



# J.M. O'REILLY & ASSOCIATES, INC.

PROFESSIONAL ENGINEERING, LAND SURVEYING & ENVIRONMENTAL SERVICES

Site Development • Property Line • Subdivision • Sanitary • Land Court • Environmental Permitting

November 30, 2020

JMO# 8446A

Barbara Huggins Carboni, Interim Town Planner  
Town of Truro  
Zoning Board of Appeals  
24 Town Hall Road  
Truro, MA 02666

RE: Cloverleaf Development – Highland Road, Truro

Dear Board Members,

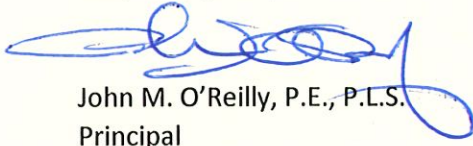
At the request of Mark Nelson, J.M. O'REILLY & ASSOCIATES, INC. has attached a Memorandum along with supporting documentation of the treatment works proposed for the above referenced property.

Also, for the Board's consideration and to satisfy the latest comments of the Peer Review we will be incorporating the following additions to the site plans for construction.

- A row of 6"x6" landscape ties will be installed along the eastern side of the proposed gravel emergency access road. the ties will help define the edge of the access road and will mitigate potential impact to the stormwater swale and forebay system.
- The drainage pipe from the gutter inlet, on the emergency access road to the forebay shall be reinforced concrete pipe capable of withstanding wheel loads (H-20 Rated).
- The Town shall be provided a complete as-built plan once the project is completed. The as-built plan will show the sewage system, drainage, pavement, buildings, edge of clearing and grading, as constructed. Plan shall be delivered within 30 days of the last occupancy permit is issued.

If you have any questions please feel free to contact me directly.

Very truly yours,



John M. O'Reilly, P.E., P.L.S.  
Principal

CC: T. Malone



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JMO-8446A

## MEMORANDUM:

November 25, 2020

FROM: John M. O'Reilly, P.E., P.L.S.  
Project Engineer

RE: Cloverleaf Project – Highland Road – Truro, MA  
Supplemental Information – Proposed Technology & WWTP Operation & Maintenance

At the request of Mark Nelson of Horsley-Witten, J.M. O'REILLY & ASSOCIATES, INC. is offering the following information and narrative relative to the proposed treatment technology for the wastewater of the proposed development, including highlights of a Contingency Plan, at the above referenced property.

## Regulatory Background:

In general, the Massachusetts Department of Environmental Protection has developed two main sets of regulations governing the on-site disposal of domestic sewage.

### 310 CMR 15.000 – Onsite Disposal of Sanitary Sewage, Title 5:

The majority of the Title 5 Regulations govern the on-site disposal of domestic wastewater up to a maximum flow of 10,000 gallon per day (gpd). Title 5 also includes the use of enhanced treatment of the wastewater so as to reduce the nitrogen values. The nitrogen reduction allowances, within Title 5, are targeted at a Total Nitrogen value of 19 ppm. The 19 ppm Nitrogen value represents about a 45% reduction over a conventional Title 5 sewage system.

### 314 CMR 5.000 - Ground Water Discharge Permit (GWDP) Program.

The GWDP program governs wastewater flows in excess of 10,000 gpd. The treatment requirements under the GWDP Program includes the reduction of Total Nitrogen, at discharge, to 10 ppm. The 10 ppm Nitrogen value represents a 70% reduction over conventional Title 5 sewage system.

The proposed Cloverleaf Development, with a total sewage flow of 7,501 gpd, falls within the rules and regulations of Title 5 (less than 10,000 gpd). However, the addition of sewage treatment of nitrogen to a discharge level of 10 ppm, the sewage system falls under both Title 5 and MA DEP Pilot Approval guidelines. Groundwater Discharge Permit requirements are not applicable for the proposed project with the sewage flow less than 10,000 gpd.



### Status of the Proposed Technology for Wastewater Treatment:

Initially the project included the use of two conventional sewage systems. The systems were designed according to the requirements of 310 CMR 15.000, Title 5. The wastewater from the development would have received little treatment as provided by a conventional system. After the projects initial review, the sewage system designed was modified to include enhanced treatment of the wastewater so as to provide a final discharge of 19 ppm of Total Nitrogen.

Upon the review of the revised treatment process and given the concerns of the Board, the direct abutters and the Pond Village Watershed Community, Horsley-Witten recommended that the wastewater be treated to a Total Nitrogen level of 10 ppm, at final discharge.

J.M. O'REILLY & ASSOCIATES, INC. began the review of possible technologies available which offer a treatment process that has demonstrated the ability to reach and provide a 10 ppm, at discharge. After review and research, it was determined that there are no known treatment processes available that process a General Use Permit from the MA DEP for a treatment level of 10 ppm, at discharge. The MA DEP is in the process of monitoring a number of technologies, under a pilot permit, for the treatment processes of nitrogen reduction levels for 19 ppm and below of Total Nitrogen.

After the review of several technologies which were offering the capability of achieving the 10 ppm of Total Nitrogen, at discharge, the Bio-Microbics technology was selected. We selected the process because of the following points:

- Our office is familiar with the manufacture and the local distributor. They both have a record of working with the design team and contractor to ensure a smooth installation and operation of the treatment process.
- The submerged membrane treatment process has a record of providing consistent treatment results.
- The treatment process allows the design to include the ability to isolate the treatment process given times of low flow. The proposed system contains two separate treatment trains as part of the treatment process. The double treatment trains are available with this type of technology without significant cost. The required treatment system components, including the dual trains, lay out well within the area identified for sewage collection and processing and did not require significant changes to the site layout, as shown on the Site Plans.
- The ability to provide duplication of the treatment train is significant when;
  - The wastewater flow is low due to occupancy (daily sewage flows less than the design total).
  - Maintenance on the submerged media filters or pump repair/replacement can be completed without interrupting the daily treatment process.
- The treatment process allows the License Operator to adjust the system so as to maximize the treatment of the wastewater during times of varied flow characteristics.

- In review of the Bio-Microbics process, we reviewed three sites which are providing treatment to a level of 10 ppm of Total Nitrogen. The testing results showed consistent treatment results for all three sites. The type of wastewater characteristics varied between the three sites which include, residential facility, medical facility and commercial facility. The Bio-Microbics process proves its flexibility to handle varied waste stream characteristics.

The word "Pilot" implies the technology is new and unproven. However, the use of submerged bio-membrane within the treatment process is well used in larger flow systems governed under the MA DEP GWDP Program. The Pilot Program is to demonstrate the same technology principals when applied to smaller sewage flows will yield the same treatment and reductions as the larger flow systems. Again, this office is unaware of any General Use technologies approved by the DEP for flows under Title 5 with a nitrogen reduction requirement of 10 ppm Total Nitrogen, at discharge.

As Outlined within Title 5, the DEP has a list of treatment technologies which are accepted processes to treat the wastewater to a level of 19 ppm. These types of permits are referred to as a General Use Permit (Recirculating Sand Filter (RSF)). The RSF and other technologies which possess a General Use Permit have gone through various stages of permitting and oversight through the MA DEP. The various levels of permits for these technologies include; Pilot, Provisional, Remedial and finally General. All recent technologies within the Commonwealth have started with a Pilot Approval Permit. This Pilot stage is to allow for a certain number of systems within the Commonwealth to be installed, so as to allow the manufacture to prove the anticipated performance of the system.

Additionally, the membrane technology (MBR), as provided by the Bio-Microbics process, has been and continues to be studied for additional removal of pharmaceuticals and micro-pollutants from the waste stream. Although the testing has been limited, the testing does show promise for the ability of the membrane to provide additional removal of these components to the waste stream. Specifically, the MBR technology is being studied in larger treatment plants for wastewater re-use and reclamation

For the Board review, we have provided a 2006 study showing some success in the removal of some pharmaceuticals and micro-pollutants.

#### Operation & Maintenance:

Under the Pilot Approval with the MA DEP, the property owner, the manufacturer and the operator need to comply with the requirements of the Pilot Permit. We have attached a copy of the DEP Pilot approval for your review. Specifically, the Board should review the Operation and Maintenance, Monitoring and Inspection (Section IV, Items 1 to 17, Pages 8 to 14); Additional System Owner and Service Contractor Requirements (Section V, Items 1-15, Pages 14 to 16) and Company (Manufacturer) Requirements (Section VI, Items 1 to 18, Pages 16 to 20) of the Pilot Approval from the MA DEP.



The Operational and Maintenance Agreement (O&M) for the Cloverleaf Project will need to include all aspects of the MA DEP Pilot Approval document. In addition to the requirements laid out in the Pilot Approval, J.M. O'REILLY & ASSOCIATES, INC. recommends the following items be included with the O&M.

1. A draft of the O&M agreement shall be provided to the BOH for review, prior to submission of the signed O&M Agreement. The review of the draft O&M will allow the BOH to confirm the reporting requirements on the Operator to the DEP, BOH and County health departments.
2. All O&M Agreements run for a period of two (2) years.
3. The System must be monitored monthly upon the system's start up and shall continue monthly for a period of a year, once the development is fully occupied. Notice of the 12 month period shall be provided to the Truro Board of Health (BOH).
4. Upon the completion of the 12 month period, the Owner and Operator shall request the monthly testing schedule be changed to quarterly from the BOH. The change from monthly to quarterly shall be approved by the BOH.
5. Prior to the start up of the system, the two (2) proposed monitor wells shall be installed as shown on the proposed Site Plans. The monitor wells shall be tested for standard groundwater parameters including Total Nitrogen and Fecal Coliform.
6. The O&M agreement shall include the As-Built Plan of the installed Sewage System.
7. The O&M should include the sampling and testing of the monitor wells. Testing shall begin prior to the system's start up and quarterly thereafter.
8. All testing results shall also be sent to both the BOH and the Barnstable County Health & Environment.
9. Within 30 days of the submission of the annual report of the System's performance, the Operator shall meet with the BOH or its agent, to review the previous year's O&M.
10. System Failure:
  - a. If the System's modifications, procedures and treatment adjustments, as outlined in the Pilot Approval, are not successful in bringing the system into compliance with the 10 ppm of Total Nitrogen, the owner and Operator shall notify the DEP and the BOH of the plans to bring the system into compliance. The required repair/replacement timelines shall conform with the requirements outlined in the Pilot Approval or as required by the BOH upon the issuance of the Disposal Works Permit.

During the noncompliance period the BOH, after a public hearing, may require the system to stop discharge of the effluent to the soil absorption systems.

#### Down Gradient:

The proposed development includes the placement of two additional monitor wells within the project area. The additional two wells will bring the total on-site monitor wells to three, with the third well being installed as part of the groundwater modeling as conducted by Horsley-Witten.

The three monitor wells will be used to test the groundwater on a quarterly basis. The test results will show the groundwater characteristics prior to leaving the project site. These three wells could be incorporated into a larger study area for the Pond Village Community. The additional groundwater monitoring will provide a great deal of information on the condition and status of the groundwater quality at the property boundary, as a result of the discharged treated effluent from the project.

Future Repair and Operations:

Once the system is installed and operational, the continual O&M will address the replacement and/or repair of the various mechanical components within the system. The Operator shall review with the Owner the necessary mechanical components which should be inventoried and available for immediate installation. Items such as float switches, process controls and final effluent pumps should all be made readily available to the Operator so as to make the necessary repairs to keep the system in compliance.

Included in the O&M agreement, the Operator shall provide an itemized list of items available, on-site, in case of emergency repair.

We hope this memorandum assists the ZBA in their review of the project.

Thank you.







Commonwealth of Massachusetts  
Executive Office of Energy & Environmental Affairs

## Department of Environmental Protection

One Winter Street Boston, MA 02108 • 617-292-5500

Charles D. Baker  
Governor

Karyn E. Polito  
Lieutenant Governor

Matthew A. Beaton  
Secretary

Martin Suuberg  
Commissioner

### PILOTING APPROVAL RENEWAL

Pursuant to Title 5, 310 CMR 15.000

#### Name and Address of Applicant:

Bio-Microbics, Inc.  
8450 Cole Parkway  
Shawnee, KS 66227

Trade name of technology and model: BioBarrier® MBR® models 0.5-N, 1.0-N, 1.5-N, 2.0-N, BioBarrier® HSMBR® models 1.5-SN, 1.5-DN, 3.0-SN, 3.0-DN, 4.5-SN, 4.5-DN, 6.0-SN, 6.0-DN, 9.0-SN, 9.0-DN (hereinafter the 'System', 'Alternative System' or 'Technology'). Schematic drawings of the models, the manuals for Design, Installation, O&M and Owner and a technology inspection checklist are part of this Approval.

Transmittal Number: X271033  
Date of Issuance: July 11, 2016  
Date of Expiration: July 11, 2021

#### Authority for Issuance

Pursuant to Title 5 of the State Environmental Code, 310 CMR 15.000, the Department of Environmental Protection hereby issues this Approval to: Bio-Microbics, Inc., 8450 Cole Parkway, Shawnee, KS 66227 (hereinafter 'the Company'), to Pilot in the Commonwealth of Massachusetts the System described herein. Sale and use of the System are conditioned on and subject to compliance by the Company, the Designer, the Installer, the Service Contractor, and the System Owner with the terms and conditions set forth below. Any noncompliance with the terms or conditions of this Approval constitutes a violation of 310 CMR 15.000.

/signed/

Marybeth Chubb, Acting Section Chief  
Groundwater/ Title 5/ Reuse  
Bureau of Water Resources

July 11, 2016  
Date



## I. Purpose

1. The purpose of Piloting Approval ('the Approval') is to allow installation and use of no more than 15 on-site sewage disposal systems utilizing the Technology in Massachusetts in order to provide field testing and a technical demonstration that a particular alternative system can or cannot function effectively under relevant physical and climatological conditions (310 CMR 15.285).
2. The Approval requires that sufficient performance testing be completed so that the Department may determine if the System can or cannot consistently provide secondary treatment and function to effectively reduce total nitrogen (TN) to less than or equal to 19 mg/L, and provide a level of environmental protection at least equivalent to that of a system designed and constructed in accordance with 310 CMR 15.100 through 15.293. *TN is equal to TKN (total Kjeldahl Nitrogen) plus NO<sub>2</sub> (Nitrite) plus NO<sub>3</sub> (Nitrate).*
3. The Approval authorizes the installation and use of a System to serve a facility with design flows less than 10,000 gallons per day, including new construction, an increase in flow at an existing facility, or an upgrade or replacement of an existing failed or nonconforming system. The facility must meet the specific siting conditions for piloting an Alternative System (310 CMR 15.285(2)), and the facility must meet the siting requirements of this Approval.
4. With the other applicable permits or approvals that may be required by Title 5, the Approval authorizes the installation and use of the Alternative System in Massachusetts. All the provisions of Title 5, including the General Conditions for all Alternative Systems (310 CMR 15.287), apply to the sale, design, installation, and use of the System, except those provisions that specifically have been varied by the Approval.

## II. System Description

The System is a Secondary Treatment Unit (STU) that includes a circuitous flow train through a primary sedimentation compartment, anaerobic treatment compartment, and aerobic contact/filtration compartment all within the treatment tank.

The Bio-Microbics BioBarrier® MBR and HSMBR are membrane bioreactor (MBR System), designed to remove BOD, TSS, nitrogen and Fecal Coliform. The system is installed before the soil absorption system (SAS), designed and constructed in accordance with 310 CMR 15.100 - 15.279. The HSMBR® models can be used in a Single Train -SN or a Dual Train - DN.

The System is in a three compartment tank. The membrane module always in the last compartment and the anoxic zone connected to the aeration zone via a baffle wall. The wastewater from a facility enters the system's settling zone in the first compartment for primary sedimentation and floatables retention. On the outlet side in this first compartment is a SaniTEE® screen, to provide screening. The second compartment serves as the anoxic zone and contains a mixing pump. The third compartment is the aeration zone containing the membrane module, a permeate pump and an air supply from the System's remote installed blower unit. The membrane module consists of flat sheet membranes arranged in a cartridge. A high mixed liquor suspended solids concentration in the aeration zone provides biological treatment and nitrification. A portion of the nitrified wastewater is returned to the anoxic chamber for denitrification by the mixing pump action via patent pending ports in the baffle

wall separating the two zones. The final effluent or permeate is pulled out by the permeate pump through the MBR membranes leaving behind large organic and inorganic particles for further digestion or wasting.

The MBR is cleaned in place according to instructions in Service Manual.

The System may be equipped with chemical feed to provide a carbon source for anoxic denitrification when required by the wastewater constituents. The aeration system runs when the permeate pump is activated by a float system. The aeration system provides scouring for the membranes and oxygen to the biological process. When the permeate pump is not running the aeration system runs on a timer that activates the blower based on a pre-determined time. The off time provides a resting period for the MBR unit. The rest periods allow the membranes to relax which helps in membrane filtration capability. When the aeration operates the solids are broken up by turbulence.

All pumps, timers, and aeration equipment are controlled at the control panel. Final effluent disposal at the SAS is by either pressure distribution or gravity.

Approved System models and associated flow rates are as follows:

| System Models                     | Flow Rate (gal/day) |
|-----------------------------------|---------------------|
| BioBarrier MBR 0.5-N              | 500                 |
| BioBarrier MBR 1.0-N              | 1,000               |
| BioBarrier MBR 1.5-N              | 1,500               |
| BioBarrier MBR 2.0-N              | 2,000               |
| BioBarrier HSMBR 1.5-SN or 1.5-DN | 1,500               |
| BioBarrier HSMBR 3.0-SN or 3.0-DN | 3,000               |
| BioBarrier HSMBR 4.5-SN or 4.5-DN | 4,500               |
| BioBarrier HSMBR 6.0-SN or 6.0-DN | 6,000               |
| BioBarrier HSMBR 9.0-SN or 9.0-DN | 9,000               |

### III. Site Application, Design and Installation Requirements

1. Each proposed site-specific use of the System to be piloted must be reviewed by the Department prior to installation of the System. The Owner shall submit to the Department the written approval of the Local Approving Authority (LAA or BOH), together with a copy of the completed Department application BRP WP 64b and obtain Department written approval as required by 310 CMR 15.285(2).
2. The Designer shall be a Massachusetts Registered Professional Engineer or a Massachusetts Registered Sanitarian, provided that such Sanitarian shall not design a system with a discharge greater than 2,000 gallons per day.
3. For new construction or increases in flow, the Alternative System may only be installed provided that:
  - a) a site evaluation, in compliance with 310 CMR 15.100 through 15.107, has been approved by the Approving Authority;
  - b) the Designer shows on the plans:



- i. an existing conforming conventional system on-site that is sized for the proposed design flow with a separate reserve area in accordance with the design standards for new construction 310 CMR 15.100 through 15.255; or
    - ii. a primary area for a conventional system that could be built on-site with a separate reserve area in accordance with the design standards for new construction of 310 CMR 15.100 through 15.255; and
  - c) the LAA approves the reserve area for a conventional system designed in accordance with the standards for new construction;
  - d) the record drawings, on file with the LAA, clearly indicate the full-sized primary area and the full-sized reserve SAS are for the sole purpose of on-site sewage disposal system;
  - e) the installation shall not disturb the site in any manner that prevents the future installation of a conventional primary SAS without encroaching on the approved conventional reserve area; and
  - f) the System Owner shall not construct any permanent buildings or structures or disturb the site in any manner that prevents the future installation of a conventional primary SAS without encroaching on the approved reserve area.
4. To upgrade or replace an existing failed or nonconforming system where a conventional system could be feasibly built on-site, with the exception of providing a reserve area (15.248), an Alternative System approved pursuant to 310 CMR 15.285 (Piloting) may only be installed, provided that:
- a) the Designer shows on the plans the area for an approvable conventional system designed in accordance with the standards of 310 CMR 15.100 through 15.255;
  - b) the record drawings, on file with the LAA, clearly indicate the area for the conventional system is reserved for the sole purpose of upgrading the on-site sewage disposal system;
  - c) the installation of the Alternative System and any changes to the site by the System Owner shall not render the site unusable for the future installation of a conventional system; and
  - d) the installation of the Alternative System is in accordance with the siting requirements of the Approval.
5. To upgrade or replace an existing failed or nonconforming system, an Alternative System approved pursuant to 15.285 (piloting) may be installed where a conventional system designed in accordance with the standards of 310 CMR 15.100 through 15.255 cannot be feasibly built on-site, provided that:
- a) there is no increase in the actual or proposed design flow;
  - b) the Designer demonstrates that the impact of the proposed Alternative System has been considered and the design requirements of 310 CMR 15.000 have been varied to the least degree necessary so as to allow for both the best feasible upgrade within the borders of the lot and the least effect on public health, safety, welfare and the environment;

- c) the Designer shows on the plans an area for the best feasible conventional upgrade without the use of any Alternative System, in the event that the System fails or is not capable of providing equivalent environmental protection;
  - d) the installation of the System, including all components and the SAS system, shall not disturb the site in any manner that would render it unusable for the future installation of the best feasible conventional upgrade;
  - e) the record drawings, on file with the LAA, shall clearly indicate the area reserved for the best feasible conventional upgrade;
  - f) the System Owner shall not construct any permanent buildings or structures in an area for the best feasible conventional upgrade or disturb the site in any manner that would render the area unusable for the future installation of the best feasible conventional upgrade; and
  - g) the installation of the System is in accordance with the siting requirements of the Approval.
6. New Construction: When the System is used in areas subject to the nitrogen loading limitations of 310 CMR 15.214, an increase in calculated allowable nitrogen loading per acre is allowed for facilities with a design flow of less than 2,000 gallons per day (gpd) as provided in 310 CMR 15.217(2). When used in such areas:
- a) for residential facilities, the design flow shall not exceed 660 gallons per day per acre (gpda), and the System shall not exceed 19 mg/L total nitrogen (TN) concentration in the effluent measured as the sum of the total TKN (total Kjeldhal Nitrogen), NO<sub>3</sub>-N (Nitrate nitrogen) and NO<sub>2</sub>-N (Nitrite nitrogen), and
  - b) for non-residential facilities, the design flow shall not exceed 550 gpda, and the System shall not exceed 25 mg/L TN concentration in the effluent.
- These limitations are based on the maximum nitrogen loading rate credit of a technology with Certification for General Use. If a System(s) needs replacement there must be an approved technology that can be installed on-site to meet the nitrogen loading limitations.
7. The System models covered by this Approval are exempt from the requirements for a standard Title 5 septic tank designed in accordance with 310 CMR 15.223 and 15.224, provided that the System is installed in accordance the Companies design and installation guidance, the approved plans, and any LAA design and installation requirements.
8. Except for septic tank covers which are not required to be at grade, the frames and covers of all other access manholes and ports of the System components shall be watertight, made of durable material, and shall be installed and maintained at grade, to allow for necessary inspection, operation, sampling and maintenance access. Manholes brought to final grade shall be secured to prevent unauthorized access. No structures which could interfere with performance, access, inspection, pumping, or repair shall be located directly upon or above the access locations.
9. For any System that does not flow by gravity to the SAS, the System shall be equipped with sensors and high-level alarms to protect against high water due to pump failure, pump control failure, loss of power, or system freeze up. The control panel including alarms and controls shall be mounted in a location always accessible to the System



Operator (or Service Contractor). Emergency storage capacity for wastewater above the high level alarm shall be provided equal to the daily design flow of the System and the storage capacity shall include an additional allowance for the volume of all drainage which may flow back into the System when pumping has ceased.

Instead of providing emergency 24-hour storage, an independent standby power source may be provided for operation during an interruption in power. With any interruption of the power supply the source must be capable of automatically activating in addition to manual start up capability. The standby power must be sufficient to handle peak flows for at least 24 hours and sufficient to meet all power needs of the System including, but not limited to, pumping, ventilation, and controls. Standby power installations must be inspected and exercised at least annually and all automatic and manual start up controls must be tested. Standby power installations must comply with all applicable state and local code requirements. Provided that a standby power installation complies with these requirements, no variance is required to the provisions of 310 CMR 15.231(2).

10. System unit malfunction and high water alarms shall be visible and audible for facility occupants and the Service Contractor. Circuit(s) for alarms shall be connected separate from the circuits to the operating equipment and pumps.
11. All System control units, valve boxes, conveyance lines and other System appurtenances shall be designed and installed to prevent freezing per the Company's recommendations.
12. Any System structures with exterior piping connections located within 12 inches or below the Estimated Seasonal High Groundwater elevation shall have the connections made watertight with neoprene seals or equivalent.
13. In compliance with 310 CMR 15.240(13), a minimum of one (1) inspection port shall be provided within the SAS consisting of a perforated four inch pipe placed vertically down into the stone to the naturally occurring soil or sand fill below the stone. The pipe shall be capped with a screw type cap and accessible to within three inches of finish grade.
14. Upon submission of an application for a Disposal System Construction Permit (DSCP), the Designer shall provide to the LAA:
  - a) if any training is required by the Company, proof that the Designer has satisfactorily completed the training for the design and installation of the Technology;
  - b) certification of the design by the Company as specified in Paragraph VI.4.
  - c) certification by the Designer that the design conforms to the Approval and Title 5; and
  - d) a certification, signed by the Owner of record for the property to be served by the Technology, stating that the property Owner:
    - i) has been provided a copy of the Approval, the Owner's Manual, and the Operation and Maintenance Manual and the Owner agrees to comply with all terms and conditions;
    - ii) has been informed of all the Owner's costs associated with the operation including, when applicable: power consumption, maintenance, sampling, recordkeeping, reporting, and equipment replacement;
    - iii) understands the requirement for a service contract;

- iv) agrees to fulfill his responsibilities to provide a Deed Notice as required by 310 CMR 15.287(10) and the Approval (Paragraph V.1.);
  - v) agrees to fulfill his responsibilities to provide written notification of the Approval to any new Owner, as required by 310 CMR 15.287(5);
  - vi) if the design does not provide for the use of garbage grinders, the restriction is understood and accepted; and
  - vii) whether or not covered by a warranty, the System Owner understands the requirement to repair, replace, modify or take any other action as required by the Department or the LAA, if the Department or the LAA determines that the Alternative System is not capable of meeting the performance standards required by Title 5.
15. The System Owner and the Designer shall not submit to the LAA a DSCP application for the use of the Technology under the Approval if the Approval has expired or has been revised, reissued, suspended, or revoked by the Department prior to the date of application.
16. The System Owner shall not authorize or allow the installation of the System other than by a locally approved System Installer and, if required by the Company, has received the necessary training by the Company.
17. Prior to the commencement of construction, the System Installer must certify in writing to the Designer, the LAA, and the System Owner that (s)he is a locally approved System Installer and, if required by the Company, has received any necessary training.
18. The Installer shall maintain on-site, at all times during construction, a copy of the approved plans, the Owner's manual, the O&M manual, and a copy of the Approval.
19. Except where the Approval specifically states otherwise, the Alternative System shall be installed in a manner which does not intrude on, replace, or adversely affect the operation of any other component of the subsurface sewage disposal system.
20. Prior to the issuance of a Certificate of Compliance by the LAA, the Company or its authorized agent shall submit to the Approving Authority, with a copy to the Designer and the System Owner, a certification that the installation conforms to the Approval. The authorized agent of the Company responsible for the inspection of the installation shall have received technical training in the Company's products.
- Prior to certifying the conformance of the installation of the System, the Company shall confirm that the System Owner has recorded the required Deed Notice.
21. Prior to the issuance of a Certificate of Compliance by the LAA, the System Installer and Designer must provide, in addition to the certifications required by Title 5, certifications in writing to the LAA that the System has been constructed in compliance with the terms of the Approval.
22. The Department has not determined that the performance of the System will provide a level of protection to public health and safety and the environment that is at least equivalent to that of a sanitary sewer system.



If it is feasible to connect a new or existing facility to the sewer, the Designer shall not propose an Alternative System to serve the facility and the facility Owner shall not install or use an Alternative System.

When a sanitary sewer connection becomes feasible after an Alternative System has been installed, the System Owner shall connect the facility served by the System to the sewer within 60 days of such feasibility and the System shall be abandoned in compliance with 310 CMR 15.354, unless a later time is allowed in writing by the Department or the LAA.

#### **IV. Operation and Maintenance, Monitoring, and Inspection**

1. The System shall be inspected, monitored, operated, and maintained by a Service Contractor under an O&M Agreement in accordance with this Approval and in accordance with any Company, Designer, or LAA requirements. The Service Contractor must be trained by the Company, must be on the Company's current list of Service Contractors, and must be certified at Grade Level IV (four) by the Board of Registration of Operators of Wastewater Treatment Facilities, in accordance with Massachusetts regulations 257 CMR 2.00.
2. As stated in 310 CMR 15.285(3), the Company shall implement a system monitoring and reporting plan as described in this Approval, covering no less than 18 months of operation at each facility to be piloted. For all Systems installed under the Approval, the Company or its authorized agent shall be responsible for oversight, monitoring, data collection, and submissions to the LAA (and the Department per Paragraph VI.16). [Upon the Company's completion of a System performance evaluation (PE) report finding the System in compliance with Title 5, effluent limits, and the performance goals and conditions of this Approval for at least the previous 12 months (see Paragraph VI.5), the System Owner and Service Contractor shall be responsible thereafter until the conditions of the Approval are modified, terminated, or superseded by a new Approval. The System Owner and the Service Contractor shall enter into an O&M Agreement and the Agreement shall be at least for one year.]
3. For the duration of the performance evaluation, the System Owner and the Company shall enter into an O&M Agreement. The Company shall be responsible for providing a qualified Service Contractor to service the System during this period. Prior to commencement of construction of a System installation, the Company shall provide to the LAA a copy of a signed O&M Agreement with the System Owner. For the duration of the performance evaluation, the Company shall maintain a copy of the current O&M Agreement.
4. The Company shall provide written notification to the Department within seven days of any cancellation or expiration of the O&M Agreement required for the duration of the performance evaluation.
5. At a minimum any O&M Agreement shall include the following provisions:
  - a) The name of the qualified Service Contractor that appears on the Company's current list of Service Contractors;
  - b) In the case of a System failure, equipment failure, alarm event, components not functioning as designed, or violations of the Approval, procedures and

- responsibilities of the Company, the Service Contractor, and the System Owner shall be clearly defined for corrective measures to be taken immediately;
- c) The Service Contractor shall agree to provide written notification within five days, describing corrective measures taken, to the System Owner, the local board of health, and the Company; and
  - d) Procedures and responsibilities for recording wastewater flows and power consumption during the performance evaluation must be defined. If direct metering of power consumption is not feasible, equipment run times shall be recorded in order for the Company to provide recorded estimates of power consumption of the facility.
6. The System Owner and the Service Contractor shall maintain on-site, at all times, a copy of the approved plans, the Owner's Manual, the O&M Manual, a copy of the Approval, and a copy of the current O&M Agreement.
7. The System Owner and the Service Contractor shall provide written notification to the LAA within seven days of any cancellation, expiration or other change in the terms and/or conditions of the required O&M Agreement.
8. At a minimum, the Service Contractor shall inspect, properly operate, and properly maintain the System:
- a) any time there is System failure, equipment failure, or an alarm event;
  - b) in accordance with the O&M manual and Designer requirements;
  - c) in accordance with the requirements of the LAA;
  - d) in accordance with the Approval; and
  - e) for seasonal use, the Service Contractor shall be on-site and responsible for the proper start-up and shut down of the Alternative System.
9. Each time a Pilot Alternative System is visited by a Service Contractor the following shall be recorded, at a minimum:
- a) date, time, air temperature, and weather conditions;
  - b) observations for objectionable odors;
  - c) observations for signs of breakout of sanitary sewage in the vicinity of the Alternative System, which indicate a failure of the Alternative System;
  - d) identification of any apparent violations of the Approval;
  - e) since the last inspection, whether the system had been pumped with date(s) and volume(s) pumped;
  - f) sludge depth and scum layer thickness, if measured;
  - g) when responding to alarm events, the cause of the alarm and any remedial steps taken to address the alarm and to prevent or reduce the likelihood of future similar alarm events;
  - h) field testing results, if any;
  - i) list of samples taken for laboratory analysis, if any;
  - j) any cleaning and lubrication performed;



- k) any adjustments of control settings, as recommended or deemed necessary;
  - l) any testing of pumps, switches, alarms, as recommended or deemed necessary;
  - m) identification of any equipment failure or components not functioning as designed;
  - n) parts replacements and reason for replacement, whether routine or for repair; and
  - o) further corrective actions recommended, if any.
10. Flow Metering – For Alternative Systems installed under Piloting Approval, wastewater flow data shall be reported each time the System is inspected and/or sampled by the Service Contractor. At a minimum, wastewater flow shall be based on:
- a) actual metering data of wastewater flow to the System; or
  - b) actual water meter data for the total facility with either metered or estimated flows for non-wastewater flow subtracted from the total facility water usage. If estimating the wastewater flow as a portion of total metered water usage, the Service Contractor shall provide the method of estimating, such as pump run times, occupancy rates, adjusting for seasonal outdoor water use, etc.

11. For the duration of the performance evaluation or PE, the required O&M Agreement shall include the following monitoring schedule at a minimum (subject to modifications that may be required by Paragraphs IV.12, 13 and 15) :

| Parameter                               | Monitoring Frequency          | Sample Type        | Location                                                    | Effluent Limits              |
|-----------------------------------------|-------------------------------|--------------------|-------------------------------------------------------------|------------------------------|
| wastewater temperature                  | each inspection               | measure            | effluent to SAS                                             | Measure and record           |
| flow                                    | each inspection               | measure            | See Paragraph IV.10                                         | Measure and record           |
| pH                                      | See frequency specified below | grab               | effluent to SAS                                             | 6 to 9                       |
| Total Nitrogen                          | See frequency specified below | grab               | effluent to SAS                                             | See Paragraph III.6          |
| BOD <sub>5</sub>                        | See frequency specified below | grab               | effluent to SAS                                             | 30 mg/l                      |
| TSS                                     | See frequency specified below | grab               | effluent to SAS                                             | 30 mg/l                      |
| turbidity                               | See frequency specified below | measure            | effluent to SAS                                             | ≤ 40 NTU                     |
| settleable solids                       | See frequency specified below | measure            | effluent to SAS                                             | Measure and record ml/l only |
| color                                   | See frequency specified below | visual observation | effluent to SAS                                             | Record observation only      |
| Depth of Ponding Within SAS             | once every year               | measure            | Inspection port to bottom of SAS                            | See Paragraph IV.15(d)       |
| Thickness of floating grease/scum layer | Once every 3 years            | measure            | Septic tank or other process tank where solids are retained | Pump out, as necessary       |



| Parameter                                                  | Monitoring Frequency | Sample Type | Location                                                    | Effluent Limits        |
|------------------------------------------------------------|----------------------|-------------|-------------------------------------------------------------|------------------------|
| Depth of Sludge and distance to effluent tee/filter/outlet | Once every 3 years   | measure     | Septic tank or other process tank where solids are retained | Pump out, as necessary |

*System Monitoring Responsibility*

12. For at least the first 18 months of operation and until a System's PE has been completed by the Company, the Company shall be responsible for the following monitoring requirements and effluent limits, as well as those required in paragraph 11 above:
  - a) For year-round properties the facility shall be inspected quarterly. The effluent shall be monitored quarterly for at least 6 quarters for pH, BOD5, TSS and for total nitrogen (TN). After at least 6 quarterly samples, the effluent shall be monitored quarterly for TN and field tested for pH, turbidity, settleable solids, and color. The influent for nonresidential facilities shall be monitored quarterly for wastewater temperature, pH, BOD5, TSS and TN for a minimum of 4 quarters; and
  - b) Seasonal properties shall be inspected and the effluent sampled at least twice per year, once 30 to 60 days after occupancy and the second sample must be taken no less than 2 months after the first sample or just prior to the seasonal end-of-use. Samples shall be analyzed for pH, BOD5, TSS and TN. After 6 samples, the effluent shall be analyzed for just TN and field tested for pH, turbidity, settleable solids, and color. During occupancy, the influent for nonresidential facilities shall be monitored once per quarter for pH, BOD5, TSS and TN for a minimum of 4 quarters.

Quarterly monitoring shall be performed not less than 2 months since the last monitoring inspection and not more than 4 months since the last inspection.
13. After a minimum of 18 months and completion of the PE of a System that shows the System was in compliance with Title 5, effluent limits, and the performance goals and conditions of this Approval for at least the previous 12 months, the System Owner and the Service Contractor shall be responsible for the following monitoring requirements:
  - a) For Systems designed to receive or receiving more than 440 gallons per day per acre that were installed to serve new construction or an increase in flow in an area subject to the Nitrogen Loading Limitations of 310 CMR 15.214 and subject to a total nitrogen concentration limit, the following monitoring requirements shall apply until the Approval is modified, terminated, or superseded:
    - i. Year-round properties shall be inspected when sampled and effluent samples shall be taken twice per year at least 5 months apart and analyzed for TN. At least one sample will be taken between December 1 and March 1 of each year.
    - ii. Seasonal properties shall be inspected when sampled and effluent samples shall be taken for TN a minimum of twice per year. At least one annual sample must be taken 30 to 60 days after occupancy. A second sample must be taken no less than 2 months after the first sample or just prior to the seasonal end-of-use.



The monitoring requirements in Paragraph 12 also apply, unless modified by 13(a, i-ii).

*(Note: The LAA (or BOH) may have additional monitoring requirements.)*

- b) For those Systems not subject to the Nitrogen Loading Limitations of 310 CMR 15.214, only the monitoring requirements of the LAA (or BOH) applies.
14. Within 60 days of each site visit, all monitoring data shall be submitted to the System Owner and the LAA with the O&M report and inspection checklist, The O&M report and inspection checklist shall include, at a minimum, results of any required wastewater analyses, flow data and all the information required to be recorded for a maintenance inspection of an Alternative System.

#### *Compliance Requirements*

15. The System shall be subject to the following performance requirements:
- a) For areas subject to the Nitrogen Loading Limitations of 310 CMR 15.214, whenever two consecutive monitoring rounds exceed the required TN limit, a written evaluation with recommendations for changes in the design, operation, and/or maintenance of the System shall be submitted to the LAA, within 90 days of the second exceedance of the limit. The written evaluation with recommendations shall be prepared by the Service Contractor or a qualified Designer and the submission shall include all monitoring data, inspection reports, and laboratory analyses since the last annual report to the LAA;
  - b) Whenever field testing indicates a pH outside the of 6 to 9 or an exceedance of the turbidity limit of 40 NTU, the Service Contractor shall collect an effluent sample from the treatment unit for laboratory analysis for BOD5 and TSS and make adjustments and/or repairs to the System, as deemed necessary during the inspection;
  - c) Whenever two consecutive monitoring rounds include at least one exceedance of the limits for BOD5 or TSS, a written evaluation with recommendations for changes in the design, operation, and/or maintenance of the System shall be submitted to the LAA, within 90 days of the second exceedance of the limits The written evaluation with recommendations shall be prepared by the Service Contractor or a qualified Designer and the submission shall include all monitoring data, inspection reports, and laboratory analyses since the last annual report to the LAA;
  - d) Whenever an SAS inspection port measurement indicates the ponding level within the SAS is above the invert of the distribution system, an additional measurement shall be made 30 days later. If the subsequent reading indicates the elevation of ponding within the SAS is above the invert of the distribution system, within 60 days of the follow up inspection, a written evaluation with recommendations for changes in the design, operation, and/or maintenance of the System shall be submitted to the LAA. The written evaluation with recommendations shall be prepared by the Service Contractor or a Designer and the submission shall include all monitoring data, inspection reports, and laboratory analyses for the previous year; and
  - e) Recommendations for any changes to the System shall be implemented, as approved by the LAA, in accordance with an approved schedule, provided that all corrective measures are implemented consistent with the limitations described in Paragraph V.8.



Responsibility for completing these compliance requirements is same as is assigned in the above Paragraphs 12 and 13 for monitoring requirements.

16. For Systems failing to comply with any other terms of the Approval not included in Paragraph 15, and until the Company submits a performance evaluation report to the System Owner and the LAA that shows the System was in compliance with Title 5, effluent limits, and the performance goals and conditions of this Approval for at least the previous 12 months, the Company or its authorized agent shall determine the causes of the noncompliance. The Company shall provide written recommendations for corrective actions to the System Owner and the LAA. Corrective actions may include but are not limited to design changes, installation changes, operation or maintenance changes including sampling modifications, and/or changes in roles and responsibilities for the manufacturer, vendors, designers, installers, service contractors and owners. Any recommended changes which are not consistent with this Approval shall first be submitted to the Department with an application for an Approval modification.

The Company shall be responsible for implementation of recommended changes, as approved by the LAA, in accordance with an approved schedule. All corrective measures implemented shall be consistent with the Approval and the other limitations described in Paragraph V.8.

17. Unless directed by the LAA to take other action, the System Owner shall immediately cease discharges or have wastewater hauled off-site, if at any time during the operation of the Alternative System the system is in failure as described in 310 CMR 15.303(1)(a)1 or 2, backing up into facilities or breaking out to the surface.

## **V. Additional System Owner and Service Contractor Requirements**

1. Prior to commencement of construction of the System and after recording and/or registering the Deed Notice required by 310 CMR 15.287(10), the System Owner shall provide to the LAA a copy of:
  - a) a certified Registry copy of the Deed Notice bearing the book and page/or document number; and
  - b) if the property is unregistered land, a Registry copy of the System Owner's deed to the property, bearing a marginal reference on the System Owner's deed to the property.

The Notice to be recorded shall be in the form of the Notice provided by the Department see <http://www.mass.gov/eea/docs/dep/water/wastewater/a-thru-n/altsysn.pdf>

2. Prior to signing any agreement to transfer any or all interest in the property served by the System, or any portion of the property, including any possessory interest, the System Owner shall provide written notice, as required by 310 CMR 15.287(5) of all conditions contained in the Approval to the transferee(s). Any and all instruments of transfer and any leases or rental agreements shall include as an exhibit attached thereto and made a part of thereof a copy of the Approval for the System. The System Owner shall send a copy of such written notification(s) to the LAA within 10 days of giving such notice to the transferee(s).

3. The System Owner shall provide access to the site for the Company and the Service Contractor to perform inspections, maintenance, repairs, responding to alarm events and field testing as may be required by the Approval, including sampling the System in accordance with the Approval.
4. The System Owner and the Service Contractor shall maintain copies of the Service Contractor's O&M reports, inspection checklists, and all reports and notifications to the LAA for a minimum of three years.
5. The System Owner shall not install, modify, upgrade, or replace the System except in accordance with a valid DSCP issued by the LAA which covers the proposed work.
6. Upon determining that the System is in violation of the Approval or the System has failed, as defined in 310 CMR 15.303, the Service Contractor shall notify the System Owner immediately.
7. Upon determining that the System has failed, as defined in 310 CMR 15.303, the System Owner and the Service Contractor shall be responsible for the notification of the LAA within 24 hours of such determination.
8. In the case of a System failure, an equipment failure, alarm event, components not functioning as designed, components not functioning in accordance with manufacturer's specifications, or violations of the Approval, the Service Contractor shall provide written notification within five days describing corrective measures to the System Owner, the local board of health, and the Company and may only propose or take corrective measures provided that:
  - a) all emergency repairs, including pumping, shall be in accordance with the limitations and permitting requirements of 310 CMR 15.353;
  - b) the design of any repairs or upgrades are consistent with the Alternative System Approval;
  - c) the design of any repairs or upgrades requiring a DSCP shall be performed by an individual meeting the qualifications of Paragraph III.2;
  - d) the installation shall be done by an Installer with a currently valid Disposal System Installers Permit (310 CMR 15.019) and the Installer shall also comply with Paragraph III.17.

The System Owner shall also be responsible for ensuring written notification is provided within five days to the local Board of Health.
9. The Service Contractor shall provide written notification to the Company within seven days of any cancellation, expiration or other change in the terms and/or conditions of a required O&M Agreement.
10. By September 30th of each year, the System Owner and the Service Contractor shall be responsible for submitting to the LAA all O&M reports, all monitoring results, and inspection checklists completed by the Service Contractor during the previous 12 months.



11. By September 30th of each year, the Service Contractor shall be responsible for submitting to the Company copies of all O&M reports including alarm event responses, all monitoring results, violations of the Approval, inspection checklists completed by the Service Contractor, notifications of system failures, and reports of equipment replacements with reasons during the previous 12 months.
12. The Service Contractor shall notify the System Owner of any changes to the terms and conditions of the Approval within 30 days of any changes.
13. Within one year of any changes to the terms and conditions of the Approval, the System Owner shall amend, as necessary, the O&M Agreement required by Paragraphs IV.2 & 3 to reflect the changes to the terms and conditions of the Approval.
14. The System Owner shall furnish the Department any information that the Department requests regarding the System, within 21 days of the date of receipt of that request.
15. The Approval shall be binding on the System Owner and on its agents, contractors, successors, and assigns, including but not limited to the Designer, Installer, and Service Contractor. Violation of the terms and conditions of the Approval by any of the foregoing persons or entities, respectively, shall constitute violation of the Approval by the System Owner unless the Department determines otherwise.

## **VI. Company Requirements**

1. The Approval shall only apply to model units with the same model designations specified in the Technology Approval and meet the same specifications, operating requirements, and plans, as provided by the Company at the time of the application. Any proposed modifications of the units, installation requirements, or operating requirements shall be subject to the review of the Department for inclusion under a modification of the Approval. The Company shall be responsible for verification of the appropriate model unit as part of the review of proposed installations under the Approval.
2. The Company must offer to the System Owner a two-year initial service policy with the purchase of the Technology that includes a minimum of eight (8) site visits (every 3 months). The Company must make available, for a fee, an extended service policy for a minimum of 5 years beyond the two-year initial service policy.
3. Prior to submission of an application for a DSCP, the Company shall provide to the Designer and the System Owner:
  - a) All design and installation specifications and requirements;
  - b) An operation and maintenance manual, including:
    - i. an inspection checklist;
    - ii. recommended inspection and maintenance schedule;
    - iii. monitoring (i.e. water use and power consumption) and sampling procedures, if any;
    - iv. alarm response procedures, if any, and troubleshooting procedures;

- c) An owner's manual, including proper system use and alarm response procedures, if any;
  - d) Estimates of the Owner's costs associated with System operation including, when applicable: power consumption, maintenance, sampling, recordkeeping, reporting, and equipment replacement;
  - e) A copy of the Company's warranty, and
  - f) Lists of Designers, Installers, and Service Contractors.
4. Upon submission of an application for a DSCP to the Approving Authority, the Company shall submit to the Approving Authority, with a copy to the Designer and the System Owner, a certification by the Company or its authorized agent that the design conforms to the Approval and that the proposed use of the System is consistent with the unit's capabilities and all Company requirements. The review shall include evaluation of the need for installation of water meter(s) at each facility. An authorized agent of the Company responsible for the design review shall have received technical training in the Company's products.
5. Upon completion of the PE of a System after a minimum of 18 months of operation, the Company shall submit to the System Owner and the LAA a PE report on the System describing and summarizing the operations of the System, any changes in operation or design that were made during the piloting performance evaluation period and the results of the piloting program for that System. The report shall also include whether the System was in compliance with Title 5, the effluent limits, and the performance goals and conditions of this Approval for at least the previous 12 months of operation. That report shall also include either recommendations for approving and ending the piloting program for that System or recommendations for continuing piloting for any System that has not performed as planned and/or required.
- a) Upon completion of the PE of a System, if a System is not in compliance with Title 5 or this Approval for at least the previous 12 months of operation, the Company shall either continue the piloting program for that system, or upgrade or replace the System with a fully complying Title 5 I/A or conventional system.
  - b) Upon completion of the PE of a System, showing the System was in compliance, for at least the previous 12 months, with Title 5, the effluent limits, the performance goals, and the conditions of this Approval, the Company may turn the responsibility for operation and monitoring of the System over to the System Owner and Service Contractor in accordance with this Approval (see paragraph IV.13 for continuing monitoring requirements).
6. The Company shall institute programs of training and continuing education for Service Contractors. Training shall be provided at least annually. If the Company requires trained Designers and Installers, the Company shall institute programs of training and continuing education that is separate from or combined with the training for Service Contractors. The Company shall maintain, annually update, and make available by March 15th of each year, lists of approved Service Contractors and, if training is required, Designers and Installers. The Company shall certify that the Service Contractors and Designers and Installers on the lists have taken the appropriate training and passed the Company's training qualifications. The Company shall further certify that



the Service Contractors on the list have submitted to the Company all the reports required by Paragraphs V.8, 9, and 11.

The Company shall not re-certify a Service Contractor if the Service Contractor has not complied with the reporting requirements for the previous year.

7. If Installer training is required by the Company, the Company shall not sell the Technology to an Installer unless the Installer is trained. The Company shall also require, by contract, the distributors and resellers of the Technology shall not sell the Technology to an Installer unless the Installer is trained.
8. As part of any training programs for Designers, Installers, and Service Contractors, the Company shall provide each trainee with a copy of the Approval with the design, installation, O&M, and owner's manuals that were submitted as part of the Approval.
9. The Company shall provide, in printed or electronic format, the System design plan, installation, O&M, and Owner's manuals, and any updates associated with this technology Approval, to the System Owners, Designers, Installers, Service Contractors, vendors, resellers, and distributors of the System. Prior to publication or distribution in Massachusetts, the Company shall submit to the Department for review a copy of any proposed changes to the manual(s) with reasons for each change, at least 30 days prior to issuance. The Company shall request Department approval for any substantive changes which may require a modification of the Approval.
10. Prior to its sale of any System that may be used in Massachusetts, the Company shall provide the purchaser with a copy of the Approval with the System design, installation, O&M, and Owner's manuals. In any contract for distribution or sale of the System, the Company shall require the distributor or seller to provide the purchaser of a System for use in Massachusetts with copies of these documents, prior to any sale of the System.
11. The Company shall furnish the Department any information that the Department requests regarding the Technology within 21 days of the date of receipt of that request.
12. Within 60 days of issuance by the Department of a revised Approval, the Company shall provide written notification of changes to the Approval to all Service Contractors servicing existing installations of the Technology and all distributors and resellers of the Technology.
13. The Company shall provide written notification to the Department's Director of the Wastewater Management Program at least 30 days in advance of the proposed transfer of ownership of the Technology for which the Approval is issued. Said notification shall include the name and address of the proposed owner containing a specific date of transfer of ownership, responsibility, coverage and liability between them.
14. The Company shall maintain records of:
  - a) the Approval;
  - b) design and installation manuals;
  - c) an owner's manual, including alarm response procedures, if any;

- d) an operation and maintenance manual, including:
    - i. an inspection checklist;
    - ii. recommended inspection and maintenance schedule;
    - iii. monitoring requirements, if any (including water use and power consumption when required) and sampling procedures, and
    - iv. alarm response procedures, if any, and troubleshooting procedures.
  - e) estimates of the operating costs provided to the Owner, including, when applicable: power consumption, maintenance, sampling, recordkeeping, reporting, and equipment replacement;
  - f) a copy of the Company's warranty, and
  - g) lists of Designers, Installers, and trained Service Contractors.
15. The Company shall maintain the following information for the Systems installed in Massachusetts:
- a) the address of each facility where the Technology was installed, the Owner's name and address (if different), the type of use (e.g. residential, commercial, institutional, etc.), the design flow, the model installed;
  - b) the installation date, start-up date, current operational status;
  - c) the name of the Service Contractor, noting any cancellations or changes to any Service Contracts;
  - d) a summary of system failures, system malfunctions, and violations of the Approval with the date of each event and corrective actions taken to reach compliance, including but not limited to: design changes; installation changes; operation/maintenance changes; monitoring changes; and/or changes in roles and responsibilities for the manufacturer, vendors, designers, installers, service contractors and owners;
  - e) copies of all Service Contractor records submitted to the Company, including all O&M reports with alarm event responses, all monitoring results, inspection checklists completed by the Service Contractor, notifications of system failures, and reports of equipment replacements with reasons; and
  - f) copies of any completed PE reports.
16. By March 15th of each year the Company shall submit to the Department an annual report that contains the following information for all Systems that were installed before January 1st of that year:
- a) a table of the information required by Sections a, b, c, d and f of the preceding Paragraph;
  - b) a table of monitoring data collected for all Systems installed to-date;
  - c) a list of pending applications for System installations which have been submitted to local approving authorities.
  - d) identification of each System failure to comply with any performance criteria of the Approval or the system monitoring and reporting plan, including but not limited to, effluent quality limits. Include the date of each event, the date that the System was returned to compliance, and the reasons for the noncompliance and the corrective actions that were taken, including but not limited to any design changes, installation changes, operation or maintenance changes including sampling, and/or changes in roles and responsibilities for the manufacturer, vendors, designers, installers, service contractors and owners;



- e) for any System in violation of the Approval or not in compliance with any performance criteria at the time of the annual report, the reasons for the noncompliance and the status of any corrective actions that are needed;
- f) any recommendations and requests for changes to the system monitoring and reporting plan or the performance criteria of the Approval; and

The report shall be signed by a corporate officer, general partner or the Company owner.

*(Service Contractor records submitted to the Company should not be included with the annual report, but shall be made available to the Department within 30 days of a request by the Department.)*

- 17. The Approval shall be binding on the Company and its officers, employees, agents, contractors, successors, and assigns, including but not limited to dealers, distributors, and resellers. Violation of the terms and conditions of the Approval by any of the foregoing persons or entities, respectively, shall constitute violation of the Approval by the Company unless the Department determines otherwise.
- 18. If the Company wishes to continue this Piloting Approval after its expiration date, the Company shall apply for and obtain a renewal of this Approval. The Company shall submit a renewal application at least 180 days before the expiration date of this Approval, unless permission for a later date has been granted in writing by the Department.

## **VII. General Requirements**

- 1. Any Alternative System for which a complete DSCP application is submitted while the Approval is in effect, may be permitted, installed, and used in accordance with the Approval, unless and until:
  - a) the Department issues modifications or amendments to the Approval which specifically affect the installation or use of an Alternative System installed under the Approval for the Technology; or
  - b) the Department, the local approval authority, or a court requires the Alternative System to be modified or removed or requires discharges to the System to cease.
- 2. All notices and documents required to be submitted to the Department by the Approval shall be submitted to:

Director  
Wastewater Management Program  
Department of Environmental Protection  
One Winter Street - 5th floor  
Boston, Massachusetts 02108

### *Rights of the Department*

- 3. The Department may suspend, modify or revoke the Approval for cause, including, but not limited to, non-compliance with the terms of the Approval, non-payment of the annual compliance assurance fee, for obtaining the Approval by misrepresentation or failure to disclose fully all relevant facts or any change in or discovery of conditions that would constitute grounds for discontinuance of the Approval, or as necessary for the protection of public health, safety, welfare or the environment, and as authorized by applicable law. The Department reserves its rights to take any enforcement action authorized by law with respect to the Approval and/or the System against the Company, a System Owner, a Designer, an Installer, and/or Service Contractor.

# Analysis of pharmaceuticals in wastewater and removal using a membrane bioreactor

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**Abstract** Much attention has recently been devoted to the life and behaviour of pharmaceuticals in the water cycle. In this study the behaviour of several pharmaceutical products in different therapeutic categories (analgesics and anti-inflammatory drugs, lipid regulators, antibiotics, etc.) was monitored during treatment of wastewater in a laboratory-scale membrane bioreactor (MBR). The results were compared with removal in a conventional activated-sludge (CAS) process in a wastewater-treatment facility. The performance of an MBR was monitored for approximately two months to investigate the long-term operational stability of the system and possible effects of solids retention time on the efficiency of removal of target compounds. Pharmaceuticals were, in general, removed to a greater extent by the MBR integrated system than during the CAS process. For most of the compounds investigated the performance of MBR treatment was better (removal rates >80%) and effluent concentrations of, e.g., diclofenac, ketoprofen, ranitidine, gemfibrozil, bezafibrate, pravastatin, and ofloxacin were steadier than for the conventional system. Occasionally removal efficiency was very similar, and high, for both treatments (e.g. for ibuprofen, naproxen, acetaminophen, paroxetine, and hydrochlorothiazide). The antiepileptic drug carbamazepine was the most persistent pharmaceutical and it passed through both the MBR and CAS systems untransformed. Because there was no washout of biomass from the reactor, high-quality effluent

in terms of chemical oxygen demand (COD), ammonium content ( $\text{N-NH}_4$ ), total suspended solids (TSS), and total organic carbon (TOC) was obtained.

**Keywords** Wastewater treatment · Membrane bioreactor · Conventional activated sludge treatment · Pharmaceuticals · Removal efficiency

## Introduction

Most pharmaceutical substances are, by nature, biologically active and hydrophilic, in order that the human body can take them up easily, and persistent, to avoid degradation before they have a curing effect. Depending on the pharmacology of a medical substance it will be excreted as a mixture of metabolites, as unchanged substance, or conjugated with an inactivating compound attached to the molecule [1]. When they enter a wastewater-treatment plant, xenobiotics are not usually completely mineralized. They are either partially retained in the sludge, or metabolized to a more hydrophilic but still persistent form and, therefore, pass through the wastewater-treatment plant (WWTP) and end up in the receiving waters. Their removal in WWTPs is variable and depends on the properties of the substance and process conditions (e.g. sludge retention time (SRT), hydraulic retention time (HRT), temperature) [2, 3]. Levels of many pharmaceutically active compounds (PhACs) are barely reduced and they are, therefore, detected in WWTP effluents. The presence of PhACs in surface, drinking, and wastewaters is well documented in the literature [1, 4–12]. Although present at low concentrations in the environment, drugs can have adverse effects on aquatic organisms. These effects are chronic rather than acutely toxic, and depend on exposure (bioavailability),

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susceptibility to the compound in question, and the degradability of the compound [13].

To ensure compliance with future discharge requirements, upgrading of existing wastewater-treatment facilities and implementation of new technologies is envisaged as the next step in improvement of wastewater treatment. In the last ten to fifteen years the use of membranes in wastewater reclamation has attracted much interest. Membrane technology has become a technically and economically feasible alternative for water and wastewater treatment, especially because of high SRTs achieved within compact reactor volumes. In the MBR the concentration of microorganisms can be increased to up to 20 mg L<sup>-1</sup>. Because of this high biomass concentration the rate of degradation is higher and specialists are grown for problematic compounds. Another advantage of membrane treatment is separation of suspended solids by membranes, so they are not limited by the settling characteristics of the sludge. The performance, in terms of effluent quality, is believed to be better, but there is a striking lack of knowledge about the behaviour of trace-pollutants. Literature data on this subject is still very limited and contradictory [2, 11, 14–16]. Ultrafiltration membranes do not enable greater retention of the drugs investigated in this study as a result of filtration effects—the molecular sizes of the compounds selected are at least a factor of 100 smaller than the pore size of the membranes. Additional removal of hydrophobic compounds by membranes can, nevertheless, be expected, because they are adsorbed by particles deposited as a layer on the membrane surface; this effect for hydrophilic compounds is not yet very well defined, however [11, 17].

The objectives of this work were detection of target pharmaceuticals in wastewater influents and effluents, observation of their elimination in the CAS process, and comparison with results obtained for a laboratory-scale MBR provided with a plate-and-frame submerged membrane module. The pharmaceutical products investigated were analgesics and anti-inflammatory drugs (ibuprofen, ketoprofen, naproxen, diclofenac, indomethacin, acetaminophen, mefenamic acid, and propyphenazone), lipid regulators and cholesterol-lowering statin drugs (clofibrilic acid, gemfibrozil, bezafibrate, pravastatin, and mevastatin), antibiotics (erythromycin, azithromycin, sulfamethoxazole, trimethoprim, and ofloxacin), psychiatric drugs (fluoxetine and paroxetine), an antiepileptic drug (carbamazepine),  $\beta$ -blockers (atenolol, sotalol, metoprolol, and propranolol), anti-histaminics (famotidine and loratidine), anti-ulcer agents (lansoprazole and ranitidine), an anti-diabetic (glibenclamide), and a diuretic (hydrochlorothiazide). These compounds had different physicochemical properties (i.e. neutral, ionic, hydrophilic, hydrophobic). Their chemical structures and CAS numbers are listed in the [Appendix](#). If their behaviour during wastewater treatment could be

more reliably related to process design and operating conditions, process performance could possibly be improved by alteration of these conditions in accordance with the types of molecule that are difficult to eliminate.

## Experimental

### Materials and standards

Chemical standards of carbamazepine, lansoprazole, loratidine, famotidine, trimethoprim, ofloxacin, atenolol, metoprolol, azithromycin dihydrate, erythromycin hydrate, fluoxetine hydrochloride, ranitidine hydrochloride, sulfamethoxazole, propranolol hydrochloride, indomethacin, acetaminophen, mefenamic acid, clofibrilic acid, bezafibrate, mevastatin, and sotalol hydrochloride were purchased from Sigma–Aldrich (Steinheim, Germany), propyphenazone, pravastatin, and paroxetine hydrochloride from LGC Promochem (London, UK), ketoprofen, diclofenac, gemfibrozil, ibuprofen, and naproxen from Jescuder (Rubí, Spain), glibenclamide from SIFA Chemicals (Liestal, Switzerland), and hydrochlorothiazide from Pliva (Zagreb, Croatia). All pharmaceutical standards were of high-purity grade (>90%).

Isotopically labelled compounds used as internal standards were <sup>13</sup>C-Phenacetin, from Sigma–Aldrich, mecoprop-d<sub>3</sub>, from Dr Ehrenstorfer (Augsburg, Germany), and ibuprofen-d<sub>3</sub>, atenolol-d<sub>7</sub>, and carbamazepine-d<sub>10</sub> from CDN Isotopes (Quebec, Canada).

All solvents (methanol, acetonitrile, and water) were HPLC-grade and were purchased from Merck (Darmstadt, Germany), as also was hydrochloric acid (HCl, 37%), ammonium acetate (NH<sub>4</sub>Ac), and acetic acid (HAc). Nitrogen for drying, purity 99.995%, was from Air Liquide (Spain).

Stock solutions of individual standards (1 g L<sup>-1</sup>) and internal standards were prepared in methanol and stored at -20 °C. Stock solutions of ofloxacin, pravastatin, and sulfamethoxazole were renewed monthly because of their limited stability. A standard mixture in which the compounds were at a concentration of approx. 20 mg L<sup>-1</sup> was prepared from the stock solutions. Further dilutions of this mixture were prepared in 25:75 (v/v) methanol–water and were used as working standard solutions. A mixture of internal standards prepared by dilution of individual stock solutions in methanol was used for internal standard calibration.

### Membrane bioreactor (MBR)

A submerged MBR of approximately 21 L active volume equipped with two flat sheet membranes (A4 size, area 0.106 m<sup>2</sup>, pore size 0.4  $\mu$ m), purchased from Kubota



(Osaka, Japan), was installed in a municipal WWTP in Rubí (Barcelona, Spain). Although the nominal porosity of the membranes was 0.4  $\mu\text{m}$  (microfiltration) a fouling layer of proteins and microorganisms formed on the surface of the membranes reduced the effective porosity to 0.01  $\mu\text{m}$ , which brought the type of filtration into the ultrafiltration range [17].

The MBR was operated in parallel with the CAS process (aeration tank and secondary settling tank). The biocenosis of the MBR was grown from inoculated sludge from the municipal WWTP (aeration basin) and cultivated over a period of approximately 1 month to reach steady-state conditions. The hydraulic retention time was set to 14 h by regulating the effluent flow and the SRT was infinite, because no sludge was discharged from the reactor.

The laboratory-scale MBR was operated dynamically in intermittent permeation mode—cycles of permeation for 8 min interrupted with 2 min of halt. Influent and permeate flows were controlled by use of flow meters and computer-controlled pumps. Continuous aeration was provided by means of a sparger pipe situated at the bottom of the reaction vessel; the oxygen concentration was kept between 1 and 2  $\text{mg L}^{-1}$ . The temperature inside the reactor was  $20 \pm 2$  °C throughout sampling.

#### Wastewater-treatment plant (WWTP)

Rubí WWTP was designed for 125,550 inhabitant equivalents. During the sampling programme the WWTP was operating with an average daily flow of  $22,000 \text{ m}^3 \text{ day}^{-1}$ . A mixture of municipal, hospital, and industrial wastewater is treated. Treatment consists of pretreatment, preliminary treatment, primary sedimentation, and secondary (biological) treatment. Pretreated wastewater goes through a physical process of settling in a primary clarifier. Secondary treatment occurs in pre-denitrification (anaerobic) and nitrification (aerobic) tanks, and two secondary clarifiers. Secondary sludge is recirculated to a primary clarifier which improves the settling characteristics of the primary sludge and increases sludge age. A mixture of primary and secondary (activated) sludge is processed (thickening, dewatering) and anaerobically digested, and biogas produced is used to heat a digester. The hydraulic retention time of CAS treatment in WWTP Rubí, calculated for the average daily flow, is approximately 12 h. During the sampling programme the plant was operating with an SRT of approximately 3 days. WWTP effluent is discharged into the river Riera de Rubí, which flows into the Mediterranean sea.

#### Sampling and sample preparation

Sampling was conducted during May and June, 2005. Twenty-eight samples were analyzed. All wastewater

samples were taken as time-proportional grab-samples, bearing in mind the HRT of the MBR and CAS processes. The sampling points were:

1. primary sedimentation tank effluent, as the inflow to the conventional treatment plant and membrane bioreactor,
2. CAS effluent, and
3. MBR effluent.

Wastewater samples were collected, in amber glass bottles pre-rinsed with ultra-pure water, as 24-h composite samples; the volume depended on the type of sample (100 mL for influent wastewater and 200 mL for effluent). Immediately on arrival at the laboratory they were filtered through 1- $\mu\text{m}$  glass fibre filters and then through 0.45  $\mu\text{m}$  Nylon membrane filters from Whatman (UK). The target compounds were extracted in one step, by a method described elsewhere [18], using a Baker vacuum system (J.T. Baker, The Netherlands) and Waters (Milford, MA, USA) Oasis HLB cartridges (60 mg, 3 mL) previously conditioned at neutral pH with 5 mL methanol then 5 mL

**Table 1** MRM transitions of the compounds analyzed

| Compound            | MRM 1       | MRM 2       | MRM 3   |
|---------------------|-------------|-------------|---------|
| Ibuprofen           | 205→161     |             |         |
| Ketoprofen          | 253→209     | 253→197     |         |
| Naproxen            | 229→170     | 229→185     |         |
| Diclofenac          | 294→250     | 294→214     |         |
| Indomethacin        | 356→297     | 356→255     |         |
| Acetaminophen       | 152→110     | 152→93      |         |
| Mefenamic acid      | 240→196     | 240→180     |         |
| Propyphenazone      | 231→201     | 231→189     |         |
| Clofibric acid      | 213→127     | 213→85      |         |
| Gemfibrozil         | 249→121     |             |         |
| Bezafibrate         | 360→274     | 360→154     |         |
| Pravastatin         | 447→327     |             |         |
| Mevastatin          | 391→185     | 391→159     |         |
| Carbamazepine       | 237→194     | 237→192     |         |
| Fluoxetine          | 310→44      | 310→148     |         |
| Paroxetine          | 330→192     | 330→123     |         |
| Lansoprazole        | 370→252     | 370→205     |         |
| Famotidine          | 338→189     | 338→259     |         |
| Ranitidine          | 315→176     | 315→130     |         |
| Loratidine          | 383→337     | 383→267     | 383→259 |
| Erythromycin        | 734.5→158   | 734.5→576.4 |         |
| Azithromycin        | 749.5→591.4 | 749.5→158   |         |
| Sulfamethoxazole    | 254→92      | 254→156     |         |
| Trimethoprim        | 291→230     | 291→261     |         |
| Ofloxacin           | 362→316     |             |         |
| Atenolol            | 267→190     | 267→145     |         |
| Sotalol             | 273→255     | 273→213     |         |
| Metoprolol          | 268→133     | 268→159     |         |
| Propranolol         | 260→166     | 260→183     |         |
| Hydrochlorothiazide | 296→269     | 296→205     |         |
| Glibenclamide       | 494→369     |             |         |



deionised water (HPLC grade). Elution was performed twice with 4 mL methanol at a flow of 1 mL min<sup>-1</sup>. The extracts were then evaporated under a nitrogen stream and reconstituted with 1 mL 25:75 (v/v) methanol–water.

### Chemical analysis

LC analysis was performed with a Waters (Milford, MA, USA) 2690 HPLC system coupled to a Micromass Quattro (Manchester, UK) triple quadrupole mass spectrometer equipped with a Z-spray electrospray interface. Chromatographic separation was achieved on a Purospher Star RP-18 endcapped column (125 mm×2.0 mm, particle size 5 µm) and a C<sub>18</sub> guard column, both from Merck.

A specific multi-residue analytical method was set up for measurement of the concentrations of the pharmaceutical compounds in wastewaters [18]. Analysis was performed in multiple-reaction-monitoring (MRM) mode, in both posi-

tive and negative electrospray-ionization mode. This method was refined for analysis of hydrochlorothiazide and glibenclamide. MRM transitions selected for each compound are summarized in Table 1. In accordance with the performance characteristics defined in EU Commission Decision 2002/657/EC for confirmation and identification of pharmaceuticals when using LC–tandem MS as the instrumental technique, a minimum of three identification points are required. When using LC–MS–MS (QqQ) analysis two MRM transitions are sufficient to confirm the identity of a compound. The MRM ratio, calculated as the relationship between the abundances of both transitions and the LC retention time are also criteria used to confirm the presence of an analyte in the samples. In this study, therefore, transitions between a precursor ion and the two most abundant fragment ions were chosen for each analyte when working in MRM mode, resulting in four identification points, enough to conform with the aforementioned EU

**Table 2** Mean recoveries of the selected compounds and method detection limits (MDL) in ng L<sup>-1</sup>

| Compound            | Recovery (%)            |              |              | MDL (ng L <sup>-1</sup> ) |                      |
|---------------------|-------------------------|--------------|--------------|---------------------------|----------------------|
|                     | Influent                | MBR effluent | CAS effluent | Influent                  | MBR and CAS effluent |
| Ibuprofen           | 131 (18.1) <sup>a</sup> | 68.8 (11.0)  | 90.4 (11.0)  | 98.0                      | 20.0                 |
| Ketoprofen          | 62.8 (2.94)             | 71.3 (3.11)  | 59.1 (0.897) | 190                       | 74.0                 |
| Naproxen            | 49.2 (20.0)             | 59.4 (1.28)  | 53.4 (2.31)  | 79.0                      | 20.0                 |
| Diclofenac          | 83.3 (1.17)             | 94.9 (10.0)  | 95.0 (12.6)  | 160                       | 40.0                 |
| Indomethacin        | 113 (2.95)              | 120 (5.63)   | 110 (3.78)   | 150                       | 31.0                 |
| Acetaminophen       | 123 (17.0)              | 108 (10.5)   | 56.0 (7.61)  | 20.9                      | 5.35                 |
| Mefenamic acid      | 93.3 (1.95)             | 92.1 (1.02)  | 91.5 (5.29)  | 5.70                      | 1.85                 |
| Propyphenazone      | 60.0 (8.00)             | 71.0 (4.00)  | 71.0 (4.00)  | 4.80                      | 1.45                 |
| Clofibric acid      | 86.0 (10.8)             | 104 (6.87)   | 74.5 (1.40)  | 16.3                      | 3.75                 |
| Gemfibrozil         | 91.0 (8.47)             | 87.5 (1.36)  | 108 (17.2)   | 8.70                      | 2.20                 |
| Bezafibrate         | 106 (3.43)              | 94.4 (9.30)  | 89.4 (4.62)  | 18.5                      | 4.35                 |
| Pravastatin         | 85.6 (2.56)             | 78.0 (12.2)  | 96.0 (19.5)  | 120                       | 30.9                 |
| Mevastatin          | 103 (8.61)              | 134 (15.6)   | 123 (9.86)   | 9.30                      | 1.30                 |
| Carbamazepine       | 84.0 (7.84)             | 89.5 (5.20)  | 88.0 (9.24)  | 2.20                      | 0.600                |
| Fluoxetine          | 46.7 (2.34)             | 93.7 (17.6)  | 59.0 (1.60)  | 19.8                      | 1.70                 |
| Paroxetine          | 62.2 (2.15)             | 109 (5.73)   | 71.4 (1.49)  | 3.50                      | 0.650                |
| Lansoprazole        | 70.0 (10.0)             | 87.0 (5.00)  | 86.0 (4.00)  | 10.9                      | 4.20                 |
| Famotidine          | 58.2 (7.76)             | 55.4 (6.30)  | 66.6 (5.39)  | 3.10                      | 0.40                 |
| Ranitidine          | 41.5 (9.85)             | 75.8 (14.8)  | 125 (11.7)   | 1.40                      | 0.300                |
| Loratidine          | 72.6 (1.81)             | 78.0 (6.97)  | 64.5 (4.98)  | 8.00                      | 2.75                 |
| Erythromycin        | 67.7 (3.15)             | 50.0 (13.0)  | 66.6 (12.0)  | 12.4                      | 2.00                 |
| Azithromycin        | 30.0 (7.00)             | 73.0 (2.00)  | 63.0 (3.00)  | 1.00                      | 0.300                |
| Sulfamethoxazole    | 33.7 (2.76)             | 95.5 (9.24)  | 78.3 (1.08)  | 16.1                      | 3.10                 |
| Trimethoprim        | 58.8 (3.29)             | 128 (6.58)   | 60.8 (3.87)  | 1.30                      | 0.350                |
| Ofloxacin           | 142 (19.0)              | 135 (5.45)   | 138 (4.47)   | 29.3                      | 7.85                 |
| Atenolol            | 83.5 (33.8)             | 60.8 (10.8)  | 131 (15.5)   | 1.70                      | 0.750                |
| Sotalol             | 47.1 (2.91)             | 31.9 (3.05)  | 52.0 (3.63)  | 4.80                      | 0.700                |
| Metoprolol          | 36.7 (1.44)             | 120 (2.64)   | 76.7 (1.43)  | 6.30                      | 1.60                 |
| Propranolol         | 60.2 (0.506)            | 90.8 (4.02)  | 70.5 (5.27)  | 2.60                      | 0.300                |
| Hydrochlorothiazide | 39.8 (7.43)             | 58.9 (1.62)  | 73.4 (22.9)  | 4.50                      | 0.900                |
| Glibenclamide       | 100 (11.7)              | 107 (10.3)   | 98.5 (11.7)  | 19.2                      | 2.30                 |

<sup>a</sup>The relative standard deviation (%) of the recoveries is given in parentheses (*n*=3)



directive. When poor fragmentation was observed for the compounds, only one transition could be monitored. Confirmation of the identities of these was achieved by matching their LC retention times with those of standards. Shifts in retention times were less than 3%, so the confirmation was regarded as sufficiently reliable. For internal standards only one transition was selected, because they were isotopically labelled compounds unlikely to be found in environmental samples.

To compensate for matrix effects from sample matrices internal standard calibration and adequate dilution of sample extracts were used, on the basis of the previously published method [18].

Recoveries of the method were determined by spiking. Influent samples and CAS and MBR effluents were spiked in triplicate with a standard mixture of selected compounds to a final concentration of  $1 \mu\text{g L}^{-1}$ . Spiked samples and a blank sample were analysed by the above mentioned method. Recoveries of the target pharmaceuticals are listed in Table 2, with method detection limits (MDL) for influent and effluent samples. MDLs and method quantification limits (MQL) were calculated on the basis of signal-to-noise ratios ( $S/N$ ) of 3 and 10, respectively.

## Results and discussion

It is well documented that WWTPs are major contributors of pharmaceuticals in the environment. WWTP Rubí mainly receives domestic, hospital, and industrial wastewater and effluent concentrations of several monitored compounds exceed  $\mu\text{g L}^{-1}$  levels. Ranges of output loads for WWTP Rubí for each pharmaceutical and mean values ( $\text{g day}^{-1}$ ) are reported in Table 3. The quantities of pharmaceuticals discharged into the environment are calculated by multiplying the detected effluent concentrations by an average daily flow rate of  $22,000 \text{ m}^3 \text{ day}^{-1}$ . The total amount of pharmaceutical compounds discharged by WWTP Rubí into the environment exceeded  $300 \text{ g day}^{-1}$  (an average value). The most abundant compounds, with average individual loads of  $21\text{--}56 \text{ g day}^{-1}$ , were the anti-inflammatory drugs ibuprofen, naproxen, and diclofenac, the lipid regulators gemfibrozil and bezafibrate, the diuretic hydrochlorothiazide, and the  $\beta$ -blocker atenolol.

To assess the efficiency of elimination by the MBR, substance-specific analysis must be performed and the bulk properties DOC and COD of wastewater influents and effluents must also be determined. The performance of the MBR system is summarized in Table 4. The data are presented for the sampling period. Removal efficiencies of 98.7% for TSS and 90.4% for total COD were achieved during the membrane process. Average effluent ammonia concentration was  $1.01 \mu\text{g L}^{-1}$  in the MBR effluent, com-

**Table 3** Average daily output loads of the investigated pharmaceuticals for Rubí WWTP

| Pharmaceutical                                               | Effluent load ( $\text{g day}^{-1}$ ) |                       |
|--------------------------------------------------------------|---------------------------------------|-----------------------|
|                                                              | Mean                                  | Range                 |
| <i>Analgesics and anti-inflammatory drugs</i>                |                                       |                       |
| Naproxen                                                     | 37.0                                  | 10.8–76.9             |
| Ketoprofen                                                   | 17.1                                  | 11.4–36.3             |
| Ibuprofen                                                    | 56.3                                  | 7.39–137.9            |
| Diclofenac                                                   | 27.3                                  | 17.3–43.8             |
| Indomethacin                                                 | 1.93                                  | nd–2.73               |
| Acetaminophen                                                | 4.55                                  | 1.06–9.2              |
| Mefenamic acid                                               | 0.44                                  | 0.27–0.85             |
| Propyphenazone                                               | 0.68                                  | 0.43–0.96             |
| <i>Anti-ulcer agent</i>                                      |                                       |                       |
| Ranitidine                                                   | 2.77                                  | 0.55–5.30             |
| <i>Psychiatric drug</i>                                      |                                       |                       |
| Paroxetine                                                   | 0.08                                  | nd <sup>a</sup> –0.16 |
| <i>Antiepileptic drug</i>                                    |                                       |                       |
| Carbamazepine                                                | 5.21                                  | 1.44–6.71             |
| <i>Antibiotics</i>                                           |                                       |                       |
| Ofloxacin                                                    | 6.93                                  | 2.40–11.2             |
| Sulfamethoxazole                                             | 3.06                                  | 1.42–5.81             |
| Erythromycin                                                 | 2.29                                  | 0.95–4.51             |
| <i><math>\beta</math>-blockers</i>                           |                                       |                       |
| Atenolol                                                     | 21.0                                  | 7.70–33.2             |
| Metoprolol                                                   | 3.32                                  | 1.14–5.43             |
| <i>Diuretic</i>                                              |                                       |                       |
| Hydrochlorothiazide                                          | 33.7                                  | 21.2–46.0             |
| <i>Hypoglycaemic agent</i>                                   |                                       |                       |
| Glibenclamide                                                | 0.74                                  | nd–0.98               |
| <i>Lipid regulator and cholesterol lowering statin drugs</i> |                                       |                       |
| Gemfibrozil                                                  | 54.3                                  | 30.1–73.9             |
| Bezafibrate                                                  | 21.6                                  | 10.9–50.8             |
| Clofibrac acid                                               | 1.75                                  | 0.40–3.43             |
| Pravastatin                                                  | nd                                    | nd                    |

<sup>a</sup>Not detectable (below the LOQ)

pared with  $48.41 \mu\text{g L}^{-1}$  in the CAS effluent. It is known that membrane processes are quite efficient at removing COD and TOC from wastewater [19, 20]. Improved COD removal is attributed to the combination of complete retention of particulate material by the membrane, including suspended COD and high molecular weight organisms, and to avoidance of biomass washout problems common in activated sludge systems. Consequently, stable conditions are provided for growth of specialized microorganisms which are the able to remove poorly biodegradable components.

Of 31 pharmaceutical products included in the analytical method, 22 were detected in the wastewater entering WWTP Rubí. Box plots of measured concentrations of each pharmaceutical are showed in Figs. 1, 2 and 3. Ten measured values are given for influent and MBR effluent concentrations and eight for CAS effluent (data are missing



**Table 4** Summary of the performance of the MBR system

| Property                                   | Influent                   | MBR effluent   | CAS effluent  |
|--------------------------------------------|----------------------------|----------------|---------------|
| TSS (mg L <sup>-1</sup> )                  | 119.2 (17.37) <sup>a</sup> | 1.600 (1.770)  | 26.72 (15.69) |
| COD <sub>total</sub> (mg L <sup>-1</sup> ) | 508.2 (124.3)              | 48.58 (22.47)  | 111.6 (53.35) |
| TOC (mg L <sup>-1</sup> )                  | 67.67 (24.29)              | 10.89 (3.470)  | 27.33 (13.75) |
| N-NH <sub>4</sub> (mg L <sup>-1</sup> )    | 49.13 (15.79)              | 1.010 (0.4200) | 48.41 (12.87) |
| pH                                         | 7.52 (0.300)               | 7.08 (0.270)   | 7.63 (0.160)  |

<sup>a</sup>Values are averages from  $n=16$  samples, with standard deviations in parentheses

for two sampling programmes). For each variable the box has lines at the lower quartile (25%), median (50%), and upper quartile (75%) values. The whiskers are the lines extending from each end of the box to show the extent of the data up to 1.5 times the interquartile range (IQR). Outliers are marked with + symbols.

The highest influent concentrations ( $\mu\text{g L}^{-1}$ ) were measured for the analgesics and anti-inflammatory drugs naproxen, ibuprofen, ketoprofen, diclofenac, and acetaminophen, the antihyperlipoproteinaemic drugs gemfibrozil and bezafibrate, the  $\beta$ -blocker atenolol, and the diuretic hydrochlorothiazide. For other compounds input concentrations were usually in the range 10–100 ng L<sup>-1</sup>. Because the low concentrations measured were sometimes close to the limits of quantification, any hypothesis about the efficiency of their elimination is questionable. Mean removal was, nevertheless, calculated for each of the pharmaceutical compounds; the results are presented in Table 5. The most important removal pathways of organic compounds during wastewater treatment are:

1. biotransformation/biodegradation,
2. adsorption by the sludge (excess sludge removal), and
3. stripping by aeration (volatilization).

Because of the low values of the Henry coefficients ( $K_H$ ) of the compounds investigated [21], the fraction removed by volatilization can be neglected [16]. The two processes abiotic (adsorption) and biotic degradation (transformation by microorganisms) could not be distinguished, because no method was developed for analysis of the target compounds in sludge. The term “removal” is therefore used here for conversion of a micropollutant to compounds other than the parent compound.

Elimination efficiency of the laboratory-scale MBR and the full-scale CAS process was comparable for naproxen, ibuprofen, acetaminophen, hydrochlorothiazide, and paroxetine. All were removed to a large extent by both systems (removal was greater than 80% except for hydrochlorothiazide, for which it was between 56 and 85%). Hydrochlorothiazide and paroxetine were eliminated slightly better by conventional treatment. Similar results for the behaviour of these drugs during conventional treatment have been reported by several authors [2, 3, 9, 11].

For ketoprofen, diclofenac, bezafibrate, and gemfibrozil removal by the MBR system was very high and uniform (>90%), with the exception of two sampling programme. It is assumed this variation could have been a result of reduced microbial activity or altered sorption and flocculation conditions. No plausible explanation can be given for the drastically reduced efficiency of removal of clofibrate and mefenamic acid by MBR in two sampling programmes; otherwise these were eliminated with efficiencies between 65 and 90%. High and steady removal (>80%) in the MBR was also observed for ranitidine and ofloxacin. In conventional treatment all these pharmaceuticals were eliminated with a wide range of efficiencies, always lower than those obtained by the MBR. Better removal of readily biodegradable micropollutants by the MBR could be because of the smaller flock size of the sludge, which enhances mass transfer by diffusion and therefore increases elimination. Taking into consideration the composition of sludge originating from a membrane bioreactor (specialized microorganisms, large amount of active biomass in suspended solids) improved removal is to be expected; this was confirmed by our experiments.

A possible explanation of substantially greater attenuation of diclofenac by the MBR (average removal efficiency 87% compared with 50% in CAS) could be the greater age of the MBR sludge. Improved removal is observed with increasing solids retention time [14]. Another explanation could be greater adsorption potential of the MBR sludge, because the organic matter content is greater than for CAS sludge. According to results from the EU project Poseidon [22], adsorption processes affect elimination of diclofenac. Literature data on this matter is still very contradictory. Clara et al. reported poor removal of diclofenac in laboratory-scale WWTPs whereas in full-scale plants removal varied from less than 20% to between 60 and 80% for some of the facilities investigated [2]. Heberer et al. [7] reported low removal efficiencies in a WWTP whereas Ternes et al. documented significant (69%) elimination of diclofenac [8].

Removal of carbamazepine was, in contrast, very poor (<20%), and effluent concentrations for both MBR and CAS were frequently greater than influent levels. Poor elimination of this neutral drug has been reported by many authors [9, 11, 23, 24]. Glucuronide conjugates of carba-

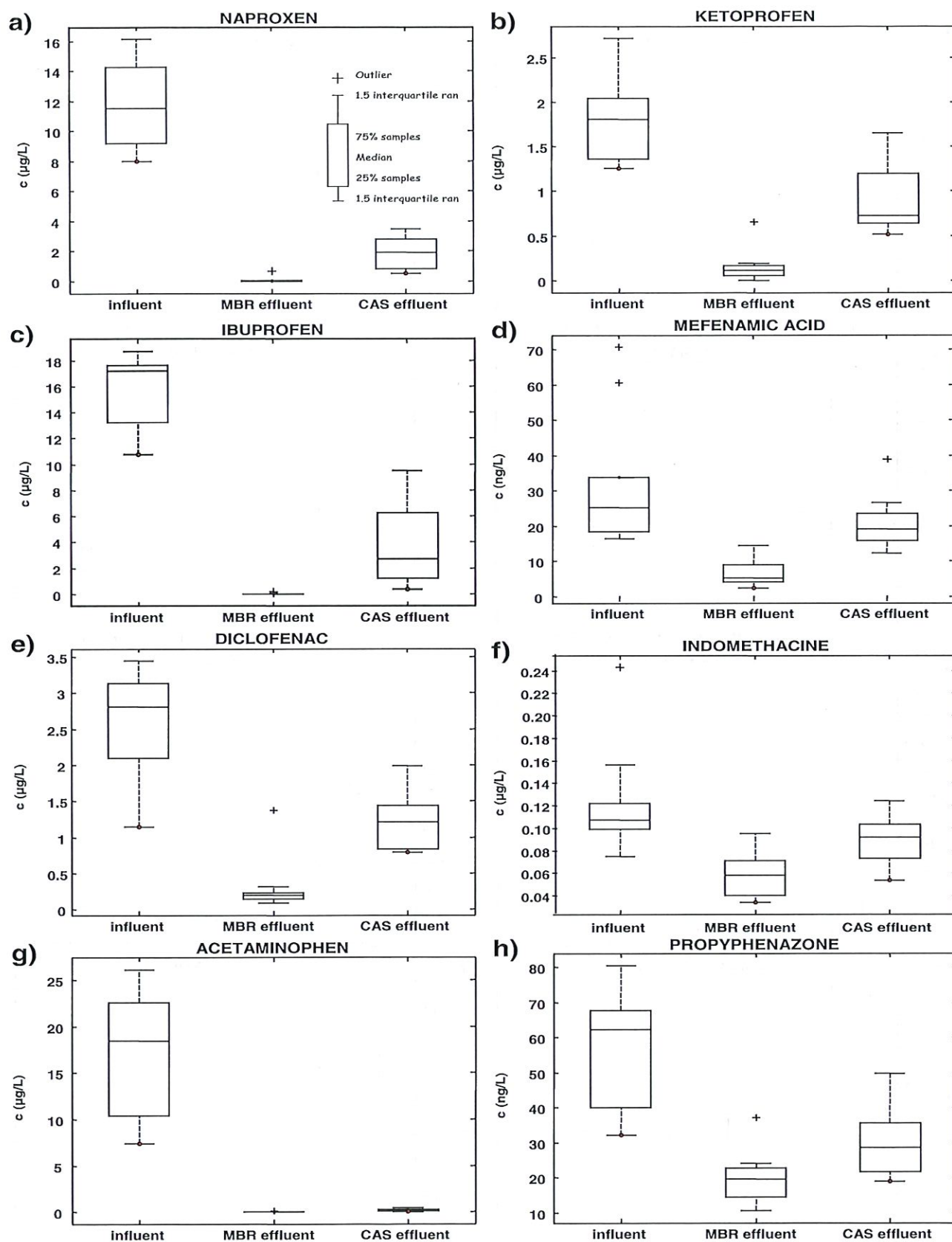
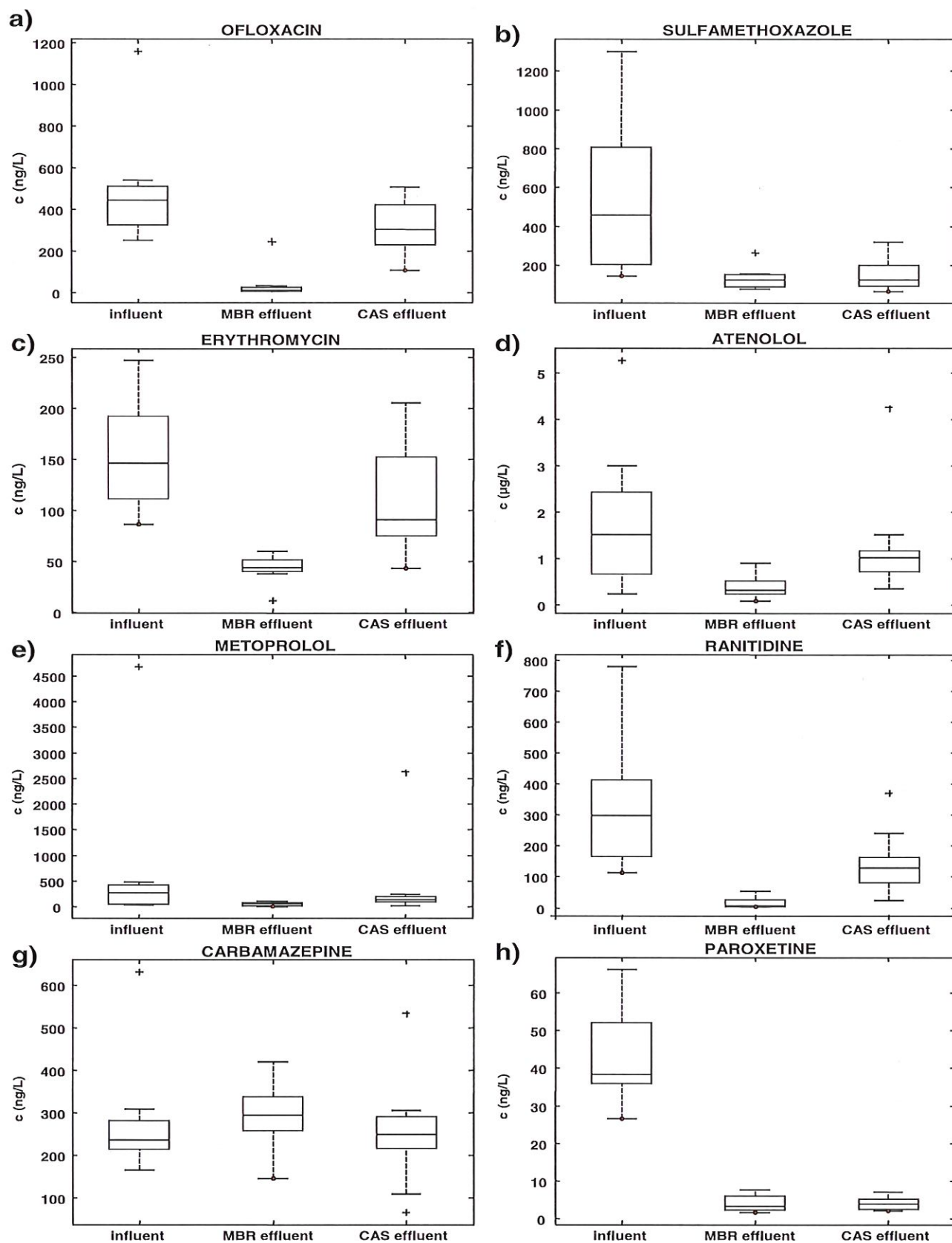


Fig. 1 Removal, during MBR and CAS treatment, of the analgesics and anti-inflammatory drugs naproxen (a), ketoprofen (b), ibuprofen (c), mefenamic acid (d), diclofenac (e), indomethacin (f), acetaminophen (g), and propyphenazone (h)





◀ Fig. 2 Removal during MBR and CAS treatment of the antibiotics ofloxacin (a), sulfamethoxazole (b), and erythromycin (c), the  $\beta$ -blockers atenolol (d) and metoprolol (e), the anti-ulcer agent ranitidine (f), the antiepileptic drug carbamazepine (g), and the psychiatric drug paroxetine (h)

mazepine can, presumably, be cleaved in sewage, thus increasing environmental concentrations [8].

Rates of removal of the antibiotic sulfamethoxazole were very variable in both treatments investigated. According to Drillia et al. its microbial degradation will depend on the

presence of readily biodegradable organic matter in wastewater; this varies during both MBR and CAS treatment [25]. Also, a substantial amount of sulfamethoxazole enters WWTPs as its human metabolite *N*<sub>4</sub>-acetylsulfamethoxazole, which can possibly be converted back to the original compound during treatment [26].

Efficiency of removal of atenolol, metoprolol, pravastatin, erythromycin, and indomethacin varied in both MBR and CAS treatment. This could not be explained. Fluctuation of elimination efficiency was also observed for propyphenazone

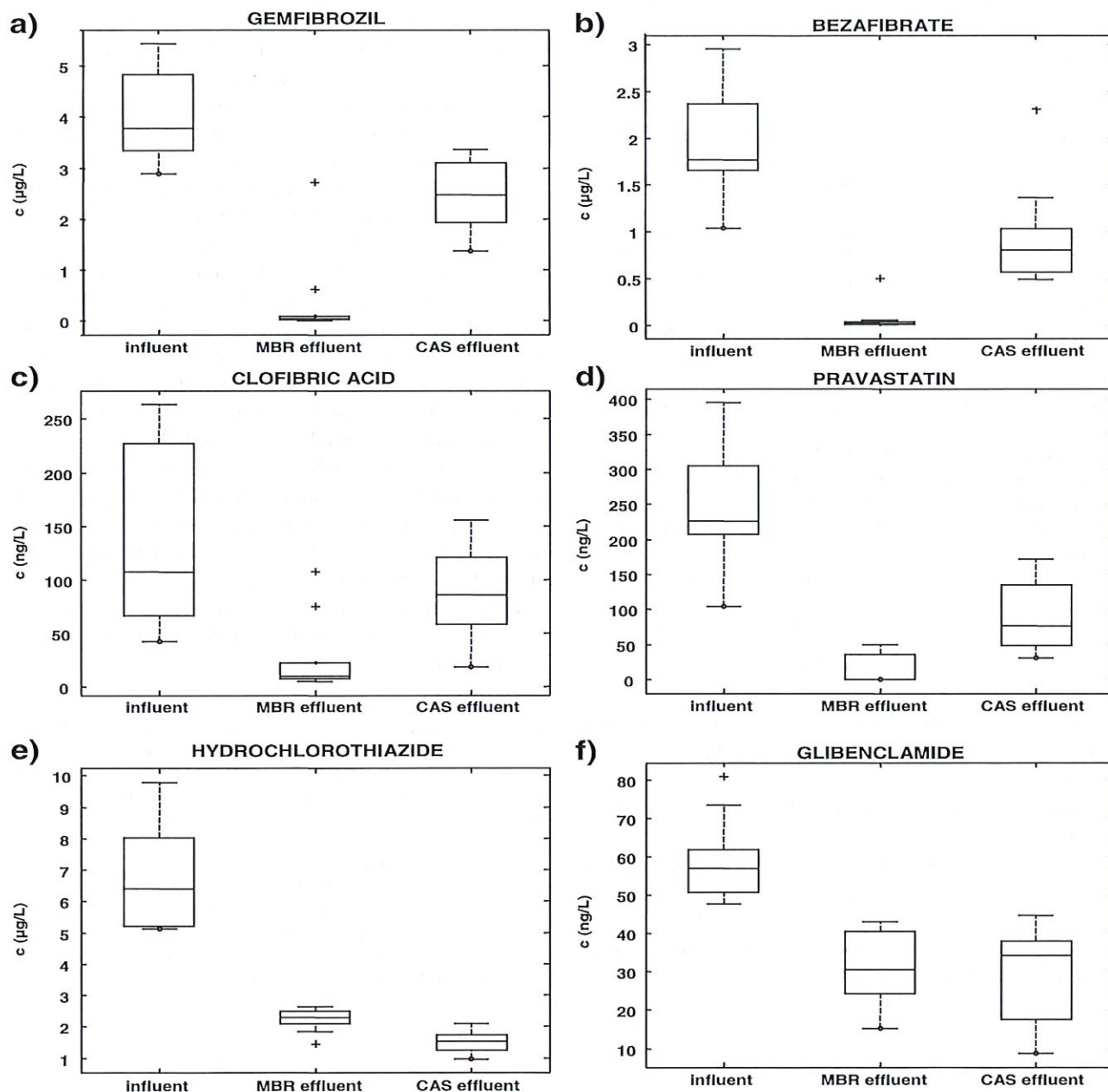


Fig. 3 Removal during MBR and CAS treatment of the lipid regulator and cholesterol-lowering statin drugs gemfibrozil (a), bezafibrate (b), clofibrilic acid (c), and pravastatin (d), the diuretic hydrochlorothiazide (e), and the hypoglycaemic agent glibenclamide (f)



**Table 5** Mean removal of selected pharmaceuticals by the MBR and CAS processes

| Compound                                                     | Elimination (%) in:         |                  |
|--------------------------------------------------------------|-----------------------------|------------------|
|                                                              | MBR <sup>a</sup>            | CAS <sup>b</sup> |
| <i>Analgesics and anti-inflammatory drugs</i>                |                             |                  |
| Naproxen                                                     | 99.3 (1.52)                 | 85.1 (11.4)      |
| Ketoprofen                                                   | 91.9 (6.55)                 | 51.5 (22.9)      |
| Ibuprofen                                                    | 99.8 (0.386)                | 82.5 (15.8)      |
| Diclofenac                                                   | 87.4 (14.1)                 | 50.1 (20.1)      |
| Indomethacin                                                 | 46.6 (23.2)                 | 23.4 (22.3)      |
| Acetaminophen                                                | 99.6 (0.299)                | 98.4 (1.72)      |
| Mefenamic acid                                               | 74.8 (20.1)                 | 29.4 (32.3)      |
| Propyphenazone                                               | 64.6 (13.3)                 | 42.7 (19.0)      |
| <i>Anti-ulcer agents</i>                                     |                             |                  |
| Ranitidine                                                   | 95.0 (3.74)                 | 42.2 (47.0)      |
| <i>Psychiatric drugs</i>                                     |                             |                  |
| Paroxetine                                                   | 89.7 (6.69)                 | 90.6 (4.74)      |
| <i>Antiepileptic drugs</i>                                   |                             |                  |
| Carbamazepine                                                | No elimination <sup>c</sup> | No elimination   |
| <i>Antibiotics</i>                                           |                             |                  |
| Ofloxacin                                                    | 94.0 (6.51)                 | 23.8 (23.5)      |
| Sulfamethoxazole                                             | 60.5 (33.9)                 | 55.6 (35.4)      |
| Erythromycin                                                 | 67.3 (16.1)                 | 23.8 (29.2)      |
| <i>B-blockers</i>                                            |                             |                  |
| Atenolol                                                     | 65.5 (36.2)                 | No elimination   |
| Metoprolol                                                   | 58.7 (72.8)                 | No elimination   |
| <i>Diuretics</i>                                             |                             |                  |
| Hydrochlorothiazide                                          | 66.3 (7.79)                 | 76.3 (6.85)      |
| <i>Hypoglycaemic agents</i>                                  |                             |                  |
| Glibenclamide                                                | 47.3 (20.1)                 | 44.5 (19.1)      |
| <i>Lipid regulator and cholesterol lowering statin drugs</i> |                             |                  |
| Gemfibrozil                                                  | 89.6 (23.3)                 | 38.8 (16.9)      |
| Bezafibrate                                                  | 95.8 (8.66)                 | 48.4 (33.8)      |
| Clofibrac acid                                               | 71.8 (30.9)                 | 27.7 (46.9)      |
| Pravastatin                                                  | 90.8 (13.2)                 | 61.8 (23.6)      |

<sup>a,b</sup> Values are averages, with relative standard deviations (%) in parentheses, for  $n=10^a$  or  $n=8^b$  samples

<sup>c</sup> Compounds were classified as “no elimination” if elimination was less than 10%

(44.8–82.9% for MBR and 6.82–62.6% for CAS) and glibenclamide (14.8–73.7% for MBR and 11.9–79.7% for CAS).

Effluent concentrations greater than those recorded for the influent could be explained by the presence of input conjugate compounds that are transformed into the original compounds during treatment. Because these conjugates were not included in the analysis, no firm conclusion can be made about their biotransformation, especially because sampling inaccuracy can also lead to errors.

## Conclusion

Several pharmaceutical products (e.g. ibuprofen, naproxen, acetaminophen, ketoprofen, diclofenac, bezafibrate, gemfi-

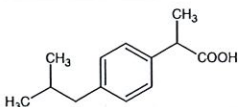
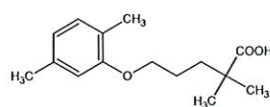
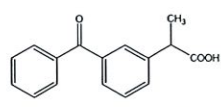
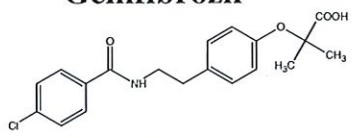
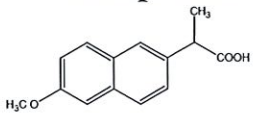
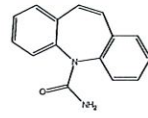
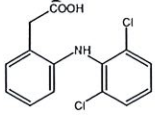
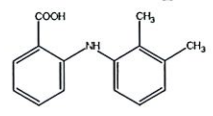
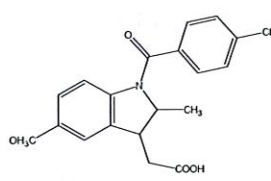
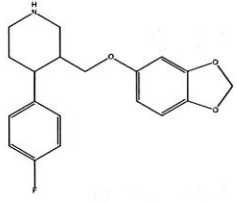
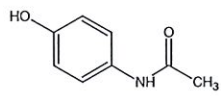
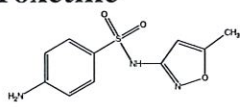
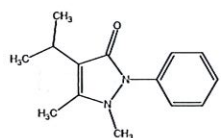
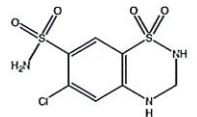
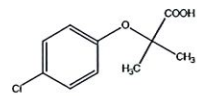
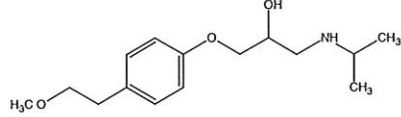
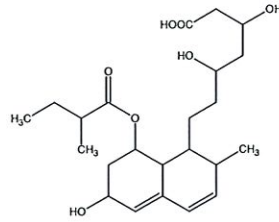
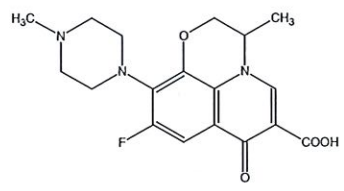
brozil, ranitidine, ofloxacin, hydrochlorothiazide, and paroxetine) with high rates of attenuation can be expected to be completely removed from wastewater by adsorption or degradation, or a combination of both, during membrane treatment. For most of the compounds investigated MBR effluent concentrations were significantly lower than in the effluent from conventional treatment. Elimination of hydrochlorothiazide and paroxetine was slightly better in CAS treatment. Some substances (e.g. carbamazepine) were not removed by either MBR or CAS treatment. No relationship was found between the structures of target compounds and their removal during wastewater treatment, however. The range of variation of the efficiency of removal by the MBR system was small for most of the compounds; in conventional treatment greater fluctuations were observed and removal efficiency was found to be much more sensitive to changes in operating conditions (temperature, flow rate, etc).

Although membrane technology seems a promising means of removal of pharmaceutical compounds, the MBR process investigated would not completely halt discharge of micropollutants. Membrane treatment processes should be optimized by modification of the membranes (variation of the materials and reduction of molecular mass cut-off limits) and/or by modification of the treatment process (inoculation of special microorganisms). The efficiencies of diverse microbial populations in elimination of selected pharmaceuticals, and optimization of design and operating conditions of a laboratory-scale MBR will be the main objectives of our future investigations. That would provide guidelines for scale-up of a biological pilot plant and its evaluation by integration into an industrial process water-recycling system. Because of the current lack of information on the behaviour of pharmaceuticals in surface and wastewaters, however, further studies are required on the occurrence, fate, and effects of these substances in the environment.

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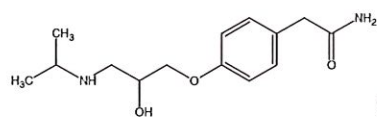
## Appendix

Structure and CAS numbers of the pharmaceutical products studied.

| Compound                                                                            | CAS number | Compound                                                                             | CAS number  |
|-------------------------------------------------------------------------------------|------------|--------------------------------------------------------------------------------------|-------------|
|    | 15687-27-1 |    | 25812-30-0  |
| <b>Ibuprofen</b>                                                                    |            | <b>Gemfibrozil</b>                                                                   |             |
|    | 22071-15-4 |    | 41859-67-0  |
| <b>Ketoprofen</b>                                                                   |            | <b>Bezafibrate</b>                                                                   |             |
|    | 22204-53-1 |    | 298-46-4    |
| <b>Naproxen</b>                                                                     |            | <b>Carbamazepine</b>                                                                 |             |
|    | 15307-86-5 |    | 61-68-7     |
| <b>Diclofenac</b>                                                                   |            | <b>Mefenamic acid</b>                                                                |             |
|   | 53-86-1    |   | 110429-35-1 |
| <b>Indomethacin</b>                                                                 |            | <b>Paroxetine</b>                                                                    |             |
|  | 103-90-2   |  | 723-46-6    |
| <b>Acetaminophen</b>                                                                |            | <b>Sulfamethoxazole</b>                                                              |             |
|  | 479-92-5   |  | 58-93-5     |
| <b>Propiphenazone</b>                                                               |            | <b>Hydrochlorothiazide</b>                                                           |             |
|  | 882-09-7   |  | 37350-58-6  |
| <b>Clofibric acid</b>                                                               |            | <b>Metoprolol</b>                                                                    |             |
|  | 81093-37-0 |  | 82419-36-1  |



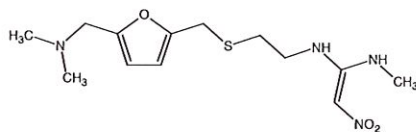
**Pravastatin**  
Continuation of **Appendix**



29122-68-7

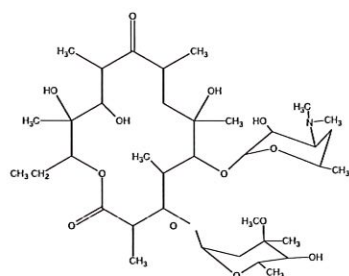
**Atenolol**

**Ofloxacin**



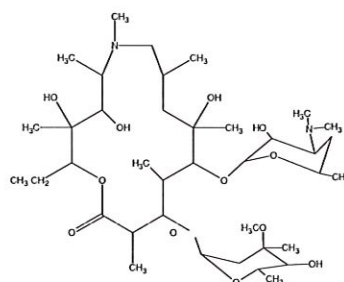
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**Ranitidine**



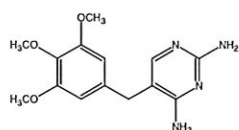
114-07-8

**Erythromycin**



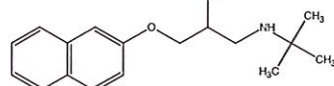
117772-70-0

**Azithromycin**



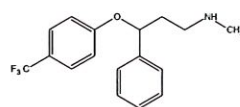
738-70-5

**Trimethoprim**



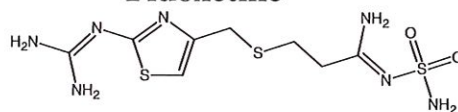
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**Propranolol**



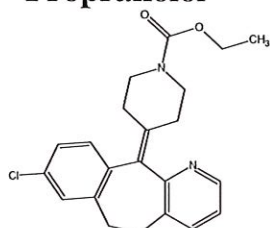
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**Fluoxetine**



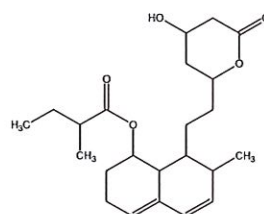
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**Famotidine**



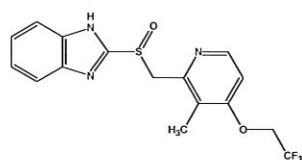
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**Loratadine**



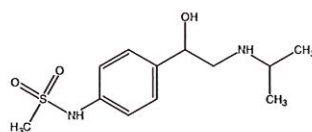
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**Mevastatin**



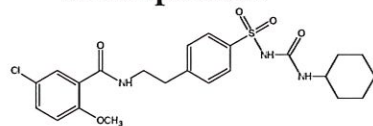
103577-45-3

**Lansoprazole**



959-24-0

**Sotalol**



10238-21-8

**Glibenclamide**

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