	374.9
May	309.6	109.6	16	4	345.7	346.2
June	292.7	92.4	12	6	300.7	303.9
July	314.2	114.2	8	4	345.8	342.2
August	268.5	68.5	20	5	296.1	300.7
September	278.7	78.7	7	2	285.1	278
October	270.5	70.5	7	3	289.6	288.8
November	270.2	70.2	10	3	288.7	284.8
December	279	79	40	5	316.3	315.3
Average	293.61	93.58	N.A.	N.A.	319.18	320.62

5.4 HISTORICAL WPCP INFLUENT WATER QUALITY ANALYSIS

Results of the water quality analysis are shown in Table 5.3. These were derived from 1990 data and applied to the 1990 and 1991 WPCP analysis.

Table 5.3 - 1990 water quality summary.

Flow Component	TSS (mg/L)	TKN (mg/L)	BOD (mg/L)
Sanitary Flow	275	39	151
Dry Weather Infiltration	137	7.7	50
Rainfall Derived Infiltration	146	4	5
Stormwater Inflow	128	4	91

These compare favourably with the concentrations used in the Hamilton Pollution Control Plan Report (Paul Theil Associates et al., 1991) which are listed, in part, in Table 5.4.

Table 5.4 - Hamilton PCP concentration data.

Flow Component	TSS (mg/L)	TKN (mg/L)	BOD (mg/L)	Comments
Dry Weather Flow	302	27.4	129	Includes sanitary flow and dry weather infiltration
Wet Weather Flow	100-150	1.35-2.84	2.0-9.0	Includes stormwater inflow and wet weather infiltration

Using the concentrations listed in Table 5.3 provides a good match between the annual mean influent loads (modelled versus actual). The short term trends were not well matched since the linear model used does not capture the daily influent load variations. However, as discussed earlier, WPCPs are generally hydraulically driven, and the day to day variations of influent water quality should not have a significant effect on the results and conclusions of this study.

One further complication was encountered when calibrating the influent water quality model to the plant records because of physical constraints. The influent sampling point at the Hamilton Woodward WPCP is downstream of the sludge recycle return. This meant that the calibration exercise was an iterative process where:

1. Raw influent concentrations are calculated using the multiple linear regression model.
2. The WPCP model is run to generate recycle stream concentrations.
3. Simulated sample point concentrations are generated and compared to actual sampled data and flow component concentrations are revised based on this comparison.

Steps 2 and 3 are repeated until a suitable match is found between simulated and observed concentrations at the specific sampling location.

5.5 WPCP Influent Quantity and Quality Time Series Generation

Influent flow and water quality time series were generated for the various flow cases described in Section 4. Results of the analysis are provided in Section 7.

Section 6
WPCP MODEL CALIBRATION

(Note: Figures 6.1 to 6.9 have been appended to the end of this section)

The Hamilton Woodward WPCP model used in this study is an extension of the model developed by Takács et al. (1989) as part of the Hamilton-Wentworth Pollution Control Plan.

6.1 SUMMARY OF WOODWARD WPCP CALIBRATION FROM A PREVIOUS STUDY

The original calibration described in Takács et al. (1989) involved a steady-state calibration and verification followed by an event based dynamic calibration and verification.

The steady-state calibration was based on the average of 9 months of plant data. Parameters were identified which provided a good fit between model output and plant effluent data. Verification involved using the model parameters identified in the 9 month calibration and running steady state simulation for each of the nine months individually. The results of this exercise were described as "very good" (Takács et al., 1989). Primary effluent BOD and final effluent BOD are shown in Figures 6-1 and 6-2, respectively.

The dynamic calibration was based on data sampled during 5 storm events. Samples were collected at the influent, primary effluent, and final effluent. In addition, necessary operating data was collected. The event with the highest peak flow (remnant of Hurricane Hugo) was used for the dynamic calibration. The calibration was performed using the non-linear optimization capabilities of a package called SIMUSOLV (Steiner et al., 1987). Dynamic calibration results for effluent suspended solids and effluent BOD are shown in Figure 6-3.

Verification of the dynamic model was conducted by using the parameters found in the dynamic calibration and applying them to 3 of the sampled storm events. Results of this verification are shown in Figures 6-4 to 6-6.

6.2 CHANGES TO WPCP MODEL

For the purpose of this project, several changes and enhancements were made to the previously developed plant model. These include:

1. Conversion of the ACSL code from ACSL Version 9 to ACSL Version 10.
2. Minor changes to plant layout to include influent equalization storage, and improved bypass modelling.
3. Application of simple rules to mimic plant operations during a storm event.
4. Updated calibration as described in Section 6.3

6.3 UPDATED CALIBRATION

The calibration described by Takács et al. (1989) was event -based. For this study, it was important to adjust the calibration for a long term (1 year) dynamic calibration. Although events of several days duration have been regularly calibrated with the GPS, with good results, a long term calibration is much more difficult since there are seasonal and other changes that may not accounted for in the model. These changes can include:

1. Temperature of influent and process waters (IAWPRC, 1986);
2. Alkalinity and pH of influent and process waters (IAWPRC, 1986);
3. Wind effects on settler performance;
4. Two and three dimensional settling effects
5. Long term changes in nature of organic matter which will affect sludge settling (IAWPRC, 1986); and
6. Changes in operational condition.

For the purpose of this study, the goal of the calibration however is not necessarily to match daily variations in effluent quality exactly, but to simulate:

1. Long term trends;
2. Approximate frequency distribution; and
3. The relative effect of flow on final effluent.

To help match long term trends, the following changes to the model were made:

1. Functions were used that set settling parameters based on Sludge Volume Index (SVI). Daily SVI data from the plant were entered into a database used by the model.
2. Sludge Retention Time (SRT) set points were based on actual daily SRT values measured at the plant. The plant is SRT controlled, however, there were variations in plant SRT from day to day.

Parameters changed during the calibration phase included:

1. Final clarifier feed height
2. Feed layer distribution variables
3. Maximum secondary throughflow when sludge blanket is too high
4. COD/VSS ratio
5. Autotroph maximum specific growth rate
6. SRT control variables
7. SRT set points (used daily plant SRTs)
8. SVI based settling parameters (maximum settling velocity, rhin, rfloc)

Figures 6.7 and 6.8 shows the probability plots of BOD and TSS daily average concentration calibration curves. For these curves, when actual data is missing, the simulated data point is also removed before the probability plot is constructed. In the analyses presented in Section 7, all simulated data is used to create the probability plots.

The TSS probability plots shows a good match in the frequency distribution between simulated data and actual data. The BOD simulated curve shows far less variability then than the actual data. Sampling by WTC in 1989 also produced lower BOD values than normally reported at the plant (Mathews and Melcer, 1991).

Several reasons can serve to explain this discrepancy (Mathews and Melcer, 1991):
1. Sampling location;
2. Use of non-refrigerated samples plant personnel; and
3. Long period of time until the analysis was performed on the sample.

This is supported by Figure 6.9 which shows actual TSS data versus actual BOD data. The minimum value for BOD should be approximately 42% of the TSS value. In Figure 6.9, many measured BOD values are far below this minimum.

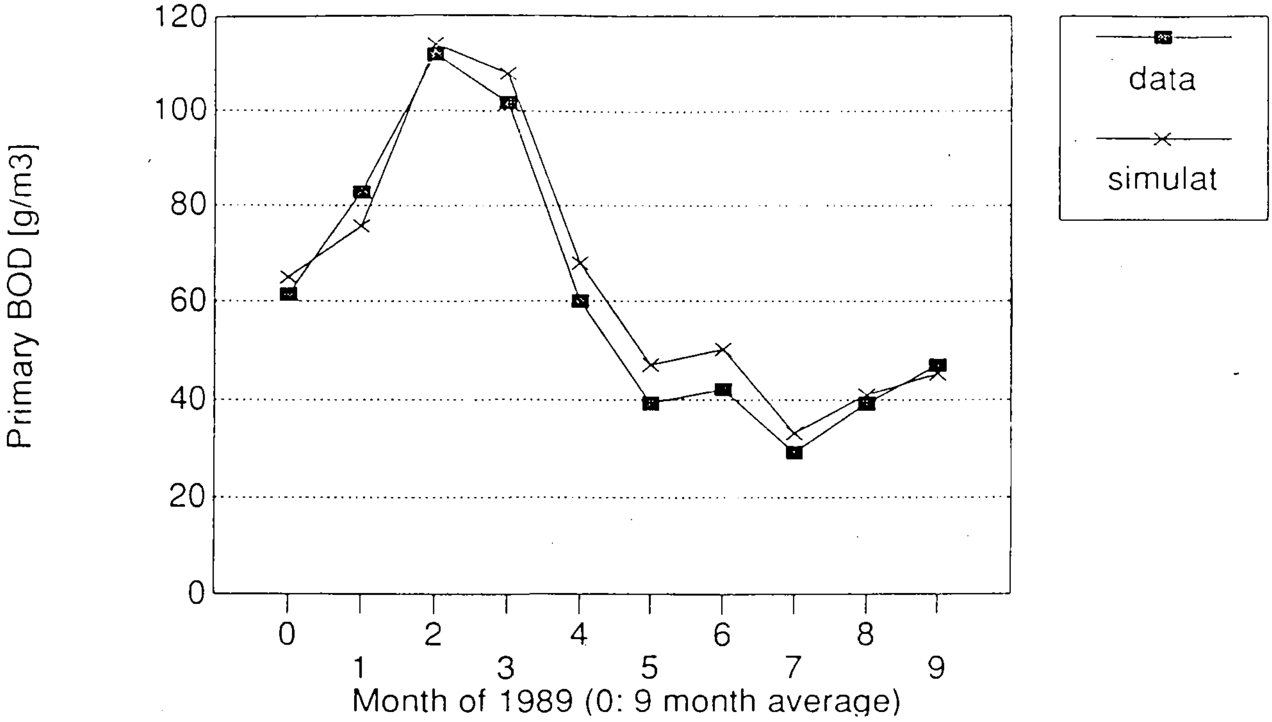

Figure 6.1 - Hamilton WPCP steady state calibration - primary BOD effluent concentration (Takács et al., 1989).

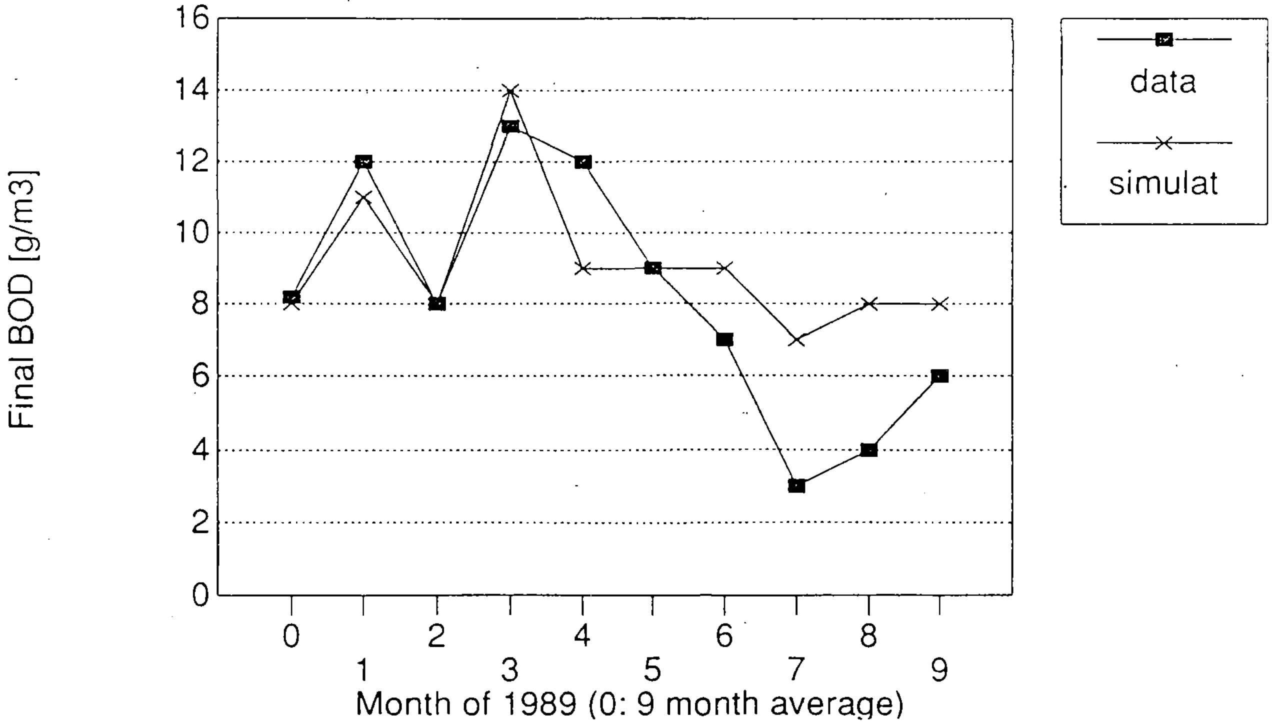

Figure 6.2 - Hamilton WPCP steady state calibration - final BOD effluent concentration (Takács et al., 1989).

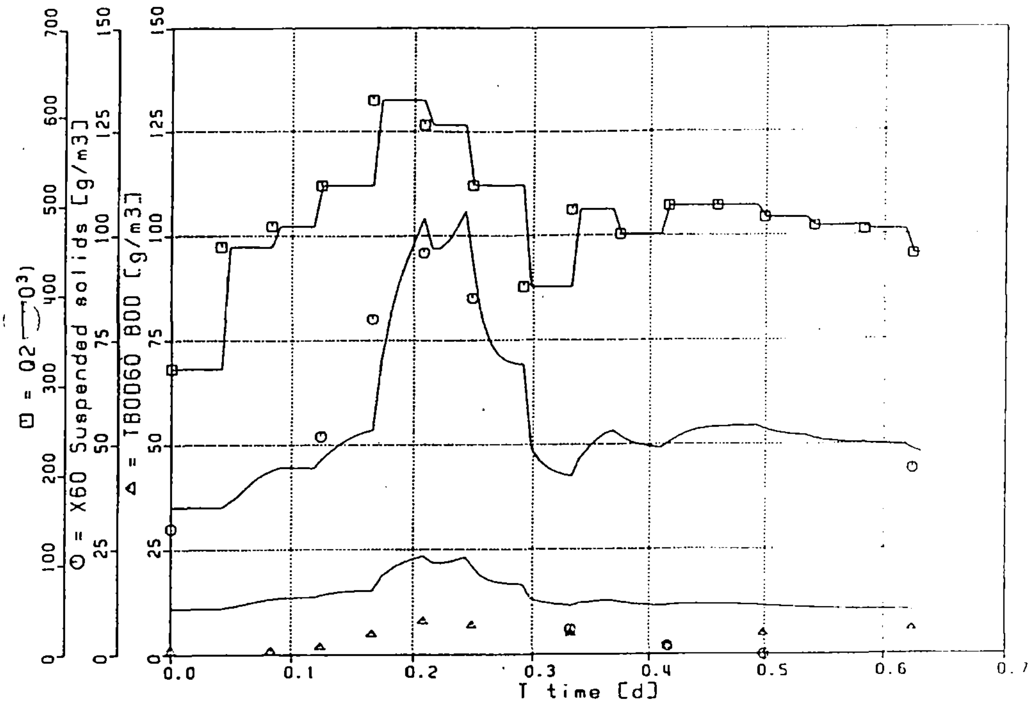

Figure 6.3 - Hamilton WPCP dynamic calibration - Hugo final effluent concentrations (Takács et al., 1989).

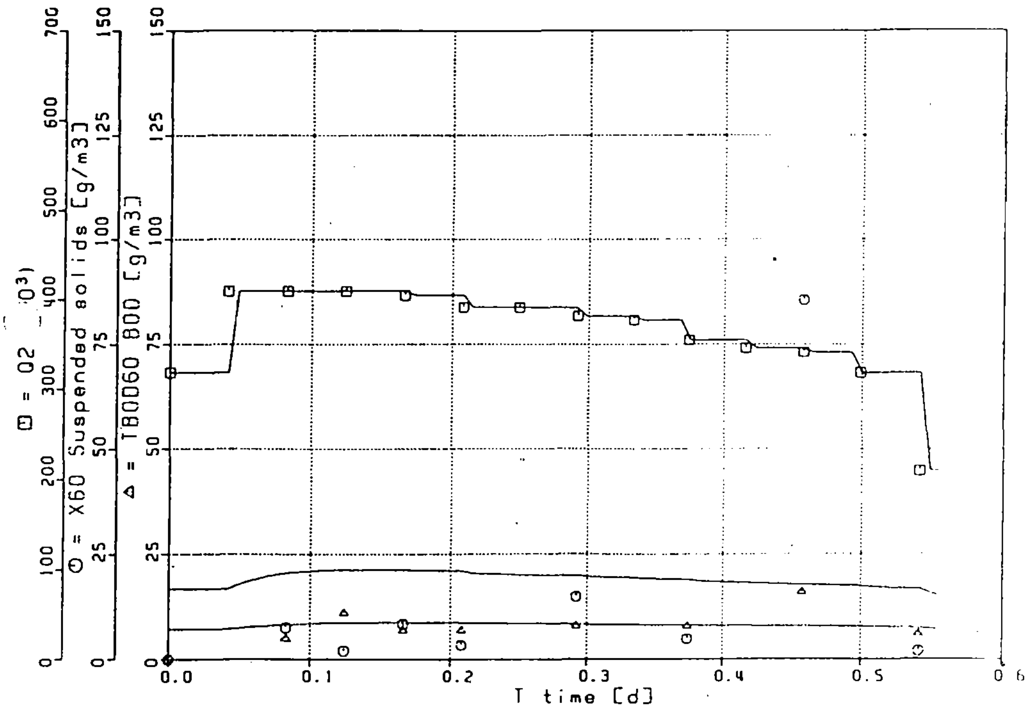

Figure 6.4 - Hamilton WPCP dynamic calibration - Storm 1 final effluent concentrations (Takács et al., 1989).

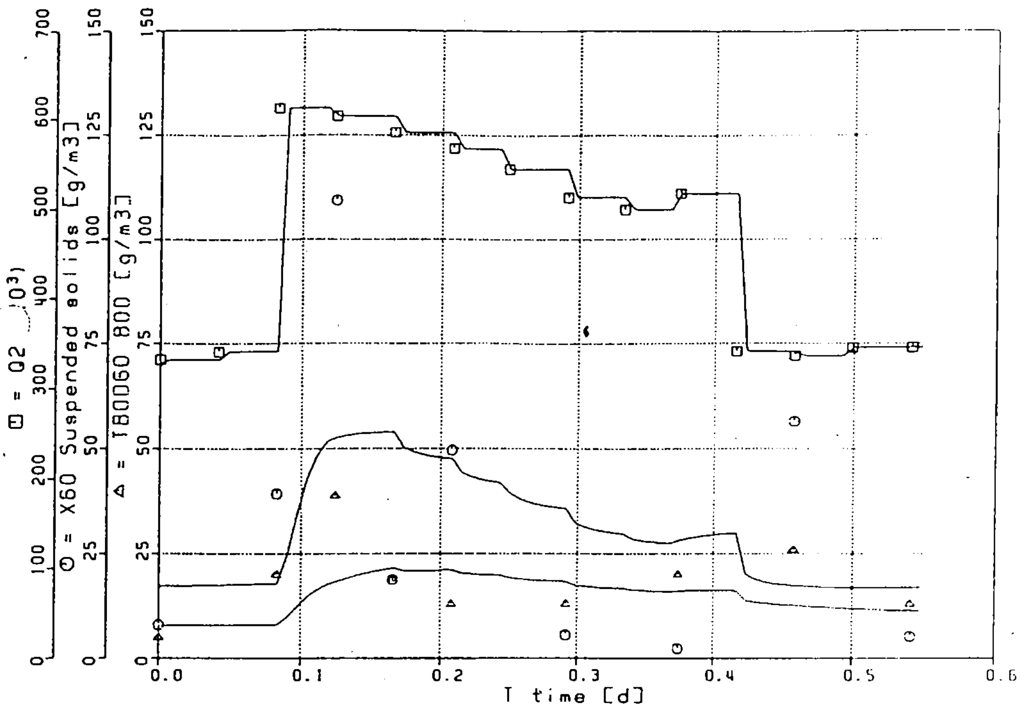

Figure 6.5 - Hamilton WPCP dynamic calibration - Storm 2 final effluent concentrations (Takács et al., 1989).

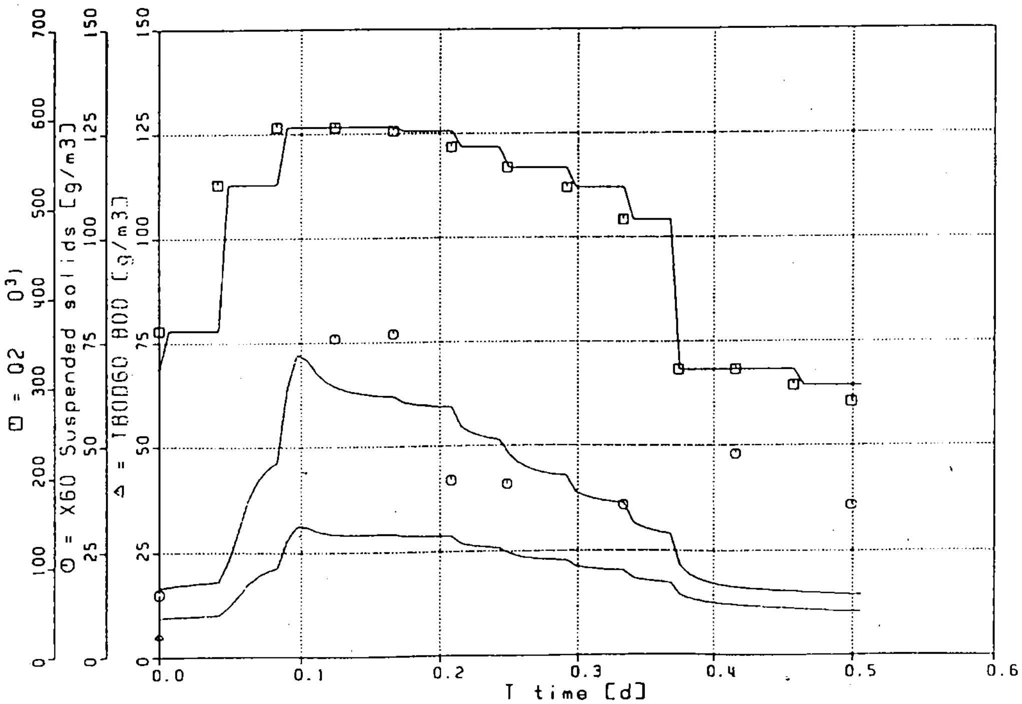

Figure 6.6 - Hamilton WPCP dynamic calibration - Storm 3 final effluent concentrations (Takács et al., 1989).

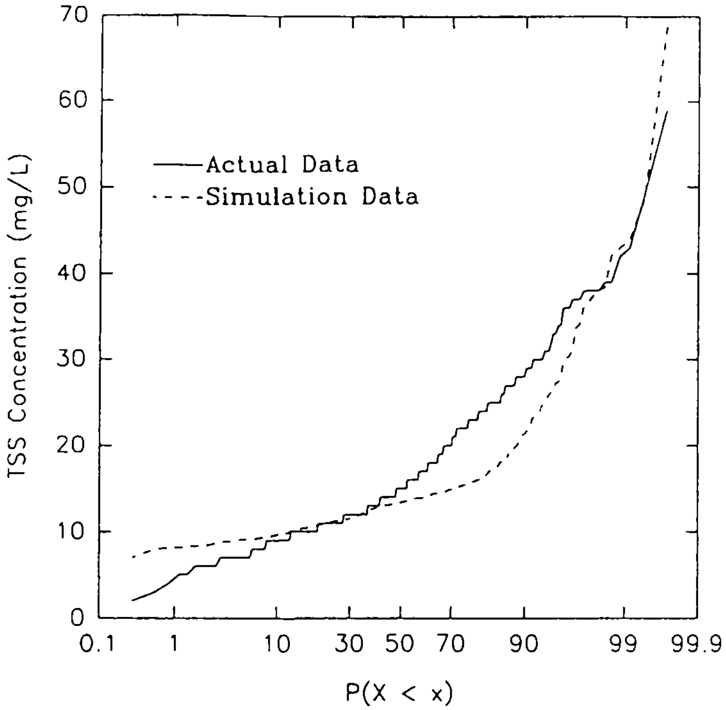

Figure 6.7 - WPCP daily TSS effluent concentrations calibration results.

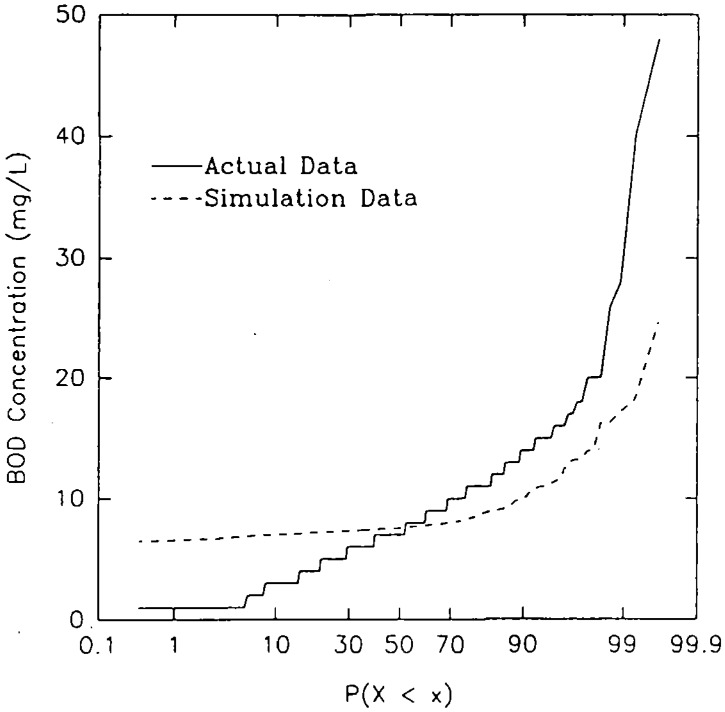

Figure 6.8 - WPCP daily BOD effluent concentrations calibration results.

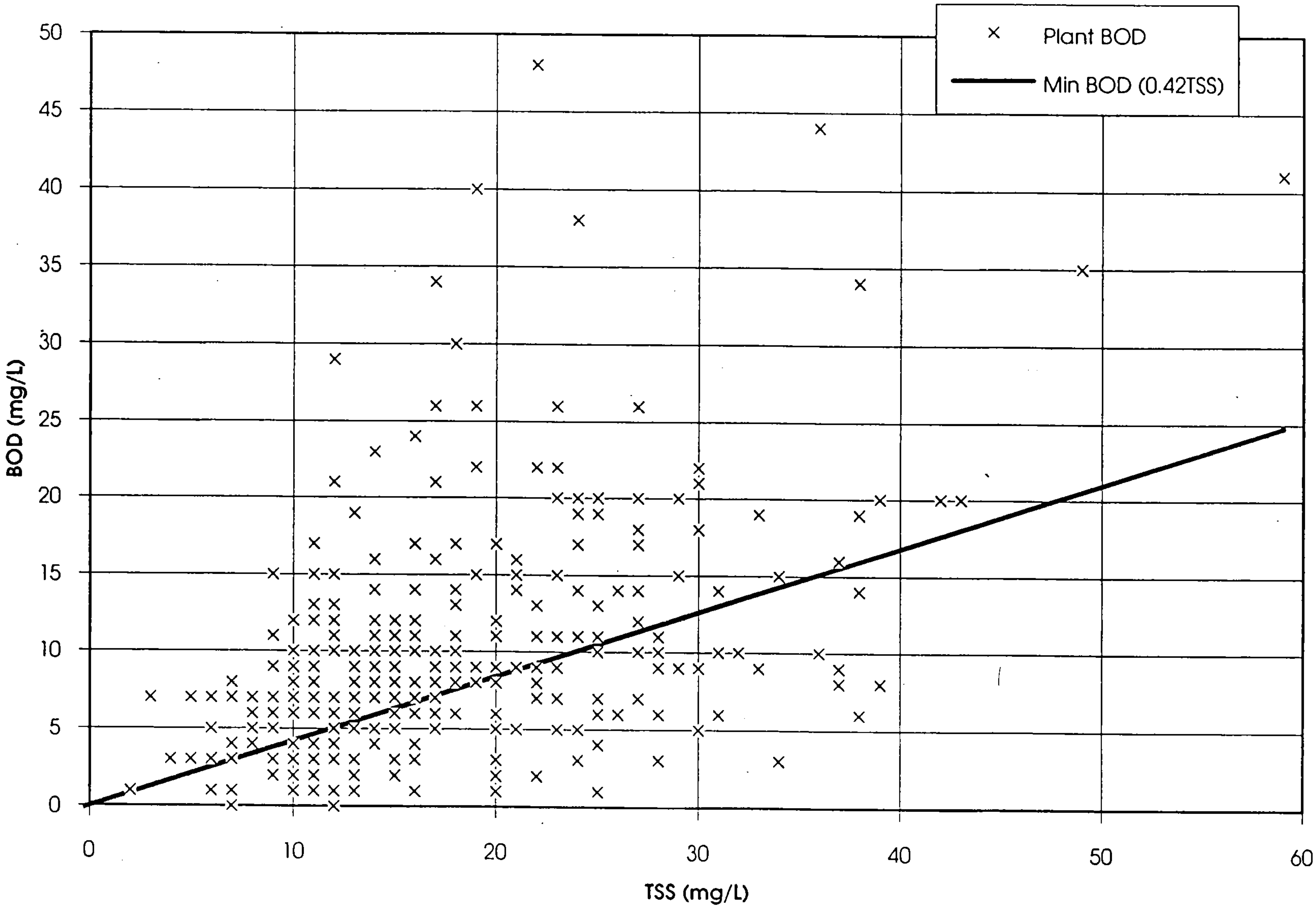

Figure 6.9 - Plant measured BOD verus TSS.

Section 7
EFFECTS OF FLOW REDUCTION ON WASTEWATER TREATMENT AND RECEIVING WATER LOADING

(Note: Figures 7.3 to 7.32 have been appended to the end of this section)

This section focuses on the effects of hydraulic load reduction on WPCP performance. Four major aspects are investigated:

1. Plant design life and effects on CSO storage requirements;
2. Hydraulic load to receiving water and plant bypass volumes;
3. WPCP effluent concentration; and
4. Total pollutant load (TSS and BOD) to receiving water.

The effects of flow reduction on expected plant life and CSO storage requirements, which is presented in Section 7.1 was determined independently of the modelled WPCP performance. The purpose of these estimates are to illustrate the effects of a water conservation program on proposed and future WPCP upgrades.

Section 7.2 describes the effects of hydraulic load reduction on hydraulic loads to the receiving water. This investigation did use the treatment plant model since secondary bypass is a function of performance. Heuristic rules, modelled on those employed by the plant operators, were used to turn secondary bypass on and off. Data presented in this section is based on 1990 rainfall data (wet year) but includes a comparison of hydraulic loads for specific cases between the years 1990 and 1991 (dry year).

Pollutant concentrations in the WPCP effluent are reported in Section 7.3. The concentrations presented do not include plant bypass data but only reflect treated effluent. The numbers presented are similar to those that would be monitored at a typical wastewater treatment facility. Once again the focus is on 1990 results but a comparison of 1990 and 1991 results are presented.

Finally, pollutant loads entering the receiving water from treated plant effluent, partially treated plant effluent, and plant bypass are presented in Section 7.4.

For the remainder of this report the several terms that refer to flow streams will be used frequently. To clarify the description of simulation results, the following definitions are provided:

Throughflow - flow that receives full treatment at the Woodward WPCP;
Secondary Bypass - flow that enters the Woodward WPCP and receives partial treatment, but is bypassed around the secondary treatment processes;
Plant Bypass - flow that receives no treatment at the Woodward WPCP. Note that this does not account for overflows upstream of the WPCP;
Total Outfall - the summation of throughflow, secondary bypass, and plant bypass;
Diverted - stormwater inflow that has been diverted away from the Woodward WPCP and directed into a receiving water due to sewer separation.
TOTAL - the summation of total outfall and diverted.

7.1 EFFECTS OF FLOW REDUCTION ON EXPECTED PLANT LIFE

Paul Theil and Associates et al. (1991) provide a prediction of future wastewater flows due to population growth in the Hamilton Woodward WPCP sewershed. The population in 2025 is estimated to be 500,000 people which leads to the flow forecasts provided in Table 7-1. In Table 7.1, average flow is defined as annual average daily flow. The estimate of average flow in 2025 does not include the effects of CSO and plant bypass control.

Table 7.1 - Forecasted flow at Woodward WPCP.

Year	Average Annual Flow (MLD)	Dry Weather Flow (MLD)	Notes
1989	315	-	From plant records as reported in Paul Theil Associates Ltd., et al. (1991)
1990	335	304	From plant records.
1991	320	294	From plant records.
2006	383	-	Forecast in Paul Theil Associates Ltd., et al. (1991)
2025	430	420	Forecast in Paul Theil Associates Ltd., et al. (1991)

The increase inflow described in Table 7.1 is illustrated in Figure 7.1 along with plots of the effects of a 10%, a 20%, and a 30% sanitary flow reduction program. The 30% sanitary flow reduction represents the effects of a comprehensive water conservation program. The water conservation reductions were applied to existing flows and future flow predictions since it was assumed that the future water use and DWF predictions were made with existing water consumption data.

From Figure 7.1, a water conservation program that creates a 30% reduction in sanitary flow will lower the average annual flow such that current average flows (~320 ML/d) will not be reached for 20 years. This gap increases in time, assuming the given flow projections, since the flow lines are not parallel. The lines are not parallel since the *rate of flow increase* is lower when a conservation program is in effect.

Upgrades currently under review for the Hamilton Woodward WPCP, are recommended in the Pollution Control Plan to "...handle dry weather flows from a population of 500,000 people..." (Paul Theil Associates Ltd. et al., 1991), which is forecasted to occur in the year 2025. It was assumed in this study that a future upgrade of the Hamilton Woodward WPCP will be required in the year 2025. This is a preliminary estimate only of plant upgrades only, as a better understanding of upgrades to the Hamilton Woodward WPCP will be available after the current Facility Plan study (CH2M HILL ENGINEERING LTD., 1991) is completed.

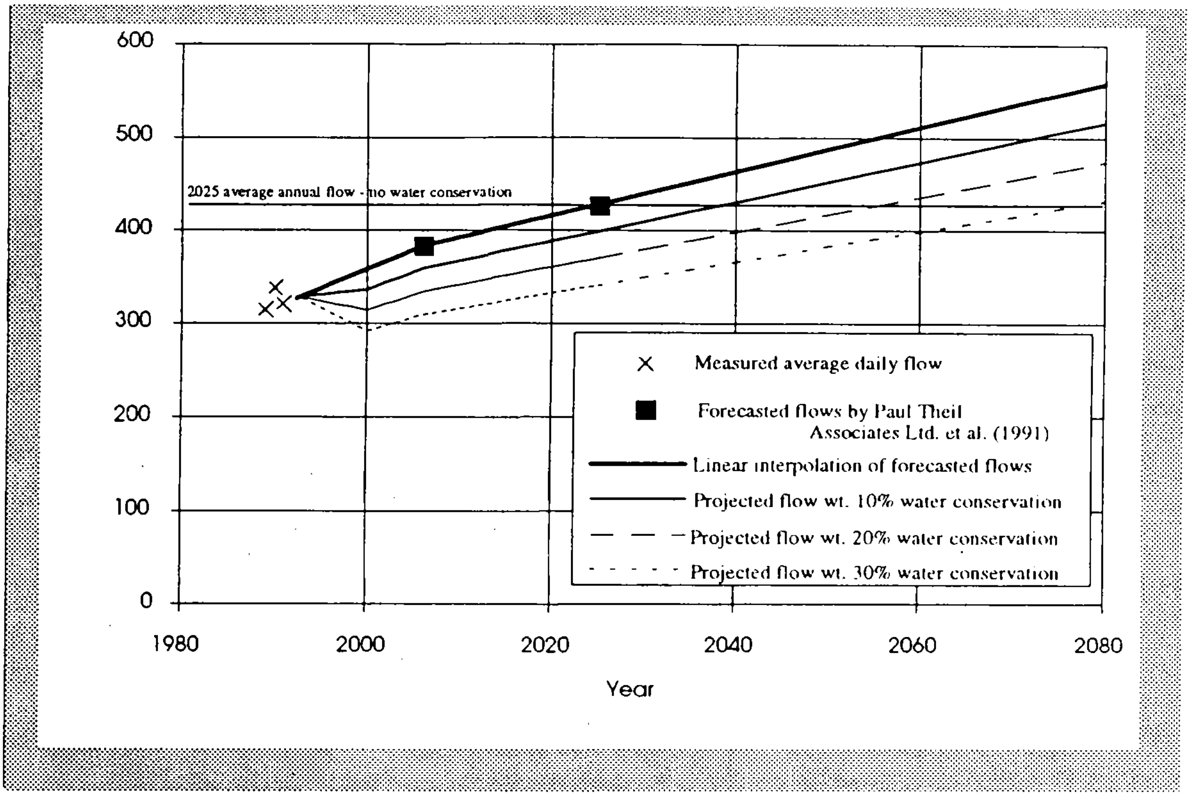

Figure 7.1 - Effect of hydraulic load reduction on forecasted annual average flows.

There are two ways to look at the effects of hydraulic load reduction on capital upgrade requirements:

1. Extend the design life of currently planned upgrades by increasing the time until the plant exceeds new design flows.
2. Reduce current investment by reducing the current level of expansion required to meet a specific design life.

If a water conservation program is implemented, the dry weather flow predicted for 2025 will be delayed, which will allow a delay in capital expenditure to upgrade the treatment plant. These delay times are shown in Table 7.2.

Table 7.2 - Delay of capital upgrade due to water conservation.

Water Conservation Program	Year of Capital Upgrade	Number of Years
No water conservation	2025	0
10% sanitary flow reduction	2040	14
20% sanitary flow reduction	2055	30
30% sanitary flow reduction	2080	55

The estimates in Table 7.2 are based on the forecasted flows in the Hamilton PCP (Paul Theil Associates Ltd. et al., 1991). Caution must be exercised in interpreting the results in Table 7.2 however, since the following assumptions were made:

1. Flow increases between 1991 and 2006 and between 2006 and 2025 were linearly interpolated.
2. Flow estimates after 2025 assumes the growth between 2006 and 2025 can be linearly projected past the year 2080. This does not account for any factors which may limit urban growth in the Hamilton Woodward WPCP tributary area.
3. The expected wet weather flow does not appreciably change from the year 2025 to 2080 and dry weather infiltration rates do not increase.
4. All forecasted flow increases are due to increases in sanitary flow and inflow and infiltration will remain constant at current levels.

Instead of extending the expected design life of the upgraded WPCP, hydraulic load reductions can be used to reduce capital investment in the proposed upgrades by reducing the required flow capacity. Essentially, water conservation can be used to offset expected flow increases due to population growth and development. Paul Theil Associates Ltd. et al. (1991) give an average flow of 315 ML/d for 1989, which is expected increase to 430 ML/d in the year 2025, which is a 115 ML/d increase. Assuming the base flow projected in Paul Theil Associates Ltd. et al. (1991) and a design period until 2025, the average flow in the year 2025 can be significantly reduced as shown in Table 7.3.

Table 7.3 - Design flow reduction due to water conservation for plant design life to the year 2025.

Case	Annual Average Flow (ML/d)	Design Flow Reduction (ML/d)
0% Sanitary flow reduction	430	0
10% Sanitary flow reduction	399	31
20% Sanitary flow reduction	370	60
30% Sanitary flow reduction	341	89

By reducing the flow expected in the "design year", currently proposed capital upgrades can be designed for lower flows which will provide capital cost savings.

The purpose of these estimates are simply to illustrate the effects of water conservation on future flows to the Hamilton Woodward WPCP. It does not account for the many other factors that will affect population growth in the future.

One further aspect of hydraulic load reduction is the effect of hydraulic load reductions on storage volumes required to control combined sewer overflows. The model used in this project did not model collection system CSOs but did provide a reasonable estimate of WPCP bypass. Therefore the effects of hydraulic load reduction on overflow volume at various levels of storage was tested for controlling plant bypass. These results are shown in Figure 7.2.

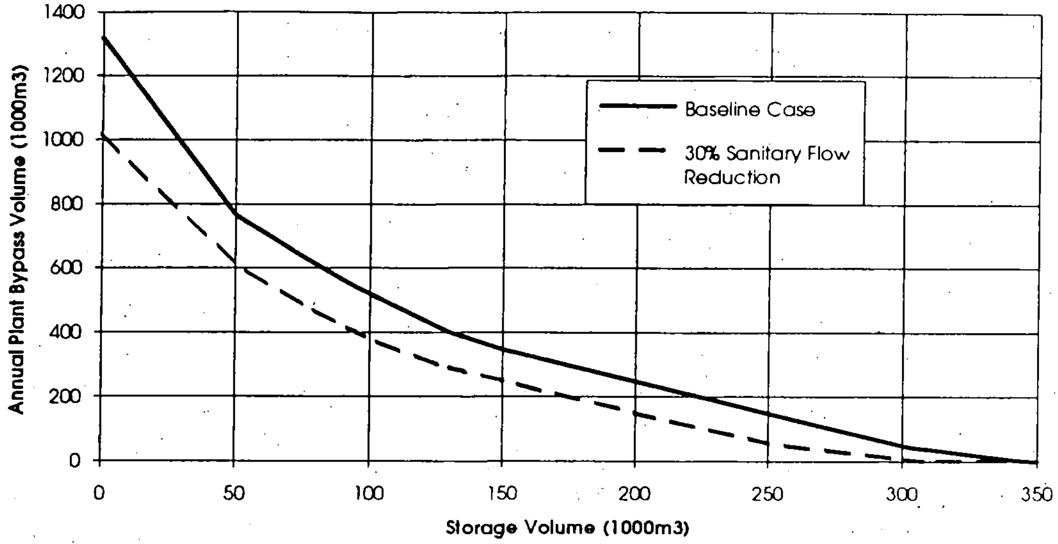

Figure 7.2 - Effect of hydraulic load reduction on annual WPCP plant bypass volumes versus storage volumes using 1990 rainfall year.

7.2 HYDRAULIC LOAD TO RECEIVING WATER

7.2.1 Baseline Case

Table 7.4 shows the hydraulic loads for the baseline case for 1990 and 1991, which are the wet and dry years respectively.

Table 7.4 - Hydraulic load comparison of baseline cases for 1990 and 1991.

Year	Throughflow (10^6 m^3/yr)	Secondary Bypass (10^6 m^3/yr)	Plant Bypass (10^6 m^3/yr)	Total Outfall (10^6 m^3/yr)
1990	121.6 (333 ML/d)	0.11	1.33	123.0 (337 ML/d)
1991	115.9 (318 ML/d)	0.02	0.47	116.4 (319 ML/d)

Definitions:

1. *Throughflow* - flow that receives full treatment at the Woodward WPCP;
2. *Secondary Bypass* - flow that enters the Woodward WPCP and receives partial treatment, but is bypassed around the secondary treatment processes;
3. *Plant Bypass* - flow that receives no treatment at the Woodward WPCP. Note that this does not account for overflows upstream of the WPCP; and
4. *Total Outfall* - the summation of throughflow, secondary bypass, and plant bypass.

In Section 5, DWF for 1990 (wet year) was determined to be 304 ML/d, which means that the average daily wet weather flow for 1990 is 29 ML/d. Dry weather flow for 1991 (dry year) was 294 ML/d, which indicates a WWF for 1991 25 ML/d. These wet weather flow calculations do not account for collection system overflow which are much higher in a wet year (Paul Theil Associates Ltd. et al., 1991).

Although collection system CSOs were not modelled, the plant bypass was modelled in both this study and the Hamilton PCP. A comparison of plant bypass estimates are provided in Table 7.5. Note that plant bypass volumes are not measured at the plant

Table 7.5 - Comparison of plant bypass estimates.

Case	Paul Theil Associates Ltd. (1991)(a)	Paul Theil Associates Ltd. (1991)(c) Annually Adjusted	This Study
Dry Year			
Year	1971(b)	1971	1991
Plant Bypass	300,000	400,000	470,000 m^3
Typical Year			
Year	1989(b)	1989	not run
Plant Bypass	470,000 m^3	634,000 m^3	
Wet Year			
Year	1981(b)	1981	1990
Plant Bypass	850,000	1,110,000 m^3	1,330,000 m^3

Notes:

(a) Wet and dry year bypass volumes read from a graph in Paul Theil Associates Ltd. (1991)

(b) Year in Paul Theil Associates Ltd. (1991) defined as May 1 to October 31.

(c) Modified by dividing overflow volume by fraction of annual rainfall that occurred between May 1 to October 31. For 1989 this fraction .741 and for 1981 the fraction was .766. Insufficient data was available for 1971, so a fraction of 0.75 was used.

A comparison of Hamilton Woodward WPCP bypass for a wet and dry year are reasonable given the uncertainties involved with the comparison. These uncertainties include:

1. Use of different years for wet and dry analysis;
2. Definition of a year, with the PCP using a "6 month" year (a common procedure in PCP studies) and this year using 12 months of data. These different definitions are due to different modelling requirements of the two studies and the effects of snowmelt on the results; and
3. The use of the rainfall fraction (rainfall between May 1 to October 31 divided by the total annual rainfall) to modify the PCP results in Paul Theil Associates Ltd. (1991) is an approximate method only since many other variables will affect the modelled CSO volume.
4. The single catchment model used in this study will tend to slightly overestimate annual WPCP plant bypass volumes

7.2.2 Flow Reduction Cases

The hydraulic loads are listed in detail in Tables C-1 and C-2 in Appendix C and shown graphically in Figures 7.3 to 7.8. *Please note the vertical scales on these graphs do not start at zero.* Hydraulic load is defined as the volume of water entering the receiving water from the following sources:

1. WPCP treated effluent;
2. WPCP partially treated effluent (secondary bypass);
3. WPCP bypass; and
4. Stormwater diverted from the combined collection system directly to the receiving water through sewer separation.

Figure 7.5 shows the effect of stormwater inflow reduction on the hydraulic load entering the receiving water. Stormwater inflow reductions creates no reduction in total hydraulic load to the receiving water since stormwater reduction would include sewer separation which would divert runoff directly to the receiving water. Stormwater inflow reduction does create a small change in the fractions of each component contributing to the hydraulic load. For example, reducing stormwater inflow by 50% reduces flow to the treatment plant (total flow exclusive of diverted stormwater) by 1.7%.

A summary of hydraulic load reductions for several cases is provided in Table 7.6.

Table 7.6 - Summary of hydraulic load reductions.

Case	% Hydraulic Load Reduction to the Receiving Water
10% Sanitary Flow Reduction	6%
30% Sanitary Flow Reduction	18%
50% Infiltration Reduction	19%
50% Stormwater Inflow Reduction	0%
50% I/I Reduction	19%
Maximum Reduction	37%

Figure 7.8 shows a comparison of total hydraulic load for between 1990 (wet year) and 1991 (dry year) for the following cases:

1. Baseline case;
2. 30% sanitary flow reduction;
3. 50% infiltration and inflow reduction; and
4. Combination of 30% sanitary flow reduction and 50% infiltration and inflow reduction.

7.3 WPCP EFFLUENT CONCENTRATION ANALYSIS

The effects of various flow reduction program on Hamilton Woodward WPCP effluent TSS and BOD concentrations are listed in Appendix C in Tables C-3 and C-4. These tables are graphically illustrated in Figures 7.9 to 7.13 for TSS and 7.14 to 7.18 for BOD.

The graphs are based the simulation time series of average daily concentrations for 1990. All averaging calculations used in this analysis are based on flow weighted averages. The plots show the effects of various flow reduction techniques on:

1. Maximum average daily concentrations;
2. Mean average daily concentration; and
3. Minimum average daily concentration.

A summary of average daily effluent concentrations for several cases is provided in Table 7.7.

Table 7.7 - Summary of average daily effluent concentrations.

Case	% TSS Concentration Reduction from Baseline Case	% BOD Concentration Reduction from Baseline Case
10% Sanitary Flow Reduction	11.9%	5.8%
30% Sanitary Flow Reduction	25.6%	10.5%
50% Infiltration Reduction	32.3%	12.8%
50% Stormwater Inflow Reduction	5.5%	4.7%
50% I/I Reduction	37.2%	17.4%
Maximum Reduction	53.7%	24.4%
RAP-based upgrades	87.2%	76.7%

A comparison of TSS and BOD effluent concentration cases for 1990 and 1991 are listed in Tables C-5 and C-6 in Appendix, and shown in Figures 7.19 and 7.20.

7.4 TOTAL LOAD TO RECEIVING WATER

As shown in Section 7.3 and 7.2, flow reductions reduce both the hydraulic load to the receiving water and effluent concentration from the WPCP. Since receiving water load is the product of flow and concentration, reducing both components will have a synergistic effect and produce even greater pollutant load reductions. A summary of pollutant load reductions is shown in Table 7.8.

Table 7.8 - Pollutant load reductions as a percent reduction from the baseline case.

Case	% TSS Load Reduction from Baseline Case	% BOD Load Reduction from Baseline Case
10% Sanitary Flow Reduction	15.6%	11.5%
30% Sanitary Flow Reduction	36.8%	25.6%
50% Infiltration Reduction	44.1%	29.5%
50% Stormwater Inflow Reduction	0.9%	-4.0%(a)
50% I/I Reduction	41.6%	23.0%
Maximum Reduction	61.4%	57.3%.
RAP-based upgrades	88.5%	79.0%

Note:

(a) Negative value indicates the pollutant load is increased by the given percentage.

A detailed listing of each flow load is provided in Tables C-7 and C-8 of Appendix C and shown in detail in Figures 7.21 to 7.25 for TSS loading, and Figures 7.26 to 7.30 for BOD loading. A comparison of selected cases using 1990 and 1991 rainfall data are provided in Tables C-9 and C-10 and Figures 7.31 and 7.32.

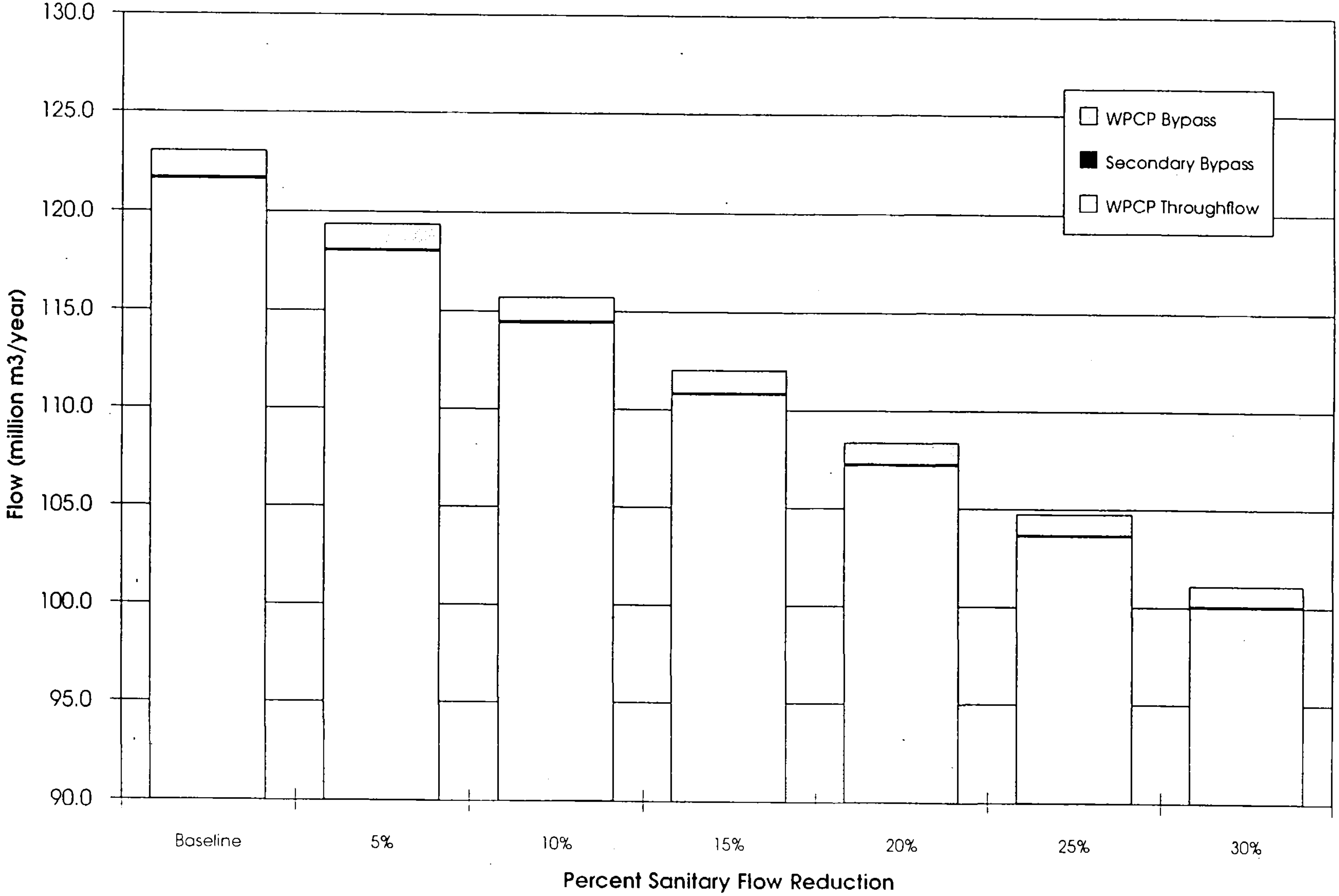

Figure 7.3 - Effect of sanitary flow reduction on hydraulic load to the receiving water.

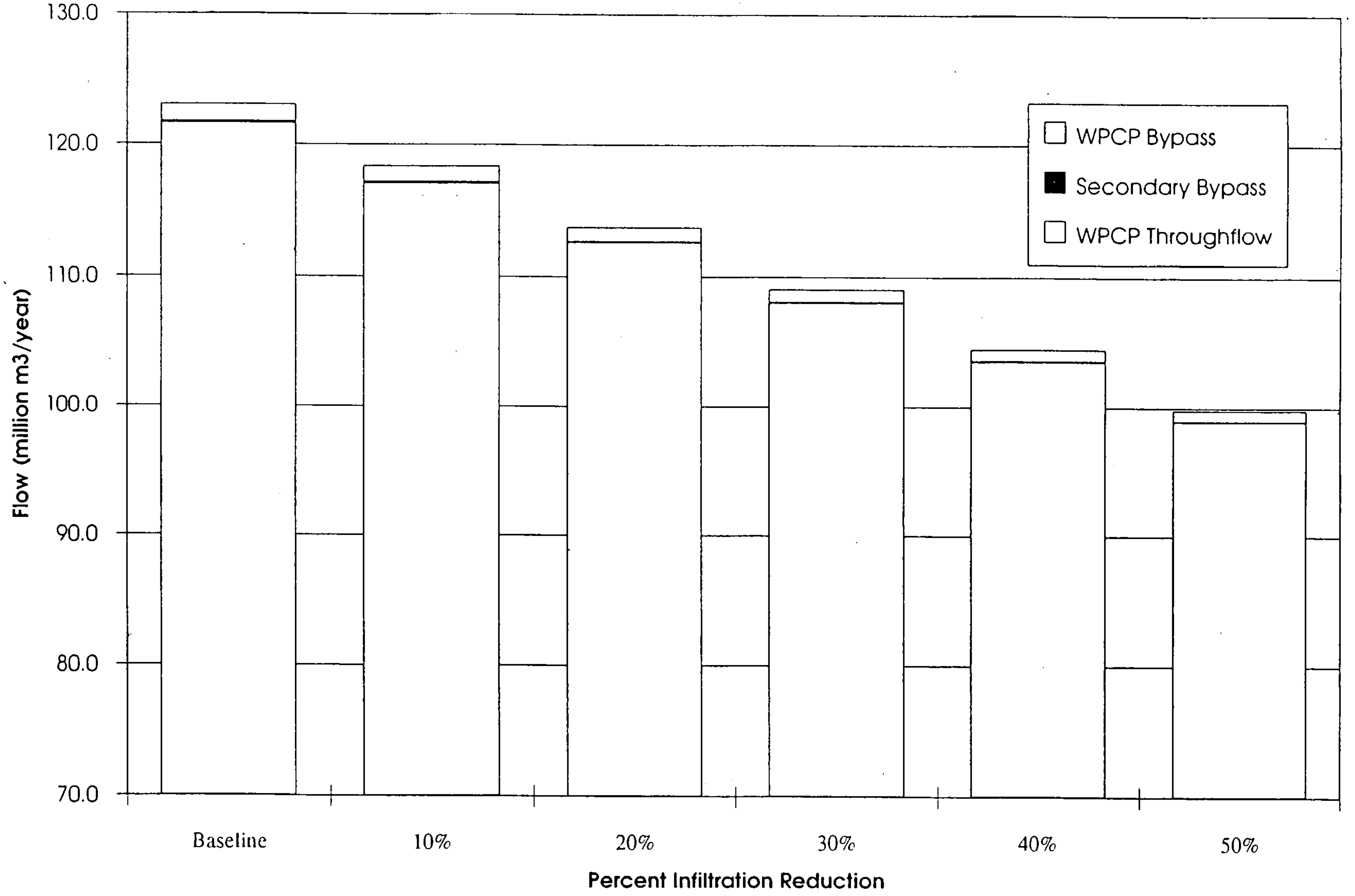

Figure 7.4 - Effects of infiltration reduction on total hydraulic load to the receiving water.

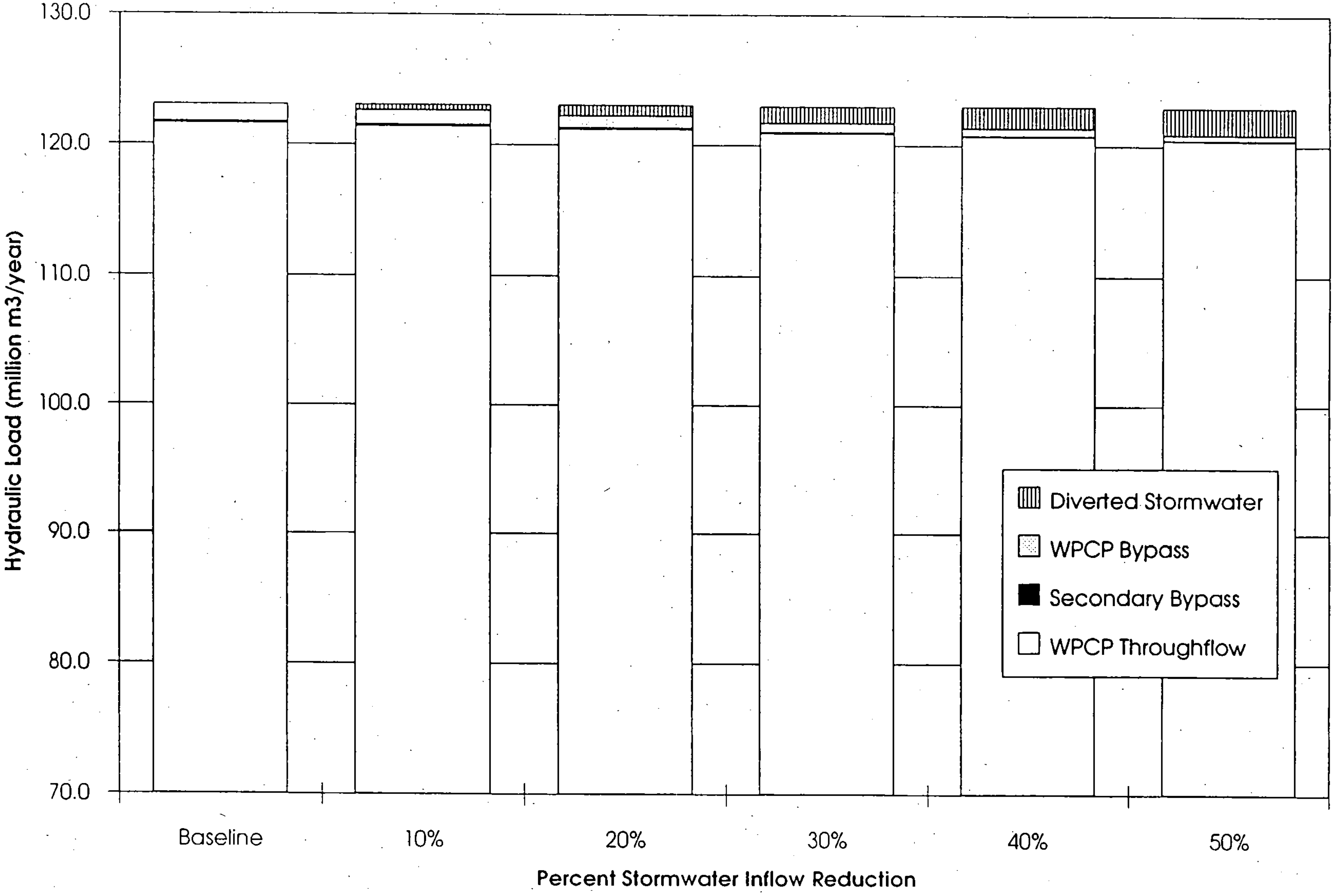

Figure 7.5 - Effect of stormwater inflow reduction on total hydraulic load to the receiving water.

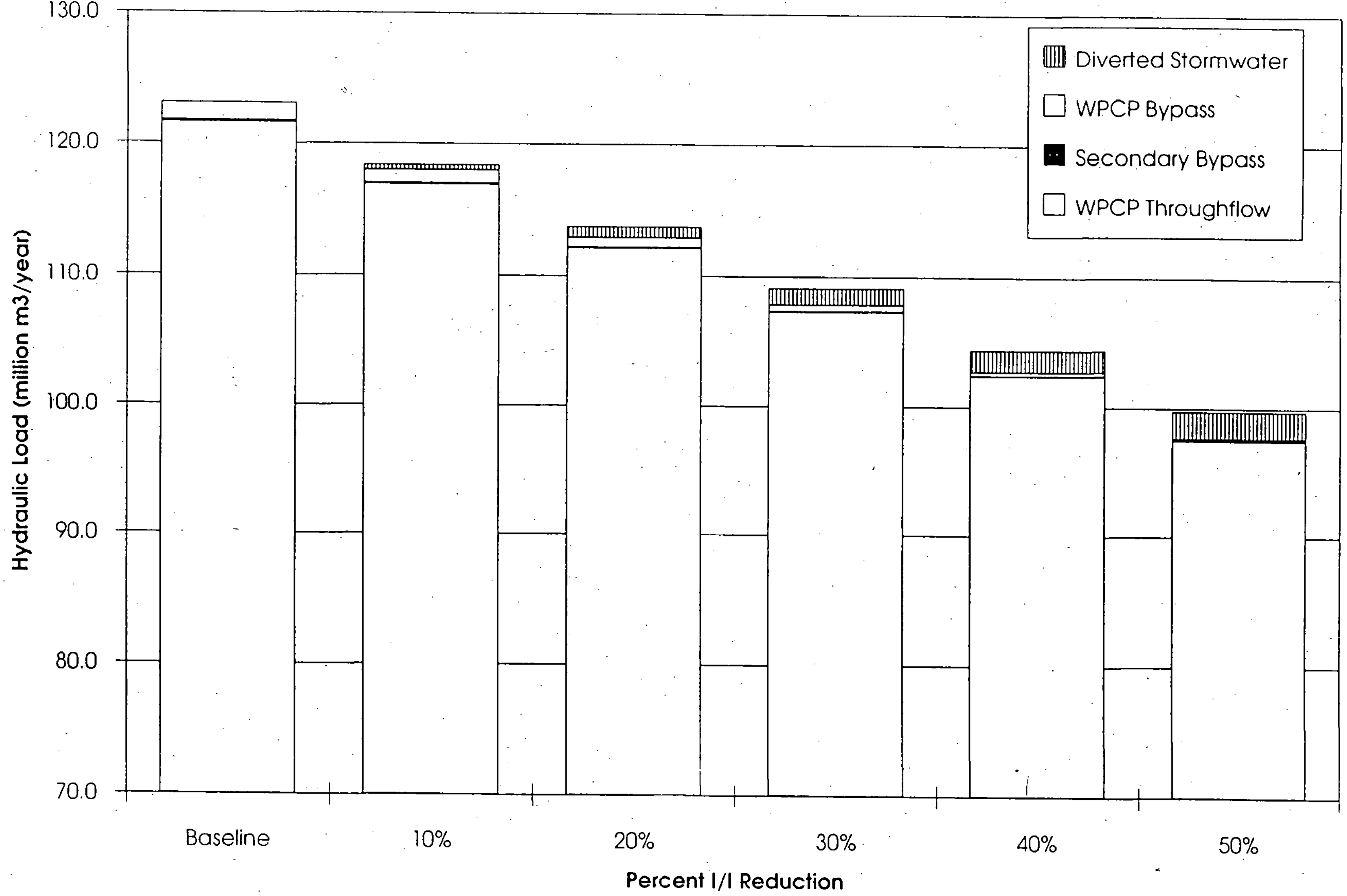

Figure 7.6 - Effect of an infiltration and stormwater inflow reduction program on hydraulic load to the receiving water.

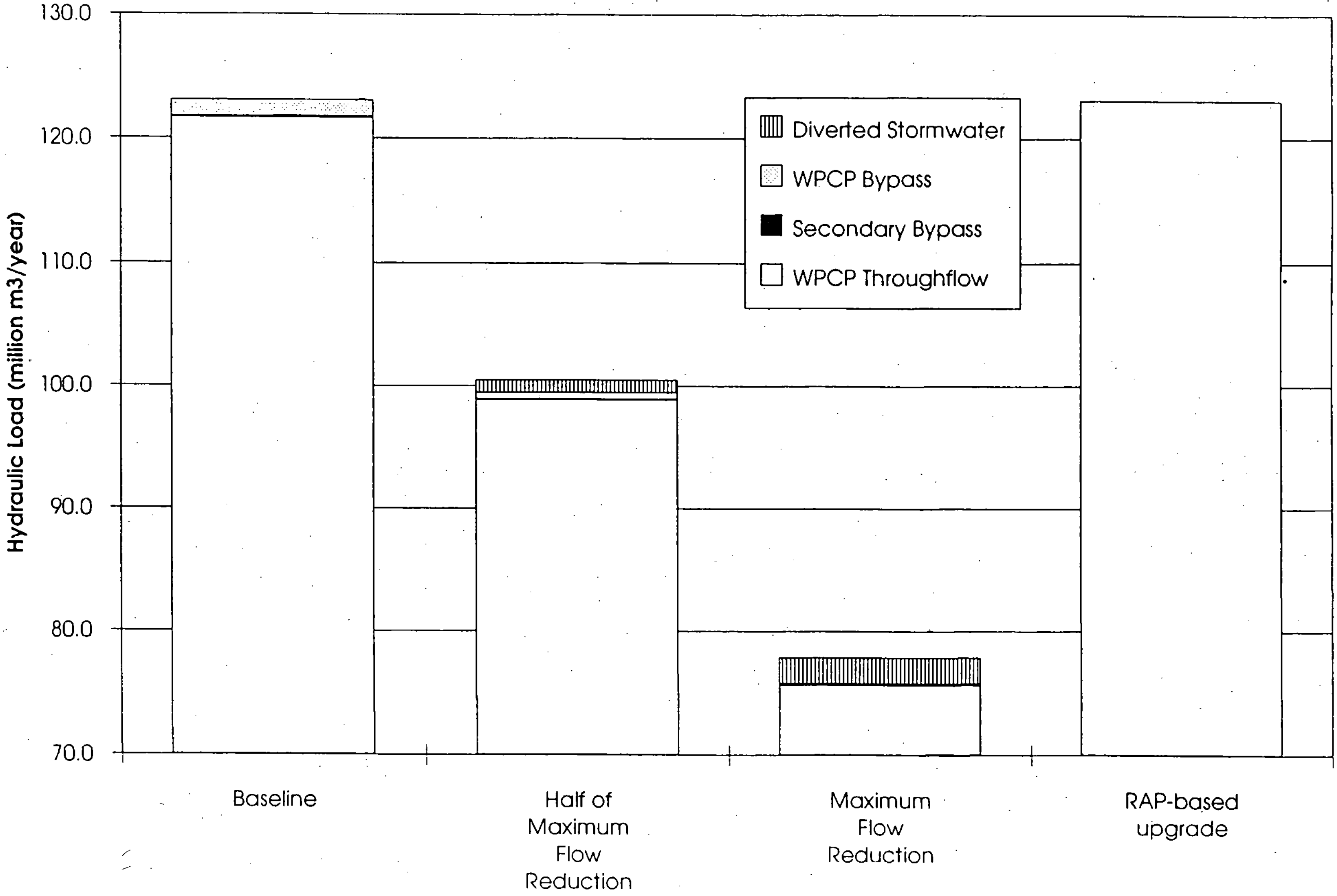

Figure 7.7 - Effect of comprehensive flow reduction programs on hydraulic load to the receiving water.

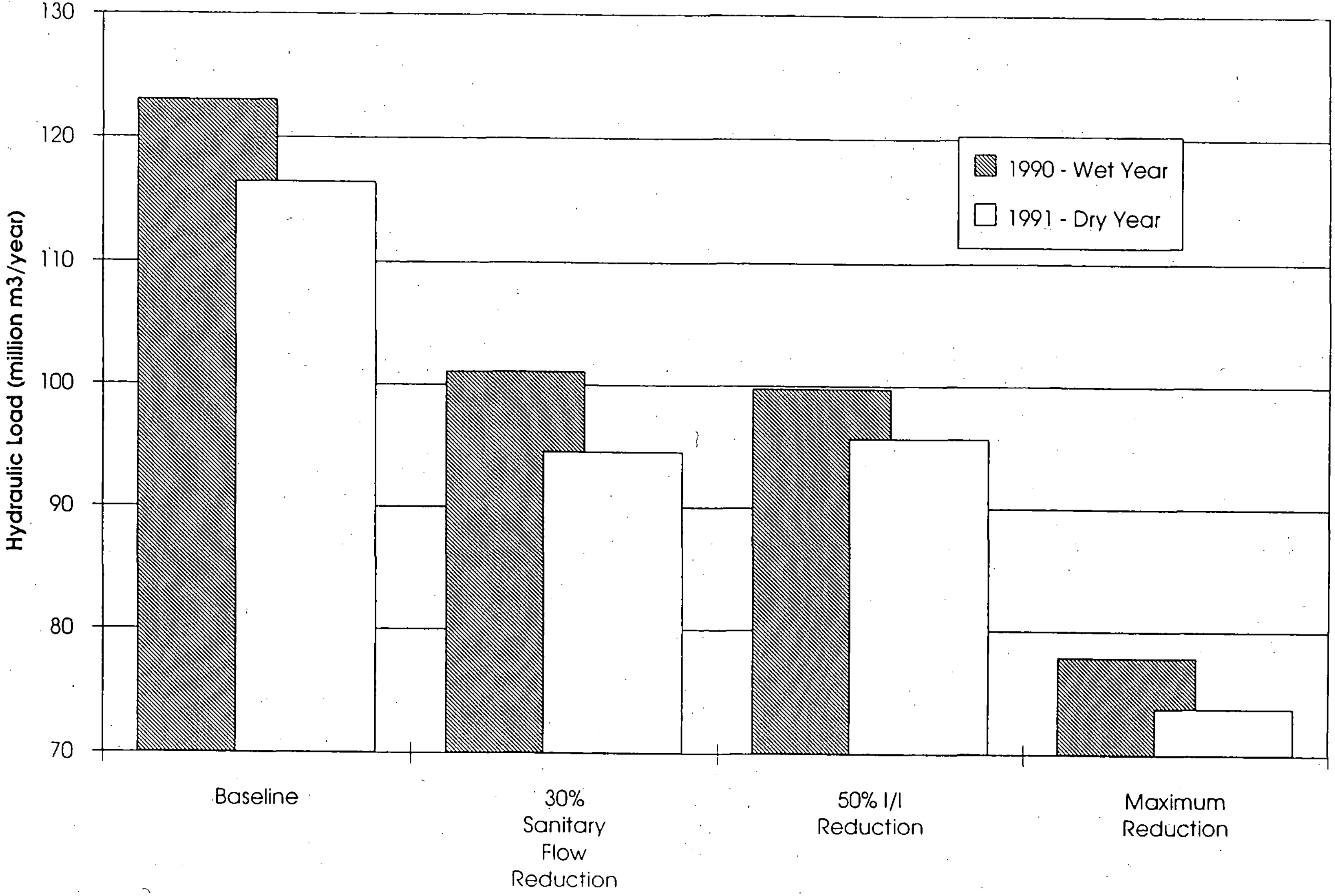

Figure 7.8 - A comparison of 1990 versus 1991 of the effect of selected flow reduction programs on total hydraulic load to the receiving water.

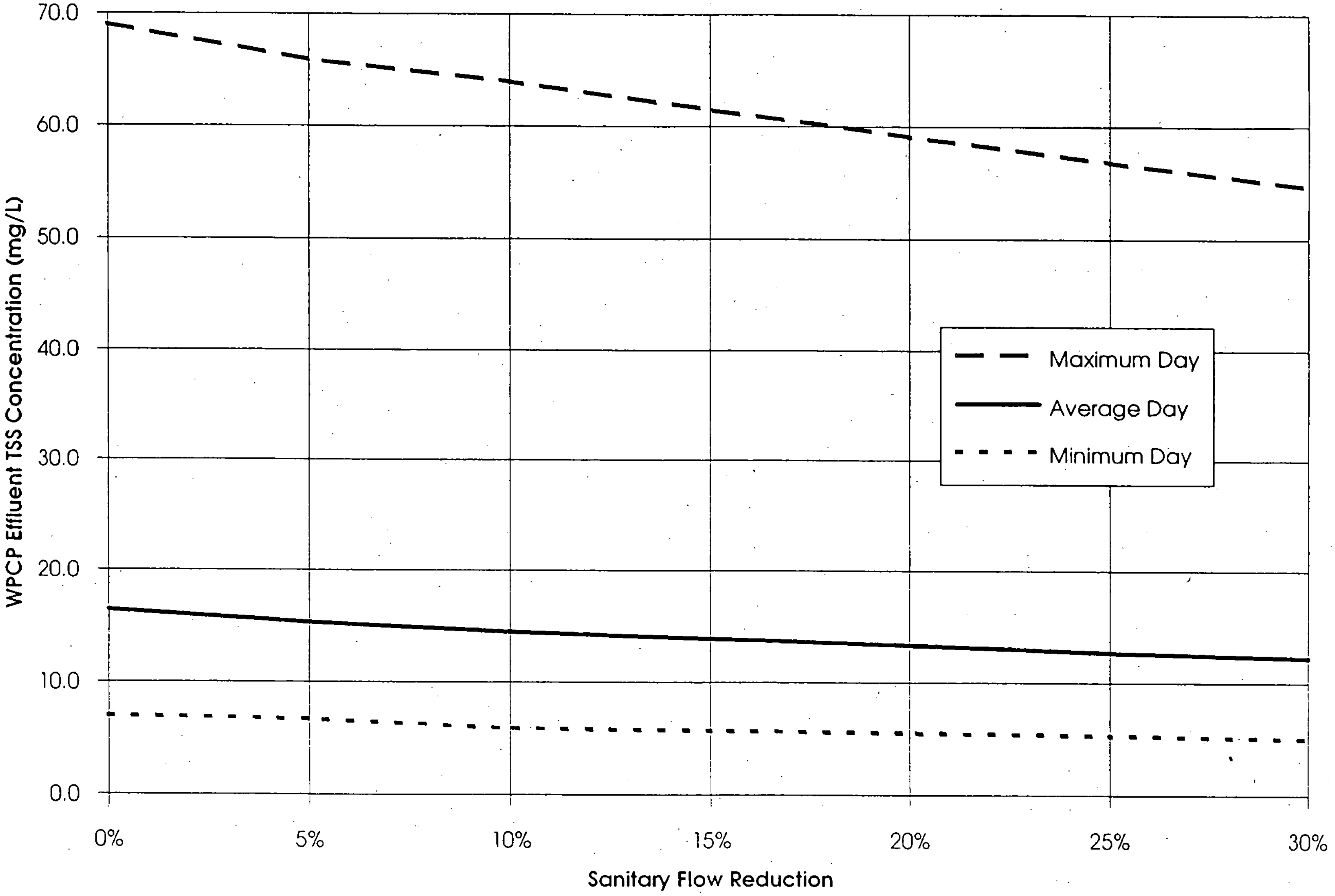

Figure 7.9 - Effect of sanitary flow reduction on WPCP effluent TSS concentration.

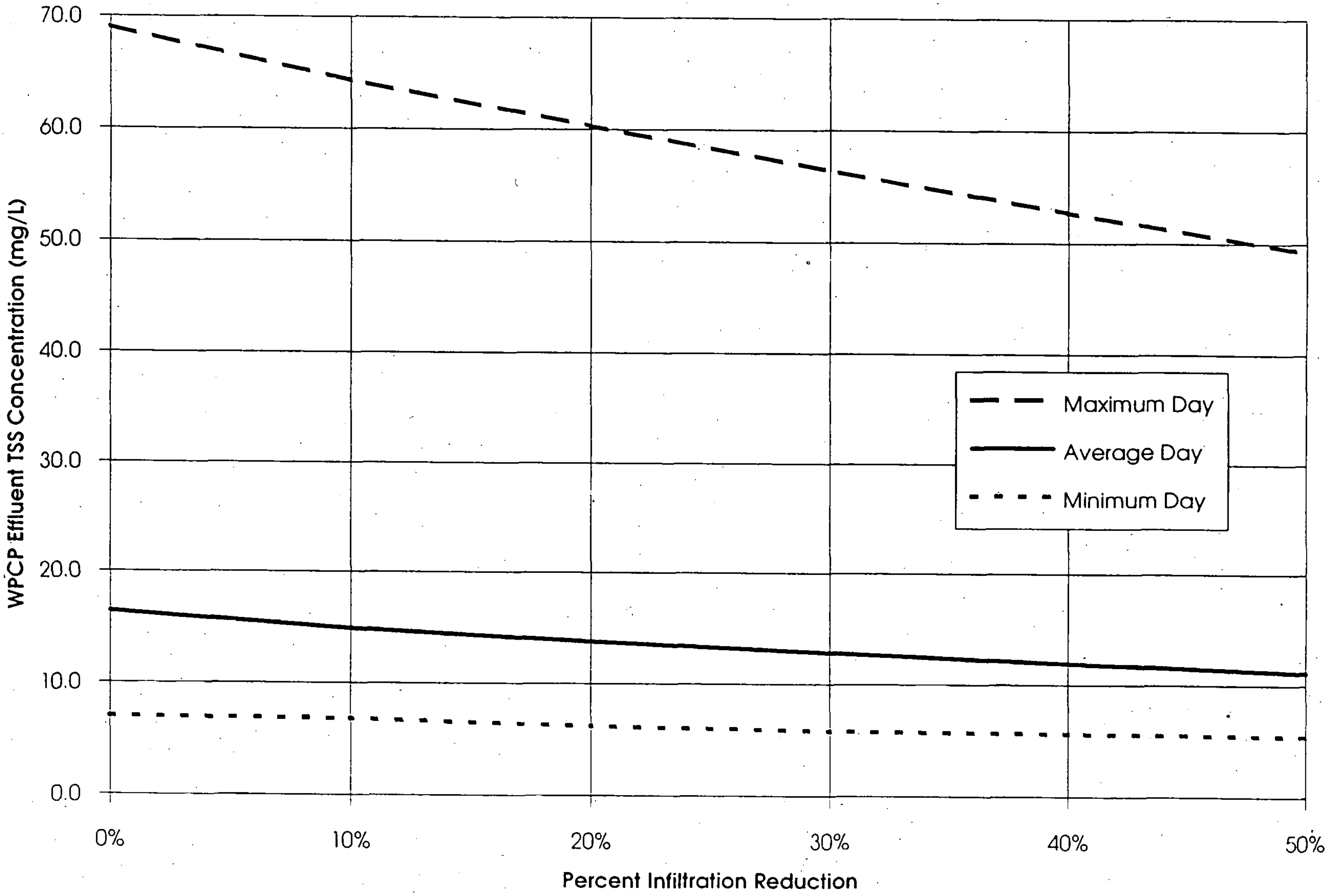

Figure 7.10 - Effect of infiltration reduction program on WPCP effluent TSS concentration.

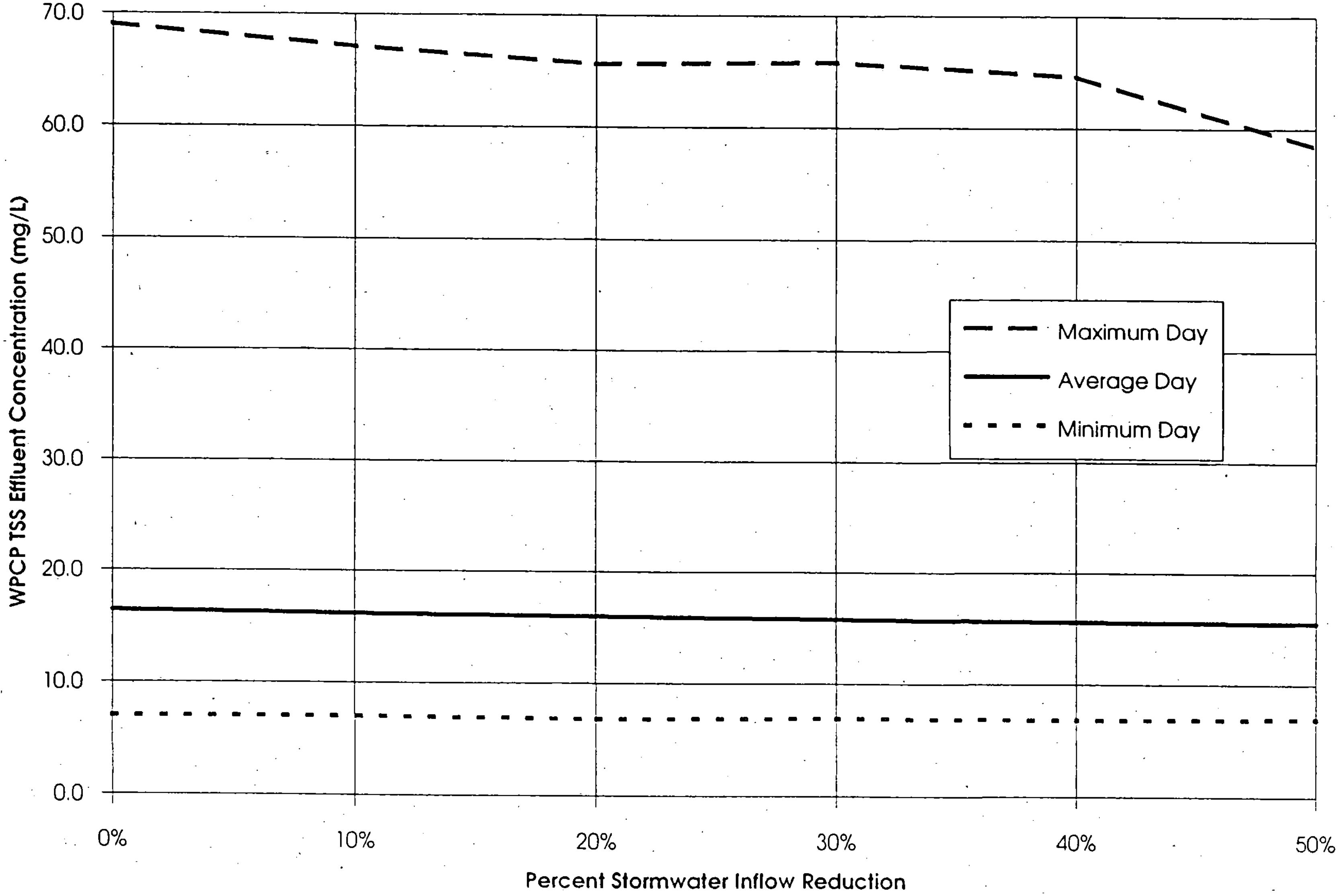

Figure 7.11 - Effect of stormwater inflow reduction on WPCP effluent TSS concentration.

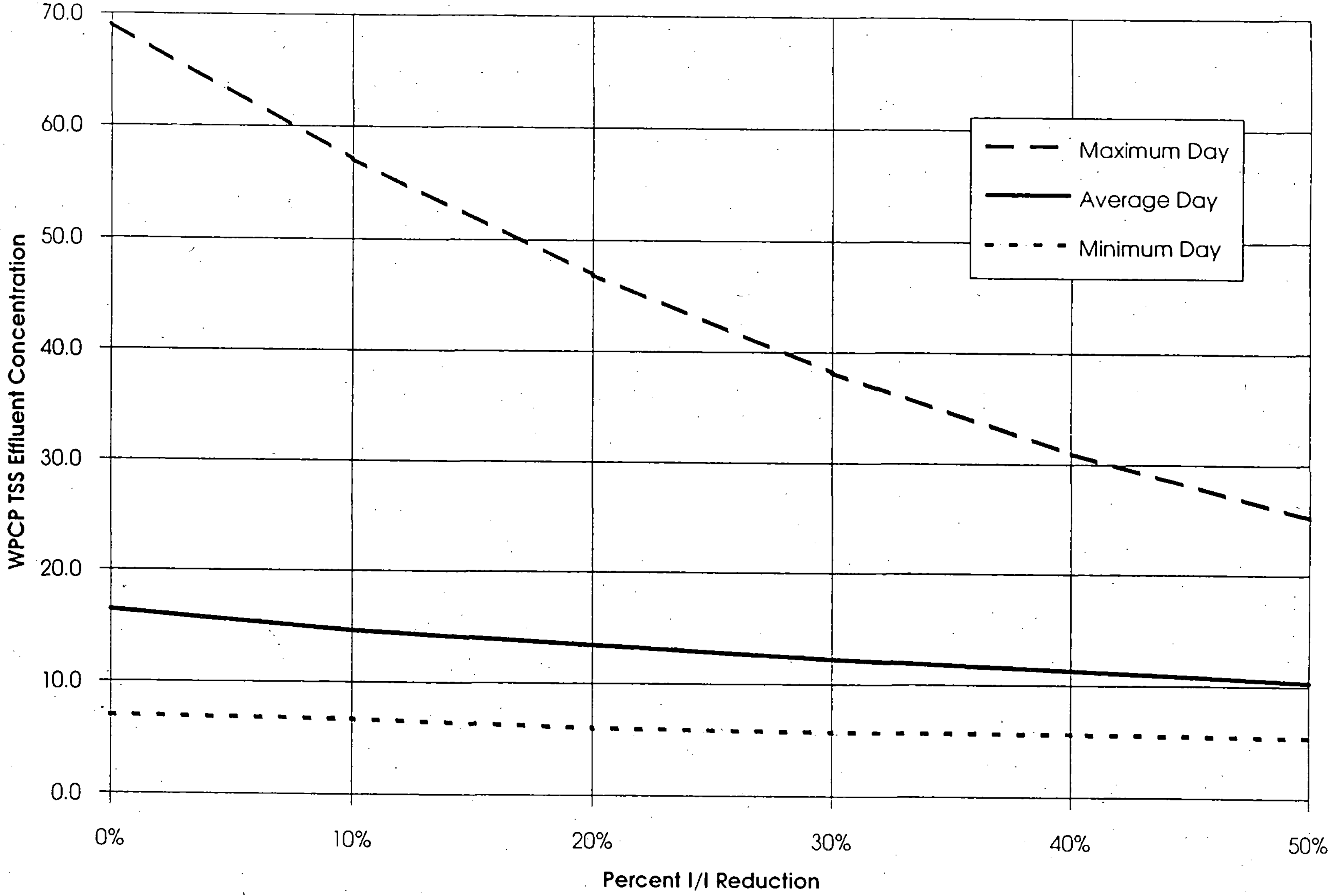

Figure 7.12 - Effect of infiltration and stormwater inflow reduction on WPCP effluent TSS concentration.

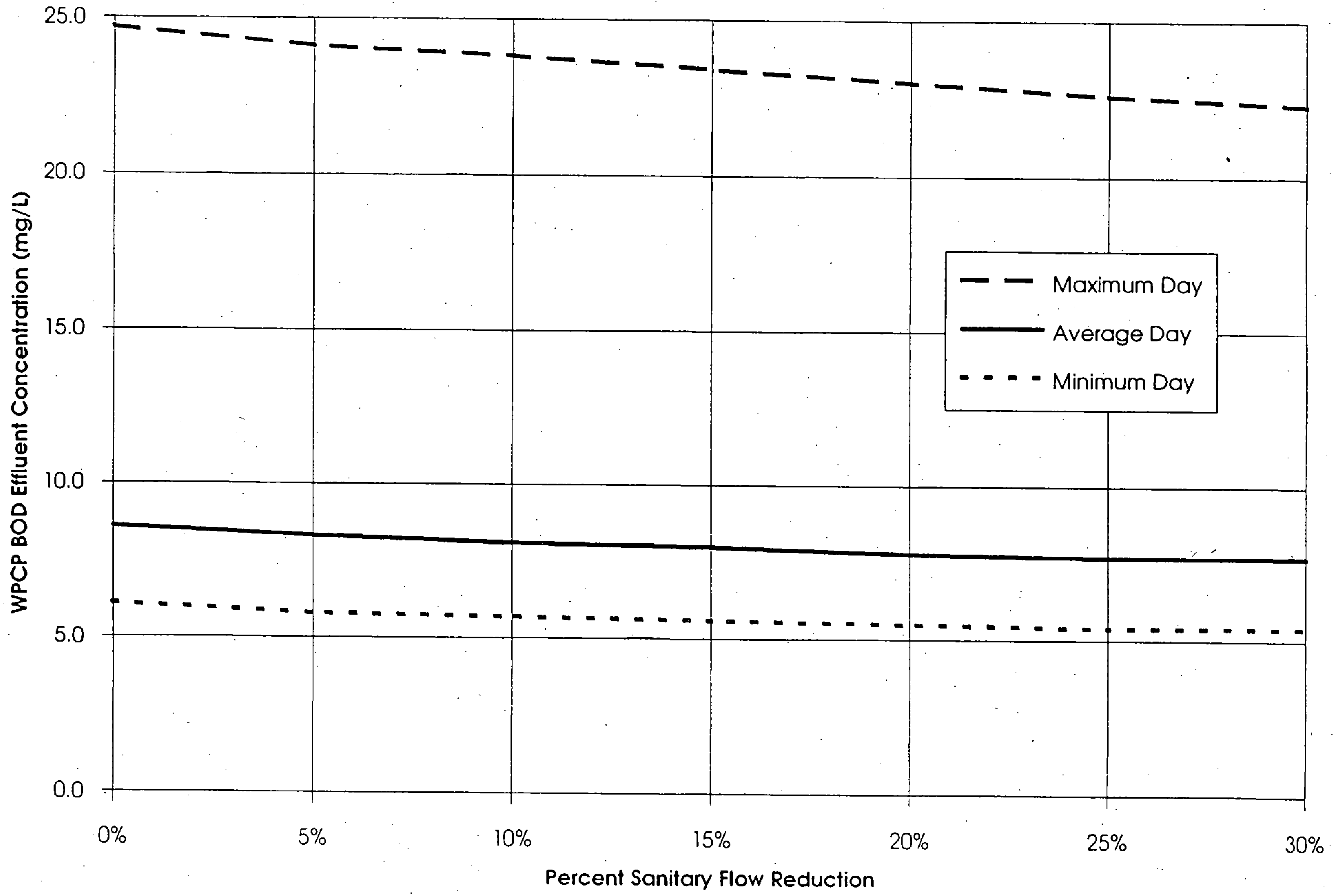

Figure 7.14 - Effect of sanitary flow reduction on WPCP effluent BOD concentration.

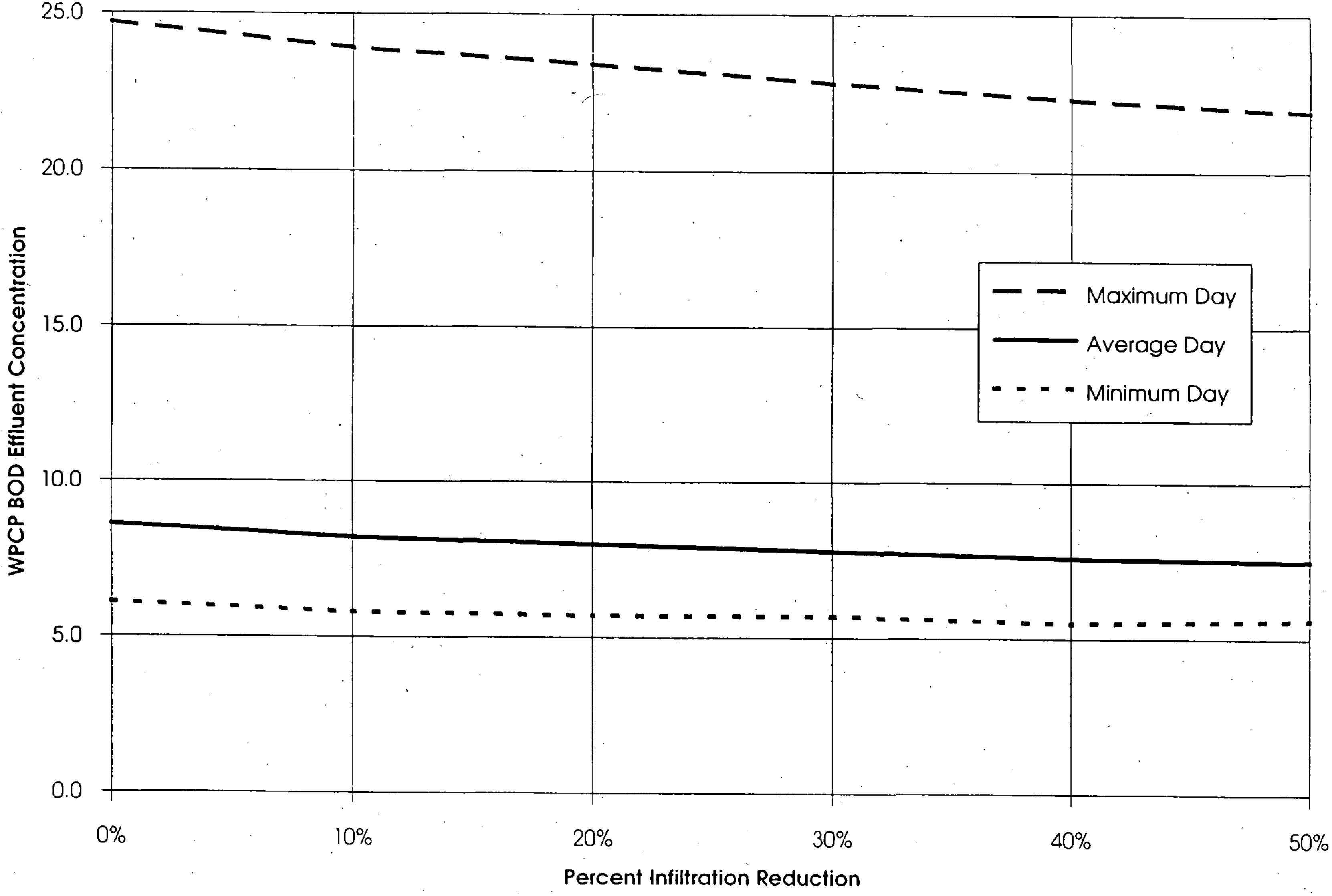

Figure 7.15 - Effect of infiltration reduction program on WPCP effluent BOD concentration.

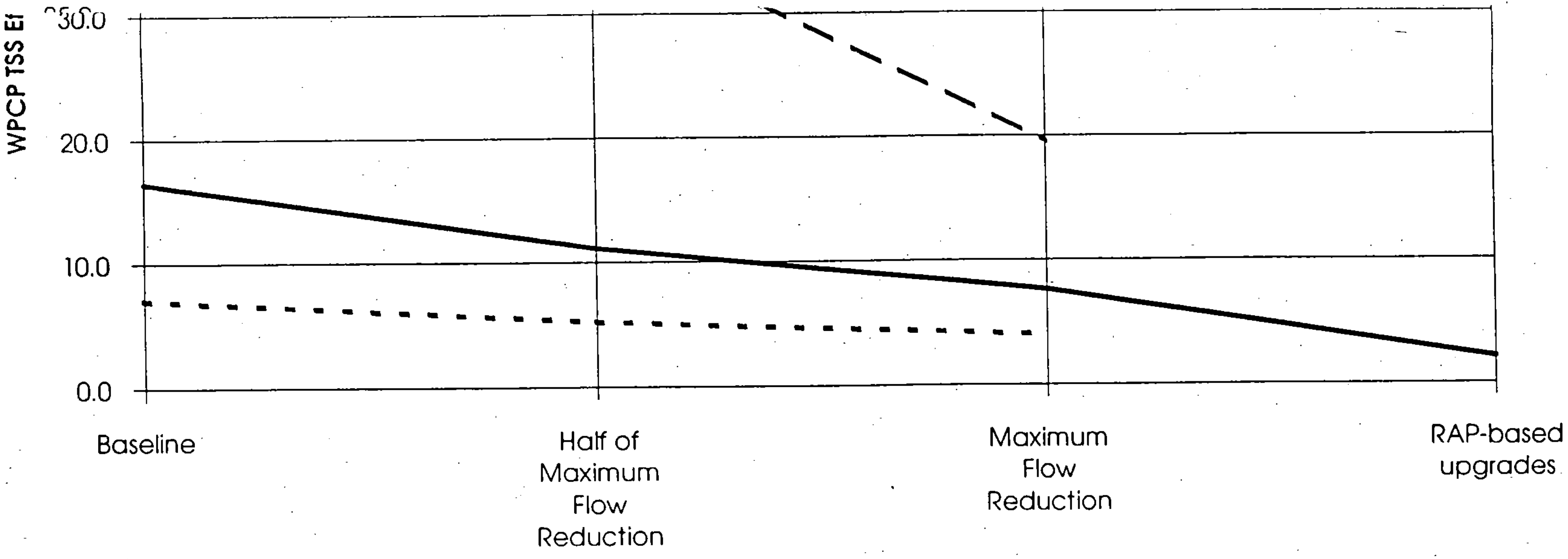

Figure 7.13 - Effect of comprehensive flow reduction programs on WPCP effluent TSS concentration.

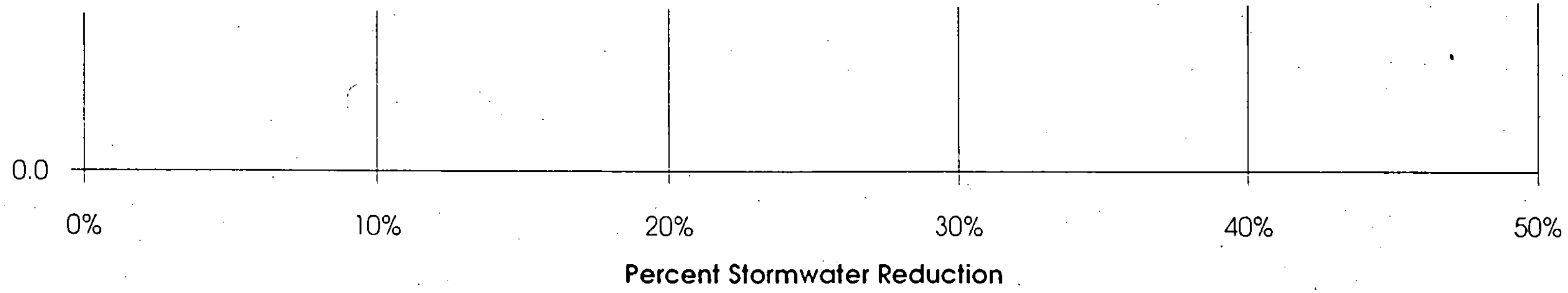

Figure 7.16 - Effect of stormwater inflow reduction on WPCP effluent BOD concentration.

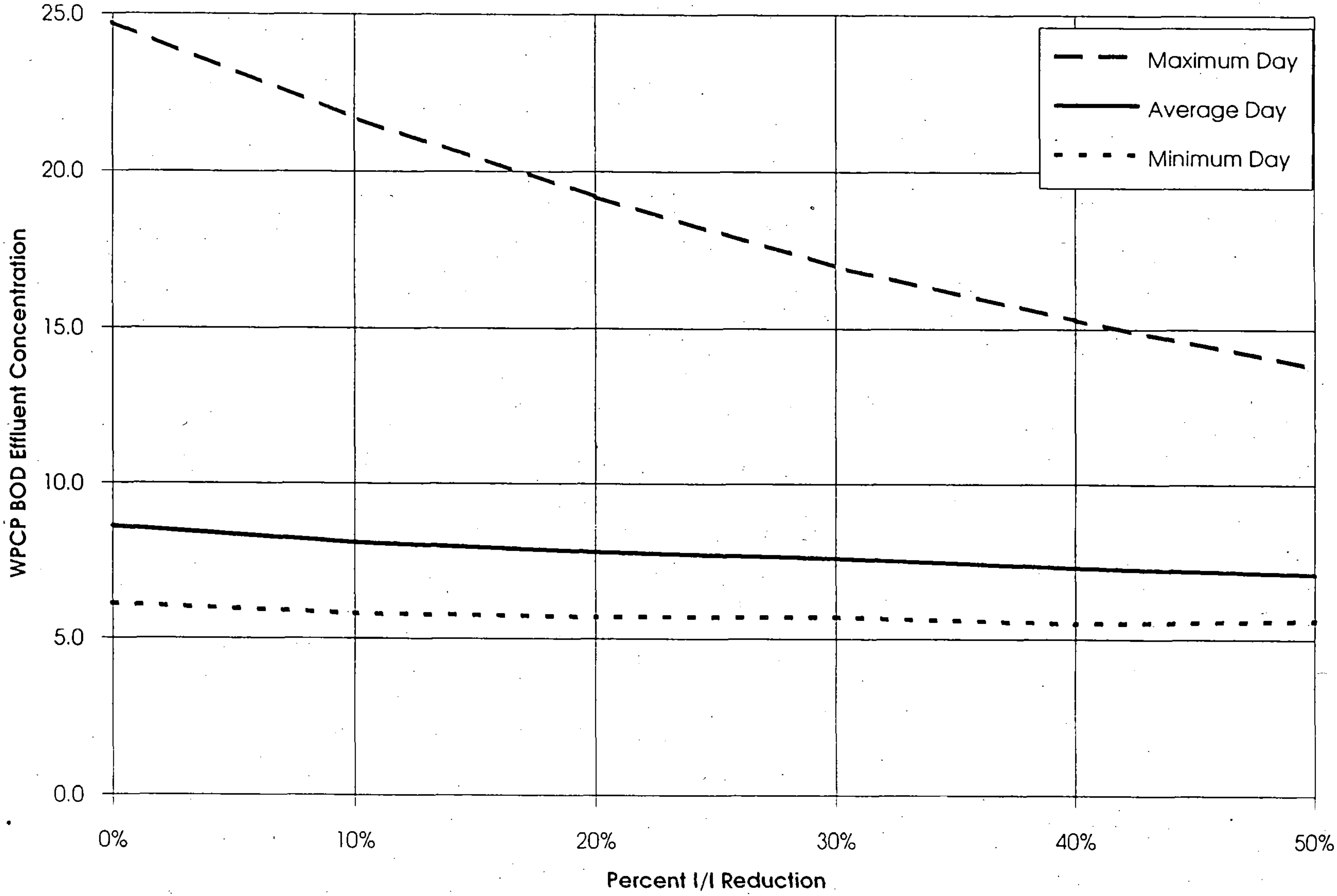

Figure 7.17 - Effect of infiltration and stormwater inflow reduction programs on WPCP effluent BOD concentration.

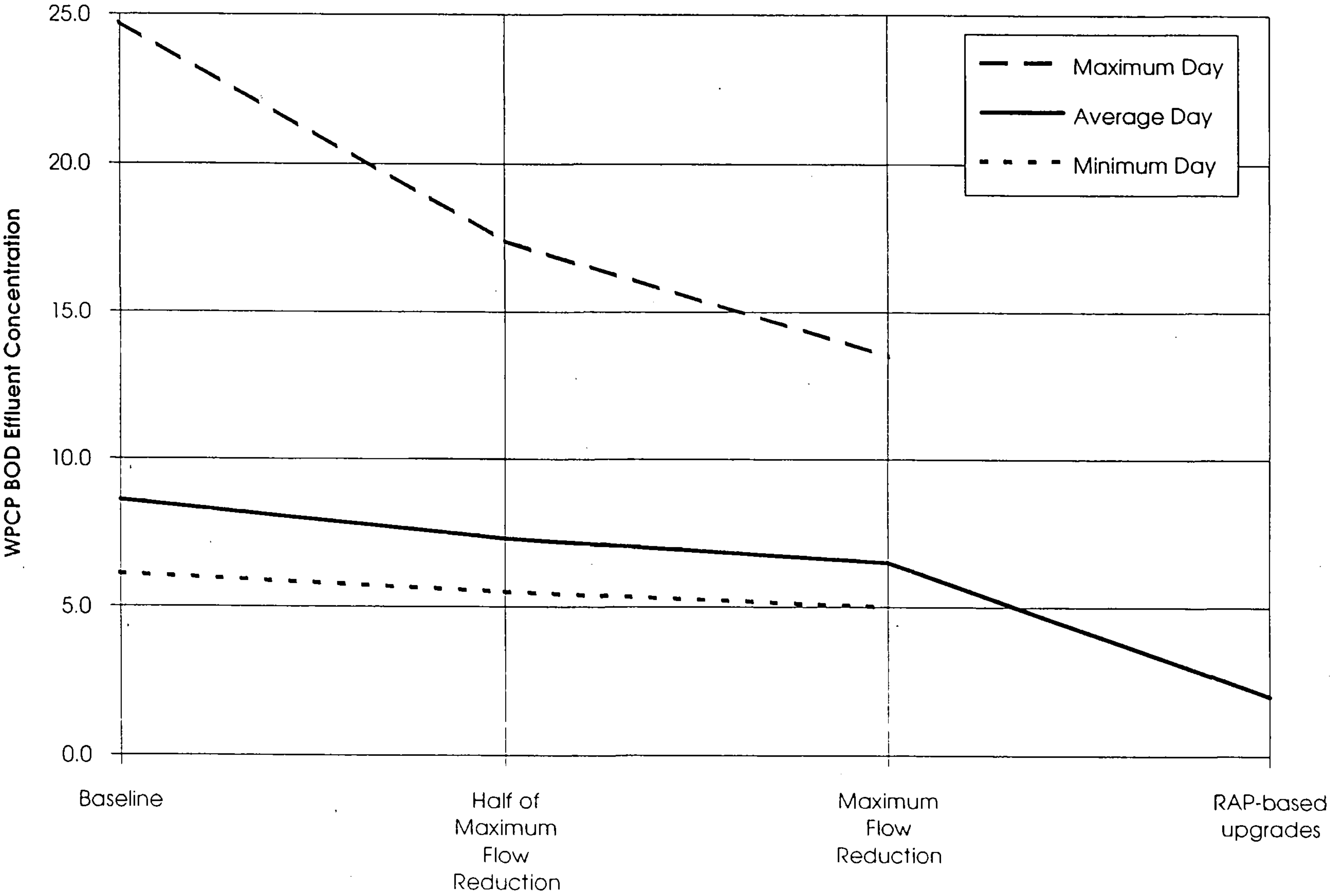

Figure 7.18 - Effect of comprehensive flow reduction programs on WPCP effluent BOD concentration.

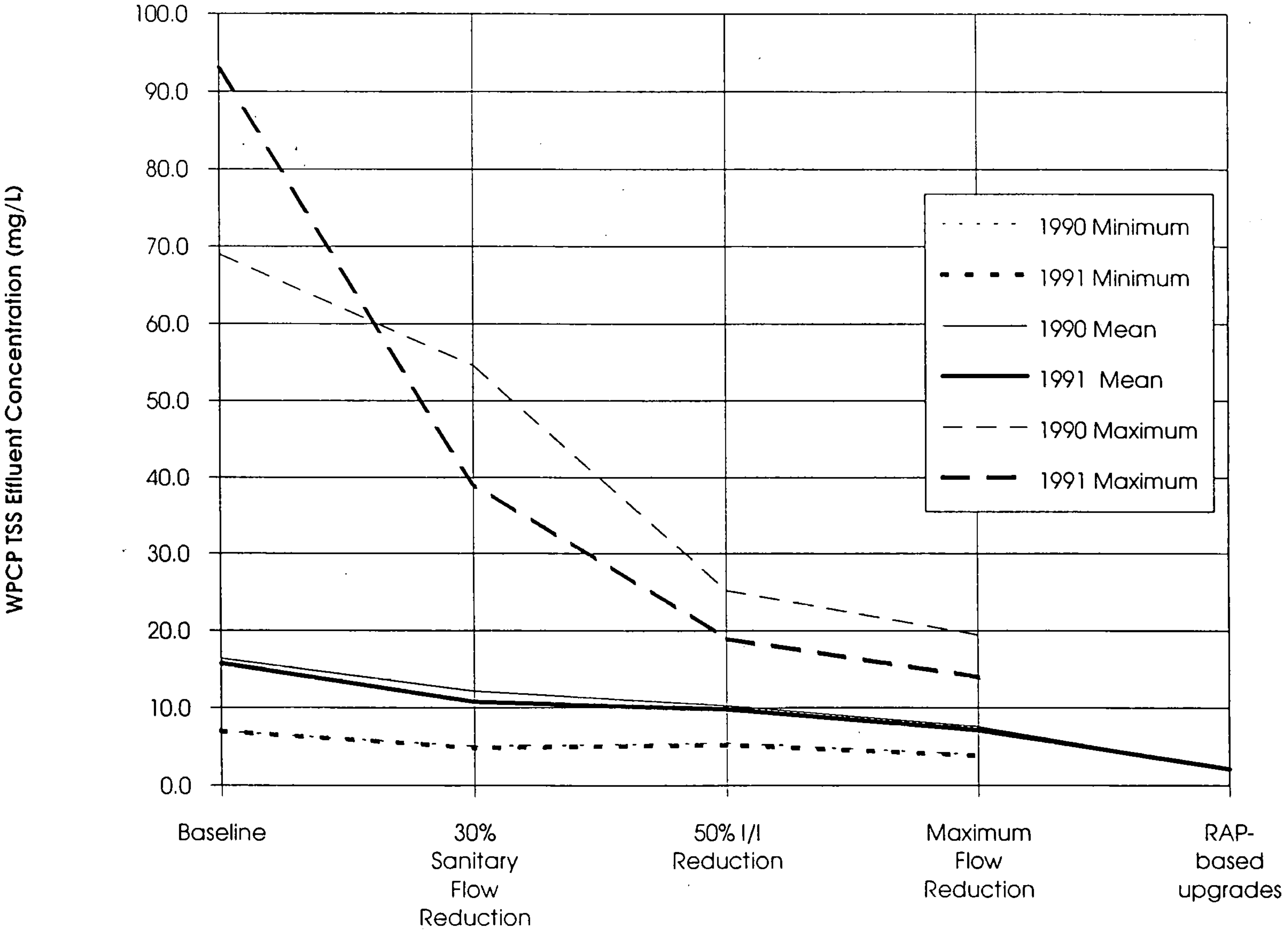

Figure 7.19 - Comparison of 1990 versus 1991 of effect of flow reduction programs on WPCP effluent TSS concentration.

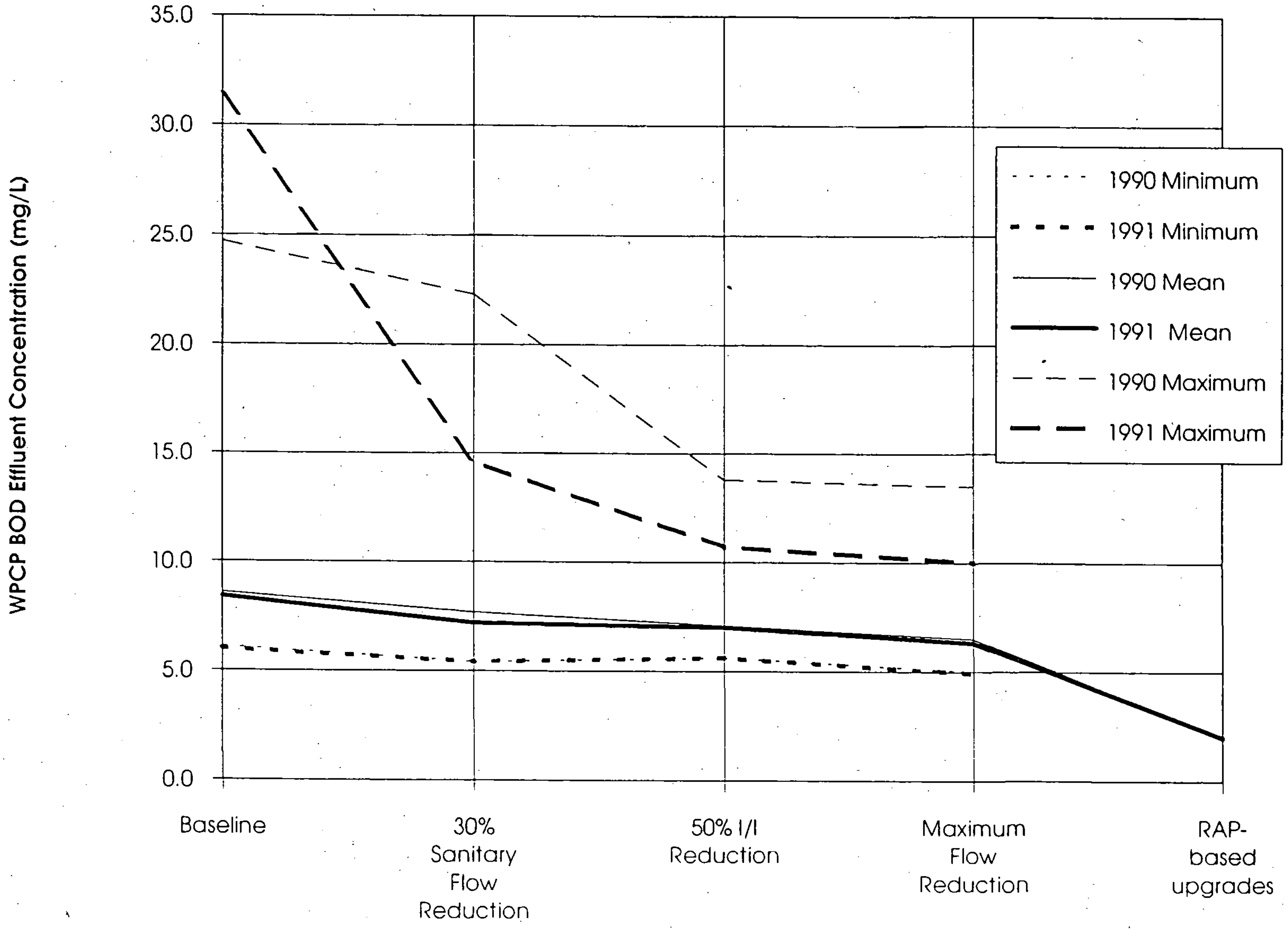

Figure 7.20 - Comparison of 1990 versus 1991 of effect of flow reduction programs on WPCP effluent BOD concentration.

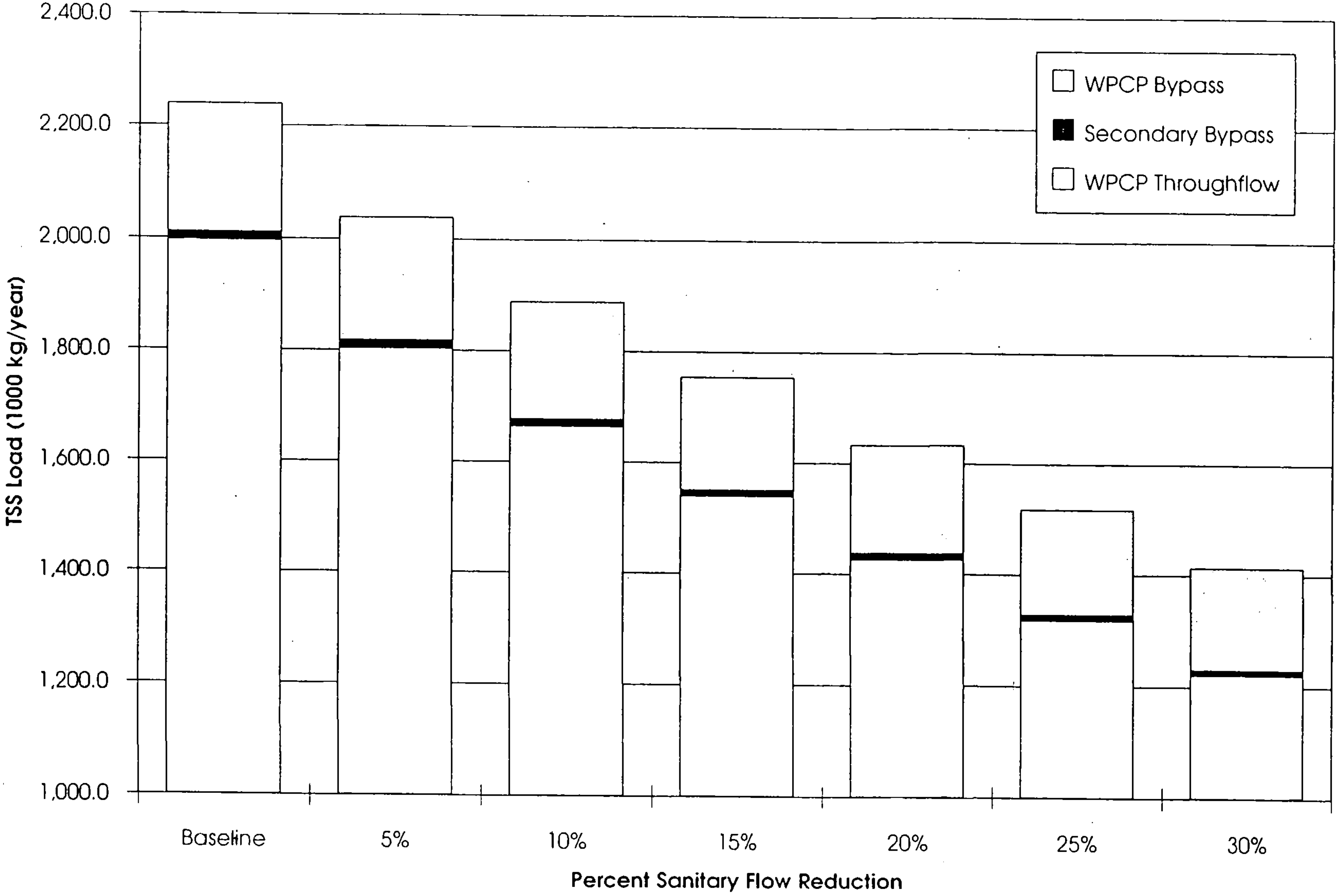

Figure 7.21 - Effect of sanitary flow reduction on annual TSS pollutant load to the receiving water.

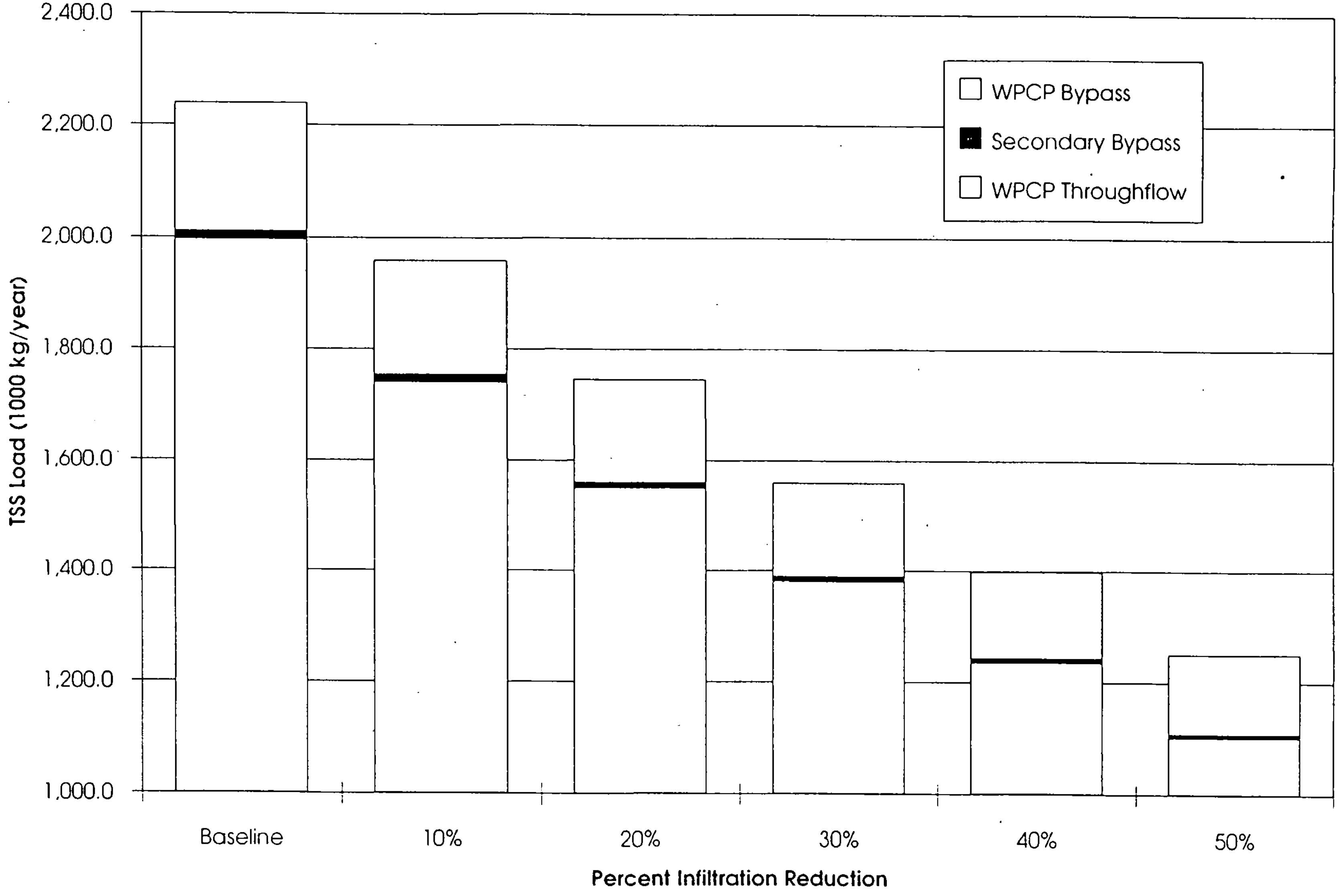

Figure 7.22 - Effect of infiltration reduction program on annual TSS load to the receiving water.

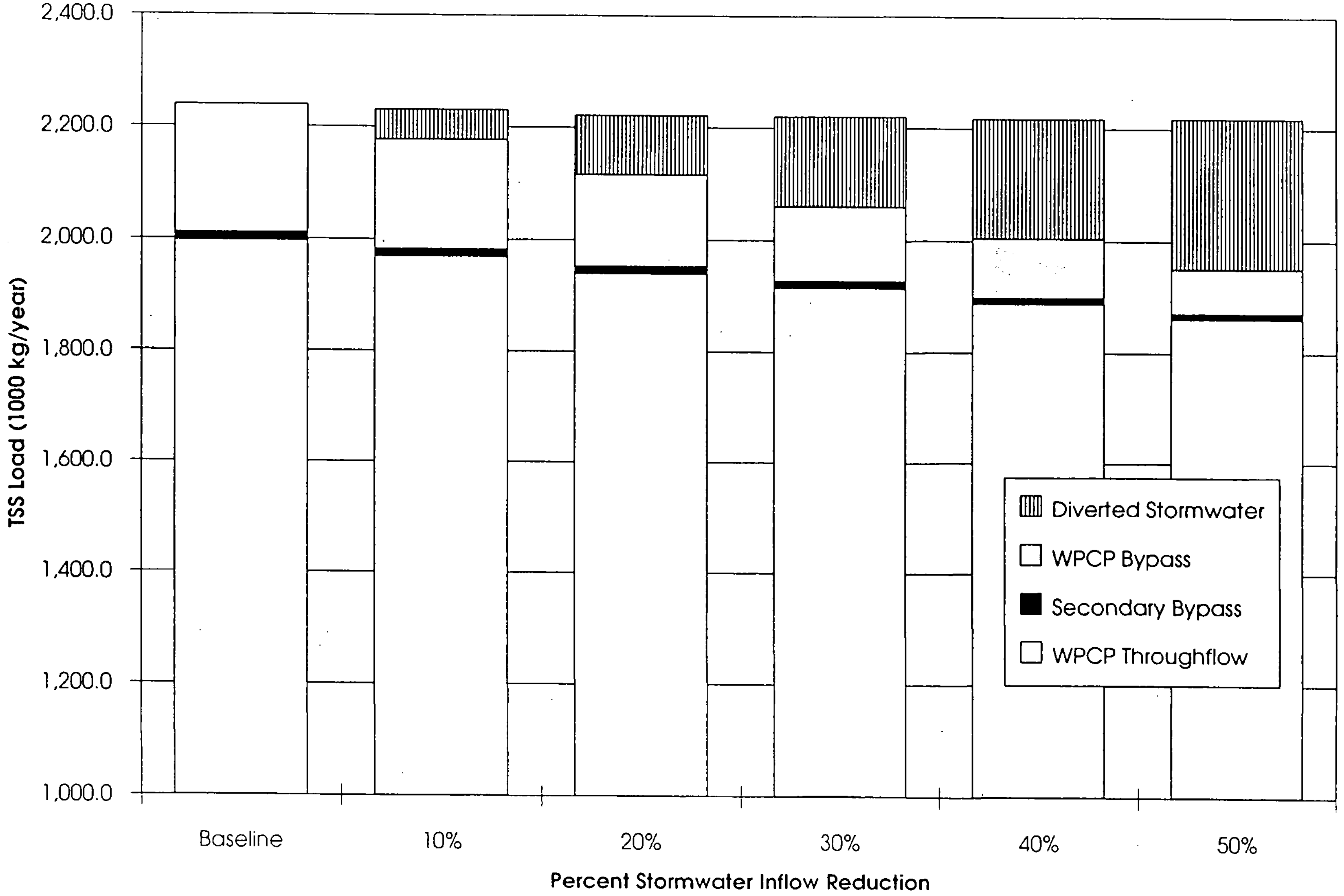

Figure 7.23 - Effect of stormwater inflow reduction program on annual TSS load to the receiving water.

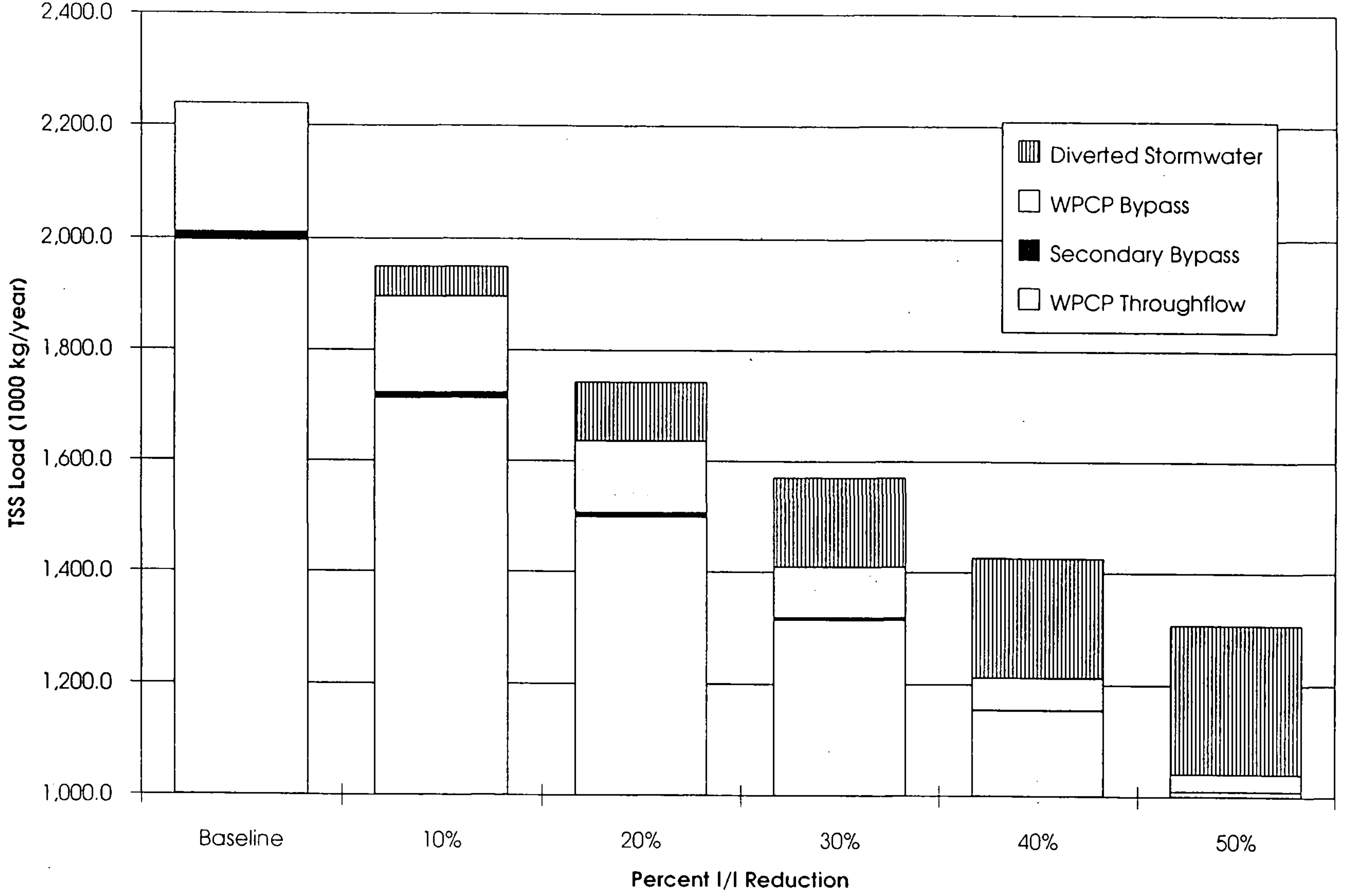

Figure 7.24 - Effect of an infiltration and stormwater inflow reduction program on annual TSS load to the receiving water.

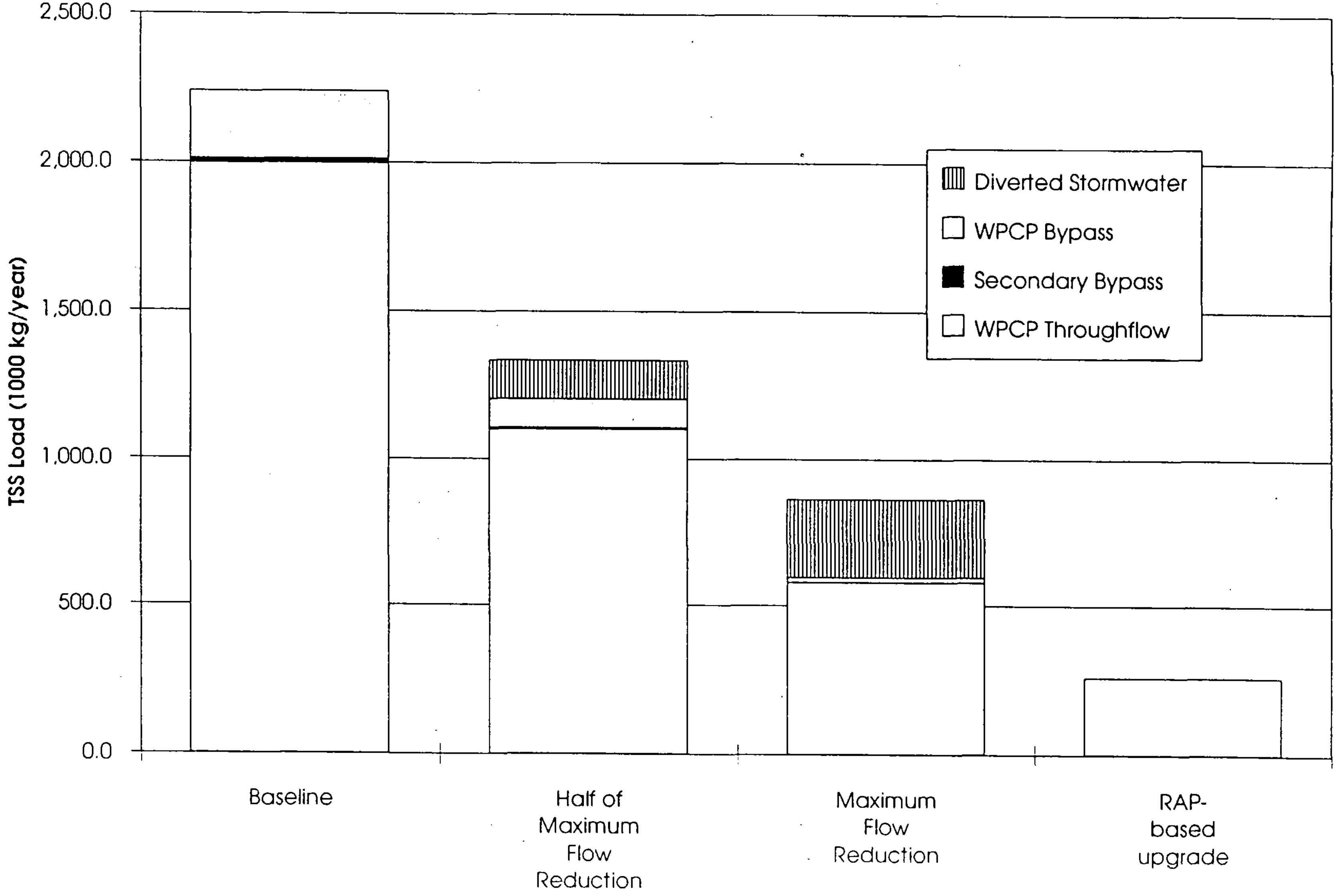

Figure 7.25 - Effect of comprehensive flow reduction programs on annual TSS load to the receiving water.

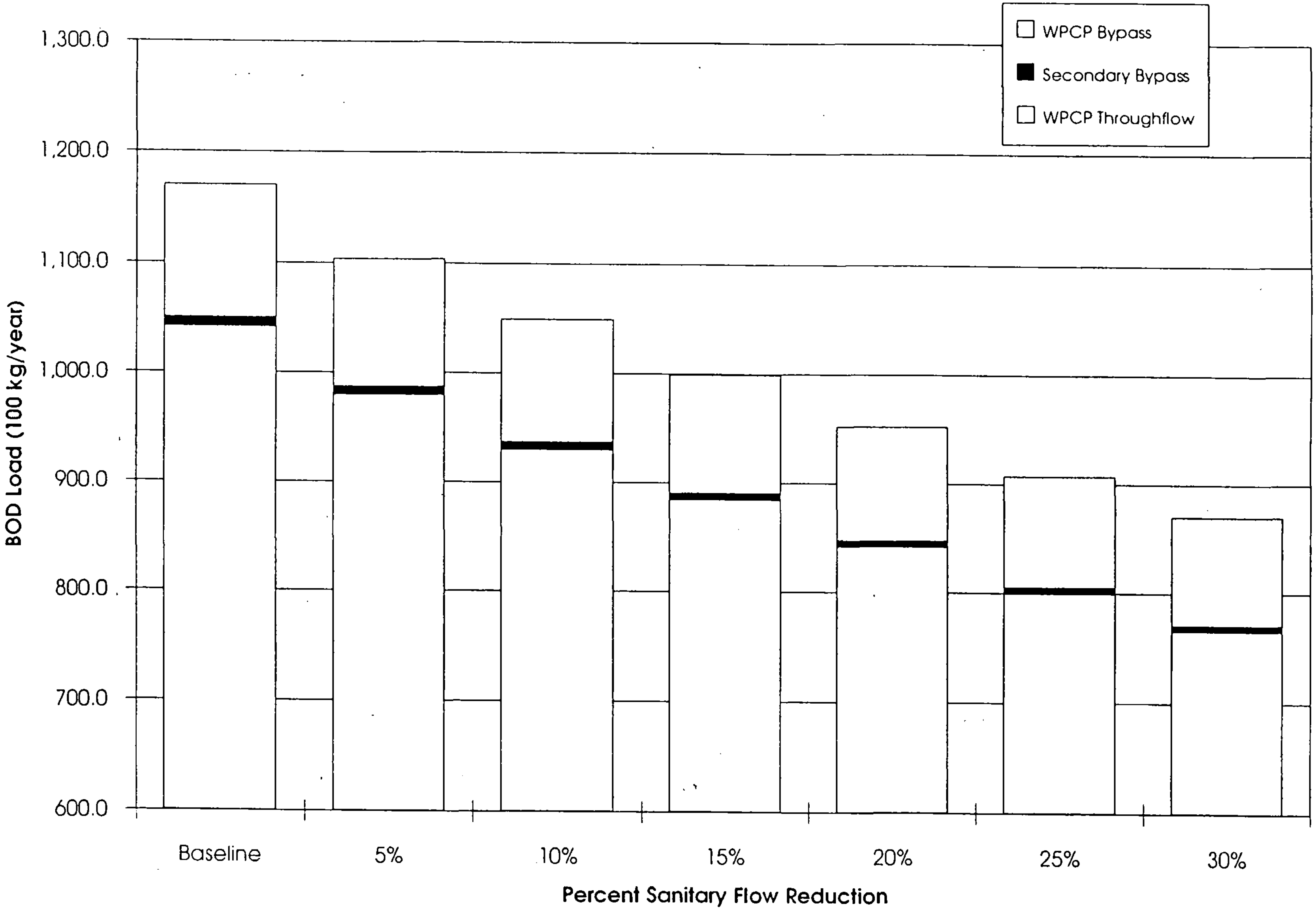

Figure 7.26 - Effect of sanitary flow reduction on annual BOD load to the receiving water.

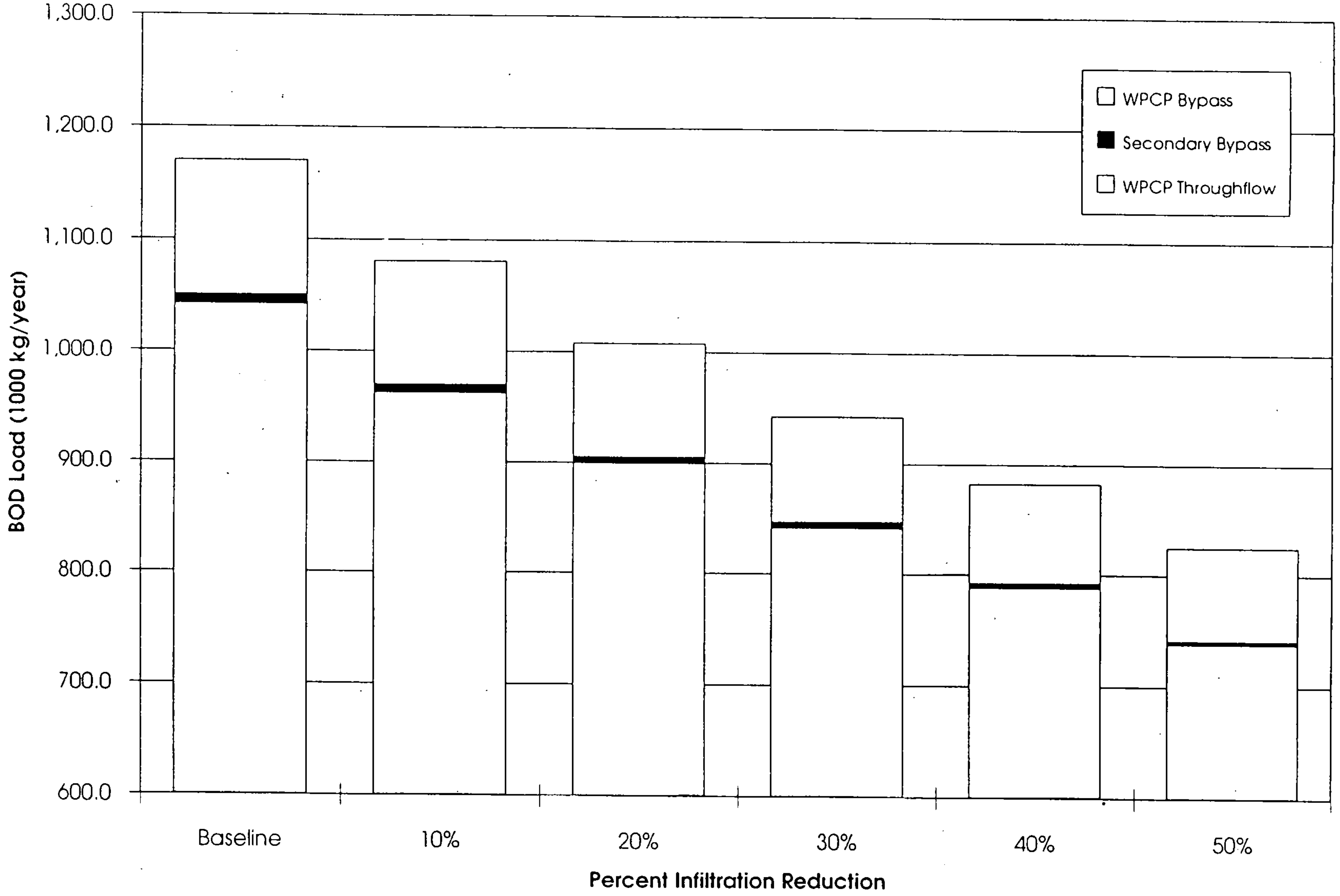

Figure 7.27 - Effect of infiltration reduction programs on annual BOD load to the receiving water.

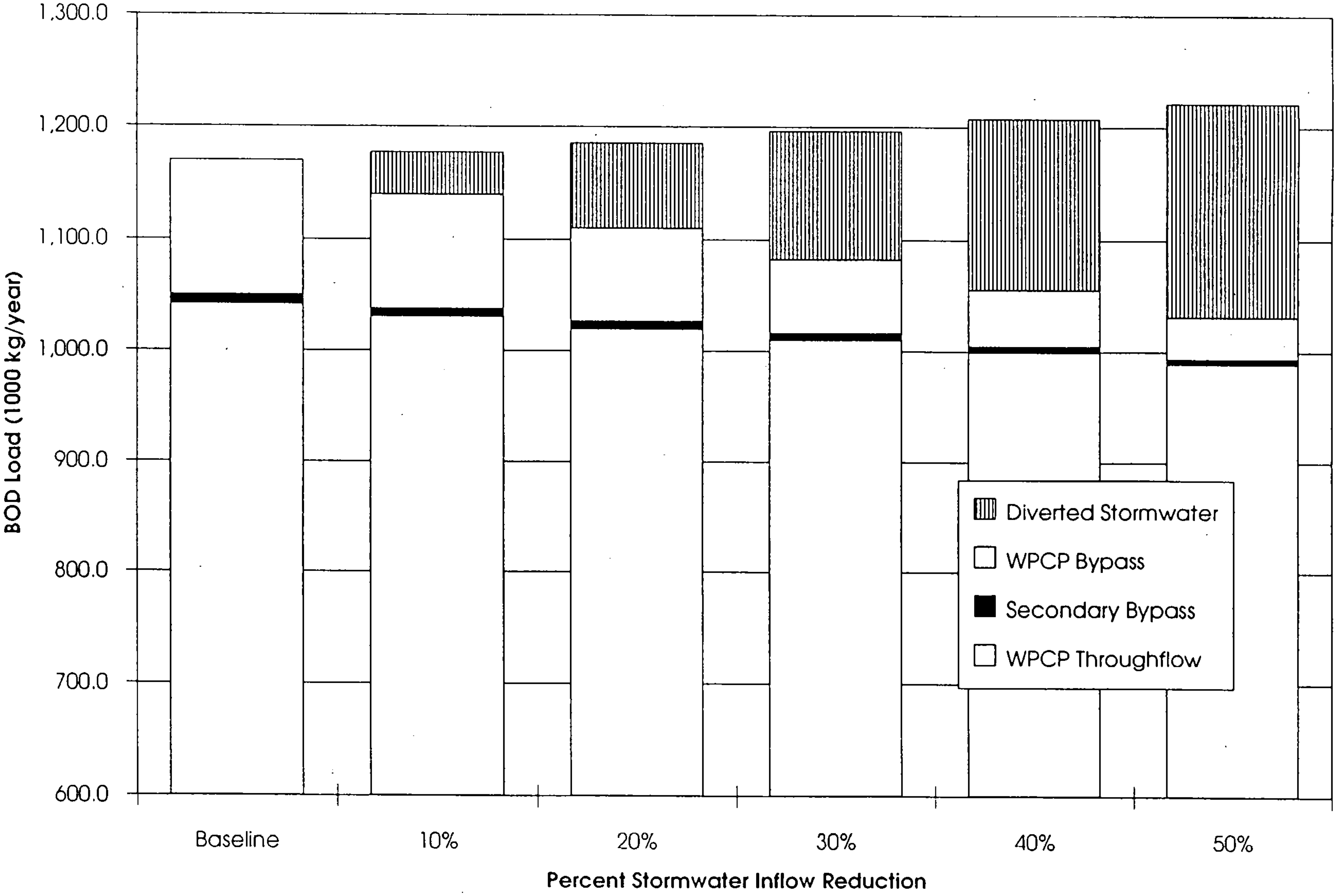

Figure 7.28 - Effect of stormwater inflow reduction program on annual BOD load to the receiving water.

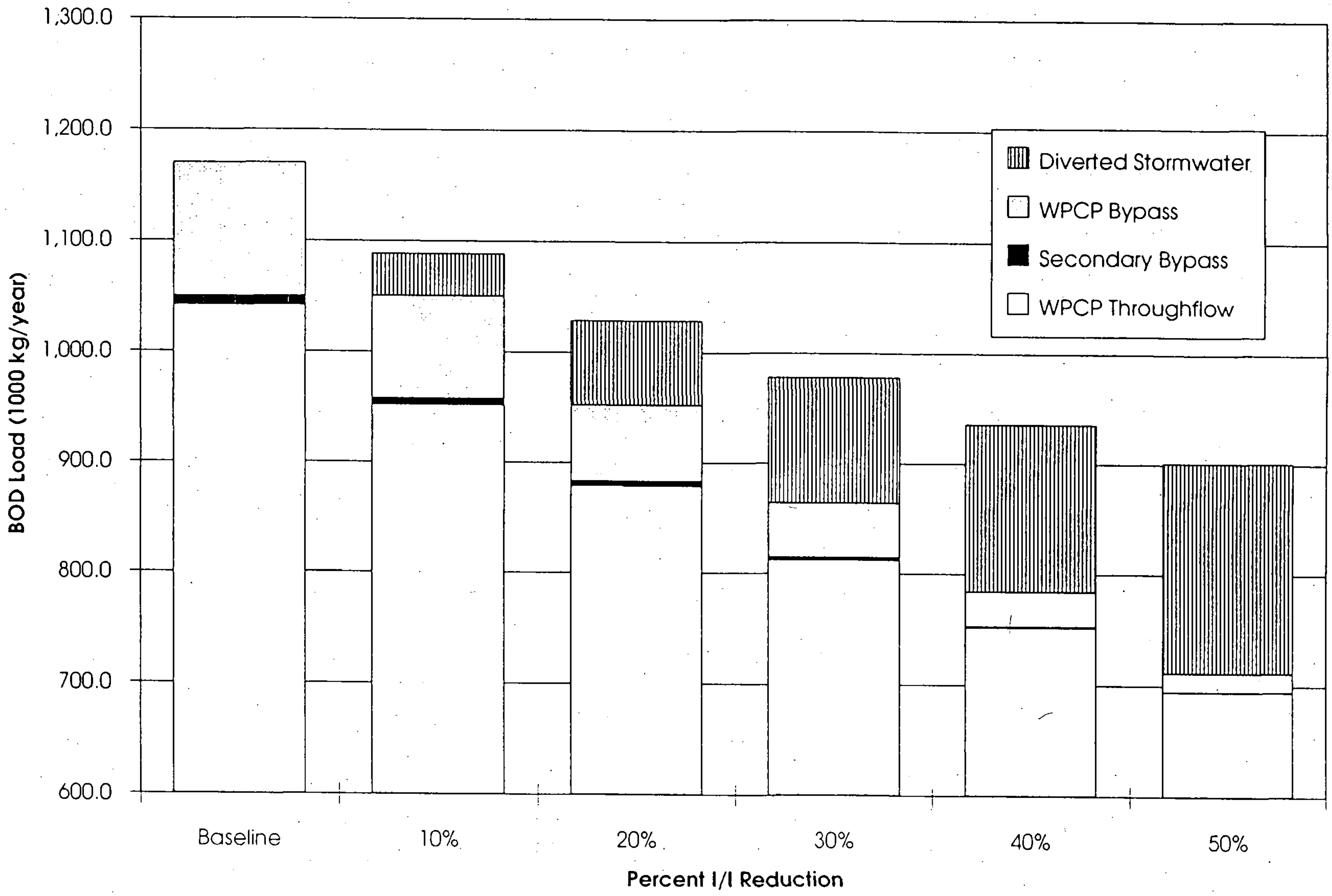

Figure 7.29 - Effect of an infiltration and stormwater inflow reduction program on annual TSS load to the receiving water.

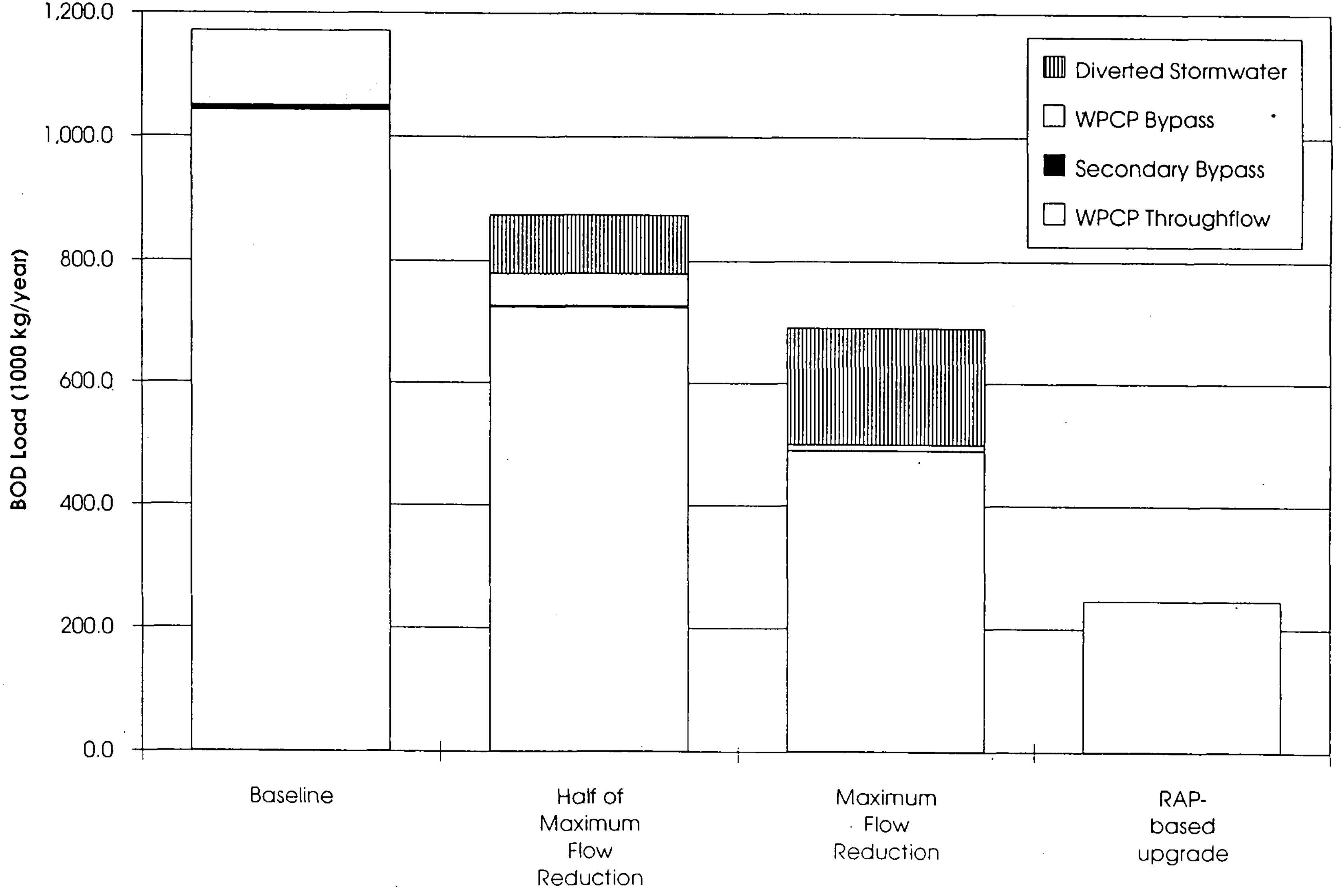

Figure 7.30 - Effect of comprehensive flow reduction programs on annual BOD load to the receiving water.

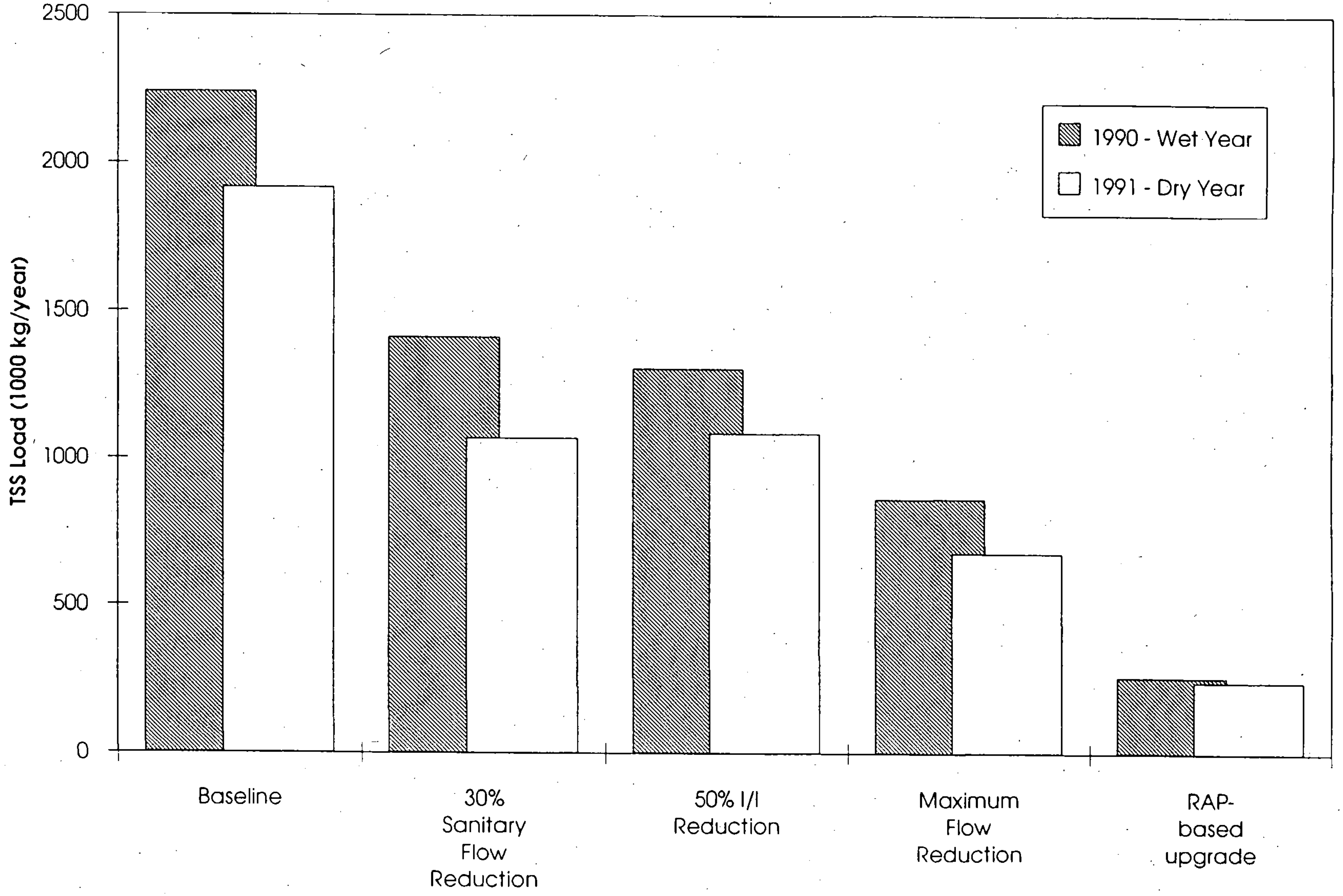

Figure 7.31 - Comparison of 1990 versus 1991 of the effect of flow reduction programs on annual TSS load to the receiving water.

Section 8
ECONOMIC ANALYSIS OF FLOW REDUCTION

This analysis focuses on the various costs and benefits associated with the implementation of a water conservation program. Costs are incurred in the development and execution of a water conservation program. Cost reductions can be gained by:

1. Reducing operation and maintenance costs of water treatment and distribution, and wastewater collection and treatment;
2. Delaying future capital works, thereby reducing the present value of the capital expenditure; and
3. Reducing the extent of current capital works.

8.1 IDENTIFICATION OF FLOW REDUCTION PROGRAMS

Key elements that can be used in developing flow reduction programs are shown in Table 8.1.

Table 8.1 - Elements of water conservation and flow reduction programs.

Flow Component	Program Element	Code #
Sanitary Flow Reduction^(a)	Pricing policy (magnitude and structure)	1
	Residential water reduction devices.	2
	Public Education	3
	Industrial/Commercial Liaison	4
I/I Reduction Program	Infrastructure needs study	5
	Sewer rehabilitation and repair	6
	Home roof disconnection	7
	Sewer separation	8
Combined Program	Database development	9
	Conservation and I/I monitoring	10
	Conservation and I/I enforcement	11

Notes:

(a) Sanitary flow reduction will be achieved through water conservation techniques. This report does not investigate water distribution leakage repair since it does not significantly impact WPCP influent flows.

Table 8.2 defines several possible flow reduction programs that are composed of some of the program elements defined in Table 8.1. Although the table shows approximate flow reductions that may be achieved with each program, it is difficult to directly link, at this point, flow reductions to program effort and costs. The development of a municipality specific flow reduction program will require considerable study and likely involve the use of pilot programs to test proposed flow reduction programs.

Table 8.2 - Water conservation and flow reduction programs investigated.

Program	Program Elements	Approximate Flow Reductions
New pricing policy only	1	5% SF reduction
Residential water use reduction (includes meters)	1, 2, 3	10% SF reduction
Comprehensive water conservation	1, 2, 3, 4	30% SF reduction
Intensive I/I reduction	5, 6, 7	50% I/I reduction
Water conservation and low I/I reduction	1, 2, 3, 4, 9, 10, 11	30% SF and 10% I/I
Water conservation and high I/I reduction	1, 2, 3, 4, 5, 6, 7, 9, 10	30% SF and 50% I/I

Definitions:
SF - sanitary flow
I/I - stormwater inflow, rainfall derived infiltration and dry weather infiltration
Note: (a) - Both programs are essentially the same but examine high and low sanitary flow reductions.

These programs and the underlying assumptions are discussed in more detail Section 8.3. The description of flow reduction program elements is divided into two parts:

1. Water conservation (Section 8.1.1); and
2. Inflow and infiltration reduction (Section 8.1.2).

8.1.1 Water Conservation

A water conservation program can be pursued through a number of initiatives. These can include indirect economic techniques such as:

1. Increase the price of water and sewer use.
2. Changes to water rate structures that promote conservation.

Other effective programs include:

1. Installation of water meters.
2. Public education program.
3. Residential audits which include the distribution of water conservation kits (low flow faucets and showerheads, toilet dams). An additional aspect of the audit could be home inflow/infiltration inspection.
4. Monitoring of water use and water conservation through a database of water users.
5. Development and enforcement of tougher water use and sewer use guidelines.
6. Industrial/commercial water use program.

Other structural techniques are not included in this analysis because they have a negligible impact on wastewater treatment plant flows (e.g., distribution system leakage detection and repair, lawn and garden watering restrictions) or are not readily applicable by a wide number of existing water users (greywater systems).

Descriptions of possible water conservation programs and cost breakdowns are provided in Appendix D. Table 8.3 shows *an example of a possible comprehensive water conservation program.* Note that this is not **the** proposed workplan for a water conservation program in Hamilton. It is a potential, high impact, high visibility, program used to estimate order of magnitude costs for a comprehensive water conservation program. Time and resources beyond the scope of this project would be required to develop a detailed water conservation program, and to estimate more precisely the costs and impacts of a water conservation program on water use.

Table 8.3 - Example comprehensive water conservation program.

Years	Programs	Cost (in 1992 dollars)	Employment Creation
1	Database Development	$175,000	1
	Public Education	$520,000	3
	Audit Development	$350,000	3
	Pricing Policy Development	$220,000	1
	Total	**$1,265,000**	**8**
2-6	Conservation and I/I Monitoring	$73,000	1
	Conservation and I/I Enforcement	$365,000	6
	Residential Audits	$6,100,000	25
	Industrial/Commercial Liaison	$230,000	3
	Total per Year	**$6,768,000**	**35**
6 on	Conservation and I/I Monitoring	$73,000	1
	Conservation and I/I Enforcement	$365,000	6
	Total per Year	**$438,000**	7

The total present value of the first 6 years of the program summarized in Table 8.3 is roughly $30 million. The range of total present value of the cost during the first 6 years for the programs in Table 8.2 is roughly $30 to $45 million. After 6 years, the monitoring and enforcement program will cost roughly $500,000 per year (in 1993 dollars). The Hamilton Harbour RAP report shows an estimate of $14 to $18 million in capital and development costs, with an annual operating cost of $500,000 to $700,000 per year. A significant part of these costs is the installation of approximately 50,000 water meters. To illustrate the importance of water metering, the following policy statement is quoted from the American Water Works Association (1992):

> **"AWWA recommends that every water utility meter all water taken into its system and all water distributed from its system to its users.**
>
> Metering of all water services is an effective means of improving and maintaining the close control of water system operations necessitated by the increasing difficulty in obtaining adequate water supplies and the increasing costs of providing water services to consumers
>
> Charging for water service on the basis of metered consumption provides a means of assessing users equitably for water service. Metering also provides a data base for system

performance studies and ***aids in the evaluation of conservation measures*** [emphasis added]. It improves accountability for water delivered through the system and, therefore, facilitates management decisions.

Continual and periodic testing of meters is an essential part of a universal metering program."

8.1.2 Inflow and Infiltration Reduction

Several methods are available to reduce the inflow and infiltration into the wastewater collection system. These include:

1. Separation of combined collection system by building storm sewers specifically for transporting rainfall runoff directly to a receiving water.
2. Repair or rehabilitation of sewers, laterals, and manholes.
3. Elimination of direct discharges to the sanitary system by storm drains, roof leaders, cellar drains, weeper drains.
4. Sump pump installation

Sewer separation costs are estimated to be in the order of $1 billion to separate the combined portion of the City of Hamilton sewer system. The cost will vary, depending if:

1. A shallow storm sewer is built to collect road drainage only, or
2. A deep storm sewer is built, and all laterals checked for inflow sources and reconnected as necessary.

The $1 billion calculation is based on 5400 ha of combined serviced area in Hamilton. The estimate assumes 200 metres of combined sewer per hectare, or roughly 1000km of sewer, and a replacement cost of $1000/m of sewer. The $1000/m of sewer includes labour, machinery, excavation, materials, road resurfacing, contingency, and engineering. The impact of massive traffic disruptions cannot be quantified.

In addition, sewer separation will not provide 100% inflow and infiltration reduction. Although massive I/I reductions were modelled with respect to WPCP hydraulic load reductions (for demonstration purposes), the cost of sewer separation has not been pursued further in this study. This is justified by comparing the costs of sewer separation with the estimated $285 to $366 million required in the Hamilton-Wentworth area to restore Hamilton Harbour. Complete sewer separation would cost far more than all RAP projects combined in the Hamilton-Wentworth area, and would not provide the pollutant load reduction provided by the proposed RAP projects. Finally, it must be recognized that although sewer separation will reduce WPCP effluent load, and collection system CSO loading, it will direct huge volumes of rainfall runoff directly into natural watercourses. Urban runoff is often highly polluted, and complete sewer separation "generally provides only a marginal reduction in pollutant loading" and "in some cases the loading of some water quality parameters" may increase. (Paul Theil Associates Ltd., et al., 1991) as was confirmed by the simulation results presented in Section 7. Therefore a costly sewer separation program may need to be followed with a stormwater treatment program.

Other options for pursuing partial I/I reduction include:

1. Roof downspout disconnection,
2. Structurally based sewer repair and rehabilitation,
3. Selected sewer separation projects for redirecting of flows due to capacity restrictions.

The Hamilton-Wentworth Pollution Control Plan (Paul Theil and Associates Ltd., and Beak Consultants Ltd., 1991) estimates a roof downspout disconnection program will cost $15 million. This assumes $100 per disconnection if each residential downspout is disconnected. This project assumes a roof disconnection program will be incorporated in the home audit program described in Appendix D and the cost of roof disconnection is included in the audit cost.

Inflow and infiltration may also be reduced through a focused sewer repair and rehabilitation study. The primary purpose of these structural changes is not flow reduction, but for structural reasons and capacity restrictions. The magnitude, cost, and effect of these projects has not been estimated for this project since they would require an Infrastructure Needs Study (INS). An INS study would likely cost in the order of $500,000 - $1,000,000 for a city the size of Hamilton and would include:

1. Flow monitoring;
2. Smoke and dye testing; and
3. Videotaping of sewers.

Even given these uncertainties, the effects of various levels of inflow and infiltration reductions on WPCP were modelled for demonstration purposes.

8.2 ECONOMIC BENEFITS OF FLOW REDUCTION

8.2.1 Reduction of Operation and Maintenance Costs

Details of water and wastewater treatment operation and maintenance (O&M) costs are shown in Appendix D. Generally, O&M costs were divided into:

1. Fixed costs;
2. Flow dependent variable costs;
3. Influent pollutant load dependent variable costs (for wastewater treatment only).

Variable costs are primarily due to energy (electrical) and chemicals, with some variability due equipment repair and replacement. Influent pollutant load dependent variable costs are due to residuals (sludge) handling.

From Appendix D, if flow changes, but the influent pollutant load remains constant, then wastewater treatment variable O&M costs are:

$$\Delta\$_{WPCP} = 4821 \times \Delta Q_{WPCP}$$

If flow changes, and influent pollutant load changes proportionately to flow, then wastewater treatment variable O&M costs is:

$$\Delta\$_{WPCP} = 8471 \times \Delta Q_{WPCP}$$

where:

$\Delta\$_{WPCP}$ - change in annual WPCP operating cost
ΔQ_{WPCP} - change in annual average WPCP flow rate expressed in ML/d

From Appendix D, change in annual O&M cost as a function of change in average daily flow for the water treatment plant is:

$$\Delta\$_{WTP} = 12,236 \times \Delta Q_{WTP}$$

where:

$\Delta\$_{WTP}$ - change in annual WTP operating cost
ΔQ_{WTP} - change in annual average WTP flow rate expressed in ML/d

Note that the water treatment plant is currently operated in the evenings to avoid peak hydroelectric charges. As water use increases, or non-peak hydro hours decreases (as recently occurred), the marginal cost of electrical energy may increase significantly. Table 8-4 illustrates the cost savings associated with various levels of flow reduction using the previous equations.

Table 8-4 - Example annual operation and maintenance cost savings due to flow reductions.

Average Annual Flow Reduction (ML/d)	Anuual WPCP Flow Variable Savings	Annual WPCP Flow and Load Variable Savings	Annual WTP Flow Varaible Savings
10	$48,210	$84,710	$122,360
20	$96,420	$169,420	$244,720
30	$144,630	$254,130	$367,080
40	$192,840	$338,840	$489,440
50	$241,050	$423,550	$611,800
60	$289,260	$508,260	$734,160
70	$337,470	$592,970	$856,520
80	$385,680	$677,680	$978,880
90	$433,890	$762,390	$1,101,240

Notes:

1. A given flow reduction scenario does not necessarily mean equal flow reductions at the WTP and WPCP.
2. Flow reductions shown are for illustrative purposes only.
3. Flow variable savings are associated with sanitary flow reduction.
4. Flow and load variable savings are associated with I/I reduction.

An additional complication is the effect RAP based upgrades will have on annual O&M costs. The RAP report provides an estimate of $2 to $6 million per year in operating costs for collection system combined sewer overflow and primary expansion at the Woodward WPCP. The report estimates a further $1-2 million in annual operating costs due to effluent filtration at Woodward. For this study, an estimate of variable costs for CSO control is:

$$\Delta\$_{CSO} = 6250 \times \Delta Q_{WPCP}$$

and for WPCP effluent filtration:

$$\Delta\$_{filtration} = 1563 \times \Delta Q_{WPCP}$$

Combined Sewer Overflow (CSO) variable control costs assume $2 million per year in variable costs for an average annual flow of 320 ML/d while WPCP effluent filtration assumes an annual variable cost of $500,000 for an annual average flow of 320 ML/d.

8.2.2 Reduction of Capital Costs

By reducing flows, capital cost savings can also be realized. These include:
1. Extending the time until the next required capacity upgrade.
2. Reduce the costs of RAP based CSO and WPCP control upgrades

Capital costs savings were not considered for the WTP since it has appears to have sufficient capacity for the foreseeable future.

Assuming annual flow increases as indicated in Section 7, current plant average capacity (410 ML/d) will be exceeded in the year 2015 which indicates a plant capacity upgrade will be required at that time. If the flow growth rate is constant for the foreseeable future, flow conservation measures could extend the current plant life an additional 35 years, to the year 2050. Delaying a capital expenditure for 35 years has a value. An example is presented in Table 8.5 for an upgrade that would cost $50 million if implemented today and assuming an average 5% inflation rate and an average 10% interest rate.

Table 8.5 - Example of present value analysis of delayed WPCP capital work.

Case	Year	Inflated Value	Present Value
If upgraded today	1993	$50,000,000	$50,000,000
Required upgrade - no conservation	2015	$169,000,000	$15,600,000
Required upgrade - with conservation	2050	$934,000,000	$3,100,000

Therefore the present value of delaying the upgrade is $12.5 million dollars ($15.6 million - $3.1 million). The capital cost of future capacity upgrades, here estimated at $50 million, is very uncertain.

Additional capital cost can be saved in the near future by reducing the RAP based plant and CSO upgrades based on reduced flows due to water conservation. However, the effects of any RAP-based upgrades on future capital expansions must be estimated. A better estimate of these future upgrades and RAP-based upgrades and controls will be possible after the current Woodward WPCP Facility Planning project is completed. Also note that the capacity upgrade term is an important aspect of the cost-benefit analysis, but that it will also vary extensively for each facility in any given municipality.

8.3 QUALITATIVE BENEFITS OF FLOW REDUCTION

In addition to the costs of implementing a water conservation program, and cost reductions due to water conservation, there are several qualitative benefits associated with a water conservation and flow reduction program. These include:

1. Reduction of pollutant loading to receiving water (Section 7),
2. Introduces, or reinforces, an awareness (and habits) of conservation in the community. This can then be applied to energy use and other consumptive practices.
3. Can provide employment (short and long term) to initiate and maintain water conservation, and inflow and infiltration reductions.
4. Frees up capacity for future development (a value can be placed on this).

8.4 COST/BENEFIT ANALYSIS

The conclusion from the cost/benefit analyses presented in Appendix D, is that, with careful planning, a comprehensive water conservation program should pay for itself in approximately 30 years. The cost benefit program shown here, and in Appendix D, assumes a five year water conservation program that costs approximately $6million annually (in 1993 dollars). This can reduced by approximately 50% by assuming the installation, and therefore cost, of water meters are not part of the water conservation program. This may be feasible since water metering has uses in addition to water conservation as outlined in the previous quote from the American Water Works Association (1992, see page 8-3). As stated earlier, the program and costs used here are only an example of a one possible water conservation program.

Specific examples of pay-back periods and flow reduction programs are shown in Table 8.6. to 8.8 which are based on an analysis of annual cost changes for various flow reduction programs shown in Table D-6 to D-11. Cost changes are defined as O&M cost decreases due to water conservation, costs of implementing water conservation, and the savings associated with delaying capital works. An additional column is included which shows the change in revenues expected due to the specified billing increase, which can be used to promote conservation.

Table 8.6 - Cost-benefit analysis of several example flow reduction programs with a 50% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue[(a)]
New pricing policy only	5% SF	$273,000	0	$20.4 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$16.8 million	> 40 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$2.4 million	32 years	13
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$2.4 million	32 years	13
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$2.4 million	32 years	13

Definition:

N.A. - not applicable
SF - sanitary flow
I/I - inflow and infiltration

Note: (a) Assumes a delayed capital works in the future which provides a present value of $5 million to $15 million.

Table 8.7 - Cost-benefit analysis of several example flow reduction programs with a 100% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue
New pricing policy only	5% SF	$273,000	0	$43.2 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$38.4 million	> 40 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$19.2 million	32 years	immediate
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$19.2 million	32 years	immediate
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$19.2 million	32 years	immediate

Table 8.8 - Cost-benefit analysis of several example flow reduction programs with a 200% water and sewer use price increase.

Program	Assumed Flow Reductions	Annual O&M Reduction	Approximate Program Cost	Annual New Revenue	Payback Period without New Revenue	Payback Period with New Revenue
New pricing policy only	5% SF	$273,000	0	$88.8 million	N.A.	immediate
Residential water use reduction (includes meters)	10% SF	$546,000	$6 million/yr for 5 years	$81.6 million	> 50 years	immediate
Comprehensive water conservation	30% SF	$1.6million	$6 million/yr for 5 years	$52.8 million	32 years	immediate
Water conservation and low I/I reduction	30% SF and 10% I/I	$1.8million	$6 million/yr for 5 years + $0.5 million ongoing	$52.8 million	32 years	immediate
Water conservation and high I/I reduction	30% SF and 50% I/I	$2.1million	$8.5million/yr for 5 years + $0.5 million ongoing	$52.8 million	32 years	immediate

The billing increases used in Tables 8.6 to 8.8 are based on the assumed need for increased revenues to pay for RAP-based capital works and the ensuing increased operation and maintenance costs. Table 8.9 shows a comparison of the "new revenues" with the cost estimates of the proposed RAP plan for projects within the jurisdiction of Hamilton-Wentworth Region. The RAP costs shown are a 10 year annualized cost and are estimated at $37 to $54 million per year, which includes $9 to $17 million in annual operating costs (Hamilton Harbour RAP Stakeholders, 1991b). Additional price increases may be justified based on the "user pay" concept, that is, if it is decided to implement a more equitable system of water billing (this aspect was not investigated for this project).

Table 8.9 - Comparison of annual new revenues at various levels of price increase to estimated annualized RAP costs.

Flow Reduction	Annualized RAP Cost ($1990)(a)(b)	New Revenues(c) from a 50% Price Increase	New Revenues(c) from a 100% Price Increase	New Revenues(c) from a 200% Price Increase
5% sanitary flow reduction	$37 to 54 million	$20.4 million	$43.2 million	$88.8 million
10% sanitary flow reduction	$37 to 54 million	$16.8 million	$38.4 million	$81.6 million
30% sanitary flow reduction	$37 to 54 million	$2.4 million	$19.2 million	$52.8 million

Notes:

(a) Annualized RAP costs do not include possible cost reductions due to flow reductions.
(b) Annualized RAP costs include capital costs and operation and maintenance costs.
(c) New revenues based on 1992 revenues from water and sewer use charges.

The flow reduction programs detailed in the spreadsheets shown in Appendix D, and summarized in Table 8.4 are only several examples of cost/benefit analyses for the described water conservation and flow reduction programs. Revisions can be made including:

1. Program element costs;
2. Estimated flow reduction due to flow reduction programs;
3. Estimated capital costs of future capacity upgrade;
4. Pumping station, WPCP, and WTP, O&M cost reduction rates;
5. Estimated RAP variable operating costs; and
6. Inflation and interest rates.

Water conservation program costs in Tables 8.6 to 8.8 all include water meter installation which is estimated to cost $2.5 to $3.8 million per year for 5 years. This estimate is based on the installation of 50,000 meters over 5 years, or 10,000 meters per year at a cost of $250 per meter (including parts and labour). The total cost range shown is due to assumed overhead costs of up to 50% that is not accounted for in the $250 installation fee. As discussed earlier, it may be feasible to remove this cost from the water conservation program since water metering has other purposes in addition to promoting water conservation.

Tables 8.6 to 8.8 are based on assumed price increases of 50%, 100% and 200%. Table 8.10 shows the effect of these, and other price increases, on a customer currently paying $100/year in sewer and water use charges.

Table 8.10 - Example of the effect of residential water use reduction and price increases on a typical water bill.

Percent Water Use Reduction	Annual Bill at Current Prices	Annual Bill at 25% Price Increase	Annual Bill at 50% Price Increase	Annual Bill at 100% Price Increase	Annual Bill at 200% Price Increase
0%	***$100*** (a)	$125	$150	$200	$300
5%	$95	$119	$142	$190	$285
10%	$90	$113	$135	$180	$270
30%	$70	$88	$105	$140	$210
50%	$50	$63	$75	$100	$150

Note: (a) Baseline case of $100/year chosen for demonstration purposes only.

Table 8.10 is for demonstration purposes only and the following factors must be taken into account when interpreting this table:

1. Actual billing in Hamilton-Wentworth is based on a flat rate (flat fee) for the first block, then a constant rate for remaining water use;
2. Flat rate block depends on the size of the water meter;
3. Price increases are assumed to affect the average price of water (i.e., both the initial flat rate and subsequent constant rate block are increased proportionately);

4. Flat rate block means that there is a minimum water bill which the consumer cannot further reduce through reducing water use; and
5. A 50% residential water use reduction is unlikely to be achieved as a community average, although some individuals consumers may achieve such reductions.

Section 9
CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to examine the effects of hydraulic load reduction on long term wastewater treatment plant performance. The intent of this report is not to provide a hydraulic load reduction program for Hamilton per se. Instead, the Hamilton Woodward WPCP and its tributary area was selected to demonstrate the potential effects of various flow reduction scenarios on wastewater treatment plant performance. In addition, the methods used in this study should be useful for dealing with hydraulic load reduction in a systematic fashion.

After disaggregating the flow into its various components (sanitary flow, dry weather infiltration, rainfall derived infiltration, and stormwater inflow), different flow reduction scenarios were examined to demonstrate these effects on WPCP effluent pollutant concentration and on total pollutant load entering the receiving water. From the analysis of the Hamilton Woodward WPCP performance under various flow reduction scenarios, the following conclusions were reached:

1. Significant reductions in TSS and BOD effluent concentrations were obtained with sanitary flow reduction and dry weather infiltration reductions;
2. Stormwater inflow reduction had only a marginal effect on WPCP effluent concentration reduction;
3. Significant pollutant loading reductions were obtained with sanitary flow reduction and infiltration reductions. This is due to the reduced hydraulic load to the receiving water coupled with the reduced WPCP effluent concentrations; and
4. The TSS loading to the receiving water decreased marginally (< 1.0%) with a 50% stormwater inflow reduction and BOD effluent loading actually increased with stormwater inflow reduction. This was because reducing stormwater inflow from the combined collection system implies that the same volume is directly diverted to the receiving water.

Hydraulic load reduction alone cannot be used at Hamilton Woodward WPCP to meet RAP specified pollutant loading requirements from the WPCP. It can, however, play a significant role in the design and expected life of currently planned collection and treatment system upgrades, including:

1. Increased expected design life of plant facilities including currently planned facility upgrades. For example a 10% sanitary flow reduction can extend the design life (based on flow) of currently planned upgrades by 10 to 15 years assuming no increases in infiltration and inflow are experienced over that time; or
2. Expected decreases in predicted future flow due to flow reduction can be used to reduce the cost of currently proposed capital works. This would include reducing the size of CSO control storage facilities and tertiary treatment at the Hamilton Woodward WPCP. By carefully staging proposed capital works and co-ordinating their design with a water conservation program, significant capital savings can be realized.

Although hydraulic load reduction did not achieve the pollutant load reductions of the RAP-based upgrades for Hamilton, it can provide significant pollutant loading reductions.

Therefore, hydraulic load reduction through water conservation or infiltration control may be sufficient for WPCPs that do not require tertiary treatment but are experiencing, or are expected to experience, capacity limiting problems.

Many options are available for reducing hydraulic loads at a wastewater treatment facility and it is important to examine the economics of various flow reduction techniques. The RAP report provides an estimate of a water conservation that includes an initial capital cost of $14 to $18 million and an annual cost $500,000 to $700,000 per year. There are three aspects that need to be explored when investigating the cost and benefits of hydraulic load reduction through water conservation and infiltration/inflow control. These aspects include:

1. Cost of implementing the flow reduction program;
2. Cost savings due the effects of reducing flows; and
3. Change in revenues due to changes in pricing policy.

Cost savings can be realized through:

1. Reduced operation and maintenance (O&M) costs: and
2. Reduced capital cost requirements or through the delay of future capital expansions.

It is important to apply the O&M and capital cost savings calculations to:

1. Water treatment facility;
2. Water distribution system;
3. Wastewater collection system (including pumping stations and CSO control facilities); and
4. Wastewater treatment facilities.

One often discussed option is the use of increased water price to promote water conservation. Theoretically, increases in water price produce a reduction in municipal water use. Increased water price alone, however attractive, is not likely to be an sufficient measure. Problems with attempting to promote water conservation through a price increase only include:

1. Water use reduction due to price increases are often temporary and eventually resume to, or near to, former levels;
2. Consumers need to be made aware of the billing increases and of methods for reducing water use (i.e., billing increases need to be accompanied by some form of public education program); and
3. Case studies show that huge billing increases are usually required to provide significant reductions in water. Using a domestic water elasticity of -0.26 (Flack, 1981), a 50% price increase would produce a 10% reduction in water consumption. It is likely that ratepayers/taxpayers would not appreciate this burden since the large increase in revenues in this scenario (35% which combines the effect of increased water cost and decreased water use) are being used to provide much smaller decreases in water and wastewater costs. In the Hamilton example, this scenario would increase revenues by approximately $17 million per year (assuming the price increase is applied to water use and sewer use) while saving only $300,000 in annual O&M costs. It is not reasonable to exert a large increase in water and sewer billing on ratepayers to achieve a marginal savings in water and wastewater costs. However, if the rate increases are justified based on the concept of user-pay and the need to pay for major capital upgrades, such as those recommended in

the RAP reports, the price increase can be used in conjunction with a comprehensive water reduction program to reduce water consumption.

A comprehensive water reduction program provides a balanced program of price increases, public education, residential water use reduction programs, and commercial/industrial water use reduction programs. In addition, this can be coupled with a infrastructure rehabilitation program to reduce extraneous flows entering the collection system. In this case marginal price increases may also be used as an incentive and to help defray short term revenues shortages due to water use reduction. This may prove necessary since a significant proportion of water and wastewater O&M cost are fixed, that is not dependent on flow rates. If billing rates are strictly a function of flow, and are not increased during a water conservation program, revenue decreases will be higher than O&M cost decreases, thereby creating a revenue shortage.

Specific programs that could be used to reduce water use and wastewater production include:

1. Pricing increases;
2. Residential audits that would include installation of low flow devices, arranging for water meter installation, and roof leader disconnection;
3. Public education program;
4. Industrial/commercial water use reduction program;
5. Infrastructure needs study and infrastructure rehabilitation and repair. This could be applied to both the public side of the collection system (sewers, pumping stations, manholes) and the private side (laterals);
6. Focused sewer separation programs; and
7. Enforcement and monitoring of I/I and water use reduction including the development and use of a database to track the municipal water budget.

Various programs could be tested as part of a pilot project in limited area of the municipality. A comprehensive program consisting of many of the above programs could cost in the order of $30 to $45 million over the next six years (which includes ~$12.5 to $19 million for residential water meter installation), with an annual cost of up to $500,000 after the six year program is complete. It could produce sanitary flow reductions of 10-30% and similar reductions in infiltration (infiltration reductions are hard to predict). Annual operation and maintenance costs reductions would be in the range of $500,000 to $2.1 million per year. The capital cost savings, which play an important factor in whether the program is feasible from a strictly economical point of view, is very hard to predict a this time. A rough estimate in the order of $5 to $15 million was made for this report based on the delay of an upgrade which would today cost $50 million.

There are other benefits that cannot be easily explained in terms of a cost/benefit analysis. Some of these qualitative benefits include:

1. Providing short term employment (1 to 5 years) during startup and implementation, and long term employment for program monitoring and maintenance; and
2. Instilling a conservationist way of thinking, and lifestyle, on the general population. This is beneficial not only in reducing water use and wastewater generation, but also with respect to other utilities (e.g., gas, electricity) as well as solid waste generation.

Summary

Conclusions can be summarized as follows:

1. A hydraulic load reduction program, particularly through water conservation and infiltration reduction, can create significant reductions in receiving water pollutant loading. This study showed TSS and BOD annual pollutant load reductions of 10% to 45% for various cases hydraulic load reduction.
2. For the Hamilton Woodward WPCP, hydraulic load reductions alone are not sufficient to achieve targeted effluent pollutant loads targeted by RAP, or that can be expected by the RAP-based upgrades.
3. RAP-based increases in water and sewer use rates can be used as an incentive for water conservation.
4. Annual operation and maintenance cost savings associated with reduced hydraulic load reduction, while significant, are lower than the projected costs of a comprehensive flow reduction program. Therefore, from a strictly economic cost-benefit point of view, the savings in capital expenditure due to flow reduction will determine if a hydraulic load reduction program is economically viable.
5. Expected decreases in predicted future flow due to flow reduction can be used to reduce the cost of currently proposed capital works. This would include reducing the size of CSO control storage facilities and tertiary treatment at the Hamilton Woodward WPCP. By carefully staging proposed capital works, and co-ordinating their design with a water conservation program, significant capital savings can be realized.
6. A better estimate of the effects of hydraulic load reduction on capital expenditures will be attainable after the completion of the Hamilton Woodward facility plan currently under development. It may be desirable to integrate the development of a water conservation plan with the staging and design of the treatment plant upgrades.

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APPENDIX A

Modelling, Simulation and Operational Control of Wastewater Treatment Plants Using the General Purpose Simulator

Modelling, Simulation and Operational Control of Wastewater Treatment Plants Using the General Purpose Simulator

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1. Introduction

Wastewater treatment plants consist of an assemblage of inter-dependent biological, physical and chemical processes operating under time-varying hydraulic and organic load conditions. While treatment plants are usually designed under steady-state conditions, the performance of these facilities is sensitive to both the time-varying loads they receive as well as to a number of environmental factors, both of which are beyond the control of operators. Such transients frequently result in short and medium-term effluent quality violations. The premise of this paper is that the simulator-based technologies centered around state-of-the-art dynamic process models can assist in the planning, design and operation of wastewater treatment plants. The first part of this paper describes the basic components of a comprehensive wastewater treatment modelling program. In the second part of the paper, the focus is on the application of the simulator to study the effect of shock loads at the Hamilton Wastewater Treatment Plant.

2. Elements of the General Purpose Simulator

The General Purpose Simulator (**GPS**) is a comprehensive software package for the simulation, analysis and control of wastewater treatment plants. Developed on a SUN workstation (Unix-based minicomputer) under Sunview, the package is now being converted to XView and is expected to run on a number of additional platforms including VAX, Macintosh, and Unix-based microcomputers.

The General Purpose Simulator provides a general approach to the analysis and simulation of wastewater treatment plants. The programme can be used to assist in the analysis, design, operation and control of wastewater treatment processes. In addition, the simulator can effectively be used for operator training purposes in much the same way as other industry simulator training packages.

The programme takes advantage of some of the most advanced hardware and software developments. An icon-based/object-oriented approach is used whenever possible to provide a natural interface between the programme and the user. In addition, the user is free from the tedious tasks of programme coding and debugging; the GPS writes ***error-free*** simulation code for the specified dynamical system. In this way, the engineer can devote more time to process understanding and development.

The General Purpose Simulator consists of three major components (programmes):

- **Screen-Oriented Modelling Interface (SOMI)**

  SOMI is graphics-based programme designed to facilitate the specification of a complex wastewater treatment plants. The graphical description of the system, including process connectivity, initial conditions and process parameters are automatically translated into ACSL - a Fortran-based continuous simulation language (Mitchell and Gauthier Associates, 1986). ACSL runs on a large number of hardware platforms ranging from micros to super-computers. SOMI-generated code will run on all ACSL supported platforms. SOMI facilitates the analysis of dynamical systems by providing a complete set of tools, including icon-based flow sheet specification, object-oriented program development, and context sensitive help, all of which are integrated in a state-of-the-art windowing environment.

- **Special ACSL Script File (SACSL)**

SACSL is a Unix script file that provides the interface between the SOMI-generated ACSL code and the Interactive Simulation Interface (ISI). In addition to the C-shell file, SACSL consists of the library of graphical routines used by the Interactive Simulation Interface. The SACSL script file provides the necessary instructions for the compilation, linking and execution of the ACSL-generated code. The interactive simulation of a dynamical system requires that SACSL be used; otherwise, the user will be restricted to the usual ACSL batch mode of operation.

- **Interactive Simulation Interface (ISI)**

The Interactive Simulation Interface provides an interactive environment for on-line control of an ACSL simulation. First of all, the ISI provides graphical and digital displays of system variables. Secondly, through the ISI a user can control (modify) any of the control variables within a simulation *as the simulation progresses*. This way, the user can immediately assess the impact of a change in control variable, process parameter, or any other system variable that a user might have changed during the course of a simulation. Finally, the ISI provides access to a number of simplified ACSL commands through simple slider bar and/or button operation, as well as a convenient steady-state analysis routine. It should be noted that the ISI is independent of SOMI. In fact, this portion of the simulator is designed to work with **any** ACSL code compiled with SACSL.

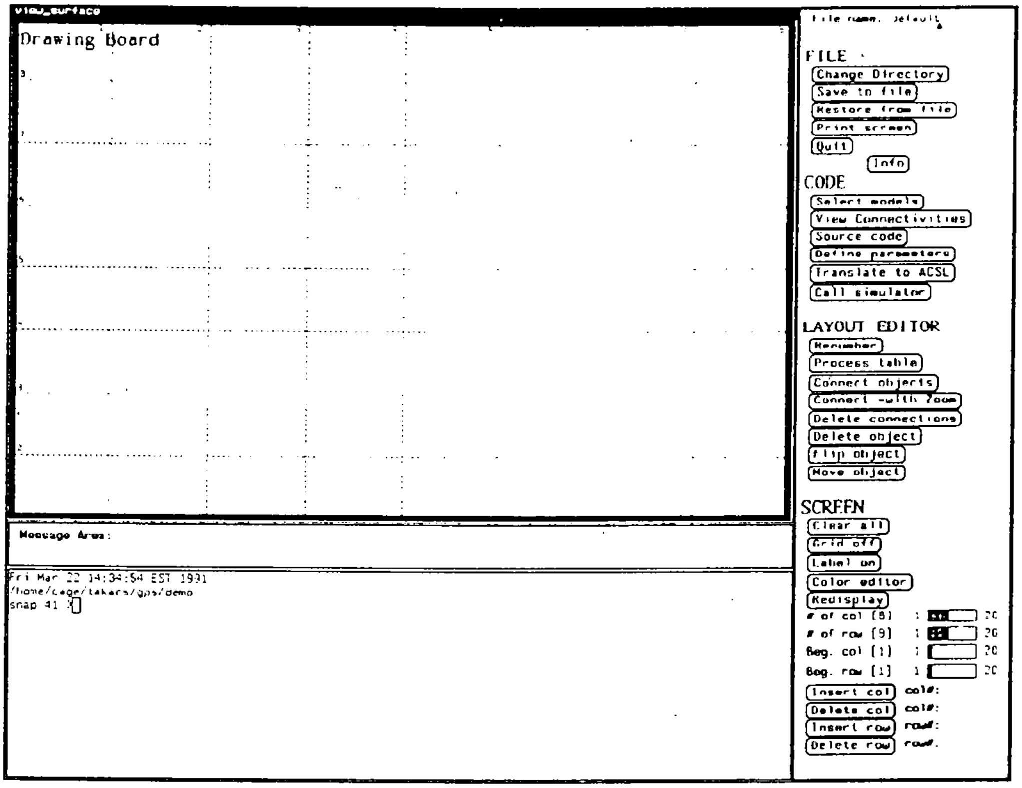
3. A Closer Look at the GPS

After issuing the SOMI command, the workstation screen shown in Fig. 1 will be displayed. The screen is divided into four windows:

• **Drawing board**	Window area for the specification of the wastewater treatment flow sheet.
• **Message area**	Window area used by SOMI to display messages and/or warnings on the use of certain commands or mouse keys.
• **Unix window**	Window area used for the usual Unix commands issued by either the user or SOMI.
• **Command window**	Window area providing access to the full functionality of SOMI through the use of buttons or pull-down menus.

3.1 Flow Sheet Specification

The first step in creating a new flow sheet on the drawing board is to open the **Process table** window. This is done by selecting the appropriate command in the **Command** window. A window containing the icons of all GPS processes will appear on the screen. The user selects the appropriate unit processes from the **Process table** window and drags them into position on the drawing board as shown in Fig. 2. After all units have been placed on the Drawing board, the user specifies their connectivity using the `Connect objects`. The flow sheet shown in Fig. 2 is rather simple, consisting of an influent stream, a flow combiner, a biological reactor, a settler and a flow splitter.



File name: default

```
Fri Mar 22 14:34:54 EST 1991
/home/cage/takacs/gps/demo
snap 41 %
```

# of col (8) 1 20
# of row (9) 1 20
Beg. col (1) 1 20
Beg. row (1) 1 20
col#:
col#:
row#:
row#:

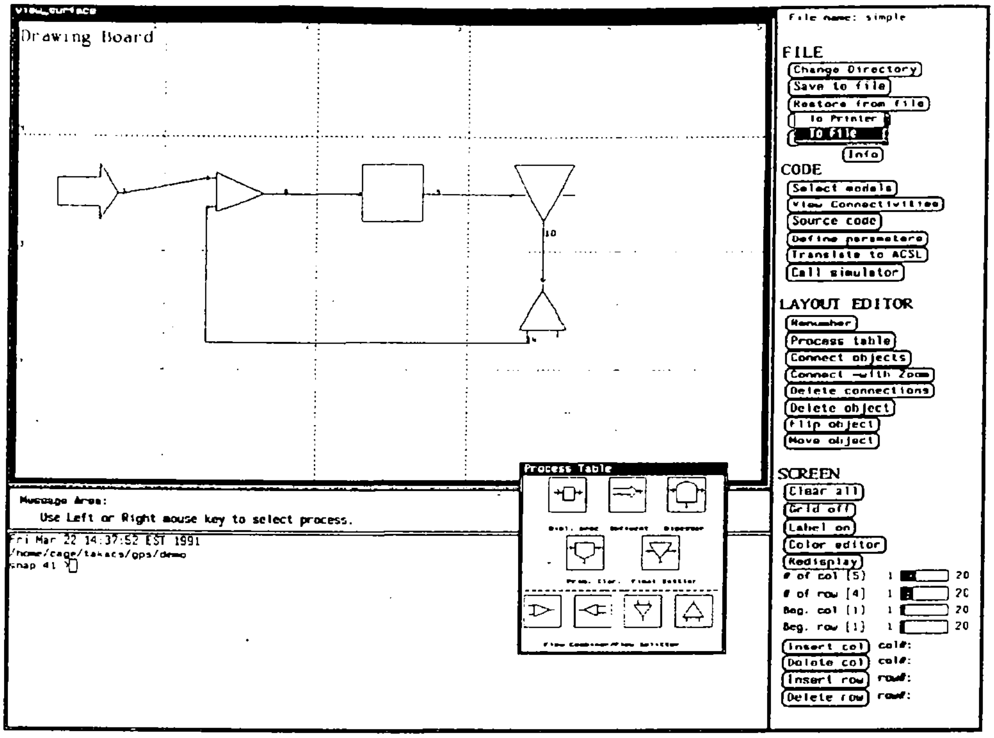
Fig. 1. Opening screen of the Screen-Oriented Modelling Interface (SOMI).

3.2 Complex Flow Sheets

SOMI can handle more complex flow sheets. For example, the full layout of the Hamilton Water Pollution Control Plant is shown in Fig. 3. In this case, the Drawing board was resized to the full workstation screen to enhance the details of the flow sheet. It may not always be necessary and/or possible to provide as much detail as shown in Fig. 3. In fact, flow sheet simplifications are recommended whenever possible. Projects rarely require that all processes be individually modelled. The user should take note of the following points:

- Even with the most powerful minicomputers, the solution of a flow sheet as complex as the one shown in Fig. 3 requires a large amount of memory and CPU time, thereby limiting the usefulness of the modelling exercise. For example, the complete solution of the Hamilton plant requires that more than 1100 nonlinear ordinary differential equations be solved simultaneously.

- Even if memory and CPU time were not an obstacle, it is questionable whether the calibration/verification of all processes in such a complex plant is feasible.



Message Area:

Use Left or Right mouse key to select process.

```
Fri Mar 22 14:37:52 EST 1991
/home/cage/takacs/gps/demo
snap 41 >
```

Fig. 2 Completed flow sheet.

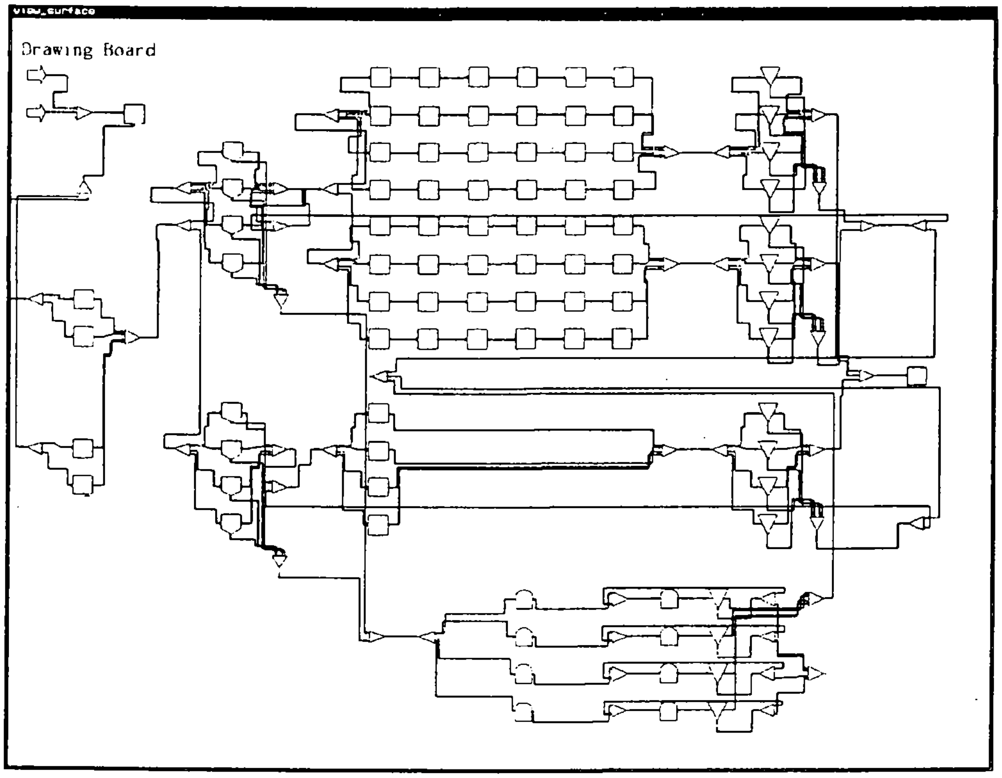


Fig. 3 Complex flow sheet of a municipal wastewater treatment plant.

A more rational approach is to develop a simplified flow sheet of the plant. In general, this is done without significant loss of information. For example, if parallel processes with comparable load are lumped together, the flow sheet can be simplified greatly. A simplified version of the Hamilton plant is shown in Fig. 4. In this way, the number of state variables was reduced to 105, while the number of flow lines was reduced from 180 to 39.

3.3 Process Models

For the first part of this paper, the basic functionality of the GPS will be illustrated using the example shown in Fig. 2. Having specified the sequence of units in the wastewater treatment plant, the user must now identify the appropriate process model for each unit. This is done by pressing the `Select models` button in the Command window and pointing to the appropriate process icon on the Drawing board. A library of models, in the form of a pull-down menu appears on the screen close to the unit in question (Fig. 5).

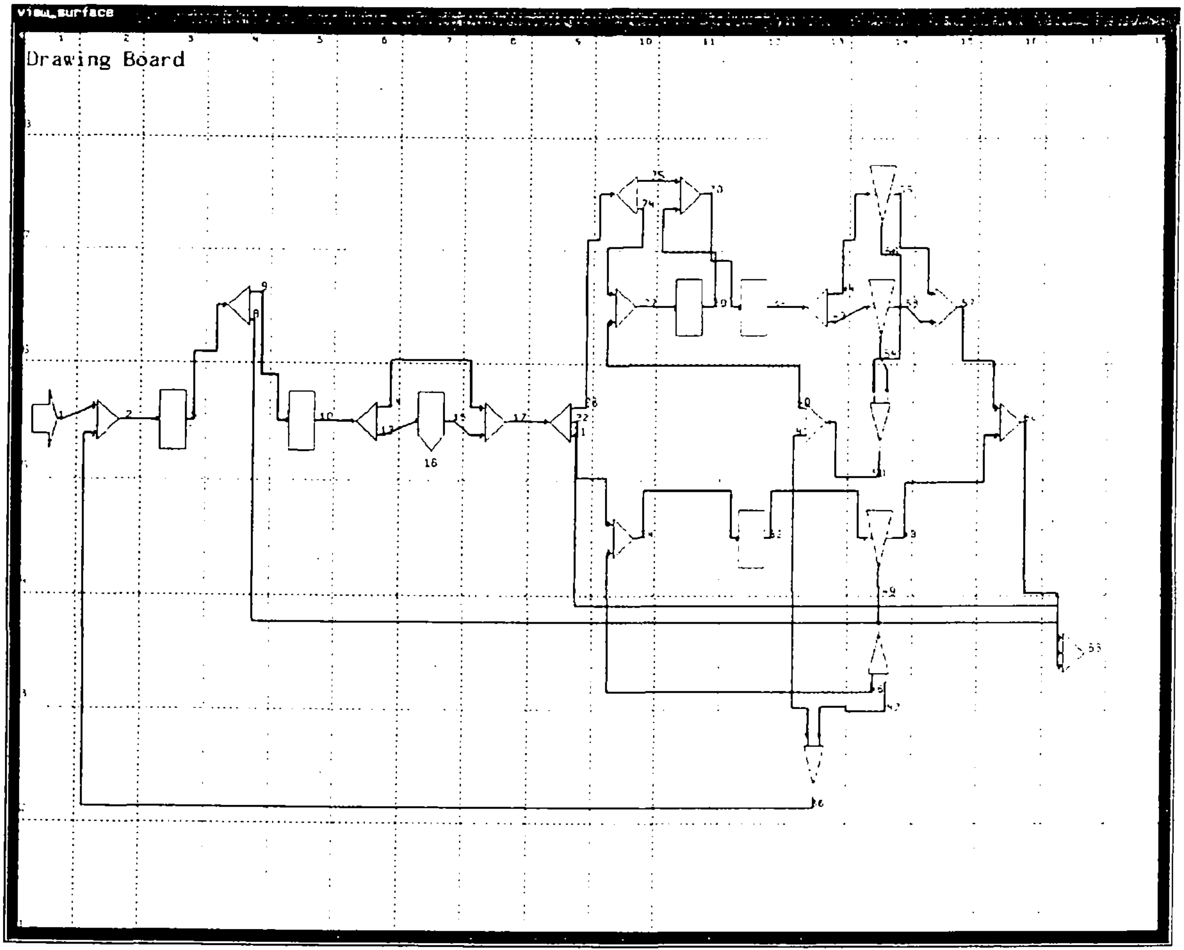


Fig. 4 Simplified flow sheet of the plant shown in Figure 3.

In its present form, the wastewater treatment library consists of approximately 45 processes and interface macros. The number is expected to reach 60-70 by the time the software is officially released. The library of process macros is summarized in Table 1.

Once a model has been selected, the source code of the underlying macro can be viewed and/or edited, as shown in Fig. 6. The experienced user can modify an existing model to meet his/her specific needs, thereby increasing the flexibility of the library.

3.4 Process Parameters

Having selected the models, the user should then review and modify the set of all process parameters. More specifically, three types of parameters should carefully be reviewed, including:

a) initial conditions;
b) hydraulic data; and
c) process data and coefficients including the physical characteristics of the units (volume, area, depth, etc.), as well as stoichiometric and kinetic coefficients.

Table 1. Subset of models in the General Purpose Simulator.

Aerobic Biological Model

• Olsson1	Olsson's four compartment model .
• Olsson2	Olsson's filamentous model
• Olsson3	Olsson's stored substrate model
• Olsson4	Olsson's nitrification model (A)
• Olsson5	Olssons nitrification model (B)
• SML	Marsili-Libelli nitrification model
• VP	VITUKI simplified bio-P model
• VNP	VITUKI nitogen-phosphorus model
• cmodel	carbonaceous IAWPRC sub-model
• IAWPRC	activated sludge Task Group model
• enhanced_P	enhanced bio-P culture model (Dold)
• mac_P	IAWPRC plus bio-P model (Dold)

Anaerobic Biological Models

• Andrews	Andrews' digester model
• VANAM	VITUKI 3-biomass model
• Moletta	Moletta's digester model
• Pavlosthatis	Pavlosthatis' digester model

Hydraulic Units

• comb_5	flow combiners
• splitt_5	flow splitters
• hydraulic	no reaction basin

Integrated Final Settler Models

• mac_basic	no reaction mac settler
• mac_iawprc	IAWPRC reaction settler
• mac_SBR	variable volume settler

Primary Settler Models

• Lessard/Beck	model of Lessard/Beck
• mac_basic	no reaction settler
• mac_IAWPRC	IAWPRC reaction settler
• mac_SBR	variable volume settler

Final Settler Models (Thickening)

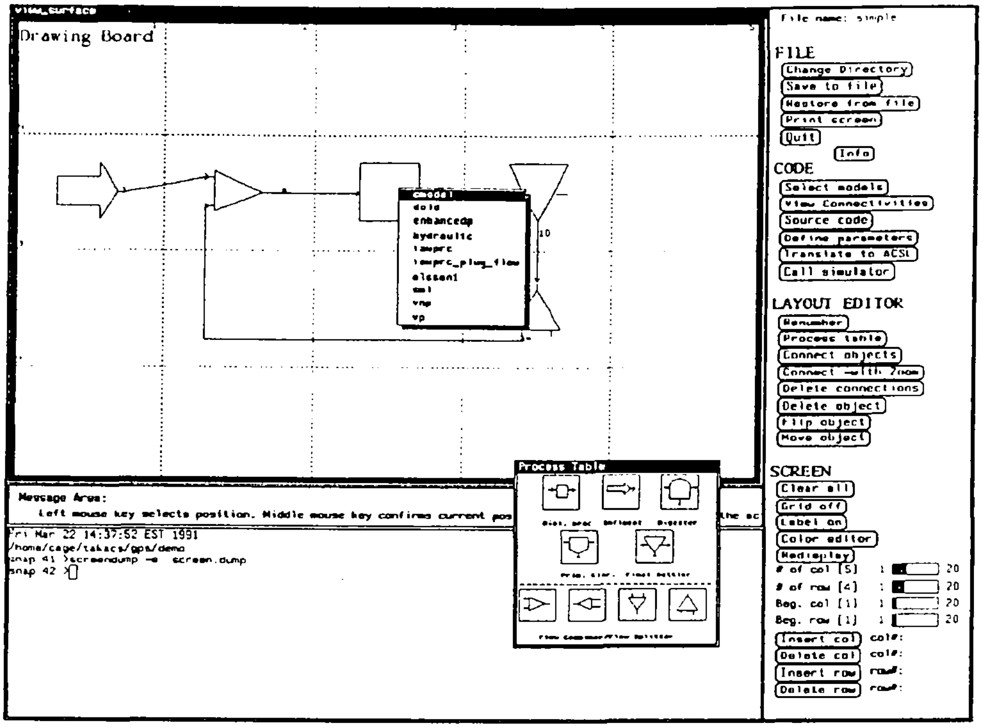
• Vitasovic	Vitasovic settler (model 1)
• Vitasovic2	Vitasovic settler (model 2)
• Olssona	steady-state settler
• Stefhest	simplified dynamic model
• SML	Marsili-Libelli
• point_settler	zero volume settler

Final Settler Models (Clarification)

• Pflanz	Pflanz's statistical model
• Hill	Hill's statistical model
• Chapman	Chapman's model

Process Configurations, among others:

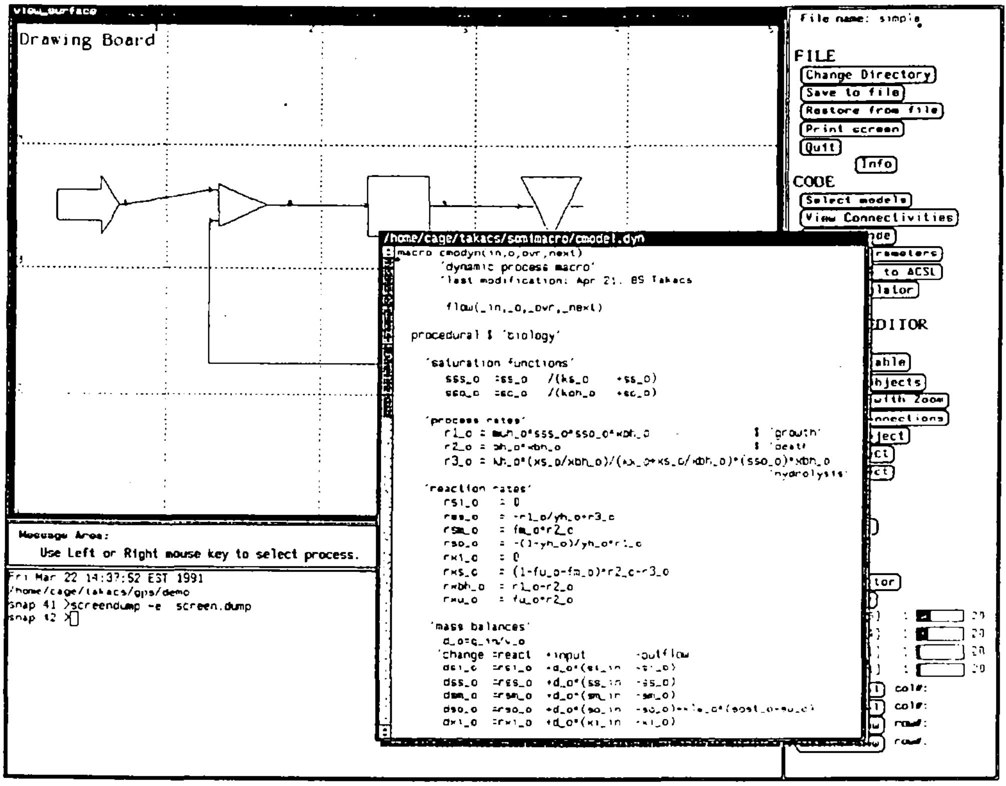
- cfstr
- plug-flow
- step-feed
- tapered aeration
- oxydation ditch
- extended aeration
- contact stabilization
- sequential batch reactors
- flow equalization
- UCT (bio-P)
- Bardenpho (bio-P)



Message Area:
Left mouse key selects position. Middle mouse key confirms current pos … the sc

```
Fri Mar 22 14:37:52 EST 1991
/home/cage/takacs/gps/demo
snap 41 >screendump -e  screen.dump
snap 42 >
```

Fig. 5 Process model selection using pull-down menus.



Message Area:
Use Left or Right mouse key to select process.

```
Fri Mar 22 14:37:52 EST 1991
/home/cage/takacs/gps/demo
snap 41 >screendump -e  screen.dump
snap 42 >
```

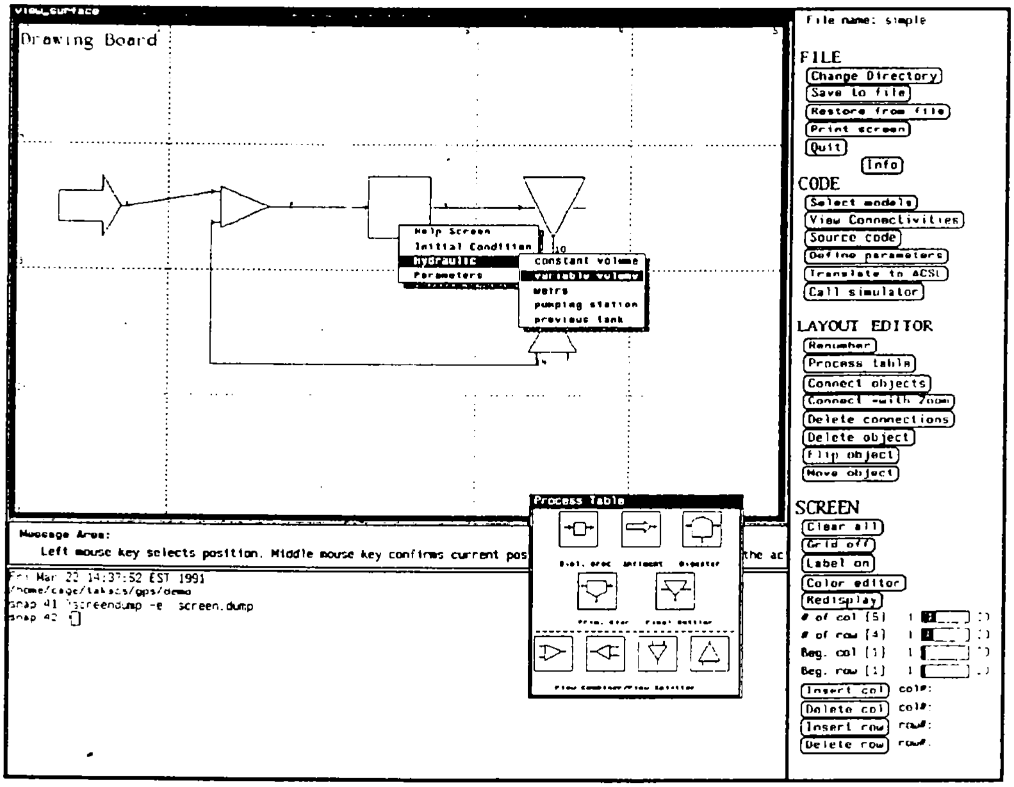
```
macro cmodyn(in,o,ovr,next)
      'dynamic process macro'
      'last modification: Apr 21. 89 Takacs

       flow(_in,_o,_ovr,_next)

  procedural $ 'biology'

    'saturation functions'
       sss_o  =ss_o   /(ks_o     +ss_o)
       sso_o  =so_o   /(koh_o    +so_o)

    'process rates'
       r1_o = muh_o*sss_o*sso_o*xbh_o                  $ 'growth'
       r2_o = bh_o*xbh_o                               $ 'death'
       r3_o = kh_o*(xs_o/xbh_o)/(kx_o+xs_o/xbh_o)*(sso_o)*xbh_o
                                                        'hydrolysis'
    'reaction rates'
       rsi_o    = 0
       rss_o    = -r1_o/yh_o+r3_o
       rsm_o    = fm_o*r2_o
       rso_o    = -(1-yh_o)/yh_o*r1_o
       rxi_o    = 0
       rxs_o    = (1-fu_o-fm_o)*r2_o-r3_o
       rxbh_o   = r1_o-r2_o
       rxu_o    = fu_o*r2_o

    'mass balances'
       d_o=q_in/v_o
      'change =react  +input        -outflow
       dsi_o  =rsi_o  +d_o*(si_in   -si_o)
       dss_o  =rss_o  +d_o*(ss_in   -ss_o)
       dsm_o  =rsm_o  +d_o*(sm_in   -sm_o)
       dso_o  =rso_o  +d_o*(so_in   -so_o)+kla_o*(sost_o-so_o)
       dxi_o  =rxi_o  +d_o*(xi_in   -xi_o)
```

Fig. 6 Macro code for the selected process.

Initial conditions refer to the values of the state variables at the start of the simulation (time t=0) by pressing the **Initialization** button. Unless the user wishes to start a simulation from a specific set of initial conditions, default values can be used. The default values are contained in the file `model_name.inc`. The user may elect to start the simulation using the steady-state conditions at time t=0. Selection of the hydraulic characteristics of the reactor is shown on Fig. 7. Finally, process parameters can be specified in one of two ways, as shown in Fig. 8. A process can *inherit* the parameters from any similar process. This feature is shown in Fig. 8, where the user would simply specify the process number from which the parameters will be inherited from. Otherwise, the user may wish to specify individual process parameters manually. A set of default parameters has also been provided to facilitate the use of the model.

3.5 Source Code Generation

At this stage, the user is ready to generate the simulation source code (ACSL code). This is done by pressing the **Translate to ACSL** button in the Command window. Following successful translation of the flow sheet, the simulator (ISI) is activated by pressing the **Call simulator** button in the Command window. The user can either compile the current flow sheet or run a previously compiled model. After compilation, the ISI programme is automatically loaded and ready for use. It should be noted that the Interactive Simulation Interface (ISI) is independent of SOMI and can be used with any ACSL programme compiled with SACSL.

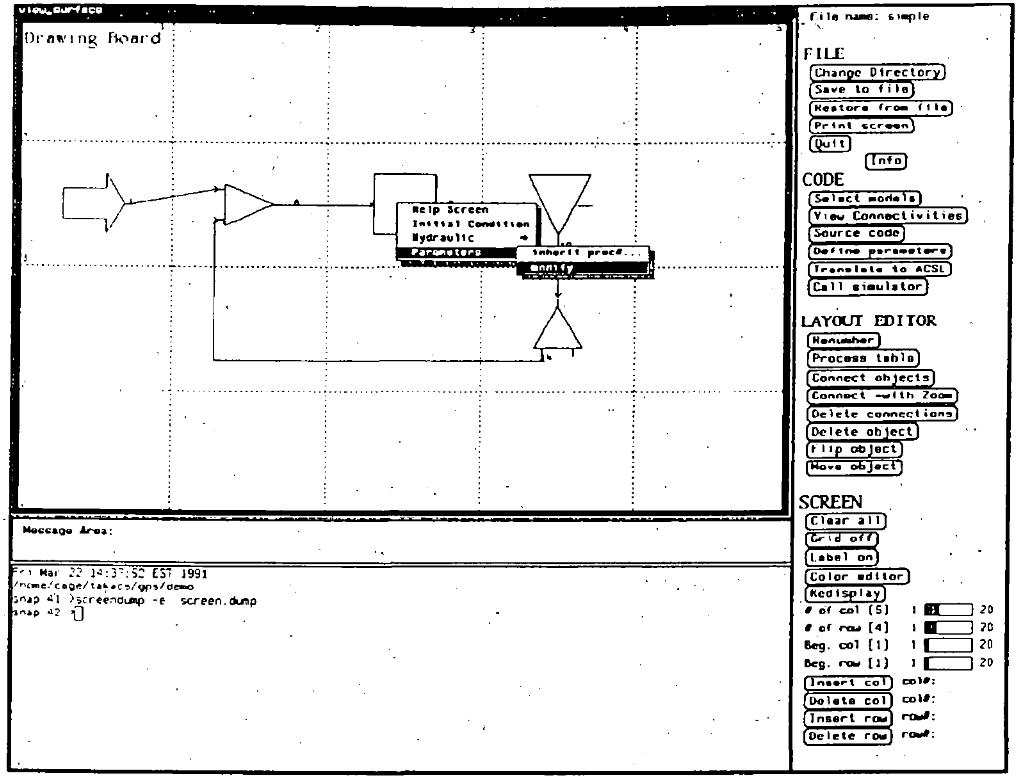


Message Area:
Left mouse key selects position. Middle mouse key confirms current pos

the ac

```
Fri Mar 22 14:37:52 EST 1991
/home/cage/takacs/gps/demo
snap 41 %screendump -e  screen.dump
snap 42
```

Fig. 7 Specification of the hydraulic characteristics of the process.



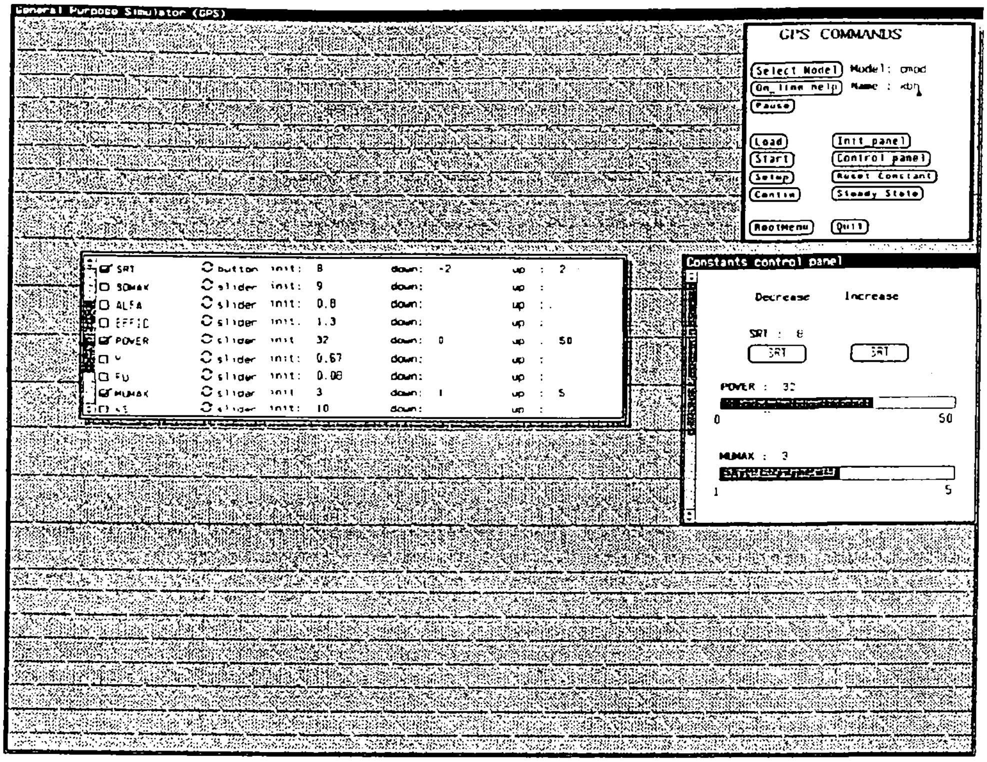
```
Fri Mar 22 14:37:52 EST 1991
/home/cage/takacs/gps/demo
snap 41 >screendump -e  screen.dump
snap 42 >
```

Fig. 8 Process parameter specification.

3.6 Interactive Simulation

Once the ISI startup screen appears on the workstation, the user must select the appropriate file (model) from the library of compiled binary files. On-line help is available to assist in the identification of specific process variables. Finally, the user will normally set up a control panel to provide interactive control of selected system variables, during the course of a simulation. The characteristics of the control panel are defined by pressing the **Init_panel** button in the Command window. The actual control panel is displayed by pressing the Control panel button located in the Command window. A window (Control panel) containing slider bars and/or buttons will then appear on the right hand side of the screen (Fig. 9).

The user can now initiate the simulation by loading and starting the program. This is done by pressing the **Start** command which will open one or two windows depending on the information stored in the `model_name.win` file. The selected variables can either be plotted or displayed in digital format. The simulation can also be suspended at anytime, as shown in Fig. 10. In this case, the activated sludge model shown in Fig. 2 (carbonaceous model and point-settler) is being simulated under diurnal flow conditions over a three day period. The following variables are plotted in the graphical portion of the screen:

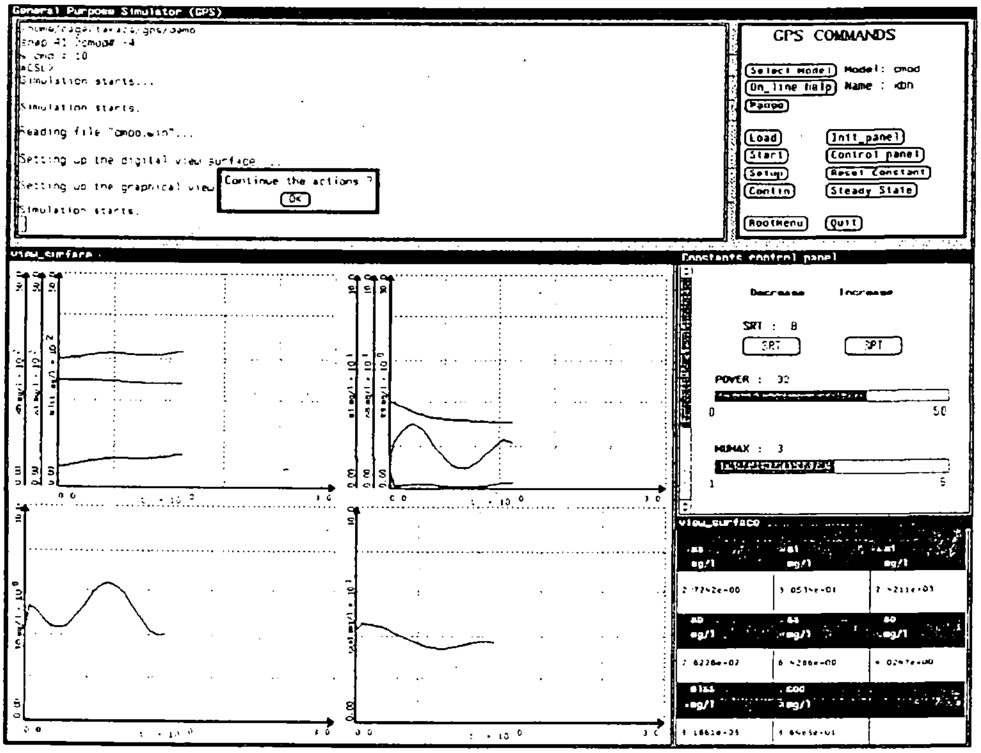


Model: cmod
Name : kbn

☑ SRT ○ button init: 8 down: -2 up : 2
☐ SOMAX ○ slider init: 9 down: up :
☐ ALFA ○ slider init: 0.8 down: up :
☐ EFFIC ○ slider init: 1.3 down: up :
☑ POWER ○ slider init 32 down: 0 up . 50
☐ V ○ slider init: 0.67 down: up :
☐ FU ○ slider init: 0.08 down: up :
☑ MUMAX ○ slider init 3 down: 1 up : 5
☐ K3 ○ slider init: 10 down: up :

SRT : 8
POWER : 32
MUMAX : 3

Fig. 9 Initializing the ISI control panel.



```
/home/cage/terate/gps/demo
Snap 41 >cmod# -4
> cmd : 10
#CSL>
Simulation starts...

Simulation starts.

Reading file "cmod.win"...

Setting up the digital view surface ..

Setting up the graphical view

Simulation starts.
```

Continue the actions ?

Model: cmod
Name : kbn

SRT : 8
POWER : 32
MUMAX : 3

Fig. 10 The ISI display environment.

Top left corner
Active biomass
Inert mass
MLSS
Bottom left corner
Dissolved oxygen

Top right corner
Soluble inert organics
Particulate substrate
Soluble substrate
Bottom right corner
Effluent COD

The oxygen mass transfer coefficient (k_La) was decreased from 100 d^{-1} to 51 d^{-1} by moving the `Power` slider bar in the Control panel. Following this interactive change in k_La, the dissolved oxygen concentration decreases while the soluble substrate concentration increases, as shown in Fig. 11. At the end of the simulation, the user can continue the simulation by pressing the **Contin** button in the command window.

In addition to biological reactors, the library contains a number of sophisticated settler models. The dynamics of a typical secondary clarifier under shock load conditions with discontinuous sludge wastage are illustrated in Fig. 12. The height of the sludge blanket is shown in the top right hand corner of the window.

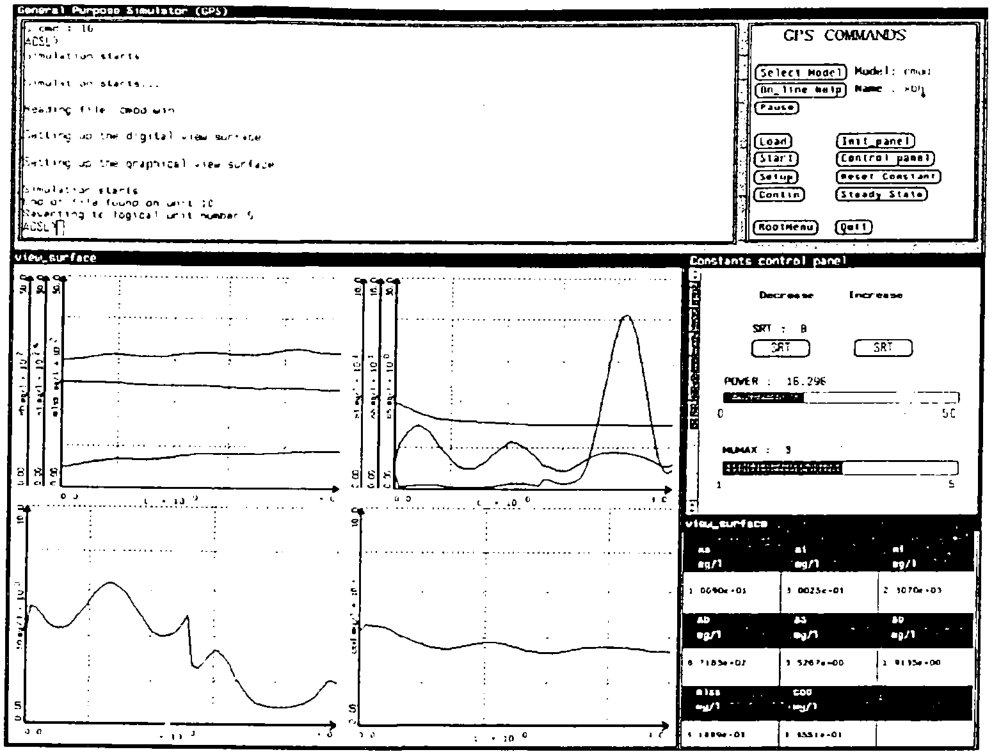
3.7 Steady-State Analysis

The simulator also provides access to a convenient steady-state analysis routine. Three options are available:

- Steady-state model initialization;
- Analysis of the steady-state response;
- Plotting the steady-state response.

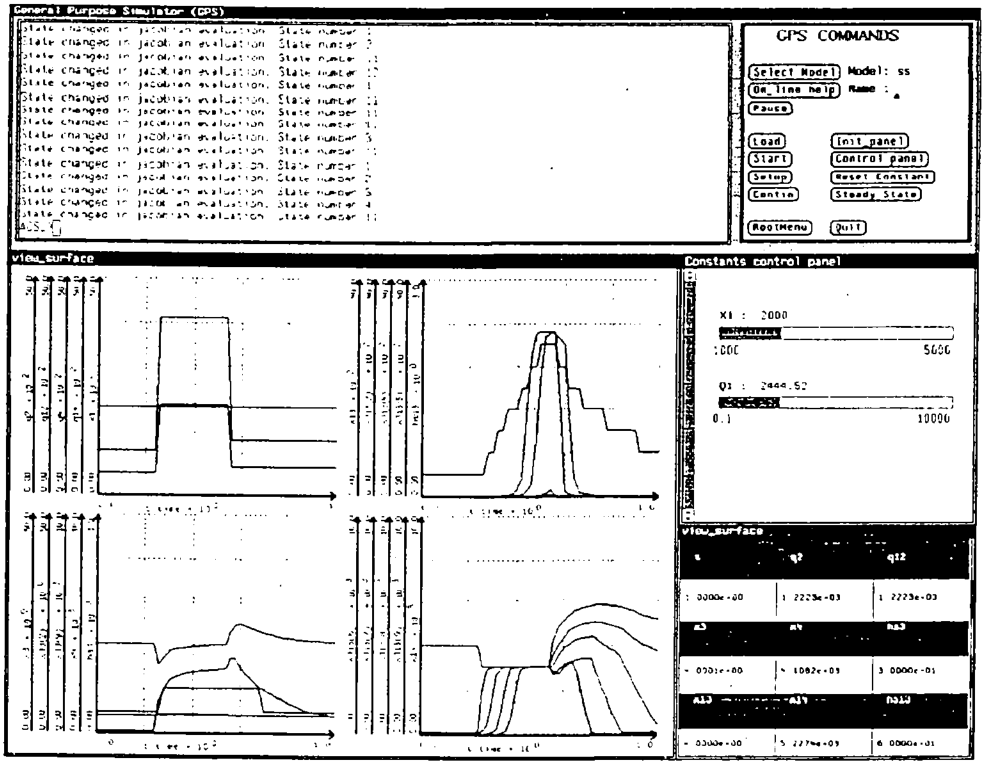
Steady-state analysis requires that the user specify the independent variable to be used in the sensitivity analysis. For computational purposes, values of the independent variable are limited to 10 levels. In addition, four response variables can be monitored. The results of the previous setup are shown in Fig. 13. The k_La was changed from 0 d^{-1} (no aeration) to 100 d^{-1} (sufficient aeration). The four response variables of interest are:

Top left corner	Dissolved oxygen response (to maintain 2 g/m^3 the necessary k_La is 60 d^{-1})
Top right corner	Soluble sustrate response
Bottom left corner	Stored substrate
Bottom right corner	MLSS



```
> cmd : 10
ACSL>
Simulation starts

Simulation starts...

Reading file cmod.win

Setting up the digital view surface

Setting up the graphical view surface

Simulation starts
End of file found on unit 10
Reverting to logical unit number 5
ACSL>
```

Fig. 11 Response of the state variables to changes in air flow rate.



```
State changed in jacobian evaluation. State number 1
State changed in jacobian evaluation. State number 2
State changed in jacobian evaluation. State number 11
State changed in jacobian evaluation. State number 12
State changed in jacobian evaluation. State number 1
State changed in jacobian evaluation. State number 11
State changed in jacobian evaluation. State number 11
State changed in jacobian evaluation. State number 11
State changed in jacobian evaluation. State number 3
State changed in jacobian evaluation. State number 11
State changed in jacobian evaluation. State number 1
State changed in jacobian evaluation. State number 2
State changed in jacobian evaluation. State number 5
State changed in jacobian evaluation. State number 4
State changed in jacobian evaluation. State number 11
ACSL>
```

Fig. 12 Dynamics of the secondary clarifier.

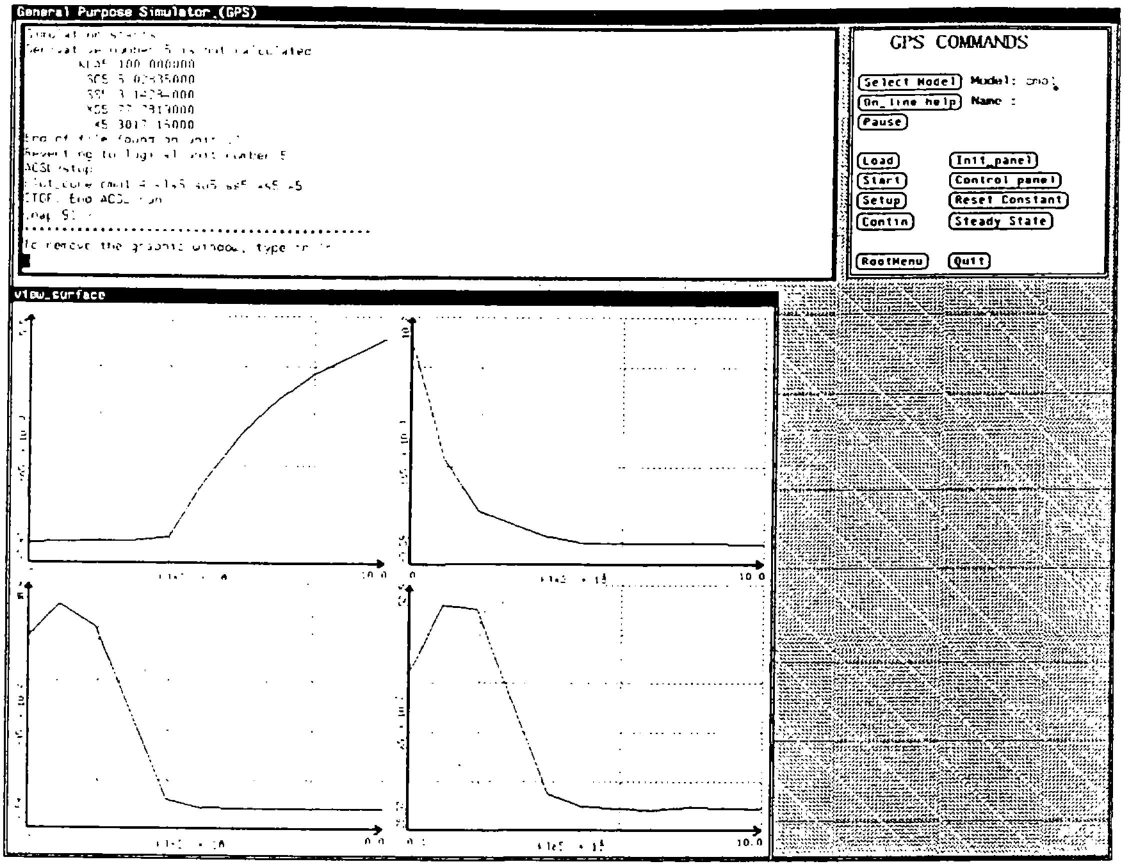


Fig. 13 Steady-state analysis response curves.

4. Case Study: The Hamilton-Wentworth Sewage Treatment Plant

The Hamilton-Wentworth sewage treatment plant (Woodward Avenue) is an activated sludge treatment facility designed to treat an average flow of 410 ML/d (90 MiGD) and a peak combined sewer flow of up to 600 ML/d (132 MiGD). However, under peak flow conditions suspended solids are frequently washed out from the North (older) portion of the plant. Partial nitrification is also adversely effected under sustained peak flow conditions. Accordingly, the purpose of this study was to investigate the use of dynamic models to develop a better understanding of the plant performance under storm flow conditions and to assess the impact of process modifications to the plant.

Nine months of historical data (8000 data elements) taken from the influent, primary effluent and final effluent streams were collected and analyzed. Interviews were conducted with plant operators to develop a better understanding of the plant performance as well as operational practices during wet and dry-weather flow conditions.

The plant was monitored during four wet-weather flow conditions (storm events) and on dry-weather flow period. Because the final clarifiers on the North side of the plant were believed to be highly susceptible to storm conditions, one additional experiment was conducted by stress-testing that particular portion of the plant.

Using the General Purpose Simulator (GPS) described in Section 3, a dynamic model of the plant was developed. The activated sludge model is based on the IAWPRC Task Group model (Henze *et al.*, 1987), while the clarifier/thickener models are based on the work of Takács *et al.* (1991) and Patry and Takács (1991).

The model was calibrated using data collected during Hurricane Hugo (Sept. 22, 1989). During that event, the hydraulic load to the plant reached 727 ML/d (160 MiGD). The maximum influent load to the plant was kept around 600 ML/d by allowing some of the flow to by-pass the plant. Because of the severity of the storm, solids from the North secondary clarifiers were washed out.

The dynamic model was verified using data collected during the storm of Sept. 14, 1989. While some of the North settlers performed rather poorly, others were capable of handling the increased hydraulic loading rather well. Because the storm was "expected", plant operators had kept the sludge blanket very low by setting the recycle rate to its maximum level.

4.1 Description of the Plant.

A schematic of the simplified plant layout used for this investigation is shown in Fig. 14. The influent point shown in Fig. 4 (unit #1) actually consists of four different flows. The major flow component comes from the Western (Burlington Street) and Eastern (Fennel Ave and Stoney Creek) combined sewer interceptors. The combined sewer flow rate from these two interceptors varies between 230 ML/d and 730 ML/d (50-160 MiGD) with an average flow of approximately 320 ML/d (70 MiGD).

Three other flow components contribute to the plant's influent: a) the filtrate from the sludge dewatering; b) the digester supernatant; and c) water from the wet scrubbing system of the incinerators. The next unit in Fig. 4 is a flow combiner (unit #2), used to combine the influent flow and the return activated sludge. In fact, it should be noted that the sludge is actually returned to the Eastern interceptor. The combined flow subsequently reaches the pumping station (unit #5). At the moment, because of the relatively small wet well volume, the pumping station was simulated as a constant volume reactor, i.e., the discharge flow is set equal to the influent flow.

The pumping station discharges the raw wastewater to the grit chamber (unit #10). Under critical flow conditions, part of the flow may be diverted to the effluent of the plant (flow line #8).

The grit chambers are modelled as pure hydraulic unit (with no biological reactions) and the aim of their incorporation is to account for the hydraulic detention of the flow. The flow is discharged into a channel before the primary clarifiers where the primary bypass (flow line #14) is located (flow splitter). The purpose of the primary by-pass is to protect the primary clarifiers from hydraulic overload. The by-pass is used regularly when the flow to the plant reaches 365 to 385 ML/d (80-85 MiGD).

The eight parallel primary settlers (unit #15 and underflow #16) are modelled as one unit in the simplified version of the plant as all eight settlers receive approximately the same loading from the distribution channel through the weirs.

After the primary settlers, a flow combiner (unit #17) is used to combine the flows from the primary settlers and the primary bypass. From this point on, the wastewater flows into an open channel, where it is split between the North and the South plant. In addition, a secondary by-pass can be activated at this point should the settlers become overloaded. Under normal flow conditions, the flow to the North part of the plant (flow line #23) represents approximately 69% of the total flow while the South portion of the plant receives approximately 31% of the load (flow line #22).

The flow diverted to the North plant (#23) is driven through a combination of flow splitters (#74 and #75) and two flow combiners (#27 and #70). This setup allows us to simulate step feed control strategies on the North side of the plant. Existing plant operation is simulated by setting the fraction (fr2374) of the flow reaching the head of the North reactors equal to one. On the other hand, step feed control is simulated by letting fr2374=0; in this case all the flow is directed to the second half of the reactors. Combiner #27 handles the recycle sludge returning to the head of the North aerators.

The North process line consists of eight parallel biological reactors, each consisting of six cells. However, only six of the eight rows are in use at any one time, and only five of the six rotors in any one row are operated. These units are modelled as a series of two tanks (units #30 and #34), with a total volume which equals the volume of the operating six rows. The reactors were split in two to account, at least partially, for the semi-plug-flow characteristics of the aeration basins. The activated sludge discharges into eight settlers, which are operated in two groups of four (units #53 and #55, underflow #54 and #56). The recycle from these settlers (unit #50) is continuously monitored; part of it (flow line #41) is wasted.

The South process line consists of four parallel (square) aeration tanks, two of which were routinely out of operation to save electrical energy during 1989. There are four rotors in each of the reactors. The distribution system to the tanks allows us to model the system as a single unit (unit #32). The four settlers following the aeration tank are modelled as single unit (unit #48 and underflow #49). A flow combiner (unit #24) handles the recycle sludge returned to the head of the South aerators.

There are three more flow combiners in Fig. 4. Unit #60 combines the effluents from the final settlers of the plant while unit #63 combines the plant effluent to the occasional secondary or pumping station by-pass. Finally, unit #36 combines the waste activated sludge from the North and South process lines and discharges the sludge to the head of the plant. The mixed sludge from the plant is wasted through the primary underflow (line #16).

4.2 Structure of the model

The IAWPRC Task Group model (Henze et al., 1987) was used to model the activated sludge process while the clarification and thickening models are based on the work of Takács *et al.* (1991).

4.2.1 Steady-state calibration

Having specified the plant configuration, default stoichiometric, kinetic and settling parameters were used initially. Steady-state model calibration was performed using average monthly historical records. While some of the stoichiometric parameters could be estimated from plant records, most of the parameters were optimized numerically.

Observed and simulated final effluent BOD from the steady-state runs (nine months and yearly average) are shown in Fig. 14. It should be noted that no temperature dependency was incorporated into these simulations, which serves to explain some of the discrepancy between observed and simulated values particularly during the summer months.

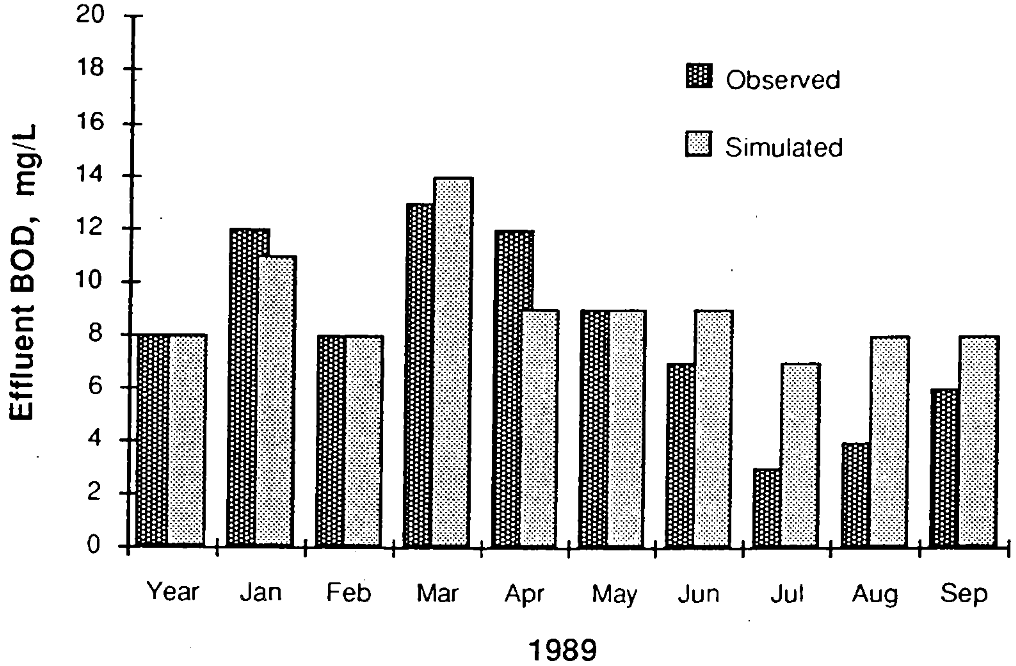


Fig. 14 Steady-state calibration.

4.2.2 Dynamic Model Calibration

Calibration of the dynamic model was performed with the use of a nonlinear optimization package known as SIMUSOLV (Steiner *et al.*, 1986). Using experimental data collected during tropical storm Hugo (Sept. 22, 1989), an "optimal" set of model parameters was identified. Results of the optimization for suspended solids, ammonia-N and nitrate-N are shown in Fig. 15.

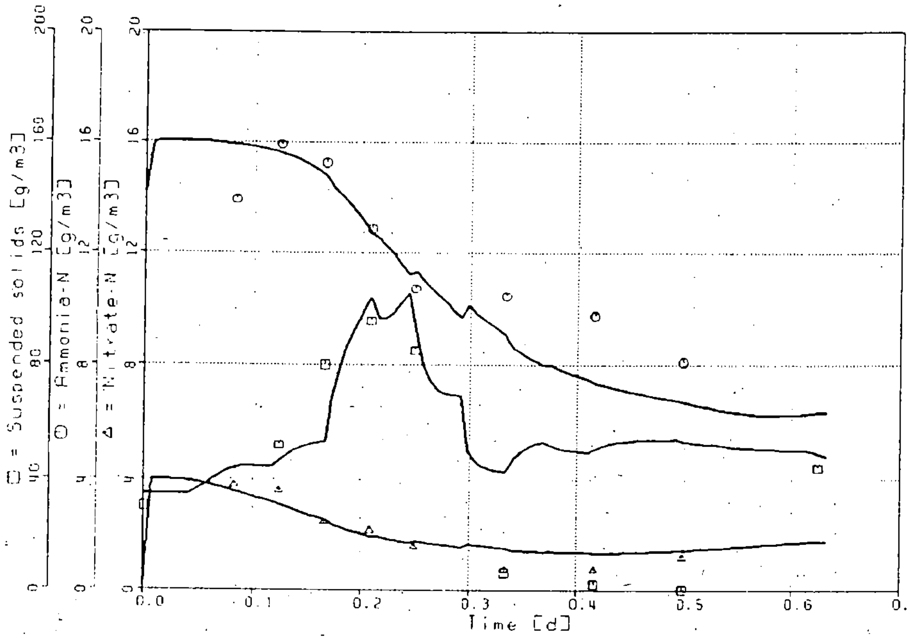


Fig. 15 Dynamic calibration results.

4.2.3 Dynamic Model Verification

Model verification was conducted using three additional set of experimental data collected during wet-weather conditions at the Woodward plant. Observed and simulated results for one of the three events are shown in Fig. 16. While there are discrepancies between the observed and simulated results, the model was able to replicate the overall performance of the plant quite well during this event.

4.3 Load Allocation

One of the benefits of the General Purpose Simulator is its use in answering "what-if" questions. Using a calibrated and verified version of the plant model, it is possible to investigate a variety of design and operational conditions different from those that exist in the calibrated model. Plant expansion alternatives, step feed control strategies, load allocation strategies can all be investigated using the GPS.

As part of this study, a number of operational strategies were investigated. However, for the purpose of this paper, discussion will be restricted to operational storm flow management strategies using step feed and load allocation control.

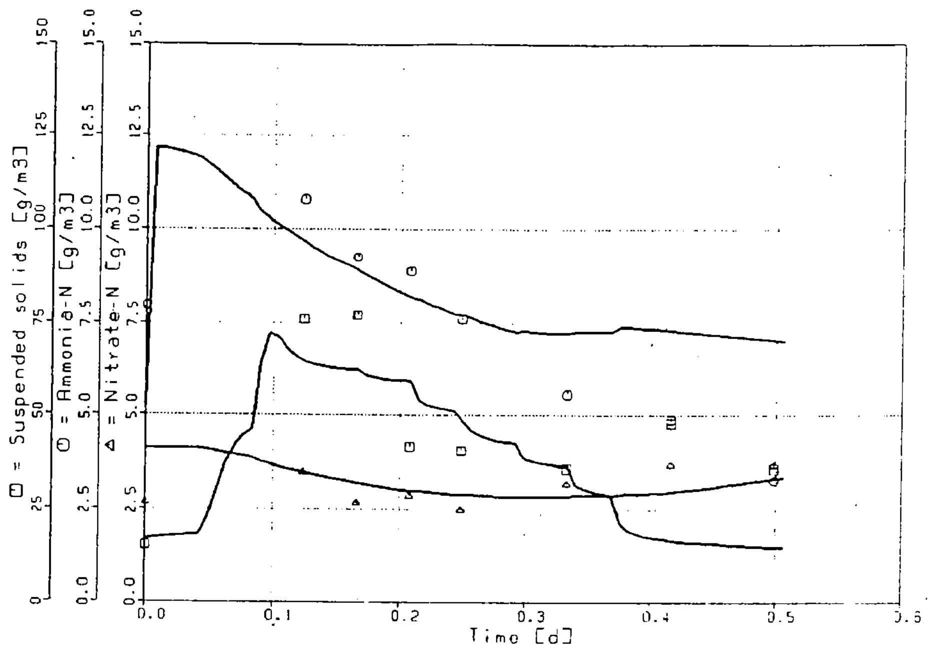


Fig. 16. Verification results.

A base event was first reconstructed by superimposing the influent characteristics associated with Hurricane Hugo to the average annual characteristics (Fig. 17). The influent flow (q1) and suspended solids (x1) are shown in the upper left graph, while the step feed control (f2374) and load allocation (fr1723) values are shown in the upper right hand corner. The MLSS in the first (x30) and second (x34) part of the aeration basin are shown in lower left graph, while the effluent suspended solids (x60) and the sludge blanket height (hs55) appear in the lower right corner.

For the purpose of this base simulation, the sludge recycle was increased in accordance with current operation practice (from 50 to 80%). However, none of the by-pass gates were opened. The peak effluent suspended solids concentration (500 g/m^3) is higher than the value measured during Hurricane Hugo. This apparent discrepancy can be accounted for in many ways: a) no bypass was applied during this simulation; b) the full aeration volume was used prior and during this event, meaning that a larger mass of sludge was in the system; and c) the yearly average MLSS is somewhat higher than the conditions that prevailed on Sept. 22, 1989.

The same run was now repeated with step-feed and load allocation control. Step feed control was implemented by diverting the influent to the second part of the North aeration tanks. Load allocation control was implemented by temporarily directing a larger fraction of the flow (50% as opposed to 30%) to the South plant, given that the South settlers are capable of handling a proportionately higher load for a limited period of time.

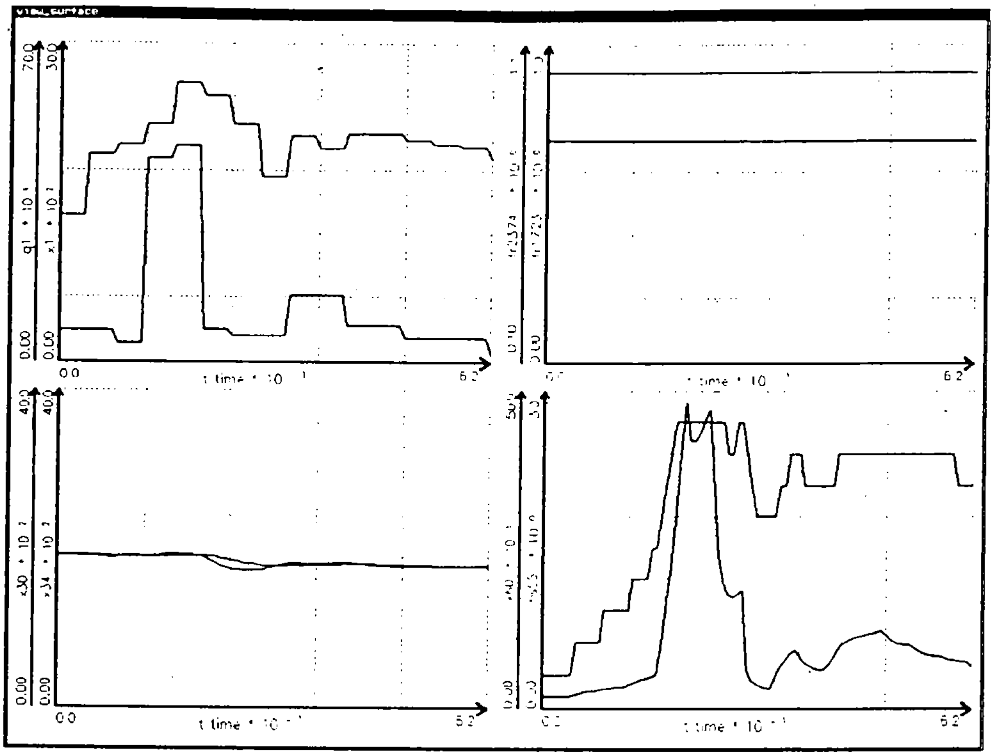


Fig. 17 Plant performance under storm flow conditions (normal operation).

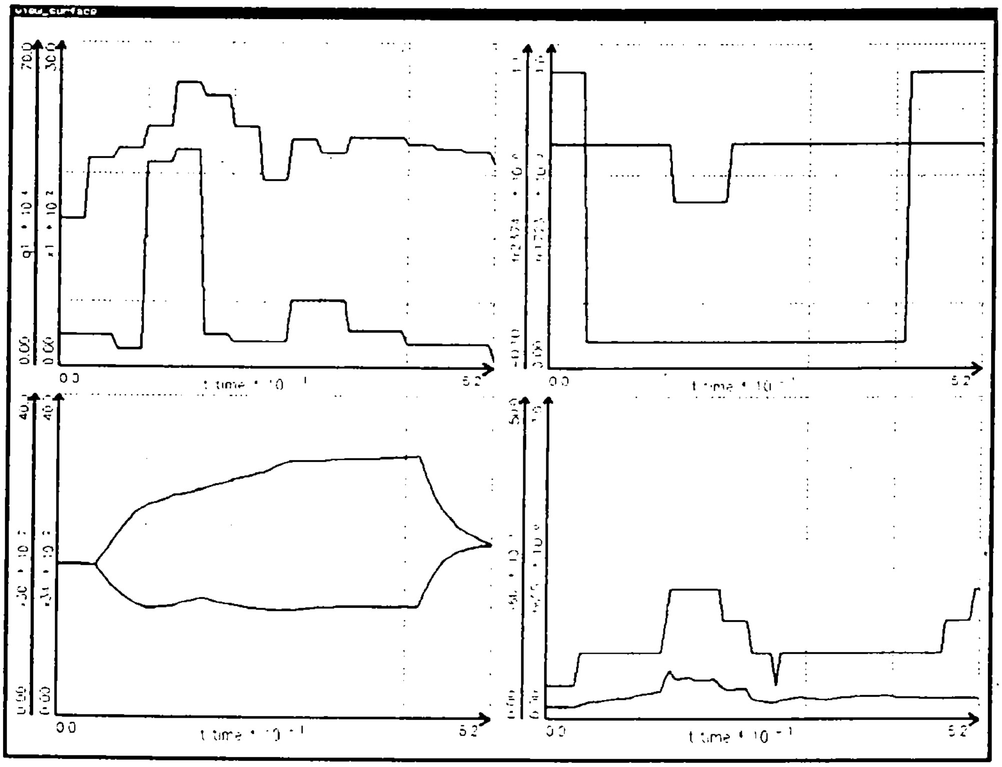


Fig. 18 Plant performance under storm flow conditions (step feed/load allocation).

Step-feed control in effect dilutes the sludge discharged into the settler, while accumulating a larger fraction of the biomass in the first part of the aeration basins. The MLSS concentration in the first and second part of the North aeration basin is shown in the lower left portion of Fig. 18. In contrast to the base simulation, the peak effluent suspended solids concentration dropped from 500 g/m^3 to 80 g/m^3. This clearly demonstrates the potential impact of operational control strategies on the performance of the plant during storm flow conditions.

Finally, the plant was simulated by replacing the North secondary settlers with settlers similar to those in the South portion of the plant. It should be noted that step feed and load allocation controls were not implemented in this simulation. Results of this analysis are shown in Fig. 19. The sludge blanket height and the effluent suspended solids have all stabilized in spite of the high hydraulic load to the plant. As with the previous simulation, the performance of the primary settlers is heavily affected by this storm resulting in heavy solids wash out during the first few hours of the storm, as seen in the upper right hand plot.

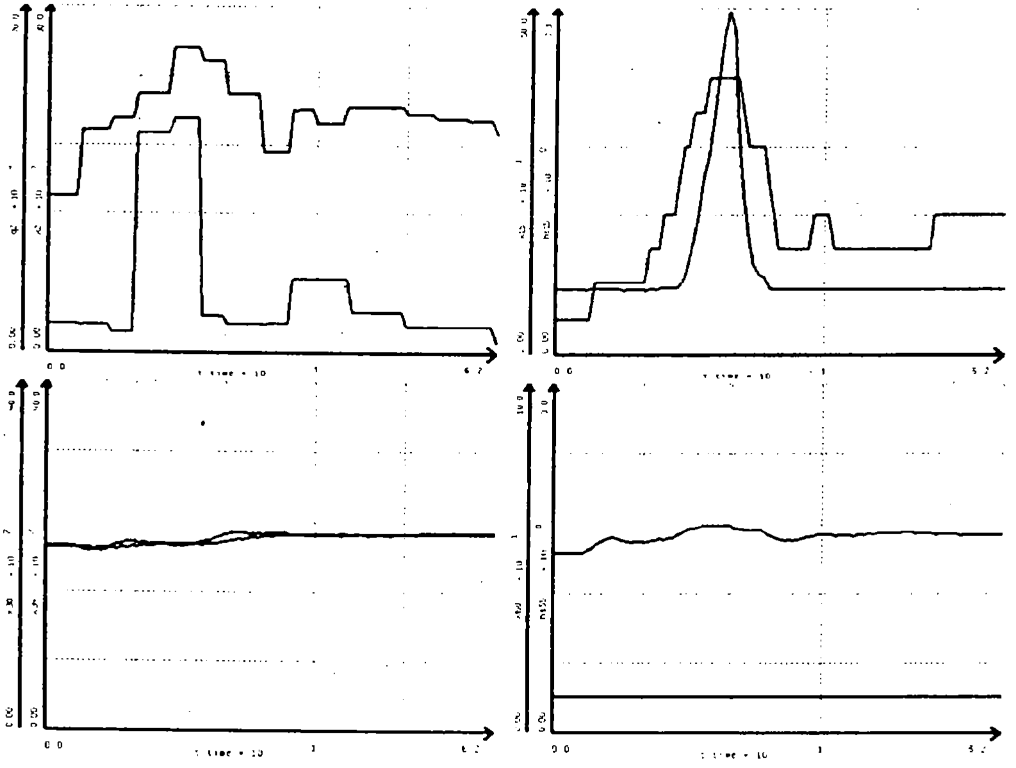


Fig. 19 Plant performance under storm flow conditions-improved North settlers.

5. Conclusions

A modular multi-purpose modelling system was developed for the simulation and control of wastewater treatment plants. Using object-oriented modelling concepts, the General Purpose Simulator provides the flexibility and power to model complex wastewater treatment plants. The GPS can be particularly useful in planning, design, and operation of wastewater treatment plants. In addition, the simulator can be used to assist in operator training.

Finally, the General Purpose Simulator can also be used to investigate alternate operational strategies. The GPS was applied to the simulation of the Hamilton-Wentworth Sewage Treatment Plant under storm flow conditions.

Acknowledgements

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Abbreviations

ACSL	Advanced Continuous Simulation Language
GPS	General Purpose Simulator
IAWPRC	International Association on Water Pollution Research and Control
ISI	Interactive Simulation Interface
MLSS	Mixed-liquor suspended solids
SACSL	Modified ACSL script file and associated graphics libraries
SOMI	Screen Oriented Modelling Interface

APPENDIX B
WPCP Flow Analysis Program

HYDRAULIC LOAD REDUCTION

Flow Analysis Program

WFAN is an MS-Windows based program that:

1. Processes actual WPCP plant flow and water quality data to create input data for an ACSL-based WPCP simulation model
2. Provides post-processing of simulation results including comparisons to actual plant effluent data.

The WPCP flow analysis program performs the following functions:

1. Case Control
2. Data Entry Utilities
    - 2.1 Data Entry Forms
    - 2.2 Data Pre-processing
3. WPCP Influent Flow and Quality Analysis
    - 3.1 Dry Weather Flow Analysis
    - 3.2 Interactive WWF Modelling
    - 3.3 Water Quality Analysis
4. Influent Model Summary
    - 4.1 Summary Table
    - 4.2 Flow Analysis Plotting Support
5. GPS Support
    - 5.1 GPS Pre-processor
    - 5.2 GPS Post-processor

See figure on page B-5.

B-1. CASE CONTROL

When the program is first invoked, the user specifies:

- directory which contains, or will contain, the data for the current project
- WPCP of interest
- rain gauge to be used for wet weather flow modelling
- month and year to be analysed
- WPCP model and workstation information

The program will automatically track the necessary time series files and summary files using this information. The user may change this information at any time or may select the files to be used directly.

B-2. DATA ENTRY UTILITIES

B-2.1 DATA ENTRY FORMS

Data entry forms are provided for:
- hourly WPCP flow data
- daily WPCP influent water quality
- daily WPCP effluent water quality

A raw AES rainfall file processing utility is also provided. AES files come with several stations in one file and can cover a duration of several years. This utility splits a raw digital hourly rainfall file into station files, and then splits station files into station-month files to facilitate a seasonal analysis.

B-2.2 DATA PREPROCESSING

The first preprocessing step is the interpolation of missing data. Interpolation occurs when flow data in a flow data entry form is saved to a file. Files are saved in monthly increments.

Between the first and second pre-processing steps, data files can be combined to allow the interpolation of data points missing at the beginning or end of files.

The second (and final) preprocessing step completes the interpolation process and removes days when too many consecutive hours have been interpolated. The final step is to separate the combined file back into monthly files for further analysis.

B-3. WPCP INFLUENT FLOW AND QUALITY ANALYSIS

B-3.1 DRY WEATHER FLOW ANALYSIS

Identifies dry weather flow and separates it into dry weather infiltration and sanitary flow. In addition, runoff coefficients are calculated and graphed. An output file suitable for wet weather flow analysis is created.

B-3.2 INTERACTIVE WWF MODELLING

Plots wet weather model results versus actual WPCP flow data. The user can adjust model parameters and see the effects of these adjustments graphically and through summary statistics.

The WWF model includes:
- direct runoff model based on a direct runoff coefficient and catchment time of concentration
- rainfall derived infiltration model based on a linear reservoir model
- dry weather infiltration adjustment to allow visual correction of dry weather flow estimate
- overflow regulator with storage and overflow/bypass volume summary

B-3.3 WPCP INFLUENT WATER QUALITY ANALYSIS

This analysis assists the user with the selection of flow component (sanitary, dry weather infiltration, rainfall derived infiltration, and wet weather inflow) unit loads. The three stages of this analysis are:

1. IMSL multiple linear regression for initial parameter estimation (needs at least three months of data to produce reasonable results). The user can identify outliers before this routine is run. Outliers are not used in the regression analysis.
2. Automatic adjustment of unit loads to set regression constant to zero.
3. User revision of unit loads.

A plot of the unit load based influent quality estimate versus actual sampling data from the plant is available after every step. In addition, summary statistics are provided to quantify the differences between plant data and model data.

B-4. INFLUENT MODEL SUMMARY

B-4.1 SUMMARY TABLE

A screen that shows all model parameters selected for the current case (month/year/WPCP/rain gauge). Model parameters shown include:

1. Dry weather flow rates.
2. Wet weather flow model parameters (Cv's, time of concentration, catchment area, rainfall derived infiltration decay).
3. Flow component water quality concentrations (i.e., unit loads)

This data is all saved in a summary file and can be updated or displayed at any time.

B-4.2 FLOW ANALYSIS PLOTTING SUPPORT

This routine uses output files from the wet weather flow analysis as input. Each file contains:

1. Monitored WPCP Flow
2. Modelled WPCP Flow
3. Rainfall
4. Sanitary Flow
5. Dry Weather Infiltration
6. Wet Weather Inflow
7. Rainfall Derived Infiltration

Plots available for each of the above are:

1. Time series plot (hourly)
2. Incremental Frequency Histogram
3. Cumulative Frequency Histogram

B-5. GPS SUPPORT

B-5.1 GPS Pre-Processor

This facility creates a time series file that can be used for GPS input. Data includes:

- Hour counter
- Flow(m^3/day)
- BOD(mg/L)
- TKN(mg/L)
- TSS(mg/L)

The user must select:

- water quality unit loads (results of water quality analysis, select defaults, or user entered)
- change in each flow component (to indicate flow reduction or increase)

The user can determine if the pollutant load decreases proportionately with the hydraulic load, or if the pollutant load is independent of the hydraulic load. When the time series file is generated , summary statistics are shown for the original WPCP flow data, calibrated flow model results, and the new flow time series. These summary statistics include:

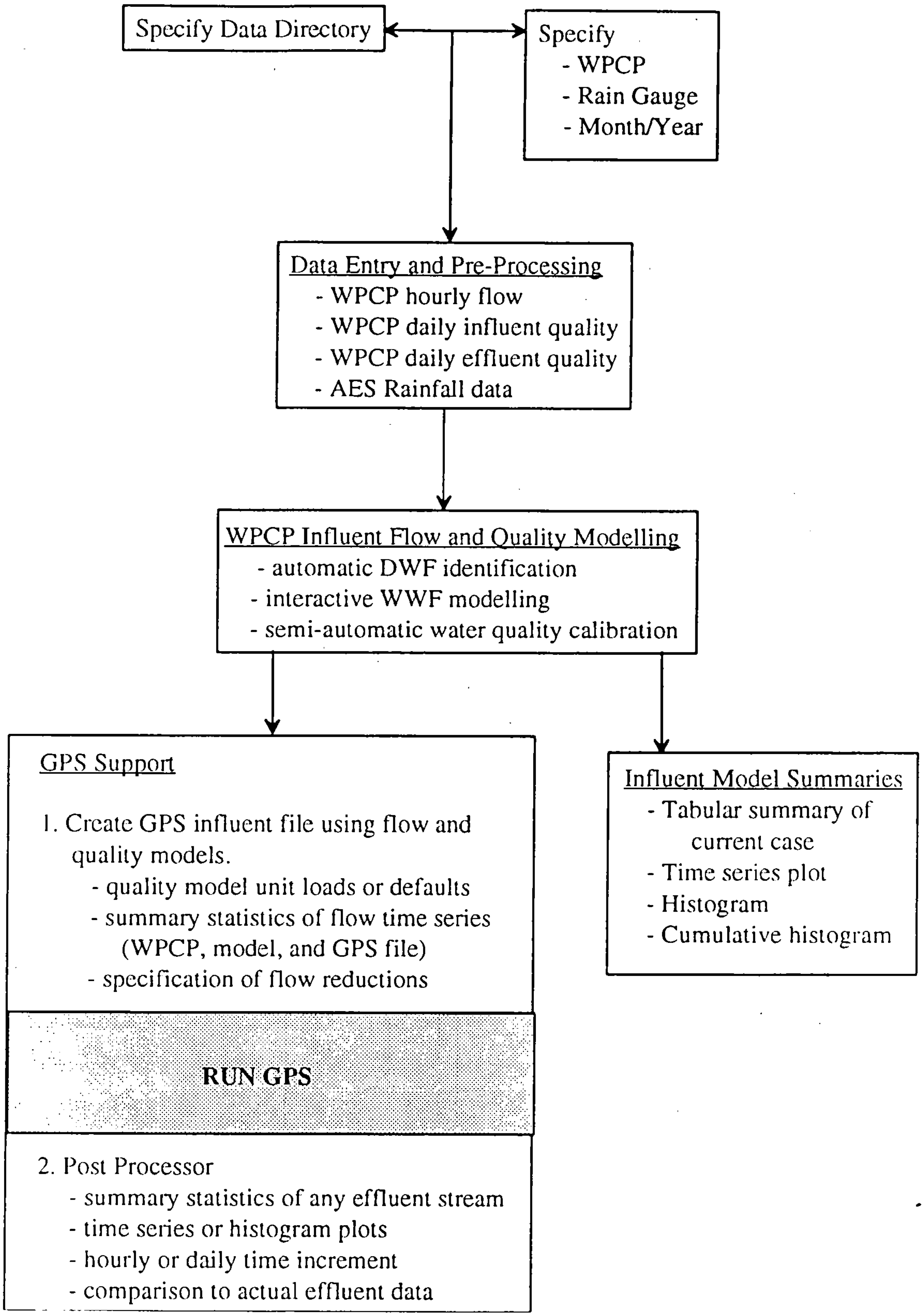
- time series mean
- maximum flow value
- minimum flow value
- standard deviation
- number of hours within 10% of peak flow
- a percentage difference between original model flow mean and new GPS input flow mean
- pollutant loads routed to a receiving water due to separation of combined sewer areas

Currently, the summary statistics show the effects of bypass/storage. However, the GPS file has not been routed through this regulator. To do so would require mass balance equations to properly estimate water quality in the influent stream after initial storage. Although this could be incorporated in this model, it is best implemented in ACSL code through the GPS.

Although bypass effects are not reflected in the file sent to GPS, bypass statistics are compiled. These include: number of bypass events, total duration of bypass, average duration of bypass per event, and volume of bypass.

B-5.2 GPS Post-Processor

ASCII data files are created by the GPS model for user specified nodes in the simulation model. These files are transferred to a PC were they are read by the GPS Post-Processor. The post-processor will allow various graphs (time series or histograms of concentration or loads) to be plotted. In addition, summary statistics (averages, standard deviation, minimum, maximum, and load for flow, BOD TSS and TKN) of a user specified node (or combination of nodes) are presented in a table. An event counter is also included.
Also included in this utility is the capability to plot actual plant effluent data in any graph. This allows a comparison between actual plant effluent data and modelled plant effluent data.


Specify Data Directory
Specify
- WPCP
- Rain Gauge
- Month/Year
Data Entry and Pre-Processing
- WPCP hourly flow
- WPCP daily influent quality
- WPCP daily effluent quality
- AES Rainfall data
WPCP Influent Flow and Quality Modelling
- automatic DWF identification
- interactive WWF modelling
- semi-automatic water quality calibration
GPS Support
1. Create GPS influent file using flow and quality models.
- quality model unit loads or defaults
- summary statistics of flow time series (WPCP, model, and GPS file)
- specification of flow reductions
RUN GPS
2. Post Processor
- summary statistics of any effluent stream
- time series or histogram plots
- hourly or daily time increment
- comparison to actual effluent data
Influent Model Summaries
- Tabular summary of current case
- Time series plot
- Histogram
- Cumulative histogram

APPENDIX C
Simulation Results

APPENDIX C- Simulation Results

Table D-1. Hydraulic loads for various hydrualic load reduction cases.

Case	Flow Reduction (%)	Through-flow (10⁶ m³/yr)	Secondary Bypass (10⁶ m³/yr)	Plant Bypass (10⁶ m³/yr)	Total Outfall (10⁶ m³/yr)	Diverted Flow (10⁶ m³/yr)	TOTAL (10⁶ m³/yr)
Baseline	0%	121.6	0.11	1.33	123.04	0	123.04
Reduce Sanitary Flow	5%	118	0.1	1.27	119.37	0	119.37
	10%	114.4	0.09	1.22	115.71	0	115.71
	15%	110.8	0.08	1.16	112.04	0	112.04
	20%	107.2	0.07	1.11	108.38	0	108.38
	25%	103.6	0.07	1.07	104.74	0	104.74
	30%	100	0.07	1.03	101.1	0	101.1
Reduce Infiltration	10%	117.1	0.09	1.2	118.39	0	118.39
	20%	112.6	0.07	1.09	113.76	0	113.76
	30%	108	0.07	1	109.07	0	109.07
	40%	103.5	0.05	0.92	104.47	0	104.47
	50%	98.9	0.04	0.85	99.79	0	99.79
Reduce Stormwater Inflow	10%	121.4	0.1	1.12	122.62	0.42	123.04
	20%	121.2	0.1	0.92	122.22	0.84	123.06
	30%	120.9	0.09	0.74	121.73	1.25	122.98
	40%	120.7	0.08	0.58	121.36	1.67	123.03
	50%	120.4	0.07	0.43	120.9	2.09	122.99
Reduce Infiltration and Inflow	10%	116.9	0.08	1	117.98	0.42	118.4
	20%	112.1	0.06	0.74	112.9	0.84	113.74
	30%	107.3	0.04	0.51	107.85	1.25	109.1
	40%	102.4	0.01	0.32	102.73	1.67	104.4
	50%	97.5	0	0.17	97.67	2.09	99.76
Reduce Sanitary Flow, Infiltration and Inflow	(a)	98.9	0.04	0.53	99.47	1.05	100.52
	(b)	75.7	0	0.09	75.79	2.09	77.88

Notes:

(a) 15% sanitary flow reduction, 25% infiltration reduction, and a 25% inflow reduction
(b) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Definitions:

1. *Throughflow* - flow that receives full treatment at the Woodward WPCP;
2. *Secondary Bypass* - flow that enters the Woodward WPCP and receives partial treatment, but is bypassed around the secondary treatment processes;
3. *Plant Bypass* - flow that receives no treatment at the Woodward WPCP. Note that this does not account for overflows upstream of the WPCP; and
4. *Total Outfall* - the summation of throughflow, secondary bypass, and plant bypass.
5. *Diverted* - stormwater inflow that has been diverted away from the Woodward WPCP and directed into a receiving water due to sewer separation.
6. *TOTAL* - the summation of total outfall and diverted.

Table C-2. Comparison of hydraulic loads for 1990 and 1991for selected cases of hydraulic load reduction.

Case	Flow Reduction (%)	Through-flow (10^6 m^3/yr)	Secondary Bypass (10^6 m^3/yr)	Plant Bypass (10^6 m^3/yr)	Total Outfall (10^6 m^3/yr)	Diverted Flow (10^6 m^3/yr)	TOTAL (10^6 m^3/yr)
Baseline - 1990	0%	121.6	0.11	1.33	123.04	0	123.04
Baseline - 1991	0%	115.9	0.02	0.47	116.39	0	116.39
Sanitary Flow - 1990	30%	100	0.07	1.03	101.1	0	101.1
Sanitary Flow - 1991	30%	94.2	0	0.3	94.5	0	94.5
Reduce I/I - 1990	50%	97.5	0	0.17	97.67	2.09	99.76
Reduce I/I - 1991	50%	94.4	0	0.02	94.42	1.28	95.7
Max Reduction - 1990	(a)	75.7	0	0.09	75.79	2.09	77.88
Max Reduction - 1991	(b)	72.5	0	0.01	72.51	1.28	73.79

Note:

(a) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-3. TSS WPCP effluent concentrations for various hydraulic load reduction cases using 1990 rainfall data.

Case	Flow Reduction (%)	Minimum Hour (mg/L)	Minimum Day (mg/L)	Flow Average (mg/L)	Maximum Day (mg/L)	Maximum Hour (mg/L)
Baseline	0%	5.3	7.0	16.4	69.0	200.4
Reduce Sanitary Flow	5%	4.9	6.7	15.3	65.9	192.7
	10%	4.6	5.9	14.5	64	186.7
	15%	4.5	5.7	13.9	61.5	177.7
	20%	4.4	5.5	13.3	59.1	173.2
	25%	4.2	5.3	12.7	56.8	166.3
	30%	4.1	5.0	12.2	54.6	159.3
Reduce Infiltration	10%	5.1	6.8	14.9	64.3	185.8
	20%	4.6	6.2	13.8	60.3	174.0
	30%	4.4	5.8	12.8	56.4	163.4
	40%	4.2	5.6	11.9	52.7	153.3
	50%	4.0	5.4	11.1	49.2	143.5
Reduce Stormwater Inflow	10%	5.3	7.0	16.2	67.1	172.0
	20%	5.3	6.8	16.0	65.6	147.3
	30%	5.3	6.9	15.8	65.8	123.3
	40%	5.3	6.8	15.6	64.6	101.3
	50%	5.3	6.9	15.5	58.4	81.3
Reduce Infiltration and Inflow	10%	4.9	6.7	14.6	57.1	161.8
	20%	4.5	6.0	13.4	46.9	125.7
	30%	4.4	5.7	12.2	38.2	98.7
	40%	4.2	5.6	11.3	31.0	74.5
	50%	4.0	5.4	10.3	25.2	55.4
Reduce Sanitary Flow, Infiltration and Inflow	(a)	4.0	5.2	11.1	37.4	99.3
	(b)	3.1	4.0	7.6	19.5	41.5
RAP Goal	0%	-	-	2.1	-	-

Notes:

(a) 15% sanitary flow reduction, 25% infiltration reduction, and a 25% inflow reduction
(b) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-4. BOD WPCP effluent concentrations for various hydraulic load reduction cases using 1990 rainfall data.

Case	Flow Reduction (%)	Minimum Hour (mg/L)	Minimum Day (mg/L)	Flow Average (mg/L)	Maximum Day (mg/L)	Maximum Hour (mg/L)
Baseline	0%	5.4	6.1	8.6	24.7	63.1
Reduce Sanitary Flow	5%	5.4	5.8	8.3	24.1	61.8
	10%	5.3	5.7	8.1	23.8	60.8
	15%	5.3	5.6	8.0	23.4	59.0
	20%	5.2	5.5	7.8	23.0	58.5
	25%	5.1	5.4	7.7	22.6	57.3
	30%	5.0	5.4	7.7	22.3	56.1
Reduce Infiltration	10%	5.4	5.8	8.2	23.9	60.7
	20%	5.3	5.7	8.0	23.4	59.0
	30%	5.2	5.7	7.8	22.8	57.6
	40%	5.2	5.5	7.6	22.3	56.3
	50%	5.1	5.6	7.5	21.9	54.9
Reduce Stormwater Inflow	10%	5.5	6.1	8.5	24.5	54.9
	20%	5.4	6.1	8.4	24.0	47.9
	30%	5.4	6.1	8.3	24.0	41.2
	40%	5.5	6.1	8.3	23.6	35.2
	50%	5.5	6.1	8.2	21.8	29.8
Reduce Infiltration and Inflow	10%	5.4	5.8	8.1	21.7	53.6
	20%	5.3	5.7	7.8	19.2	44.6
	30%	5.2	5.7	7.6	17.0	38.0
	40%	5.2	5.5	7.3	15.3	32.0
	50%	5.1	5.6	7.1	13.8	27.4
Reduce Sanitary Flow, Infiltration and Inflow	(a)	5.1	5.5	7.3	17.4	39.6
	(b)	4.5	5.0	6.5	13.5	27.0
Effect of RAP upgrade	0%	-	-	2.0	-	-

Notes:

(a) 15% sanitary flow reduction, 25% infiltration reduction, and a 25% inflow reduction
(b) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-5. Comparison of TSS WPCP effluent concentration for selected cases of hydraulic load reduction in 1990 and 1991

Case	Flow Reduction (%)	Minimum Hour (mg/L)	Minimum Day (mg/L)	Flow Average (mg/L)	Maximum Day (mg/L)	Maximum Hour (mg/L)
Baseline - 1990	0%	5.3	7.0	16.4	69.0	200.4
Baseline - 1991	0%	5.5	7.0	15.8	92.8	241.2
Sanitary Flow - 1990	30%	4.1	5.0	12.2	54.6	159.3
Sanitary Flow - 1991	30%	3.8	4.8	10.8	39.2	83.5
Reduce I/I - 1990	50%	4.0	5.4	10.3	25.2	55.4
Reduce I/I - 1991	50%	3.9	5.2	9.8	19.0	34.4
Max Reduction - 1990	(a)	3.1	4.0	7.6	19.5	41.5
Max Reduction - 1991	(a)	3.0	3.8	7.1	14.0	29.0
RAP - 1990 &1991	0%	-	-	2.1	-	-

Note:

(a) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-6. Comparison of BOD WPCP effluent concentration for selected cases of hydraulic load reduction in 1990 and 1991.

Case	Flow Reduction (%)	Minimum Hour (mg/L)	Minimum Day (mg/L)	Flow Average (mg/L)	Maximum Day (mg/L)	Maximum Hour (mg/L)
Baseline - 1990	0%	5.4	6.1	8.6	24.7	63.1
Baseline - 1991	0%	5.0	6.0	8.4	31.4	75.1
Sanitary Flow - 1990	30%	5.0	5.4	7.7	22.3	56.1
Sanitary Flow - 1991	30%	4.7	5.4	7.2	14.6	35.1
Reduce I/I - 1990	50%	5.1	5.6	7.1	13.8	27.4
Reduce I/I - 1991	50%	4.7	5.6	7.0	10.7	20.0
Max Reduction - 1990	(a)	4.5	5.0	6.5	13.5	27.0
Max Reduction - 1991	(a)	4.3	4.9	6.3	10.0	20.6
RAP - 1990 &1991	0%	-	-	2.0	-	-

Note:

(a) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-7. TSS Load 1990

Case	Flow Reduction (%)	Through-flow (10^3 kg/yr)	Secondary Bypass (10^3 kg/yr)	Plant Bypass (10^3 kg/yr)	Total Outfall (10^3 kg/yr)	Diverted Flow (10^3 kg/yr)	TOTAL (10^3 kg/yr)
Baseline	0%	1,995.7	14.8	228.6	2,239.1	0	2,239.1
Reduce Sanitary Flow	5%	1,803	14	220.3	2,037.3	0	2,037.3
	10%	1,664	13.2	211.9	1,889.1	0	1,889.1
	15%	1,538.9	11.4	203.9	1,754.2	0	1,754.2
	20%	1,426.4	10.7	196.6	1,633.7	0	1,633.7
	25%	1,318	10.2	190.1	1,518.3	0	1,518.3
	30%	1,220.8	9.7	183.9	1,414.4	0	1,414.4
Reduce Infiltration	10%	1,740.2	13	205.4	1,958.6	0	1,958.6
	20%	1,548.9	10.5	185.7	1,745.1	0	1,745.1
	30%	1,379.9	9.4	170.5	1,559.8	0	1,559.8
	40%	1,235.1	7.1	156.8	1,399	0	1,399
	50%	1,102.2	4.9	143.9	1,251	0	1,251
Reduce Stormwater Inflow	10%	1,968	14.2	194.7	2,176.9	53.5	2,230.4
	20%	1,938.6	13.6	162.6	2,114.8	107	2,221.8
	30%	1,914.8	12.7	132.3	2,059.8	160.5	2,220.3
	40%	1,888	10.7	105	2,003.7	214	2,217.7
	50%	1,861.1	9.7	80	1,950.8	267.4	2,218.2
Reduce Infiltration and Inflow	10%	1,711.6	11.3	173.3	1,896.2	53.5	1,949.7
	20%	1,498.5	8.6	128.7	1,635.8	107	1,742.8
	30%	1,314.1	5.4	90.3	1,409.8	160.5	1,570.3
	40%	1,153.6	1.4	57.4	1,212.4	214	1,426.4
	50%	1,009.2	0.3	30.5	1,040	267.4	1,307.4
Reduce Sanitary Flow, Infiltration and Inflow	(a)	1,102	5	96	1,203	133.7	1,336.7
	(b)	578.4	0	17.5	595.9	267.4	863.3
RAP		258.4	0	0	258.4	0	258.4

Notes:

(a) 15% sanitary flow reduction, 25% infiltration reduction, and a 25% inflow reduction
(b) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-8. BOD Load 1990

Case	Flow Reduction (%)	Through-flow (10^3 kg/yr)	Secondary Bypass (10^3 kg/yr)	Plant Bypass (10^3 kg/yr)	Total Outfall (10^3 kg/yr)	Diverted Flow (10^3 kg/yr)	TOTAL (10^3 kg/yr)
Baseline	0%	1,041.7	7.9	120.6	1,170.2	0	1,170.2
Reduce Sanitary Flow	5%	979.4	7.4	116.6	1,103.4	0	1,103.4
	10%	929.7	7.1	112.6	1,049.4	0	1,049.4
	15%	884.2	6.1	108.8	999.1	0	999.1
	20%	841.4	5.7	105.2	952.3	0	952.3
	25%	799.8	5.5	102	907.3	0	907.3
	30%	766.1	5.2	99	870.3	0	870.3
Reduce Infiltration	10%	962.7	7	111	1,080.7	0	1,080.7
	20%	899.4	5.7	102.7	1,007.8	0	1,007.8
	30%	841.1	5.2	96.1	942.4	0	942.4
	40%	788.4	4	90.1	882.5	0	882.5
	50%	738.2	2.8	84.3	825.3	0	825.3
Reduce Stormwater Inflow	10%	1,030.5	7.5	101.3	1,139.3	38	1,177.3
	20%	1,019.5	7.1	83.1	1,109.7	76.1	1,185.8
	30%	1,009.5	6.6	66.2	1,082.3	114.1	1,196.4
	40%	999	5.4	51.1	1,055.5	152.1	1,207.6
	50%	988.7	4.9	37.6	1,031.2	190.1	1,221.3
Reduce Infiltration and Inflow	10%	951.7	6	92.5	1,050.2	38	1,088.2
	20%	878.5	4.6	69.2	952.3	76.1	1,028.4
	30%	812.3	2.9	48.9	864.1	114.1	978.2
	40%	751.8	0.8	31.4	784	152.1	936.1
	50%	694.3	0.2	16.9	711.4	190.1	901.5
Reduce Sanitary Flow, Infiltration and Inflow	(a)	723.6	2.7	52.2	778.5	0	778.5
	(b)	490	0	10	500	0	500
Effect of RAP upgrade	0%	246	0	0	246	0	246

Notes:

(a) 15% sanitary flow reduction, 25% infiltration reduction, and a 25% inflow reduction

(b) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-9. TSS 1990 versus 1991

Case	Flow Reduction (%)	Through-flow (10^3 kg/yr)	Secondary Bypass (10^3 kg/yr)	Plant Bypass (10^3 kg/yr)	Total Outfall (10^3 kg/yr)	Diverted Flow (10^3 kg/yr)	TOTAL (10^3 kg/yr)
Baseline - 1990	0%	1,995.7	14.8	228.6	2,239.1	0	2,239.1
Baseline - 1991	0%	1,830.4	2.7	84.8	1,917.9	0	1,917.9
Sanitary Flow - 1990	30%	1,220.8	9.7	183.9	1,414.4	0	1,414.4
Sanitary Flow - 1991	30%	1,017	0	53.5	1,070.5	0	1,070.5
Reduce I/I - 1990	50%	1,009.2	0.3	30.5	1,040	267.4	1,307.4
Reduce I/I - 1991	50%	920.6	0	3.5	924.1	163.5	1,087.6
Max Reduction - 1990	(a)	578.4	0	17.5	595.9	267.4	863.3
Max Reduction - 1991	(a)	513.1	0	1.5	514.6	163.5	678.1
RAP - 1990	0%	258.4	0	0	258.4	0	258.4
RAP - 1991	0%	244.4	0	0	244.4	0	244.4

Note:

(a) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

Table C-10. BOD 1990 versus 1991

Case	Flow Reduction (%)	Through-flow (10^3 kg/yr)	Secondary Bypass (10^3 kg/yr)	Plant Bypass (10^3 kg/yr)	Total Outfall (10^3 kg/yr)	Diverted Flow (10^3 kg/yr)	TOTAL (10^3 kg/yr)
Baseline - 1990	0%	1,041.7	7.9	120.6	1,170.2	0	1,170.2
Baseline - 1991	0%	974.9	1.4	43.1	1,019.4	0	1,019.4
Sanitary Flow - 1990	30%	766.1	5.2	99	870.3	0	870.3
Sanitary Flow - 1991	30%	677.9	0	28.8	706.7	0	706.7
Reduce I/I - 1990	50%	694.3	0.2	16.9	711.4	190.1	901.5
Reduce I/I - 1991	50%	656.4	0	2	658.4	116.2	774.6
Max Reduction - 1990	(a)	490	0	10	500	190.1	690.1
Max Reduction - 1991	(a)	454.2	0	0.8	455	116.2	571.2
RAP - 1990	0%	246	0	0	246	0	246
RAP - 1991	0%	231.8	0	0	231.8	0	231.8

Note:

(a) 30% sanitary flow reduction, 50% infiltration reduction, and a 50% inflow reduction

APPENDIX D

Water Conservation Program Description, Costs, and Cost Benefits

Appendix D
Water Conservation Program Description, Costs, and Cost Benefits

D-1 DESCRIPTION OF WATER CONSERVATION PROGRAMS USED IN COST ESTIMATES

Macy and Maddaus (1989) report that "a carefully planned and implemented water conservation program can reduce water consumption by 30 percent". They also recognize the beneficial impact water conservation can have on "overburdened wastewater treatment facilities." The following is a description of the water conservation program used to develop the costs summarized in Section 8. This is a fairly comprehensive and visible program. The actual water conservation program for any municipality or city would need to be carefully, and specifically, developed.

Development of a detailed water conservation program is not one of the goals of this report. But, some idea of the costs of a water conservation program must be determined. Therefore, this appendix outlines several possible flow reduction programs elements. The proposed program does not include options such as landscaping changes, a comprehensive distribution system leak detection program, nor implementation of water use restrictions. The proposed program does consist of:

1. Development of a comprehensive database to track flow volumes from water treatment, distribution and use, and wastewater collection and treatment.
2. Public education program.
3. Pricing policy development and implementation.
4. Residential audits.
5. Industrial and commercial liaison (audits).
6. Conservation and I/I monitoring and enforcement.
7. Infrastructure needs study.
8. I/I rehabilitation and repair.

Proposed program implementation includes:

1. This assumes a year (1993) to plan the water conservation program. No costs are provided for this stage.
2. The programs described in this Appendix are assumed to start in 1994. The first year is effectively a start up year which involves final planning of the selected water conservation measures.
3. Full water conservation programs are not scheduled to start until 1995, and would last until 1999.
4. From the year 2000 on, a small staff would monitor and enforce conservation and I/I reduction.

This proposed timetable could be revised to allow a slower project initiation and wind down. It may prove worthwhile to spend a year or so planning the conservation program, and then another year to conduct test projects to determine the feasibility of various options.

The following are detailed descriptions of aspects of a water conservation program. Detailed cost breakdowns are provided in section D-2.

Database Development

Description

This one year program will include the development and installation of a detailed water and wastewater database and analysis system. Costs include database design by an external consultant (or internal labour if appropriate expertise is available), hardware and software purchases, data entry and transfer, and analysis development and system evaluation. Data entry and transfer reflects the work required to convert all existing data into a form usable by the database.

For a full description of the use of this database, see the **Conservation and I/I Monitoring and Enforcement** description.

Case Studies

Padmanabha (1992) describes the development of a water consumption database that will be used to

1. Compare water flow to sewer flow,
2. Identify water losses,
3. Develop water conservation strategies, and
4. Measure program success.

The database described by Padmanabha (1992) includes:

1. Water consumption data by billing period,
2. Customer classification
3. Property location
4. Water pumping information
5. Sewer district, water district and census tract information.

Cost: $174,000

Duration: 1 year

Public Education

Description

This one year program will be used to inform the public about water conservation in general and the proposed residential audits and changes in water billing in particular. The public education team would consist of three people who will:

1. Oversee the development of a portable display and handout materials;
2. Man the display at high visibility locations such as malls, festivals, schools, etc.;
3. Attend and participate in local seminars and workshops put on by local service, public interest, and neighbourhood groups;
4. Organize seminars and workshops for the general public;
5. Promote water conservation in the local media (press releases, advertising); and
6. Inform public of upcoming home audit program and other water conservation initiatives.

In addition, inserts and notices can be included with the each water bill.

After the first year, public education would become part of the residential audit and industrial/commercial liaison programs.

Case Studies

Padmanabha (1992) describes a program in Washington, D.C. which includes:

1. Inform users of benefits of water conservation
2. Public service and paid announcements in print, radio, and television
3. Notices on water and sewer bill envelopes
4. Water bill inserts
5. Handbook available to the public on request
6. Video for neighbourhood meetings, schools, and other meetings
7. Colouring books for elementary school children
8. Plumbing clinics and training programs for plumbing inspectors, building maintenance staff, resident managers, and others

Cost: $520,000

Duration: 1 year

Pricing Policy Development

Description

The purpose of this program is to develop a new water price policy (if necessary) that will help promote conservation and *consider* the economic criteria described in Environment Canada (1989): cost recovery; equity (fairness, especially to users who conserve); and economic efficiency (achieving a given objective at least cost).

Issues to resolve will include:

1. What water rates and water rate schedules (e.g., flat rate, declining block rate, constant rate, and increasing block rate, others) should be used?
2. How can revenue shortfalls (or frequent rate adjustments) be avoided when a conservation program is implemented. (Vickers and Markus, 1992)?
3. What will be the effect of new water rates on water use?

Case Studies

JAWWA Roundtable (1992) provides several key points with respect to water conservation and pricing:

- Conservation pricing is absolutely critical for conservation.
- Conservation pricing will change personal habits unlike, for example, the installation of low flow showerheads.
- Structuring of price is the key (an inclining rate structure is good).
- Price essential water at alower rate, but price "discretionary use" water much higher.
- Recognize the difference between conservation rates and cost of service rates.
- Billing period is very important to the effects of water rate increases and conservation.
- An option is bill forecasting, that is to predict how much the next bill will be unless they cut back.
- Water rates should be based on fairness, revenue sufficiency, stability, and conservation.
- It is very hard to predict conservation effects water rates (considering elasticity, revenue neutral water rates, etc.).
- Conservation based rate structures are getting more innovative (there are other options than the standard four rate structures described above).

Cost: $220,000

Duration: 1 year

Audit Development and Residential Audits

Description

Details of the residential audit program would need to be developed over the first year. It may prove advisable to conduct a pilot project in a small test area to determine the feasibility and monitor the results. Tasks to be conducted during the home audit could include:

1. Conduct an interview on water use and recommend ways to reduce water use.
2. Arrange water meter installation if necessary.
3. Test for leaks (especially toilets) by dye testing.
4. Measure water use by various fixtures and appliances.
5. Install, or give out, low flow devices, toilet dams, faucet aerators, etc.
6. Inspect and measure external water fixtures and use. Inspect lawn and sprinkling system and recommend watering schedule.
7. Conduct inflow/infiltration audit, especially roof disconnection (smoke testing could be conducted on a street, block or neighbourhood basis before individual home audits are conducted).
8. Provide general information (pamphlets) on water conservation.

Case Studies

Nelson (1992) describes a comprehensive residential water audit program in the North Marin (California) Water District conducted in 1988. This audit was conducted on a voluntary basis in the top quartile of residential water users. Costs of the program were:

1. $17 per home in materials and $38 for labour (1.5 hours per audit)
2. Total of $55 per audit, which could be reduced to $45 per audit by removing the a half hour interview and eliminating promotional gifts.

The program achieved an overall 5% reduction in water use in audited homes (actual reduction was 15.5%, median reduction was 19%, however, these numbers were compared to a control group, and a net reduction of 5% was attributed to the audits). Water use was reduced in 76% of the homes and 90% of the homes followed through on leak repair. However, 15% of the low flow showerheads were removed 20 months after the audit, and the same rate of removal for toilet tank displacement devices occurred. A simple cost benefit analysis shows a payback period of 2 years from the consumers point of view (if the consumer pays for the audit), or 30 year payback from the utilities point of view.

The Region of Waterloo is currently involved in a pilot study involving 300 detached single-family residences. A contractor was hired to install low flow shower heads and toilets, and faucet aerators in kitchen and bathroom sinks. An earlier project involved sending out kits to water consumers. Although 80% penetration was achieved, it is difficult to predict the long term impact since it is difficult to know what was actually installed in each residence, and how long it will remained installed. By installing low flow fixtures, better estimates of long term water reductions are possible.

The following tables are reproduced from Metcalf and Eddy (1991). Typical low flow devices and appliances include:

Device/Appliance	Description/Application
Faucet aerators	Increases the rinsing power of water by adding air and concentrating flow, thus reducing the amount of wash water used.
Limiting-flow shower heads	Restricts and concentrates water passage by means of orifices that limit and divert shower flow for optimum use by the bather.
Low-flush toilets	Reduces the amount of water discharged per flush.
Pressure-reducing valve	Maintains home water pressure at a lower level than that of the water distribution system; decreases the probability of leaks and dripping faucets.
Retrofit kits for bathroom fixtures	Kits may consist of shower-flow restrictors, toilet dams, or displacement bags, and toilet leak detector tablets.
Toilet dam	A partition in the water closet that reduces the amount of water per flush.
Toilet leak detectors	Tablets that dissolve in the water closet and release dye to indicate leakage of the flush valve.
Water-efficient dishwasher	Reduces the water used.
Water-efficient clothswasher	Reduces the water used.

Flow reduction by flow reduction appliances and devices include (Metcalf and Eddy, 1991):

Device/Appliance	Flow Reduction gal/capita/day or unit
Faucet aerators	0.5
Limiting-flow shower heads	
3 gal/min	7
0.5 gal/min	14
Low-flush toilets	
3.4 gal/flush	8
0.5 gal/flush	20
Pressure-reducing valve	3-6
Retrofit kits for bathroom fixtures	4-7
Toilet dam	4
Toilet leak detectors	24
Water-efficient dishwasher	1
Water-efficient clothswasher	1.5

Cost:	$350,000 for audit development $6,100,000 per year for five years for residential audits
Duration:	1 year for audit development 5 years for residential audits

Industrial and Commercial Liaison

Description

This program is similar to residential audits but is provided as a service to local industries and commercial developments that use the municipal water supply and wastewater treatment systems. This program should be carried out by well trained, experienced individuals. The goal is to work with local commercial and industrial concerns, in an advisory role, which will include:

1. Help non-residential water users to understand the benefits of water conservation.
2. Explain new water use regulations and prices.
3. Help set up a water audit (maybe actively participate in smaller ones) and water conservation programs.

There are two aspects to commercial/industrial water conservation that will need to be considered:

1. Sanitary water use
2. Process/cooling water use

Case Studies

Ploeser et.al. (1992) provide a review of many non-residential water conservation programs, which include:

1. site visits
2. guidebooks
3. seminars
4. conservation planning, employee education
5. advisory committee
6. trade shows, organizations
7. awards
8. financial incentives, assistance
9. ordinances, regulations
10. water use research studies
11. industrial reuse

Behling and Bartilucci (1992) reviewed office water consumption and found it is highly dependant on: occupancy, gender demographics, restroom usage, and volume of fixture units.

Cost: $230,000 per year for five years

Duration: 5 year

Conservation and I/I Monitoring and Enforcement

Description

This is a two part program that involves montoring and enforcement. Monitoring refers to an analysis using the database system described earlier. Enforcement refers to the field work and the gathering of information and evidence with respect to water and sewer use.

Monitoring involves one person whose responsibility is to maintain and update the water and sewer use database. This person, who will be office based, will integrate all water use and wastewater flow data (water treated, water pumped at all pumping stations, water use through metering, wastewater flow from pumping stations and flow monitors, and WPCP flows). Effectively this is conducting an analysis on the municipal water budget as shown in Figure 2.3 (Section 2). This task will also involve:

1. Reporting on the successes and failures of water conservation
2. Working with the enforcement team by helping to focus the work of enforcement teams on critical areas, and by analyzing the data collected by the enforcement teams.

Enforcement will be composed of 3 teams of 2 people each. These teams will track down and document water loss, water use, and I/I generation problems. An efficient mechanism for informing the responsible homeowner, business, or government agency will need o be set up. Bylaws and codes may need to be established to provide an incentive to offenders to correct An additional use of the data collected by the enforcement team will be to provide data which can be used to set reasonable water rates based on water use by various types of water users. Tools of the enforcement teams can include flow monitors, flourimeters (dye testing), smoke testing, video camera inspection, and water quality samplers. It may be possible (although maybe not politically possible) to integrate this function with MISA sewer use bylaw enforcement.

In addition, implementation and enforcement of a stricter plumbing code for new and renovated buildings should be considered.

Case Studies

Rothstein (1992) describes water demand monitoring in Austin Texas. Austin spent $375 million upgrading water and wastewater systems between 1980 and 1989 and $85 million in storage , transmission, and distribution infrastructure. The annual growth rate not as high as expected, therefore, revenues are much lower than expected and has necessitated an increase in water rates of 136% in 9 years. By collecting demand data, new rates will better reflect system use.

The description of the Washington, D.C. plumbing code is described by Padmanabha (1992). It includes:

1. Use of water saving fixtures (shower heads, faucets, toilets, urinals, and appliances) in new developments or substantially renovated properties.

2. Use of standards and recommendation from American Society of Mechanical Engineers, American National Standard Institute, and the Plumbing Manufacturers Institute.

Cost: $73,000 per year for monitoring
$365,000 per year for enforcement

Duration: Permanent (subject to periodic review)

D-2 WATER CONSERVATION PROGRAM COSTS AND COST BENEFITS

Tables D-1 to D-4 provide details on conservation program cost estimates, and water conservation cost benefits, and a cost/benefit analysis.

Description of Table D-1

Table D-1 shows a breakdown of costs of the programs described in Section D-1. A 50% overhead cost is added to each program which accounts for:

1. Labour overhead which includes benefits, overtime, vacation, supervision, and personnel functions (e.g., accounting and payroll related to labour).
2. Other overhead which includes minor, unknown, or overlooked expenses (contingency), cost overruns, and support services.

Description of Table D-2

A listing of WPCP operation and maintenance (O&M) costs are shown in Table D-2. Total costs are divided into:

1. Fixed costs
2. Flow dependant costs
3. Influent pollutant load dependant costs

The costs provided were for all of Hamilton-Wentworth, including Woodward WPCP, Dundas WPCP, and Waterdown WPCP. Costs therefore had to be determined for the area tributary to Woodward WPCP. Methods for determining Woodward collection and treatment were:

1. For pumping station O&M, 23 pumping stations out of 33 are tributary to the Woodward WPCP, therefore used the fraction $\frac{23}{33}$ (or 70%) to determine O&M costs of pumping in Woodward WPCP sewershed
2. Woodward treats 94% of flow in region, therefore, assumed 94% of total O&M costs were attributed to Woodward.

Costs needed to be divided up into fixed costs and variable costs. Variable costs primarily consist of energy costs (hydro), chemical costs, and some equipment repair and replacement which was determined to be flow dependent. Not all energy costs are flow dependent as considerable amount of energy is used for building lighting and heating. Variable flow had to be divided between flow variable cost and load variable costs. A considerable portion of the variable cost is based on residuals pumping and treatment which means a portion of the variable costs are based primarily on the mass of solids removed during treatment. In this project, when sanitary flow is reduced, we are assuming the pollutant load entering the plant does not decrease (concentration increase is inversely proportional to the decrease in flow), which means the solids produced during treatment does not change, therefore, no savings is realized in residuals management. However, when inflow and infiltration is reduced, flow and pollutant load is reduced, therefore the mass of solids removed is lower, therefore residuals management costs are decreased.

From Table D-2, if flow changes, but influent pollutant load is constant, then:

$$\Delta\$ = 4821.45 \times \Delta Q$$

If flow changes, and influent pollutant load changes proportionately to flow, then:

$$\Delta\$ = 8470.86 \times \Delta Q$$

where:

$\Delta\$$	-	change in annual WPCP operating cost
ΔQ	-	change in annual average WPCP flow rate expressed in MLD

Description of Table D-3

An analysis of water treatment costs, similar to the analysis for WPCP costs, is shown in Table D-3. Once again, the primary variable costs are electrical energy and chemicals. Note that although total water treatment cost is less than wastewater treatment costs, the variable cost of water treatment is higher than the variable cost of water treatment

From Table D-3, change in annual operating cost as a function of change in average daily flow (over a year) is:

$$\Delta\$ = 12,236 \times \Delta Q$$

where:

$\Delta\$$	-	change in annual WTP operating cost
ΔQ	-	change in annual average WTP flow rate expressed in MLD140

Note that the WTP is currently operated in the evenings to avoid peak Hydro charges. As water use increases, or non-peak hour decreases (as recently occurred), the marginal cost of electrical energy may increase significantly above the average rate shown in Table D-3

Description of Table D-4

This is a simple look-up table that shows the percentage change in water use for given levels of price increase and price elasticity. The eqution used to construct this table is based on the equation:

$$Q = kP^E$$

where:

Q = water consumption rate
k = constant
P = unit price of water
E = price elasticity

from which the following equation was derived:

$$\frac{\%\Delta Q}{100} = \left(\frac{\%\Delta P}{100} + 1\right)^{E} - 1$$

where:

$\%\Delta Q$ = percentage change in water consumption
$\%\Delta P$ = percentage change in price
E = price elasticity

Description of Table D-5

This look up table is used to determine the percentage change in revenues for given price increases and changes inwater use. This table is required because for any given price increase, the water consumption will decrease (theoretically) which means that revenue will not increase at the same rate as price increases. This table was constructed with the following equation:

$$\frac{\%\Delta\$}{100} = \frac{\%\Delta P}{100} + \frac{\%\Delta Q}{100} + \frac{\%\Delta P}{100} \bullet \frac{\%\Delta Q}{100}$$

where:

$\%\Delta\$$ - percentage increase in water billing revenues due to a price increase

Description of Table D-6 to D-11

Fifty years of annual cost changes due to flow reduction are shown in Table D-6 to D-11. Cost changes are defined as O&M cost decreases due to water conservation, costs of implementing water conservation, and the savings associated with delaying capital works. An additional column is included which shows the required change in revenues expected due to increases to promote conservation, and increases to ensure complete cost recovery (assuming the current rates ensure complete cost recovery). The spreadsheet shown is only one example of a cost/benefit analysis for the described water conservation program. Revisions can be made including:

1. Conservation program cost
2. Estimated flow reduction due to conservation program
3. Estimated capital costs of future capacity upgrade
4. Pumping station, WPCP, and WTP, O&M cost reduction rates
5. Estimated RAP variable operating costs
6. Inflation and interest rates

The capital cost of future capacity upgrades, even without any RAP-based controls, is very uncertain. A better estimate of these future upgrades, and RAP-based upgrades and controls, will be possible after the current Woodward WPCP Facility Planning project is completed. Another source of uncertainty in the spreadsheet are in cost estimates associated with the Hamilton Harbour RAP program. The RAP program is proposing a major upgrade at the

Woodward WPCP and extensive CSO control. These upgrades have three effects on cost estimates:

1. Effect of water conservation on size of RAP-based WPCP upgrades and CSO facilities.
2. Annual O&M costs associated with RAP-based WPCP upgrades and CSO facilities.
3. Cost of future capacity upgrades for proposed RAP-based WPCP upgrades and CSO facilities.

Other minor problems in the cost/benefit spreadsheet include:

1. CSO control variable costs should be based on CSO frequencies, but, are currently based on total flow to the WPCP.
2. Cost of reading the newly installed water meters on a regular basis is not included.
3. The cost of replacing low flow devices based on their service life is not included. This analysis assumes all fixtures, including existing fixtures, are replaced on a regular basis and that conversion to water conservation devices is a one time cost.

Table D-1. Cost of various flow reduction program elements.

Program	Activity	Effort	Unit	Unit Cost	Cost	Notes
YEAR 1						
Database Development						1 year project
	Consulting Services	1		$50,000	$50,000	
	Software	1		$5,000	$5,000	
	Hardware	1	workstation	$10,000	$10,000	includes peripherals
	Data Entry/Transfer	1	person-year	$35,000	$35,000	
	Analysis Development	0.25	person-year	$45,000	$11,250	
	System Evaluation	0.10	person-year	$45,000	$4,500	
	Sub-Total				**$115,750**	
	Overhead	50%	of sub-total		$57,875	
	TOTAL				***$173,625***	one time cost
Public Education						first year kick off
	Staffing	3	people	$40,000	$120,000	
	Display	1	portable display	$25,000	$25,000	
	Handouts	200,000		$1	$200,000	
	Sub-Total				**$345,000**	
	Overhead	50%	of sub-total		$172,500	
	TOTAL				**$517,500**	one time cost
Audit Development						one time cost
	Consulting Services	1		$100,000	$100,000	
	In-house Development	3	person year	$45,000	$135,000	plus contact for conultant
	Sub-Total				**$235,000**	
	Overhead	50%	of sub-total		$117,500	
	TOTAL				**$352,500**	one time cost
Pricing						one time cost
	Consulting Services	1		$100,000	$100,000	
	In-house Conversion	1	person year	$45,000	$45,000	plus contact for conultant
	Sub-Total				**$145,000**	
	Overhead	50%	of sub-total		$72,500	
	TOTAL				**$217,500**	one time cost
Infrastructure Needs Study						
	Consulting Services	1		$500,000	$500,000	
	In-house liaison	1	person year	$45,000	$45,000	plus contact for conultant
	Sub-Total				**$545,000**	
	Overhead	50%	of sub-total		$272,500	
	TOTAL				**$817,500**	one time cost

Table D-1. Cost of various flow reduction program elements.

YEARS 2-6						
Residential Audits						5 year program
	Auditors	20	person-year	$35,000	$700,000	2000 hrs/year/auditor @2.0 hrs/home
	Management	2	person-year	$45,000	$90,000	Manage, supervise, coordinate
	Other Staff	3	person-year	$35,000	$105,000	Office work, backup auditors
	Conversion Kits	20,000	kits	$25	$500,000	20000 homes per year + followup
	Meter & Installation	10,000	meters/year	$250	$2,500,000	
	Diconnect roof leader	10,000	elbow, packing	$50	$500,000	say 50% are connected
	Advertising	100,000	mailouts	$2	$200,000	100,000 dwelling unit mailout.
	Sub-Total				**$4,595,000**	
	Overhead	50%	of sub-total		$2,297,500	
	TOTAL				**$6,892,500**	per year
Industrial/Commercial Liason						5 year program
	Auditors	3	person-year	$50,000	$150,000	
	Equipment	3	kits	$1,000	$3,000	
	Sub-Total				**$153,000**	
	Overhead	50%	of sub-total		$76,500	
	TOTAL				***$229,500***	per year
YEARS 2 on						
Conservation and I/I Monitoring						Annual Budget - ongoing program
	Data Transfer	0.10	person-year	$35,000	$3,500	
	Analysis	0.50	person-year	$45,000	$22,500	
	Enforcement Liason	0.30	person-year	$45,000	$13,500	Help inspectors
	Reporting	0.20	person-year	$45,000	$9,000	
	Sub-Total				**$48,500**	
	Overhead	50%	of sub-total		$24,250	
	TOTAL				***$72,750***	per year
Conservation and I/I Monitoring and Enforcement						Annual Budget - ongoing program
	Inspector	6	person-year	$40,000	$240,000	3 teams of 2 inspectors
	Inspectors Equipment	1	annual purchase	$10,000	$10,000	annual equipment budget
	Sub-Total				**$250,000**	
	Overhead	50%	of sub-total		$125,000	
	TOTAL				***$375,000***	per year
Collection System Rehabilitation and Repair						
	Annual Budget				$500,000	
	Overhead	50%	of sub-total		$250,000	
	TOTAL				***$750,000***	per year
Notes:	1. Overhead includes vacation, benefits and overtime on labour as well as accounting costs.					
	2. Overhead includes contingency fees on materials.					
	3. Could add other I/I reduction programs to audit program.					
	4. There are 110,000 service connection in Hamilton-Wentworth (res, com, ind, inst)					
	5. Of these, 56,000 are metered, 54,298 non-metered.					
	6. Assume 100,000 residences (to account for multi-family dwellings)					

Table D-2. WPCP operation and maintenance costs.

Hamilton-Wentworth 1992 Budget									
Pumping Stations and Treatment Facilities									
		All WPCPs				Woodward			Notes
Activity - Item	Total	Fixed	Flow-Var	Load-Var	Total	Fixed	Flow-Var	Load-Var	
P.S. - Operations									23 out of 33 P.S.'s are tributary
Wages	$26,700	$26,700	$0	$0	$18,609	$18,609	$0	$0	to Woodward WPCP
Motor Vehicle	$7,400	$7,400	$0	$0	$5,158	$5,158	$0	$0	
Protective Clothing	$200	$200	$0	$0	$139	$139	$0	$0	
Hydro	$95,000	$0	$95,000	$0	$66,212	$0	$66,212	$0	
Water	$5,400	$5,400	$0	$0	$3,764	$3,764	$0	$0	
Natural Gas	$5,300	$5,300	$0	$0	$3,694	$3,694	$0	$0	
Sewage Haulage	$10,700	$0	$10,700	$0	$7,458	$0	$7,458	$0	
TOTAL	**$150,700**	**$45,000**	**$105,700**	**$0**	**$105,033**	**$31,364**	**$73,670**	**$0**	
P.S. - Maintenance									23 out of 33 P.S.'s are tributary
Wages	$149,600	$149,600	$0	$0	$104,267	$104,267	$0	$0	to Woodward WPCP
Motor Vehicle	$7,400	$7,400	$0	$0	$5,158	$5,158	$0	$0	
New Equipment	$17,000	$8,000	$9,000	$0	$11,848	$5,576	$6,273	$0	see original
Repairs - Equipment	$36,100	$25,600	$10,500	$0	$25,161	$17,842	$7,318	$0	see original
Repairs - Buildings	$26,700	$26,700	$0	$0	$18,609	$18,609	$0	$0	
Horticultural Services	$12,100	$12,100	$0	$0	$8,433	$8,433	$0	$0	
TOTAL	**$248,900**	**$229,400**	**$19,500**	**$0**	**$173,476**	**$159,885**	**$13,591**	**$0**	
WPCP - Operations									94% of treated @ Woodward
Wages	$1,819,700	$1,819,700	$0	$0	$1,710,518	$1,710,518	$0	$0	
Chemicals	$476,700	$17,867	$458,833	$0	$448,098	$16,795	$431,303	$0	see breakdown
Motor Vehicle	$39,900	$39,900	$0	$0	$37,506	$37,506	$0	$0	
Protective Clothing	$22,700	$22,700	$0	$0	$21,338	$21,338	$0	$0	
Operating Supplies	$2,100	$2,100	$0	$0	$1,974	$1,974	$0	$0	
New Equipment	$0	$0	$0	$0	$0	$0	$0	$0	
Repairs - Radio	$3,000	$3,000	$0	$0	$2,820	$2,820	$0	$0	
Hydro	$1,635,300	$81,765	$981,180	$572,355	$1,537,182	$76,859	$922,309	$538,014	95% process
Water	$380,000	$380,000	$0	$0	$357,200	$357,200	$0	$0	
Natural Gas	$450,000	$112,500	$0	$337,500	$423,000	$105,750	$0	$317,250	75% process
Data Line	$3,000	$3,000	$0	$0	$2,820	$2,820	$0	$0	
Medical Fees	$25,000	$25,000	$0	$0	$23,500	$23,500	$0	$0	
Contract Services	$20,000	$20,000	$0	$0	$18,800	$18,800	$0	$0	
Residuals Dispose	$321,700	$0	$0	$321,700	$302,398	$0	$0	$302,398	
Meals	$0	$0	$0	$0	$0	$0	$0	$0	
C.A. - Regional Labs	$22,600	$22,600	$0	$0	$21,244	$21,244	$0	$0	
C.A. - Waste Mngmnt	$224,800	$224,800	$0	$0	$211,312	$211,312	$0	$0	
TOTAL	**$5,446,500**	**$2,774,932**	**$1,440,013**	**$1,231,555**	**$5,119,710**	**$2,608,436**	**$1,353,612**	**$1,157,662**	
WPCP - Maintenance									94% of treated @ Woodward
Wages	$1,163,500	$1,163,500	$0	$0	$1,093,690	$1,093,690	$0	$0	
Stand by	$14,700	$14,700	$0	$0	$13,818	$13,818	$0	$0	
Motor Vehicle	$18,200	$18,200	$0	$0	$17,108	$17,108	$0	$0	
Protective Clothing	$22,700	$22,700	$0	$0	$21,338	$21,338	$0	$0	
New Equipment	$55,800	$13,500	$31,500	$10,800	$52,452	$12,690	$29,610	$10,152	see breakdown
Repairs - Equipment	$364,000	$287,000	$77,000	$0	$342,160	$269,780	$72,380	$0	see breakdown
Repairs - Buildings	$130,000	$130,000	$0	$0	$122,200	$122,200	$0	$0	
Horticultural Services	$30,900	$30,900	$0	$0	$29,046	$29,046	$0	$0	
Rent-Pager	$1,000	$1,000	$0	$0	$940	$940	$0	$0	
Medical Fees	$25,000	$25,000	$0	$0	$23,500	$23,500	$0	$0	
Meals	$0	$0	$0	$0	$0	$0	$0	$0	
Tax Stab Reserve	$0	$0	$0	$0	$0	$0	$0	$0	
TOTAL	**$1,825,800**	**$1,706,500**	**$108,500**	**$10,800**	**$1,716,252**	**$1,604,110**	**$101,990**	**$10,152**	
GRAND TOTAL	***$7,671,900***	***$4,755,832***	***$1,673,713***	***$1,242,355***	***$7,114,471***	***$4,403,795***	***$1,542,863***	***$1,167,814***	
Notes:	1. Based on 320 MLD								
	2. For flow change only (d$ = 4821.45 dQ) where dQ is in MLD.								
	3. For flow and load change, then (d$ = 8470.86 dQ) where dQ is in MLD.								

Table D-3. Water treatment plant operation and maintenance costs.

Hamilton-Wentworth 1992 Budget					
Water Treatment and Distribution					
			All		Notes
Activitity - Item		Total	Fixed	Flow-Var	
P.S. - Operations					
	Wages	$234,300	$234,300	$0	
	Motor Vehicle	$3,100	$3,100	$0	
	Chemicals	$9,600	$0	$9,600	
	Hydro	$1,377,200	$0	$1,377,200	
	TOTAL	**$1,624,200**	**$237,400**	**$1,386,800**	
P.S. - Maintenance					
	Wages	$124,600	$124,600	$0	
	Motor Vehicle	$11,400	$11,400	$0	
	Repairs - Equipment	$65,600	$0	$65,600	
	Repairs - Buildings	$0	$0	$0	
	Horticultural Services	$3,000	$3,000	$0	
	TOTAL	**$204,600**	**$139,000**	**$65,600**	
WPCP - Operations					
	Wages	$539,900	$539,900	$0	
	Chemicals	$342,300	$0	$342,300	
	Motor Vehicle	$6,600	$6,600	$0	
	Protective Clothing	$3,400	$3,400	$0	
	Repairs - Radio	$3,000	$3,000	$0	
	Hydro	$1,282,600	$0	$1,282,600	
	Data Line	$3,000	$3,000	$0	
	Steam	$27,200	$27,200	$0	
	C.A. - Sewage	$360,100	$0	$360,100	
	C.A. - Regional Labs	$299,200	$299,200	$0	
	TOTAL	**$2,867,300**	**$882,300**	**$1,985,000**	
WPCP - Maintenance					
	Wages	$408,800	$408,800	$0	
	Motor Vehicle	$7,500	$7,500	$0	
	Protective Clothing	$2,000	$2,000	$0	
	Operating Supplies	$1,500	$0	$1,500	
	New Equipment	$18,000	$5,000	$13,000	
	Repairs - Equipment	$110,400	$14,000	$96,400	
	Repairs - Buildings	$47,000	$47,000	$0	
	Horticultural Services	$15,500	$15,500	$0	
	TOTAL	**$610,700**	**$499,800**	**$110,900**	
GRAND TOTAL		*$5,306,800*	*$1,758,500*	*$3,548,300*	
Notes:					
	1. Based on 290 MLD				
	2. For variable flow: d$ = 12,236 dQ.				

Table D-4. Percent change in water use at given levels of price increase and price elasticity.

	Price Increases (%)													
Elasticity	5%	10%	15%	20%	25%	30%	40%	50%	75%	100%	150%	200%	500%	1000%
0.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
-0.01	-0.05%	-0.10%	-0.14%	-0.18%	-0.22%	-0.26%	-0.34%	-0.40%	-0.56%	-0.69%	-0.91%	-1.09%	-1.78%	-2.37%
-0.02	-0.10%	-0.19%	-0.28%	-0.36%	-0.45%	-0.52%	-0.67%	-0.81%	-1.11%	-1.38%	-1.82%	-2.17%	-3.52%	-4.68%
-0.05	-0.24%	-0.48%	-0.70%	-0.91%	-1.11%	-1.30%	-1.67%	-2.01%	-2.76%	-3.41%	-4.48%	-5.34%	-8.57%	-11.30%
-0.10	-0.49%	-0.95%	-1.39%	-1.81%	-2.21%	-2.59%	-3.31%	-3.97%	-5.44%	-6.70%	-8.76%	-10.40%	-16.40%	-21.32%
-0.15	-0.73%	-1.42%	-2.07%	-2.70%	-3.29%	-3.86%	-4.92%	-5.90%	-8.05%	-9.87%	-12.84%	-15.19%	-23.57%	-30.21%
-0.20	-0.97%	-1.89%	-2.76%	-3.58%	-4.36%	-5.11%	-6.51%	-7.79%	-10.59%	-12.94%	-16.74%	-19.73%	-30.12%	-38.10%
-0.23	-1.12%	-2.17%	-3.16%	-4.11%	-5.00%	-5.86%	-7.45%	-8.90%	-12.08%	-14.74%	-19.00%	-22.33%	-33.77%	-42.39%
-0.26	-1.26%	-2.45%	-3.57%	-4.63%	-5.64%	-6.59%	-8.38%	-10.01%	-13.54%	-16.49%	-21.20%	-24.85%	-37.24%	-46.39%
-0.30	-1.45%	-2.82%	-4.11%	-5.32%	-6.48%	-7.57%	-9.60%	-11.45%	-15.45%	-18.77%	-24.03%	-28.08%	-41.58%	-51.29%
-0.40	-1.93%	-3.74%	-5.44%	-7.03%	-8.54%	-9.96%	-12.59%	-14.97%	-20.06%	-24.21%	-30.69%	-35.56%	-51.16%	-61.68%
-0.50	-2.41%	-4.65%	-6.75%	-8.71%	-10.56%	-12.29%	-15.48%	-18.35%	-24.41%	-29.29%	-36.75%	-42.26%	-59.18%	-69.85%
-0.60	-2.88%	-5.56%	-8.04%	-10.36%	-12.53%	-14.57%	-18.28%	-21.59%	-28.52%	-34.02%	-42.29%	-48.27%	-65.87%	-76.28%
-0.70	-3.36%	-6.45%	-9.32%	-11.98%	-14.46%	-16.78%	-20.98%	-24.71%	-32.41%	-38.44%	-47.34%	-53.65%	-71.47%	-81.34%
-0.80	-3.83%	-7.34%	-10.58%	-13.57%	-16.35%	-18.93%	-23.60%	-27.70%	-36.09%	-42.57%	-51.96%	-58.48%	-76.15%	-85.31%
-0.90	-4.30%	-8.22%	-11.82%	-15.13%	-18.19%	-21.03%	-26.13%	-30.57%	-39.57%	-46.41%	-56.16%	-62.80%	-80.06%	-88.45%
-1.00	-4.76%	-9.09%	-13.04%	-16.67%	-20.00%	-23.08%	-28.57%	-33.33%	-42.86%	-50.00%	-60.00%	-66.67%	-83.33%	-90.91%
-1.20	-5.69%	-10.81%	-15.44%	-19.65%	-23.49%	-27.01%	-33.22%	-38.53%	-48.91%	-56.47%	-66.70%	-73.24%	-88.35%	-94.37%
-1.50	-7.06%	-13.32%	-18.91%	-23.93%	-28.45%	-32.53%	-39.63%	-45.57%	-56.80%	-64.64%	-74.70%	-80.75%	-93.20%	-97.26%
-2.00	-9.30%	-17.36%	-24.39%	-30.56%	-36.00%	-40.83%	-48.98%	-55.56%	-67.35%	-75.00%	-84.00%	-88.89%	-97.22%	-99.17%
-5.00	-21.65%	-37.91%	-50.28%	-59.81%	-67.23%	-73.07%	-81.41%	-86.83%	-93.91%	-96.88%	-98.98%	-99.59%	-99.99%	-100.00%

Table D-5. Percent change in revenues at given price increases and water conservation levels.

Change in water use	Price Increases (%)													
	5%	10%	15%	20%	25%	30%	40%	50%	75%	100%	150%	200%	500%	1000%
0%	5.00%	10.00%	15.00%	20.00%	25.00%	30.00%	40.00%	50.00%	75.00%	100.00%	150.00%	200.00%	500.00%	1000.00%
-1%	3.95%	8.90%	13.85%	18.80%	23.75%	28.70%	38.60%	48.50%	73.25%	98.00%	147.50%	197.00%	494.00%	989.00%
-2%	2.90%	7.80%	12.70%	17.60%	22.50%	27.40%	37.20%	47.00%	71.50%	96.00%	145.00%	194.00%	488.00%	978.00%
-3%	1.85%	6.70%	11.55%	16.40%	21.25%	26.10%	35.80%	45.50%	69.75%	94.00%	142.50%	191.00%	482.00%	967.00%
-4%	0.80%	5.60%	10.40%	15.20%	20.00%	24.80%	34.40%	44.00%	68.00%	92.00%	140.00%	188.00%	476.00%	956.00%
-5%	-0.25%	4.50%	9.25%	14.00%	18.75%	23.50%	33.00%	42.50%	66.25%	90.00%	137.50%	185.00%	470.00%	945.00%
-7%	-2.35%	2.30%	6.95%	11.60%	16.25%	20.90%	30.20%	39.50%	62.75%	86.00%	132.50%	179.00%	458.00%	923.00%
-8%	-3.40%	1.20%	5.80%	10.40%	15.00%	19.60%	28.80%	38.00%	61.00%	84.00%	130.00%	176.00%	452.00%	912.00%
-9%	-4.45%	0.10%	4.65%	9.20%	13.75%	18.30%	27.40%	36.50%	59.25%	82.00%	127.50%	173.00%	446.00%	901.00%
-10%	-5.50%	-1.00%	3.50%	8.00%	12.50%	17.00%	26.00%	35.00%	57.50%	80.00%	125.00%	170.00%	440.00%	890.00%
-15%	-10.75%	-6.50%	-2.25%	2.00%	6.25%	10.50%	19.00%	27.50%	48.75%	70.00%	112.50%	155.00%	410.00%	835.00%
-20%	-16.00%	-12.00%	-8.00%	-4.00%	0.00%	4.00%	12.00%	20.00%	40.00%	60.00%	100.00%	140.00%	380.00%	780.00%
-25%	-21.25%	-17.50%	-13.75%	-10.00%	-6.25%	-2.50%	5.00%	12.50%	31.25%	50.00%	87.50%	125.00%	350.00%	725.00%
-30%	-26.50%	-23.00%	-19.50%	-16.00%	-12.50%	-9.00%	-2.00%	5.00%	22.50%	40.00%	75.00%	110.00%	320.00%	670.00%
-35%	-31.75%	-28.50%	-25.25%	-22.00%	-18.75%	-15.50%	-9.00%	-2.50%	13.75%	30.00%	62.50%	95.00%	290.00%	615.00%
-40%	-37.00%	-34.00%	-31.00%	-28.00%	-25.00%	-22.00%	-16.00%	-10.00%	5.00%	20.00%	50.00%	80.00%	260.00%	560.00%
-50%	-47.50%	-45.00%	-42.50%	-40.00%	-37.50%	-35.00%	-30.00%	-25.00%	-12.50%	0.00%	25.00%	50.00%	200.00%	450.00%
-60%	-58.00%	-56.00%	-54.00%	-52.00%	-50.00%	-48.00%	-44.00%	-40.00%	-30.00%	-20.00%	0.00%	20.00%	140.00%	340.00%
-70%	-68.50%	-67.00%	-65.50%	-64.00%	-62.50%	-61.00%	-58.00%	-55.00%	-47.50%	-40.00%	-25.00%	-10.00%	80.00%	230.00%
-80%	-79.00%	-78.00%	-77.00%	-76.00%	-75.00%	-74.00%	-72.00%	-70.00%	-65.00%	-60.00%	-50.00%	-40.00%	20.00%	120.00%
-100%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%	-100.00%

Table D-6. Present value and cost/benefit analysis.

Case: Pricing policy only

	Program	Annual Cost	Year 1?	Year 2-6?	Year 6 on?	Year 1	Year 2-6	Year 6 on
			On/Off Switches				Annual Cost	
SF	Pricing	$220,000	0	0	0	$0	$0	$0
	Res Audit develop	$350,000	0	0	0	$0	$0	$0
	Res audit	$6,100,000	0	0	0	$0	$0	$0
	Public Education	$520,000	0	0	0	$0	$0	$0
	Ind/Comm Lias	$230,000	0	0	0	$0	$0	$0
I/I	INS Study	$817,500	0	0	0	$0	$0	$0
	Sewer rehab and repair	$750,000	0	0	0	$0	$0	$0
	Res roof disconnection	$1,000,000	0	0	0	$0	$0	$0
	Sewer separation	$2.00E+08	0	0	0	$0	$0	$0
Both	Database development	$175,000	0	0	0	$0	$0	$0
	Consvtion and I/I monitor	$73,000	0	0	0	$0	$0	$0
	Consvtion and I/I enforce	$365,000	0	0	0	$0	$0	$0
						$0	**$0**	**$0**

Water and Sewer

Base Revs	% Price Inc	%Elast	% Wat Red	% Del Rev	New Revenues	Cumulative Include?			
								Inflation =	**3%**
$25,000,000	***50%***	***-0.1265***	-5.00%	42.50%	$10,625,070	**0**	Indicates if revenues are included in cumulative "cost - savings" column.	**Interest =**	**6%**

		Water Red =	12	MLD	(adjusted for external flows)	
chk	10	SF Reduced	10	MLD	(change bolded #s only)	
		I/I Reduced	0	MLD		
		WTP Save	$146,832	/year in 1993 $	d$ = $12,236 dQ	
		WPCP Save	$126,340	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)	
		RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000
		d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000
			(Note: RAP O&M is applied in 1995, this is early)			

Captial Savings			Inflated Cost
	Year	Inflated $	P.V.
Upgrade cost today	1993	$50,000,000	$50,000,000
Year - no conservation	2025	$128,754,138	$19,951,406
Year - with conservation	2030	$149,261,334	$17,283,445

Note: Need to include effects of RAP upgrade on future upgrade.

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$10,625,070	$10,023,651	$10,023,651	$0	$0	$0	$0
2	1995	$26,807	$23,858	$31,155	$27,728	$51,586	$10,943,822	$9,739,962	$19,763,613	$0	$0	$0	$51,586
3	1996	$55,222	$46,365	$64,179	$53,886	$151,837	$11,272,137	$9,464,303	$29,227,916	$0	$0	$0	$151,837
4	1997	$85,318	$67,580	$99,156	$78,541	$297,958	$11,610,301	$9,196,446	$38,424,362	$0	$0	$0	$297,958
5	1998	$117,170	$87,556	$136,175	$101,758	$487,271	$11,958,610	$8,936,169	$47,360,531	$0	$0	$0	$487,271
6	1999	$150,856	$106,348	$175,325	$123,597	$717,216	$12,317,368	$8,683,258	$56,043,789	$0	$0	$0	$717,216
7	2000	$155,382	$103,338	$180,585	$120,099	$940,653	$12,686,889	$8,437,506	$64,481,295	$0	$0	$0	$940,653
8	2001	$160,043	$100,413	$186,002	$116,700	$1,157,766	$13,067,496	$8,198,708	$72,680,003	$0	$0	$0	$1,157,766
9	2002	$164,844	$97,571	$191,582	$113,397	$1,368,735	$13,459,520	$7,966,669	$80,646,673	$0	$0	$0	$1,368,735
10	2003	$169,790	$94,810	$197,330	$110,188	$1,573,732	$13,863,306	$7,741,198	$88,387,870	$0	$0	$0	$1,573,732
11	2004	$174,883	$92,126	$203,250	$107,069	$1,772,928	$14,279,205	$7,522,107	$95,909,978	$0	$0	$0	$1,772,928
12	2005	$180,130	$89,519	$209,347	$104,039	$1,966,487	$14,707,581	$7,309,217	$103,219,195	$0	$0	$0	$1,966,487
13	2006	$185,534	$86,985	$215,628	$101,095	$2,154,567	$15,148,809	$7,102,353	$110,321,548	$0	$0	$0	$2,154,567
14	2007	$191,100	$84,524	$222,097	$98,234	$2,337,324	$15,603,273	$6,901,343	$117,222,891	$0	$0	$0	$2,337,324
15	2008	$196,833	$82,131	$228,759	$95,453	$2,514,909	$16,071,371	$6,706,022	$123,928,912	$0	$0	$0	$2,514,909
16	2009	$202,738	$79,807	$235,622	$92,752	$2,687,467	$16,553,512	$6,516,229	$130,445,141	$0	$0	$0	$2,687,467
17	2010	$208,820	$77,548	$242,691	$90,127	$2,855,143	$17,050,118	$6,331,807	$136,776,948	$0	$0	$0	$2,855,143
18	2011	$215,085	$75,354	$249,972	$87,576	$3,018,072	$17,561,621	$6,152,605	$142,929,553	$0	$0	$0	$3,018,072
19	2012	$221,537	$73,221	$257,471	$85,097	$3,176,390	$18,088,470	$5,978,475	$148,908,028	$0	$0	$0	$3,176,390
20	2013	$228,183	$71,149	$265,195	$82,689	$3,330,228	$18,631,124	$5,809,273	$154,717,300	$0	$0	$0	$3,330,228
21	2014	$235,029	$69,135	$273,151	$80,349	$3,479,712	$19,190,058	$5,644,859	$160,362,160	$0	$0	$0	$3,479,712
22	2015	$242,080	$67,178	$281,345	$78,075	$3,624,965	$19,765,760	$5,485,099	$165,847,259	$0	$0	$0	$3,624,965
23	2016	$249,342	$65,277	$289,786	$75,865	$3,766,107	$20,358,732	$5,329,860	$171,177,119	$0	$0	$0	$3,766,107
24	2017	$256,822	$63,430	$298,479	$73,718	$3,903,255	$20,969,494	$5,179,015	$176,356,134	$0	$0	$0	$3,903,255
25	2018	$264,527	$61,634	$307,434	$71,632	$4,036,521	$21,598,579	$5,032,439	$181,388,574	$0	$0	$0	$4,036,521
26	2019	$272,463	$59,890	$316,657	$69,604	$4,166,015	$22,246,537	$4,890,012	$186,278,585	$0	$0	$0	$4,166,015
27	2020	$280,637	$58,195	$326,156	$67,634	$4,291,844	$22,913,933	$4,751,615	$191,030,201	$0	$0	$0	$4,291,844
28	2021	$289,056	$56,548	$335,941	$65,720	$4,414,112	$23,601,351	$4,617,136	$195,647,336	$0	$0	$0	$4,414,112
29	2022	$297,727	$54,948	$346,019	$63,860	$4,532,920	$24,309,391	$4,486,462	$200,133,798	$0	$0	$0	$4,532,920
30	2023	$306,659	$53,392	$356,400	$62,053	$4,648,365	$25,038,673	$4,359,487	$204,493,285	$0	$0	$0	$4,648,365

31	2024	$315,859	$51,881	$367,092	$60,297	$4,760,543	$25,789,833	$4,236,105	$208,729,390	$0	$0	$0	$4,760,543
32	2025	$325,335	$50,413	$378,105	$58,590	$4,869,547	$26,563,528	$4,116,215	$212,845,605	$0	$0	$0	$7,537,508
33	2026	$335,095	$48,986	$389,448	$56,932	$4,975,465	$27,360,434	$3,999,719	$216,845,323	$0	$0	$0	$7,643,426
34	2027	$345,148	$47,600	$401,131	$55,321	$5,078,385	$28,181,247	$3,886,519	$220,731,842	$0	$0	$0	$7,746,346
35	2028	$355,502	$46,253	$413,165	$53,755	$5,178,393	$29,026,684	$3,776,523	$224,508,365	$0	$0	$0	$7,846,354
36	2029	$366,167	$44,944	$425,560	$52,234	$5,275,570	$29,897,485	$3,669,640	$228,178,006	$0	$0	$0	$7,943,531
37	2030	$377,152	$43,672	$438,327	$50,755	$5,369,997	$30,794,409	$3,565,783	$231,743,788	$0	$0	$0	$8,037,958
38	2031	$388,467	$42,436	$451,477	$49,319	$5,461,751	$31,718,242	$3,464,864	$235,208,653	$0	$0	$0	$8,129,713
39	2032	$400,121	$41,235	$465,021	$47,923	$5,550,909	$32,669,789	$3,366,802	$238,575,455	$0	$0	$0	$8,218,870
40	2033	$412,124	$40,068	$478,972	$46,567	$5,637,543	$33,649,883	$3,271,515	$241,846,970	$0	$0	$0	$8,305,504
41	2034	$424,488	$38,934	$493,341	$45,249	$5,721,725	$34,659,379	$3,178,925	$245,025,895	$0	$0	$0	$8,389,687
42	2035	$437,223	$37,832	$508,141	$43,968	$5,803,525	$35,699,160	$3,088,956	$248,114,851	$0	$0	$0	$8,471,487
43	2036	$450,339	$36,761	$523,385	$42,724	$5,883,010	$36,770,135	$3,001,532	$251,116,383	$0	$0	$0	$8,550,971
44	2037	$463,849	$35,721	$539,087	$41,515	$5,960,245	$37,873,239	$2,916,583	$254,032,966	$0	$0	$0	$8,628,207
45	2038	$477,765	$34,710	$555,259	$40,340	$6,035,295	$39,009,437	$2,834,038	$256,867,005	$0	$0	$0	$8,703,256
46	2039	$492,098	$33,727	$571,917	$39,198	$6,108,220	$40,179,720	$2,753,830	$259,620,835	$0	$0	$0	$8,776,181
47	2040	$506,861	$32,773	$589,075	$38,089	$6,179,081	$41,385,111	$2,675,891	$262,296,726	$0	$0	$0	$8,847,042
48	2041	$522,067	$31,845	$606,747	$37,011	$6,247,937	$42,626,665	$2,600,158	$264,896,884	$0	$0	$0	$8,915,898
49	2042	$537,729	$30,944	$624,949	$35,963	$6,314,844	$43,905,464	$2,526,569	$267,423,453	$0	$0	$0	$8,982,805
50	2043	$553,860	$30,068	$643,698	$34,945	$6,379,857	$45,222,628	$2,455,062	$269,878,516	$0	$0	$0	$9,047,819
Present Value Sum			$2,950,630		$3,429,228			$269,878,516			$0		
Yr#	**Year**	**Savings WPCP Inflated**	**Savings WPCP P.V.**	**Savings WTP Inflated**	**Savings WTP P.V.**	**Cumulative Savings P.V.**	**New Revenues Inflated**	**New Revenues P.V.**	**Cumulative New Revs P.V.**	**Conservation Costs Inflated**	**Conservation Costs P.V.**	**Cumulative Costs P.V.**	**Cumul Summary P.V.**
P.V. SUMMARY - 50 years													
WPCP Savings		$2,950,630											Above includes
WTP Savings		$3,429,228											capital savings
Capital Savings		$2,667,961											in year 2025.
Total Savings		**$9,047,819**											
Program Cost		$0											
New Revenues		$269,878,516											
Net P.V. Benefit		**$9,047,819**	(50 years)	0	revenues included in Net P.V. Benefit (0-no, 1-yes)								

Table D-7. Present value and cost/benefit analysis.

Case: Residential water conservation

	Program		On/Off Switches			Annual Cost		
	Program	**Annual Cost**	**Year 1?**	**Year 2-6?**	**Year 6 on?**	**Year 1**	**Year 2-6**	**Year 6 on**
SF	Pricing	$220,000	1	0	0	$220,000	$0	$0
	Res Audit develop	$350,000	1	0	0	$350,000	$0	$0
	Res audit	$6,100,000	0	1	0	$0	$6,100,000	$0
	Public Education	$520,000	1	0	0	$520,000	$0	$0
	Ind/Comm Lias	$230,000	0	0	0	$0	$0	$0
I/I	INS Study	$817,500	0	0	0	$0	$0	$0
	Sewer rehab and repair	$750,000	0	0	0	$0	$0	$0
	Res roof disconnection	$1,000,000	0	0	0	$0	$0	$0
	Sewer separation	$2.00E+08	0	0	0	$0	$0	$0
Both	Database development	$175,000	0	0	0	$0	$0	$0
	Consvtion and I/I monitor	$73,000	0	0	0	$0	$0	$0
	Consvtion and I/I enforce	$365,000	0	0	0	$0	$0	$0
						$1,090,000	**$6,100,000**	**$0**

Water and Sewer

Base Revs	**% Price Inc**	**% Elast**	**% Wat Red**	**% Del Rev**	**New Revenues**	**Cumulative , Include?**
$25,000,000	*50%*	*-0.26*	-10.01%	34.99%	$8,747,961	0

Indicates if revenues are included in cumulative "cost - savings" column.

Inflation = 3%

Interest = 6%

		Water Red =	24	MLD	(adjusted for external flows)
chk	20	SF Reduced	20	MLD	(change bolded #s only)
		I/I Reduced	0	MLD	
		WTP Save	$293,664	/year in 1993 $	d$ = $12,236 dQ
		WPCP Save	$252,679	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)

RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000
d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000

(Note: RAP O&M is applied in 1995, this is early)

Captial Savings	Year	Inflated $	Inflated Cost P.V.
Upgrade cost today	1993	$50,000,000	$50,000,000
Year - no conservation	2025	$128,754,138	$19,951,406
Year - with conservation	2039	$194,752,186	$13,347,888

Note: Need to include effects of RAP upgrade on future upgrade.

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$8,747,961	$8,252,794	$8,252,794	-$1,122,700	-$1,059,151	-$1,059,151	-$1,059,151
2	1995	$53,613	$47,716	$62,310	$55,455	$103,171	$9,010,400	$8,019,224	$16,272,017	-$6,471,490	-$5,759,603	-$6,818,754	-$6,715,583
3	1996	$110,444	$92,731	$128,358	$107,772	$303,673	$9,280,712	$7,792,265	$24,064,282	-$6,665,635	-$5,596,595	-$12,415,349	-$12,111,676
4	1997	$170,635	$135,159	$198,313	$157,082	$595,915	$9,559,133	$7,571,729	$31,636,011	-$6,865,604	-$5,438,201	-$17,853,551	-$17,257,636
5	1998	$234,339	$175,112	$272,350	$203,516	$974,543	$9,845,907	$7,357,435	$38,993,446	-$7,071,572	-$5,284,290	-$23,137,841	-$22,163,298
6	1999	$301,712	$212,695	$350,650	$247,195	$1,434,432	$10,141,285	$7,149,205	$46,142,651	-$7,283,719	-$5,134,734	-$28,272,575	-$26,838,143
7	2000	$310,763	$206,675	$361,170	$240,198	$1,881,306	$10,445,523	$6,946,869	$53,089,521	$0	$0	-$28,272,575	-$26,391,269
8	2001	$320,086	$200,826	$372,005	$233,400	$2,315,532	$10,758,889	$6,750,260	$59,839,781	$0	$0	-$28,272,575	-$25,957,043
9	2002	$329,689	$195,142	$383,165	$226,795	$2,737,469	$11,081,655	$6,559,215	$66,398,995	$0	$0	-$28,272,575	-$25,535,106
10	2003	$339,579	$189,619	$394,660	$220,376	$3,147,465	$11,414,105	$6,373,577	$72,772,572	$0	$0	-$28,272,575	-$25,125,110
11	2004	$349,767	$184,253	$406,500	$214,139	$3,545,857	$11,756,528	$6,193,192	$78,965,765	$0	$0	-$28,272,575	-$24,726,718
12	2005	$360,260	$179,038	$418,695	$208,078	$3,932,973	$12,109,224	$6,017,913	$84,983,678	$0	$0	-$28,272,575	-$24,339,602
13	2006	$371,068	$173,971	$431,255	$202,189	$4,309,133	$12,472,501	$5,847,595	$90,831,273	$0	$0	-$28,272,575	-$23,963,442
14	2007	$382,200	$169,047	$444,193	$196,467	$4,674,648	$12,846,676	$5,682,097	$96,513,370	$0	$0	-$28,272,575	-$23,597,927
15	2008	$393,666	$164,263	$457,519	$190,907	$5,029,817	$13,232,076	$5,521,283	$102,034,653	$0	$0	-$28,272,575	-$23,242,758
16	2009	$405,476	$159,614	$471,245	$185,504	$5,374,935	$13,629,038	$5,365,020	$107,399,674	$0	$0	-$28,272,575	-$22,897,640
17	2010	$417,640	$155,097	$485,382	$180,254	$5,710,285	$14,037,910	$5,213,180	$112,612,854	$0	$0	-$28,272,575	-$22,562,290
18	2011	$430,169	$150,707	$499,943	$175,152	$6,036,144	$14,459,047	$5,065,637	$117,678,491	$0	$0	-$28,272,575	-$22,236,431
19	2012	$443,074	$146,442	$514,942	$170,195	$6,352,781	$14,892,818	$4,922,270	$122,600,761	$0	$0	-$28,272,575	-$21,919,794
20	2013	$456,366	$142,297	$530,390	$165,378	$6,660,456	$15,339,603	$4,782,961	$127,383,722	$0	$0	-$28,272,575	-$21,612,119
21	2014	$470,057	$138,270	$546,302	$160,698	$6,959,424	$15,799,791	$4,647,594	$132,031,316	$0	$0	-$28,272,575	-$21,313,151
22	2015	$484,159	$134,357	$562,691	$156,150	$7,249,930	$16,273,785	$4,516,058	$136,547,374	$0	$0	-$28,272,575	-$21,022,645
23	2016	$498,684	$130,554	$579,571	$151,730	$7,532,214	$16,761,998	$4,388,245	$140,935,619	$0	$0	-$28,272,575	-$20,740,361
24	2017	$513,644	$126,859	$596,958	$147,436	$7,806,509	$17,264,858	$4,264,050	$145,199,669	$0	$0	-$28,272,575	-$20,466,066
25	2018	$529,054	$123,269	$614,867	$143,263	$8,073,041	$17,782,804	$4,143,369	$149,343,038	$0	$0	-$28,272,575	-$20,199,534
26	2019	$544,925	$119,780	$633,313	$139,209	$8,332,030	$18,316,288	$4,026,104	$153,369,141	$0	$0	-$28,272,575	-$19,940,545
27	2020	$561,273	$116,390	$652,313	$135,269	$8,583,688	$18,865,777	$3,912,157	$157,281,299	$0	$0	-$28,272,575	-$19,688,887
28	2021	$578,111	$113,096	$671,882	$131,440	$8,828,225	$19,431,750	$3,801,436	$161,082,735	$0	$0	-$28,272,575	-$19,444,350
29	2022	$595,455	$109,895	$692,038	$127,720	$9,065,840	$20,014,702	$3,693,848	$164,776,583	$0	$0	-$28,272,575	-$19,206,735
30	2023	$613,318	$106,785	$712,800	$124,106	$9,296,731	$20,615,143	$3,589,305	$168,365,888	$0	$0	-$28,272,575	-$18,975,844

31	2024	$631,718	$103,763	$734,184	$120,593	$9,521,087	$21,233,598	$3,487,721	$171,853,610	$0	$0	-$28,272,575	-$18,751,488
32	2025	$650,669	$100,826	$756,209	$117,180	$9,739,093	$21,870,606	$3,389,012	$175,242,622	$0	$0	-$28,272,575	-$11,929,963
33	2026	$670,189	$97,972	$778,895	$113,864	$9,950,929	$22,526,724	$3,293,097	$178,535,718	$0	$0	-$28,272,575	-$11,718,127
34	2027	$690,295	$95,200	$802,262	$110,641	$10,156,770	$23,202,526	$3,199,896	$181,735,614	$0	$0	-$28,272,575	-$11,512,286
35	2028	$711,004	$92,505	$826,330	$107,510	$10,356,785	$23,898,601	$3,109,333	$184,844,947	$0	$0	-$28,272,575	-$11,312,271
36	2029	$732,334	$89,887	$851,120	$104,467	$10,551,140	$24,615,559	$3,021,333	$187,866,280	$0	$0	-$28,272,575	-$11,117,917
37	2030	$754,304	$87,343	$876,654	$101,511	$10,739,994	$25,354,026	$2,935,823	$190,802,103	$0	$0	-$28,272,575	-$10,929,063
38	2031	$776,933	$84,871	$902,953	$98,638	$10,923,502	$26,114,647	$2,852,734	$193,654,837	$0	$0	-$28,272,575	-$10,745,554
39	2032	$800,241	$82,469	$930,042	$95,846	$11,101,818	$26,898,086	$2,771,996	$196,426,833	$0	$0	-$28,272,575	-$10,567,239
40	2033	$824,248	$80,135	$957,943	$93,133	$11,275,086	$27,705,029	$2,693,544	$199,120,377	$0	$0	-$28,272,575	-$10,393,970
41	2034	$848,976	$77,867	$986,681	$90,497	$11,443,451	$28,536,180	$2,617,311	$201,737,688	$0	$0	-$28,272,575	-$10,225,606
42	2035	$874,445	$75,663	$1,016,282	$87,936	$11,607,051	$29,392,265	$2,543,236	$204,280,924	$0	$0	-$28,272,575	-$10,062,006
43	2036	$900,679	$73,522	$1,046,770	$85,447	$11,766,020	$30,274,033	$2,471,258	$206,752,182	$0	$0	-$28,272,575	-$9,903,036
44	2037	$927,699	$71,441	$1,078,173	$83,029	$11,920,490	$31,182,254	$2,401,317	$209,153,499	$0	$0	-$28,272,575	-$9,748,566
45	2038	$955,530	$69,419	$1,110,519	$80,679	$12,070,589	$32,117,722	$2,333,355	$211,486,854	$0	$0	-$28,272,575	-$9,598,468
46	2039	$984,196	$67,455	$1,143,834	$78,396	$12,216,440	$33,081,253	$2,267,317	$213,754,170	$0	$0	-$28,272,575	-$9,452,617
47	2040	$1,013,722	$65,546	$1,178,149	$76,177	$12,358,162	$34,073,691	$2,203,147	$215,957,318	$0	$0	-$28,272,575	-$9,310,894
48	2041	$1,044,133	$63,690	$1,213,494	$74,021	$12,495,874	$35,095,902	$2,140,794	$218,098,112	$0	$0	-$28,272,575	-$9,173,183
49	2042	$1,075,457	$61,888	$1,249,898	$71,926	$12,629,688	$36,148,779	$2,080,205	$220,178,317	$0	$0	-$28,272,575	-$9,039,369
50	2043	$1,107,721	$60,136	$1,287,395	$69,891	$12,759,715	$37,233,242	$2,021,332	$222,199,649	$0	$0	-$28,272,575	-$8,909,342
Present Value Sum			$5,901,260		$6,858,455			$222,199,649			-$28,272,575		
Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Summary P.V.

P.V. SUMMARY - 50 years			
WPCP Savings	$5,901,260		
WTP Savings	$6,858,455		
Capital Savings	$6,603,518		
Total Savings	**$19,363,233**		
Program Cost	-$28,272,575		
New Revenues	$222,199,649		
Net P.V. Benefit	-$8,909,342	(50 years)	0 revenues included in Net P.V. Benefit (0-no, 1-yes)

Above includes capital savings in year 2025.

Table D-8. Present value and cost/benefit analysis.

	Case:	Comprehensive water conservation											
					On/Off Switches			Annual Cost					
	Program		Annual Cost	Year 1?	Year 2-6?	Year 6 on?	Year 1	Year 2-6	Year 6 on				
SF	Pricing		$220,000	1	0	0	$220,000	$0	$0				
	Res Audit develop		$350,000	1	0	0	$350,000	$0	$0				
	Res audit		$6,100,000	0	1	0	$0	$6,100,000	$0				
	Public Education		$520,000	1	0	0	$520,000	$0	$0				
	Ind/Comm Lias		$230,000	0	1	0	$0	$230,000	$0				
I/I	INS Study		$817,500	0	0	0	$0	$0	$0				
	Sewer rehab and repair		$750,000	0	0	0	$0	$0	$0				
	Res roof disconnection		$1,000,000	0	0	0	$0	$0	$0				
	Sewer separation		$2.00E+08	0	0	0	$0	$0	$0				
Both	Database development		$175,000	0	0	0	$0	$0	$0				
	Consvtion and I/I monitor		$73,000	0	0	0	$0	$0	$0				
	Consvtion and I/I enforce		$365,000	0	0	0	$0	$0	$0				
							$1,090,000	**$6,330,000**	**$0**				
	Water and Sewer						**Cumulative**						
	Base Revs	**% Price Inc**	**%Elast**	**% Wat Red**	**% Del Rev**	**New Revenues**	**Include?**			**Inflation =**	**3%**		
	$25,000,000	*50%*	***-0.26***	-10.01%	34.99%	$8,747,961	0	Indicates if revenues		**Interest =**	**6%**		
								are included in cumulative					
								"cost - savings" column.					
			Water Red =	72	MLD	(adjusted for external flows)							
	chk	20	SF Reduced	60	MLD	(change bolded #s only)							
			I/I Reduced	0	MLD					Captial Savings			Inflated Cost
			WTP Save	$880,992	/year in 1993 $	d$ = $12,236 dQ					Year	Inflated $	P.V.
			WPCP Save	$758,037	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)				Upgrade cost today	1993	$50,000,000	$50,000,000
										Year - no conservation	2025	$128,754,138	$19,951,406
				RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000		Year - with conservation	2080	$654,347,660	$4,113,375
				d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000		Note:	Need to include effects of RAP upgrade		
					(Note: RAP O&M is applied in 1995, this is early)						on future upgrade.		

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$8,747,961	$8,252,794	$8,252,794	-$1,122,700	-$1,059,151	-$1,059,151	-$1,059,151
2	1995	$160,840	$143,147	$186,929	$166,366	$309,513	$9,010,400	$8,019,224	$16,272,017	-$6,715,497	-$5,976,768	-$7,035,919	-$6,726,406
3	1996	$331,331	$278,192	$385,073	$323,315	$911,020	$9,280,712	$7,792,265	$24,064,282	-$6,916,962	-$5,807,615	-$12,843,534	-$11,932,514
4	1997	$511,906	$405,478	$594,939	$471,247	$1,787,745	$9,559,133	$7,571,729	$31,636,011	-$7,124,471	-$5,643,248	-$18,486,782	-$16,699,037
5	1998	$703,018	$525,336	$817,049	$610,547	$2,923,628	$9,845,907	$7,357,435	$38,993,446	-$7,338,205	-$5,483,534	-$23,970,316	-$21,046,688
6	1999	$905,136	$638,085	$1,051,951	$741,584	$4,303,296	$10,141,285	$7,149,205	$46,142,651	-$7,558,351	-$5,328,339	-$29,298,655	-$24,995,359
7	2000	$932,290	$620,026	$1,083,509	$720,595	$5,643,918	$10,445,523	$6,946,869	$53,089,521	$0	$0	-$29,298,655	-$23,654,737
8	2001	$960,259	$602,478	$1,116,014	$700,201	$6,946,597	$10,758,889	$6,750,260	$59,839,781	$0	$0	-$29,298,655	-$22,352,058
9	2002	$989,066	$585,427	$1,149,495	$680,384	$8,212,408	$11,081,655	$6,559,215	$66,398,995	$0	$0	-$29,298,655	-$21,086,247
10	2003	$1,018,738	$568,858	$1,183,980	$661,128	$9,442,394	$11,414,105	$6,373,577	$72,772,572	$0	$0	-$29,298,655	-$19,856,261
11	2004	$1,049,300	$552,758	$1,219,499	$642,417	$10,637,570	$11,756,528	$6,193,192	$78,965,765	$0	$0	-$29,298,655	-$18,661,085
12	2005	$1,080,780	$537,114	$1,256,084	$624,235	$11,798,919	$12,109,224	$6,017,913	$84,983,678	$0	$0	-$29,298,655	-$17,499,736
13	2006	$1,113,203	$521,913	$1,293,766	$606,568	$12,927,400	$12,472,501	$5,847,595	$90,831,273	$0	$0	-$29,298,655	-$16,371,255
14	2007	$1,146,599	$507,142	$1,332,579	$589,401	$14,023,943	$12,846,676	$5,682,097	$96,513,370	$0	$0	-$29,298,655	-$15,274,712
15	2008	$1,180,997	$492,789	$1,372,557	$572,720	$15,089,452	$13,232,076	$5,521,283	$102,034,653	$0	$0	-$29,298,655	-$14,209,203
16	2009	$1,216,427	$478,842	$1,413,734	$556,511	$16,124,805	$13,629,038	$5,365,020	$107,399,674	$0	$0	-$29,298,655	-$13,173,850
17	2010	$1,252,920	$465,290	$1,456,146	$540,761	$17,130,855	$14,037,910	$5,213,180	$112,612,854	$0	$0	-$29,298,655	-$12,167,800
18	2011	$1,290,507	$452,121	$1,499,830	$525,456	$18,108,433	$14,459,047	$5,065,637	$117,678,491	$0	$0	-$29,298,655	-$11,190,222
19	2012	$1,329,222	$439,325	$1,544,825	$510,585	$19,058,343	$14,892,818	$4,922,270	$122,600,761	$0	$0	-$29,298,655	-$10,240,312
20	2013	$1,369,099	$426,892	$1,591,170	$496,134	$19,981,368	$15,339,603	$4,782,961	$127,383,722	$0	$0	-$29,298,655	-$9,317,287
21	2014	$1,410,172	$414,810	$1,638,905	$482,093	$20,878,271	$15,799,791	$4,647,594	$132,031,316	$0	$0	-$29,298,655	-$8,420,384
22	2015	$1,452,477	$403,070	$1,688,072	$468,449	$21,749,789	$16,273,785	$4,516,058	$136,547,374	$0	$0	-$29,298,655	-$7,548,866
23	2016	$1,496,052	$391,662	$1,738,714	$455,191	$22,596,642	$16,761,998	$4,388,245	$140,935,619	$0	$0	-$29,298,655	-$6,702,013
24	2017	$1,540,933	$380,577	$1,790,875	$442,308	$23,419,527	$17,264,858	$4,264,050	$145,199,669	$0	$0	-$29,298,655	-$5,879,128
25	2018	$1,587,161	$369,806	$1,844,602	$429,790	$24,219,123	$17,782,804	$4,143,369	$149,343,038	$0	$0	-$29,298,655	-$5,079,532
26	2019	$1,634,776	$359,340	$1,899,940	$417,626	$24,996,089	$18,316,288	$4,026,104	$153,369,141	$0	$0	-$29,298,655	-$4,302,566
27	2020	$1,683,819	$349,170	$1,956,938	$405,806	$25,751,065	$18,865,777	$3,912,157	$157,281,299	$0	$0	-$29,298,655	-$3,547,589
28	2021	$1,734,334	$339,288	$2,015,646	$394,321	$26,484,675	$19,431,750	$3,801,436	$161,082,735	$0	$0	-$29,298,655	-$2,813,980
29	2022	$1,786,364	$329,685	$2,076,115	$383,161	$27,197,521	$20,014,702	$3,693,848	$164,776,583	$0	$0	-$29,298,655	-$2,101,134
30	2023	$1,839,955	$320,355	$2,138,399	$372,317	$27,890,193	$20,615,143	$3,589,305	$168,365,888	$0	$0	-$29,298,655	-$1,408,462

31	2024	$1,895,153	$311,288	$2,202,551	$361,780	$28,563,261	$21,233,598	$3,487,721	$171,853,610	$0	$0	-$29,298,655	-$735,394
32	2025	$1,952,008	$302,478	$2,268,627	$351,541	$29,217,279	$21,870,606	$3,389,012	$175,242,622	$0	$0	-$29,298,655	$15,756,656
33	2026	$2,010,568	$293,917	$2,336,686	$341,591	$29,852,788	$22,526,724	$3,293,097	$178,535,718	$0	$0	-$29,298,655	$16,392,164
34	2027	$2,070,885	$285,599	$2,406,787	$331,924	$30,470,311	$23,202,526	$3,199,896	$181,735,614	$0	$0	-$29,298,655	$17,009,687
35	2028	$2,133,012	$277,516	$2,478,990	$322,530	$31,070,356	$23,898,601	$3,109,333	$184,844,947	$0	$0	-$29,298,655	$17,609,732
36	2029	$2,197,002	$269,662	$2,553,360	$313,401	$31,653,419	$24,615,559	$3,021,333	$187,866,280	$0	$0	-$29,298,655	$18,192,796
37	2030	$2,262,912	$262,030	$2,629,961	$304,532	$32,219,981	$25,354,026	$2,935,823	$190,802,103	$0	$0	-$29,298,655	$18,759,357
38	2031	$2,330,800	$254,614	$2,708,860	$295,913	$32,770,507	$26,114,647	$2,852,734	$193,654,837	$0	$0	-$29,298,655	$19,309,883
39	2032	$2,400,724	$247,408	$2,790,125	$287,538	$33,305,453	$26,898,086	$2,771,996	$196,426,833	$0	$0	-$29,298,655	$19,844,829
40	2033	$2,472,745	$240,406	$2,873,829	$279,400	$33,825,258	$27,705,029	$2,693,544	$199,120,377	$0	$0	-$29,298,655	$20,364,635
41	2034	$2,546,928	$233,602	$2,960,044	$271,492	$34,330,353	$28,536,180	$2,617,311	$201,737,688	$0	$0	-$29,298,655	$20,869,729
42	2035	$2,623,336	$226,990	$3,048,845	$263,809	$34,821,152	$29,392,265	$2,543,236	$204,280,924	$0	$0	-$29,298,655	$21,360,528
43	2036	$2,702,036	$220,566	$3,140,311	$256,342	$35,298,060	$30,274,033	$2,471,258	$206,752,182	$0	$0	-$29,298,655	$21,837,437
44	2037	$2,783,097	$214,324	$3,234,520	$249,087	$35,761,471	$31,182,254	$2,401,317	$209,153,499	$0	$0	-$29,298,655	$22,300,848
45	2038	$2,866,590	$208,258	$3,331,556	$242,038	$36,211,767	$32,117,722	$2,333,355	$211,486,854	$0	$0	-$29,298,655	$22,751,143
46	2039	$2,952,587	$202,364	$3,431,502	$235,188	$36,649,319	$33,081,253	$2,267,317	$213,754,170	$0	$0	-$29,298,655	$23,188,695
47	2040	$3,041,165	$196,637	$3,534,447	$228,531	$37,074,487	$34,073,691	$2,203,147	$215,957,318	$0	$0	-$29,298,655	$23,613,863
48	2041	$3,132,400	$191,071	$3,640,481	$222,064	$37,487,621	$35,095,902	$2,140,794	$218,098,112	$0	$0	-$29,298,655	$24,026,998
49	2042	$3,226,372	$185,664	$3,749,695	$215,779	$37,889,064	$36,148,779	$2,080,205	$220,178,317	$0	$0	-$29,298,655	$24,428,440
50	2043	$3,323,163	$180,409	$3,862,186	$209,672	$38,279,145	$37,233,242	$2,021,332	$222,199,649	$0	$0	-$29,298,655	$24,818,521
Present Value Sum			$17,703,779		$20,575,365			$222,199,649			-$29,298,655		
Yr#	**Year**	**Savings WPCP Inflated**	**Savings WPCP P.V.**	**Savings WTP Inflated**	**Savings WTP P.V.**	**Cumulative Savings P.V.**	**New Revenues Inflated**	**New Revenues P.V.**	**Cumulative New Revs P.V.**	**Conservation Costs Inflated**	**Conservation Costs P.V.**	**Cumulative Costs P.V.**	**Cumul Summary P.V.**
P.V. SUMMARY - 50 years													
WPCP Savings		$17,703,779											Above includes capital savings in year 2025.
WTP Savings		$20,575,365											
Capital Savings		$15,838,031											
Total Savings		**$54,117,176**											
Program Cost		-$29,298,655											
New Revenues		$222,199,649											
Net P.V. Benefit		**$24,818,521**	(50 years)	0	revenues included in Net P.V. Benefit (0-no, 1-yes)								

Table D-9. Present value and cost/benefit analysis.

Case: Intensive I/I reduction

			On/Off Switches				Annual Cost	
	Program	Annual Cost	Year 1?	Year 2-6?	Year 6 on?	Year 1	Year 2-6	Year 6 on
SF	Pricing	$220,000	0	0	0	$0	$0	$0
	Res Audit develop	$350,000	0	0	0	$0	$0	$0
	Res audit	$6,100,000	0	0	0	$0	$0	$0
	Public Education	$520,000	0	0	0	$0	$0	$0
	Ind/Comm Lias	$230,000	0	0	0	$0	$0	$0
I/I	INS Study	$817,500	1	0	0	$817,500	$0	$0
	Sewer rehab and repair	$750,000	0	1	0	$0	$750,000	$0
	Res roof disconnection	$1,000,000	0	1	0	$0	$1,000,000	$0
	Sewer separation	$2.00E+08	0	0	0	$0	$0	$0
Both	Database development	$175,000	0	0	0	$0	$0	$0
	Consvtion and I/I monitor	$73,000	0	0	0	$0	$0	$0
	Consvtion and I/I enforce	$365,000	0	0	0	$0	$0	$0
						$817,500	**$1,750,000**	**$0**

Water and Sewer							**Cumulative**						
	Base Revs	**% Price Inc**	**%Elast**	**% Wat Red**	**% Del Rev**	**New Revenues**	**Include?**			**Inflation =**	**3%**		
	$25,000,000	*0%*	***-0.26***	0.00%	0.00%	$0	**0**	Indicates if revenues		**Interest =**	**6%**		
								are included in cumulative					
								"cost - savings" column.					
			Water Red =	0	MLD	(adjusted for external flows)							
	chk	0	SF Reduced	0	MLD	(change bolded #s only)							
			I/I Reduced	60	MLD					Captial Savings			Inflated Cost
			WTP Save	$0	/year in 1993 $	d$ = $12,236 dQ					Year	Inflated $	P.V.
			WPCP Save	$508,252	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)				Upgrade cost today	1993	$50,000,000	$50,000,000
										Year - no conservation	2025	$128,754,138	$19,951,406
				RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000		Year - with conservation	2050	$269,582,572	$9,733,241
				d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000		Note:	Need to include effects of RAP upgrade		
					(Note: RAP O&M is applied in 1995, this is early)						on future upgrade.		

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$0	$0	$0	-$842,025	-$794,363	-$794,363	-$794,363
2	1995	$107,841	$95,978	$0	$0	$95,978	$0	$0	$0	-$1,856,575	-$1,652,345	-$2,446,708	-$2,350,730
3	1996	$222,152	$186,523	$0	$0	$282,501	$0	$0	$0	-$1,912,272	-$1,605,581	-$4,052,289	-$3,769,788
4	1997	$343,225	$271,866	$0	$0	$554,367	$0	$0	$0	-$1,969,640	-$1,560,140	-$5,612,429	-$5,058,061
5	1998	$471,362	$352,229	$0	$0	$906,597	$0	$0	$0	-$2,028,730	-$1,515,985	-$7,128,413	-$6,221,817
6	1999	$606,879	$427,826	$0	$0	$1,334,423	$0	$0	$0	-$2,089,592	-$1,473,080	-$8,601,493	-$7,267,070
7	2000	$625,085	$415,717	$0	$0	$1,750,140	$0	$0	$0	$0	$0	-$8,601,493	-$6,851,353
8	2001	$643,838	$403,952	$0	$0	$2,154,092	$0	$0	$0	$0	$0	-$8,601,493	-$6,447,401
9	2002	$663,153	$392,519	$0	$0	$2,546,611	$0	$0	$0	$0	$0	-$8,601,493	-$6,054,882
10	2003	$683,048	$381,410	$0	$0	$2,928,021	$0	$0	$0	$0	$0	-$8,601,493	-$5,673,472
11	2004	$703,539	$370,616	$0	$0	$3,298,637	$0	$0	$0	$0	$0	-$8,601,493	-$5,302,856
12	2005	$724,645	$360,126	$0	$0	$3,658,764	$0	$0	$0	$0	$0	-$8,601,493	-$4,942,730
13	2006	$746,385	$349,934	$0	$0	$4,008,698	$0	$0	$0	$0	$0	-$8,601,493	-$4,592,795
14	2007	$768,776	$340,030	$0	$0	$4,348,728	$0	$0	$0	$0	$0	-$8,601,493	-$4,252,765
15	2008	$791,839	$330,407	$0	$0	$4,679,135	$0	$0	$0	$0	$0	-$8,601,493	-$3,922,358
16	2009	$815,595	$321,056	$0	$0	$5,000,191	$0	$0	$0	$0	$0	-$8,601,493	-$3,601,302
17	2010	$840,062	$311,969	$0	$0	$5,312,160	$0	$0	$0	$0	$0	-$8,601,493	-$3,289,333
18	2011	$865,264	$303,140	$0	$0	$5,615,300	$0	$0	$0	$0	$0	-$8,601,493	-$2,986,193
19	2012	$891,222	$294,561	$0	$0	$5,909,861	$0	$0	$0	$0	$0	-$8,601,493	-$2,691,632
20	2013	$917,959	$286,224	$0	$0	$6,196,085	$0	$0	$0	$0	$0	-$8,601,493	-$2,405,408
21	2014	$945,498	$278,123	$0	$0	$6,474,208	$0	$0	$0	$0	$0	-$8,601,493	-$2,127,285
22	2015	$973,863	$270,252	$0	$0	$6,744,460	$0	$0	$0	$0	$0	-$8,601,493	-$1,857,033
23	2016	$1,003,079	$262,603	$0	$0	$7,007,063	$0	$0	$0	$0	$0	-$8,601,493	-$1,594,430
24	2017	$1,033,171	$255,171	$0	$0	$7,262,234	$0	$0	$0	$0	$0	-$8,601,493	-$1,339,259
25	2018	$1,064,166	$247,949	$0	$0	$7,510,183	$0	$0	$0	$0	$0	-$8,601,493	-$1,091,310
26	2019	$1,096,091	$240,932	$0	$0	$7,751,115	$0	$0	$0	$0	$0	-$8,601,493	-$850,378
27	2020	$1,128,974	$234,113	$0	$0	$7,985,228	$0	$0	$0	$0	$0	-$8,601,493	-$616,265
28	2021	$1,162,843	$227,487	$0	$0	$8,212,715	$0	$0	$0	$0	$0	-$8,601,493	-$388,778
29	2022	$1,197,728	$221,049	$0	$0	$8,433,764	$0	$0	$0	$0	$0	-$8,601,493	-$167,729
30	2023	$1,233,660	$214,793	$0	$0	$8,648,557	$0	$0	$0	$0	$0	-$8,601,493	$47,064

31	2024	$1,270,670	$208,714	$0	$0	$8,857,270	$0	$0	$0	$0	$0	-$8,601,493	$255,777
32	2025	$1,308,790	$202,807	$0	$0	$9,060,077	$0	$0	$0	$0	$0	-$8,601,493	$10,676,749
33	2026	$1,348,054	$197,067	$0	$0	$9,257,144	$0	$0	$0	$0	$0	-$8,601,493	$10,873,815
34	2027	$1,388,495	$191,490	$0	$0	$9,448,633	$0	$0	$0	$0	$0	-$8,601,493	$11,065,305
35	2028	$1,430,150	$186,070	$0	$0	$9,634,703	$0	$0	$0	$0	$0	-$8,601,493	$11,251,375
36	2029	$1,473,055	$180,804	$0	$0	$9,815,507	$0	$0	$0	$0	$0	-$8,601,493	$11,432,179
37	2030	$1,517,246	$175,687	$0	$0	$9,991,194	$0	$0	$0	$0	$0	-$8,601,493	$11,607,866
38	2031	$1,562,764	$170,715	$0	$0	$10,161,908	$0	$0	$0	$0	$0	-$8,601,493	$11,778,580
39	2032	$1,609,647	$165,883	$0	$0	$10,327,791	$0	$0	$0	$0	$0	-$8,601,493	$11,944,463
40	2033	$1,657,936	$161,188	$0	$0	$10,488,980	$0	$0	$0	$0	$0	-$8,601,493	$12,105,651
41	2034	$1,707,674	$156,626	$0	$0	$10,645,606	$0	$0	$0	$0	$0	-$8,601,493	$12,262,277
42	2035	$1,758,904	$152,193	$0	$0	$10,797,799	$0	$0	$0	$0	$0	-$8,601,493	$12,414,471
43	2036	$1,811,671	$147,886	$0	$0	$10,945,685	$0	$0	$0	$0	$0	-$8,601,493	$12,562,357
44	2037	$1,866,021	$143,701	$0	$0	$11,089,386	$0	$0	$0	$0	$0	-$8,601,493	$12,706,057
45	2038	$1,922,002	$139,634	$0	$0	$11,229,019	$0	$0	$0	$0	$0	-$8,601,493	$12,845,691
46	2039	$1,979,662	$135,682	$0	$0	$11,364,701	$0	$0	$0	$0	$0	-$8,601,493	$12,981,373
47	2040	$2,039,052	$131,842	$0	$0	$11,496,543	$0	$0	$0	$0	$0	-$8,601,493	$13,113,214
48	2041	$2,100,224	$128,110	$0	$0	$11,624,653	$0	$0	$0	$0	$0	-$8,601,493	$13,241,325
49	2042	$2,163,230	$124,485	$0	$0	$11,749,138	$0	$0	$0	$0	$0	-$8,601,493	$13,365,809
50	2043	$2,228,127	$120,961	$0	$0	$11,870,099	$0	$0	$0	$0	$0	-$8,601,493	$13,486,771
Present Value Sum			$11,870,099		$0			$0			-$8,601,493		
		Savings	**Savings**	**Savings**	**Savings**	**Cumulative**	**New**	**New**	**Cumulative**	**Conservation**	**Conservation**	**Cumulative**	**Cumul**
Yr#	**Year**	**WPCP**	**WPCP**	**WTP**	**WTP**	**Savings**	**Revenues**	**Revenues**	**New Revs**	**Costs**	**Costs**	**Costs**	**Summary**
		Inflated	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**P.V.**
P.V. SUMMARY - 50 years													
WPCP Savings		$11,870,099											Above includes
WTP Savings		$0											capital savings
Capital Savings		$10,218,165											in year 2025.
Total Savings		**$22,088,264**											
Program Cost		-$8,601,493											
New Revenues		$0											
Net P.V. Benefit		**$13,486,771**	(50 years)	0	revenues included in Net P.V. Benefit (0-no, 1-yes)								

Table D-10. Present value and cost/benefit analysis.

Case: Comprehensive flow reduction - low I/I reduction

					On/Off Switches			Annual Cost					
	Program		Annual Cost	Year 1?	Year 2-6?	Year 6 on?	Year 1	Year 2-6	Year 6 on				
SF	Pricing		$220,000	1	0	0	$220,000	$0	$0				
	Res Audit develop		$350,000	1	0	0	$350,000	$0	$0				
	Res audit		$6,100,000	0	1	0	$0	$6,100,000	$0				
	Public Education		$520,000	1	0	0	$520,000	$0	$0				
	Ind/Comm Lias		$230,000	0	1	0	$0	$230,000	$0				
I/I	INS Study		$817,500	0	0	0	$0	$0	$0				
	Sewer rehab and repair		$750,000	0	0	0	$0	$0	$0				
	Res roof disconnection		$1,000,000	0	1	0	$0	$1,000,000	$0				
	Sewer separation		$2.00E+08	0	0	0	$0	$0	$0				
Both	Database development		$175,000	1	0	0	$175,000	$0	$0				
	Consvtion and I/I monitor		$73,000	0	1	1	$0	$73,000	$73,000				
	Consvtion and I/I enforce		$365,000	0	1	1	$0	$365,000	$365,000				
							$1,265,000	**$7,768,000**	**$438,000**				
Water and Sewer							**Cumulative**						
	Base Revs	**% Price Inc**	**%Elast**	**% Wat Red**	**% Del Rev**	**New Revenues**	**Include?**			**Inflation =**	**3%**		
	$25,000,000	***50%***	***-0.26***	-10.01%	34.99%	$8,747,961	0	Indicates if revenues		**Interest =**	**6%**		
								are included in cumulative					
								"cost - savings" column.					
			Water Red =	72	MLD	(adjusted for external flows)							
	chk	20	SF Reduced	60	MLD	(change bolded #s only)							
			I/I Reduced	15	MLD					Captial Savings			Inflated Cost
			WTP Save	$880,992	/year in 1993 $	d$ = $12,236 dQ					Year	Inflated $	P.V.
			WPCP Save	$885,100	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)				Upgrade cost today	1993	$50,000,000	$50,000,000
										Year - no conservation	2025	$128,754,138	$19,951,406
				RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000		Year - with conservation	2080	$654,347,660	$4,113,375
				d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000		Note:	Need to include effects of RAP upgrade		
					(Note: RAP O&M is applied in 1995, this is early)						on future upgrade.		

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$8,747,961	$8,252,794	$8,252,794	-$1,302,950	-$1,229,198	-$1,229,198	-$1,229,198
2	1995	$187,800	$167,142	$186,929	$166,366	$333,508	$9,010,400	$8,019,224	$16,272,017	-$8,241,071	-$7,334,524	-$8,563,722	-$8,230,214
3	1996	$386,869	$324,823	$385,073	$323,315	$981,646	$9,280,712	$7,792,265	$24,064,282	-$8,488,303	-$7,126,943	-$15,690,665	-$14,709,020
4	1997	$597,713	$473,444	$594,939	$471,247	$1,926,337	$9,559,133	$7,571,729	$31,636,011	-$8,742,952	-$6,925,237	-$22,615,903	-$20,689,565
5	1998	$820,859	$613,393	$817,049	$610,547	$3,150,277	$9,845,907	$7,357,435	$38,993,446	-$9,005,241	-$6,729,240	-$29,345,142	-$26,194,866
6	1999	$1,056,856	$745,041	$1,051,951	$741,584	$4,636,902	$10,141,285	$7,149,205	$46,142,651	-$9,275,398	-$6,538,790	-$35,883,932	-$31,247,030
7	2000	$1,088,561	$723,955	$1,083,509	$720,595	$6,081,453	$10,445,523	$6,946,869	$53,089,521	-$538,685	-$358,256	-$36,242,188	-$30,160,736
8	2001	$1,121,218	$703,466	$1,116,014	$700,201	$7,485,120	$10,758,889	$6,750,260	$59,839,781	-$554,845	-$348,117	-$36,590,305	-$29,105,185
9	2002	$1,154,855	$683,557	$1,149,495	$680,384	$8,849,061	$11,081,655	$6,559,215	$66,398,995	-$571,491	-$338,264	-$36,928,570	-$28,079,509
10	2003	$1,189,500	$664,211	$1,183,980	$661,128	$10,174,400	$11,414,105	$6,373,577	$72,772,572	-$588,635	-$328,691	-$37,257,261	-$27,082,861
11	2004	$1,225,185	$645,412	$1,219,499	$642,417	$11,462,229	$11,756,528	$6,193,192	$78,965,765	-$606,294	-$319,388	-$37,576,649	-$26,114,420
12	2005	$1,261,941	$627,146	$1,256,084	$624,235	$12,713,610	$12,109,224	$6,017,913	$84,983,678	-$624,483	-$310,349	-$37,886,998	-$25,173,388
13	2006	$1,299,799	$609,397	$1,293,766	$606,568	$13,929,575	$12,472,501	$5,847,595	$90,831,273	-$643,218	-$301,566	-$38,188,564	-$24,258,989
14	2007	$1,338,793	$592,149	$1,332,579	$589,401	$15,111,125	$12,846,676	$5,682,097	$96,513,370	-$662,514	-$293,031	-$38,481,594	-$23,370,469
15	2008	$1,378,957	$575,390	$1,372,557	$572,720	$16,259,236	$13,232,076	$5,521,283	$102,034,653	-$682,390	-$284,737	-$38,766,332	-$22,507,096
16	2009	$1,420,326	$559,106	$1,413,734	$556,511	$17,374,853	$13,629,038	$5,365,020	$107,399,674	-$702,861	-$276,679	-$39,043,010	-$21,668,158
17	2010	$1,462,935	$543,282	$1,456,146	$540,761	$18,458,895	$14,037,910	$5,213,180	$112,612,854	-$723,947	-$268,848	-$39,311,859	-$20,852,963
18	2011	$1,506,823	$527,906	$1,499,830	$525,456	$19,512,258	$14,459,047	$5,065,637	$117,678,491	-$745,666	-$261,239	-$39,573,098	-$20,060,840
19	2012	$1,552,028	$512,965	$1,544,825	$510,585	$20,535,808	$14,892,818	$4,922,270	$122,600,761	-$768,036	-$253,846	-$39,826,944	-$19,291,136
20	2013	$1,598,589	$498,448	$1,591,170	$496,134	$21,530,390	$15,339,603	$4,782,961	$127,383,722	-$791,077	-$246,661	-$40,073,605	-$18,543,216
21	2014	$1,646,547	$484,341	$1,638,905	$482,093	$22,496,823	$15,799,791	$4,647,594	$132,031,316	-$814,809	-$239,680	-$40,313,286	-$17,816,463
22	2015	$1,695,943	$470,633	$1,688,072	$468,449	$23,435,904	$16,273,785	$4,516,058	$136,547,374	-$839,253	-$232,897	-$40,546,183	-$17,110,279
23	2016	$1,746,821	$457,313	$1,738,714	$455,191	$24,348,408	$16,761,998	$4,388,245	$140,935,619	-$864,431	-$226,306	-$40,772,488	-$16,424,081
24	2017	$1,799,226	$444,370	$1,790,875	$442,308	$25,235,086	$17,264,858	$4,264,050	$145,199,669	-$890,364	-$219,901	-$40,992,389	-$15,757,303
25	2018	$1,853,203	$431,794	$1,844,602	$429,790	$26,096,669	$17,782,804	$4,143,369	$149,343,038	-$917,075	-$213,677	-$41,206,066	-$15,109,397
26	2019	$1,908,799	$419,573	$1,899,940	$417,626	$26,933,868	$18,316,288	$4,026,104	$153,369,141	-$944,587	-$207,630	-$41,413,696	-$14,479,828
27	2020	$1,966,063	$407,698	$1,956,938	$405,806	$27,747,372	$18,865,777	$3,912,157	$157,281,299	-$972,925	-$201,753	-$41,615,449	-$13,868,077
28	2021	$2,025,045	$396,160	$2,015,646	$394,321	$28,537,853	$19,431,750	$3,801,436	$161,082,735	-$1,002,112	-$196,043	-$41,811,493	-$13,273,639
29	2022	$2,085,796	$384,948	$2,076,115	$383,161	$29,305,962	$20,014,702	$3,693,848	$164,776,583	-$1,032,176	-$190,495	-$42,001,988	-$12,696,026
30	2023	$2,148,370	$374,053	$2,138,399	$372,317	$30,052,332	$20,615,143	$3,589,305	$168,365,888	-$1,063,141	-$185,104	-$42,187,091	-$12,134,759

31	2024	$2,212,821	$363,467	$2,202,551	$361,780	$30,777,578	$21,233,598	$3,487,721	$171,853,610	-$1,095,035	-$179,865	-$42,366,956	-$11,589,378
32	2025	$2,279,205	$353,180	$2,268,627	$351,541	$31,482,298	$21,870,606	$3,389,012	$175,242,622	-$1,127,886	-$174,774	-$42,541,731	$4,778,599
33	2026	$2,347,582	$343,184	$2,336,686	$341,591	$32,167,074	$22,526,724	$3,293,097	$178,535,718	-$1,161,723	-$169,828	-$42,711,558	$5,293,547
34	2027	$2,418,009	$333,471	$2,406,787	$331,924	$32,832,469	$23,202,526	$3,199,896	$181,735,614	-$1,196,575	-$165,021	-$42,876,580	$5,793,920
35	2028	$2,490,549	$324,033	$2,478,990	$322,530	$33,479,032	$23,898,601	$3,109,333	$184,844,947	-$1,232,472	-$160,351	-$43,036,931	$6,280,132
36	2029	$2,565,266	$314,863	$2,553,360	$313,401	$34,107,296	$24,615,559	$3,021,333	$187,866,280	-$1,269,446	-$155,813	-$43,192,744	$6,752,584
37	2030	$2,642,224	$305,952	$2,629,961	$304,532	$34,717,779	$25,354,026	$2,935,823	$190,802,103	-$1,307,529	-$151,403	-$43,344,147	$7,211,664
38	2031	$2,721,491	$297,292	$2,708,860	$295,913	$35,310,984	$26,114,647	$2,852,734	$193,654,837	-$1,346,755	-$147,118	-$43,491,265	$7,657,751
39	2032	$2,803,135	$288,879	$2,790,125	$287,538	$35,887,401	$26,898,086	$2,771,996	$196,426,833	-$1,387,158	-$142,954	-$43,634,219	$8,091,213
40	2033	$2,887,229	$280,703	$2,873,829	$279,400	$36,447,503	$27,705,029	$2,693,544	$199,120,377	-$1,428,773	-$138,908	-$43,773,127	$8,512,407
41	2034	$2,973,846	$272,758	$2,960,044	$271,492	$36,991,754	$28,536,180	$2,617,311	$201,737,688	-$1,471,636	-$134,977	-$43,908,104	$8,921,681
42	2035	$3,063,062	$265,039	$3,048,845	$263,809	$37,520,601	$29,392,265	$2,543,236	$204,280,924	-$1,515,785	-$131,157	-$44,039,261	$9,319,372
43	2036	$3,154,953	$257,538	$3,140,311	$256,342	$38,034,482	$30,274,033	$2,471,258	$206,752,182	-$1,561,258	-$127,445	-$44,166,706	$9,705,807
44	2037	$3,249,602	$250,249	$3,234,520	$249,087	$38,533,818	$31,182,254	$2,401,317	$209,153,499	-$1,608,096	-$123,838	-$44,290,544	$10,081,305
45	2038	$3,347,090	$243,166	$3,331,556	$242,038	$39,019,022	$32,117,722	$2,333,355	$211,486,854	-$1,656,339	-$120,333	-$44,410,877	$10,446,176
46	2039	$3,447,503	$236,284	$3,431,502	$235,188	$39,490,494	$33,081,253	$2,267,317	$213,754,170	-$1,706,029	-$116,927	-$44,527,805	$10,800,720
47	2040	$3,550,928	$229,597	$3,534,447	$228,531	$39,948,622	$34,073,691	$2,203,147	$215,957,318	-$1,757,210	-$113,618	-$44,641,423	$11,145,231
48	2041	$3,657,456	$223,099	$3,640,481	$222,064	$40,393,785	$35,095,902	$2,140,794	$218,098,112	-$1,809,926	-$110,403	-$44,751,826	$11,479,990
49	2042	$3,767,179	$216,785	$3,749,695	$215,779	$40,826,348	$36,148,779	$2,080,205	$220,178,317	-$1,864,224	-$107,278	-$44,859,104	$11,805,276
50	2043	$3,880,195	$210,649	$3,862,186	$209,672	$41,246,669	$37,233,242	$2,021,332	$222,199,649	-$1,920,151	-$104,242	-$44,963,345	$12,121,355
Present Value Sum			$20,671,304		$20,575,365			$222,199,649			-$44,963,345		
		Savings	**Savings**	**Savings**	**Savings**	**Cumulative**	**New**	**New**	**Cumulative**	**Conservation**	**Conservation**	**Cumulative**	**Cumul**
Yr#	**Year**	**WPCP**	**WPCP**	**WTP**	**WTP**	**Savings**	**Revenues**	**Revenues**	**New Revs**	**Costs**	**Costs**	**Costs**	**Summary**
		Inflated	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**Inflated**	**P.V.**	**P.V.**	**P.V.**
P.V. SUMMARY - 50 years													
WPCP Savings		$20,671,304											Above includes
WTP Savings		$20,575,365											capital savings
Capital Savings		$15,838,031											in year 2025.
Total Savings		**$57,084,701**											
Program Cost		-$44,963,345											
New Revenues		$222,199,649											
Net P.V. Benefit		$12,121,355	(50 years)	0	revenues included in Net P.V. Benefit (0-no, 1-yes)								

Table D-11. Present value and cost/benefit analysis.

	Case:	Comprehensive flow reduction - Intensive I/I reduction											
				On/Off Switches				Annual Cost					
	Program		Annual Cost	Year 1?	Year 2-6?	Year 6 on?	Year 1	Year 2-6	Year 6 on				
SF	Pricing		$220,000	1	0	0	$220,000	$0	$0				
	Res Audit develop		$350,000	1	0	0	$350,000	$0	$0				
	Res audit		$6,100,000	0	1	0	$0	$6,100,000	$0				
	Public Education		$520,000	1	0	0	$520,000	$0	$0				
	Ind/Comm Lias		$230,000	0	1	0	$0	$230,000	$0				
I/I	INS Study		$817,500	1	0	0	$817,500	$0	$0				
	Sewer rehab and repair		$750,000	0	1	0	$0	$750,000	$0				
	Res roof disconnection		$1,000,000	0	1	0	$0	$1,000,000	$0				
	Sewer separation		$2.00E+08	0	0	0	$0	$0	$0				
Both	Database development		$175,000	1	0	0	$175,000	$0	$0				
	Consvtion and I/I monitor		$73,000	0	1	1	$0	$73,000	$73,000				
	Consvtion and I/I enforce		$365,000	0	1	1	$0	$365,000	$365,000				
							$2,082,500	**$8,518,000**	**$438,000**				
Water and Sewer							**Cumulative**						
	Base Revs	**% Price Inc**	**% Elast**	**% Wat Red**	**% Del Rev**	**New Revenues**	**Include?**			**Inflation =**	**3%**		
	$25,000,000	***50%***	***-0.26***	-10.01%	34.99%	$8,747,961	0	Indicates if revenues		**Interest =**	**6%**		
								are included in cumulative					
								"cost - savings" column.					
			Water Red =	72	MLD	(adjusted for external flows)							
	chk	20	SF Reduced	60	MLD	(change bolded #s only)							
			I/I Reduced	60	MLD					Captial Savings			Inflated Cost
			WTP Save	$880,992	/year in 1993 $	d$ = $12,236 dQ					Year	Inflated $	P.V.
			WPCP Save	$1,266,289	/year in 1993 $	d$ = 4821.45 dSF + 8470.86 dII + d$(RAP)				Upgrade cost today	1993	$50,000,000	$50,000,000
										Year - no conservation	2025	$128,754,138	$19,951,406
				RAP upgrade O&M=	$2,500,000	/year from	CSO (/year)	$2,000,000		Year - with conservation	2080	$654,347,660	$4,113,375
				d$(RAP) =	7812.5	x dSF	WPCP (/year)	$500,000		Note:	Need to include effects of RAP upgrade		
					(Note: RAP O&M is applied in 1995, this is early)						on future upgrade.		

Yr#	Year	Savings WPCP Inflated	Savings WPCP P.V.	Savings WTP Inflated	Savings WTP P.V.	Cumulative Savings P.V.	New Revenues Inflated	New Revenues P.V.	Cumulative New Revs P.V.	Conservation Costs Inflated	Conservation Costs P.V.	Cumulative Costs P.V.	Cumul Save-Cost P.V.
0	Present												
1	1994	$0	$0	$0	$0	$0	$8,747,961	$8,252,794	$8,252,794	-$2,144,975	-$2,023,561	-$2,023,561	-$2,023,561
2	1995	$268,681	$239,125	$186,929	$166,366	$405,491	$9,010,400	$8,019,224	$16,272,017	-$9,036,746	-$8,042,672	-$10,066,233	-$9,660,742
3	1996	$553,483	$464,715	$385,073	$323,315	$1,193,521	$9,280,712	$7,792,265	$24,064,282	-$9,307,849	-$7,815,049	-$17,881,282	-$16,687,761
4	1997	$855,131	$677,344	$594,939	$471,247	$2,342,113	$9,559,133	$7,571,729	$31,636,011	-$9,587,084	-$7,593,869	-$25,475,151	-$23,133,038
5	1998	$1,174,380	$877,565	$817,049	$610,547	$3,830,225	$9,845,907	$7,357,435	$38,993,446	-$9,874,697	-$7,378,948	-$32,854,099	-$29,023,874
6	1999	$1,512,015	$1,065,911	$1,051,951	$741,584	$5,637,719	$10,141,285	$7,149,205	$46,142,651	-$10,170,937	-$7,170,110	-$40,024,208	-$34,386,489
7	2000	$1,557,375	$1,035,743	$1,083,509	$720,595	$7,394,058	$10,445,523	$6,946,869	$53,089,521	-$538,685	-$358,256	-$40,382,464	-$32,988,406
8	2001	$1,604,097	$1,006,430	$1,116,014	$700,201	$9,100,689	$10,758,889	$6,750,260	$59,839,781	-$554,845	-$348,117	-$40,730,581	-$31,629,892
9	2002	$1,652,219	$977,946	$1,149,495	$680,384	$10,759,019	$11,081,655	$6,559,215	$66,398,995	-$571,491	-$338,264	-$41,068,846	-$30,309,826
10	2003	$1,701,786	$950,268	$1,183,980	$661,128	$12,370,416	$11,414,105	$6,373,577	$72,772,572	-$588,635	-$328,691	-$41,397,537	-$29,027,121
11	2004	$1,752,840	$923,374	$1,219,499	$642,417	$13,936,207	$11,756,528	$6,193,192	$78,965,765	-$606,294	-$319,388	-$41,716,925	-$27,780,718
12	2005	$1,805,425	$897,241	$1,256,084	$624,235	$15,457,683	$12,109,224	$6,017,913	$84,983,678	-$624,483	-$310,349	-$42,027,274	-$26,569,591
13	2006	$1,859,588	$871,847	$1,293,766	$606,568	$16,936,098	$12,472,501	$5,847,595	$90,831,273	-$643,218	-$301,566	-$42,328,840	-$25,392,741
14	2007	$1,915,375	$847,172	$1,332,579	$589,401	$18,372,671	$12,846,676	$5,682,097	$96,513,370	-$662,514	-$293,031	-$42,621,870	-$24,249,199
15	2008	$1,972,836	$823,196	$1,372,557	$572,720	$19,768,587	$13,232,076	$5,521,283	$102,034,653	-$682,390	-$284,737	-$42,906,608	-$23,138,020
16	2009	$2,032,021	$799,898	$1,413,734	$556,511	$21,124,996	$13,629,038	$5,365,020	$107,399,674	-$702,861	-$276,679	-$43,183,286	-$22,058,291
17	2010	$2,092,982	$777,259	$1,456,146	$540,761	$22,443,016	$14,037,910	$5,213,180	$112,612,854	-$723,947	-$268,848	-$43,452,135	-$21,009,119
18	2011	$2,155,772	$755,261	$1,499,830	$525,456	$23,723,733	$14,459,047	$5,065,637	$117,678,491	-$745,666	-$261,239	-$43,713,374	-$19,989,641
19	2012	$2,220,445	$733,886	$1,544,825	$510,585	$24,968,203	$14,892,818	$4,922,270	$122,600,761	-$768,036	-$253,846	-$43,967,220	-$18,999,016
20	2013	$2,287,058	$713,116	$1,591,170	$496,134	$26,177,453	$15,339,603	$4,782,961	$127,383,722	-$791,077	-$246,661	-$44,213,881	-$18,036,428
21	2014	$2,355,670	$692,933	$1,638,905	$482,093	$27,352,479	$15,799,791	$4,647,594	$132,031,316	-$814,809	-$239,680	-$44,453,562	-$17,101,083
22	2015	$2,426,340	$673,322	$1,688,072	$468,449	$28,494,249	$16,273,785	$4,516,058	$136,547,374	-$839,253	-$232,897	-$44,686,459	-$16,192,210
23	2016	$2,499,130	$654,265	$1,738,714	$455,191	$29,603,705	$16,761,998	$4,388,245	$140,935,619	-$864,431	-$226,306	-$44,912,764	-$15,309,059
24	2017	$2,574,104	$635,748	$1,790,875	$442,308	$30,681,761	$17,264,858	$4,264,050	$145,199,669	-$890,364	-$219,901	-$45,132,665	-$14,450,904
25	2018	$2,651,327	$617,756	$1,844,602	$429,790	$31,729,306	$17,782,804	$4,143,369	$149,343,038	-$917,075	-$213,677	-$45,346,342	-$13,617,036
26	2019	$2,730,867	$600,272	$1,899,940	$417,626	$32,747,204	$18,316,288	$4,026,104	$153,369,141	-$944,587	-$207,630	-$45,553,972	-$12,806,768
27	2020	$2,812,793	$583,283	$1,956,938	$405,806	$33,736,293	$18,865,777	$3,912,157	$157,281,299	-$972,925	-$201,753	-$45,755,725	-$12,019,432
28	2021	$2,897,177	$566,775	$2,015,646	$394,321	$34,697,390	$19,431,750	$3,801,436	$161,082,735	-$1,002,112	-$196,043	-$45,951,769	-$11,254,379
29	2022	$2,984,092	$550,734	$2,076,115	$383,161	$35,631,285	$20,014,702	$3,693,848	$164,776,583	-$1,032,176	-$190,495	-$46,142,264	-$10,510,979
30	2023	$3,073,615	$535,147	$2,138,399	$372,317	$36,538,749	$20,615,143	$3,589,305	$168,365,888	-$1,063,141	-$185,104	-$46,327,367	-$9,788,618

31	2024	$3,165.823	$520,002	$2,202,551	$361,780	$37,420,531	$21,233,598	$3,487,721	$171,853,610	-$1,095,035	-$179,865	-$46,507,232	-$9,086,701
32	2025	$3,260,798	$505,285	$2,268,627	$351,541	$38,277,356	$21,870,606	$3,389,012	$175,242,622	-$1,127,886	-$174,774	-$46,682,007	$7,433,381
33	2026	$3,358,622	$490,984	$2,336,686	$341,591	$39,109,932	$22,526,724	$3,293,097	$178,535,718	-$1,161,723	-$169,828	-$46,851,834	$8,096,129
34	2027	$3,459,381	$477,088	$2,406,787	$331,924	$39,918,944	$23,202,526	$3,199,896	$181,735,614	-$1,196,575	-$165,021	-$47,016,856	$8,740,119
35	2028	$3,563,162	$463,586	$2,478,990	$322,530	$40,705,059	$23,898,601	$3,109,333	$184,844,947	-$1,232,472	-$160,351	-$47,177,207	$9,365,884
36	2029	$3,670,057	$450,466	$2,553,360	$313,401	$41,468,926	$24,615,559	$3,021,333	$187,866,280	-$1,269,446	-$155,813	-$47,333,020	$9,973,938
37	2030	$3,780,159	$437,717	$2,629,961	$304,532	$42,211,174	$25,354,026	$2,935,823	$190,802,103	-$1,307,529	-$151,403	-$47,484,423	$10,564,783
38	2031	$3,893,563	$425,328	$2,708,860	$295,913	$42,932,416	$26,114,647	$2,852,734	$193,654,837	-$1,346,755	-$147,118	-$47,631,541	$11,138,906
39	2032	$4,010,370	$413,291	$2,790,125	$287,538	$43,633,244	$26,898,086	$2,771,996	$196,426,833	-$1,387,158	-$142,954	-$47,774,495	$11,696,781
40	2033	$4,130,681	$401,594	$2,873,829	$279,400	$44,314,238	$27,705,029	$2,693,544	$199,120,377	-$1,428,773	-$138,908	-$47,913,403	$12,238,866
41	2034	$4,254,602	$390,228	$2,960,044	$271,492	$44,975,958	$28,536,180	$2,617,311	$201,737,688	-$1,471,636	-$134,977	-$48,048,380	$12,765,609
42	2035	$4,382,240	$379,184	$3,048,845	$263,809	$45,618,951	$29,392,265	$2,543,236	$204,280,924	-$1,515,785	-$131,157	-$48,179,537	$13,277,445
43	2036	$4,513,707	$368,452	$3,140,311	$256,342	$46,243,745	$30,274,033	$2,471,258	$206,752,182	-$1,561,258	-$127,445	-$48,306,982	$13,774,795
44	2037	$4,649,118	$358,024	$3,234,520	$249,087	$46,850,857	$31,182,254	$2,401,317	$209,153,499	-$1,608,096	-$123,838	-$48,430,820	$14,258,068
45	2038	$4,788,592	$347,892	$3,331,556	$242,038	$47,440,787	$32,117,722	$2,333,355	$211,486,854	-$1,656,339	-$120,333	-$48,551,153	$14,727,665
46	2039	$4,932,249	$338,046	$3,431,502	$235,188	$48,014,020	$33,081,253	$2,267,317	$213,754,170	-$1,706,029	-$116,927	-$48,668,081	$15,183,970
47	2040	$5,080,217	$328,478	$3,534,447	$228,531	$48,571,029	$34,073,691	$2,203,147	$215,957,318	-$1,757,210	-$113,618	-$48,781,699	$15,627,362
48	2041	$5,232,623	$319,182	$3,640,481	$222,064	$49,112,275	$35,095,902	$2,140,794	$218,098,112	-$1,809,926	-$110,403	-$48,892,102	$16,058,204
49	2042	$5,389,602	$310,148	$3,749,695	$215,779	$49,638,201	$36,148,779	$2,080,205	$220,178,317	-$1,864,224	-$107,278	-$48,999,380	$16,476,853
50	2043	$5,551,290	$301,370	$3,862,186	$209,672	$50,149,244	$37,233,242	$2,021,332	$222,199,649	-$1,920,151	-$104,242	-$49,103,621	$16,883,654
Present Value Sum			$29,573,879		$20,575,365			$222,199,649			-$49,103,621		
Yr#	**Year**	**Savings WPCP Inflated**	**Savings WPCP P.V.**	**Savings WTP Inflated**	**Savings WTP P.V.**	**Cumulative Savings P.V.**	**New Revenues Inflated**	**New Revenues P.V.**	**Cumulative New Revs P.V.**	**Conservation Costs Inflated**	**Conservation Costs P.V.**	**Cumulative Costs P.V.**	**Cumul Summary P.V.**
P.V. SUMMARY - 50 years													
WPCP Savings		$29,573,879											Above includes
WTP Savings		$20,575,365											capital savings
Capital Savings		$15,838,031											in year 2025.
Total Savings		**$65,987,275**											
Program Cost		-$49,103,621											
New Revenues		$222,199,649											
Net P.V. Benefit		**$16,883,654**	(50 years)	0	revenues included in Net P.V. Benefit (0-no, 1-yes)								