Final Report

Evaluation & Optimization of Design/Operation of Sequencing Batch Reactors for Wastewater Treatment

Prepared for

Ministry of the Environment
Ontario

Water Environment
Association of
Ontario

Environment Canada Environnement Canada

GREAT LAKES 2000
CLEANUP FUND

FONDS D'ASSAINISSEMENT
DES GRANDS LACS 2000

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Ontario Ministry of the Environment

The Ontario Ministry of the Environment supports scientific research to provide a better understanding of interactions between human activities and ecosystem health, as well as the development, demonstration and implementation of innovative and cost-effective technologies, which maintain and enhance the natural environment. To date, the Water and Wastewater Optimization Section has supported and/or worked cooperatively with federal and municipal governments and universities on numerous projects to advance the development of innovative approaches and technologies to provide more efficient water, sewage, combined sewer overflow and stormwater management services. For more information regarding the optimization programs contact:

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Great Lakes 2000 Cleanup Fund

Environment Canada's Great Lakes 2000 Cleanup Fund supports the development and implementation of cleanup technologies to restore beneficial use in Canada's 16 Areas of Concern. The Cleanup fund has provided about $60 million in support of more than 300 projects in the areas of sediment cleanup, combined sewer overflows, stormwater management, sewage treatment, and habitat rehabilitation. For more information or copies of project reports contact:

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Water Environment Association of Ontario

The Water Environment Association of Ontario (WEAO) is a non-profit professional organization, dedicated to the transfer of information and concepts regarding all areas of the water environment. The Association serves its membership by publishing bi-monthly newsletter, organizing a number of seminars each year, as well as an annual conference/ equipment exhibition. The Association membership comprises of scientists, operators, engineers, and academics dedicated to improving the water environment. Members come from consulting firms, industries, equipment manufacturers, municipalities, colleges and universities, and provincial and federal government agencies. WEAO is also an association member of the Water Environment Federation, which is an international organization with a vision of "Clean Water Everywhere". For further information regarding WEAO contact:

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DISCLAIMER

This report was prepared for the Ontario Ministry of the Environment, Environment Canada, and the Water Environment Association of Ontario as part of a cooperative project. The views and ideas expressed in this report are those of the authors and do not necessarily reflect the views and policies of the Ministry of the Environment, Environment Canada or the Water Environment Association of Ontario nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

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Executive summary

Program background and objectives

SBR can be a cost-effective technology for treating municipal and industrial wastewater

The Water Environment Association of Ontario (WEAO), Environment Canada's Great Lakes 2000 Cleanup Fund (GL2000CUF), and the Ontario Ministry of the Environment (MOE) recognize that Sequencing Batch Reactors (SBRs) may be a cost-effective technology for treating municipal and industrial wastewater.

There are a growing number of SBR plants in Ontario and Canada in general. Unlike conventional technology, SBRs tend to be designed and marketed by equipment suppliers. Before the implementation of this program, there was little well-documented evidence on how existing SBRs are performing in Ontario, including their cost-effectiveness, reliability, optimal design and operation, cost and performance associated with different SBR configurations and equipment suppliers.

For these reasons, WEAO, GL2000CUF, and the MOE agreed to jointly sponsor the Evaluation & Optimization of Design/Operation of Sequencing Batch Reactors (SBRs) program to:

- Evaluate and document the design and operation of SBR technology in Ontario and other provinces/states.
- Recommend/conduct optimization studies.
- Recommend optimum design and operating strategies/procedures.
- Promote the use of this technology in Ontario.

The program has been divided into three main phases. The major objectives may be summarized as:

- To document the application and performance of municipal SBR treatment facilities in Ontario and in other jurisdictions with similar climatic conditions and raw sewage characteristics (Phase 1)

- To optimize the design and operation of representative SBR plants (Phase 2)
- To produce a guidance manual on the process selection, design, and operation of SBRs (Phase 3)

This Final Report contains the results from Phase 1, initiated in October 1997.

Evaluation of SBR facilities

The Hydromantis Team compiled and documented the application and performance of municipal SBRs

In Phase 1, the Hydromantis Team (Hydromantis, Inc. and SBR Technologies, Inc.) compiled and documented the application and performance of municipal SBR treatment facilities in Ontario and in selected nearby Great Lakes facilities in the US.

Information from 75 SBR facilities in the US and Canada was obtained through a questionnaire sent to these plants and/or to suppliers of their SBR equipment. Additional information was gathered from communications with suppliers, government organizations, plant operators, consultants, and US regulatory groups.

Twelve facilities, six in the US and six in Ontario, were visited.

From the long list of SBR plants compiled and assessed, twelve facilities (six in the US and six in Ontario) were visited.

The visits to the US facilities augmented Ontario's experience with these technologies and provided data from SBR suppliers, which are currently not present in the Ontario market.

The design pitfalls and operational problems encountered in the plants visited and assessed by the Hydromantis Team were still able to achieve an excellent effluent quality. Therefore, in this report, the design pitfalls and operational problems will be referred to as 'concerns'. These concerns were ranked based on their frequency of occurrence, prevalence of occurrence, and their impact on operating costs, plant capacity and effluent limit compliance.

The concerns ranked as follows:

Design and operating concerns were ranked based on their occurrence and impact.

1. Operators do not have formal training on SBR operation and process control. *(Please see the note below)*

2. Mechanical equipment located outdoors (e.g., air valves, solenoid valves, decanter arms, level floats, etc.) may freeze due to lack of proper heating/protection and/or maintenance.

3. Decanters may be unable to adequately control the discharge of floatables present in the reactor which may adversely affect downstream processes (e.g., grease clogging sand filters and UV lamps).

4. Variable rate discharges from the SBR due to fixed level decanters may cause inadequate treatment in post SBR processes (e.g., continuous sand filters, UV disinfection).

5. Lack of online DO monitoring instrumentation and control.

6. Optimum MLSS is rarely provided to operators, who have to find it based on operating experience (trial and error selection).

7. Lack of automation for selection of wasting time (manually selected by operators based on MLSS concentrations).

8. Inadequate design of pre-treatment systems may cause several problems, including: floating and coarse material get in SBR and end up in decant, impact on flow metering accuracy, frequent maintenance, etc.

9. Foam on tank surface freezes and blocks level floats affecting normal cycle. Pressure transducers are more expensive, but require less maintenance.

10. Secondary phosphorus release in aerobic digesters.

***Note**: The Michigan Department of Environmental Quality offers an operator's training course on SBRs about once a year, depending on demand. Interested parties can contact either Mr. Douglas Hill at (517) 373-4754; e-mail: hilld@deq.state.mi.us or Mr. Dan Holmquist at (517) 373-4753; e-mail: holmquid@deq.state.mi.us.*

11. Reactors located above ground result in significant heat loss in winter.

12. Problems with SBR control program during peak flows.

13. Lack of connections between SBR tanks does not allow the transfer of MLSS between tanks.

14. Lack of adequate access to SBRs (e.g., walkways), and WAS and recirculation pumps, especially those without hoists.

15. Sharing of the influent and sludge wasting line decreases WAS concentration and increases O&M costs of dewatering equipment.

16. Solenoid valves may fail during electrical power interruptions, sending untreated sewage to effluent.

17. WAS sump not properly designed (too small or not well located).

18. Control system not robust enough to withstand power failure/recovery.

19. Lack of adequate digested sludge storage for winter.

Lack of SBR-specific operator training has the largest impact on effluent quality and operation costs.

Three main observations can be made from the questionnaire results:

1. Lack of SBR-specific operator training has the largest impact on effluent quality and operation costs. In many SBR plants, operators were certified and received training on wastewater treatment. However, most operator training courses do not target SBR operation.
2. Many of the concerns ranked can apply to any type of wastewater treatment plant (e.g., inadequate pre-treatment, lack of DO control) and are not SBR-specific.
3. In spite of the concerns listed, the majority of the 75 SBRs evaluated met and in many cases exceeded the effluent requirements.

Despite these concerns, in most cases effluent quality is not adversely affected.

Opportunities for optimization

Based on our team's extensive experience with SBR technology, the information gathered was used to identify probable causes, recommend remedial actions and identify opportunities and means to optimize the design and operation of SBRs.

The goal of the optimization activities and areas listed below is to reduce capital and O&M costs, improve effluent quality, and make the most of the technology.

The main opportunities for optimization found in this evaluation are:

The information gathered was used to identify opportunities for SBR optimization.

- Development of SBR-specific operator training courses that could be used to complement traditional wastewater operation training programs.
- Proper selection of decanter design to meet treatment objectives and protect post-treatment processes (i.e., processes downstream the SBR).
- Improvement and implementation of DO-based SBR control strategies.
- Proper selection and sizing of pre- and post-treatment systems.
- Development of automated sludge wasting strategies using online instrumentation (e.g., SS online monitors).
- Assessment of impact of phosphorus release in aerobic digesters on phosphorus removal and development of operating strategies to mitigate this impact.

Phase 2

Our team recommends two sites for implementation of Phase 2.

Based on the information gathered from this evaluation, two SBR plants, Drumbo and Horseshoe Valley Resort, are proposed for on-site evaluation and demonstration of optimization strategies during Phase 2. A workplan was developed for implementation, testing, and refinement of the remedial actions, optimization strategies and evaluation methodologies to be conducted during Phase 2. The main goal of Phase 2 is to optimize the design and/or operation of these two SBR facilities and to document the methodology followed, so that it can be applied at other facilities.

Both sites selected met the following criteria:

- Suitability of the site for implementation of optimization techniques

- Accessibility of the site and proximity to laboratory/analytical facilities

- Willingness of the owners/operators to participate in this demonstration project

An experimental plan was developed and is presented in this Final Report. The experimental plan includes a description of methodologies proposed to evaluate and verify the effectiveness of these remedial actions and strategies.

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Section 1: Introduction

Hydromantis, Inc. and SBR Technologies, Inc., the Hydromantis Team, are pleased to present the Final Report for the Evaluation and Optimization of Design/Operation of Sequencing Batch Reactors for Wastewater Treatment.

Report organization

This report is organized in three sections and four appendices:

- **Section 1: Introduction,** covers the project background and the main reasons that triggered this program. A brief description of the SBR treatment technology, general history of its development and operating characteristics is presented. The project objectives, scope of work and study approach/methodology are included in this section.

- **Section 2: Evaluation of SBR plants,** describes in detail the information compiled by the Hydromantis Team in Phase 1 of this program. Statistical information on the complete set of plant data compiled, description of technologies assessed, effluent limits achievable, and cost comparisons between continuous flow activated sludge systems and periodic systems (SBRs) are presented in this section. Common design pitfalls and operating bottlenecks (referred to in this report as 'concerns') are prioritized. Opportunities for process optimization are discussed.

- **Section 3: Development of Phase 2,** suggests a workplan for Phase 2 of this program. Potential sites for implementation of Phase 2 are described and recommended. Estimates for required budget and schedule for Phase 2 are presented.

- **Appendix** contains a summary table of SBR plant data.

Background on sequencing batch reactors

The operation of an activated sludge process using a "batch process" was identified around the turn of the century (1900s) when activated sludge treatment was first discovered.

The batch mode of operation was originally regarded as interesting but not practical. It is only over the last two decades that this operation mode has earned the attention of the scientific and manufacturing community. This most recent interest corresponds to the appearance on the market of logic controls (1980) to overcome the basic step operation problematic of such a system.

During the last two decades, such evolution corresponded to major discoveries in microbiology applied to biological wastewater treatment. These "two driving forces" (logic controls and microbiology) are today responsible for the growing recognition of the batch mode operation of activated sludge systems.

Batch treatments were reintroduced officially in the United States in the early 80s, particularly for the municipal market. The technology had been used in the 70s in Canada, the United States and Europe. It was also popular in Australia during the same period.

An SBR is a time-oriented system with flow, energy input, and tank volume varying according to some periodic operating strategy

An SBR is a time-oriented system with flow, energy input, and tank volume varying according to some periodic operating strategy. An SBR can be broadly classified as an unsteady-state activated sludge system. Such systems can be operated to achieve strong control over micro-organism selection.

The SBR has been shown to be a cost effective and energy efficient means of removing hazardous organic compounds found in contaminated leachates and industrial wastewaters, and of removing organics and nutrients from municipal wastewaters. SBRs are suited for the selection and enrichment of desired microbial populations because of the ease with which a diverse array of selective pressures can be implemented. The flexibility in its operation stems from the time-oriented nature of the process, which, through simple operational modifications, can alter the nature and extent of organic carbon, nitrogen, and phosphorus removal, and can be used to control bulking sludge, a common problem in continuous flow wastewater treatment systems.

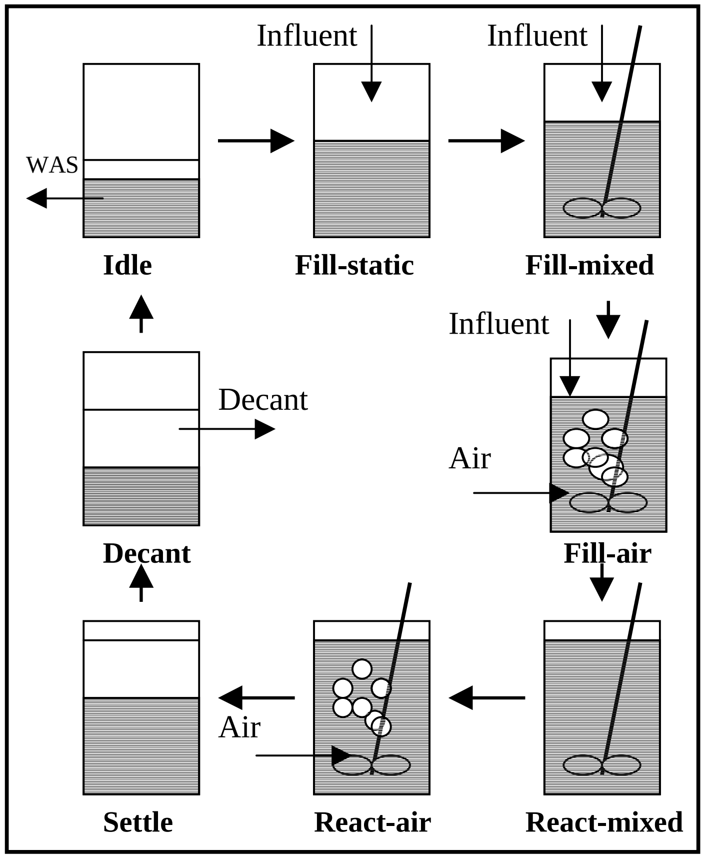


Figure 1: Typical SBR cycle

The operation of the SBRconsists of five distinct periods.

The operation of the SBR, shown in Figure 1, consists of five distinct periods, which comprise one complete reactor cycle. Each tank in the SBR system is filled during a discrete period of time. During this FILL period, organism selection can be controlled by manipulating the actual specific growth rates of the microbes and by regulating the oxygen tension in the reactor (e.g., from anaerobic, to anoxic, to fully aerobic). Thus, a FILL period may be static, mixed or aerated. After a tank is filled, treatment continues with the SBR operating as a batch reactor. During this REACT period, further selective pressures are applied by controlling the length of time the organisms are subjected to starvation conditions. After treatment, the microbes are allowed to separate by sedimentation during a period called SETTLE. The treated effluent is subsequently drawn from the reactor during an additional, distinct DRAW period. IDLE, the period between DRAW and the beginning of the next cycle, provides excess capacity for times when the actual flow exceeds the average or design flow. Periodic sludge wasting can be implemented, as needed, during REACT, SETTLE, DRAW, or IDLE.

The advantage of the time-oriented nature of the SBR is that reaction times and the initial conditions of each period within a cycle can be adjusted by changing the system operating policy (e.g., cycle times, aeration strategy, etc.). This flexibility in operation is not easily matched in more conventional continuous-flow activated sludge systems.

Project background

There are a growing number of SBR plants in Ontario and Canada in general. Unlike conventional continuous-flow activated sludge technology, SBRs tend to be designed and marketed by equipment suppliers. Before the implementation of this program, there was little well-documented evidence on how existing SBRs are performing; their cost-effectiveness; reliability, optimal design and operations, cost and performance associated with different SBR configurations and equipment suppliers.

WEAO, GL2000CF, and MOEE recognized that SBRs can be a cost-effective technology.

The Water Environment Association of Ontario (WEAO), Environment Canada's Great Lakes 2000 Cleanup Fund (GL2000CUF), and the Ontario Ministry of the Environment (MOE) recognize that SBRs can be a cost-effective technology for treating municipal and industrial wastewater. However, these associations also recognize that there has been little design and operating experience in Ontario to ensure that this process is correctly applied, designed, and operated. There was also limited information to optimize the performance and improve the cost-effectiveness of this technology.

Project objectives

WEAO, GL2000CUF, and the MOE agreed to jointly sponsor this program to:

- Evaluate and document the design and operations of SBR technology in Ontario and other provinces/states.

- Recommend/conduct optimization studies.
- Recommend optimum design and operating strategies/procedures.
- Promote the use of this technology in Ontario.

The program has been divided into three main phases. The major objectives may be summarized as:

- To document the application and performance of municipal SBR treatment facilities in Ontario and in other jurisdictions with similar climatic conditions and raw sewage characteristics (Phase 1)
- To optimize the design and operation of representative SBR plants (Phase 2), if warranted from the findings of Phase 1
- To produce a guidance manual on the process selection, design, and operation of SBRs (Phase 3)

Scope of work and study approach

In Phase 1, the Hydromantis Team compiled and documented the application and performance of municipal SBR treatment facilities in Ontario and in selected nearby Great Lakes facilities in the US.

Information from 75 SBR facilities in the US and Canada was obtained through a questionnaire

Information from 75 SBR facilities in the US and Canada was obtained through a questionnaire sent to these plants and/or to suppliers of their SBR equipment. Additional information was gathered from communications with suppliers, government organizations, plant operators, consultants, and US regulatory groups.

Based on our team's extensive experience with SBR technology, the information gathered was used to identify probable causes, recommend remedial actions and identify opportunities and means to optimize the design and operation of SBRs.

Twelve facilities (six in the USA and six in Ontario) were recommended to the Technical Steering Committee for site visits. The visits were conducted and/or reported during November 1997 and January 1998.

The visits to the US facilities augmented Ontario's experience with these technologies and provided data from SBR suppliers, which are currently not present in the Ontario market.

Our team recommends two sites for implementation of Phase 2.

Based on the information gathered from the plant visits, two plants, Drumbo and Horseshoe Valley Resort, are proposed for Phase 2. A workplan was developed for implementation, testing, and refinement of the remedial actions, optimization strategies and evaluation methodologies to be conducted during Phase 2. The main goal of Phase 2 is to optimize the design and/or operation of these two SBR facilities.

The selection of these sites was based on the following criteria:

- Suitability of the site for implementation of optimization techniques
- Accessibility of the site and proximity to laboratory/analytical facilities
- Willingness of the owners/operators to participate in this demonstration project

An experimental plan was developed. The experimental plan includes a description of methodologies proposed to evaluate and verify the effectiveness of these remedial actions and strategies.

Section 2: Evaluation of SBR plants

Assessment of SBR plants and data compilation

The Hydromantis Team prepared a questionnaire form prompting for key information pertaining to SBR design and operation.

At project initiation, The Hydromantis Team prepared a questionnaire for obtaining key information pertaining to SBR design and operation. The information requested in the questionnaire was classified in five sections:

- General information (e.g., location, design engineer, SBR supplier)
- Design parameters (flow rate, influent characteristics, effluent objectives)
- Actual influent and effluent characteristics
- Installation characteristics (e.g., pre-treatment equipment, type of decanter, SBR operating cycle, control strategies applied)
- Capital and O&M costs
- Common operating concerns

This questionnaire was improved with discussions with the Technical Steering Committee (TSC Meeting No. 4) and a final questionnaire was developed and distributed to a large number of selected SBR facilities.

From the long list of SBR plants compiled and assessed, twelve facilities (six in the USA and six in Ontario) were recommended to the Technical Steering Committee for site visits. The plant name, average and peak design flows, and SBR supplier of the plants visited in Ontario and in the US are listed in Table 1 and Table 2, respectively.

A total of twelve SBR plants were visited during Phase 1: six in the US and six in Ontario.

The visits to the US facilities augmented Ontario's experience with these technologies and provided data from SBR suppliers, which are currently not present in the Ontario market.

The Hydromantis Team documented the tours with extensive field notes and digital photographs. The photographic files and word processing files with field notes and plant data were delivered to the Technical Steering Committee at the end of each visit.

SBR installations and performance

The questionnaires were filled out for 75 plants: 12 from Canada and 63 from the United States.

The questionnaires were filled out for 75 plants: 12 from Canada and 63 from the United States. The distribution of the responses was:

- Information from 12 facilities was compiled during site visits.
- Information from 29 facilities was sent directly by SBR suppliers (using the questionnaire and/or plant operating data sheets).
- Information from 34 facilities was supplied by plant staff (using the questionnaire and/or through phone and e-mail communications)

The main characteristics of the plants assessed are summarized in a table presented in theAppendix (Excel format).

The plants were classified in three groups based on achievable effluent quality.

The plants were classified by achievable effluent quality in three groups, based on three sets of effluent limits (non compliance) defined by the Technical Steering Committee:

Limit 1: Conventional limit

$CBOD_5$ = 25 mg/L TSS = 25 mg/L ***Annual***
TP = 1 mg/L ***Monthly***

Limit 2: Conventional w/nitrification requirements – *All Monthly*

$CBOD_5$ = 10 mg/L TSS = 10 mg/L
TP = 0.5 mg/L
NH_3-N = 3 mg/L (summer) 5 mg/L (winter)

Limit 3: BNR/RAP-type limit – *All Monthly*

$CBOD_5$ = 5 mg/L, TSS = 5 mg/L,
TP = 0.2 mg/L, and
TN = 5 mg/L (summer) 10 mg/L (winter)
NH_3-N = 2 mg/L (summer) 4 mg/L (winter)

Table 1 **List of Ontario Plants Visited during Phase 1**			
Plant Name	**SBR Supplier**	**Qavg/Qpeak (design, m^3/d)**	**Date of visit**
Casinorama	ABJ	2100/6300	28-Jul-97
Horseshoe Valley	ABJ	540/1863	28-Jul-97
Cardinal	Eco Process & Equipm.	2500/6900	6-Nov-97
Rockland	Eco Process & Equipm.	6800/20,400	6-Nov-97
Long Sault	ABJ	2700/11,500	7-Nov-97
Drumbo	AquaClear	272/774	24-Jan-98

Table 2 **List of US Plants Visited during Phase 1**			
Plant Name	**SBR Supplier**	**Qavg/Qpeak (design, m^3/d)**	**Date of visit**
Chester, WV.	Fluidyne	1700/4540	13-Nov-97
New Middletown, OH	Fluidyne	2080/3790	13-Nov-97
Weedville, PA	Aqua Aerobics	379/?	13-Nov-97
Oak Point, MI	Jet Tech	1700/?	14-Nov-97
Dundee, MI	CASS	2839/9463	15-Nov-97
Catawba Is., OH	CASS	5072/14383	15-Nov-97

Many of the plants evaluated do not have to meet the effluent phosphorus criteria shown in these limits. For this reason, many plants reaching good levels of nitrification, BOD, SS, and nitrogen removal, but not achieving the effluent P levels specified, were classified within less stringent limits. For example, plants meeting Limit 3 criteria for $CBOD_5$, TSS, NH_3-N and TN, were classified within Limit 2 because their effluent P concentrations were within the value stated for Limit 2.

The results of this classification were:

- Fourteen of the plants assessed met the effluent requirements for Limit 1. Most of these plants had considerably lower $CBOD_5$ and TSS concentrations than those stated in this limit, and were classified within this group due to their effluent phosphorus concentrations. Some of the plants fitting within Limit 1 had good levels of nitrification and in some cases, low effluent concentrations of total nitrogen.

- Nine plants met the effluent requirements for Limit 2. As in the case of plants meeting Limit 1 criteria, many of these plants classified within Limit 2 met more stringent effluent limits for ammonia and total nitrogen than those specified for this limit, but were classified within this group due to the effluent phosphorus concentrations.

- No facilities met the effluent requirements for Limit 3. Even though five facilities met the ammonia and nitrogen limits of Limit 3, none of these plants met the TP requirements stated in this limit.

- The remaining facilities did not fit within Limits 1, 2, or 3.

- The specific effluent requirements (as stated in their C. of A. or NPDES) were met in all but one of the 75 facilities assessed in Phase 1.

- The average effluent $CBOD_5$ and SS concentrations for all the plants evaluated were below 10 mg/L.

- 53 facilities reported yearly average effluent NH_3-N concentrations. The average of all the NH_3-N concentrations reported was 1.5 mg/L.

- 32 facilities reported yearly average effluent TP concentrations. The average of all the TP concentrations reported was 1.4 mg/L.
- 9 facilities reported yearly average effluent TN concentrations. The average of all the TN concentrations reported was 4.3 mg/L.

Examples of plants meeting stringent effluent criteria in Canada and the US Great Lakes States are shown in Table 3.

Table 3
Examples of plants meeting stringent effluent criteria in Great Lakes Region

Plant/ Supplier	Actual/ Design Flow [m^3/d]		$CBOD_5$ [mg/L]	TSS [mg/L]	NH_3-N [mg/L]	NO_3-N [mg/L]	TP [mg/L]	Filters	Chem. Add'n
New Freedom, PA Aqua Aerobics	4100/ 8520	Inf	73	81	N/A	N/A	N/A	No	No
		Eff	**< 5**	**5**	**0.8**	**N/A**	**0.9**		
Garden Spot, PA Aqua Aerobics	90/ 1060	Inf	276	380	33	N/A	10	Yes	Yes
		Eff	**< 5**	**< 5**	**0.4**	**N/A**	**1.0**		
Flushing, MA Jet Tech	6880/ 7570	Inf	120	122	13	N/A	2.8	No	No
		Eff	**< 5**	**< 5**	**0.5**	**0.2**	**0.5**		
Soaring Eagle, MI Jet Tech	760/ 2200	Inf	285	190	65	N/A	7.0	Yes	Yes
		Eff	**< 5**	**< 5**	**0.5**	**N/A**	**0.2**		
Catawba Is., OH CASS	1730/ 5070	Inf	236	394	21	N/A	7.5	No	Yes
		Eff	**10**	**12**	**3.6**	**0.9**	**0.5**		
Casinorama, ON ABJ	700/ 2100	Inf	289	375	18.3	N/A	9.5	Yes	No
		Eff	**<4**	**<5**	**0.6**	**0.7**	**0.3**		
Frackville, PA ABJ	3030/ 5300	Inf	207	188	N/A	N/A	5.95	Yes	Yes
		Eff	**<5**	**<5**	**1.0**	**5.0**	**0.5**		

Many of the facilities shown in Table 3 are operating at flows that are well below their design capacity. However, to compensate for the low flows and reduce energy expenditures and equipment maintenance costs, some of these facilities are being operated with part of the SBRs out of service. Final effluent values are shown in this table (i.e., if there are filters, the effluent concentration shown is after filtration). Actual and design average flows are shown.

Prioritization of common concerns

The design pitfalls and operational problems will be referred to as 'concerns'.

In spite of design pitfalls and operational problems encountered in the plants visited and assessed by the Hydromantis Team, these plants met and in most cases exceed their effluent requirements. Therefore, in this report, the design pitfalls and operational problems are referred to as 'concerns'.

A prioritized list of concerns encountered in the plants investigated was prepared.

A prioritized list of concerns encountered in the plants investigated was prepared. The ranking was based on the following criteria:

- Frequency of occurrence
- Prevalence of occurrence among plants investigated
- Impact on plant treatment capacity, final effluent quality (effluent compliance), and O&M costs

The nature of the concerns was not found to be related to the effluent requirements. Therefore, it was not necessary to subdivide the list of concerns into three lists, each for a given set of effluent criteria.

A description of each concern, with field notes, data, and digital photo records (when possible) is provided.

A summary description of each concern with field notes, data, and digital photographic records (when possible) is provided in the following paragraphs. The concerns are presented according to their priority. The first ones shown are those with higher priority.

The number in [brackets] following the title of the concern corresponds to the plant number in the summary table provided in the Appendix. The plants indicated in the brackets are those where the concerns were detected. The longer the list of plants is, the larger is the prevalence of occurrence of the concern. Having a large number of facilities with a certain concern does not move it up to the top of the list. The other two key factors (i.e., impact on treatment capacity and effluent quality and frequency of

Whenever possible, remedial or optimization actions are presented for each concern.

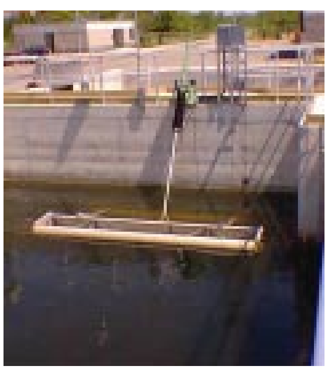
occurrence) were also taken into account and influence the position of the concern in the ranking. Whenever possible, remedial or optimization actions are presented after the concern.

1. Operators do not have formal training on SBR operation/process control [most plants]

Operators knowledgeable in SBR treatment can improve plant performance.

Many SBR treatment plant operators lack either the analytical equipment or the professional expertise needed to operate SBRs effectively. Some operators are unable to make the required adjustments in reactor operational strategies needed to meet specific treatment objectives. During reactor upsets, operators without sufficient training cannot take effective corrective actions in a timely manner. To address this concern, operators should attend seminars on SBRs that are geared towards developing a better understanding of the SBR process. Alternatively, SBR-specific courses should be developed to complement operator certification courses. The Michigan Department of Environmental Quality offers an operator's training course on SBRs about once a year, depending on demand. Interested parties can contact either Mr. Douglas Hill at (517) 373-4754; e-mail: hilld@deq.state.mi.us or Mr. Dan Holmquist at (517) 373-4753; e-mail: holmquid@deq.state.mi.us.

2. Mechanical equipment located outdoors (e.g., air valves, solenoid valves, decanter arms, level floats, etc.) may freeze due to lack of proper heating/protection [11, 12, 55, 59, 64, 41, 56]

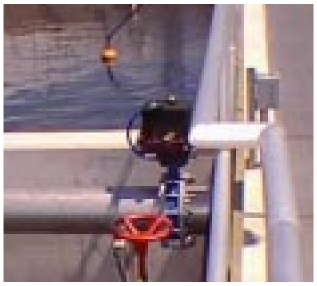


Telescopic arms of movable decanters can freeze under cold temperatures.

The freezing of mechanical equipment is a potential problem with most outdoor wastewater treatment facilities located in cold weather environments. As for most wastewater treatment facilities, pumps and valves may freeze causing system upsets.

SBRs have unique equipment (e.g., decanters and liquid level indicators) that other treatment plants may not have. This equipment is more susceptible to freezing problems. Accordingly, SBRs in cold climates should be constructed with as many valves, pumps, etc. as possible indoors or protected from the elements. Equipment that cannot be moved into a building can be fitted with heat tracers and/or specialized equipment/products designed especially for low temperatures (e.g., low temperature grease).

3. Decanters may be unable to adequately control the discharge of floatables present in the reactor [most installations reviewed], which may adversely effect downstream processes (e.g., grease clogging sand filters and UV lamps) [11, 12, 34, 51]



Air control valves should be properly designed and installed to avoid freezing.

The objective of the decanter is to remove the supernatant from the SBR during the DECANT period while minimizing the discharge of suspended solids. Many types of decanters exist (e.g., fixed level, floating, and telescopic), and each has advantages and disadvantages. Properly designed decanters should minimize the discharge of floatables.

One method to minimize this problem is to use decanters that draw liquid from below the liquid surface (e.g., 20 to 30 cm below). While this will minimize the discharge of floatables, grease and other compounds with neutral buoyancy would still be discharged. In addition to this, in this type of decanters with submerged suction pipes, the operator cannot directly see the water that is entering the decanter.

4. Variable rate discharges from the SBR due to fixed level decanters and discrete Draw periods can cause inadequate treatment in post SBR processes (e.g., continuous sand filters, UV disinfection) [12, 11, 20]

The objective of the decanter is to remove the supernatant from the SBR minimizing the discharge of suspended solids or foam.

Some post SBR treatment equipment is designed to operate under continuous flow conditions (e.g., continuous backwash sand filters), while SBR effluent is discharged discontinuously (i.e., batch discharge). One method to handle this discontinuous-to-continuous flow requirement is by installing post SBR treatment equipment that can handle discontinuous discharges (e.g., non-continuous backwash filters). Alternatively, an SBR effluent storage tank can be used. The decanted effluent in the storage tank would then be pumped to the filtration units at a constant rate. However, this solution requires additional capital equipment expenses (i.e., tanks and/or pumps) and may require a larger plant footprint.

5. Lack of online dissolved oxygen (DO) monitoring instrumentation and control [most plants]

Online DO monitoring equipment can be used to optimize the operation of the aeration system. For example, if the optimum DO in the SBR tanks is 2 mg/L during the REACT cycle, then a control system that uses online DO measurements could be used to control the blowers and regulate the air flow rate to maintain the desired set point.

At this SBR, high initial flows from a fixed decanter impacted UV disinfection until corrective measures were taken.

Since variable speed blowers can be expensive, two blowers could be used to create the same effect. Both blowers would operate during periods of high oxygen demand, but only one would be used during periods of low oxygen demand.

Portable DO probes should be used to monitor the calibration of the online DO probes.

Small plants (e.g., less than 0.75 MGD), however, may not need online DO control. For these plants, the beneficial effects of the online control may be offset by problems encountered with increased system complexity, capital equipment costs, and probe fouling.

In small facilities, two or more blowers could be used to control DO without VFD drives.

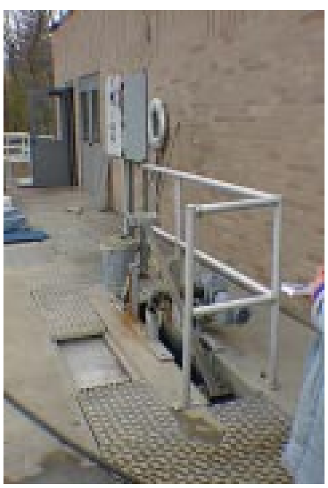
In these small facilities, the operators could measure the DO of the SBRs with a handheld probe. Adjusting the blower airflow rate based on these readings will still produce excellent effluent quality. However, the operator must be trained and skilled in SBR operation to make good decisions based on the data collected. For small systems, using portable DO probes may be easier and less expensive than automatic online DO control systems.

6. Optimum MLSS is rarely provided to operators, who have to find it based on operating experience (trial and error selection) [most plants]

The limiting factor in most SBRs is the ability of the system to handle hydraulic loads (e.g., peak loads). In fact, SBRs can be operated over a wide range of MLSS concentrations with excellent results.

Accordingly, MLSS levels in municipal SBRs can range from 1,800 mg/L to 3,500 mg/L. The higher end MLSS concentration in SBRs is usually dictated by the ability of the aeration system to meet the oxygen requirements of the system, and by the settling characteristics of the sludge.

Pre-treatment equipment with poor performance caused accumulation of floatables at this SBR facility in Ontario.



This underdesigned screening system at this 1700 m^3/d SBR plant caused wastewater overflows under high flow conditions.

7. Lack of automation for selection of wasting time (manually selected by operators based on MLSS concentrations) [most plants]

A useful control system should be able to waste sludge as often as necessary. One method to do this is to set the control system to waste sludge for a set period each day (e.g., 5 minutes).

It should be noted that in municipal systems, sludge wasting does not need to occur every day. In fact, for small systems, sludge wasting can occur once per week, e.g., Drumbo WWTP (see visit notes in Appendices).

Sludge wasting can be adjusted to maintain a fairly constant MLSS level (e.g., 2,500 mg/L +/- 15%). For example, if the MLSS concentration is increasing for a given sludge wasting time, then the duration of the WASTE period should be lengthened. Conversely, if the MLSS concentration is decreasing for a given sludge wasting time, then the duration of the WASTE period should be shortened. A maximum increase or decrease per adjustment of the sludge wasting timer could be set (e.g., 1 minute) and the operator should wait at least 5 days between adjustments to allow the change to begin to take effect.

The use of online MLSS monitors for automatic WAS control is discussed in another section of this report.

8. Inadequate design of pre-treatment system [12, 59, 57, 19, 18, 39, 40, 46, 48, 51]

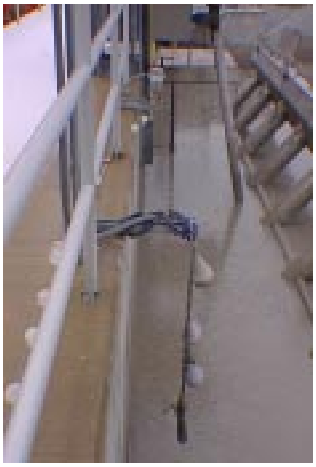
Inadequate design of pre-treatment systems can cause several problems. In plants where this occurs, floating and coarse material may enter the SBR and end up in the decant. Other related problems are flow metering inaccuracies, high operation and maintenance costs, etc.

As with any treatment plant, SBRs should be constructed with an adequate pretreatment system. Some possible pretreatment processes are bar screens, grit chambers, and comminutors. In plants that are not full-time staffed, pre-treatment systems should be able to operate automatically for extended periods of time.

9. Foam on tank surface freezes and blocks level floats affecting normal cycle [64, 58, 25]

In cold climates, scum or foam accumulated around level floats may freeze generating false water level readings. False water level readings can alter the normal cycle duration, leading to poor effluent quality.

If funds permit, other types of level indicator equipment (e.g., pressure transducers) can be used to avoid this problem. Alternatively, the floats should be observed and de-iced frequently during extremely cold periods. Small enclosures heated by a standard 60-Watt light bulb could be built around the floats to protect them from freezing.



At this plant in Michigan, floats were preferred over other level sensors for their simplicity.

10. Phosphorus release in aerobic digesters [57, potentially many more plants]

Inadequate operation of aerobic digesters may lead to excessive phosphorus release and recycle back to the liquid train. The impact of aerobic digesters on phosphorus removal in biological phosphorus removal SBR plants should be assessed and quantified. Methods to minimize phosphorus return to the liquid train by optimizing the operation of aerobic digesters should be investigated.

Poor operation of aerobic digesters may result in high P loadings being recycled to the SBRs.

11. Uncovered or elevated reactors enhance heat loss in winter [57, 18, 37, 39]

Reactors designed for cold climates should include proper precautions to reduce heat loss during winter. One concern is trying to get nitrification in the winter, since nitrification rates are considerably reduced at temperatures less than 10^{o}C.

Tanks constructed inside or with covers will minimize this concern. Alternatively, SBR tanks could be constructed such that the lower portion of the reactors is underground. Decreasing the surface area of the tank will also minimize heat loss.

12. Problems with SBR control program during peak flows [66]

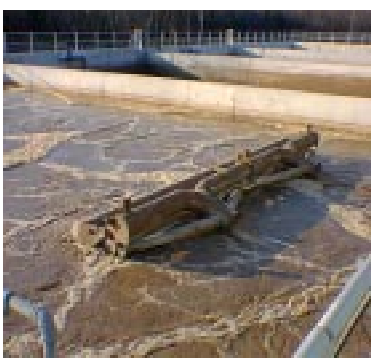
A good SBR control program should be able to automatically adjust setpoints and liquid levels to handle peak flow rates. Operators of smaller plants without sophisticated control systems must manually make adjustments during peak flow periods. Some of these adjustments include: raising the high water level in the tanks to the maximum extent possible; decreasing the time of static FILL, anoxic FILL, REACT, and SETTLE periods; or allowing a short (e.g., 10 minutes) period of overlapping Static FILL and DECANT.

At this plant in Ohio, this uncovered and elevated reactor had lower water temperatures than the contiguous and less exposed reactors.

13. Foaming in reactors [35, 25, and more plants]

In plants that decant below the liquid level in the reactor, foaming does not significantly affect the performance of the SBR and is an unsightly byproduct.

In plants with fixed level decanters that terminate the DECANT period when the liquid level is at the decanter openings, some of the foam may be discharged with the effluent. To solve this problem, a float switch may be installed to terminate DECANT above the decanter openings (e.g., 8 to 15 cm).



At this plant in Ontario, there were no connecting pipes between the SBRs. For this reason, the MLSS had to be transferred from a tank to be serviced to one in operation using portable transfer pumps. Notice lack of access (walkways) to tanks located in the centre.

14. Lack of connections between SBRs does not allow the transfer of MLSS between tanks [35, 57, potentially more]

Large plants should have piping installed that would allow MLSS to be transferred from tank to tank. Smaller plants may find it more economical to purchase a portable pump and hoses, which will work equally well.

Two reasons an operator would want to transfer sludge between tanks would be to empty a tank for cleaning, and to shutdown/startup tanks as needed to handle seasonal changes in wastewater volumes (e.g., for a summer or winter resort community).

15. Lack of adequate access to SBRs (e.g., walkways) [35, 57], and WAS and recirculation pumps, especially those without hoists [18]

SBRs should be constructed with adequate access to all major components. If possible, submersed equipment should be installed with equipment to raise it from the tank for maintenance and repair. A simple hoist is a cost-effective method. Additionally, a way to completely drain the tank should be designed to access equipment that cannot be raised.

16. Same pipe used for influent and WAS [21]

This type of design is not uncommon in small SBR facilities. Sharing the same pipe for influent and sludge wasting decreases the WAS concentration and increases O&M costs of dewatering equipment. Therefore, using the same pipeline for both influent and sludge wasting should be avoided.

17. Solenoid valves may fail during electrical power interruptions, sending untreated sewage to effluent [59]

Failure of the SBR equipment (e.g., power interruptions, stuck valves) should activate an alarm and initiate an emergency procedure. The scope of this procedure should depend on the type of failure and the size of the plant. For large plants, an emergency sequence should be added to the control system to allow for maximum SBR performance during the failure period. Additionally, all valves should be designed in a "safe" position (i.e., either open or closed) depending on which position protects against the discharge of untreated sewage.

18. WAS sump not properly designed [59]

WAS pumps not properly designed may impact SRT control and sludge treatment.

WAS sumps not properly designed (i.e., too small or not properly located) impact wasting efficiency and sludge treatment. If the sump is not properly located, supernatant can be drawn into the WAS sumps during the WASTE period, thereby impacting SRT control and reducing the concentration of the WAS.

19. Control system not robust enough to withstand power failure/recovery [59, 57]

Control systems should reboot automatically after a power failure.

Control systems should reboot automatically after a power failure, and should restart in the appropriate mode. If the SBR control system is not properly designed or programmed, power failures may impact SBR operation and effluent water quality.

20. Lack of adequate digested sludge storage for winter [58, 25]

As with any WWTP, proper care should be taken when sizing all tanks and unit processes. For systems that dispose of the sludge by land applying digested sludge, adequate storage facilities must be provided for winter months.

Observations

Several observations can be made from the list of concerns compiled:

- Lack of proper operator training has the largest impact on operating costs and effluent quality.

- Many of the concerns found during this evaluation are not SBR-specific and could apply to any type of activated sludge wastewater treatment plant.

- The average effluent data from the reporting plants show that in spite of experiencing some degree of concern with design/operation issues, the plants met, and in many cases, exceeded their effluent criteria.

The average effluent data from the reporting plants is shown in Table 4. The number of plants reporting results for each parameter listed is also shown in this table. It should be noted that not all plants reporting phosphorus and nitrogen values had to requirements to remove these pollutants. Therefore, even with all the concerns listed above, in most cases effluent quality is not adversely affected.

Even with all the concerns listed above, in most cases evaluated, effluent quality was not adversely effected. Photo of SBR effluent (unfiltered) from a plant in Ohio.

Table 4
Average effluent quality from SBRs evaluated

Parameter reported	Average of reported values [mg/L]	Number of plants reporting
CBOD5	< 10	most plants
TSS	< 10	most plants
NH3-N	1.5	32
TP	1.4	53
TN	4.3	9

A summary of the top-10 concerns with the recommendations made is presented in Table 5.

Table 5 **List of concerns and related recommendations**	
Concern	**Recommendation**
1. Operators do not have formal training on SBR operation/process control: When compared to conventional continuous flow systems, SBRs are a relatively new activated sludge process. Conventional training does not prepare new SBR staff to operate these facilities effectively.	**Develop SBR operator training programs:** These programs should complement traditional activated sludge operator training with SBR-specific theoretical and practical concepts.
2. Mechanical equipment located outdoors may freeze: In some facilities, air valves, solenoid valves, decanter arms, and level monitoring floats freeze or malfunction when exposed to low temperatures.	**Specify proper heating, insulation, and O&M procedures to protect exposed equipment from the elements:** Using heat tracing, cold-weather grease for lubrication decanter arms, and designing the system to have sensitive equipment located inside buildings are some of the low-cost options available for preventing SBR malfunctioning during cold weather conditions.
3. Decanters not adequate for specific treatment requirements: In some plants, the decanters used were unable to adequately control the discharge of floatables present in the reactor. This impacted downstream processes (e.g., grease clogging in sand filters and floatables covering UV lamps).	**Select decanters that meet the plant treatment objectives:** There are many types of decanters on the market, each has different performance characteristics and cost. Some of the factors to take into account when selecting a decanter are the effluent quality required, type of downstream processes, and the budget available.
4. Discontinuous SBR effluent flow impacted downstream treatment processes: Two examples of the impact of the discontinuous discharge from SBRs on post-treatment processes are: 1. Initial high flow rate discharges from fixed level decanters resulted in reduced degree of UV disinfection; and 2. Operation of continuous backwashing filters was affected by discontinuous decant discharges.	**Design adequately SBR post-treatment processes:** For example, the discontinuity between the SBR intermittent discharge and the post-treatment unit process can be eliminated by providing adequate flow equalization downstream of the SBR. If flow equalization is not desirable, the post-treatment systems selected should be able to work properly under discontinuous flow conditions.
5. Lack of online DO monitoring instrumentation and control: In many of the plants evaluated, there was no specific aeration control strategy in place. These plants still met and in some cases, exceeded their effluent criteria. However, potential energy savings related to DO control were not achieved.	**Development and implementation of aeration control strategies:** Energy savings could be achieved by using DO monitors to control blower operation. In small facilities (under 3000 m^3/d), hand-held probes and on/off aeration control are recommended. In larger facilities, online DO monitors and automatic aeration control systems may prove more economic and also achieve considerable energy savings.

Table 5 (cont.)
List of concerns and related recommendations

Concern	Recommendation
6. **SBRs are supplied without a specific SRT control strategy:** In several plants, SRT control is achieved by maintaining an optimum MLSS concentration in the reactors. However, the optimum MLSS is rarely provided to plant staff and operators, who have to determine the target MLSS based on their experience or using a trial-and-error approach.	**Provide target MLSS:** If SRT control is MLSS-based, the target MLSS should be initially provided by the supplier or consultant. The target MLSS could be modified later based on operating experience or when changes in influent characteristics or effluent limits require an adjustment of the SBR operation.
7. **Inadequate design of pre-treatment systems:** In a large number of facilities, inadequately designed bar screens, comminutors, and other pre-treatment systems caused accumulation of floating and coarse material in the SBRs, flow metering inaccuracies, and frequent O&M problems.	**Design pre-treatment systems taking into account operating conditions:** For example, if the plant is going to be part-time staffed, self-cleaning pre-treatment units should be selected and back-up pre-treatment capacity should be considered.
8. **Lack of automation for selection of wasting time:** In most facilities evaluated, the operators manually select the wasting time. The WAS time is changed to increase or decrease the MLSS, thereby controlling the SRT of the system.	**Develop a system for automatic WAS control:** Sludge wasting can take place during React, Settle, Draw, or Idle (i.e., when the sludge is completely mixed or settled). An automatic SRT-control system can be developed to control WAS time. The system can be based on online measurements of MLSS concentration during the MIX period and if necessary in the WAS line. Using the WAS pump capacity and these SS measurements, the time for wasting can be automatically set to meet the target SRT.
9. **Potential secondary phosphorus release in aerobic digesters:** A large percentage of the facilities evaluated used aerobic digesters for sludge treatment. When biological phosphorus removal is used, a considerable portion of the phosphorus is accumulated in the biomass and removed in the WAS. If the WAS is aerobically digested prior to disposal, inefficient operation of the digesters may result in phosphorus being recycled back to the plant headworks.	**Assess the impact of sludge recycle streams and evaluate aerobic digestion strategies:** sampling from the sludge recycle streams at SBR facilities is unusual. Therefore, at this stage, the impact of aerobic digestion on P removal is not easily quantifiable. It is recommended to assess this impact and if found necessary, investigate optimum operating strategies for the SBR – aerobic digestion treatment system in bio-P removal plants.
10. **Partial failure of the SBR control program during peak flows**: Automatic control systems at some facilities worked properly under average diurnal flow variations, but failed to adjust to peak flow conditions (e.g., high flows caused by I/I during rainfall events). This led to high effluent concentrations during the storm event.	**Improve control system programming:** The time-oriented nature of the SBR allows the system to have flexibility to achieve a wide range of treatment objectives including BOD, suspended solids, nitrogen, and phosphorus removal under various flow regimes. The facilities where this concern was reported had the control equipment in place. In these cases, appropriate settings should be entered in the control program to allow the SBR cycles to adjust to peak flow conditions.

Identification of opportunities for optimization

The following optimization opportunities were developed taking into account the concerns found in the SBR plants evaluated. The objective of the following list is to reduce capital and O&M costs, and whenever possible, improve effluent quality:

The goal of the optimization opportunities is to reduce capital and O&M costs, and whenever possible, improve effluent quality.

Optimization of SBR cycle times

The time-oriented nature of the SBR allows the system to have flexibility to achieve a wide range of treatment objectives including BOD, suspended solids, nitrogen, and phosphorus removal. Operational modifications can alter the nature and extent of organic carbon, suspended solids, nitrogen, and phosphorus removal, and to control bulking sludge, a common problem in continuous flow wastewater treatment systems. The performance of many SBRs could be enhanced with minor modifications to the cycle times. The following tasks are suggested to develop guidelines for optimizing SBR cycle times:

The performance of many SBRs could be enhanced with minor modifications to the cycle times.

- Document the significance and the impact of Static FILL, Mixed FILL, Aerated FILL, REACT, SETTLE, DECANT, and IDLE phases on reactor performance.
- Develop a guideline for the selection of cycle times to enhance BOD, SS, nitrogen, and phosphorus removal.
- Assess the potential energy savings of appropriate cycle times.
- Assess the potential effluent quality improvements of appropriate cycle times.

Optimization of operator education and training programs

As compared to conventional continuous flow systems, SBRs are a relatively new wastewater treatment process, and therefore, most operators are not trained well enough to operate SBRs effectively. Additional knowledge and training needs to be transferred to the plant operators to ensure that systems are operated in the best manner possible.

Additional knowledge needs to be transferred to plant operators to ensure that SBRs operation is optimized.

- Develop a list of various analytical and process equipment needs of an SBR operator.
- Describe how to interpret analytical data and make appropriate process changes.
- Document routine and non-routine operating procedures.

- Develop a standard operating manual.

Optimization using DO measurements

While most operators do not take full advantage of DO measurements for SBR control, the performance of many plants could be optimized if a protocol that details the significance of DO measurements is developed. The following steps are suggested for the development of such a protocol:

The performance of many plants could be optimized if a protocol for process control using DO measurements was developed.

- Investigate the use of online DO control at SBR plants.
- Develop a protocol to interpret DO measurements from hand held probes, DO recorders, or online DO readings and make appropriate process changes.
- Assess the potential energy savings of DO control strategies.
- Assess the potential effluent quality improvements of DO control strategies.

Optimization of SBR post-treatment systems

The goal of SBR post-treatment systems is to improve SBR effluent quality. The impact of post-treatment systems on SBR performance should be fully assessed when designing a new SBR facility. The selection of adequate post-treatment systems should take into account plant needs and capital and O&M funds available.

Optimization of sludge wasting strategies

Sludge wasting can occur during the REACT, SETTLE, DECANT, or IDLE phases. Therefore, sludge wasting can occur when the sludge is completely mixed or when the sludge is settled. The following tasks are suggested to develop sludge wasting strategies:

- Investigate different sludge wasting strategies.
- Conduct field studies for different strategies.
- Perform a cost-benefit analysis for different strategies.

Optimization using online measurements for SBR control

For larger plants, online measurements and control can offer many advantages.

For larger plants, online measurements can offer many process control advantages. Most control systems in use today do not offer significant online capabilities. The use of the following online monitors should be assessed at selected facilities:

- Effluent turbidity meter to eliminate the discharge of solids during DECANT
- Sludge blanket level indicator to optimize SETTLE and DECANT
- DO monitors in SBR tanks to optimize aeration strategies
- Suspended solids and flow meters to control solids retention time (SRT)

Minimization of phosphorus release in aerobic digesters
Many SBRs use aerobic digesters for sludge treatment. Improper operation of the digesters may result in excessive phosphorus release and subsequent recycle of phosphorus back into the SBR. The following steps are suggested to minimize this effect:

Steps could be taken to improve the operation of aerobic digesters and reduce phosphorus release and subsequent recycle back to the SBR.

- Review the typical operating strategies of aerobic digesters and recycle lines in SBR facilities.
- Analyze of impact of recycle streams on SBR carbon, nitrogen, and phosphorus loadings.
- Perform a cost-benefit analysis on recycle line treatment prior to discharge into the SBR tanks to improve biological phosphorus removal.
- Conduct field studies to maximize aerobic digester performance.

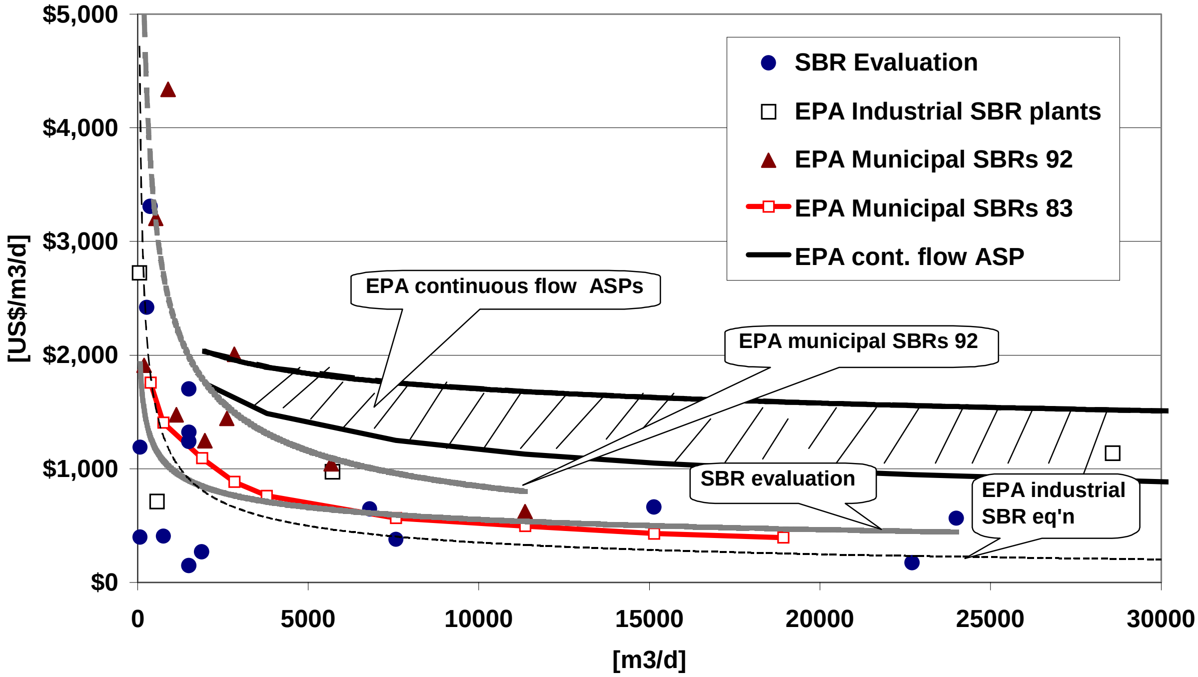
Cost comparison: SBR vs. continuous flow activated sludge systems

Limited historical data have been compiled comparing the cost of SBRs with other types of activated sludge treatment systems.

Evaluations performed in the 1980's indicated that SBRs are a cost-effective wastewater treatment technology [5]. Other literature sources indicate that SBR systems are likely to be extremely cost-effective over a wide range of flows [7]. Unfortunately, limited historical data have been compiled comparing the cost of SBRs with other types of activated sludge treatment systems. Clearly, the lack of need for an external secondary clarifier and return sludge pumping system offers potential savings in construction costs. In addition, primary clarification is not normally employed (none of the 75 plants evaluated had primary clarifiers).

Determining the cost-effectiveness of this technology was not an objective of Phase 1 of this project. However, cost information submitted by 17 of the facilities evaluated was compared to cost estimates provided in the literature [5,6,7,8,9]. The results of this cost comparison are shown in Figure 2.

Figure 2
Unit construction cost as a funcion of plant capacity
Comparison between SBR evaluation and EPA figures



Cost information submitted by 17 of the facilities evaluated was compared to cost estimates provided in the literature.

Only two sources of construction costs for municipal SBR facilities were found in the literature [5,6]. These data are shown in Figure 2 as EPA Municipal SBRs 83 and EPA Municipal SBRs 92, for 1983 and 1992 construction cost data, respectively.

Costing data for SBR systems treating high strength industrial wastewater and leachate were also used in this comparison [8,9,10]. To compare on an equal basis these construction costs to those of municipal plants, the flow rate capacities of the high strength wastewater facilities were increased using the ratio of their influent wastewater oxygen demand to that of a typical municipal WWTP. Two sets of data are shown in Figure 2: construction costs from actual industrial SBRs (EPA Industrial SBR plants) and construction costs derived from a proposed equation (EPA industrial SBR eq'n).

Typical costs for continuous flow municipal activated sludge plants (ASPs) were obtained from the literature and used in this comparison [11]. Two levels of treatment were considered:

- advanced wastewater treatment with nutrient removal (BOD/SS/TP/TN = 10/10/3/5), and

- advanced secondary treatment with nutrient removal (BOD/SS/TP/TN = 25/25/3/5).

These construction costs are valid for plants with flow rate capacities of over 1800 m^3/d and are shown in Figure 2 as a range (EPA continuous flow ASPs). The upper and lower limits of this range represent the unit costs for the most and less stringent of these two effluent requirements, respectively. It should be pointed out that most SBR plants evaluated in Phase 1 met the most stringent of these two limits.

The values reported from all sources were actualized to 1998 values using published construction cost indexes.

The values reported from all sources were actualized to 1998 values using published construction cost indexes [12].

This comparison indicates that the construction costs recorded during Phase 1 of this program fit between the values derived from the EPA equation for industrial SBRs (corrected according to equivalent oxygen demand) and those from actual SBR facilities reported by EPA (EPA municipal SBRs 92). Also, the construction costs recorded during Phase 1 matched very closely those proposed for municipal SBR facilities in 1983 (EPA Municipal SBRs 83).

The construction cost differences between SBRs and continuous flow ASPs are drastic. However, this comparison should only be used as an indication of the relative construction costs of SBRs and continuous flow ASPs.

The construction cost differences between SBRs and continuous flow ASPs are drastic. However, this comparison should only be used as an indication of the relative construction costs of SBRs and continuous flow ASPs. Additional cost analyses involving a larger number of facilities and more detailed construction cost information will be required. More up to date information from continuous flow ASPs achieving N and P removal should also be used (the EPA equations used for this comparison are from 1980). Also, life cycle cost analyses using operation and maintenance data should be performed.

Contact with other regulatory agencies

The Hydromantis Team established contact with several US States regulatory agencies.

During Phase I, the Hydromantis Team established contact with several US States Regulatory Agencies, either directly or through members of the SBR Technical Steering Committee.

The agencies contacted are in the process of developing guidelines for design and operation of SBR facilities and are currently at different stages of this task.

Development of an information web site

A web page was developed as a forum for information exchange.

After receiving approval from the TSC, The Hydromantis Team developed a web page and included it in the Hydromantis, Inc. web site (http://www.hydromantis.com).

During Phase 1, the project web site was used as a forum for information exchange on evaluation, optimization, guidelines, and other topics related to the SBR project. The web page included links to WEAO, Environment Canada, and MOE web sites.

Conduct workshops

Three workshops will be presented in Ontario.

The Hydromantis team will convey the results obtained from Phase 1 of this program in three half-day presentation/training workshops that will be organized by WEAO in Ontario.

The material used for the presentation (slides, overheads, layouts and computer files) will be provided to the Technical Steering Committee for future use in training sessions.

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Section 3 Development of Phase 2

Introduction

Our team recommends two sites for implementation of Phase 2.

The Hydromantis Team recommends two sites to implement the demonstration study in Phase 2: Horseshoe Valley Resort WWTP and Drumbo WWTP, both located in South Western Ontario.

The selection of these sites was based on the following criteria:

- Suitability of the site for implementation of optimization techniques. Some of the factors taken into account in the selection were:
  - effluent requirements,
  - potential impact of demonstration project on receiving water body and/or effluent compliance,
  - current problems encountered at the site,
  - type of SBR process,
  - pre-treatment and tertiary treatment installations,
  - instrumentation available, and
  - degree of automation.

- Accessibility of the site and proximity to laboratory/analytical facilities.

- Willingness of the owners/operators to participate in this demonstration project,

A workplan was developed for implementation, testing, and refinement of the remedial actions, optimization strategies and evaluation methodologies to be conducted during Phase 2. The main goal of Phase 2 is to optimize the design and/or operation of these two SBR facilities.

The experimental plan includes:

- A description of methodologies proposed to evaluate and verify the effectiveness of these remedial actions and strategies.

- Detailed budget and schedule required to achieve these objectives.

- Documentation with sufficient detail to assist the TSC with request for proposal for Phase 2 of this program.

The main objective of Phase 2 is to develop and use a systematic approach to optimize the design and operation of SBRs at two selected demonstration facilities.

Objectives

The main objective of Phase 2 is to develop and use a systematic approach to optimize the design and operation of SBRs at two selected demonstration facilities. The demonstration facilities currently have several problems that should be identified and corrected. The areas for optimization and list of common concerns developed in Phase 1 should be used to develop the optimization methodology used in Phase 2. The proposing firms should have extensive experience in SBR design and operation, and in process control. Laboratory tests can be conducted by the MOE, and graduate students will be provided to collect samples and perform other onsite functions. A final report detailing the problems and optimization areas in the demonstration facility should be provided. Results should be presented in training workshops organized by the WEAO.

Workplan

Task 1: Review the two SBR facilities to be used in the demonstration study

- Obtain and review all operating data and review plant operational history.
- Obtain all design plans and specifications.
- Visit sites and have discussions with plant operators.
- Evaluate plant organic and hydraulic loadings.
- Evaluate SBR tank number and sizes, aeration system, control system, and decanter type.
- Evaluate pre-treatment and post-treatment systems.
- Review all recycle streams (e.g., from sludge thickening and/or dewatering).
- Determine if there are any factors that will inhibit the optimization of the plant. If minor modifications are needed, make appropriate system changes (e.g., add pipes).

Task 2: Optimize pre-treatment systems

- Optimize pre-treatment systems to make sure that the operation of these system will not interfere with the optimization of the SBR tanks (e.g., calibrate flow meters to avoid incorrect flow monitoring).

Task 3: Optimize sludge treatment systems

- Optimize the return of the recycle streams to the SBR (e.g., minimize shock loads).
- Evaluate the need for nitrification and/or denitrification on the recycle streams.
- Evaluate sludge wasting strategy on post-treatment system and recycle streams.
- Goal is to find solutions such that the operation of the post-treatment system will not interfere with the optimization of the SBR tanks.

Task 4: Optimize the SBR operation

- Train and educate plant owners and operators and provide or modify operating manual.
- Explain system changes to owners and operators, and provide technical rationale for the changes.
- Train operator on any new analytical procedures that may be needed.
- Provide new sampling strategy and explain how the analytical results should be interpreted.
- Analyze plant data in more detail (e.g., historical DO profiles).
- Collect operational data (e.g., MLSS, MLVSS, BOD, SS, SVI, DO, oxygen uptake rate, pH, etc.) at regular intervals (e.g., 15 minutes to 1 hour) for a given period of time (e.g., 24 hours). The plant flow rates and equipment status (e.g., pumps on/off) should also be recorded.
- Conduct settling tests in the lab and on the full-scale reactor.
- Determine sludge SVI.
- Probe reactor with a sampling rod throughout Settle.
- Identify and correct any equipment limitations.
- Propose and test new operating strategy.
- Adjust cycle times, aeration strategy, etc.
- Implement the new control strategy using the current control system (may need operator assistance for some functions).
- Evaluate the effect of the changes in SBR operation on downstream processes (i.e., effluent and sludge treatment) and re-optimize post-treatment systems, if needed.

- Evaluate the suitability of automatic monitoring and control equipment, including a cost benefit analysis for three options:
    1. no changes (may need increased operator assistance).
    2. additional process control, but not entirely automated.
    3. complete automatic control.

Task 5: Recommend information to be included in a guidance manual

- Recommendations should be made as to the content of the guidance manual to assist municipalities to select, design, and operate an SBR. (Phase 3)

Task 6: Produce a final report

- A final report should include description of the process used to optimize the demonstration facilities.

Task 7: Training workshops

- Conduct half-day presentation/training workshops at three locations in Ontario to be organized by WEAO.