Monitoring Environmental Impact of Ocean Disposal of Sewage: Experience from New South Wales, Australia

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Abstract
Discharges of treated and untreated sewage to natural waterways can result in a range environmental impacts including poor recreational water quality due to pathogens; eutrophication due to nutrient loadings; toxicity to humans and ecosystems due to a range of chemicals in sewage; accumulation of contaminants in organisms and sediments due to chemicals in sewage; and changes to biological communities due to physical and chemical disturbances caused by sewage discharges. Planning and design of outfalls should be focussed around eliminating or minimising these impacts. Monitoring is essential to determine if the objectives of the design and operation of the outfalls are meeting expectations. Monitoring can be considered to operate in three Stages. Stage 1 (Design) involves definition of expected environmental outcomes as performance criteria and detailed design work to ensure that these outcomes can be met. Stage 2 is Verification and involves intensive physical, chemical and biological monitoring of the outfall's performance against the performance criteria. Stage 3, or performance monitoring is the long-term, usually less intensive stage which provides confidence to operators, regulators and the public that the plant and outfall continues to meet environmental expectations. The effective operation of these three stages will be illustrated using examples from the monitoring of sewage outfalls along the NSW coast. Monitoring is only useful and effective if there are clear actions identified in case outfall and plant performance is less than expectations.

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INTRODUCTION

Concern about unintended consequences of discharges of human derived pollutants continues to grow. We are now starting to see large scale consequences such as dead zones (Diaz and Rosenberg 2008) resulting from discharges of organic materials and nutrients to marine waters. On a smaller, more local scale, discharges from sewage treatment plants and overflows from sewage reticulation systems can impact on human health, environmental amenity, recreational opportunity and ecological processes, particularly in aquatic environments such as beaches, rivers, lakes and lagoons. These impacts also affect tourism and economic development. Unless outfalls are appropriately designed and located, sustainable use of the coastal zone can become impossible. Monitoring of sewage treatment systems is essential to understand the performance of the systems and enable informed management responses to impacts.

In this paper I will describe a framework for planning monitoring associated with sewage discharge and present a number of examples of how monitoring is done in NSW (Australia). I will look at the types of impacts that have been associated with sewage disposal at some of the small shoreline outfalls along the NSW coast and the example of the large Environmental Monitoring Programme (EMP) and subsequent studies associated with the commissioning of deepwater sewage outfalls off the NSW capital city, Sydney.

Discharges of treated and untreated sewage to natural waterways can result in a range of environmental impacts (Scanes 2007) including:

- Poor recreational water quality (swimming, wading and boating) due mainly to pathogens;
- Changes to biological communities due to physical and chemical disturbances caused by sewage discharges.

- Accumulation of contaminants in organisms and sediments due to chemicals in sewage;
- Eutrophication (excessive plant growth including algal blooms) due to nutrient loadings;
- Toxicity to humans and ecosystems due to a range of chemicals in sewage;

Unfortunately, when many of NSW's ocean outfalls were initially built there was little consideration of ecosystem impacts. This lack of explicit consideration was based entirely on the premise that effluent dilution in the ocean would provide adequate protection (Scanes 2007).

The broader community in Australia has a number of expectations about waste disposal, including that all waters will remain suitable for recreation; there will be minimal environmental damage; that there will be maximum re-use and/or re-claiming of water from sewage and lastly, there will be effective monitoring at all stages.

Government attempts to meet these expectations through regulation which:

- Maximises re-use of sewage and harvesting of water and biosolids
- Minimises discharge by demand management
- Controls contamination using load based licences and strong regulation of industrial discharges
- Enforces regular toxicity testing of whole effluent
- Licences sewerage system wet-weather overflows

Figure 1. Sewage outfalls along the central NSW coast. Blue symbols are the main Sydney offshore outfalls. Orange symbols are discharges to the Hawkesbury River. Yellow symbols show the location of smaller outfalls to the north (Newcastle) and south (Wollongong).

Case Study Area
Eighty five percent of the population of the State of New South Wales lives in three cities located along a 200 km stretch of coast. Another 7% of the population is spread out over the remaining 2000 km of coast and the remainder live in non-coastal areas. The three main cities are Sydney (4.3 M people), Wollongong (0.28 M people) and Newcastle (0.29 M people). All 3 cities have multiple offshore ocean outfalls, and there are a number of smaller municipal outfalls in between them. Sydney also disposes sewage into a large coastal river, the Hawkesbury River. The volume of treated wastewater discharged from Sydney to the environment from ocean and inland STPs in 2007-08 was 426,718 and 66,389 million litres respectively.

EFFECTIVE MONITORING

Why Monitor?
Environmental impact of waste disposal is determined by a number of factors:

- Quality of effluent
- Method and effectiveness of dispersal
- Types of habitats/ in the vicinity

The most important outcome is to operate plants/outfalls so that they have the smallest environmental outcome – both for the natural environment and for human uses. Without monitoring it is impossible to know how a plant is performing against its performance targets and therefore whether any changes to operation are required.

The approach of the NSW government regulators is to seek continual improvement through management responses until the activity has an acceptable impact on the environment. Licences with strict performance criteria and stiff penalties for non-compliance are used to influence plant managers to reduce impacts of activities and to protect the environment. Monitoring is an essential component of effective regulation and is required as a condition of the licence to discharge sewage or other substances to the environment.

How to monitor
Monitoring of a large development like a sewage outfall should, in most cases, move through a series of stages (Scanes 2007).

Stage 1. The Design Phase
This stage begins with a series of stated expectations about the performance criteria for a plant/outfall. These need to be expressed as environmental outcomes (e.g. no change in ecological communities more than 50 m from outfall, or no visible plume, or beaches passing health criteria >90% of time). Plant and diffuser designers then use data and predictions of likely effluent composition and volumes, along with extensive engineering and biological theory on plant process and outfall/diffuser modelling to provide solutions which satisfy the environmental outcomes.

Stage 2. Verification Phase
Intensive monitoring of the outfalls' performance against the performance criteria needs to be done to determine whether, under a wide range of environmental conditions, the outfalls are performing to expectation. Monitoring in this stage can often be very detailed and address a wide range of physical and biological processes and outcomes. This monitoring needs to be very carefully targeted to ensure that it addresses questions related to plant/outfall performance and stated performance criteria. The results should feed back to the outfall operating procedures until the environmental expectations are met.

Stage 3. Performance Monitoring

This is the long-term, usually less intensive stage which provides confidence to operators, regulators and the public that the plant and outfall continues to meet environmental expectations. This Stage of monitoring typically involves three distinct types of monitoring:

- Intensive investigation of plant inputs and internal performance criteria. This is the point where regulators impose licence conditions to ensure that the plant stays within operating criteria that, based on Stages 1 and 2, should lead to environmental outcomes continuing to be met.
- Targeted ambient monitoring of a small number of key environmental criteria which provide triggers to more detailed monitoring if expectations are not maintained (examples below)
- Special studies may required to provide more detailed explanation of some patterns observed in Stage 2 (examples below)

It is important to note that monitoring is not trivial and needs to be carefully designed to achieve desired outcomes. Large amounts of money can be wasted if monitoring is not well designed (i.e. capable of providing unambiguous answers) and focussed on the correct issues. The actual experimental designs for monitoring studies will be dependent on objectives of each Stage, but in every case the objectives/hypotheses that are being tested need to be clearly stated.

Many early studies into the impacts of ocean outfalls on the environment were purely descriptive in nature. Despite general improvements in the way outfall impacts have been investigated, however, the quality of some ecological impact studies can still be questioned. In some cases this can be attributed to poor experimental design or in other cases to poor implementation. For example, the majority of outfall impact studies in NSW have been conducted many years after the specific outfall(s) were constructed. For these studies there is often little or no knowledge of the local environment prior to the outfall discharge and the causal effects of changes in the local environment are in some cases ambiguous. There have often been relatively low levels of replication of experimental units in many of these studies and the scale (both spatial and temporal) of the impact has rarely been considered in any detail.

Underwood (1994) proposed a rigorous experimental design structure for avoiding these types of problems when investigating impacts. This structure was known as Before/After Control/Impact or BACI designs (see Scanes 2007). BACI designs are a strict hypothesis-testing framework which clearly establishes whether a site/variable is significantly different from a reference condition/place. With current advances in statistical tests BACI is amenable to both univariate (ANOVA) and multivariate statistics (e.g. non-metric multidimensional scaling – ANOSIM, PERMANOVA, Warwick and Clarke 1991; Primer software). The greatest shortcoming of the BACI designs, as originally proposed, has been that, whilst they detect impact at a site, there has been no overt attempt made to include an assessment of the extent of impact into the analyses.

A common alternative approach is based on modelling of spatially arranged data (gradients etc) allowing the development of statistical models to explain patterns in the data. Whilst this approach has many adherents, it also has some fundamental short-comings in that the causality of patterns in the data are usually much less ambiguously assigned, there are no strong tests for significance in differences and there is the associated concern that the models may be describing natural variations in data.

The choice of statistical frameworks for monitoring is therefore not always straightforward and careful consideration should be given to all alternatives and the most appropriate framework chosen for each situation. A good monitoring programme would usually cover a variety of approaches according to the particular requirements of each variable being monitored.

APPLICATION OF MONITORING FRAMEWORK - SYDNEY DEEPWATER OCEAN OUTFALLS ENVIRONMENT MONITORING PROGRAMME

Stage 1 – Design

In NSW, prior to 1991, sewage from Australia's largest city, Sydney, which has about 4.5 million people, was discharged through shoreline outfalls. These outfalls caused significant bacterial and faecal pollution of nearby beaches, poor swimming water quality, alteration of marine communities and chemical contamination of marine life.

The sewage received at the North Head, Bondi and Malabar sewage treatment plants (STPs) consists of waste waters from residential, industrial and commercial premises, as well as substantial amounts, at times, of rainwater and groundwater. The input concentrations of most of the contaminants were broadly similar at all three sewage treatment plants. They included a range of organochlorine compounds, trace metals, PAHs, suspended solids and nutrients.

Detailed oceanographic studies and plume modelling were done to facilitate the design of an outfall system that would minimise these impacts. The key oceanographic processes that controlled the physical dispersion of effluent off Sydney included the East Australian Current, coastal trapped waves, internal waves and tides and local wind-driven currents.

The outfall was designed to produce a highly diluted effluent that would be trapped below a thermocline most of the year and rapidly dispersed by currents. It was predicted that this would lead to a plume that was not visible; would not cause any disruption to fish, benthic or pelagic communities; would reduce faecal contamination of beaches; and would reduce chemical contamination of inshore fish but not result in contamination of offshore fish. These predictions form the basis for the Stage 2 Verification Monitoring.

Stage 2 – Verification

Since 1993, Sydney's ocean disposal of sewage has been through three major offshore outfalls (North Head, Bondi, Malabar) which end about 3 to 5 km offshore in 60 to 80 m water depth (Fig 1, Table 1).

A five year, multi-disciplinary Environmental Monitoring Program (EMP) measured the environmental performance of Sydney's deepwater outfalls against a wide range of criteria related to impacts on marine ecosystems and on human utilization of marine resources (results below summarised from papers in Marine Pollution Bulletin Vol 33).

Table 1: Sydney's deepwater outfalls

Outfall	Water Depth (m)	Outfall Length (to 1st diffuser) (m)	Diffuser Length (m)	Outfall Capacity (ML/d)	Average Flow (ML/d)
North Head	60	2900	765	2400	385
Bondi	60	1700	510	700	165
Malabar	80	2900	720	2250	490

The EMP developed a predictive understanding of the behaviour of sewage plumes so it was possible to assess the extent to which monitoring sites were exposed to the sewage effluent during the EMP. The fate of a range of known effluent constituents was investigated directly through monitoring in the water column (faecal bacteria, nutrients and suspended solids), in deployed oysters and in fish (contaminants), in sediments (contaminants and sediment characteristics) and on beaches (faecal bacteria and sewage grease). Other studies measured the impacts of effluent on marine ecosystems (fish and benthos) and on human utilisation of marine resources (seafood contamination and recreation).

Effluent discharged from the deepwater outfalls experienced rapid initial dilution, typically within 500 metres of the outfall, before reaching either a level of neutral buoyancy or the ocean surface. Median initial dilutions of 400 -500 were one to two orders of magnitude greater than those achieved at the former cliff face outfalls. Model results also indicate that effluent plumes from the deepwater outfalls remain trapped below the sea surface for more than 80% of the time. Plumes reached the surface when the water column becomes unstratified, mainly during winter. Far field plume behaviour was investigated by radioisotope tracer experiments. Typical results (Malabar June 17-18 1992) indicated that initial dilutions were over 1:1000 and the plume remained submerged (depth >40 metres) and travelled parallel to sea floor contours to the south with slow subsequent (far field) dilution.

Beach and bathing water quality dramatically improved since effluent was diverted offshore to the deepwater outfalls, although some residual problems remained. These are mostly attributed to local stormwater contamination.

After commissioning of the deepwater outfalls, concentrations of organochlorines in fish and deployed oysters declined to background in the vicinity of the shoreline outfalls and did not increase measurably at the new deepwater outfalls. The studies showed that contamination of sediments in the vicinity of the new outfalls did not change to an extent that can be readily measured by the technology and methods utilised in these studies. It appears from the computer modelling of plume behaviour and the studies of biota and sediments that the enhanced rate of dilution and dispersion has resulted in a decreased likelihood of any given organism or area of sediment encountering (and therefore accumulating) high loads of a contaminant, but concomitantly there has been an increased likelihood of more organisms accumulating small amounts of contaminants.

Ecological studies in the vicinity of the cliff face outfalls and the deepwater outfalls showed that there were some changes in fish and benthic (hard and soft) assemblages around the deepwater outfalls. There was also some recovery of the intertidal assemblages previously affected by the cliff face outfall. The specific causes of the changes near the deepwater outfalls are unknown. There was little consistency among outfalls and no apparent relationship between abundances of predator and prey groups. The changes do not appear to be accounted for by the presence of toxicants.

These changes were observed at sites close to the outfalls. At this stage it is unclear how far the impacts may extend. Further studies were implemented to establish whether the changes already identified persist and whether other chronic effects develop in the longer term.

Stage 3- Performance Monitoring

Ambient (Stage 3b). After extensive evaluation of the data from the EMP and detailed consideration of the likely on-going impacts, two main monitoring programs for the impacts of Sydney deepwater outfalls remained in place. There is monitoring of faecal coliforms and enterococci at swimming beaches to guard public health and monitoring of sediments around the largest outfall (Malabar) to assess ongoing environmental harm. These were supported an extensive monitoring within the sewage treatment plants to ensure that effluent quality remains within the original design criteria and was not directly toxic.

Sydney swimming beaches are still monitored once every 6 days and results evaluated monthly. Many beaches have gone from 100% failure when discharges were at the shoreline to more than 80% pass, with most of the infrequent failures being due to local stormwater influences rather than sewage discharge.

During the EMP, impacts on soft sediment benthos were detected. The changes detected were neither large nor consistent and the benthos was still abundant and diverse. , There was no data, however, about the spatial extent of these impacts or whether they getting worse. So two main questions need were addressed in the on-going monitoring.

- Will chronic impacts occur?
- Is any existing impact spreading?

It was decided that soft sediments and associated benthic assemblages were the most appropriate habitat to assess these questions. The two questions require different experimental designs. The first was examined by comparing data from sites near each of the outfalls with near and distant control sites. The second question was examined by sampling at increasing distances southward (downcurrent) of the Malabar outfall.

The variables were chosen to provide two levels of information.

- Surveillance indicators (e.g. total organic carbon and percent fines) are relatively cheap and easy to assess, are monitored at a relatively high frequency (in our case, annually).
- Assessment indicators (e.g. benthos, trace metals and organochlorins) are sampled less frequently (typically every 3 years).

The surveillance indicators act as triggers to increase the sampling frequency (for assessment indictors) if a potential problem is detected. To enable this, samples for assessment indicators are collected every time the surveillance indicators are sampled, but are archived without analysis. This enables retrospective analysis of these samples if required. The coupling of physical, chemical and biological variables presents an opportunity to investigate possible causal relationships which, in the event of an adverse impact, may assist in identifying appropriate management actions.

Special Studies (Stage 3c). The main special studies, which are generally short term and focussed on specific issues, on Sydney's Outfalls related to effluent toxicity assessment and frequency of coastal algal blooms.

The EMP had found that there were impacts of the effluent on fish and benthos, raising the potential that the effluent may contain toxic components. A combination of detailed effluent analysis, risk assessment methods and extensive toxicity testing was undertaken to determine the likely ecological toxicity of effluent. It was found that, whilst the effluent contained potentially toxic components, the effective dilution suggested that it was unlikely to be directly toxic except in the immediate vicinity of the discharge point. Ambient toxicity was found in river treatment plants. A pesticide toxin was identified and removed at source. Dechlorination of effluents was enforced. Regular toxicity testing still occurs.

One contentious issue that arose subsequent to the EMP was an apparent increase in the frequency of algal blooms in the coastal waters off Sydney. A special study was commissioned to investigate potential sources of nutrients to support the algal bloom development. Three potential sources were investigated, ocean outfalls, oceanic upwelling and riverine discharges. In all cases the occurrence of algal blooms correlated with upwelling events irrespective of proximity to the outfalls.

APPLICATION OF MONITORING FRAMEWORK TO SMALLER MUNICIPAL OUTFALLS

Most of the small outfalls were built a number of decades ago, and as noted above, there was poor consideration of monitoring or environmental impact. These outfalls all have considerably smaller discharge volumes (15 - 40 ML/day; 200 – 700 L/sec), but due to their simpler diffuser design also have poorer dilutions (nearfield 4 – 50; far field 100 – 900). Treatment levels also tend to be higher, generally secondary, sometimes with chlorination. Most monitoring has been instituted in the last decade and a half and is primarily Stage 3 Performance Monitoring. The exception is the Boulder Bay outfall which was commissioned in the late 90s. Monitoring which would qualify as Stage 2 Monitoring was done at this outfall.

These outfalls discharge into a quite different environment. The waters are shallow (6-20 m) with high wave energy. Surrounding habitats are primarily hard substratum and, from a monitoring perspective, they are more accessible than the Sydney Deepwater Outfalls, with a greater potential for direct observation.

The monitoring has focussed on two main areas, water quality for recreational bathing at nearby beaches and disruption to local ecology. Experimental designs have tended to be comparisons between control and impact locations, with some integration of gradients. Before and after data are available for one more recently constructed outfall. Ecological techniques used are mainly settling plates, monitoring of existing biota (sessile invertebrates, macroalgae, fish, large mobile invertebrates) and bioaccumulation monitors.

Stage 2 – Verification Monitoring

The environmental impact assessment assessments for the Boulder Bay outfall predicted that there would be rapid dilution and dispersion of effluent, would not be any measurable changes in the surrounding biological assemblages, no impact on nearby recreational swimming beaches and no bioaccumulation of contaminants.

There was no single co-ordinated monitoring program established to test these predictions, but there were a number of individual studies. Roberts et al. (1998) looked at changes in hard substratum benthic communities following the commencement of discharge at an outfall in 20m of water. They showed that within 3 months there had been a significant reduction in the cover of crustose and foliose algae and in the cover of several species of sponge, but no significant changes in the number of species of sponge nor the overall cover of fauna. Smith et al (1999) examined the abundance of fish and mobile invertebrates at the same outfall. They found significant decreases in the abundance of some common fish, a 33% reduction in species richness of fish and a 50% decrease in the abundance of a large sea urchin. The abundances of some cryptic fishes increased after discharge commenced. Smith and Suthers (1999) showed that one of the fish species that had showed a reduction in abundance had a smaller body size and a greater number of smaller eggs at outfall locations. Ajani et al (1999) showed that, at the same outfall, there were not any significant changes in abundance of kelp nor any increases in bioaccumulation of pesticides or trace metals.

Subsequent modelling studies done as part of considerations for a Stage 2 indicated that faecal coli forms exceeded guidelines for up to 1 km from the outfall, which does not extend to the bathing beaches but is greater than predicted. These studies also showed that the effluent is trapped within the bay where the diffuser is located.

In summary, most of the initial predictions were not supported, with the exception of negligible bioaccumulation. If the deviations from predictions are large enough, or cause sufficient concern, the findings should trigger managerial action to rectify them. In the case of this outfall, the findings are informing design considerations for an upgrade to the outfall.

Stage 3 – Performance Monitoring

The monitoring described here was mostly done around outfalls which have been established for many decades, with varying amounts of community and managerial concern about their operations.

Roberts and Scanes (1999) investigated the assemblages living in kelp forest on hard substrata around 3 outfalls that had been in operation for decades and 3 control locations. They found evidence of substantial patchiness within assemblages and the only variable that appeared to be affected by proximity to outfalls was the number of sponge species, which was greater at outfall locations.

Roberts and Murray (2006) examined benthic flora and fauna in the vicinity of two long established outfalls, Burwood (hard substratum) and Belmont (soft substratum) in comparison to two reference sites. They found greater number of species of sponges and smaller richness of algae around Burwood and fewer polycheates near Belmont outfall.

The same study also re-examined the fauna around the Boulder Bay outfall (see Stage 2 above) a decade after the initial studies. They did not detect any differences in the macrobenthic assemblages in comparison to the reference sites. This suggests that, after the initial pulse disturbance detected in Stage 2, the assemblage has adjusted to the new conditions.

CONCLUSIONS

Discharges from sewage treatment plants and overflows from sewage reticulation systems have the potential to cause impact on human health, environmental amenity, recreational opportunity and ecological processes. Most outfall disposal schemes are built to reduce or avoid these types of disturbance. Without effective monitoring programs which are well designed (to provide unambiguous results) and targeted to issues of concern there is no way to evaluate whether the expenditure of substantial funds required to design and build the outfalls has achieved the desired result. Monitoring is also essential to provide the feedback required for adaptive management of outfall systems and for effective regulation of discharges from outfalls.

The monitoring framework described here provides an effective reference system for the design and implementation of outfall monitoring.

The effective operation of ocean outfalls can be facilitated by well designed assessment programmes incorporating a variety of strategies for monitoring. This monitoring can identify impacts and human health risk and provide information back to operators that can inform better plant and outfall management. Careful use of licences by regulators will ensure that operation of plants and outfalls remains within appropriate criteria and minimise environmental and environmental harm.

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