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SUBMARINE OUTFALLS AS PART OF THE SOLUTION TO ACHIEVE SDGs

BY PHILIP ROBERTS , JAMES BRADLEY, ROBIN MORELISSEN & DANIEL A. BOTELHO

Central to the task of achieving Sustainable Development Goals (SDGs) is the provision of potable water, sanitation, and economic development to the poorest. According to the United Nations, half of the world's population lives within 60 km of the sea and three-quarters of all large cities are located on the coast. Many cities in developing countries lack adequate sanitation. Sewage may run untreated in the streets into lakes or rivers, contaminating local water supplies. The rivers ultimately flow to the ocean, causing pollution as they enter the local coastal environment. Even in cases where wastewater is collected it is often discharged right at the shoreline resulting in contamination and potential health risks to bathers.

According to the World Health Organization (WHO), even advanced treatment does not mitigate this health risk. Inevitably, drinking water production, collection of domestic and industrial effluent, as well as increased demand for energy will result from efforts to reach SDGs and will lead to increased pressure on marine ecosystems, as much of the produced effluent will be discharged in the ocean. In this regard, submarine outfalls will form an essential part of a sustainable and environmentally sensitive wastewater management strategy for coastal regions.

Before discussing how marine outfalls can assist in reaching SDGs, it is of benefit to define outfall systems, as many readers may be unfamiliar with their characteristics and purpose. Put simply, an outfall system is an engineering structure designed to convey domestic and/or industrial effluent into ambient waters as a means of reducing the impact of (treated or untreated) anthropogenic waste to acceptable levels. Outfalls, however, do not work in isolation and need to be seen in the context of a broader treatment system quite often necessitating considerable capital investment. For example, domestic effluent requires a sewerage system for wastewater collection and conveyance to a treatment plant, and a means of ultimate discharge in receiving waters. For relatively large discharges in a coastal setting, this means of discharge commonly consists of an outfall. More specifically, the outfall comprises a pipeline or tunnel, or combination of the two, which terminates in a diffuser (Figure 1). Outfalls typically range from 1 to 4 km long and discharge into waters 20 to 70 m deep, although they may be longer or shorter if the seabed slope is unusually flat or steep.

Because they convey the effluent to the ocean, outfalls are frequently (and erroneously) perceived as the source of pollution. However, extensive experience around the world has shown that disposing of properly treated wastewater through well-designed ocean outfalls is an economical and reliable strategy for wastewater disposal with acceptable environmental effects [1].

Outfalls and SDGs

Given the definition and aspects of outfalls provided above, a discussion of how outfalls can support achievement of SDGs is provided below.

Goal 6.1 Universal and equitable access to safe and affordable drinking water for all

Marine outfalls for wastewater discharge remove the need for discharge/disposal into inland waters and/or land application where there is the possibility of water supply contamination. Marine outfall systems therefore play an important role in protecting freshwater systems and are crucial to meeting this goal. Seawater

Figure 1. Underwater Picture of the Alkimos Sewerage Outfall in Perth, Western Australia. In detail, one of the diffuser ports in operation. Photo courtesy of BMT Oceanica

desalination and water reclamation also rely on outfalls for discharge of the return brine effluent. Effective outfalls are crucial components of these water supply options.

Goal 6.2 Access to adequate and equitable sanitation and hygiene for all

Effective sanitation requires considerable capital investment, and advanced treatment requires expertise that may be beyond the capabilities and resources of developing countries. Therefore, it is important that the level of treatment and the disposal method be chosen appropriately and together to ensure efficient allocation of resources with a technology that is sustainable, reliable, and protects the receiving water environment and human health.

Noting the above, the adoption of an effective outfall can often be achieved by relinquishing onerous advanced wastewater treatment and be implemented at lower cost than higher technology and nutrient removal and disinfection before discharging to inland waters and/or land. This is especially the case when considering the ongoing operating costs of advanced treatment plants, sludge management, and expertise required for plant operation.

An effective outfall is one that discharges far from shore into relatively deep water that results in high dilution, thus reducing concentrations of contaminants to safe levels with minimal effects to primary and secondary recreation, fisheries, and the local ecosystem. In practice, outfalls separate people and fragile ecosystems from effluents. The disposal options are sometimes posed as a dichotomy between advanced treatment or an outfall, but in fact an outfall will still be needed even with advanced treatment. As financial availability for capital expenditure are quite often restricted, it is often desirable to ensure the construction of an outfall as early as possible in the overall implementation of sanitation planning.

Current technological advancements allow outfalls to be implemented relatively quickly following a proper design process, and with lower costs than other solutions. New methods of outfall construction, especially the increasing use of HDPE (high density polyethylene) pipe and prefabricated treatment units means that systems can be readily put together in developing countries at reasonable cost. An example of such systems ready for installation is the Mar del Plata sewerage outfall in Argentina (Figure 2). Furthermore, outfalls, when properly designed and installed, require little maintenance over their lifetime. In this context, outfalls are likely to be more practical and affordable than higher cost solutions such as advanced treatment.

Outfalls are not only required for effective domestic sewage discharge. Noting that food production and economic development are essential requirements to achieving SDGs, adequacy and cost efficiency in terms of equitability are also important considerations for many industrial wastewater discharges. In this respect, high organic strength (Biological and Chemical Oxygen Demand) wastes from industries such as food and meat processing, are more amenable to discharge into the marine environment, where the assimilative capacity is much greater than for inland waters. Appropriate outfall design can efficiently guarantee hygienic conditions for coastal populations.

Figure 2. HDPE pipes comprising the manifold of the Mar del Plata (Argentina) sewerage outfall ready for installation. This photo was taken during a technical visit at the International Symposium on Outfall Systems in Mar del Plata Argentina, 2011

Goal 6.3 Improve water quality by reducing pollution, halving the proportion of untreated wastewater and sustainably increasing recycling and safe reuse

Outfall systems provide flexibility in terms of reducing pollution and facilitating increased recycling and safe water reuse. Specific mechanisms and infrastructure arrangements that can be used to facilitate these objectives include:

- Appropriate control of industrial wastes at their source that adopt cleaner technologies and recycling of pre-treated wastewater schemes
- Separate collection, conveyance and treatment before combined discharge through an outfall, thereby facilitating recycling and reuse of one or the other wastewater streams. For example, combination of fresh and saline (i.e. brine) effluent can be used for energy recovery as a means of reducing energy requirements for desalination.
- Use of multi-port outfall diffusers that can be operated in various modes to accommodate variable discharge flow rates that may result from recycling and reuse of variable amounts of the treated wastewater.

Goal 6.4 Substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals of freshwater to address water scarcity

Measures can be imposed and adopted in voluntary ways in any reticulated wastewater collection system and also in on-site wastewater systems to increase water use efficiency.
In the urban/domestic systems measures of water conservation and demand management, such as universal water supply metering and associated cost charging, water efficient plumbing and other water saving devices, water pressure management in the water supply network, consumer education and stewardship all available to achieve various degrees of water efficiency.

In industrial wastewater management appropriate controls at the industry promise cleaner technology with or without water reuse and pretreatment of pollutants in the wastewater, all forming parts of water efficiency measures.
The adoption of such water efficiency measures

can result in significant cost and infrastructure efficiencies, reducing the requirements for wastewater outfall systems. These include:

- The collection, conveyance, treatment and outfall infrastructure does not need to be as large as wastewater volumes are reduced thereby reducing capital and ongoing operating costs
- Pre-treatment of industrial wastes at the source (at the industrial premises or at joint industry pre-treatment plants) reduces the pollutants requiring treatment in the outfall treatment plant, thereby reducing treatment infrastructure needs and ongoing operation costs
- With less industrial wastewater pollution outfall systems may be able to discharge nearer to the shoreline and accordingly be shorter and at lower cost.

Goal 6.5 Implement integrated water resources management at all levels

Outfall systems provide a wide range of integrated water resource management needs. These for example include procedures for reduction of domestic and industrial wastewater at the source, flexibility and modular development of treatment facilities, and beneficial reuse of treated wastewater and other residuals, particularly sludges and biosolids. A further key approach in terms of integration is the efficient use of the assimilative capacity of the receiving marine environment to ensure that a long term sustainable solution is attained.

Goal 6.6 Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

Marine outfall systems for treated wastewater discharges obviously provide a high degree of protection of fresh water ecosystems by removing the discharges from rivers, lakes, wetlands, aquifers or land areas where contamination could occur.

If treated wastewater discharges are diverted from inland waters, aquifers, wetlands, and land to the marine environment through a marine outfall, this would result in some restoration (depending on the impacts of the former discharge) of the freshwater, aquifer, wetlands and land into or onto which the discharge was previously made.

Goal 6.6.a Expand international cooperation and capacity-building support of development countries in water and sanitation related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

The sharing of outfall case histories, including investigations, design, construction and operating experience can expand international co-operation and capacity building and are all vital planks in advancing the sustainable development goals for water that are included in the United Nations 2030 Agenda. The existence and activities of the IAHR-IWA Joint Committee on Outfall Systems play an important role in this respect. The Committee's activities, including the regular Outfall Symposia, provide a sound vehicle that covers many of the sustainable water management topics covered in the above goals.

Goal 6.6.b Support and strengthen the participation of local communities in improving water and sanitation management

One of the IWA's Joint Committee on Marine Outfall Systems initiatives is to develop activities that promote local communities who are closely involved in outfall system projects being planned or already functioning in their locales. Local communities play an important role in providing knowledge of their local marine water body and other environmental factors to those designing outfalls, outfall owners, and regulatory authorities. Local groups can also be closely involved in the ongoing performance monitoring of outfalls.

In order to facilitate such local involvement it is not uncommon in some countries, such as New Zealand, for the regulatory authorities to include conditions on the outfall permits that require the outfall owners and operators to regularly involve local communities. Such involvement can include the establishment of local liaison and monitoring groups.

These local groups can also have ongoing involvement in assessing the outfall systems' monitoring results, of input into (any) future outfall system and treatment upgrades, and in assessing the appropriateness and updating the monitoring and reporting procedures. The latter activity is important as advances in technology and understanding of the marine environment continue and it is appropriate to adopt technologies and monitoring procedures that ensure long term sustainable approaches.

Goal 7 Energy (affordable, reliable, sustainable and clean energy)

Outfall systems, particularly those that do not require advanced wastewater treatment often result in lower overall energy usage. Accordingly, they can be more affordable, reliable and sustainable, particularly if the energy comes from clean renewable sources.

Further, substitution of coal-fired by less carbon-intensive gas-fired thermal power plants are likely to be an important step in the transition to cleaner energy production. The use of outfalls will still be required to properly discharge cooling water to acceptable levels of impact in the receiving environments (both freshwater and marine).

Goal 11 - Cities – (safe, resilient and sustainable)

The maintenance of safe, resilient and sustainable cities will be bound by water security, economic activity and energy requirements.

The establishment of Industrial Coastal Cities should be carefully considered by both developed and developing nations noting that the ocean is a vital transport route for manufactured products, has a much larger pollution-absorbing capacity compared to inland waters, and is often suited to both water and energy production. Thus, it is not unrealistic to link these industrial hubs to potential wealth creation and economic health of nearby urban populations.

Whilst the creation of these Industrial Cities is intended to optimize land use, there is a potential for the release of multiple marine discharges within close proximity to each other, which may lead to unintended environmental outcomes. Outfalls can help mitigating these unintended environmental impacts by combining the discharge of different wastewater streams to a specific area (e.g. an area that has been identified as having low ecological risk or possessing suitable mixing characteristics). It is recognized that the implementation of such resilient Industrial Cities would face many challenges (e.g. careful planning from project conception, regulatory oversight, clean and transparent information sharing, stakeholder engagement and coordination, etc.). However, identifying the design and operation of outfalls as a means of conciliating these competing interests can be used as an opportunity for a more sustainable implementation of Industrial Cities.

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Robin Morelissen **– Vice Chair - Joint IAHR-IWA Leadership Committee on Marine Outfall Systems, has over 15 years experience in multi-scale numerical modelling of coastal hydrodynamics, dredge plumes and outfalls and is working at Deltares, The Netherlands. His research focuses on the coupling of near field and far field models used in recirculation studies for (seawater) intakes and outfalls and dredge plume studies and on advanced modelling techniques used in engineering practice. Mr Morelissen had a key role as a project manager in (multi-disciplinary) projects concerning studies for new reclamations, flushing studies, dredging (sediment dispersion) impact studies and recirculation studies. Within Deltares, Mr Morelissen also works on new business development and innovation focusing on collaborative innovation. Furthermore, Mr Morelissen is currently Vice Chair of the IAHR/IWA Marine Outfall Committee.**

Daniel A. Botelho **– Chair - Joint IAHR-IWA Leadership Committee on Marine Outfall Systems, is the Principal Engineer at the Catchments and Receiving Environments at BMT WBM in Brisbane, Australia. His expertise lies in the understanding of hydrodynamic processes and how they drive the ecology and water quality of freshwater and marine environments. Adequate and sustainable use of marine outfalls for effluent discharges is one of his main technical pursuits. Of particular relevance, Dr. Botelho has developed advanced numerical tools to support reliable assessments of the impacts of existing and proposed outfall systems. Over the last 6 years, Dr. Botelho has actively contributed to the activities of the Joint IAHR-IWA Leadership Committee on Marine Outfall Systems.**

Additionally, resilient cities require alternative water sources such as desalination and water reclamation. The resulting return brine effluent will require disposal through an efficiently designed outfall. Recent technological developments such as pressure retarded osmosis (PRO) and reverse electrodialysis (RED) are being investigated to aid in energy recovery. While the adoption of these new technologies would contribute to the resilience and sustainability of coastal cities, changes in physico-chemical characteristics of the brine stream will demand more flexibility in outfall designs.

Goal 13 Climate change

Appropriately sized outfall systems can accommodate the results of climate change that may lead to prolonged wet periods and high intensity rain that may partially enter the wastewater systems. As mentioned previously, water security will rely more and more on desalination, as droughts are expected to last longer and the world's population is expected to grow. Properly designed outfalls will be needed to effectively dispose the brine resulting from water desalination.

An efficient outfall can obviate the need for advanced wastewater treatment that can be a significant source of greenhouse gases such as methane.

Goal 14 Oceans (conserve and sustainably use the oceans, seas and marine resources)

Suitably located outfall discharges, with the appropriate level of treatment, can achieve long-term sustainable solutions for domestic and industrial wastewater discharges. The matching of the receiving environment's assimilative capacity to the quantity and quality of the discharges is key to the achievement of such sustainable solutions. It is imperative that siting and design of outfalls are undertaken within the broader context of coastal zone and ocean management so that human recreation, fisheries, and ecosystem health are preserved. Inherently, the design of an efficient ocean outfall is a multi-disciplinary endeavor requiring expertise in oceanography, mathematical modeling to predict the fate and transport of wastewater, water quality and water microbiology, hydraulic engineering, coastal engineering, geotechnical engineering, and environmental engineering. Integration of these disciplines is one of the principal remits of the Committee on Marine outfall Systems.

Proposed Actions – Guiding principles for development of sustainable outfall systems

Noting the above, submarine outfall systems have an important role in helping the achievement of SDG's. It is clear that technology advancement, stakeholder engagement, and a multidisciplinary approach will be pivotal for effective implementation of outfalls within the context of SDGs. With this in mind the Leadership of the Committee on Marine Outfall Systems promotes the adoption of a few guiding principles for the design and implementation of outfalls.

For developing countries that lack clean drinking water, one of the challenges is to separate the wastewater streams from the water sources. When the wastewater and drinking water source mix, this could seriously impact the health of the population or animals (e.g. cattle) in that region. It is therefore essential to develop infrastructure that can separate wastewater from drinking water sources.

Sustainable development ideas can be implemented in the design of such infrastructure. The design philosophy starts from the existing situation and the various functions it serves, such as residential functions, agriculture, industry, etc. By understanding the needs of these existing functions, as well as the problems they face, infrastructure design options could be developed that not only mitigate the negative effects that wastewater could have if not properly handled, but at the same time create opportunities for the existing functions. Furthermore, since in developing countries, resources to develop such infrastructure are typically scarce, a wise combination of functions could lead to a more sustainable design for the overall water infrastructure. This provides interesting opportunities to minimise outfall impacts with opportunities for innovative and sustainable designs.

The following design steps, adopted from Vriend et al. [2], could be applied to the sewage and outfall system design process:

Step 1: Understand the system
This step aims at gathering the main characteristic of the wastewater collection and outfall system. It includes a solid understanding of the natural environment and existing functions and the ecosystem services that the system provides to the local population and industry. It also includes understanding the cultural vocation of the region and its relationship with nature. This step identifies:

- the physical and ecological environment in which the wastewater collection and the outfall will be placed;
- the values and interests the local community places on available freshwater and marine ecosystems;
- stakeholders that need to be involved to advance the sustainable solution development process; and
- coarse screening of potential alternatives and prioritising for maximising the services and functions to be provided to the local community.

Information about the system at hand can be derived from various sources, including historic documentation, academic research, but also fundamentally from local knowledge and its cultural practices. Analysis of this information will form the principles for the identification of the functioning of local communities and how ecosystem services beyond those relevant for the primary objective (i.e. separation of water and wastewater) can be developed and harvested.

Step 2: Identify realistic alternatives that use and/or provide ecosystem services.
In this step, realistic alternatives for wastewater collection and the outfall are developed. To identify feasible solutions, it is important to involve academic experts, business owners, decision makers and other stakeholders in their formulation. The approach in identifying the alternatives should proactively seek for options to utilise and/or provide ecosystem services. In other words, it should not only minimise possible impacts but should seek opportunities to improve existing services and functions. Such opportunities could be created in different ways, such as:

- Creating opportunities for nature (e.g. habitats) with the outfall system
- Using the natural processes and system in the project area to optimise the functioning of the outfall system
- Combining the design with other functions or operations in the project area

In addition to the above ways of creating opportunities with the outfall design, these systems have a number of characteristics that could create opportunities, such as:

- High kinetic energy of the outfall flow
- Density differences between effluent and ambient water
- Nutrients contained in the effluent
- Discharge-induced residual flow

Some initial examples of such sustainable design options for wastewater infrastructure could be:

- Reuse of wastewater for aquaculture, e.g. using a wastewater outfall as nutrition for (coastal) aquaculture with proper management of health risks [3].
- Using fresh wastewater in combination with saline marine water to generate energy [4]
- Use the kinetic energy of a wastewater outfall to generate energy [5]
- Wastewater channels with levees that double as flood protection
- Collection of wastewater and reuse as irrigation water
- Reuse of wastewater for industrial use
- Use natural options to treat wastewater before reuse (e.g., filtering by duckweed widely applied in Asia), which could again be used as food for fish or livestock, or as fuel.

Step 3: Evaluate the qualities of each alternative and preselect an integral solution.
This step requires the adoption of conceptual and pre-feasibility studies to test whether the potential of each of the alternatives selected in Step 2 can be realised. This step should be undertaken by a team of experts using suitable methodologies for assessing whether the intended outcomes can be achieved. As practicable as possible, these assessments should contemplate engineering, economical, environmental, and social aspects of the proposed solutions.

The merits and shortcomings of each solution should be discussed with stakeholders for valuation and selection of preferred solutions.

Step 4: Fine-tune the selected solution (practical restrictions and the governance context)
After selecting the optimal solution, its design must be refined and detailed. This will typically be done by a team of engineers, but a close connection should be kept with experts in the fields of economics, environment, and governance to ensure the feasibility of all aspects of the selected solution. It is particularly important to involve the stakeholders in this step, who need to support the eventual solution and can assist in overcoming restrictions. This is especially important in the implementation phase.

Step 5: Prepare the solution for implementation
Finally, the solution needs to be prepared for implementation and construction using a suitable approach (e.g. by involving local work force). It is important to keep the stakeholders involved at this stage in the operational phase to maintain support for the development. Furthermore, it is important to secure a solid knowledge transfer about the wastewater collection and outfall system to the local stakeholders. This way, a feeling of ownership of the development is promoted, which helps in a long-term, sustainable operation and maintenance of the system. ■

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