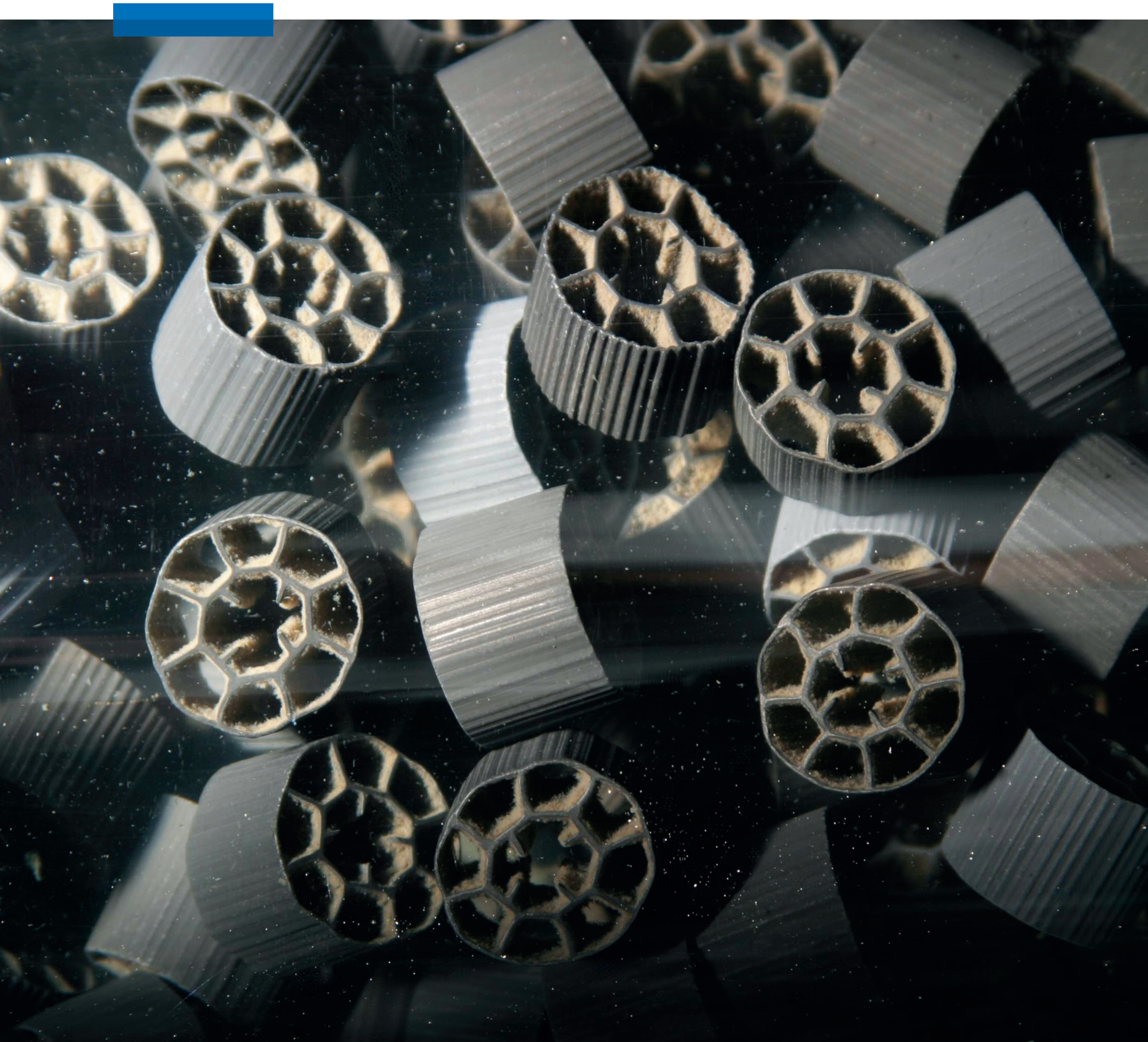
PLASTIC BIOCARRIERS

RECOMMENDATIONS FOR THE USE IN WASTEWATER TREATMENT PLANTS



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DISCLAIMER

This publication was initiated by the Swedish Environmental Protection Agency and the Nordic Council of Ministers. However, its content does not necessarily reflect their views, opinions, or recommendations.

Illustration | ***Cover picture*** | *Bacterial colonisation on biocarriers.*

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DEFINITION OF TERMS

AUDIT Official inspection of processes and measures in place by the manufacturing or operating site to prevent biocarrier loss.

BIOCARRIER Plastic support for bacterial growth used in fluidised bed biological treatment processes (MBBR, etc).

LIFE CYCLE Sequence of steps from biocarrier production to their final use.

PREVENTIVE MEASURES All protocols and installations intended to preclude the risk of loss of biocarrier to the natural environment.

LEAKAGE Unintentional loss of biocarriers into the natural environment.

STAKEHOLDERS All institutions, project owners and their subcontractors, and any organisation that may be involved in the biocarrier life cycle.

SPILL Discharge of untreated wastewater into the natural environment. It may also involve the discharge of untreated industrial water into the municipal sewer system.

DISCHARGE Release of treated wastewater into the natural environment.

BASIN Storage space for effluent during the treatment process, usually open.

TANK Same function as a basin but usually closed.

BIOFILM A multicellular community of bacterial micro-organisms adhering to each other & to a surface and marked by the secretion of an adhesive and protective matrix. It is usually formed in water or in an aqueous medium.

PRODUCTION SITE The industrial site where biocarriers are produced.

TRANSPORT Long-distance transport between the production site and the storage site.

STORAGE SITE Any area where biocarriers can be stored in large quantities and for long periods. It can be located inside the production site, on the transport platform, or in the Wastewater Treatment Plant enclosure before being introduced into the tanks.

HANDLING Means used to move or transport containers over short distances, to fill or pour biocarriers.

ACRONYMS AND ABBREVIATIONS USED IN THE RECOMMENDATIONS

EU European Union

NGO Non-Governmental Organisation

OSPAR The Convention for the Protection of the Marine Environment of the North-East Atlantic or OSPAR Convention is the current legislative instrument regulating international cooperation on environmental protection in the North-East Atlantic.

RAP ML2 2nd Regional Action Plan for Marine Litter

HIRA Hazard Identification & Risk Analysis

CMMS Computerized Maintenance Management System

MBBR Moving Bed Biofilm Reactor

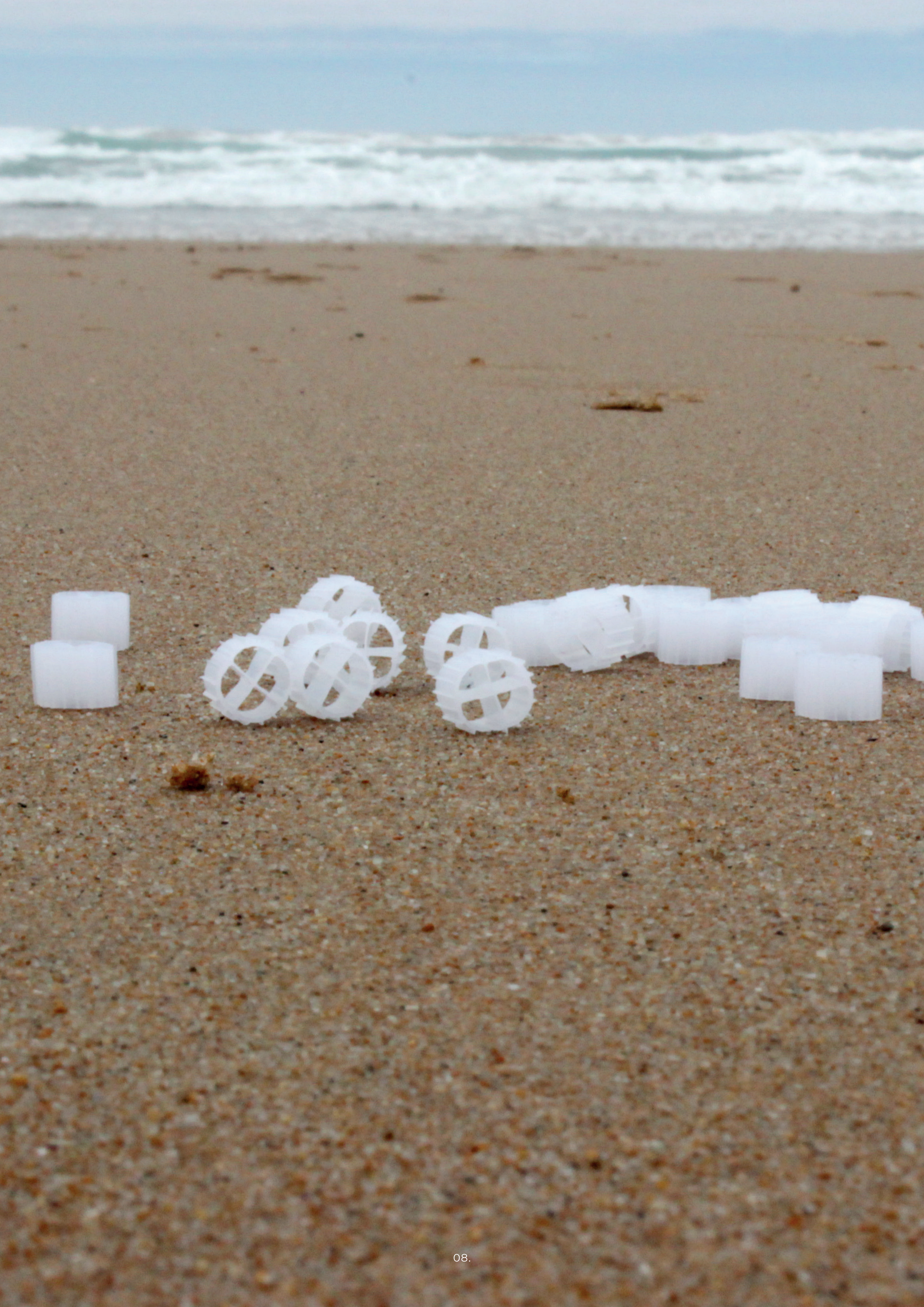
UWWTD Urban Wastewater Treatment Directive - European Directive 91/271/EEC

MSFD Marine Strategy Framework Directive - European Directive 2008/56/EC

WFD Water Framework Directive - European Directive 2000/60/EC

UNEA United Nations Environment Assembly

WWTP WasteWater Treatment Plant



1 EXECUTIVE SUMMARY

Every year, an estimated 8 to 12 million tons of plastic enter the Ocean. All the world's oceanic and coastal ecosystems are currently threatened by plastic pollution, detrimental to marine species (strangulation, ingestion...), sea beds (deterioration of the sea floor) and to human through adverse socio-economic impacts.

Over the 15 past years, leakages of millions of plastic biocarriers - supports for bacterial growth used in certain types of Wastewater Treatment Plants (WWTPs) - have been reported in riverine and marine environments. In most cases, these biocarriers are not recovered in the aquatic environment, thus contributing to the issue of global plastic pollution.

Different studies were undertaken to identify the sources of such leakages and around 40 study cases were analysed to improve understanding of the causes of this type of pollution from WWTPs. In Nordic countries, pollution cases have been reported in Sweden, Iceland, Denmark and Norway. The physical properties of biocarriers, make them highly mobile pollutants with the capacity for rapid dispersion in the aquatic environment.

Of the 15 contracting parties of the OSPAR Convention, at least 11 are directly affected by biocarrier pollution.

Biocarrier leakages fall into two principal categories: either massive one-off (acute) leakages or more difficult-to-track chronic diffuse leaks. Municipal and industrial WWTPs of any size and location can be affected.

***Illustration** | **Left page** | Biocarriers on the beach in the Basque Country. © Surfrider Foundation Europe*

To address this type of plastic pollution and reduce its environmental impact, the Swedish Environmental Protection Agency has become involved in the issue.

The objective herein is to develop guidelines for the safe management of biocarriers based on proven-effective existing technical solutions and management measures, with the overarching goal of preventing releases of biocarriers in the marine and riverine environments.

A holistic approach, encompassing every step of the biocarriers' life cycle, helped to identify possible improvements in production, transportation, storage, engineering, facility operation, and biocarrier disposal.

To ensure the feasibility of these guidelines, stakeholders representing the different stages were conferred with for their feedback and suggestions regarding good practices. A wide variety of proposals were considered, from administrative procedures to on-site equipment upgrades and installations to establish a solid basis for future preventive and remedial actions.

This report will also contribute to shared policy development between the Nordic countries and to identify & follow up on possible areas for further improvements, cooperation, and collaboration regarding plastic pollution.

2 PREAMBLE

These guidelines aim to provide a series of good practices for the Nordic countries and guidance for all stakeholders, public or industrial, involved in the overall biocarrier life cycle: from permitting authorities to the designers and operators of wastewater systems.
Implementation of these proposals should help reduce the risk of unintentional leakage of biocarriers into marine and riverine environments due to wastewater treatment plant malfunction.

BIOCARRIERS: AN ADDITIONAL CONTRIBUTION TO PLASTIC POLLUTION

The accumulation of plastic in the ocean and on shorelines has become a global problem. Every year, an estimated 8-12 million tons of plastic waste enters the ocean. From surface waters to deep marine sediments, plastic is everywhere, threatening marine and coastal ecosystems. Fifteen years ago, a new form of plastic pollutants was observed along the North Atlantic coast. These were identified as the biocarriers used to improve the efficiency of biological wastewater treatment. Due to unintentional leakage from various types of sewage treatment processes, biocarriers end up in the aquatic environment and on the coast, where they contribute to plastic pollution.

WHAT ARE BIOCARRIERS?

Biocarriers are plastic media used in WasteWater Treatment Plants (WWTPs) in the secondary treatment (biological) phase. During this phase, bacteria break down organic and nitrogen compounds as well as phosphorus [1]. In this type of fixed-bed culture system, the bacteria are grown on a variety of supports to form biofilms. Added in millions into the tanks, biocarriers offer a significantly larger surface area for biofilms to grow, thereby increasing the purification capacity.

At the same time, the inclusion of biocarriers reduces the amount of land occupied by installations.

Depending on treatment requirements (nature and volume of the effluent, receiving waters), different technologies using biocarriers can be implemented. Some of the most commonly used are:

→ Moving Bed Biofilm Reactor (MBBR)

→ Integrated Fixed Film Activated Sludge (IFAS)

Since the late 1990s, multiple techniques using biocarriers have been developed to achieve compliance of wastewater treatment discharges in accordance with the European Urban Wastewater Treatment Directive (UWWTD) requirements. Biocarriers can be either fixed or fluidised (i.e., set in motion in the water column) and composed of different materials. These can be natural-origin minerals such as clay balls and volcanic rocks or synthetic supports made of plastic. In the event of a leak, the main environmental concern evidently relates to plastic media.

The three main categories of plastic supports used in fluidised processes are the following:

▸Biocarriers
Usually, small 1 to 5 cm cylinders, but can also be in flat chip form. They are made of high-density polyethylene (HDPE) or polyethylene (PE). They are principally used in Moving Bed Biofilm Reactor (MBBR) -type processes.

▸Biobeads
Irregular 3-5mm beads constructed from polyethylene PE and heterogeneous recycled PE (rPE), which are potentially non-compliant with current hazardous plastic waste regulations[2].

▸Polystyrene beads
Spherical and regular 3-5mm beads

PROBLEM STATEMENT

A number of WWTPs using the Moving Bed Biofilm Reactor (MBBR) process experience malfunctions and thus may leak plastic biocarriers into the environment.

Since the end of the 2010s, massive releases of biocarriers (from several thousand to several million pieces) into aquatic environments have been observed in Europe[3,4,5]. Of the 15 countries signatory of the OSPAR Convention, at least 11 are directly affected by biocarrier pollution (CH, DK, FR, DE, IS, NL, NO, PT, ES, SE, UK) (Annex 1).

***Illustrations** | **Left page** | Biocarriers accumulated on river banks after an important leakage. Seine river France. © Renaud François) | **Above (bottom)** | Biostyrene beads © Surfrider Foundation Europe | **Above (top)** | Black biobeads from Plympton Beach. © Claire Wallerstein*

__Notes__ | __1.__ Lustig, G., 2012, Moving bed biofilm reactors (MBBR) I Sverige, Svenskt Vatten. __2.__ Turner, A., Wallerstein, C., Arnold, R., 2019, Identification, origin and characteristics of bio-bead microplastics from beaches in western Europe, Science of The Total Environment, Volume 664, pp. 938-947. __3.__ Bautista Barrera, S. , 2021, Att stänga av kranen för marint skräp: en rapport om fyra föremål, Master's thesis at the University of Gothenburg. __4.__ Bencivengo, P., Barreau, C., Bailly, C., Verdet, F., 2018, Wastewater filter media and pollution of aquatic environments. __5.__ Tunstad, A. , 2021, The biocarrier escape routes, Identifying leaks through a Product Chain Organisation study, MSc thesis in Industrial Ecology, University of Chalmers

Other diffuse and chronic cases of leakage into the environment have also been observed, but knowledge gaps concerning the WWTP operators in general makes identifying the sources of these releases difficult.

In most cases, biocarriers reaching the aquatic environment are not recovered and thus contribute to global plastic pollution. They are washed up on shorelines or are ingested by marine animals (turtles, birds, etc.), thus contributing to the degradation of ecosystems.

The physical properties of biocarriers, particularly their density close to that of water, make them highly mobile pollutants with the capacity for rapid dispersion in the aquatic environment and all the more difficult to contain.

SOLUTIONS AVAILABLE

Reducing risks at the source remains the most efficient solution for addressing plastic pollution. The guidelines follow the biocarrier's life cycle, from WWTP design to the final usage or disposal of biocarriers. There is a broad scope of action to resolve the issue of biocarrier pollution.

***Illustration** | **Left page** | Biocarriers and microplastics removed from the digestive tract of a fulmar from the Faroe Islands. © J.A. van Franeker / Wageningen Marine Research*

Interviews of stakeholders involved in different stages of the biocarrier life cycle identified risk-mitigating measures, either already implemented or requiring implementation from scratch. These measures vary from regulatory oversight to technological upgrades to improvements in crisis management plans. To reach the objective of reduced biocarrier leakage, the mobilization of all stakeholders is essential to ensure that this type of pollution is considered in relation to its environmental impact. The implementation of preventive measures and the securing of wastewater treatment systems also appeared as key steps to effectively reducing the risk of leakage.

The recommendations in this document focus on biocarriers. However, it would be relevant to extend their application to the 3 types of plastic supports mentioned above, given the similarity of their physical properties and use.

INTERNATIONAL COOPERATION

The report will contribute to policy development between the Nordic countries and to identify and follow up on possible areas for further cooperation and collaboration.

It will also advance the United Nations Environment Assembly (UNEA) resolution 3/7, which stresses the long-term ambition of eliminating the discharge of plastic litter and microplastics into the oceans and to UN Sustainable Development Goals 14.1.

Furthermore, this document represents a contribution to the work of the Convention for the Protection of the Marine Environment of the North-East Atlantic (more commonly known as the OSPAR Convention) in relation to its objective on marine litter, namely "to reduce substantially the amount of marine litter in the OSPAR maritime area to levels where its properties and quantities do not cause harm to the marine environment".

Even if these guidelines are initially addressed to Nordic Countries, it should be noted that although each WWTP has its own environmental specificities the core of the issue remains the same wherever its location. Therefore, these recommendations apply to a wide range of facilities.

3 METHODOLOGY

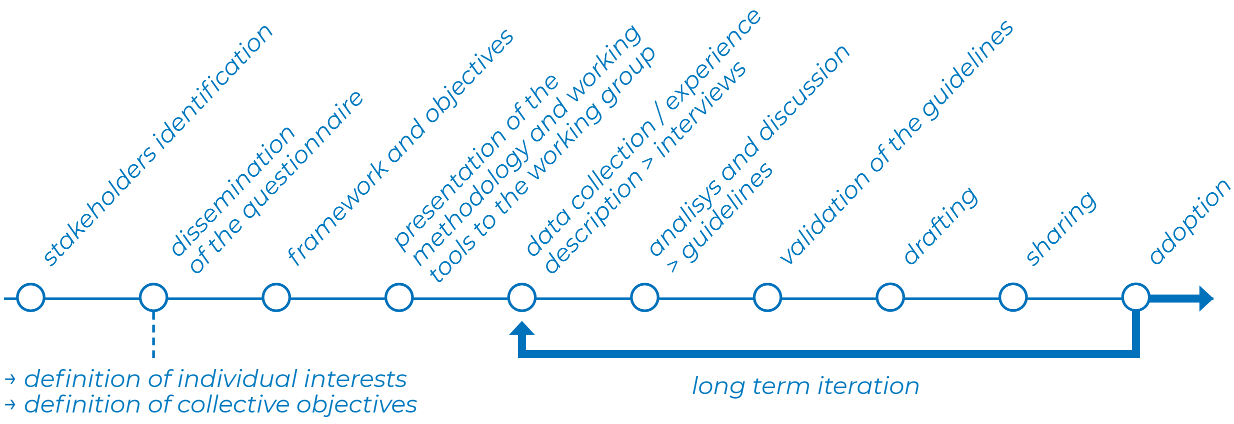
All the proposals mentioned in this document are the result of expertise acquired over 12 years of studying the processes involved, analysis of the pollution cases referred to, and of interviews conducted with a representative panel of all stakeholders involved in WWTP operation (Annex 2)**.**

The primary objective was to determine the measures/actions to implement to secure the use of biocarriers throughout their life cycle.

The definition of the different stages of the life cycle of the biocarriers that has been chosen considers all stages of their use, from production sites to their end of life, either accidental or controlled [6][7]. Besides the product life cycle, linking regulatory and administrative procedures within WWTPs was also shown to be an opportunity to improve the management of the use of biocarriers and associated facilities.

***Illustrations** | **Above (picture)** | Activated sludge treatment plant © Irstea E. Cotteux | **Above (figure)** | Stages of the biocarrier life cycle. © Surfrider Foundation Europe*

***Notes** | **6.** Agence de la Santé et des Services Sociaux de la Montérégie (Québec), 2015, Manuel d'élaboration d'un guide de bonnes pratiques. **7.** EUNOMIA (2019) Preventing plastic pellet loss in supply chains. Design of a supply chain approach to prevent pollution from plastic pellets. A report for Zero Waste Scotland.*



The recommendations are the result of an iterative process in which each stakeholder was consulted several times.

The various stages to establish the guidelines were as follows:

→ Synthesis of available information, previous studies, and reports.

→ Collection of additional unpublished data and information from environmental authorities and expert NGOs:

— Specific questions at meetings and in emails;
— OSPAR shared documents (Summary of information shared by the OSPAR contracting parties in response to the request for information of 22nd of June 2022).

→ Identification of stakeholders involved in the biocarrier life cycle (Annex 2).

→ Interviews and questionnaires on stakeholders' experiences regarding the use of biocarriers (Annex 3).

→ Analysis of experiences and Best Available Techniques (BATs) and determination of appropriate measures to be implemented.

→ Discussions on recommendations (iterative approach, including new recommendations with each new discussion or interview).

More details on this method are provided in A. Tunstad 2021, The biocarrier escape routes, which describes the socio-material approach as a means of data collection and analysis, the development of new questions, and the elaboration of recommendations as a simultaneous procedure where the different steps influence each other.

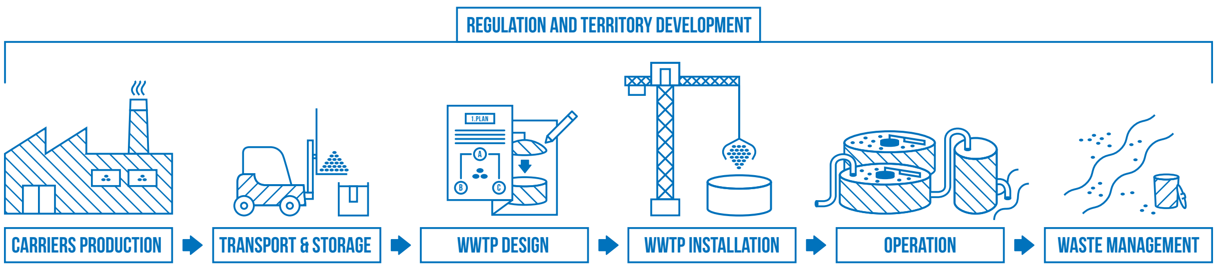
***Illustrations** | **Above** | Long-term iterative process for the implementation of good practices. | **Below** | Biocarriers collected on the shore of Serre-Poncon Lake, France, 2021. ©JP Coulomb | **Right page** | Above view of a WWTP. © Ivan Bandura*

4 RECOMMENDATIONS

This study is based on observed cases and testimonies collected over several months but is not exhaustive. Given the complexity of biocarrier life cycles and associated wastewater systems, facilities will always be somewhat vulnerable due to their permanent exposure to environmental hazards.

Considering the weak points identified, many improvements can be implemented in installation design, purification practices, training of operating personnel and administrative authorities, or crisis management.

For the sake of consistency and readability, the recommendations are presented by chronology in the biocarrier life cycle and by stakeholder type.



4.1 EUROPEAN AND NATIONAL REGULATIONS

TARGET National authorities

PHASE System design / installation

4.1.1 EXISTING MEASURES AT EUROPEAN LEVEL AND REPORTED WEAKNESSES

European and national regulations establish the normative framework within which sanitation installations should be designed in order to limit their impact on the aquatic environment. This concerns municipal, industrial, and individual wastewater treatment systems.

The presence of plastic litter in the environment is increasingly considered as an indicator of good environmental status, such as descriptor 10 of the **EU Marine Strategy Framework Directive 2008/56/EC (MSFD)** "Marine litter - Properties and quantities of marine litter do not cause harm to the coastal and marine environment". This type of measure involves the establishment of monitoring protocols to quantify and identify reduction targets.

The European Water Framework Directive 2000/60/EC (WFD) does not include plastic waste as an indicator of good ecological status (GES) in rivers. However, it is proven that rivers are the main transfer pathway from land-based sources to the ocean. As a result, there is a visible lack of coordination between the WFD and the MSFD and consequently a lack of preventive measures at the catchment basin scale.

The current **Urban Wastewater Directive 91/271/EEC (UWWD)**, which regulates the discharge of treated wastewater into the environment, does not include targets for the reduction of plastic/microplastic waste in discharged water and does not take into account the presence of plastic biocarriers in the installation operations.

In light of this non-exhaustive regulatory review, biocarriers may be insufficiently covered by European legislation. The lack of a link in the land-sea continuum and the age of certain directives may also be a hindrance to the implementation of preventive or corrective measures consistent with current issues. Penalties for pollution are rarely applied due to a lack of clear legal recognition of the issue.

4.1.2 RECOMMENDATIONS: IMPLEMENTATION OF NEW MEASURES

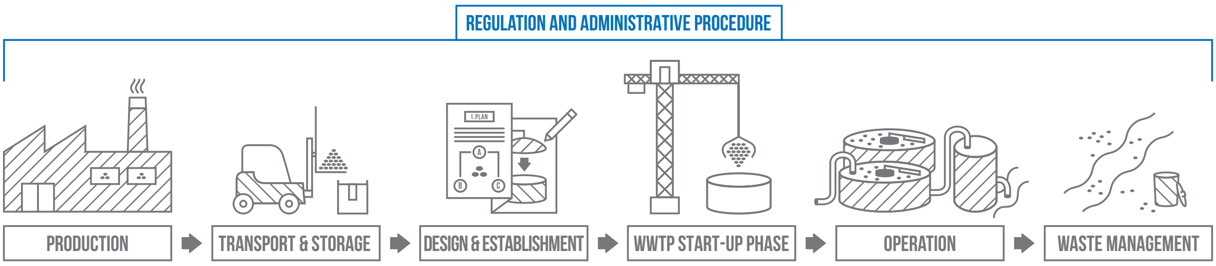
Regulation is an essential means of action that allows local, regional, national, or European authorities to determine standards and control requirements: release thresholds, technical documents for risk assessment & emergency procedures, and specific equipment to be used.

▸**Adoption of ambitious measures**
Bring about major improvements in the prevention of biocarrier leakage into aquatic environments through European and national legislation. In particular, the Urban Wastewater Treatment Directive could add biocarriers as a potential environmental hazard.

▸**Integration of plastic waste as an indicator of the good ecological status of the waters targeted by the WFD**
Take the transfer routes of continental origin into consideration and thus safeguard the land-sea continuum in accordance with MSFD provisions.

Illustration | ***Below*** | *Collect of Biocarriers after a leakage in Vindafjord, Norway, 2018. © R.R.*

4.2 ADMINISTRATIVE PROCEDURE FOR DISCHARGE AUTHORISATION



TARGET Licensing authorities

PHASE System installation

4.2.1 EXISTING MEASURES AND REPORTED WEAKNESSES

To ensure effective treatment of effluent before discharge into the receiving environment, all urban wastewater from agglomerations of 2,000 population equivalent (p.e.) and above, as well as all industrial wastewater, should comply with national/European regulations.

When a wastewater system is created or upgraded, an environmental discharge permit must be issued. Requests for discharge authorisations are addressed to the appropriate government agencies. Depending on the size and type of facility, these may be different departments with a local, regional, or national scopes of intervention.

→ At present, only general details (effluent to be treated, general process, treatment capacity) of the biological treatment processes used are provided to the authorities responsible for authorising discharges into the environment.

→ The authorities responsible for the approval of wastewater treatment plant applications are not always sufficiently trained to analyse the technical specifications of the wastewater treatment systems to be installed.

→ Information on the characteristics of treatment plants and details of biological processes (e.g. type and volume of biocarriers used) are not collected in a central database and data on industrial and individual systems are not readily available.

In some countries, such as Sweden[8] , Norway or France, an assessment of the risks and sustainability of WWTPs' is required as part of the permit approval process. This document is intended to evaluate the risks related to the system itself, but does not cover all potential risks related to MBBR processes.

Nevertheless, there is no obligation to declare the use of plastic supports, such as biocarriers for biofilm growth, during biological treatment. The purpose of the discharge permit is principally to ensure that the treated effluent complies with (European or national) regulations and does not include plastic pollution as an indicator of water quality.

4.2.2 RECOMMENDATIONS: EVOLUTION OF DISCHARGE AUTHORISATION PROCEDURE

One of the first steps could be to consider biocarriers as a potential environmental hazard in case of leakage.

▸Training the authorities in charge of the discharge permit

→ Inform relevant authorities of the risks associated with biocarriers so that they can make an informed assessment of the application for the WWTP at an early stage. They could then guarantee that risk prevention measures are adopted.

▸Additional requirements for the application

→ Report on the technologies used for biological wastewater treatment by WWTP manufacturers and/or operators, including, if applicable, the type and volume of plastic biocarriers.

→ Description of the specific retention devices deployed to prevent biocarrier leakage both within

***Notes** | **8.** Swedish Environmental Protection Agency, 2017, Swedish Environmental Law, An introduction to the Swedish legal system for environmental protection, Report 6790* the plant and into aquatic environments and the integration of control measures into the operator's self-monitoring.

▸Request a hazard identification and risk assessment for each WWTP

→ The approval of a discharge permit by the competent authorities should be conditional on a Hazard Identification and Risk Analysis (HIRA) for a particular system.

The objective of the HIRA for each plant is to assess the reliability of the installations in terms of compliance with their wastewater collection and treatment objectives. In particular, it allows the identification of structures/equipment at risk that may impact the proper functioning of the entire system, and thus the quality of the discharges and ultimately the quality of the receiving environment. It also includes relevant and sustainable measures to control and manage these risks.

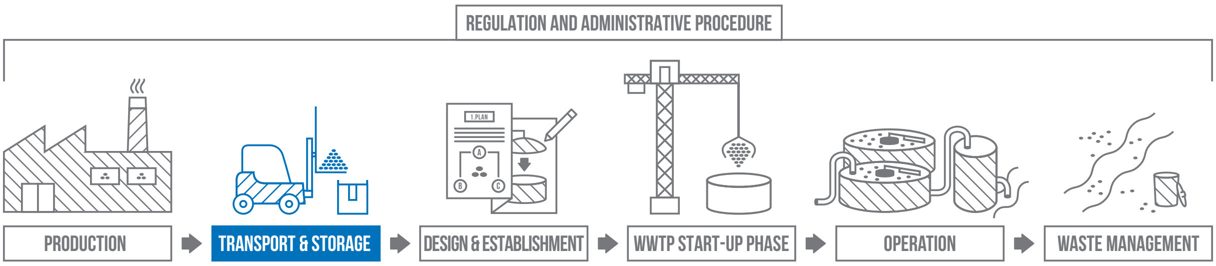
→ Instructing bodies will need to ensure that two key points are incorporated into the HIRA:

— Biocarriers are considered a potential environmental hazard;
— The identification of preventive measures to minimise the risks and be better prepared in case of an incident.

The HIRA is a key document that will accompany the WWTP throughout its operational lifetime and it is therefore essential that it is prepared correctly. See Chapter 4.4 for more details on how to prepare a HIRA.

***Illustration** | **Above** | Stomach contents of a Mediterranean sea turtle, 2021. © G. Darmon & D. Gambaiani*

4.3 PRODUCTION, TRANSPORT, STORAGE AND HANDLING



TARGET Biocarrier manufacturers	
PHASE Production, transport, storage	

4.3.1 REPORTED WEAKNESSES

Information regarding the precautionary measures taken during the production phase of the biocarrier life cycle is limited. The recommendations for this stage are based mainly on common sense and by extrapolating similarities with plastic pellet production sites.[9 10]

It was observed that surface water drains were insufficiently secured where plastics could wash away. Unattended outdoor storage was also repeatedly identified as a cause of leakage of biocarrier into the natural environment.

4.3.2 RECOMMENDATIONS: SAFE TRANSPORT AND STORAGE

The following recommendations focus on the early stages of the biocarrier life cycle, prior to their introduction into treatment tanks.

Most of the production sites are located in Asia, but some companies also produce their media in Europe, making it possible to implement safer management of biocarrier from production to end-of-life at the European level.

Measures to reduce and eliminate losses of biocarrier at manufacturing sites during transport and storage fall into two categories: preventive and remedial. Priority should be given to preventive measures to mitigate risks (leak prevention and spill containment) and recover biocarriers from losses at production, storage, and use sites.

▸Production and storage site design

→ Equip production and storage sites with smooth floors to enable easier cleaning of surfaces in case of incidents. Loose, permeable flooring such as gravel should be avoided.

→ Install removable collection screens and baskets over all surface water drainage outlets to stop and collect biocarriers in the event of spillage. These protections should be easily accessible and easy to install as soon as a leakage occurs.

▸Storage conditions

→ Store biocarriers in high-strength containers without risk of damage or breakage during handling. Big bags (1m^3) as well as smaller bags (100L) could be considered.

→ Prefer bags with eyelets and sleeves to allow handling by cranes and cables for better stability. This type of bags should allow for better control during the loading of the biocarriers into the tanks.

→ Avoid packaging sensitive to sunlight or water. UV rays may strongly deteriorate materials (especially plastics), so storage of biocarriers in a sheltered area is recommended. If stored outside, the bags should be covered with properly secured additional tarpaulin.

→ Ensure the use of suitable, sealed containers during each stage of biocarrier transport and storage, and check container integrity at each stage.

→ Keep biocarriers out of areas susceptible to natural hazards. Prefer closed buildings to outdoor sites. If storage in flood-prone areas is necessary, it should not exceed 2 weeks and special monitoring

Notes | ***9.*** *OSPAR Commission,2021, OSPAR Guidelines in support of Recommendation 2021/06 on the reduction of plastic pellet loss into the marine environment.* ***10.*** *OSPAR Commission, 2018, OSPAR Background Document on Pre-production Plastic Pellets.*

should be carried out with daily checks of the weather forecast and flood risk.

→ Plan the delivery of the biocarriers to the WWTP just before introduction into the tanks to avoid long storage times at the treatment plant. Storage time on the ground should be as short as possible.

▸Handling

→ At the site of production load biocarriers into bags with a pneumatic device to improve filling accuracy and reduce the risk of overflow.

→ Minimise the transport and handling of biocarriers throughout the supply chain.

▸Loading of biocarriers into the tanks

→ When loading biocarriers into tanks, some commonsense parameters should be considered:

— Prefer a windless day;
— Use stable and appropriate handling equipment;
— Do not transfer the biocarriers to an already-full tank.

▸Training of on-site managers and staff

→ Train staff in good bagging, handling, storage, containment, and spill recovery practices.

→ Train staff in crisis management.

▸Emergency plan within the production site

→ About the risk of spillage within the production or storage site:
— Add the risk of biocarrier spillage to existing contingency plans;

— Equip production and storage sites with containment and cleaning equipment such as industrial vacuum cleaners and spare recovery tanks to allow facility managers to quickly and easily recover from container damage or other minor spills within their working area;

— Establish a list of priority measures in the event of biocarrier-related incident to contain the spill to the production or storage site;

— Report any spills in the production/storage area to the company's safety officers.

→ In case of spillage into the natural environment:
— Map nearby rivers and water bodies and their catchments to identify dams and areas where temporary dams can be placed (refer to existing maps and procedures for the diffusion of oil pollution, floating waste, etc.);

— Report any losses of biocarriers as soon as possible in order to implement appropriate containment and clean-up measures at the production or storage site and in the surrounding environment;

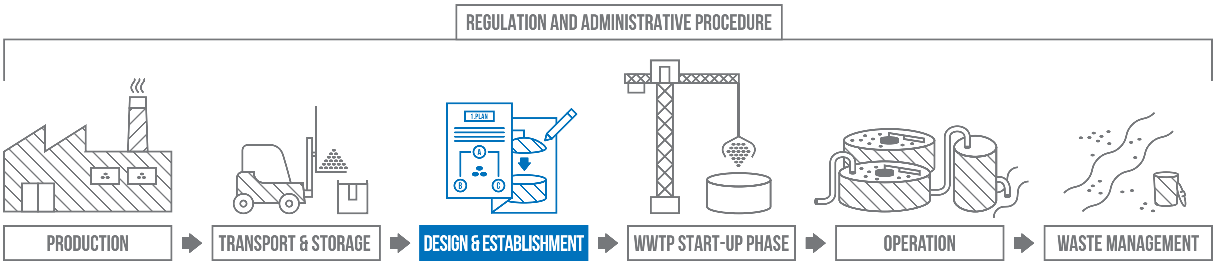
— Report any loss of biocarriers in the environment outside the company premises to the local environmental authorities.

▸Control

→ Demonstrate facility compliance. All companies in the supply chain should regularly report and be audited on the prevention, containment, and clean-up procedures in place within their facilities.

***Illustration** | **Above** | Transport and storage of bulk bags and big bags of biocarriers.© R.R.*

4.4 SECURING INSTALLATIONS: PERFORMING THE HAZARD IDENTIFICATION & RISK ANALYSIS (HIRA)



TARGET Client or project manager	
PHASE Design of the WWTP	

4.4.1 DEFINITION OF THE OBJECTIVES OF THE HIRA

For each function of the effluent treatment chain concerned by the risk of biocarrier loss, it is necessary to make an inventory of all possible malfunctions or failures, material or human, and their effects, and to identify those that could significantly affect the system and therefore the receiving environment.[11]

→ Cataloguing of sensitive equipment and interventions that may lead to malfunction.

→ Analysis of the impact of maintenance periods and major repairs .

→ Proposals for corrective action adapted to each scenario:
— In terms of functional architecture;
— The particular specifications of the equipment;
— Detection and warning systems.

→ The list of parts to be made available or the availability of spare parts off-site,

→ Organisation and timing of the maintenance policy.

For existing installations, this is an opportunity to review the history of site failures and to develop recommendations to avoid their recurrence or to mitigate their effects.

For new installations, it allows reliability concerns to be integrated at the design stage and introduced into ongoing operations. The contents of the analysis should be adapted to the system and proportionate to the possible consequences of a failure by integrating the issues and the vulnerability of the receiving environment.[12]

An easy-to-consult operational version for daily use could be created, for example, in the form of procedure sheets distributed to the operating staff.

4.4.2 RESPONSIBILITY FOR RISK ANALYSIS

The responsibility for the document lies with the owner of the wastewater system. The analysis can be carried out by the owner of the WWTP, the designer of the WWTP, or a third-party contractor. Wherever possible, this work should be carried out before the plant is commissioned. The report can be provided by the designer, who is familiar with the weaknesses of their system and is best placed to provide the necessary guarantees.

In the case of an existing installation, the analysis (or its update) can be carried out by the owner, delegated to its operator, or to a specialised consultancy. However, it is preferable to have the HIRA carried out by a specialised consultancy to have an external evaluation of the WWTP and the risks present.

4.4.3 METHODOLOGY AND CONTENT

Malfunctions or failures that may occur and cause the biocarrier leakage into the natural

Notes | *11.* *Association Scientifique et Technique pour l'Eau et l'Environnement (ASTEE), 2021, Analyse des risques de défaillance, Note de cadrage.* ***12.*** *J.S. Zabe, 2018, Reliability of the start-up stage of an activated sludge treatment plant. Engineering Sciences [Physics]* environment can be determined by studying the wastewater treatment system from a functional point of view, or by considering essential structures and equipment. Several methods can be considered, such as FMEA (Failure Mode & Effects Analysis) or HAZOP (HAZard OPerability).

Rating tables considering frequency and severity are essential to determinate the rates of risk associated with each parameter. The harmonization of such tables could help project owners and permit-issuing authorities implement and examine such documents.

What are the principal failures to be considered?
In order to determine the level of risk presented by each failure, a rating should be used to establish a hierarchy of risks, taking into account:

— The frequency of the failure;
— The severity of the failure (or its consequences);
— The detectability of the failure can also be included in the scoring.

When creating the rating system, the following principles should be taken into account:

— Any spillage, however small, at a high frequency (to be defined in consultation with the national or local water agency) should result in an unacceptable rating. The definition of the frequency will be based on the operator's experience and on the analysis of all available information (operating logs, accident reports, monitoring records, etc.).

— The combination of the severity and frequency factors enables fine gradation of the risk over a broad scale and the differentiation of incidents according to their risk level.

— Whatever rating system is chosen for a WWTP, it is important to maintain the same model over time so that changes can be prioritised and monitored temporally.

What should the HIRA deliverable contain?
→ A description of the methodology used for the study (scoring method, scoring grid, etc.).

→ The scope of the study (description of the system/network) and any justified exclusions.

→ A list of people involved in the study.

→ A summary of the risks identified (with a hierarchy according to the rating), particularly highlighting weak points: the most critical equipment or installations.

→ A summary of the recommendations at the end of the study (with a hierarchy in relation to the presented risks) relating to the technical, human, or organisational devices and provisions contributing to the control of the malfunction risk, concerning:

— Instrumentation and automation: addition of sensors, safety level gauges, low/high threshold alarms, and all the instrumentation to allow good remote monitoring of the system;

— Equipment: changes of or modification of critical equipment such as doubling pumps, overflow installations, and storage of emergency equipment or spare parts;

— Operating instructions defining procedures for each type of malfunction. These may include the designation of the emergency power supply, instructions for the exchange of damaged equipment, diversion of flows, who to notify in the event of a crisis, etc.

In general, the prioritisation of recommendations can be done according to the following principles:

→ Weighting of the recommendation on risk reduction. Some recommendations are likely to reduce the frequency/probability of accidental scenarios or their consequences. Therefore, the recommendations that reduce the most critical risks should be prioritised.

→ Effectiveness of prevention and protection measures. It is common practice to rank the effectiveness of a measure in the following hierarchy, from most to least effective:

— Eliminate the hazard (stop use of a product or equipment...);

— Replace a hazard with a lesser hazard;

— Reduce risks at the source by modifying the design of a process or the operating parameters to make it more suitable for maintenance, for example.

→ Organisational and management measures (awareness raising, training, changes in working and supervision methods, planning and organisation of tasks, signposting, etc.).

→ Expected cost/benefit ratio: risk analysis is not intended to introduce disproportionately costly measures, but rather to ensure that the main deficiencies are met with the appropriate responses.

This cost/benefit approach should make it possible to prioritise the recommendations by considering the means and resources available as well as the associated economic factors.

4.4.4 USE OF THE HIRA

▸From the perspective of permit-issuing authorities

→ Making the HIRA an official document to be sent to permit-issuing authorities would allow for tighter control of risks from the early stages of the project. Review by competent authorities would also allow, depending on the findings, to request additional supplies, equipment, or software appropriate and proportionate to the identified risks.

This administrative requirement could bring significant benefits to wastewater treatment systems and would improve the management of critical situations.

▸From the perspective of the WWTP designer or operator

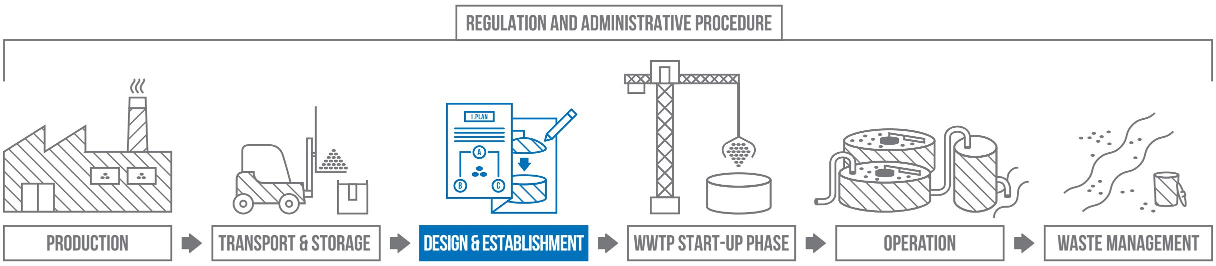
For a new installation, the HIRA would allow certain design choices to be approved or modified. For existing installations risk analysis would lead to an action plan to improve the current situation.

Note: During the lifetime of a system, technical and/or organisational changes may impact the HIRA and its conclusions. Any significant changes should entail an update.[13]

***Illustrations** | **Above** | Biocarriers found on a beach in Corsica, France, 2018. © Mare Vivu*

***Notes** | **13.** Association Scientifique et Technique pour l'Eau et l'Environnement (ASTEE), 2020, Implementation of the permanent diagnosis.*

4.5 DESIGN AND ESTABLISHMENT



TARGET Owner, operator, contractor

PHASE Design of the WWTP

4.5.1 EXISTING MEASURES AND REPORTED WEAKNESSES RELATED TO WWTP ENGINEERING

Urban wastewater treatment consists of a series of physical, biological, and chemical actions carried out to collect and transport liquid urban effluents to a treatment plant, and then to eliminate and/or reduce the pollution present. It is therefore a matter of ensuring, in succession, certain operations on an incoming flow to produce one or more outgoing flows (see figure next page):

— Collection and storage of effluent;
— Primary treatment (screening, grit removal, degreasing);
— Secondary treatment (aeration tank, MBBR);
— Tertiary treatment (physicochemical);
— Quaternary treatment (removal of other chemical molecules and faecal bacteria).

Design choices for a WWTP using biocarriers aim to maintain at least two crucial sets of parameters and to avoid biocarrier leakage:

— Maintaining appropriate physicochemical conditions for the proper development of activated sludge;

— Ensuring the reliability of the installations, processes, and equipment required to keep the biocarriers in the tanks.

All actions upstream of the biocarrier-containing tanks affect the functioning of the technology and, by extension, the tanks' or basins' biocarrier retention capacity. All actions downstream of the fluidised bed reactor are potentially impacted by the leakage of biocarriers from the tank. Therefore, the loss of biocarriers from WWTPs is usually the result of a series of minor incidents leading to more serious malfunctioning.

Among other things, malfunctions can be related to:

— Wasterwater input;
— Mixing of effluents;
— Aeration of the biological treatment;
— Sensors (O2, water level, etc.);
— Retention measures (missing sieves or meshes);
— The structure of the tanks (type of materials);
— Pumps (sizing/backup pumps, etc.).

It is therefore important to integrate protective measures that take all the treatment operations of the installation into account.

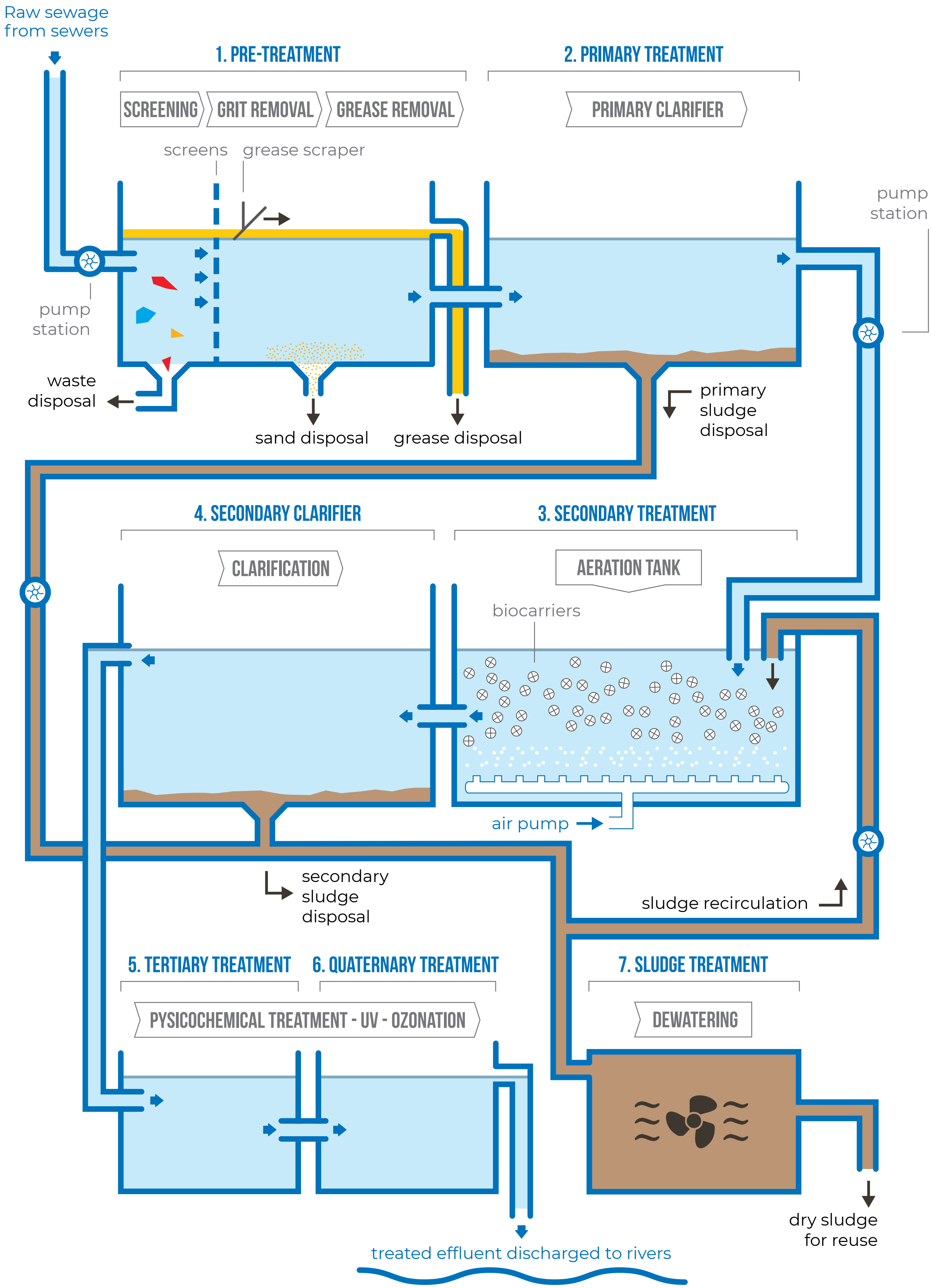
4.5.2 GENERAL RECOMMENDATIONS

In this context, all identified failures leading to biocarrier leakage should be anticipated at the design stage. Some recommendations go beyond the scope of biological treatments or are not specific to MBBR systems, but problems related to other stages of the system may indirectly lead to biocarrier losses.

The following topics will be addressed in the following recommendations:

— Strict quality requirements for civil engineering;
— Correct sizing of ventilation and mixers;
— Global flow management, including collection networks;
— Protection of outgoing flows;
— Easy access for maintenance allowing the control of biocarriers at any time;
— Appropriate training for good knowledge transfer from designer to operator.

***Illustrations** | **Right page** | Stages of a wastewater treatment plant. © Surfrider Foundation Europe*


Raw sewage from sewers
1. PRE-TREATMENT
SCREENING
GRIT REMOVAL
GREASE REMOVAL
2. PRIMARY TREATMENT
PRIMARY CLARIFIER
screens
grease scraper
pump station
pump station
waste disposal
sand disposal
grease disposal
primary sludge disposal
4. SECONDARY CLARIFIER
3. SECONDARY TREATMENT
CLARIFICATION
AERATION TANK
biocarriers
air pump
secondary sludge disposal
sludge recirculation
5. TERTIARY TREATMENT
6. QUATERNARY TREATMENT
7. SLUDGE TREATMENT
PYSICOCHEMICAL TREATMENT - UV - OZONATION
DEWATERING
dry sludge for reuse
treated effluent discharged to rivers

The project managers and owners should ensure that these parameters can be easily monitored by the operator in charge of the WWTP. The operator should anticipate and monitor the risks of failure while taking into account the evolution of environmental, technical, and physicochemical constraints that vary over time. This implies good transfer of information and skills through continual staff training, and provisioning plans and instructions adapted to the installation.

4.5.3 RECOMMENDATIONS: RAINWATER MANAGEMENT

Reducing the amount of rainwater collected in combined sewer systems is essential to limiting hydraulic surges that can saturate treatment facilities.[14]

This can be implemented at catchment basin-scale and within the collection network.

▸Separating the collection of rainwater and domestic wastewater
→ Prefer separate networks to maintain optimal treatment of domestic wastewater even in the case of heavy rainfall.

▸Development of stormwater management plans
→ Increase the permeability of cities by creating larger vegetated areas, ditches, or green roofs to naturally direct water into the soil.

→ Create natural open stormwater basins or underground buffer tanks in the collection network.

4.5.4 RECOMMENDATIONS: LOCATION OF THE WWTP AND ITS EXTERNAL ENVIRONMENT

Some external disturbances have an impact on WWTP integrity and consequently on the proper functioning of the installation. Several precautions should be taken regarding:

▸Natural disasters protection
→ Install lighting rods to prevent damage to electrical and control systems.

→ Avoid building in flood-prone areas. If this is not possible, some equipment such as electrical and control centres should be elevated. Provisions should also be made for pumping and/or evacuating water in the event of flooding.

→ Carry out geotechnical studies to ensure the building durability and confirm the bearing capacity of the soil in support of the structures.

▸Malicious acts
→ Installing detection and intruder alarm systems.

→ Ensure cyber security of the WWTP's control or management tools.

▸Surrounding natural features
→ Avoid installing open basin near deciduous trees to prevent leaves from interfering with biological functioning, clogging pipes, and pumping systems.

4.5.5 RECOMMENDATIONS: STRUCTURAL ENGINEERING

→ Prefer closed systems for new construction.

→ Anticipate the installation of easy-access hatches to facilitate maintenance of ventilation equipment and grids inside the tank.[15]

→ Build the inner linings of the tanks to be as smooth as possible. This prevents organic matter build-up and the advent of stagnation zones in

Illustrations | ***Above*** | *Mesh added on top of an open basin in a fish farm © Surfrider Foundation Europe*

Notes | **14.** *Groupe de Recherche, Animation Technique et Information sur l'Eau (GRAIE), 2020, Opérations exemplaires pour la gestion des eaux pluviales.* **15.** *Castanie, S., 2016, Mise en service de la station d'épuration d'Ota Porto, Master's thesis at the Ecole Nationale du Génie de l'Eau et de l'Environnement of Strasbourg.*

the effluent favourable for the development of filamentous bacteria.

→ Install a smooth floor around the pools for quick, mechanical cleaning of the surfaces in case of leaks. Flooring material should provide some traction and gravel should be avoided.

→ Raise the height of the walls of basins (open tanks) containing biocarriers.

→ Equip the perimeter of the tanks with fine-mesh screens to catch biocarriers in the event of overflow or foam formation.

4.5.6 RECOMMENDATIONS: FLOW MANAGEMENT

▸Flow velocity
High effluent concentration and low-velocity flows combined with low aeration are parameters that favour the development of filamentous bacteria that can surpass purifying bacteria. This phenomenon is observed in long and low gradient collection networks particularly.

→ Maintain sufficient flow in the collection system. Installation of treatment stations (addition of oxidants, metallic salts) in the collectors can be considered to avoid sulphide formation.

▸Buffer tank
Industrial effluents may require rebalancing pH, suspended solids, nitrogen, and phosphorus concentrations, or the removal of molecules interfering with the proper functioning of the biological treatment.

→ Provide a buffer tank for dilution, aeration, or the addition of reagents. This tank should be entirely emptiable and equipped with a pumping pit.

▸Design of lift stations and network lift stations
Poor design of lift stations can lead to settling zones favourable to the growth of filamentous anaerobic bacteria. To avoid this situation, it is recommended to:

→ Place the pump at the lowest point to avoid any organic matter accumulation;

→ Provide sufficient slope at the bottom of the tank to carry the deposits to the pumping point;

→ Mix sufficiently to prevent deposits;

→ Ensure that there is no roughness on the tank walls to limit undesired bacterial growth.

▸Stormwater basin - Stormwater storage tank
→ Install a storm water basin upstream of the plant to regulate flow.

It should be located either on the collection network or at the plant entrance. This type of installation enables the storage of excess effluents occurring during rainy weather and thus prevents network overflows or spills in the WWTP. It also plays a role in contaminant removal, allowing the screening of solids and supplementary decantation of suspended matter during storage.

▸Storm overflow
→ Equip the plant with a bypass system to maintain constant flow in the event of large inflows and regulate flow without endangering the treatment process. Manual/mechanical systems should be activatable in the event of a power failure and guarantee the possibility of discharge if necessary.

▸Reactors in series or in parallel
→ For larger installations, series reactors and/or several parallel lines should be preferred to a single tank. This configuration makes it possible to better cope with the potential variations in load, for example in high tourism areas. It also makes it possible to maintain certain reactors on standby with very short aeration phases when the total treatment capacity of the installation is not required and it enables high treatment capacity during peak periods.

▸Emergency pumps
→ Throughout the system, secondary pumps can be activated to increase admitted flow rates (without exceeding the capacity of the downstream system). They also function as a backup and take over if the main pump fails.

▸Non-return valve
→ Equip the outfall to the natural environment with a non-return valve to prevent water from entering the plant in the event of flooding at the discharge outfall.

4.5.7 RECOMMENDATIONS: BIOLOGICAL & PHYSICOCHEMICAL PARAMETERS

▸Ventilation
Biological tanks are aerated to keep biocarriers

in suspension to improve sludge/effluent contact and to promote bacterial biofilm development. Under-ventilation is one of the main factors triggering or aggravating biological malfunctions. Therefore, it is important to ensure that the aeration unit is appropriately dimensioned (compressor power, distribution of aerators, etc.).

→ Adapt the air flow rate to the volumes to be ventilated.

→ Avoid dead zones and deposits by suitable diffuser arrangement.

→ Include a de-scaling reagent injection port on air blowers.

→ Avoid under-ventilation or prolonged stoppage of ventilation (more than 2 hours), which may increase overflow risk.

→ Adapt the number of dissolved oxygen sensors to the structure and flow rate of the system.

→ Double the oxygen probes to guarantee measurements in case of electromechanical failure or obstruction by sludge or foam.

→ Provide a degassing area between the biological reactor and the clarifier to facilitate the removal of air bubbles and improve the recovery of extractable sludge.

▸**Mixing**

Incorrect positioning of the agitators in the tank (angle, immersion height, etc.) or the presence of an obstacle (lateral guides of the diffusers, transverse channels, etc.) can negatively affect its effectiveness and can create hydraulic movements contrary to those intended. It is therefore necessary to:

→ Ensure ideal mechanical mixing by optimising the positioning of the agitators in the tank (angle, immersion height, etc.) and by eliminating obstacles (lateral guides for the diffusers, transverse channels, etc.)

→ Keep a backup agitator in case of electromechanical failure of the main system.

4.5.8 RECOMMENDATIONS: RETENTION EQUIPMENT

▸**Design closed tanks for new construction**

→ In the case of an upgrade of an existing installation, all outfalls and basins containing biocarriers should be equipped with grids with a mesh size smaller than their diameter.

→ Installing other gooseneck and/or non-return valves on effluent inflow pipes could also prevent backflow circulation of biocarriers in the case of water level rise.

Illustrations* | *Opposite* | *Installation of a strainer on a discharge opening in a biological treatment tank, 2020. © Acqua Publica

→ In the case of a new system, the inflow could be directly poured from the top (upper dale) of the tank, top-down oriented, to prevent biocarriers from entering the pipes. This type of installation requires less maintenance than grids/mesh, which have a higher tendency to clog.

▸Retention Screens
→ Ensure that all inlet and outlet streams of reactors containing biocarriers are equipped with retention systems (screens, check valves, goosenecks, etc.) with mesh sizes selected according to the biocarrier geometry.

→ Equip all openings with physical barriers to prevent the passage of biocarriers.

The principle of the MBBR process is based on the use of bacterial carriers set in motion in the water column. Every effort should thus be made to ensure that these biocarriers remain in the tanks where they are used to purify the effluent. Therefore, all openings should be equipped with physical barriers to prevent their escape.

The installation of such protective devices should also prevent the biocarriers from being transported upstream of the WWTP in case of pump malfunction.

→ Add strainers on wastewater pump flow leading to the MBBR to prevent the transfer of biocarriers from the reactor to the lift station in the event of accidental pump reversal.

→ Equip each of the following circuits in the same way:
— Exhaust air;
— Reagent addition hoses;
— Sludge disposal system.

→ Add multiple screws or weld the entire length of the protective equipment rather than at a few attachment points that could cause structural weaknesses and breakage, allowing the biocarriers to escape.

→ Install filters or collection grids at all surface water drainage outlets.

This should enable recovery of biocarriers in stormwater in the event of spillage on the ground within the WWTP. These screens should be easy to check and maintain to avoid clogging.

4.5.9 RECOMMENDATIONS: PREVENTION OF CLOGGING

The accumulation of biocarriers at the outlets limits outflow, consequently increasing the volume of liquid in the tank, which can lead to overflowing.[16] Limiting this phenomenon is therefore essential.

Ensure that it is possible to check if air supply ramps are blocked through pressure gauges on the supply pipes.

▸Unclogging mechanism
→ Injecting water or air under pressure onto or through the grilles can prevent clogging. This operation can be programmed automatically for regular grill maintenance.

▸Special precautions when upgrading an existing WWTP
→ The protective elements should be adapted to avoid the risk of clogging due to the accumulation of biocarriers on their surface. Specifically, flat grids should be replaced by cylindrical grids.

4.5.10 RECOMMENDATIONS: SECURING ELECTROMECHANICAL EQUIPMENT

▸Power supply network
→ Ensure the doubling of the supply networks at each station. A fault detection system is imperative.

▸Control-command system
→ Install a backup system to ensure the two principal functions of the control system: to coordinate all the equipment in the treatment plant and to monitor the equipment's operational capacity by emitting alarms in the event of a malfunction.

▸Reagent injection station
→ Ensure that visual verification of correct sensor function and reagent stock levels is possible.

→ Enable manual addition of reagents, supply of dilution water, and homogenisation of the effluent in the event of a motor or valve failure.

***Notes** | **16.** González Vázquez, B., Choubert, J.M. , Paul, E., Canler, J. P. , 2020, Comment éviter le colmatage irréversible des installations de biofiltration ? Techniques Sciences Méthodes, ASTEE/EDP Sciences, 11, pp.71-86.*

▸In the biological treatment tank
→ Double the equipment in critical areas to protect against failure of the main sensors.

→ Equip biological tanks with level sensors.
As biocarriers can escape open tanks in effluent overflow, it is necessary to equip open tanks with probes and sensors to prevent abnormal increases in effluent volume. The installation of a radar probe non-affected by foam disturbances could be an alternative solution.

→ Connect the water level sensors to a system that shuts off the effluent supply to the tank.

→ Implement a multiple alarm system (visual, audible, sending SMS-type messages) to warn of malfunction as soon as possible.

→ Install cameras to check for blockage of screens or probes in closed tanks inaccessible by staff.

→ Install an alert system to warn of a malfunction when no personnel is on site. The alert should be able to send automatic notifications to the phone of an on-call operator or to a central office that controls several installations.

▸In the clarifier
→ Install an alarm system for extraction pump malfunction, measuring the volume and turbidity of the sludge at the clarifier outlet to ensure it is properly removed and does not spill back into the aeration tank.

4.5.11 RECOMMENDATIONS: MEANS OF SYSTEM MAINTENANCE

The monitoring of wastewater treatment plants, whether carried out by the operator or through external control bodies, requires suitable installations and equipment for intended methods of measurement, particularly in terms of permanent accessibility and good representativeness of the samples taken. Similarly, cleaning and maintenance operations should be facilitated.

→ Provide an access hatch for closed tanks.

→ Provide a control opening that is always functional and above water to allow for visual inspection the biocarrier mix, sampling to monitor adequate colonisation of the biocarriers, and to facilitate cleaning operations.

→ Facilitate cleaning operations:
— Install guide bars and jibs equipped with winches or hoists to raise the often-heavy equipment installed at the bottom of the pools (baskets, pumps, etc.);

— Provide cleaning areas for equipment that require regular maintenance or changing (pumping device strainers, grids, etc.);

— Provide immediately operable emergency equipment to deal with any accidental shutdown;

→ Ensure access to treatment basins and maintenance points at all times of the year, especially in snowy areas.

4.5.12 RECOMMENDATIONS: INSTRUCTIONS FOR SAFE OPERATIONS

▸Creation of a good-practice guide
Wherever biocarriers are used in treatment systems, contractors should provide guidance to subcontractors and operators on the best practices for managing biocarriers.

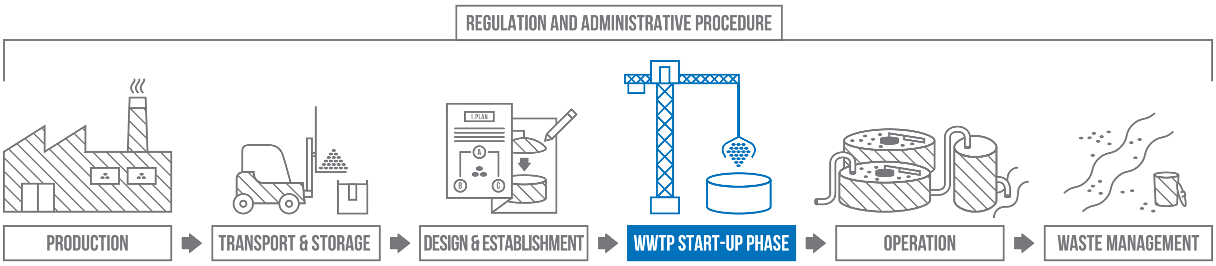
This document should help to define appropriate measures for optimal management of biocarrier such as:

— Preliminary audits;
— Terms and conditions of use;
— Storage conditions;
— Handling and introduction into tanks;
— Overflow protection;
— Appropriate retention systems;
— Aeration and parameters;
— Processes for monitoring the effectiveness of the system;
— Self-monitoring protocol;
— Key maintenance operations.

▸Train operators
→ Plan training sessions to ensure that operators stay up to date and that good practices specific to biocarriers are understood.

Additional physical protective / preventive measures should not be a reason to reduce the attention paid to biological processes. Continuous observation of biocarriers and system maintenance are essential. The aim of such measures should be to limit the risk of pollution without hindering the quality of the process.

4.6 WWTP START-UP PHASE



TARGET Owner or operator, contractor

PHASE Start-up

4.6.1 EXISTING MEASURES AND REPORTED WEAKNESSES

The start-up phase of wastewater treatment plants is a particularly critical phase during which many cases of biocarrier leakage into the environment have occurred. When it is underway, the entire plant is set into operation under real conditions, and operations are gradually ramped up to give bacterial biofilms time to develop. Operators are getting familiar with the new operating conditions, and the system may be particularly vulnerable to load variations and large water inflows.

Many cases of pollution have occurred during the WWTP's commissioning phase.

In order to anticipate malfunctions, it is common practice for the contractor to provide best practice guidelines covering all operations. [17] However, the multiplication of subcontractors in the construction process of a WWTP can lead to information shortcomings and the non-application of operating instructions, even when good practice guidelines on biological parameter settings or handling exist.

External constraints (political pressure, architectural obligations, contractual deadlines, etc.) can also disrupt smooth start-up.

4.6.2 RECOMMENDATIONS: ESTABLISHMENT

▸Framing of the start-up and stakeholder involvement

→ Commissioning should be carried out in strict accordance with the procedure proposed by the installer, who should be present and accompany the operator.

→ Recommendations for use should be provided by the treatment plant designers to help operators run the plant more safely and include biocarrier-related specificities. (cf 5.5.10)

Recommendations for operators should include:
— Quality control of facilities;
— Storage;
— Handling;
— Operating parameters;
— Maintenance.

The manual for WWTP operators should also contain a chapter on risks and good practices for WWTP maintenance operations involving tank emptying, temporary modification of conventional treatment processes, or the decommissioning of monitoring systems that may result in the loss of biocarriers.

→ The installer should be present in the weeks and months following commissioning (according to a set schedule) to monitor the ramp-up and optimal functioning of the WWTP.

→ Start-up phase engineers and operators should have a detailed knowledge of the HIRA. They should check the correct functioning of the control points and upgrade them if necessary.

→ Regulatory authorities should be informed at the time of impoundment and final acceptance of the facility.

Notes | 17. Multi Umwelttechnologie AG, Instructions and recommendations for the operation of Mutag BioChip 30™ support media

▸**Test phase**
When commissioning a WWTP, the test phases must be completed in the correct order. Final approval should not be given until all stages have been completed. External political, financial/economic, or tourism constraints should not prevent the thorough completion of the entire process validation chain.

The general procedure for starting up the WWTP should be as follows:

▸**Requirements before the start-up period**
→ Ensure that no chemical pollutants are present in the effluent that could deteriorate the plastic materials.

→ Check that all drains and outlets are protected by screens, grates, or cages with a suitable mesh size to prevent biocarriers from passing through.

→ Check that the biocarriers are not in contact with installations (pumps, mixers, etc.) that could accelerate wear.

→ One month before the planned commissioning date, a start-up review should be carried out to ensure that the equipment is ready. This involves:

— Performing leakage tests on tanks and pipes;
— Carrying out initial tests and trials of the pumping systems;
— Checking electrical connections;
— Carry out electromechanical tests on the hydraulic, aeraulic, and pneumatic installations in order to check their proper functioning (check the power supplies and the correct direction of rotation of the motors, test all the station's sensors);
— Check, under the supervision of the automation engineer, the automation and the correct linkages between the instrumentation and the equipment.

▸**During the start-up phase**
The commissioning period should include:
→ Setting up the facilities.

→ Verification of the proper functioning of all mechanical, electrical, electronic, thermal, and hydraulic equipment in accordance with the relevant standards and the operating conditions stipulated in the contract.

→ Drafting of operating instructions and training of the operating personnel who will be responsible for the installations.

→ Progressive input of effluent with the measurements and analysis necessary to assess the flow and load received at the plant.

→ Close monitoring to quickly detect possible failures.

→ A performance test to certify the compliance of the system with its stated objectives and the functioning of the MBBR biological treatment.

▸**Introduction of biocarriers into tanks**
→ Pouring biocarriers carrefully

To fill MBBR tanks, hang the container about 1.5m above the tank water level and cut 3 of the 4 sides of the bottom of the bag with a knife to ensure that it empties completely. Undo the tie if using a reusable bag. It is essential to ensure that no plastic cuttings from the bag end up in the tank to avoid clogging the grids.

New (uncolonised) biocarriers tend to float. Beware of the risk of accumulation on the surface and leakage out of the pond, particularly during foaming or in the event of windy weather. The addition of biocarriers should be gradual to give them time to mix and be colonised.

→ Determining the optimal volume of biocarriers to introduce into the tank.

***Illustration* | *Below* |** *Safe pouring of biocarriers into an open tank. © Mutag*

Gradually increase the amount of biocarriers. Start tests with a low filling level. Gradually increase the volume of media while regularly measuring the relevant parameters until reaching the required concentration of pollutants in the treated effluent. Observe a pre-defined interval between each stage of filling increase to ensure that removal rates stabilise, and that the newly added plastic media are fully colonised and reach 100% biodegradation performance.

▸Colonisation

→ Stirring biocarriers

Until they are sufficiently colonised (which can take up to several weeks), the biocarriers will have a lower density than water and remain at the surface. Agitation should be stronger than normal to force them to mix with the water and disperse uniformly in the liquid.

→ Optimising the physical parameters of effluents

The effluent should be adjusted for ideal growth temperature, for pH levels to be in an appropriate range, sufficient nutrient load, and the effluent adequately mixed.

→ Starting with external sludge

Biomass growth (in a new plant, after an accidental shutdown, or following a massive sludge loss) can also be accelerated by the introduction of seeding sludge from another plant treating a similar type of wastewater. When introducing external sludge, it is necessary to provide a sufficient oxygen concentration in the aeration tank to ensure treatment and floc formation. Flocculation can also be assisted through the addition of coagulation-flocculation reagents.

→ Mud-free starting

— **With clear water:** water can be taken directly from the natural environment (freshwater, free of sediments). The filling time of the pond should not exceed a few days with active aeration during the entire process.

— **With wastewater:** wastewater is only admitted to the aeration tank after it has passed through pre-treatment. The solution is often to promote the start of the flocculation mechanism of the bacteria by limiting the load to be treated to reduce the mass load and facilitate flocculation (transient bypass) or by adding coagulation-flocculation reagents.

__Illustration__ | __Below__ | BigBag being transported by crane. © Mutag

▸Observation period

Guarantee the proper functioning of the installations for a period of 30 days. During this period, the installations should operate in a steady state without malfunction or failure (hydraulic, mechanical, or electrical). No biocarriers must be found outside the biological tank.

▸Acceptability of the work

At the end of the commissioning period and after validation of the contractual observation period, the installation should be accepted by the project owner, subject to subsequent guarantee tests. A list of reservations may be drawn up to be resolved within a prescribed period after a final inspection and the deliberation of compliance with the contract; it should also include:

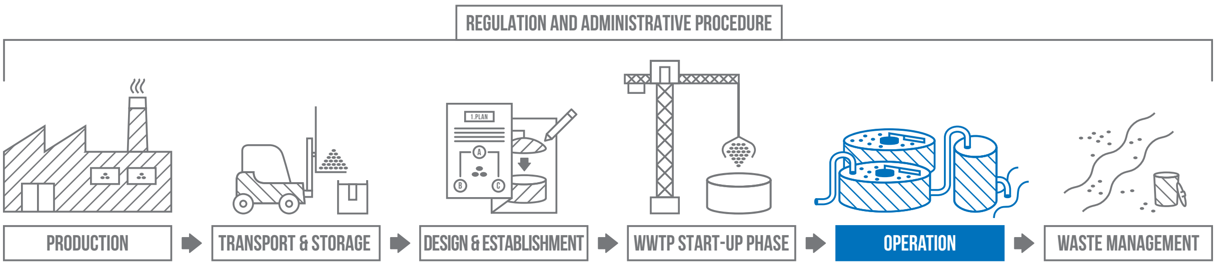
— Proper removal of construction equipment and restoration of the site;

— Validation of the results of the tests, with corresponding trials and performance checks.

▸Handover and defects liability warranty

Carry out a series of third-party testing for at least one year to validate compliance with the contract. During this period, ensure that no biocarrier losses occur within the WWTP and that protective measures are adequate.

4.7 OPERATION OF THE WWTP



TARGET WWTP operators

PHASE Start-up / Operation

4.7.1 EXISTING MEASURES AND REPORTED WEAKNESSES

Wastewater treatment is based on the balance between the input of effluents as characterised by their specific parameters (flow rates, physicochemical composition, temperature, etc.) and the capacity of the purifying bacteria to treat these effluents. Thus, the main objective of the operator will be to guarantee that all conditions are met to ensure the proper development of the purifying bacteria.

In combined sewerage systems, heavy rainfall can cause significant variations in water levels and alter effluent parameters (oxygenation, suspended solids, chemical or organic pollutants, etc.), thus directly impacting ongoing biological processes. Furthermore, other factors such as tourist influxes or industrial discharges can also impact the nature of the effluents.

Keeping the biocarriers in the tank is an additional and specific parameter to be taken into account by the operators and doing so is directly influenced by the biological parameters of the effluents.

Although the purification performance and reliability of activated sludge are well-proven, several types of biological malfunctions can affect its behaviour. Signs of disturbance can include excess foam or sludge, fluctuations in tank water levels, or variations in flow rates.[18 19]

As such, close attention should be paid to biofilm development on biocarriers and to identifying and detecting any unsuitable conditions and the resulting malfunctions.

Some key parameters to control bacterial growth are:
— Effluent composition and its variations;
— Mud levels;
— Aeration/mixing rate;
— Development of filamentous bacteria which can lead to the deterioration of sludge: non-settling or over production;
— Infiltration, deposits, heterogeneity, grease;
— The advent of foams trapping biocarriers at the surface and disrupting level probes.

Notable conditions affecting the safe operation of the facilities include:
— Uninformed or insufficiently-trained operators on the specificities of biocarrier processes;
— Non-anticipation of the need for rapid intervention in the case of bad weather forecasts;
— Bacterial imbalances leading to the development of filamentous bacteria and foaming.

Filamentous growth is the presence in a floc (or between flocs) of filamentous organisms. In excessive amounts, these organisms form hydrophobic flocs which capture air bubbles that disrupt the settling properties of the sludge thus compromising the quality of the treated water. The nuisance caused by filaments is proportional to their density and, especially, to their length. It also depends on the filamentous species present, some being more detrimental than others.[20]

***Notes** | **18.** Fond National pour le Développement des Adduction d'Eau (FNDAE), 2005, Dysfonctionnements biologiques des stations d'épuration : origines et solutions, document technique, N°33. **19.** Fond National pour le Développement des Adduction d'Eau (FNDAE), 2002, Stations d'épuration : dispositions constructives pour améliorer leur fonctionnement et faciliter leur exploitation, document technique, N°22 bis. **20.** Duchene, P. , 1994, Dysfonctionnements biologiques dans les stations d'épuration en boues activées, Actes du colloque Pollutec.*

The main malfunctions due to filamentous bacteria in the plant take two forms:
— poor sludge settling due to increased sludge volume;

— Formation of a thick layer of floating material on the surface, which in turn provides a favourable environment for the development of filamentous bacteria.

This type of problem can occur due to :
— a rapid increase in load with a punctual and massive input of organic substrates (industrial effluents, sewage, etc.) causing a relative lack of oxygen (the immediate need is not satisfied even if the overall oxygen input seems correct) or

— the arrival of a large amount of a toxic product causing the destruction of a large part of the biomass and leading to a loss of installation performance.

The second major area for preventing biocarrier leakage is **the reliability of wastewater treatment plants which is highly dependent on good maintenance and safety of the systems. However, shortcomings in maintenance operations can affect WWTP reliability, notably:**

— Neglected maintenance of equipment preventing biocarrier loss;
— Obsolete maintenance plans and non-reported incidents;
— Unanticipated requirement of spare parts.

4.7.2 RECOMMENDATIONS NATURE OF THE EFFLUENT

▸Ensuring the quality of effluents
The water to be treated should contain a sufficient load of nutrients to ensure the growth and regeneration of the fixed biomass. Dumping of grease, brine, heavy metals, and toxic substances (phenols, cyanides, etc.) into the networks should be strictly regulated.

▸Limit the introduction of salts into the network
Variations in salinity in collection systems due to seawater seepage, road salting, food processing, etc. should be kept as low as possible. A sudden change in salinity can cause partial deflocculation of the sludge and damage the bacterial biofilm. To avoid this, a buffer tank can be installed to control input salinity.

▸Limiting the concentration of sulphur
→ Increasing the flow rate in collection networks to limit sulphide levels
Effluents that remain in the system for a long time or fermentable effluents (from the food industry or the sludge industry) often generate high concentrations of sulphides (H2S) that promote the development of filamentous bacteria. In long or slow-flowing collection systems prone to septicity, increasing flow rates, injecting air, and introducing oxidants or metal salts can limit these effects.

→ Regularly check lift stations
Regular cleaning of the lift stations is necessary to limit hydrogen sulphide and the accumulation of grease and deposits. It should be noted that the detection of hydrogen sulphide in the air at lift stations may be useful for system management and monitoring.

▸Monitor non-domestic discharges to sewer systems
The impact of industrial effluents on plant operations depends on their relative proportion in terms of pollutant load compared to typical urban effluents. Thus, plants in small municipalities

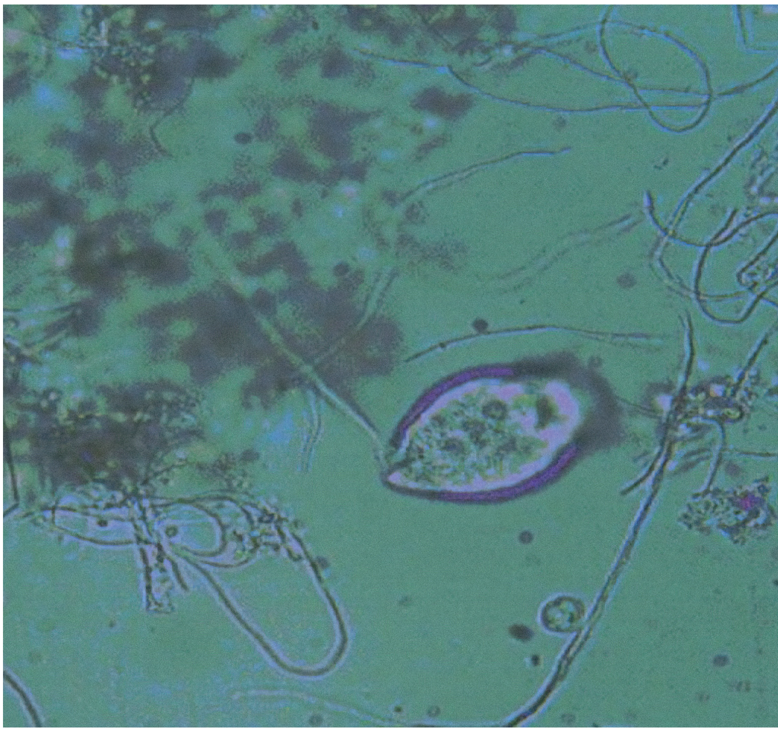


Illustration *|* ***Below*** *| Filamentous bacteria. © Syndicat Mixte Recyclage Agricole du Haut-Rhin* receiving industrial effluent are often more sensitive to this type of discharge than larger facilities where higher dilution rates are expected.

4.7.3 RECOMMENDATIONS: PREVENTION OF FOAMING AND THE DEVELOPMENT OF FILAMENTOUS BACTERIA

Given the diversity of filamentous bacteria and the conditions that can promote foaming, the practical approach is to assess the extent of colonisation by filamentous micro-organisms, identify the species involved through microscopic examination, and determine appropriate remedies such as modifying the sludge recirculation flow or controlling the physicochemical properties of the effluent.

The main problems caused by filamentous bacteria are due to the formation of a thick layer of floating material at the surface and the settling of sludge.

To deal with this type of biological malfunction, the operator will have to implement both preventive and curative measures. [21] [22]

▸Preventive measures

→ Adapting aeration requirements to the nature of the effluent:

— Have a surplus oxygen production capacity available to cover peak demand, combined with a good oxygen measurement system in the different parts of the tank to ensure optimal aeration (based on the installer's recommendations and possibly modified according to the operator's observations);

— Ensure that the ventilation system continuously and evenly agitates the biocarriers;

— If the oxygen requirements of the biomass are greater than the agitation requirements, the air supply must be adjusted to the biomass requirements;

— Otherwise, to save energy, it is possible to limit the ventilation input to the biomass needs and add mechanical ventilation.

→ Check the proper functioning of the mixers

— Check the effective rotation of the blades and their direction of rotation by detecting hydraulic movements or by reassembling the unit if necessary (checking for blade wear and dross) [24];

— Check the power consumption of the agitator for optimum operation and the presence of dirt. The measured power should correspond with the manufacturer's power setting;

— Check the mixing at different points in the tanks to ensure that the desired objective is achieved and that there are no zones of sludge accumulation.

→ Ensuring mass load stability

Ensure that the optimum mass loading is stable (ratio of the mass of oxygen to be supplied over the mass of microorganisms in the aeration tank).

→ Monitor the temperature of the effluent

The temperature of the sludge or effluent affects the treatment and can cause malfunctions. Therefore, care should be taken to maintain the temperature range for the optimum development of the purifying bacteria.

▸Curative actions

→ Removing floats

The removal of floats from the biological reactors should avoid recirculation and permanent reseeding.

→ Ballasting of effluents

This technique is based on the addition of a high-density substance, usually mineral (talc, ash, calcium carbonates, metallic salts, etc.), which, when added to the bacterial floc, improves its settling. Ballasting is useful for reconstituting a bacterial floc following major sludge losses. Ballasting of the floc can also be achieved by adding sludge from a neighbouring treatment plant with a good sludge index or by bypassing part of the water in the primary stage to ballast the floc with the particulate fraction of the raw water.

→ Adding oxidants

Use of chemical agents (oxidants) that have a bactericidal action on the sludge. Their addition

***Notes** | **21.** Groupement d'Intérêt Scientifique (GIS) Biostep, 2013, Dysfonctionnements biologiques, un digesteur qui mousse ? **22.** Collivignarelli, M.C., Baldi, M., Abbà, A., Caccamo, F.M., Carnevale Miino, M., Rada,E.C. and Torretta, V., 2020, Foams in Wastewater Treatment Plants: From Causes to Control Methods, applied science , mdpi. **23.** Groupement d'Intérêt Scientifique (GIS) Biostep, 2013, Dysfonctionnements biologiques, Pourquoi et comment vérifier le bon fonctionnement d'un agitateur ?*

leads to a modification of the structure of the sludge by breaking the filaments. It should be noted that the results obtained cannot be definitive because these products do not act on the causes of overflow. [24]

→ Managing large load variations
Injection of a nitrogen substrate during a sudden increase in load should increase the usually slow-growing nitrifying biomass.

4.7.4 RECOMMENDATIONS: LIMITATION OF SLUDGE OVERABUNDANCE

There are several ways to reduce the risk of abnormal sludge bed levels:

— Ensure the proper functioning of the turbidity and sludge flow sensors to monitor the sludge concentration in the aeration tank;
— Smooth out the hydraulic load and control the recirculation of sludge;
— Ensure proper operation of the clarifier scraper arm.

4.7.5 RECOMMENDATIONS: MAINTENANCE

▸Carry out preventive maintenance
Preventive maintenance ensures longer operational capacity of equipment and allows for rational management of the operator's work. [25] Particular attention should be paid to the proper mounting of protective systems to contain biocarriers. [26]

For this purpose, the operator should have the following at their disposal:

→ A calendar indicating the dates and frequency of maintenance of the main electromechanical parts (motors, etc.) and protection systems (grids, nets, cages, etc.);

→ A datasheet for each piece of equipment, indicating its characteristics, but also the contact details of the manufacturer and suppliers;

→ Spare parts for all equipment classified as having a high risk of biocarrier loss in the event of an incident (pumps, grids, etc.).

→ The essential tools, spare parts, and consumables subject to frequent replacement (screws, repair tools).

→ Appropriate tools (shovel, rigid container, industrial vacuum, etc.) to recover biocarriers before they reach stormwater or wastewater outfalls, the surrounding environment, or waterways.

▸Establish a maintenance contract
If the project owner or its delegate cannot provide preventive maintenance, a maintenance contract should be set up with an external service provider, offering operational technical assistance over a wide range of hours, seven days a week.

▸Implementing a computer-aided maintenance management system (CMMS)
This tool enables to anticipate needs for spare parts and to modify the frequency of controls according to real-time anomaly reports. This tool should facilitate the correct application of the HIRA and allow for immediate adaptation in case of changes in the protocols and monitoring of the WWTP.

→ Regularly check several parameters:
— Sensors in the collection network and the WWTP (O2, H2S, water level, ...);
— Presence of foam;
— Correct positioning of grids and meshes;
— No clogging;
— No biocarrier outside the tanks.

→ The data from this self-monitoring, including the monitoring of biocarriers, should be transmitted to the authorities responsible for monitoring the treatment plants concerned on a regular basis.

▸Additional measures in case of incidents
→ Determine the causes and effects of the failure.

→ Define the severity, occurrence, and detectability of the failure.

***Notes** | **24.** Cailleux, G., 2001, L'épuration biologique: fonctionnements et dysfonctionnements. Dissertation. D.E.S.S. " Qualité et Gestion de l'Eau ", Fac. Sciences, Univ. Picardie Jules Verne, 63 p. **25.** Thivel, P.X. , Hus, P., Depriester, M., Rougeot, F., 2004, Diagnostic maintenance of a paper mill wastewater treatment plant. Environnement, Ingénierie & Développement, N°34, pp.27-35. **26.** Maintenance report, 2019, WWTP of Sanremo, Italy*

→ Define corrective solutions (preventive, corrective, complementary, curative, palliative measures, emergency spare parts to be stored).

→ Recalculating the risk index
Assess the quality of the crisis management plan, readjusting it if necessary, in the light of recent events.

→ Rectify maintenance protocols and frequency to prevent the recurrence of the failure.

4.7.6 RECOMMENDATIONS: OPERATOR TRAINING

▸Organise training sessions
Appropriate training of WWTP operators is essential to guarantee the implementation of good practices for the proper functioning of biological treatment with biocarriers.

This training should be conducted according to the usage recommendations provided by the project designer.

As seen above, some recommendations are not specific to biocarriers, but it is important to remember that as this is a balance between biological processes and mechanical systems, the approach should be holistic and the good management of the biological and physicochemical parameters of the effluents is essential.

In particular, operators should be informed and trained on the specificities of biocarriers:

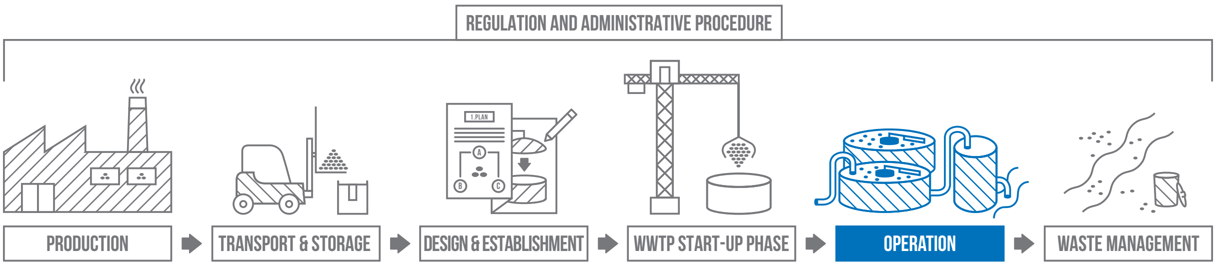
— Grille and other protective device maintenance;
— Identification of failures that can lead to biocarrier losses and corresponding response measures;
— Alert and recovery protocols.

Further training sessions should be organised for any new operator.

Subcontractors in the construction of an MBBR wastewater treatment plant should be informed of relevant biocarrier-specific risks for proper preventive measures to be implemented.

Illustration | Above | Biocarriers stranded on a beach after an accident in Denmark, 2021. © RKSK Kommune

4.8 INSTALLATION MONITORING



TARGET Project owners / Regulatory agencies

PHASE Operation / Control

4.8.1 EXISTING MEASURES AND REPORTED WEAKNESSES

In order to guarantee the long-term reliability of sanitation facilities, regular monitoring by both internally and by external bodies is essential. As biocarriers can be environmental hazards, regulatory agencies should ensure that protective measures are in place and that operators are prepared for a crisis.

Self-monitoring requirements do not include reporting of biocarrier loss or the status of equipment preventing biocarrier loss.

The frequency of monitoring may be too low to detect failures.

Generally, regulatory agencies are not trained in biocarrier processes and the following specific control points are not the subject of oversight:

— Biocarrier loss within the plant, at the WWTP outlet, or in sludge;
— Presence of protective measures (grilles...);
— Emergency plans in case of biocarrier leakage in the environment.

4.8.2 RECOMMENDATIONS: MONITORING BY THE PROJECT OWNER

▸Implementing self-monitoring involving biocarriers
Self-monitoring should encompass all practices to assess and improve the sanitation system's status and functioning, as well as planning required investments. The aim is to reduce the installations environmental impact.[27 28]

The first phase is based on rigorous collection and analysis of all the existing data, which is presented in the form of a simple and operational dashboard providing an overall view of the indicators by issue, recommendations, operational levers to be activated and the progress of the action plans.

The second phase aims to improve the performance of the service by evaluating the effects of prior actions and anticipating the steps and investments required for a continuous improvement loop. It is an approach built, supported, and coordinated by the project owner based on both operational knowledge and the results of field investigations.

Self-monitoring should be based on the Hazard Identification & Risk Analysis.

Concerning biocarriers, self-monitoring should focus on the status of protective installations in particular (grids, cages, etc.). Regular reporting of their state of wear and tear will help anticipate leakage risks and maintenance operations. Water level sensors in the basins/tanks should also be checked to ensure that they are working properly, particularly before periods of heavy rainfall. Instruments for mixing, oxygenation, and monitoring the oxygenation level of the basins / tanks should also be monitored.

The effectiveness of the treatment may also be a good indicator of biocarrier loss. Indirect checking is possible through the monitoring of operating parameters and performance of the biological treatment (dissolved O2 consumption,

***Notes** | **27.** Portail de l'assainissement collectif du Ministère du Développement Durable, France, 2011, Manuel d'autosurveillance. **28.** Préfecture Haute Savoie, France, 2011, Modèle de bilan annuel sur le système d'assainissement.*

oxydation rH)... Define alert thresholds and verify biocarrier integrity through sampling if there is a drop in performance not attributable to the quality of the incoming effluent.

▸Train the operator to implement self-monitoring.
For more details refer to Chapter 4.7.6

▸Self-monitoring reports
→ On an annual basis self-monitoring reports including biocarriers related hazard history should be transmitted to regulatory agencies.

4.8.3 RECOMMENDATIONS: REGULATORY AGENCY OVERSIGHT

▸Regulatory agent training
Environmental authorities responsible for the oversight of control bodies (inspection and audit services) also require training. This training should allow the integration of inspector feedback to improve the inspection protocol.

▸National database
→ Enter technologies used for biological wastewater treatment in national WWTP databases and update them regularly with a supranational Agency such as the European Environment Agency.

This data should be centralised on a national scale and will facilitate the identification of treatment plants using biocarriers, whether they are individual, municipal, or industrial. This will make it possible to be more reactive in the event of pollution or the need for inspection. These databases will also make it possible to identify the communities or companies to invite to training sessions and to share good practices with the appropriate network.

Illustration | Below | Basket installed just before discharge allowing biocarriers collection. © Acqua Publica

→ Minimum information to be provided:
— Installer and operator of the WWTP;
— Type of technology used (MBBR, IFAS, ...);
— Start date;
— Type of biocarrier;
— Quantity introduced;
— History of biocarrier-related malfunctions.

▸Monitoring programmes
In addition to performance monitoring, the definition of appropriate inspections of WWTPs by the competent public authorities should ensure that the equipment provided to prevent leakage of biocarriers is present and functioning properly, in accordance with the initial Hazard Identification and Risk Assessment.

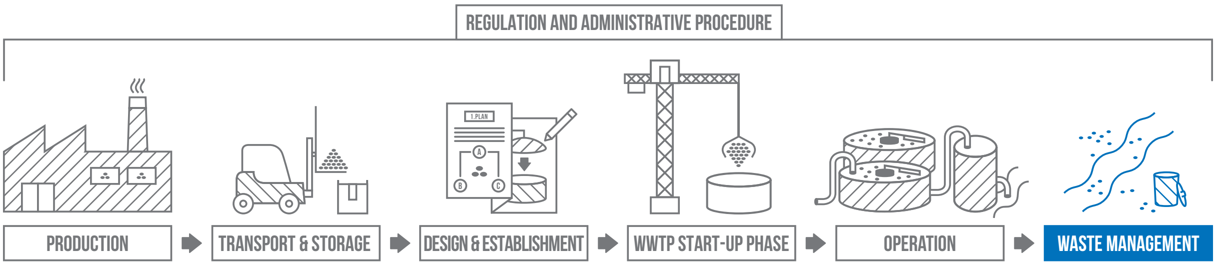
Key control parameters:

— Arrival of wastewater;
— Aeration and good mixing within the biological treatment;
— Sensors (o_2, water level...);
— Retention measures (presence of grids);
— The durability of materials;
— The structure of the tanks (materials);
— Pumps (sizing/backup pump...).

▸Environmental monitoring protocol
→ Establish a dedicated environmental monitoring protocol
In addition to structural and functional supervision, it is important to establish an environmental monitoring protocol. Its objective would be to follow the presence of biocarriers after the final stage of treatment and to ensure the proper functioning of all preventive measures within the plant. This will also allow for the early detection of diffuse pollution.

One possibility for this monitoring is the installation of detection cameras at the WWTP outlet that can automatically detect the presence of biocarriers in the treated effluent or the installation of recovery baskets and regular counting.

4.9 EMERGENCY PLANS



TARGET Operators

PHASE Disposal / Crisis management

4.9.1 REPORTED WEAKNESSES

Existing emergency plans usually do not generally take the presence of biocarriers into account. As a result, no specific organisational measures or mobilisable equipment are ready in the case of a spill within the installation or into the environment. The operations manager of the WWTP is generally the person of reference in case of accident and their knowledge regarding the impact of biocarrier leakage on the environment is essential for following intervention. Unfortunately, managers are generally uninformed of this hazard.

From the known pollution cases, recurring failures were observed:

— Local authorities and municipalities are not informed of possible risks of pollution induced by WWTPs using biocarriers on their territories;

— There is no clear plan of action in case of leakage of biocarriers into the environment;

— Companies and NGOs capable of responding to pollution incidents are not identified in advance and are not contacted in time;

— Operators tend to underestimate, or even hide, the impact of leaks thus delaying the adoption and implementation of appropriate measures;

— When they do occur, clean-up actions are often launched too late due to the rapid spread of plastic carriers in river and marine environments.

4.9.2 RECOMMENDATIONS

The establishment of new WWTPs requires the development of emergency response plans. In its broadest sense, an emergency is a present or imminent situation that requires rapid and coordinated action to protect human health and safety or limit damage to property or the environment. Every owner is required to design, implement, and maintain an emergency management plan that covers a wide range of emergencies and responses: from severe weather to power outages and infrastructure failures.

Biocarriers should be considered an environmental hazard in the event of leakage into the natural environment. Therefore, it is essential to include them in emergency plans to anticipate response measures and the means of intervention.

WWTP operators should immediately report any leakage of biocarrier to the competent authorities and inform them of the severity of the incident.

▸Definition and implementation of the crisis management plan

Given the rapid spread of biocarriers in the environment, taking action as soon as possible is essential.

→ Have a crisis management plan that includes the risks posed by biocarrier leakage

The objective of the crisis management plan is to improve the containment of pollution and reduce its scope, and then restore the facility and/or the natural environment. It is about getting the right people and equipment - in working order - at the right time and place.

The plan should be devised in consultation with crisis management companies, local administrative or environmental authorities, and neighbouring landowners who may be affected by the biocarrier leak.

It should enable:

— Contacting stakeholders to help reduce biocarrier dispersion:
- Local municipalities
- Local water agencies
- Local environmental NGOs
- Remediation companies
- Representatives of the press (to inform riverside communities and citizens)

— Listing existing containment and recovery solutions.

— To establish an appropriate recovery plan for biocarriers dispersed in the environment, including:
- The installation of booms and stop nets in the water column;
- The development of a dedicated website that allows citizens to report the presence of biocarriers in the environment (date, location, quantity, with the possibility of uploading photos), allowing recovery operations on the main accumulation areas;
- The possibility of partnering with local NGOs that have experience in organising and managing waste collection.

— Mapping of nearby rivers and water bodies and their catchment areas. Identify existing dams and potential areas for temporary dams as well as natural areas for biocarrier accumulation.

— Identifying a closed storage site for the collected biocarriers to prevent supplementary incidents and identify a reprocessing channel.

— Allocating a budget for immediate mobilisation in the event of a crisis.

→ Display the crisis management plan in the treatment plant in a visible manner, in sufficient size and quality, including contact information for operators who can answer questions on-site.

→ Make essential instructions available in the vicinity of recovery facilities and equipment.

→ Present the crisis management plan to the local authorities.

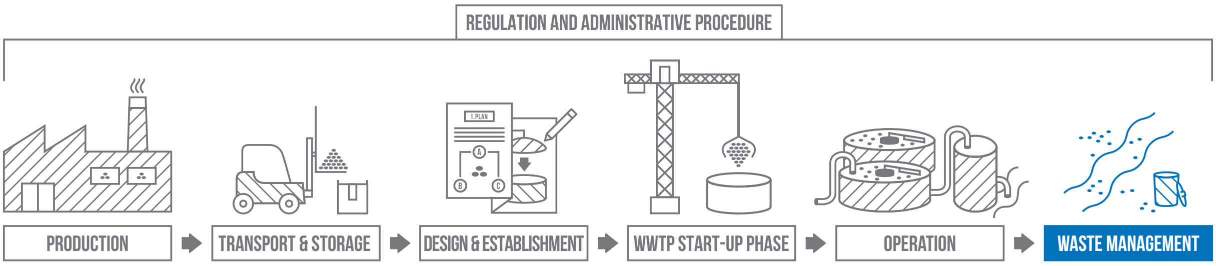
→ Inform stakeholders of developments in the event of pollution.

→ Monitor the weather daily, to prevent possible supplementary incidents.

▸Update of the crisis management plan
→ Carry out an annual inspection of:

— The relevance and validity of the crisis management plan after possible changes in the operation of installations and equipment;
— The validity of the reference persons' contacts
— Presence and conformity of informational posters;
— Presence and condition of containment and cleaning equipment.

4.10 ENVIRONMENTAL RESPONSIBILITY



TARGET environmental authorities

PHASE Disposal / Crisis Management

4.10.1 REPORTED WEAKNESSES

Despite recurrent incidents of clearly-identified origin, the polluter pays principle is applied insufficiently regarding biocarrier pollution and the release of millions of pieces of plastic in marine and riverine environments.

To the best of our knowledge, out of 40 identified cases of biocarrier pollution in Europe, only once has a company covered the cost of remediation (Atlantic Sapphire in Denmark), and only two cases resulted in legal action (Salerno, Italy and Corbeil-Essonnes, France).

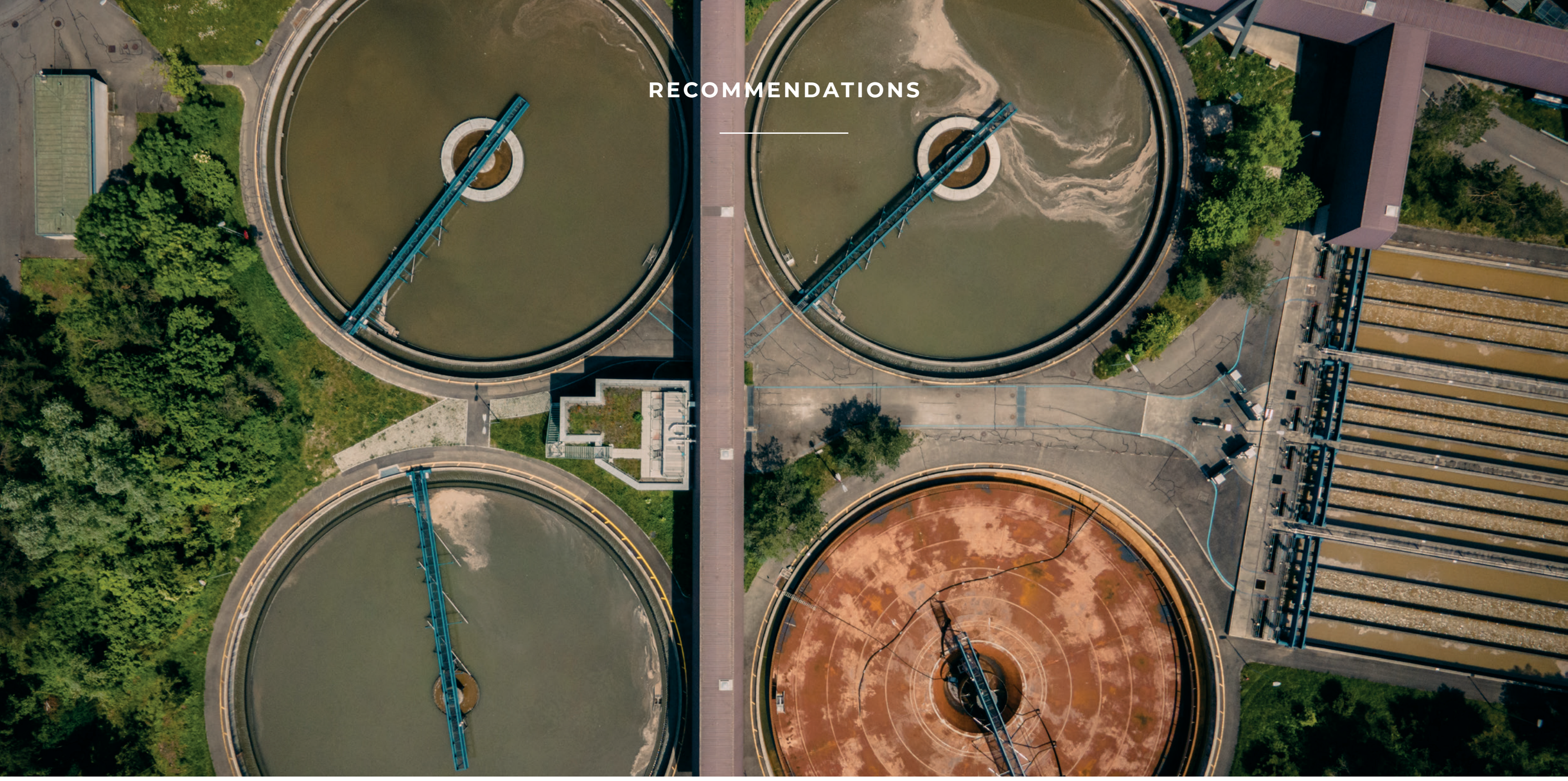
The insufficient application of this principle and the failure to hold polluters legally accountable does not encourage WWTP builders/operators to proactively prevent environmental damage and improve the safety of their systems.

4.10.2 RECOMMENDATIONS: POLLUTER PAYS PRINCIPLE

Polluters should be held responsible for the pollution they cause and bear the costs of said pollution, including the costs of measures taken to prevent, monitor, and remedy pollution.

Depending on the scope of their responsibility, all companies involved in the design, manufacture, use, or handling of biocarriers should be held legally accountable and be required to implement appropriate corrective measures in case of biocarrier leakage into riverine and marine environments.

Illustrations | ***Below*** | *Recovery operation after an important leakage in Evolene, Switzerland in 2012.*
© Commune Evolene



5 PRIORITISATION OF MEASURES

The stakeholders involved in the chain of biocarrier use intervene in a wide variety of fields and the solutions available to them fall into many different categories. This raises the question of how to prioritise them.

Among the solutions proposed above, some are of a regulatory or administrative nature. Others are much more technical. In the absence of regulatory or administrative measures, the implementation of measures to prevent biocarrier leakage relies solely on the voluntary commitments of stakeholders. The role of environmental authorities is therefore crucial.

Based on the analysis of the incidents listed, it appears that certain particularly effective and inexpensive improvements could be implemented in priority to prevent biocarrier leaks into the natural environment. These recommendations could then form the basis of a charter of best practices, to be distributed within networks of actors in the sanitation field.

A summary of the proposed measures is accompanied with an estimation of their cost-benefit rating. This indicative classification essentially highlights the measures that are easiest to implement. Multiple methods exist to determinate this ratio and should be based on the HIRA, which is specific to each installation.

Priority should be given to preventive and corrective actions to avoid losses of biocarrier to the natural environment. Containment and cleaning measures, although important, should be considered at a later stage.

***Illustration** | **Above** | WWTP in Zürich, Schweiz. © Patrick Federi*

SUMMARY OF MAIN MEASURES AND EXAMPLES OF RATING SYSTEMS TO IDENTIFY PRIORITY ACTIONS

STAGE	MEASURE	COST	EFFECTIVENESS / IMPACT	EASY TO SET UP	RATING
Regulation	Training in environmental agencies	+	++	+++	1
	Adding requirements for the authorisation procedure concerning process declaration and retention measures	+	++++	++	1
	Application for a HIRA	+	++	++	1
Production / Transport / Storage	Improved storage conditions	+	+	++++	1
	Limited and safer handling	+	+	+++++	1
	Employee training	+	+	+++++	1
	Adaptation of the Emergency Plan	++	+	++	3
	Monitoring the implementation of prevention measures	++	+	++	2
Engineering	Improvement of general conditions (geological and building design)	+++++	+	+	3
	Improving stormwater management and the collection network	+++++	++++	+	1
	Improvement of basin/tank construction	++++	++	+	3
	Improvement of aeration /mixing equipment	+++	+++	++	3
	Improved grille design	++	+++++	++	2
Operation	Quality control	+	+	+	2
	On-site storage	+	+++++	+++++	1
	Test phase security	+++	+++++	++	1
	Effluent management	+	+++	+++	2
	Maintenance	+++	+++++	+++	1
	Operator training	+	+++	+++++	1
Self-monitoring	Implementation of a CMMS	++++	+++	++	3
	Setting up a biocarrier monitoring system	++	++	++	2
Supervision	National Data Base	+	++++	++++	1
	Specific control plan	++	++	++	3
Crisis Management	Adapting the crisis management plan and integrating containment and clean-up resources	++	++	++	3
	Improving information resources in the event of a crisis	+	+	+++++	2
	Develop the inspection / maintenance plan	+	+	+	2

6 CONCLUSION

WWTPs play an essential role in cleaning our water, maintaining the overall resilience of aquatic ecosystems, and protecting biodiversity.

Biocarrier leakage from municipal and industrial wastewater treatment plants to the environment undermines this objective and contributes to the already significant accumulation of plastic waste in the marine environment.

Given the widespread use of biocarriers in Europe, the transboundary nature of their pollution, and the increasing risk of leakage due to extreme weather events, there is a need for a harmonised and ambitious set of prevention measures among the Nordic countries.

This study, carried out in conjunction with the designers and operators of biocarrier-using WWTPs, identified a wide variety of actions to reduce the risk of biocarrier leakages, from the preliminary design stage to the monitoring of a functional WWTP operation. Some of the recommendations are common sense and very inexpensive to implement. Their effect can be quick. Other measures, whether regulatory or related to the design of the plants themselves, may take longer to implement and be more costly. Although the design of a WWTP is a compromise between the costs of achieving an optimal facility and the budget available, certain safety-related expenditures should not be ignored. At each stage of the biocarrier life cycle, the training of designers, operators, regulators, or inspectors is the basis of informed and appropriate decisions concerning biocarriers in WWTPs. Therefore, stakeholder implication is particularly important during the start-up phase for smooth operations from the outset.

From now on, and depending on their situation, it is up to stakeholders to implement the most obvious measures that can be carried out quickly and at low cost.

Illustration *|* ***Above*** *| Basin at České Budějovice, Czech Republic. © Martin Kníže |* ***Right page*** *| Different models of biocarriers collected on a beach. © Surfrider Foundation Europe*

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Illustration | ***Above*** | *WWTP at Santa Clara, CA, USA. © John Cameron*

8 ANNEXES

8.1 ANNEX 1: LIST OF BIOCARRIER POLLUTION IN EUROPE

NUMBER OF POLLUTION CASE	COUNTRY	LOCATION	DATE	RECEIVING WATER	BIOCARRIERS USED
2	Denmark	Hvide Sand	March 2021	North Sea	BCP 750
		Mølleåværket / Charlottenlund	2014	Mølleå river and Oresund	K5
7	France	Corbeil-Essonnes	February 2010	Seine river	K1
		Nive d'Arnéguy	Autumn 2012	Nive river	K3
		Bastia	March - May 2020	Mediterranean sea	K5
		Saint Maur des Fosses	May 2011	Marne river	K5
		Molines en Queyras - Saint Véran	2016 / Juillet 2021	Le Guil, La Durance and lake of Serre-Ponçon	BioChip M
		Ladoix-Serrigny	2011	Saone River	K3/K5
		Vallouise	2010 /June 2017	La Durance and Lake of Serre-Ponçon	Hel-X HXF17KLL

NUMBER OF POLLUTION CASE	COUNTRY	LOCATION	DATE	RECEIVING WATER	BIOCARRIERS USED
1	Iceland	Iceland	2021	North Atlantic Ocean	Unknown
3	Italy	Salerno	February 2018	Sele river and Mediterranean sea	Biochip P
		Itri	December 2020	Medierranean sea	Hel-X
		Limone Tremosine	2013/2020	Adda River > Po River	K3 and Hel-X HX17KL
4	Norway	Hisøy	June 2015	North Sea	BWT15
		Vindafjord	December 2018	Atlantic Ocean	KNS
		Halden	2017	Iddefjorden and Skagerrak Sea	BWT15
		Sørumsand or Blaker	November 2012	Probably Glomma river and North Sea	K3
1	Portugal	Açores	2018	Atlantic Ocean	K3
5	Spain	Miño river (Spain/Portugal border)	Summer 2013	Miño river and Atlantic ocean	K1
		Nemiña beach	November 2017 January 2018	Castro river and Atlantic ocean	K1
		Villabona / Tolosa	September 2009 November 2009	Oria river and Atlantic ocean	AMB and KNS
		Galice	Autumn 2012	Ria de Pontevedra and Atlantic ocean	K5
		Santesteban	December 2021	Bidassoa River > Bay of Biscay	K3
14	Sweden	Vansbro	Summer 2018	Västerdalälven river	K3
		Vamas	2016	Västerdalälven river	Unknown
		Munkedal	2016	Örekilsälven	Unknown
		Sotenäs	2014	North Sea	Unknown
		Sandviken	April 2020	Lake Storsjön	K3 and Hel-X
		Idre	2016	Storan Österdalälven	Unknown
		Lysekil			K1
		Brandholmen/ Nyköping	January 2023	Baltic Sea	K1 / Hel-X

NUMBER OF POLLUTION CASE	COUNTRY	LOCATION	DATE	RECEIVING WATER	BIOCARRIERS USED
	Sweden	Pinan / Öckerö	March 2021	North Sea	K1 / K3
		Sjölunda / Malmö	2020/2022	Baltic Sea	K1
		Bergsjö	2000 - 2008	lake Bergsjøen	K2 / K3
		Klippan	2004	Baltic Sea	BioChip M
		Lessebo	2006	Lake Öjen	K1
		Kungsgårdens (Sandviken)	April 2020	Lake Storsjön	K3 / Hel-X
3	Switzerland	Saillon	January 2012	Salentse (tributary of the Rhône)	Biochip
		Saint-Prex	September 2012	Lake Geneva and Mediterranean	BWT 15
		Evolène	March 2012	Le Borgne (tributary of the Rhône)	Biochip

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8.2 ANNEX 2: CONTRIBUTORS TO THE INTERVIEWS AND QUESTIONNAIRES

COUNTRY	COMPANY	CONTACT
Denmark	Danish Ministery of Environment	Frank Jensen
Denmark	Ringkobing-Skjern Kommune	Anders Norskov Stidsen
France	Loire-Bretagne Water Agency	Regis le Quillec
France	Rhone-Méditerranée-Corse Water Agency	Fabien Abad
France	MWWTP Bastia	Bernard Bombardi/ Stéphane Casella
France	MWWTP Chateauneuf Le Rouge	Marie Bonnamy/ Rémi Grac
France	MWWTP La Plagne	Marc Pelissier
France	MWWTP Menton – Roquebrune	Fidele Vingelli
France	MWWTP Vallouise - Pelvoux	Amandine Fiot
France	MWWTP Abriès – Ristolas / Chateau Ville vieille – Molines en Queyras	Cécile Belon
France	MWWTP Carhaix-Plouguer	Fabien Pann
France	French Ministery of Ecological transition – (DGALN)	Bénédicte Jénot / Augustin Ayoub
France	DDTM 64	Arnaud Bidart
France /Europe	SAUR	Adélaïde Combret
France/ Europe	SOCOTEC	Aurélien Brottes
Germany	MUTAG	Louise Munk
Iceland	Arctic Fish Aquaculture	Steinumm G. Einarsdottir
Iceland	Environment Agency of Iceland	K. Sóley Bjarnadóttir Hólmfríður Þorsteinsdóttir
Norway	Norwegian Environment Agency	Maria Hedenstad / Caroline
Sweden	Swedish Environmental Protection Agency	Helen Klint / Maximilian Ludtke / Martin Holm
Sweden	Swedish Agency for Marine and Water Management	Robert Almstrand

COUNTRY	COMPANY	CONTACT
Sweden	MWWTP Göteborg	Asa Magnusson / Tove Rappmann
Sweden	MWWTP Gislaved	Theodor Ekman Larsson / Hannah Steinhausen
Sweden	Tanum Kommune	Karin Görfelt and Michael Viberg
Sweden	MWWTP Mellanfjärden and Bergsjö	Linda Almqvist
Sweden	MWWTP Ekebro	Anders Jeppsson
Sweden	MWWTP Göteborg GRYAAB	Emma Nivert
Sweden	MWWTP Klippan	Andersson Börje
Sweden	MWWTP Lessebo	Katarina Karlsson Palm
Sweden	MWWTP Lysekil	Johanna Torberntsson
Sweden	MWWTP Nyköping	Oliver Teichert
Sweden	MWWTP Öckerö	Mats Kjellberg
Sweden	MWWTP Vansbro	Åsa Ekvall
Sweden	MWWTP Vrigstad and Farstorp	Kim Tietze
Sweden	Independent – Master Thesis on Biocarriers	Agnes Tunstad
Sweden	West Coast Trust - Sweden	Florina Lachmann
Sweden / Europe	Anox Kaldnes – Veolia Water	Sofia Lind
France	Suez France	no answer
France	FP2E - Fédération Professionnelle des Entreprises de l'Eau	no answer
Norway	Standard Norge	no answer
world	Global Salmon Initiative	no answer
world	Aquaculture Stewardship Council	no answer
world	Global Seafood Alliance	no answer

8.3 ANNEX 3: STAKEHOLDER QUESTIONNAIRE

SHARING OF YOUR EXPERIENCE WITH BIOCARRIERS - EN

Surfrider Foundation Europe* is commissioned by the SWedish Environmental Protection Agency (SWEPA) to propose guidelines on the safe management of biocarriers.

This assignment will contribute to the OSPAR Working Group on Marine Litter. (https://www.ospar.org/work-areas/eiha/marine-litter)

Biocarriers are small bacteriological supports introduced in WasteWater Treatment Plant (WWTP) to improve treatment efficiency. Unfortunately, regular malfunctionnings occur, leading to leakages in the environment. They can especially be found in secondary treatment processes such as MBBR (Moving Bed Biofilm Reactor).

Our mission will be organised around a group of experts (Environmental agencies from Nordic countries, WWTP designers, operators, municipalities) who, through their involvement in the life cycle of biocarriers, will be able to share their experiences.

In order to reinforce this guide of good practices, we are looking for more experts who could provide new recommendations and/or validate those already proposed.

We identified you as a valuable stakeholder for this project and we would really appreciate you sharing your experience regarding bio carriers with us.

This questionnaire will help us better understand your experience.

The following form will take you 5-10 min to fill.

If you feel more confortable, feel free to answer in your mother tongue.

The results of this questionnaire will be kept private and no data will be shared publicly without your authorisation.

Please do not hesitate to contact us for further information.

Thank you in advance for your contribution.

Philippe Bencivengo - Surfrider Foundation Europe
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** Surfrider Foundation Europe is a European NGO who has become a reference in the protection of the ocean and its users. Its work has been aknowledged through numerous European expert groups.*

SHARING OF YOUR EXPERIENCE WITH BIOCARRIERS - EN

Tell us a bit more about who you are

1. What is your name? (first name / last name)

. . . .

2. Which organisation are you working for? (company / minister / NGO ...)

. . . .

3. What is the territory covered by your activity ? (Local, National, European, International...)

. . . .

Your experience regarding biocarriers

4. For how long have you been working with biocarriers?

. . . .
. . . .

5. In which phase of the biocarriers' life cycle are you involved?

O Regulation / Control
O Bio-carriers production / supply
O Transport / Storage
O WasteWater Treatment Plant Design and Installation
O WasteWater Treatment Plant Operation
O Waste management (end of life / overspill)
O Other

6. Can you please tell us a bit more about your role in few lines?

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

7. Have you ever faced incidents or difficulties regarding the management of biocarriers?

O Yes O No O I don't know

8. If yes, can you please explain what happened?

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

SHARING OF YOUR EXPERIENCE WITH BIOCARRIERS - EN

9. Has your experience with biocarriers been documented within your organisation?

O Yes O No O I don't know

10. If yes, what kind of document / media? (information page, website, user guide, recommendations, process of control, incidents report ...)

....

....

Participating to the "experience capitalization"

11. Do you want to contribute to this participatory process?

It will consist in sharing your feedbacks about your experience with biocarriers, participating in online working groups and help validating the guidelines with other actors working on biocarriers.

O Yes O No O other

If other, please explain:...

....

....

Promotion and dissemination

12. Will you be able to share recommendations and good practices within your organisation?

....

13. Do you know 1 or 2 people who would be interested in taking part in this experience capitalization process?

If so, would you agree to send them this questionnaire or give us their contact details so we can further contact them.

....

....

14. Feel free to share any useful information regarding biocarriers

....

....

....

15. May we contact you back for anu futher information?

O Yes O No O other

16. Email to be contacted:...