

Evaluation of marine response tools: Subtidal containment and treatment system

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Abstract

This report presents the development, manufacture and field assessment of a fully operational system capable of delivering chemical treatments used in response to incursions of non-indigenous marine species (NIMS). The system can be deployed from land or vessel to subtidal soft sediment substrate. It is currently capable of containing and re-circulating chemical treatments to a 5 x 5 m area to depths of 20 m, but could be scaled up to 12 x 12 m with minor modification.

The design process and manufacture of a prototype system are documented, including comprehensive laboratory tests to ensure that the circulation of chemicals throughout the system was accurately assessed with the tracer dye, fluorescein. Design features and costs of the prototype are presented. The process of obtaining the necessary approvals, permits and consents to undertake field trials is presented, and later assessed in relation to the current legislative framework and how this could impact on the future use of the system in an incursion response.

Field tests were undertaken in Otago harbour and involved the deployment of the system to soft sediment from land (i.e. a wharf) and a vessel. Data collected from these trials was used to assess and discuss the efficacy and usefulness of the system as an incursion response tool in the marine environment. Assessment and discussion were guided by the following criteria:

- Efficacy of deployment
- Efficacy of containment and circulation
- Logistic and resource requirements
- Ecological and social impacts
- The use of toxic substances in an incursion response
- Target non-indigenous species and alternative applications

Keywords: marine biosecurity, chemical agents, pesticides, subtidal, rapid response tools, incursion response, non-indigenous marine species.

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Glossary and Abbreviations

BSP	British Standard Pipe
Bulwark	The extension of the ship's side above the level of the weather deck
CMA	Coastal Marine Area
Derrick	A lifting device composed of one mast or pole and a boom or jib which is hinged freely at the bottom.
DOM	Dissolved Organic Matter
ERMA	Environmental Risk Management Authority
Finger punt	A long narrow pontoon or flat-bottomed boat.
Gunwale	Upper edge of a ship's hull.
HaSEP	Health and Safety and Environment Plan
HDPE	High Density Polyethylene
HNSO Act 1996	Hazardous Substances and New Organisms Act 1996
IBC	Intermediate Bulk Container
LD ₁₀₀	100% Lethal Dose
MAF-BNZ	Ministry of Agriculture and Fisheries - Biosecurity New Zealand
MSDS	Material Safety Data Sheets
NIMS	Non-Indigenous Marine Species
ORC	Otago Regional Council
PPE	Personal Protection Equipment
PVC	Polyvinylchloride
RMA 1991	Resource Management Act 1991
RPC	Regional Coastal Plan: Coast for Otago
Scupper	Hinged openings in a ship's bulwark to drain water overboard from the weather deck.
SE	Standard Error
TCMTB	2-(thiocyanomethylthio)benzothiazole

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1. Introduction

1.1 BACKGROUND INFORMATION

The increasing rate of non-indigenous marine species (NIMS) introductions has become a matter of global concern (Carlton 1989, Ruiz et al. 1997, Cohen & Carlton 1998, Grosholz 2005). Introduced NIMS can adversely affect natural ecosystems, commerce and human health (Ribera 1995, Ruiz et al. 1997, AFF-Australia 2002). New Zealand's geographic isolation presents the opportunity to protect its unique biodiversity and economy, but New Zealand's capacity to respond rapidly to NIMS introductions is currently limited by few effective tools for the treatment of pathways and rapid response to NIMS incursions (Wotton & Hewitt 2004, Hewitt et al. 2004).

Successful application of rapid response tools depends on the efficacy of the treatment against the target species and the ease of their application in the marine environment. Many possible rapid response tools have been tested in the laboratory, or applied effectively in the management of freshwater pests, but few have successfully made the transition from the laboratory to the field or from freshwater to seawater (Stuart 2002). Documented cases of successful eradication of NIMS are limited to four species, the dreissenid mussel *Mytilopsis sallei*, the sabellid polychaete *Terebrasabella heterounicata*, the green alga *Caulerpa taxifolia*, and the Asian kelp, *Undaria pinnatifida* (Bax 1999, Culver & Kuris 2000, Wotton et al. 2004, Woodfield & Merkel 2006). Amongst the many factors contributing to successful eradication, each example is characterised by the application of techniques in a manner that catered to the unique circumstances of each site.

For example, broadcast addition of sodium hypochlorite and copper sulphate to eradicate *M. sallei* was made possible by containment of the chemicals within a locked marina, whereas the eradicated populations of *C. taxifolia* and *U. pinnatifida* occurred in a sheltered lagoon and on a sunken vessel, respectively, where treatments were effectively encapsulated (Russell & Hewitt 2000, Anderson 2002, Wotton et al. 2004). It is unlikely that future eradications will be attempted in exactly the same circumstances, but it is clear that the use of physical barriers to limit subsequent dispersal of target species and contain treatments such as chemicals is particularly important to eradication success.

Broadcast application of chemicals is unlikely to have public support owing to the widespread environmental impacts on non-target species and risks to human health and wellbeing. The greatest practical limitations of chemical treatments in the marine environment is that the chemical treatments must be contained within a restricted area to maximise delivery of the chemical to the target species, whilst reducing impacts to non-target species and managing risks to human health and safety.

The use of chemicals as a rapid response tool in the marine environment presents a number of challenges, but also offers a great option for effective and cost efficient eradication of target species. Most chemicals used presently impact heavily on a wide range of species but a number of suitable chemicals are available that target specific taxa such as molluscs, crustacea and fish, with limited impacts on non-target species (e.g., TCMTB, Carbaryl, Trichlorfon (Dichlorvos), Azamethiphos, Antimycin and Rotenone) (Stuart 2002). However, effective chemical treatment of bivalve molluscs is particularly problematic as it typically requires exposure to chemical agents over a period of days. This presents problems in

relation to the containment of chemicals and the maintenance of required concentrations through numerous tidal cycles (Bax 1999, Stuart 2002). Field evaluation of eradication tools for the clubbed tunicate *Styela clava*, however, indicate that lethal treatments of 1% acetic acid are possible after treatment periods of as little as 10 min (Coutts & Forrest 2005). Chemical treatments therefore offer feasible options for incursion response, provided they can be effectively contained and lethal doses achieved in the marine environment.

1.2 PURPOSE AND SCOPE

1.2.1 Introduction

The purpose of this work was to design, develop and test a subtidal containment and chemical treatment delivery system for use on subtidal natural substrates up to a depth of 20 metres. The scope of the work initially included trials of the system on rocky reef and soft sediment substrates. Resource consent was obtained on this basis, but the trial on rocky reef was not possible due to inclement weather. The scope was therefore varied to comprise trials of the system on soft sediment as deployed from land and from a vessel.

1.2.2 Specific Objective

To design, develop and test a subtidal containment and chemical treatment delivery system for use in the marine environment up to a depth of 20 metres.

1.2.3 Specific Deliverables

1.2.3.1 Specific Deliverable One: Pre-field testing preparation

1. Conduct laboratory trials to ensure that a rhodamine or fluorescein fluorometer employed in experiments is functional and of adequate sensitivity for the purpose of the work outlined below i.e. fit for purpose;
2. Determine the most appropriate sites for testing of the system on soft sediment and rocky reef substrates;
3. Obtain all necessary permits and consents as required by local, regional, and national regulatory authorities and/or local stakeholders for testing of the system in the marine environment at the identified sites.

1.2.3.2 Specific Deliverable Two: Pilot Trials - Deployment, testing and refinement of containment system and chemical treatment delivery system

1. Develop and manufacture a prototype containment and chemical treatment delivery system that can be tested and used in the marine environment to a depth of 20 metres. The containment area should not be less than 5 x 5 m (i.e. 25 m²);
2. Determine the most appropriate equipment specifications (e.g. pump size, valve numbers, coupling requirements, pipe diameters and lengths, etc) required for the system to operate effectively at the depths of identified field sites;

3. Develop the system to encapsulate target organisms in subtidal conditions and provide a facility to circulate aqueous chemicals and pesticides;
4. Ensure all aspects of the containment and chemical treatment delivery system are repeatable and, where appropriate, scalable;
5. Ensure the containment and chemical treatment delivery system is applicable to a range of functional or taxonomic groups;
6. Undertake pilot trials in an easily accessible area to deploy, test and refine the system, and identify any issues and risks associated with deploying the system under field conditions.

1.2.3.3 Specific Deliverable Three: Trial of containment and chemical delivery treatment system on soft sediment deployed from land and from a vessel.

For each and every trial undertaken, evaluate the following:

1. Efficacy of the system based on how quickly and effectively the system can be deployed in a real time situation;
2. Efficacy of the system based on how quickly and effectively the chemicals mix throughout the encapsulated area;
3. Efficacy of the system based on the ability to effectively encapsulate and contain the chemicals within the treated area.

1.2.3.4 Specific Deliverable Four: Data analysis, evaluation and completion of technical report

1. Collect, collate and analyse all data and use scientifically robust statistical techniques to analyse the efficacy of the system on different substrate types and deployment times;
2. Prepare a technical report that:
 - a) Outlines the design and manufacture of the containment and chemical treatment system including, but not limited to: planning requirements; equipment specifications; diagrams, resource requirements (e.g. materials and staff); consents and approvals required, stakeholder liaison; consumables; challenges; and any other considerations;
 - b) Discusses and evaluates the effectiveness and applicability of the system to MAF Biosecurity New Zealand marine rapid response requirements, based on, but not limited to: deployment ability; practicality; operational, logistics and staffing requirements; permitting/approval requirements; legal considerations;
 - c) Identifies and discusses the likely taxonomic/functional groups and environmental applications for the containment and chemical treatment system;

- d) Identifies, evaluates and discusses the cost effectiveness and usefulness of the containment and chemical treatment system as an incursion response tool for use in the marine environment.

2. Methods

2.1 OBTAINING THE REQUIRED CERTIFICATES AND PERMITS FOR FIELD TRIALS

Methods employed in the field trials were intentionally chosen to comply with provisions of permitted activity rules as detailed in the Regional Plan: Coast for Otago (RPC) where possible. This included the choice of field sites outside of coastal protection areas and the use of a non-toxic dye (fluorescein) as a chemical surrogate. An application for a certificate of compliance was therefore made to the Otago Regional Council (ORC) to ensure that all proposed activities undertaken during the trials were indeed permitted. However, a request for further information by the ORC indicated that the permitted activity rules did not allow for such discretionary activities as occupation of the Coastal Marine Area (CMA) at Moeraki, the taking of coastal water from Otago Harbour, and the placement of a structure on the seabed and associated disturbance. As field trials could not be completed without undertaking these discretionary activities, an application for a coastal permit was made to the ORC. Further advice from the ORC indicated that consent to occupy the CMA at the selected site in Otago Harbour was unnecessary because the site did not occur on Crown Land, but on land owned by Port Otago. During the consenting process, the ORC identified the Department of Conservation, Port Otago and Kai Tahu Ki Otago Limited as potentially affected parties. Written approval was sought from and given by each party before the coastal permits were approved. Issues raised by potentially affected parties formed the basis of subsequent conditions placed on the coastal permits.

2.2 LABORATORY TESTS OF FLUOROMETER

2.2.1 Introduction

Fluorescein dye was used as a chemical surrogate to evaluate the efficacy of chemical containment and circulation through the system. Several laboratory experiments were conducted to confirm that accurate measurements of fluorescence could be obtained and identify features that could be incorporated into the system design to overcome any technical constraints imposed by the use of fluorescein. The specific purpose of the experiments was to determine:

1. the sensitivity of the fluorometer to fluorescein in seawater, and confirm that the detection limits accommodate the range of fluorescence expected in field trials;
2. whether photo-degradation of fluorescein is likely to affect measurement of fluorescence over the duration of the trials;
3. whether flowing water has an effect on real-time measurements of fluorescence;
4. the concentration of suspended sediment that obscures fluorescence to a point that it is not visible to the naked eye; and
5. whether suspended sediment interferes with the performance of the fluorometer.

2.2.1.1 Sensitivity of the fluorometer to fluorescein in seawater.

The fluorometer was calibrated to a 1 mg/L reference sample of fluorescein in seawater. Triplicate stepwise dilutions from a 1 mg/L stock solution were made to obtain triplicate dilution series of 1, 0.5, 0.25, 0.125, 0.063, 0.031, 0.016, 0.008, 0.004, 0.002, 0.001, 0.0005, and 0.00025 mg/L. Triplicate measurements of fluorescence were taken from static solutions and concentrations required for visible detection were recorded from visual observation.

The linear relationship between fluorescein concentration and fluorescence was determined by regression analysis and the strength of the relationship assessed using a Pearson product moment coefficient (r).

2.2.1.2 Sensitivity of the fluorometer to suspended sediment.

Soft sediment collected from Otago Harbour was passed through a 1 mm sieve to remove coarse sediment, shell and biological material before mixing with distilled water. The solution was allowed to settle before the fluid was decanted and the remaining sediment oven dried at 60°C. The dried sediment was lightly ground to a powder. Sediment was added in 25 g and 50 g increments to 100 ml solutions of 1 mg/L, 0.1mg/L and 0.001 mg/L of fluorescein in seawater and mixed thoroughly with a magnetic mixer. Fluorescence was measured using an Opti-Sciences GFP-Meter fluorometer calibrated to 1 mg/L of fluorescein in seawater.

To determine the minimum concentration of suspended sediment at which fluorescein is obscured from view, sediment was added to triplicate 200 ml seawater solutions each of 1 mg/L, 0.5 mg/L and 0.1 mg/L of fluorescein in seawater. Solutions were mixed continuously with a magnetic mixer and the fluorescence recorded each time the added sediment was fully suspended. Sediment was added until the fluorescein was no longer visible.

The linear relationship between fluorescence and sediment concentration was determined by regression analysis and the strength of the relationship assessed using a Pearson product moment coefficient (r).

2.2.1.3 The effect of flowing water on real-time measurement of fluorescence

The ability to compare fluorescence measured at two positions in the header tank was critical to the evaluation of the system. As sensors positioned at each of these positions was subject to different flow rates, an experiment was necessary to determine whether water flow past the sensor affected measurements of fluorescence. This was accomplished by filling a 1000 mL beaker with a 0.125 mg/L solution of fluorescein. The beaker was placed on a magnetic mixer and fluorescence was measured in static water, at a low water velocity (0.6 m/sec), at a medium water velocity (0.8 m/sec) and a high water velocity (1.1 m/sec). Fluorescence was measured using an Opti-Sciences GFP-Meter fluorometer calibrated to 1 mg/L of fluorescein in seawater. Six measurements of fluorescence were taken for each treatment.

2.2.1.4 Photo-degradation of fluorescein

The decrease in fluorescence due to photo-degradation was measured by placing triplicate solutions of 1 mg/L and 0.5 mg/L of fluorescein in seawater within opaque High Density Polyethylene (HDPE) and glass containers; then exposed to direct sunlight. HDPE was similar to the compound from which the Intermediate Bulk Container (IBC) header tank was manufactured. Triplicate control solutions were stored in HDPE containers in complete darkness. Fluorescence was measured each hour for a total period of five hours using an Opti-Sciences GFP-Meter fluorometer calibrated to each initial concentration.

2.3 DEVELOPMENT, MANUFACTURE AND PRELIMINARY ASSESSMENT OF PROTOTYPE

2.3.1 Introduction

There are significant operational and logistic difficulties and limitations surrounding deployment and monitoring of a system under water. Equipment also degrades rapidly in the marine environment due to the corrosive nature of seawater and the physical stresses associated with inclement sea conditions. With this in mind, a functional design was produced that was sturdy and compact, with a degree of simplicity that would enable rapid deployment and efficient operation over a range of substrate types and environmental conditions. As the intended use of the system in marine pest management would include the addition of chemicals and pesticides, the system was designed to withstand a range of standard chemicals and pesticides that could be used for aquatic pest management (e.g., hypochlorite, acetic acid, glyphosphate, carbaryl and rotenone).

2.3.2 System Design

The general concept and key design features are presented in Figs. 2.1 & 2.2 and comprise:

- 1000L IBC header tank allowing for active capacity of 500L with additional capacity in the event of a loss of equilibrium between the inflow and outflow of water.
- A 6 x 6 m industrial grade rip-stop PVC tarpaulin (690 grams/m²), comprising a 5 x 5 m treatment area and half meter skirt around tarpaulin allowing for the deposition of steel girder and sandbags about periphery of tarpaulin.
- Two marine pumps (Lowara SV205 T304 and CO350/03) made of non-ferrous metals capable of withstanding corrosion and each powered by a Honda GX200 petrol motor with a recommended engine speed of 2000 to 3600 rpm.
- D-rings and eyelets were positioned about the periphery of the tarpaulin to aid deployment.
- Polypropylene camlock dust caps to prevent leakage from attachments when they are not in use.
- In-line filters were introduced to collect sediment before it was introduced or extracted from the header tank.
- The tank was painted black with spray paint so as to prevent photo-degradation of fluorescein; identified as a possibility in earlier laboratory tests (refer to Section 3.2.4).
- Barfell Black Magic 38 mm hose was fitted with polypropylene female camlock hoses/hose fittings at each end for rapid attachment to the tarpaulin and pumps. Hoses were joined to the tarpaulin by 40mm PVC bulkhead fittings attached with polycarbonate sealant through reinforced perforations in the tarpaulin (Fig. 2.3). Polypropylene camlock male adapters (40 mm) were threaded onto the topside of the bulkhead fittings and an elbow was attached to the underside to deflect the water flow from the sea bed and thereby reduce the amount of sediment suspended by the inflowing water and entrained within the system. All threaded couplings and hose fittings were rendered watertight through the use of thread tape and stainless steel hose clips. Stainless steel fittings were used in areas requiring high strength and corrosion resistance.

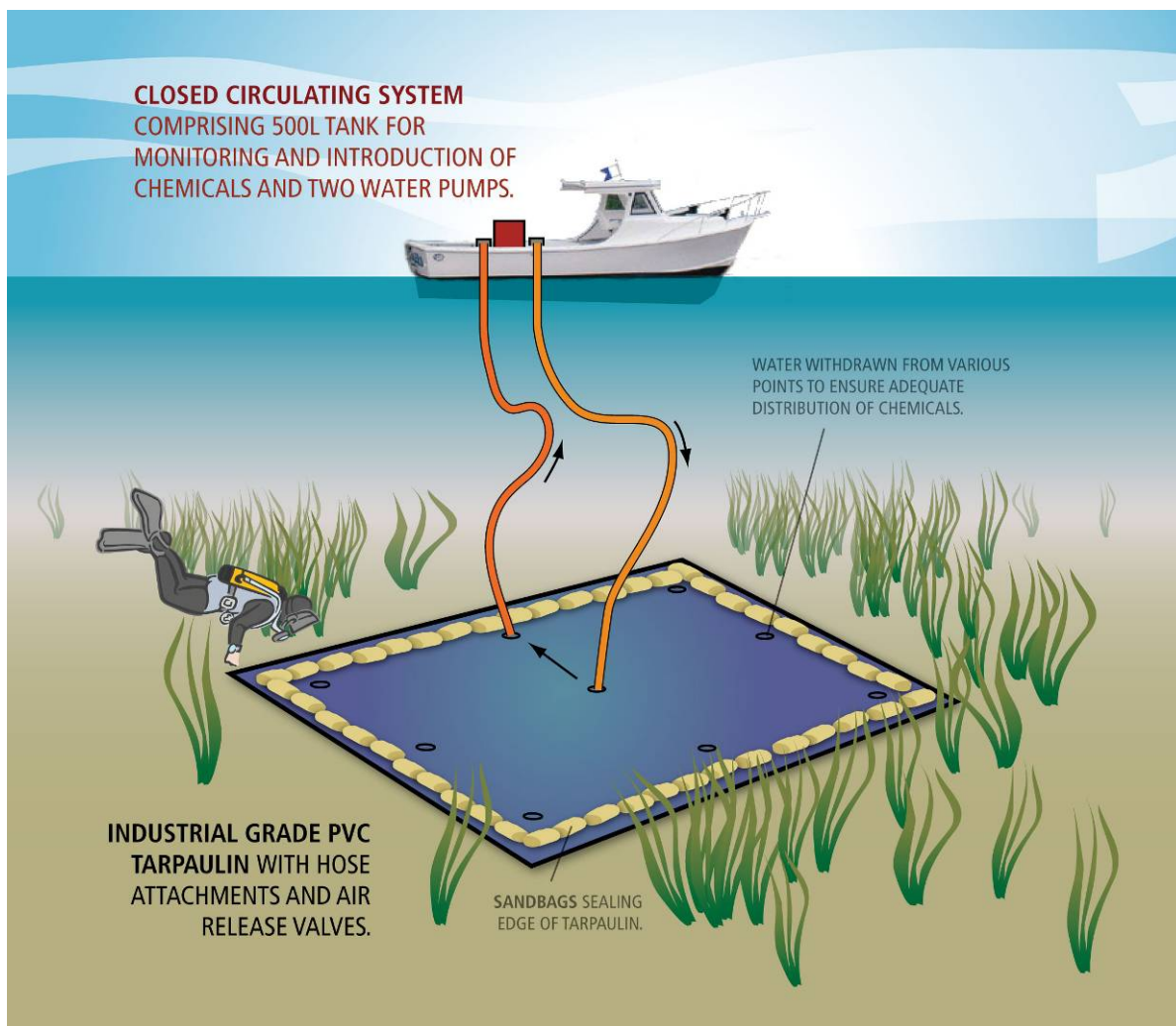


Figure 2.1: Diagram showing deployment and operation of the containment and treatment system.

Water flow into the header tank was partitioned from out-flowing water by inserting a 1 m length of 100 mm PVC pipe through the top of the tank. A watertight cap was attached to the base of the pipe and four rectangular holes cut 180 mm from the top end of the pipe. The in-flowing hose was placed within the pipe and in-flowing water allowed to overflow through the holes. The volume of the water filled pipe was 0.006 m³. Fluorescence was measured within the pipe by inserting an optical sensor through the top of the tank. However, readings of fluorescence within the header tank were obtained with an optical sensor inserted through a rubber grommet near the bottom of the tank and adjacent to the water outlet.

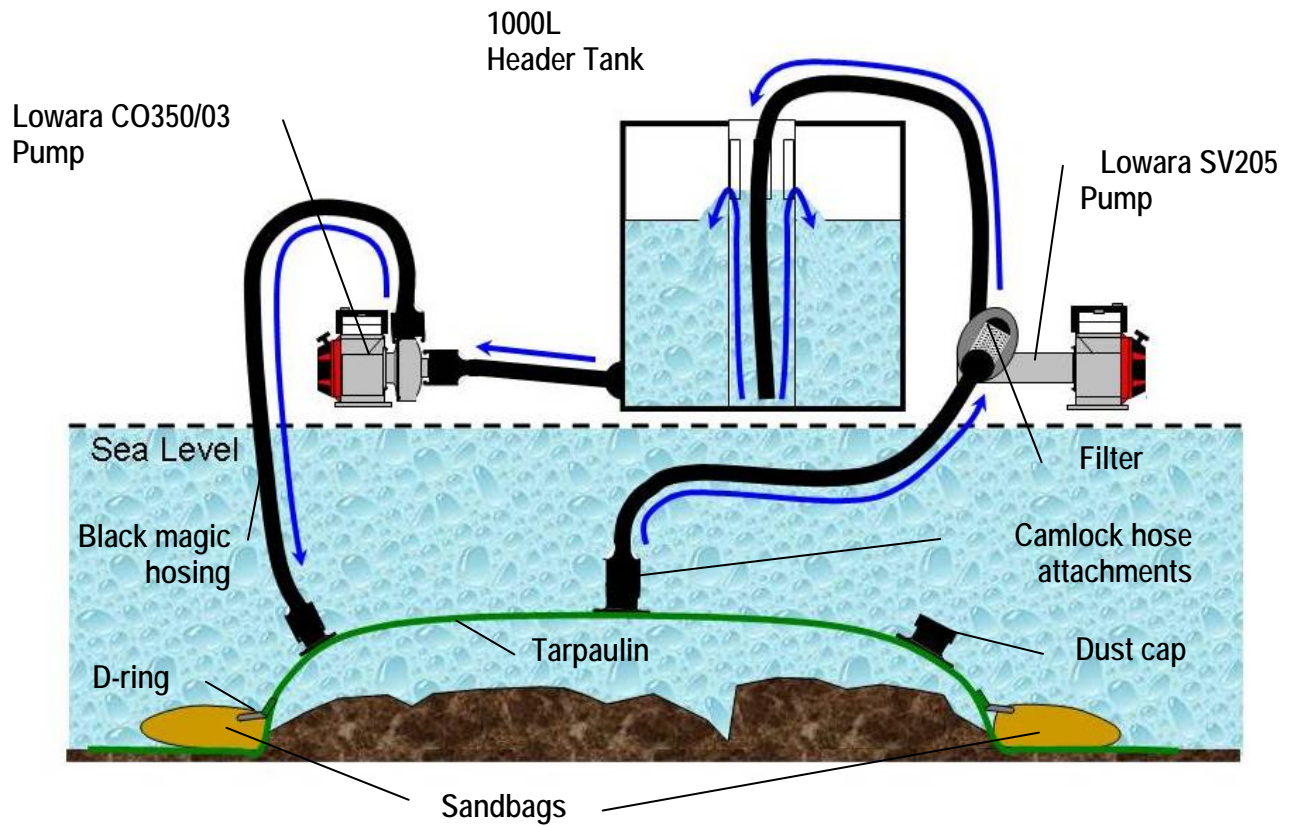


Figure 2.2: General layout and initial design features of the prototype system (not to scale).

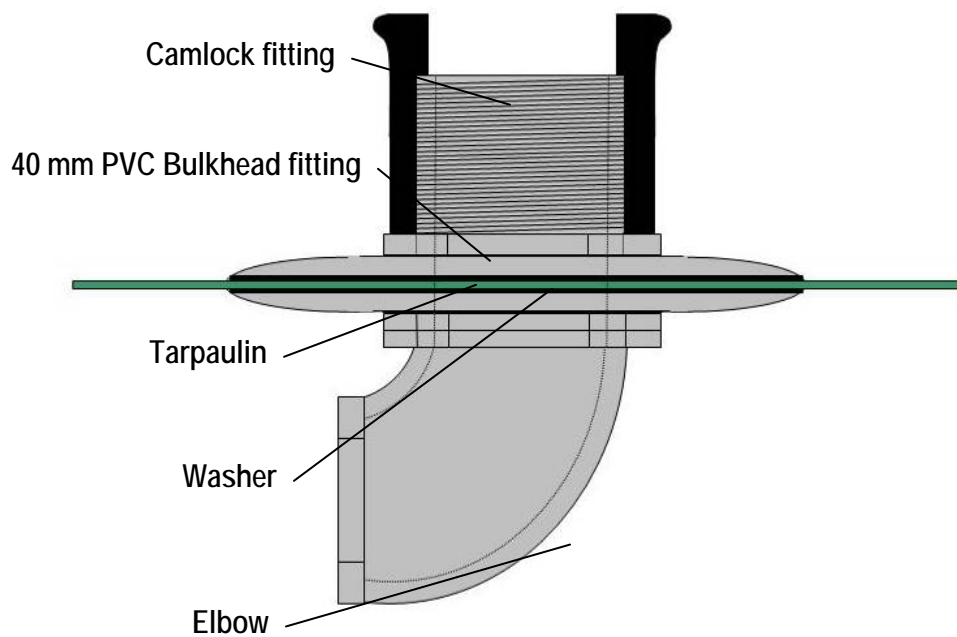


Figure 2.3: Design features and components of the tarpaulin attachments.

2.3.3 Manufacture of the prototype

Manufacture of the pumps (i.e. coupling of the pump and drive mechanisms) and fabrication of the tarpaulin were undertaken by specialist suppliers. Manufacture of the prototype comprised principally the assembly of assorted hoses and fittings, and the attachment of fittings to the tarpaulin. Most materials were obtained from local suppliers. However, the IBC header tank was obtained from Christchurch and required a specialist IBC heavy duty female-female thread adaptor (NW50-2" BSP) that was sourced from Napier. Local seed and grain merchants were identified as a source of sacks suitable for sandbags (i.e. double thickness).

Material costs of the system are indicated in Table 2.1. To reduce costs, stainless steel and brass fittings were employed only where a high degree of strength was required or when there were no other alternative polypropylene fittings available. Polypropylene was used on all camlock fittings as these are less expensive than stainless fittings while still providing chemical resistance and reasonable strength. Such fittings could be easily and inexpensively replaced in the event of damage or loss. There was no option other than to manufacture the tarpaulin and attachments from PVC. A length of used chain was obtained from a metal merchant, with the box-steel girders supplied at no cost provided they were returned on completion of the project.

2.3.4 Preliminary assessment of the prototype

A preliminary field assessment of the prototype was undertaken in Otago Harbour on April 15 and April 16, 2008 to ensure that the prototype was fit for purpose. Field assessment of the prototype would not have been possible in the following circumstances:

- Failure of the tarpaulin system to contain the circulating water, resulting in the continuous and unabated exchange of water with the surrounding water column;
- An inability to effectively manage an equal flow into and out of the header tank;
- An inability to collect meaningful data; and
- Any of the above circumstances were not remedied within 48 h.

Table 2.1: Material costs of the system.

Item	Quantity	Cost (GST excl.)
Pumps		
Lowera SV205 T304 Vane Pump + Honda GX200	1	\$4,300.00
Lowera C305/03 Centrifical Pump + Honda GX200	1	\$2,450.00
Amiad 11/2" T Filter	1	\$200.00
Hose and Fittings		
Hosing	80 m	\$850.00
Assorted fittings	68	\$550.00
Containment System		
Tarpaulin	1	\$1550.00
Tank (IBC) and thread adaptor	1	\$250.00
Assorted fittings	18	\$200.00
Chain	18 m	\$400.00
Sandbags	75	\$100.00
	Total	\$10,850.00

The containment and treatment systems were deployed and assessed separately on April 15 and integrated on April 16. Each was deployed from the Rattray Street wharf in the same manner as described in Section 2.5.2.1. Once a seal was established about the tarpaulin and equal flow maintained throughout the system, 0.5 g of fluorescein (i.e. 0.5 L of 1 mg/L of fluorescein in seawater) was introduced to the header tank and monitored intermittently to confirm that meaningful measures of fluorescence could be collected throughout a trial.

2.4 FIELD TRIALS

2.4.1 Site location & characterisation

The preliminary trial and subsequent field trials on soft sediment substrate were conducted within Otago Harbour immediately adjacent to the Rattray Wharf (Figs. 2.4 and 2.5). Preliminary and field trials from land involved deployment from the wharf, which is approximately 4 m above the chart datum. Later trials involved deployment over the starboard side of the vessel, *Clan MacLeod* (Fig. 2.5).

The seabed immediately adjacent to the wharf consisted of fine sediment, sloping steeply under the wharf to a depth of 6.5 m and then easing to a depth of 7 m approximately 6 m from the outer pilings. A large amount of debris was observed on the seabed including bottles, rope and a metal rod extending vertically 500 mm from the seabed. Intermittent clumps of



Figure 2.4: Site location of preliminary assessment and field trial in Otago Harbour adjacent to Rattray Street wharf, 45°52'46.35"S 170°30'26.56"E (red cross).



Figure 2.5: View of study site showing starboard side of *Clan MacLeod* from which the system was deployed beneath the vessel (left) and the region forward of the *Clan MacLeod* where the system was earlier deployed from the wharf (right).

sponges and ascidians littered the seabed, as well as individual sea tulips, *Pyura pachydermatina* (Fig. 2.6). A shield limpet (*Scutus antipodes*), cushion star (*Patiriella regularis*) and a juvenile red crab (*Nectocarcinus antarcticus*) were observed on and about such clumps. Burrows and individuals of the stalk-eyed mud crab (*Macrophthalmus hertipes*) were observed, as were Cancer crabs (*Metacarcinus novaezelandiae*) and adult red swimming crabs (*N. antarcticus*).

2.4.2 Deployment to soft sediment from a fixed or attached structure i.e. a wharf

2.4.2.1 System design & deployment

Deployment of the system from a fixed structure such as a wharf allowed for the gravitational flow of water from the header tank to the tarpaulin, thereby not requiring a pump to deliver water to the tarpaulin (Fig. 2.7). A 1000 L IBC header tank was generally half to three quarters full, with a water level between 2.5 and 4.5 m above sea level throughout the trial. A Lowara SV205 T305 pump was positioned near sea level on a finger punt and returned water from the tarpaulin to the header tank at a maximum flow rate of 100 L per min.

The tarpaulin was lowered vertically from the wharf with the leading edge weighted at corners by 20 kg sandbags. Divers then laid the tarpaulin horizontally on the seabed before stretching the tarpaulin flat and laying sandbag at the corners. Four 5 m girders of box steel (50 mm x 20 mm) were then laid 500 mm from each edge of the tarpaulin. Sandbags were initially lowered vertically by rope to the base of one of the wharf pilings before being transported along a short job-line between the piling and tarpaulin. This method stirred up the sediment and resulted in poor visibility. Sandbags were subsequently lowered directly onto the tarpaulin using a weighted drop line, down which they were delivered using a second rope and shackle.



Figure 2.6: Epifauna encountered at the study site comprising clumps of sponges and ascidians, including sea tulip *Pyura pachydermatina* and cushion star *Patiriella regularis* (top); red swimming crab juvenile *Nectocarcinus antarcticus* and shield limpet *Scutus antipodes* (middle); Cancer crab *Metacarcinus novaezealandiae* and stalk-eyed mud crab *Macrophthalmus hertipes* (bottom).

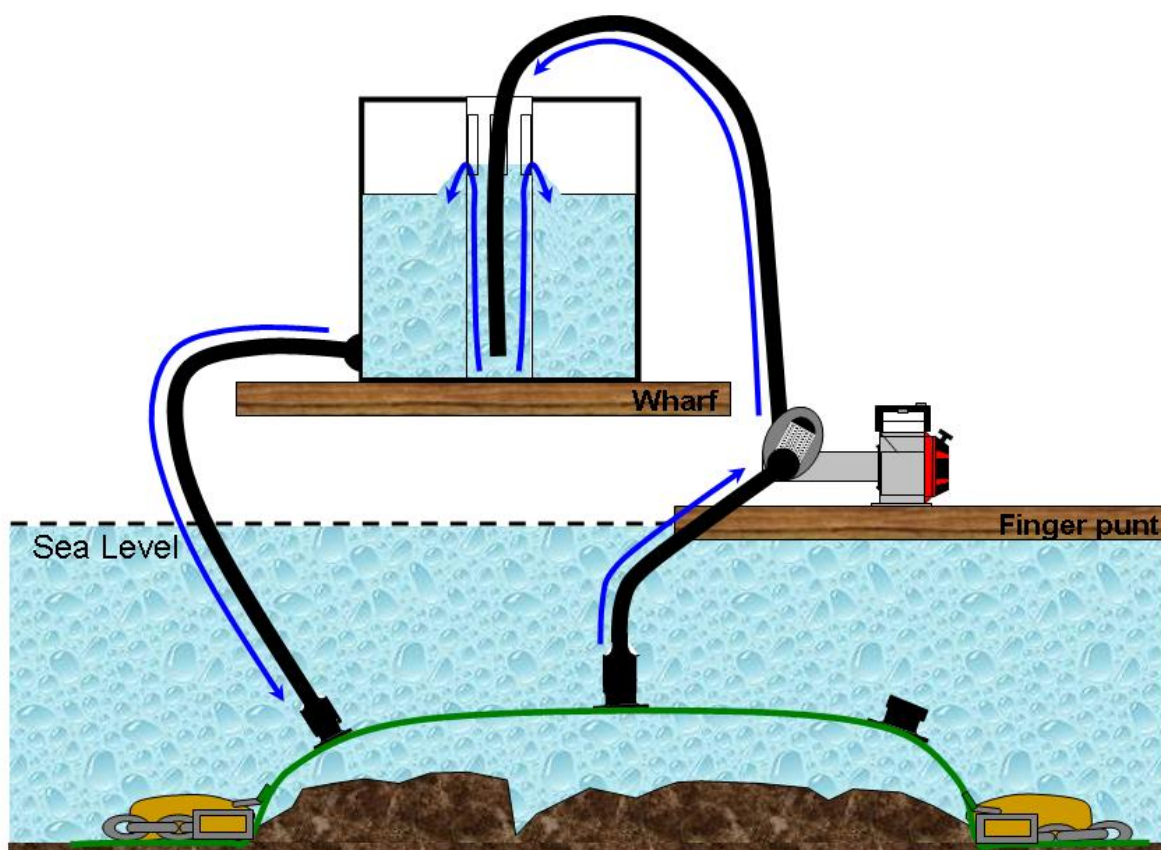


Figure 2.7: Final layout and design features of the system as deployed from a fixed structure i.e. wharf (not to scale).

Sandbags were placed on top of the box steel and around the corners where the girders did not meet. Additional sandbags were placed on top of the girders where leaks were detected visually or more weight was required to prevent movement of the sandbags and box steel during inflation of the tarpaulin with water. Deployment of the tarpaulin on 15 April, 2008 required a total of 48 sandbags and four 5 m girders. Twenty meters of chain was deposited along one edge of the tarpaulin on 16 April, 2008 to stem a leak that occurred during inflation of the tarpaulin. Deployment of the tarpaulin on 30 April, 2008 required a total of 55 sandbags and four 5 m girders. No leaks were detected and the chain was not deployed.

A 1000 L IBC header tank was positioned near the edge of the wharf and both the Lowara SV205 T304 and CO350/03 pumps (henceforth referred to as SV205 and CO350 pumps respectively) were secured near sea-level on a finger punt positioned beneath the wharf (Fig. 2.8).

A hose was initially attached to the tarpaulin via a peripheral attachment and water pumped from the SV205 pump to the tarpaulin. However, the CO350 pump was later used as it provided greater flow and permitted more rapid 'inflation' of the tarpaulin. An in-line filter, positioned down-stream of the SV205 pump to collect sediment, also provided a means of priming the pump through the attachment of a valve and garden hose attached to reticulated supply (gold circle, Fig. 2.8). The CO350 pump was primed using a non-return valve



Figure 2.8: IBC header tank, hoses and hose fittings established on the wharf (left). Pumps secured near sea-level on finger punt positioned below the wharf (right). Lowara SV205 T304 (left) and CO350/03 (right).

attached to the inlet by a short length of hosing and by pouring water into the outlet. The brass non-return valve can be seen resting on top of the header tank in Fig. 2.8 (green circle). The SV205 pump was used to half fill the header tank with 500 L of seawater.

Once the tarpaulin was inflated and header tank half full, a hose was attached directly between the header tank outlet and a peripheral coupling on the tarpaulin. Care was taken to ensure that the hose was not raised above the level of the tank outlet so as to prevent any airlocks. A valve was also introduced at a T-junction established immediately down-stream of a gate valve at the tank outlet to allow the system to be primed (red circle, Fig. 2.8). A hose was also attached between the inlet of the SV205 pump and the central coupling on the tarpaulin. A second hose was attached to the SV205 outlet and discharged into the central pipe within the header tank. The SV205 pump and hose down-stream of the header tank were primed, the pump started, and the gate valve opened at the header tank outlet. Airlocks were resolved and an even flow into and out of the header tank established and maintained by varying the throttle on the pump and the aperture of the gate valve at the tank outlet.

2.4.2.2 Evaluation of the integrated system

Once a steady flow was established and the water level within the header tank maintained at approximately 500 L, fluorescein was added and real-time measurements of fluorescence recorded. In the first field trial conducted on 17 April 2008, 0.5 g of fluorescein was added to the header tank (i.e. 500 ml of 1 g/L of fluorescein in seawater). Peripheral couplings were moved through four positions and fluorescence measured at 30 second intervals for a total period of 4 hours 9 minutes. In the second trial on 30 April 2008, 1.5 g of fluorescein was added to the header tank (i.e. 1500 ml of 1 g/L fluorescein in seawater) and fluorescence measured at 60 second intervals through a single coupling for 85 minutes.

2.4.2.3 Demobilisation

On completion of the trial the SV205 pump was turned off and the hoses uncoupled from the tarpaulin. Dust-caps were also removed and all encapsulated water evacuated. Both pumps were retrieved from the finger punt and placed on the wharf. All hoses were disconnected and pulled onto the wharf, and the header tank was evacuated.

One end of the finger punt (with pumps removed) was then positioned directly above the tarpaulin with the other end positioned under the wharf. Sandbags were hauled manually to the surface using the same system by which they were deposited, placed on the finger punt and then hauled manually up to the wharf. Once all the sandbags had been retrieved, ropes were attached to the chain, box steel and tarpaulin before they too were hauled to the surface and then onto the wharf. The pumps were washed down with freshwater, and the tarpaulin and sandbags water-blasted before subsequent deployment or short-term storage.

2.4.3 Deployment to soft sediment from a floating structure i.e. a moored vessel

2.4.3.1 System design & deployment

Deployment of the treatment system from a floating structure was in most respects the same as from a wharf (Section 2.5.2), but differed in that the deck of the vessel was less than one meter above sea-level and the amount of head too little to maintain adequate gravitational flow from the header tank to the tarpaulin. It was therefore necessary to use the CO350 pump to maintain water flow to the tarpaulin, and the SV205 pump to return water to the header tank (Fig. 2.9). However, the flow rate from the CO350 pump was approximately three times that of the SV205 pump and a bypass was used to divert some of this flow back to the header tank and help maintain the volume of the header tank at approximately 500 L (yellow circle, Fig. 2.10).

The tarpaulin, sandbags and box steel were deployed over the gunwale of the vessel (Fig. 2.11). Deployment of the tarpaulin occurred on 8 May, 2008. A total of 60 sandbags and four

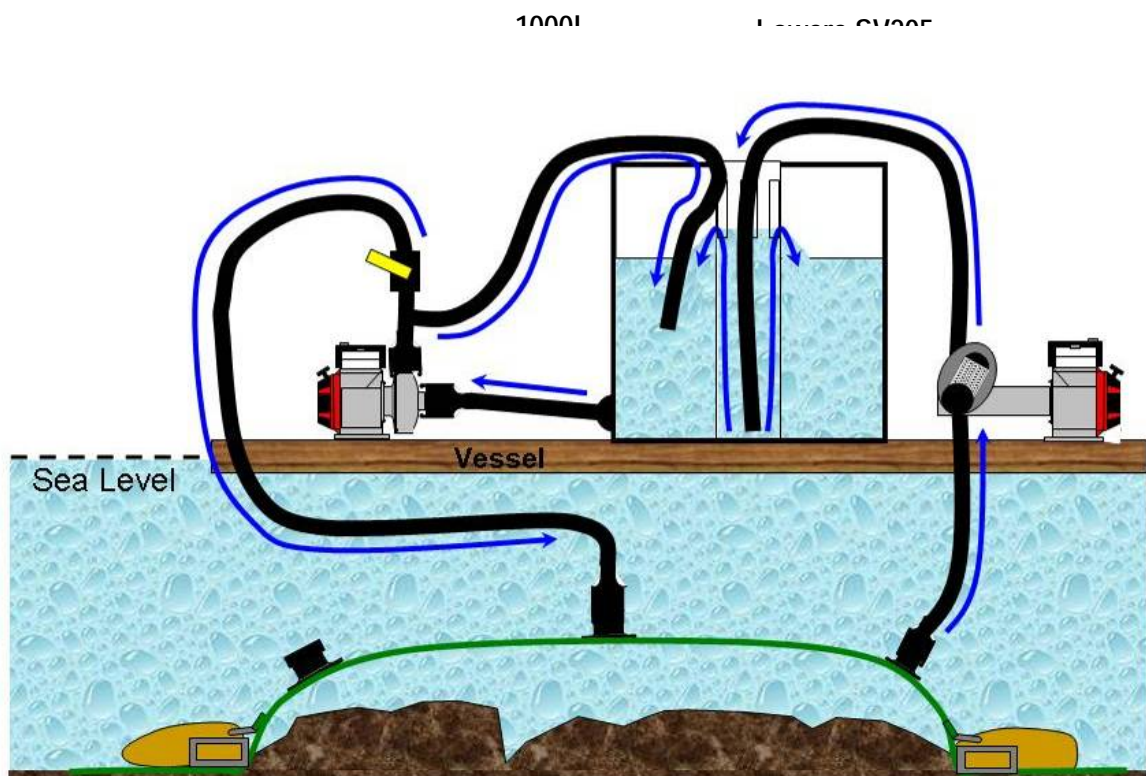


Figure 2.9: Final layout and design features of the system as deployed from a floating structure i.e. vessel (not to scale).



Figure 2.10: IBC header tank, pumps and hoses established on the vessel (top left). Lowara CO350/03 (top right) and Lowara SV205 T304 (bottom left) pumps secured to the deck. Sandbags being recovered using the ship's derrick, rope and pulley (bottom right).

5 m lengths of box steel girder were laid about the perimeter of the tarpaulin. The tarpaulin was deployed immediately below the vessel and sandbags were simply dropped over the side onto the tarpaulin. The steel girders were lowered on rope to prevent it from puncturing the tarpaulin if dropped.

The 1000 L IBC header tank and pumps were loaded onto the vessel (Fig. 2.11). The SV205 pump was deployed in the same manner as indicated in Section 2.4.1.1 and used to half-fill the header tank. The CO350 pump was used to inflate the tarpaulin and, once this was complete, the pump inlet was coupled to the header tank and a hose coupled between the CO350 outlet and the central coupling on the tarpaulin. A hose was attached between the



Figure 2.11: Deployment of the tarpaulin over the gunwale (left). Header tank being loaded onto vessel (right).

inlet of the SV205 pump and a peripheral coupling on the tarpaulin. A second hose was attached to the SV205 outlet and discharged into the central pipe within the header tank. Care was taken to ensure that all hoses were passed through scuppers (opening in the side of the ship) at deck level and that significant airlocks were not formed by passing the hoses over the gunwales. Airlocks were resolved and an even flow into and out of the header tank established. The SV205 pump was run continuously at full throttle and the water level within the header tank maintained about 500 L via the CO350 throttle, and fine adjustment via an in-line ball valve (red circle, Fig. 2.10).

2.4.3.2 Evaluation of the integrated system

Once a steady flow was established and the water level within the header tank maintained at approximately 500 L, fluorescein was added and real-time measurements of fluorescence recorded according to methods detailed in Section 2.4.3. In the third field trial conducted on 8 May 2008, 1.5 g of fluorescein was added to the header tank (i.e. 1500 ml of 1 g/L of fluorescein in seawater) and fluorescence measured at 60 s intervals through a single coupling for 4 h 4 min. In the fourth trial conducted on 9 May 2008, 1 g of fluorescein was added to the header tank (i.e. 1000 ml of 1 g/L fluorescein in seawater) and the entire contents of the header tank discharged into the tarpaulin and the header tank then refilled from within the tarpaulin. This differed from previous trials (i.e. trials 1-3) where the contents of the header tank were left to discharge gradually into the tarpaulin. Peripheral couplings were moved through four positions and fluorescence measured at 60 s intervals for a total period of 4 hours and 30 minutes.

2.4.3.3 Demobilisation

On completion of the trial both pumps were turned off and the hoses uncoupled from the tarpaulin. Dust-caps were also removed and all encapsulated water evacuated. Sandbags were then hauled manually to the surface using the ship's derrick (Fig. 2.10). Once all the sandbags had been retrieved, ropes were attached to the chain, box steel and tarpaulin before they too were hauled manually to the surface and deposited on the vessel. All equipment was subsequently unloaded from the vessel and deposited on the wharf. The pumps were washed down with freshwater, and the tarpaulin and sandbags water-blasted before subsequent deployment or storage.

2.4.4 Data Collection and Analysis

Each trial differed in experimental design, with these differences detailed in Table 2.2.

Table 2.2: Differences in experimental design between the various trials.

	Fluorescein added		Hose configuration		Water samples		Header tank	
	Batch ¹	Cumulative ²	Peripheral	Central	External	Internal	Inflow	Outflow
Preliminary Trial								
15-16 April, 2008	0.5 g	-	Inflowing	Outflowing	×	×	✓	✓
Field trials from a wharf								
Trial 1: 17 April, 2008	0.5 g	1 g	Inflowing	Outflowing	✓	✓	✓	✓
Trial 2: 30 April, 2008	1.5 g	-	Inflowing	Outflowing	×	✓	✓	✓
Field trials from a vessel								
Trial 3: 8 May, 2008	1.5 g	-	Outflowing	Inflowing	×	✓	✓	✓
Trial 4: 9 May 2008	1 g	2.5 g	Outflowing	Inflowing	✓	✓	✓	✓

Note 1: Fluorescein added as single batch to header tank
 2: Cumulative amount of fluorescein over consecutive treatments

Different experimental designs were necessary to collect the best possible data within the time constraints imposed by limited daylight hours and the amount of time required to deploy the containment system. Deployment of the containment system left too little time to sample fluorescein concentrations at all points and to circulate fluorescein through the entire system before divers had to stop work due to limited visibility. More detailed data collection was possible in the extra time provided if the tarpaulin was not re-deployed between trials conducted on consecutive days.

Batch releases of fluorescein into the system occurred at the beginning of each trial, but residual amounts of fluorescein remained in the system between consecutive trials. It is possible that some or all of the fluorescein was lost to the surrounding water column between consecutive trials, but no leakage of fluorescein from the system would have resulted in the accumulation of fluorescein between consecutive trials. Batch and cumulative amounts of fluorescein for consecutive trials are therefore indicated in Table 2.2.

It was apparent throughout the trials that assessment of the system would be greatly enhanced through more frequent *in situ* sampling of fluorescence within the tarpaulin, thereby resulting in further changes to the sampling regime.

Real-time measurements of fluorescence were logged separately from within the header tank and within the central pipe capturing water returning from the tarpaulin. Fluorescence was measured with an Opti-Sciences GFP-Meter fluorometer calibrated to 1 mg/L of fluorescein in seawater. Time limitations meant that one trial each from land and vessel was conducted from a single coupling. However, mixing of the encapsulated water was aided by changing hoses to various attachments around the periphery of the tarpaulin during one further trial each from land and vessel. The order of treatment via the peripheral attachments is indicated in Fig. 2.12, but only the four corner couplings were utilised.

In situ measurements of fluorescence were made under the tarpaulin to confirm that the measurements of fluorescence taken top-side reflected those experienced under water. Samples of encapsulated water were collected through tubes introduced through holes drilled in dust-caps closing off each of the peripheral attachments. 50 ml syringes were attached to the tubes and purged before samples were collected. Samples were collected from three positions around the tarpaulin during the first trial, whereas triplicate water samples were collected through each of the peripheral attachments to which a hose was not attached at the end of the second trial. Such sampling occurred in the middle and at the end of the third trial, and was intensified further during the fourth trial, when triplicate water samples were collected at the end of circulation through each of the four corner couplings.

To record leakage of fluorescein from under the tarpaulin into the surrounding water column, triplicate water samples were collected in 50 ml syringes at intervals of 0 m, 0.5 m, 2 m and 4 m along transects at positions around the periphery of the tarpaulin indicated in Fig. 2.13. Samples from the periphery of the tarpaulin were collected before, during and after the first and fourth trials.

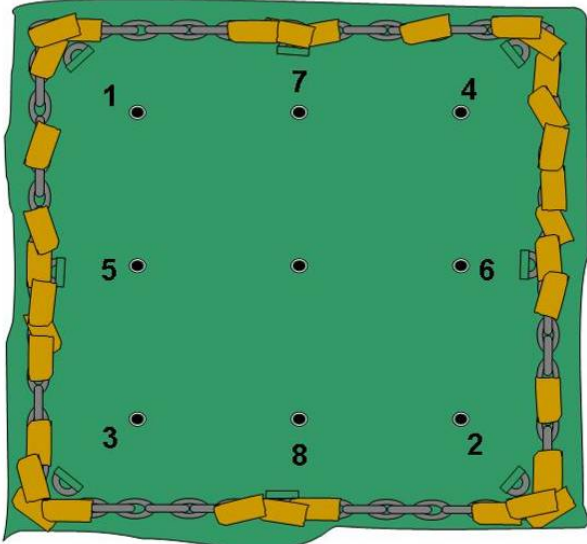


Figure 2.12: Order of hose couplings via peripheral attachments.

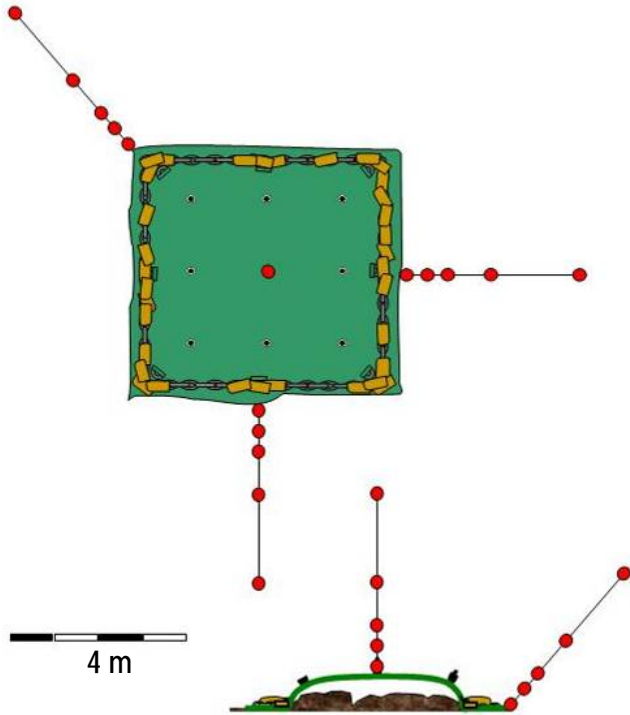


Figure 2.13: Sample design showing sampling points (red dots) along three 4 m transects positioned at 45 degrees to the seabed at the tarpaulin periphery and a single 4 m transect perpendicular to the middle of the tarpaulin.

Calibration tables were generated prior to the field trials to provide for accurate measurement of fluorescence over visible (1 mg/L) and trace (0.01 mg/L) fluorescein concentrations. Each calibration table was stored in the fluorometer's memory for use in the field. Fluorescein concentration was later calculated by reference to the standard curves corresponding to each specific calibration (Appendix A, Figs. A1 & A2).

It was apparent throughout the trials that fluorescence of out-flowing water measured using the optical sensor inserted through a grommet into the header tank were consistently lower when compared to readings measured using a second optical sensor positioned in the central pipe. Water samples were therefore removed from the header tank at regular intervals throughout the second trial from a vessel and fluorescence measured with the second optical sensor. These data were then used to generate a calibration curve by which the fluorescence measured with the first sensor was corrected (Appendix A, Fig. A3).

Interpretation of the data was based on the assumption that complete mixing of a known amount of fluorescein throughout the system would be demonstrated by similar concentrations of fluorescein when measured at several points throughout the system. The total volume of the system was therefore calculated using the pump flow rate and time taken to fill the tarpaulin. A target concentration was then calculated from the known amount of fluorescein and volume of water. In trials where residual fluorescein may have been present, a target range was defined by the batch and cumulative amounts of fluorescein added to the system (refer to Table 2.3). Convergence of measured and target fluorescein concentrations was interpreted to indicate mixing of the encapsulated water, and complete mixing of the fluorescein throughout the system was assumed to have occurred when all measured concentrations were consistently within the target range. Time taken to reach this point was crucial to subsequent evaluation of the system.

A detailed activity log was kept. Activities logged included:

- Establishment at the site
- Health and Safety and site briefings
- Deployment of the containment system
- Deployment of the treatment system
- Establishment of an integrated system (i.e. effective and constant flow)
- System tests (i.e. coupling to peripheral attachments one to four)
- Dis-establishment of the treatment system
- Retrieval of the containment system
- Dis-establishment
- Departure from site
- Down-time required for maintenance and repairs etc.

Fuel consumption, flow rate and running time were recorded for each pump.

2.4.5 Evaluation of the system

The efficacy of the containment system was evaluated and discussed on the basis of the following assessment criteria:

- **Efficacy of deployment** – The efficacy of deployment was assessed with consideration of the technical and logistic limitations of the system including the

relative time taken to deploy the system to soft sediments from land and a floating structure.

- **Efficacy of containment and circulation** – The efficacy of containment and circulation was assessed in relation to how effectively the system contained and circulated chemicals (i.e. fluorescein) throughout the system. Specific consideration was made to the time required to effectively mix the chemical (i.e. reach the target fluorescein concentration), and how this rate of delivery compared to the lethal doses of chemical agents previously considered or used in the management of NIMS.
- **Logistic and resource requirements** – The number of personnel and logistic support (i.e. number of vessels and barges) required for deployment of the system were identified and are discussed in terms of the different methods of deployment. Logistics of the transportation, storage and deployment of the system and chemicals were also considered, with particular attention to the need to ensure adequate health and safety, and environmental protection. The relevance of scale in the use of the system during an incursion response and how effectively the prototype could be scaled up were assessed in terms of the impact this could have on its functionality and resource requirements (i.e. possible efficiencies of scale).
- **Ecological, social and cultural impacts** – The potential ecological and social impacts of the system were considered in terms of how these could be perceived by stakeholders and regulatory agencies. The effect of these perceived impacts on obtaining the necessary approvals and consents to undertake the work was assessed in relation to the Resource Management Act 1991 (RMA 1991), and how this could impact on the future use of the system in an incursion response.
- **The use of hazardous substances in an incursion response** – The application of effective chemical treatments using the system was evaluated in relation to how relevant the treatment parameters (i.e. LD₁₀₀) were to the effective application of chemical treatments in the field. Effective monitoring of chemical treatments and their circulation within the system were considered in terms of the relative merits of tracer dyes and direct monitoring of chemical concentrations. Potential release of hazardous substances (i.e. chemical agents and pesticides) to the marine environment were assessed in relation to regulation under the Hazardous Substances and New Organisms Act 1996 (HSNO Act 1996).
- **Target non-indigenous species and other applications** – The taxonomic and functional groups targeted by the system were identified, and the merits of the system for incursion responses in other environments and substrates was evaluated (i.e. freshwater, rocky reef, sunken vessels, vessel hulls, marina pontoons).

3. Results

3.1 OBTAINING THE REQUIRED CERTIFICATES AND PERMITS FOR FIELD TRIALS

A schedule of dates associated with significant milestones toward ensuring that the field trials complied with the RMA 1991 is presented in Table 3.1. This shows that it took just over three months to obtain the necessary certificates and coastal permits. It took 40 days to obtain three certificates of compliance and 83 days to obtain two coastal permits, of which 57 days were taken to obtain written approval of potentially affected parties.

Table 3.1: Schedule of dates toward obtaining the required certificates of compliance and coastal permits issued under the Resource Management Act 1991.

	Certificates of Compliance ¹	Coastal Permits ²
Application submitted	10 January 2008	22 January 2008
Application acknowledged	14 January 2008	25 January 2008
Request for further information received	21 January 2008	-
Further information submitted	22 January 2008	-
Potentially affected parties identified	-	4 February 2008
Written approvals sought	-	12 February 2008
All written approvals received	-	01 April 2008
Certificates, consents or permits approved	19 February 2008	14 April 2008

Note 1: Certificates of Compliance to discharge non-toxic tracer dye to the CMA (Certificate No: 2008C01); to occupy the CMA at Moeraki (Certificate No: 2008C05); and to take coastal water from the CMA at Moeraki (Certificate No: 2008C06).
 2: Coastal permits to take and use coastal water from Otago Harbour for the purpose of supplying water for pest containment and treatment system trial (Consent No: 2008.049); and to place and remove structures on the seabed for the purpose of undertaking a pest containment and treatment system trial (Consent No: 2008.050).

3.2 LABORATORY TRIALS FOR FLUOROMETER

3.2.1 Sensitivity of the fluorometer to fluorescein in seawater

Figure 3.1 shows a significant linear relationship between fluorescein concentration and fluorescence over all tested concentrations ($y = 0.001x - 0.25$, $r = 0.96$). However, variability between replicates increased with decreasing fluorescein concentration and was greatest at concentrations lower than 0.25 mg/L (the slope of the graph indicates that one A-D tic equates to 0.001 mg/L of fluorescein). Visual detection of fluorescein was strongest at 1 mg/L and weakest at 0.125 mg/L. Concentrations of fluorescein less than 0.125 mg/L were not visible to the naked eye.

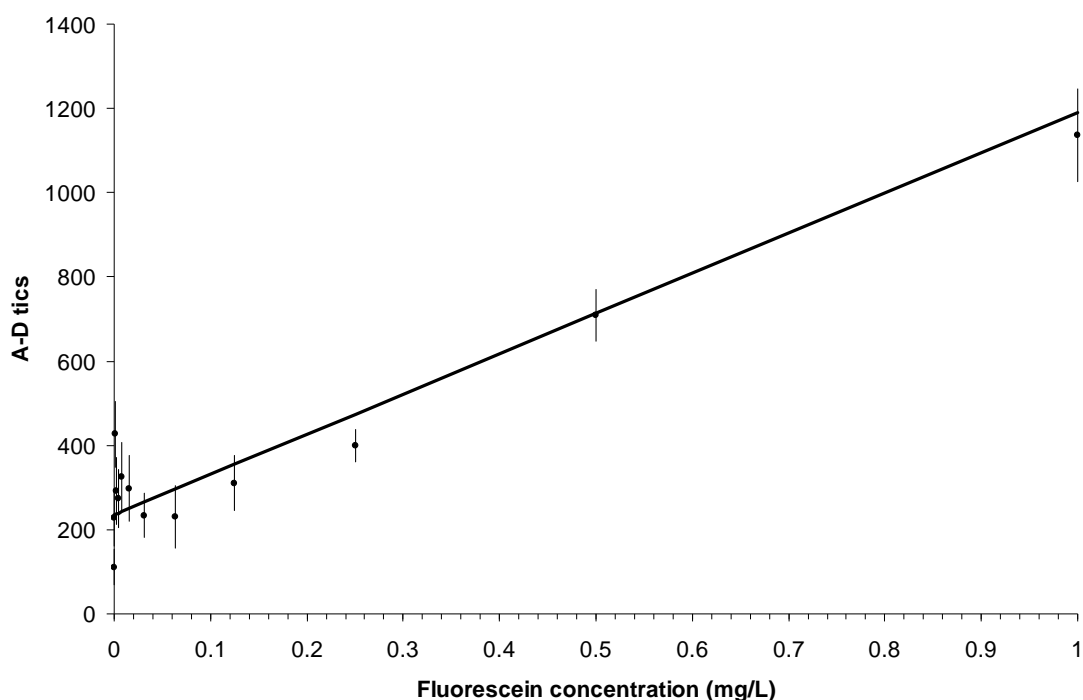


Figure 3.1: Fluorescence measured by Opti-Sciences GFP-Meter. Black dots represent mean fluorescence of each replicate \pm one standard error ($n = 6$).

3.2.2 Sensitivity of the fluorometer to suspended sediment.

Fluorescence decreased with increasing sediment indicating that suspended sediment attenuates the optical signal received by the fluorometer (Fig. 3.2). The degree of attenuation differed between concentrations of fluorescein, but was within the margin of error of measurements presented previously in Figure 3.2 (Table 3.2). Comparison of the attenuated fluorescence and accuracy of the fluorometer indicates that it would take 143 g/L of sediment in 1 g/L of fluorescein before attenuation of fluorescence exceeded the fluorometer's margin of error (i.e. 0.1/0.0007). This equates to 71.4 kg of suspended sediment in the 500 L header tank. This amount of sediment did not occur within the system during any of the trials because the system design incorporated filters to remove sediment and design features to prevent the entrainment of sediment.

Visual detection of fluorescein was obscured by 15.7 ± 1.3 g/L of suspended sediment at 1 mg/L, 6.9 ± 0.3 g/L of suspended sediment at 0.5 mg/L, and 1.3 ± 0.1 g/L of suspended sediment at 0.1 mg/L (Fig. 3.3).

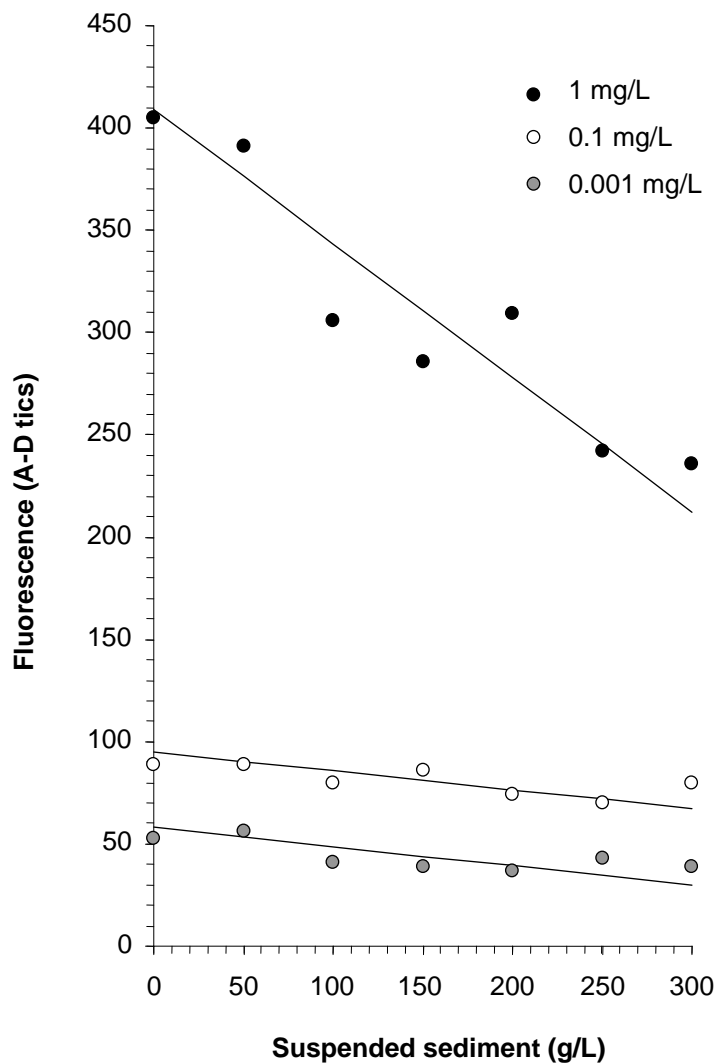


Figure 3.2: Attenuation of fluorescence with increasing sediment concentration.

Table 3.2: Regression analysis of the attenuation of fluorescence by suspended sediment measured using a fluorometer calibrated to 1 mg/L.

Fluorescein (mg/L) ¹	Regression	Pearson coefficient (r)	Attenuated fluorescence ²
1 ± 0.1	y = -1.5x + 624	-0.94	0.0007
0.1 ± 0.07	y = -10.9x + 1037	-0.74	0.00001
0.001 ± 0.08	y = -10.8x + 624	-0.74	0.00001

Note: 1: Fluorescein concentration and standard error presented previously in Figure 3.2.
2: mg/L of fluorescein per gram of suspended sediment

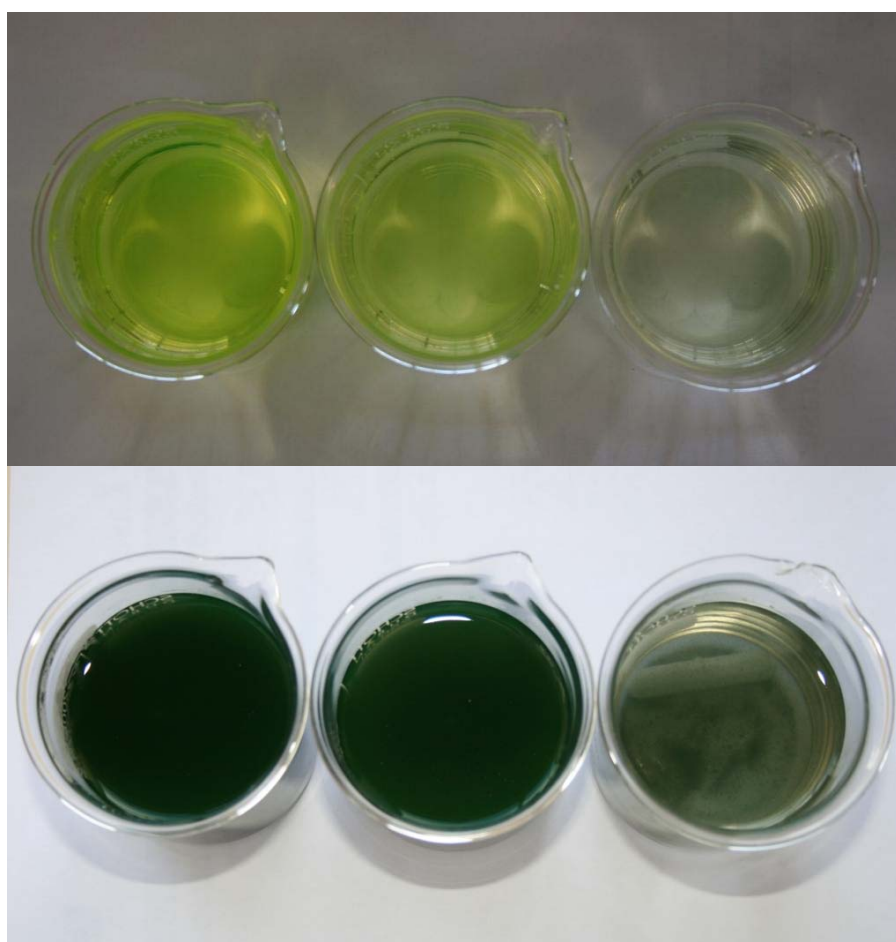


Figure 3.3: Visual appearance of fluorescein at 1 mg/L (top left), 0.5 mg/L (top middle) and 0.1 mg/L (top right) and appearance of corresponding solutions once fluorescein is obscured by sediment.

3.2.3 The effect of flowing water on real-time measurement of fluorescence

Data indicate that fluorescence was significantly lower in the static solution compared to fluorescence measured in flowing water. Fluorescence did not differ between measurements taken at different water velocities (Fig. 3.4).

Results indicate that the measurement of fluorescence is enhanced by circulation of the water, possibly owing to better mixing compared to a static solution. However, fluorescence was not affected by the velocity of water passing the optical sensor and indicates that variable water flow through the system will not affect the accuracy of the fluorometer during the field trials.

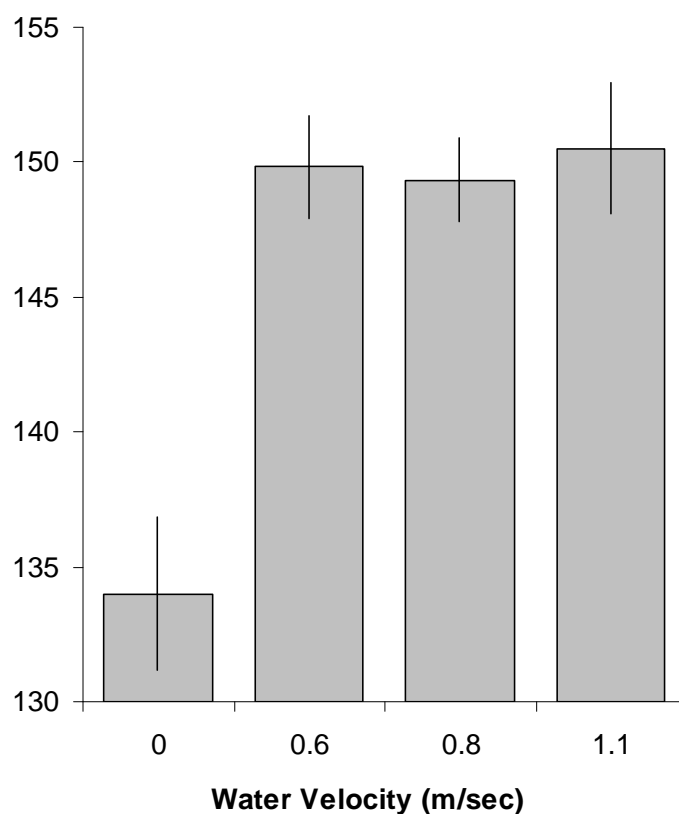


Figure 3.4: Mean fluorescence (\pm one standard error) measured by Opti-Sciences GFP-Meter at different flow rates ($n = 6$).

3.2.4 Photo-degradation of fluorescein

Exposure of fluorescein to direct sunlight in both HDPE and glass containers resulted in the loss of between 60 and 80 percent of fluorescence within the first hour of exposure and was almost complete after 4 hr (Fig. 3.5). No loss of fluorescence occurred in dark treatments. Loss of fluorescence occurred slightly faster in the 0.5 mg/L solution of fluorescein compared to 1 mg/L.

These data indicate that direct sunlight rapidly degrades fluorescein and that photodegradation could influence the results of the field trials if actions are not taken to prevent this from occurring by blacking out the header tank with paint or polyethylene sheet.

3.3 FIELD TRIALS

3.3.1 System parameters

The total volume of the system was approximately 9500 L. This included average volumes within the tarpaulin of 9000 L (Table 3.3) and 500 L in the header tank. Approximately 3 L of seawater was also present in the hoses and central pipe. The maximum flow rate through the system was determined by the SV205 pump with the lowest flow rate of 100 L/min. Hence, a minimum of 95 minutes was required for complete turn-over of the entire system volume. Each pump consumed fuel at a rate of 0.78 L/hr when run continuously at full throttle.

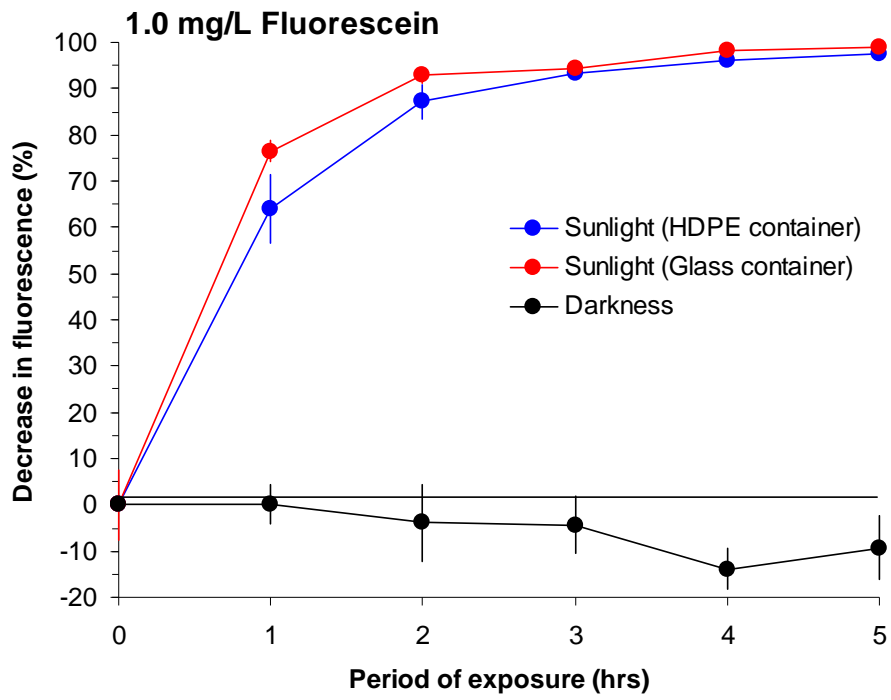


Figure 3.5: Photodegradation of fluorescein when exposed to sunlight. Values represent the mean \pm one standard error ($n = 3$).

Table 3.3: Volume of the inflated tarpaulin.

	Time to inflate tarpaulin (min)	Pump used	Flow rate (L/min)	Volume (L)
Preliminary Trial				
16 April, 2008	90	SV205	100	9000
Field Trials				
Trial 1: 17 April, 2008	30	CO350	240	7200 ¹
Trial 2: 30 April, 2008	40	CO350	240	9600
Trial 3: 8 May, 2008	35	CO350	240	8400
Trial 4: 9 May 2008	5	CO350	240	1200 ¹
		Average volume (± 1 S.E, n = 3)		9000 \pm 346

Note 1: Calculated volume required to replace water lost since deployment of the tarpaulin occurring the previous day and therefore not included in calculations of the average volume.

3.3.2 Deployment from land and fixed structures (e.g., a wharf)

3.3.2.1 Time and personnel

A total of 17 hours and 25 minutes was required to complete the first trial (Table 3.4). This work occurred over two days, as the initial health and safety brief and deployment of the containment system occurred during the preliminary trial, allowing a longer test (i.e. 390 min) of the system than would have otherwise been possible if the tarpaulin had been retrieved and redeployed on each of the two days. The second trial was completed in just under 10 hrs, but this only permitted testing of the system for 85 min due to the amount of time required to deploy the containment system and establish an integrated system. It should be noted that not all activities occurred sequentially, particularly at the beginning and end of the day when personnel were often engaged in multiple tasks. Times therefore exceed the real time taken to complete all tasks.

Demobilisation of the treatment system took 40 min less time in the second trial due to people being more familiar with the process, but the containment system took 30 min longer to retrieve, owing to the seven more sandbags deployed in the second trial and an attempt to remove the sandbags directly to the wharf without double-handing them on the finger punt. Sandbags had been deployed and retrieved vertically via a drop line in the first trial, with a line stretched between the wharf and tarpaulin enabling sandbags to be deposited directly to the tarpaulin during the second trial. Securing the line to the tarpaulin was difficult, however,

Table 3.4: Deployment from land: time and personnel

Activity	Total time taken		Personnel required
	Trial 1	Trial 2	
Site establishment	15 ¹	25	3 persons
Health and Safety brief	60 ²	15	4 persons
Deployment of containment system	265	185	4 persons (incl. 2 divers)
Deployment of treatment system	30	10	3 persons (incl. 1 diver)
Establishment of integrated system	120	130	3 persons
System test	390	85	3 persons (incl. 1 diver)
Demobilisation of treatment system	60	20	2 persons
Retrieval of containment system	80	110	4 persons (incl. 1 diver)
Dis-establishment	25 ¹	15	4 persons
TOTAL	1045	595	

Note 1: Average time taken over three consecutive days.
2: Time taken for comprehensive health and safety briefing on first day at site.

and a gradual loss of tension in the drop line meant that the sandbags often landed on the surrounding seabed. This was even more of an issue when the sandbags were retrieved using the same method, so much so that it was soon abandoned in favour of the earlier and more efficient method.

3.3.2.2 Encapsulation and containment of the chemicals

Visual leaks initially detected during deployment of the tarpaulin could be sealed using chain and additional sandbags. After the preliminary trial, however, leakage from the tarpaulin had almost completely deflated the tarpaulin, requiring re-inflation with approximately 7200 L of water at the beginning of trial one (Table 3.3). Water flow from the outlet hose at sea level did not occur, which also suggested a loss of water about the periphery of the tarpaulin (refer to Section 2.3.3.3).

Leakage from the system was confirmed by the detection of fluorescein in the surrounding water column during the first trial (Fig. 3.6). The presence of fluorescein in the surrounding water column before the trial indicated leakage during inflation of residual fluorescein from the preliminary trial, and were on average 1.4 % of the target concentration of the preliminary trial (i.e. 0.05 mg/L). Levels of fluorescein during and after the first trial were consistently higher than before the trial, indicating that fluorescein was leaking from the tarpaulin and mixed through the water column throughout the trial. Mean fluorescein concentrations in the surrounding water column during and after the trial were 2 - 4 % and 0.1 - 2.4 % of the target concentration (i.e. 0.05 - 0.11 mg/L), respectively.

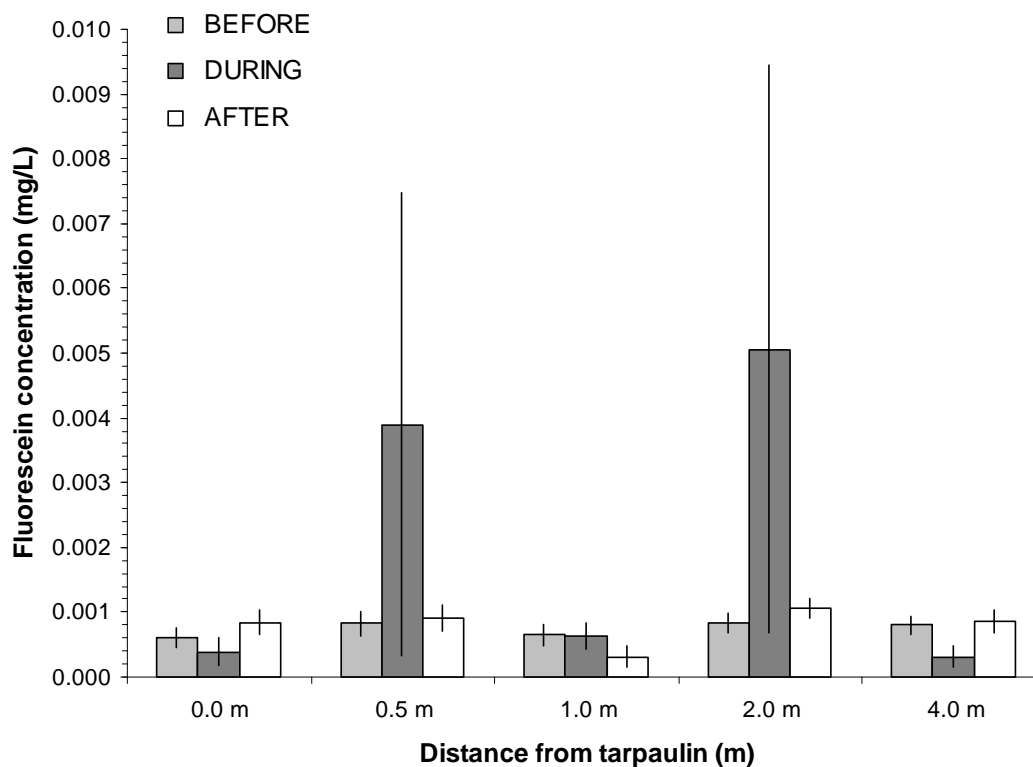


Figure 3.6: Fluorescein concentration within the water column surrounding the tarpaulin during the first trial. Values represent the mean \pm one standard error. ($n = 12$).

3.3.2.3 Circulation and mixing of the chemicals

It has been indicated previously in Section 2.5.4 that convergence of measured and target fluorescein concentrations was interpreted to indicate mixing of the encapsulated water. Complete mixing of the fluorescein throughout the system was assumed to have occurred when all measured concentrations were consistently within the target range.

Data presented in Figure 3.7 shows that the fluorescein concentration in water flowing into and out of the header tank was consistently within the target range after 230-235 min of circulation, equating to a maximum system turn-over of just under 2.5 times through a series of four peripheral couplings. Fluorescein concentration flowing into and out of the header tank equilibrated after approximately 56 min, but never equalled the target concentration throughout the 85 min trial (Fig. 3.8). Circulation occurred through a single coupling and would not have occurred for long enough to re-circulate the entire encapsulated water volume.

Too few measurements of fluorescein concentration were taken *in situ* during the first and second trials to indicate how quickly the fluorescein concentration equilibrated to the target concentration within the tarpaulin. The few measurements taken in the first trial were within the target range after 192 min of circulation. Fluorescein concentrations with the tarpaulin during the second trial were more equivocal, with some matching the target concentration, whereas others were higher than the target concentration.

Gravitational flow from the header tank to the tarpaulin varied greatly with tidal amplitude. Constant vigilance to maintain a static water level within the header tank was required. Airlocks often prevented the continuous and even circulation of water through the entire system. An average of 110 min over both trials from land was required to integrate the systems and ensure that the airlocks had been resolved to the extent that tests could proceed.

3.3.3 Deployment from a floating structure (e.g. a vessel)

3.3.3.1 Time and personnel

As occurred previously for deployment from land, the tarpaulin was not retrieved and redeployed between trials conducted from a vessel, thereby allowing for longer tests of the system (Table. 3.5). Just under 9 h was required to complete the third trial, including a system test of 4 h (Table 3.4). The fourth trial took approximately 11 h, including a system test of 5.5 h.

The tarpaulin was deployed under the vessel which allowed for 60 sandbags to be dropped directly onto the tarpaulin. This greatly reduced the time otherwise required to lower individual sandbags to the seabed. Familiarity with the system and means to efficiently resolve issues such as airlocks enabled the system to be quickly integrated and circulation established throughout the system. However, retrieval of the system had to occur over the gunwales of the vessel, which was more difficult and time consuming than in previous trials.

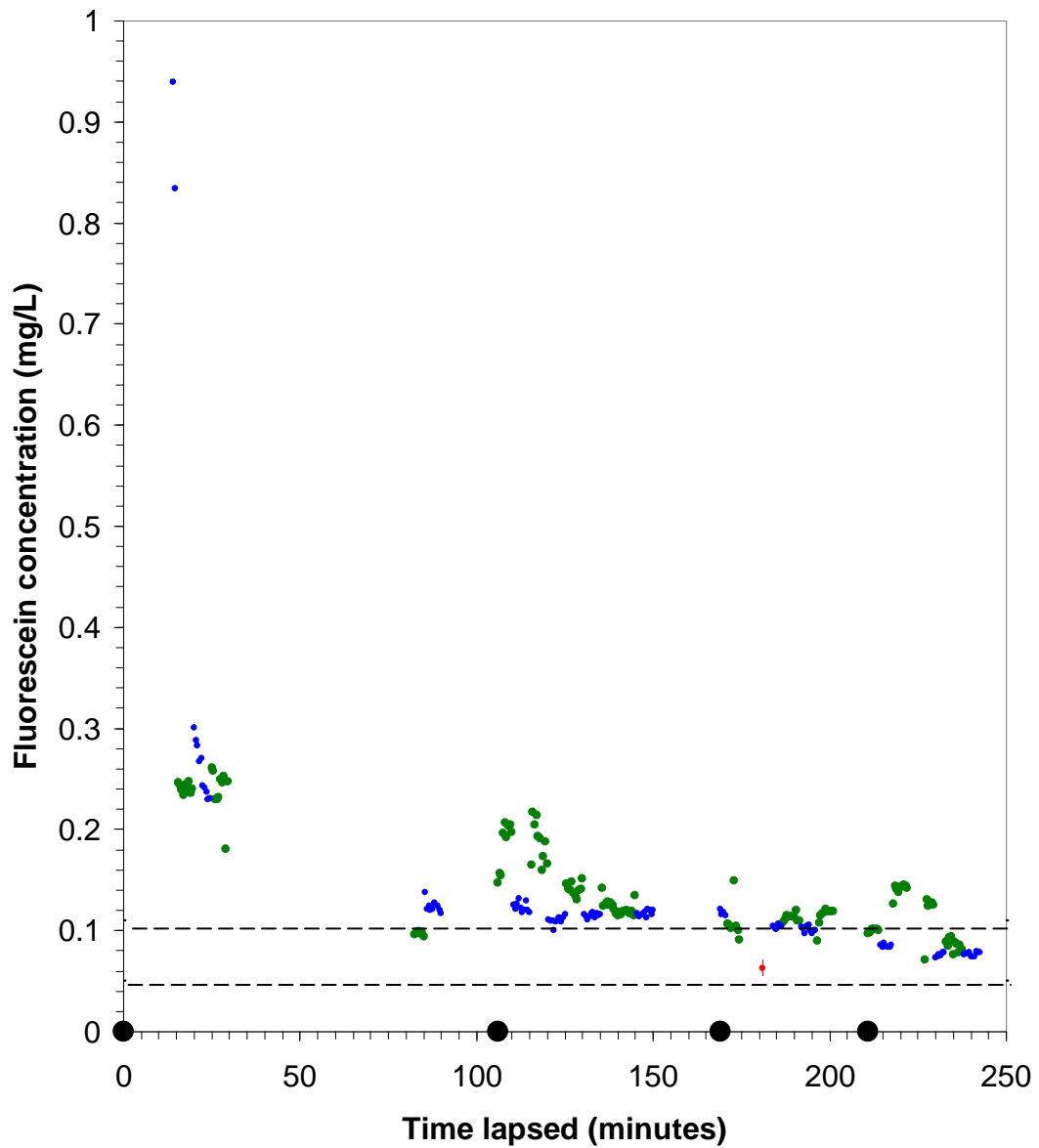


Figure 3.7: Trial One: Time series of fluorescein concentration after the release of 0.5 g of fluorescein into the header tank. Circulation occurred through multiple couplings indicated on x-axis. Measurements were taken at 30 s intervals within the out-flowing header tank (blue circles) and in-flowing water (green circle). Fluorescein concentration within tarpaulin (red circles) represent the mean (\pm one standard error, $n = 3$). Target concentration within the tarpaulin was 0.05-0.11 mg/L (dashed lines).

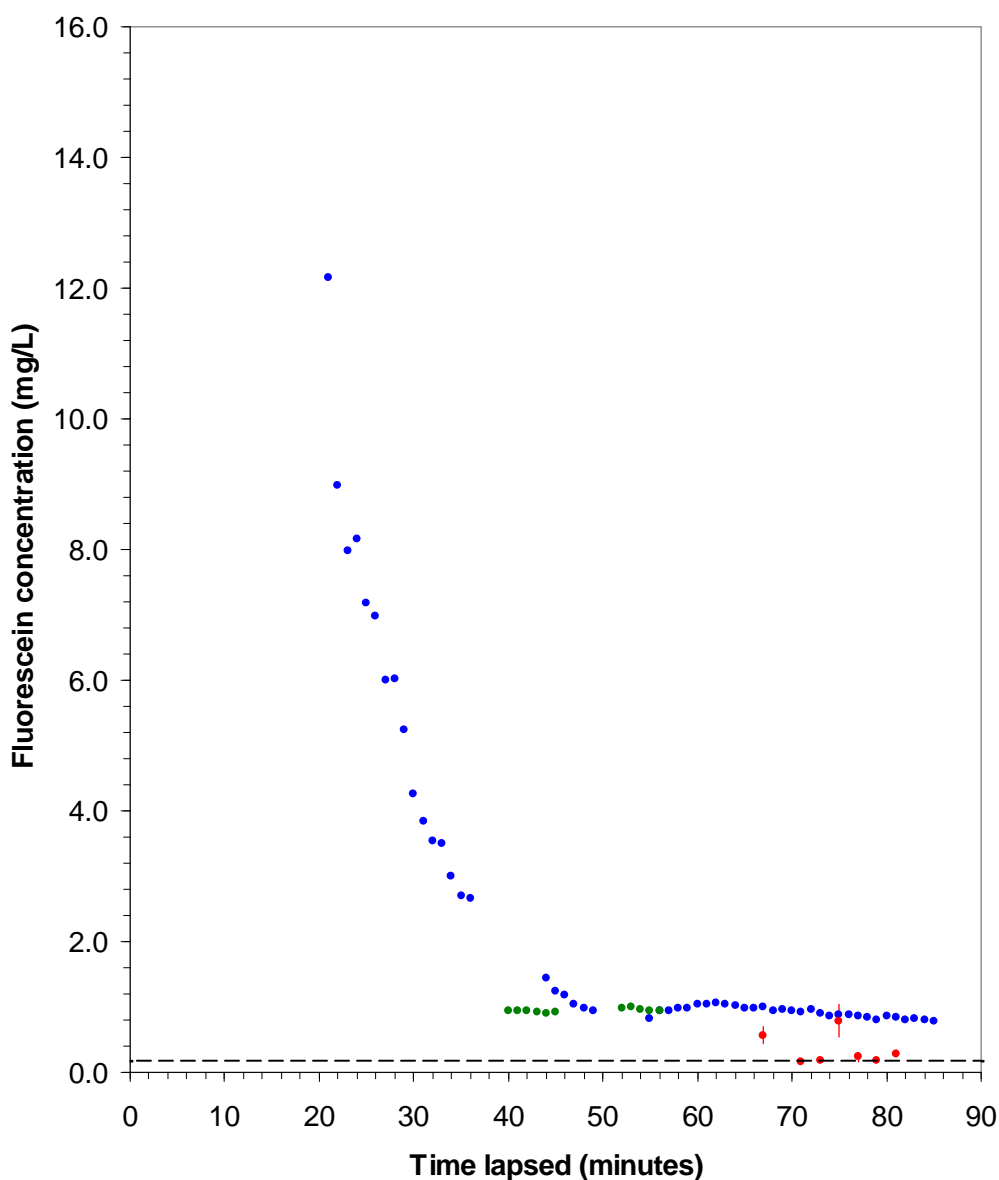


Figure 3.8: Trial Two: Time series of fluorescein concentration after the release of 1.5 g of fluorescein into the header tank. Circulation occurred through a single coupling. Measurements were taken periodically at 60 s intervals within out-flowing header tank (blue circles) and in-flowing water (green circles). Fluorescein concentration within tarpaulin (red circles) represent the mean (\pm one standard error, $n = 3$). Target concentration within the tarpaulin was 0.16 mg/L (dashed line).

Table 3.5: Deployment from a vessel: time and personnel

Activity	Total time taken (mins)		Personnel required
	Trial 3	Trial 4	
Health and Safety brief	20	5	4 persons
Site establishment	40	35	4 persons
Deployment of containment system	80	-	4 persons (incl. 2 divers)
Deployment of treatment system	70	25	3 persons (incl. 1 diver)
Establishment of integrated system	60	75	3 persons
System test	240	325	3 persons (incl. 1 diver)
Demobilisation of treatment system	-	15	2 persons
Retrieval of containment system	-	150	4 persons (incl. 1 diver)
Dis-establishment	20	15	4 persons
TOTAL	530	645	

3.3.3.2 Encapsulation and containment of the chemicals

No visual leaks were detected once the tarpaulin was first inflated and flow from the outlet hose was established at sea level. The tarpaulin remained mostly inflated between the two trials, requiring only an additional 1200 L to fully inflate the tarpaulin at the beginning of the fourth trial (Table 3.3). However, it is possible that re-inflation of the tarpaulin could have increased internal pressure, which placed strain on the seal and may have lead to leakage that was not otherwise visible to divers. Deployment of the SV205 pump, returning water to the surface, would have reduced the internal pressure and is likely to have reduced any leakage.

Leakage from the system was confirmed by the detection of fluorescein in the surrounding water column during the fourth trial (Fig. 3.9). Levels of fluorescein in the surrounding water column before the trial reflects leakage (during inflation) of residual fluorescein from the third trial, but was on average 4 % of the target concentration from the third trial (i.e. 0.16 mg/L). With the exception of water 4 m from the tarpaulin, fluorescein concentrations in the surrounding water column generally decreased during and after the trial, when the drawing of water back to the surface may have reduced the pressure within the tarpaulin and thereby reduced the amount of leakage. Average concentrations of fluorescein in the surrounding water column, both during and after the trial, were 0.7 - 1.0 % of the maximum target concentration for the fourth trial (i.e. 0.16 - 0.26 mg/L).

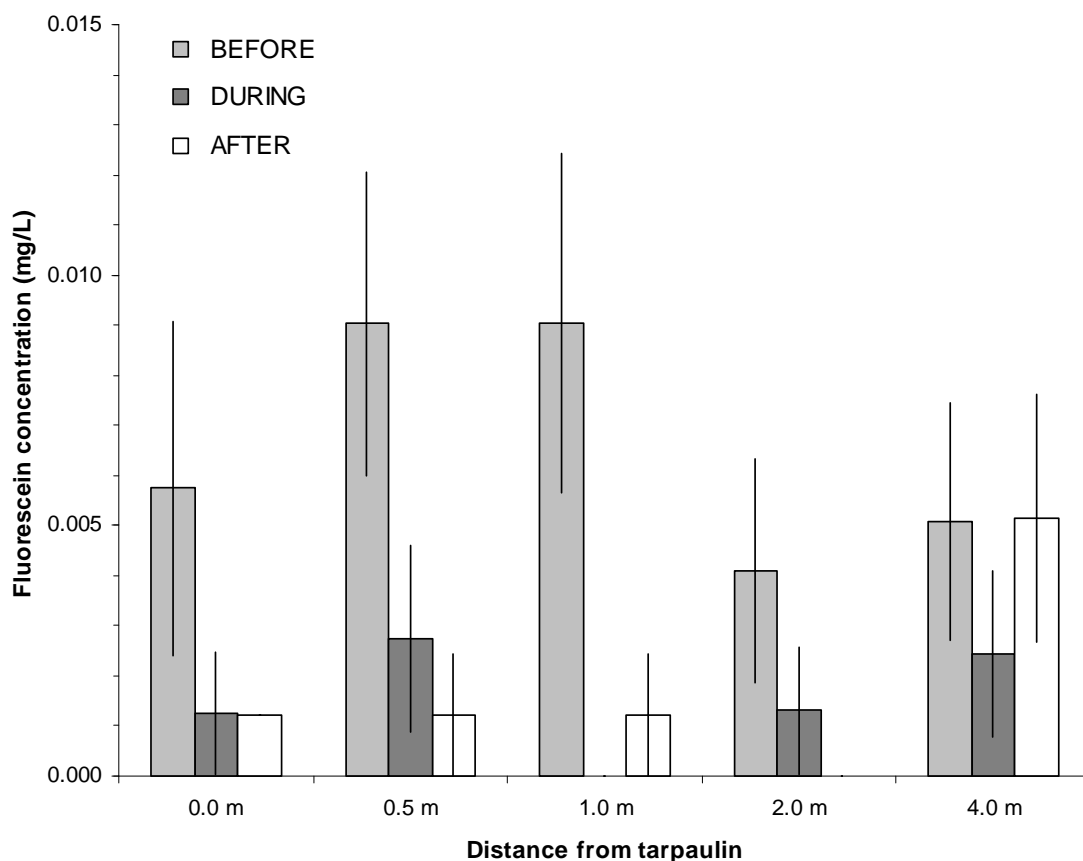


Figure 3.9: Fluorescein concentration within the water column surrounding the tarpaulin during fourth trial. Values represent the mean \pm one standard error ($n = 12$).

3.3.3.3 Circulation and mixing of the chemicals

Data presented in Figure 3.10 shows that the fluorescein concentration in water flowing into and out of the header tank and within the tarpaulin was never consistent within the target concentration of 1.6 mg/L throughout 244 min of circulation during the third trial. This equates to a maximum system turn-over of just over 2.5 times through a single coupling. However, data from the fourth trial shows that the fluorescein concentration in water flowing into the header tank and within the tarpaulin was consistent within the target range after 210 min of circulation, equating to a maximum system turn-over of 2.2 times through a series of four peripheral couplings (Fig. 3.11).

Fluorescein concentrations in out-flowing water from the header tank were consistently above the target range in previous trials, but were consistently below the target range in the fourth trial. This reflects the different methodology during which the entire contents of the header tank were discharged into the tarpaulin shortly after the addition of fluorescein; evident as a rapid decrease of fluorescein concentration within the header tank outflow and equally rapid increase in fluorescein concentration within water returning to header tank from the tarpaulin (i.e. inflow).

Maintenance of equal flow into and out of the header tank was easily accomplished using the two pump system and deployment from a vessel, primarily because the flow of water did not vary with tidal amplitude. Airlocks still prevented the continuous and even circulation of water through the entire system, but were resolved on average in 68 min, reflecting greater ease of priming the system at sea level compared to the wharf. It was also apparent during the trial that the tarpaulin was continuously inflating, placing increased pressure on the seal. This was later traced back to the introduction of water through an attachment to the filter used to prime the SV205 pump, highlighting the importance of preserving the integrity of the seal by ensuring that the tarpaulin is not over inflated through the introduction of water from outside sources.

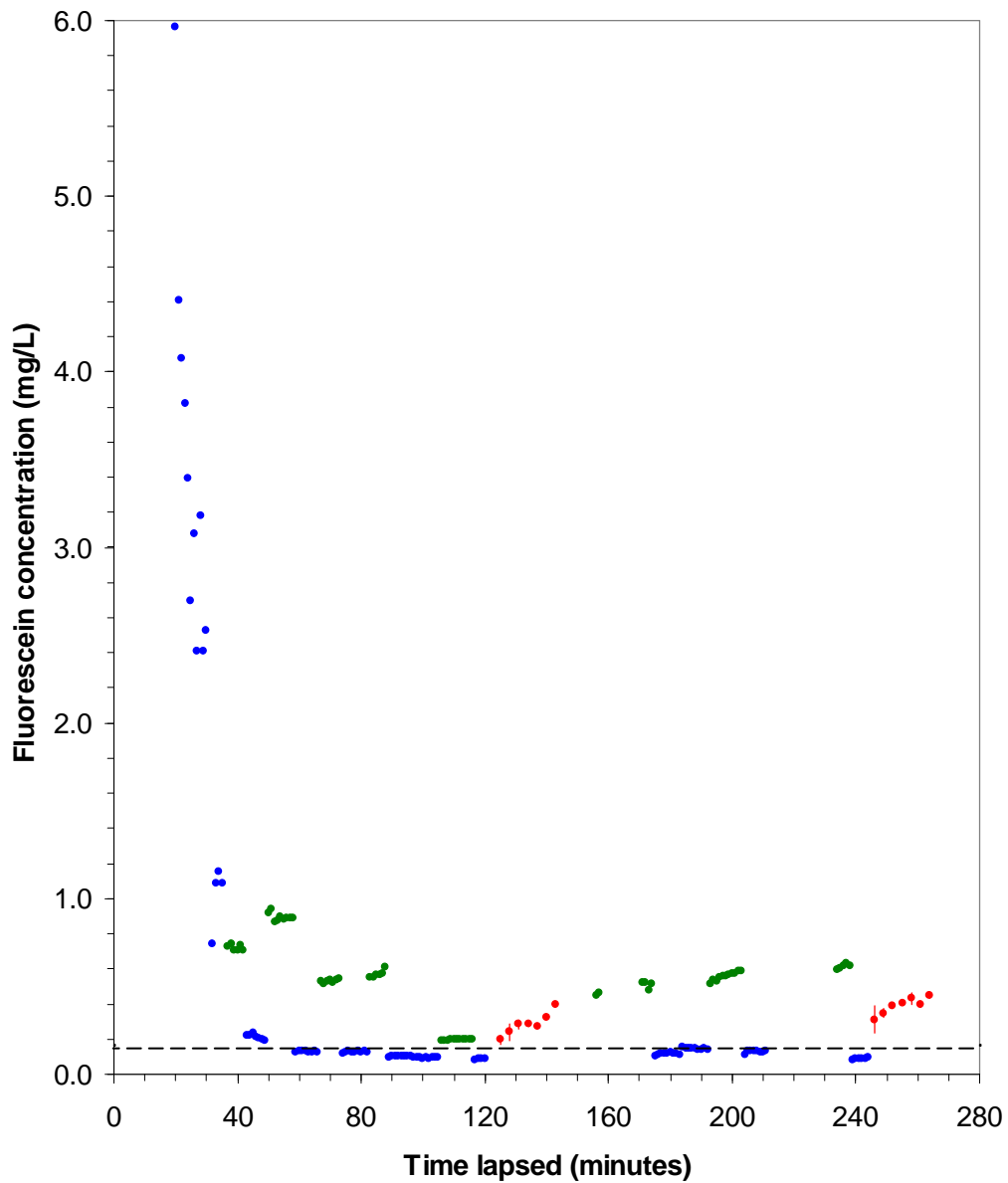


Figure 3.10: Trial Three: Time series of fluorescein concentration after the release of 1.5 g of fluorescein into the header tank. Circulation occurred through a single coupling. Measurements were taken at 60 s intervals within the out-flowing header tank (blue circles) and in-flowing water (green circles). Fluorescein concentration within tarpaulin (red circles) represent the mean (\pm one standard error, $n = 3$). Target concentration within the tarpaulin was 0.16 mg/L (dashed line).

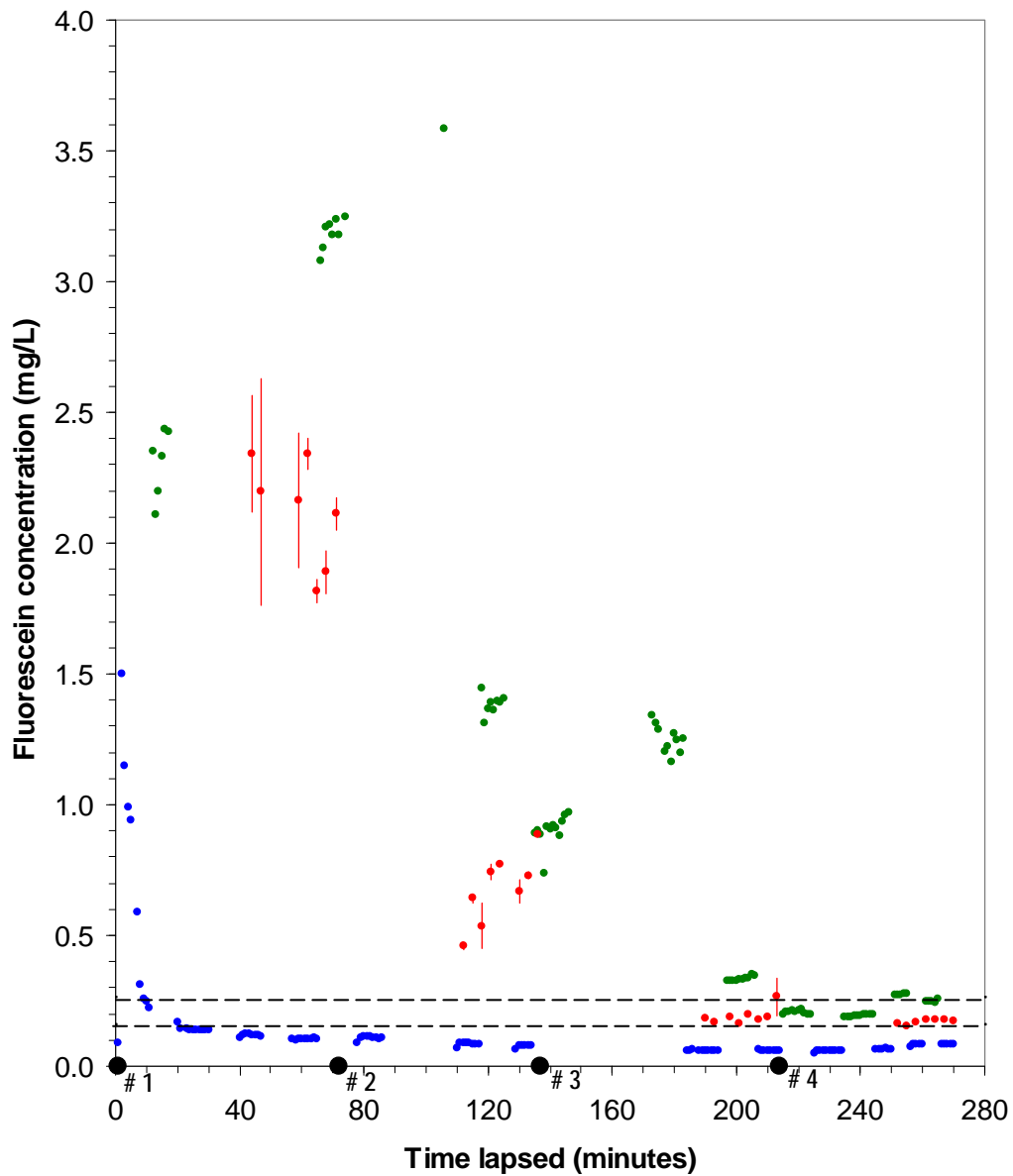


Figure 3.11: Trial Four: Time series of fluorescein concentration after the release of 1 g of fluorescein into tarpaulin. Circulation occurred through multiple couplings indicated on x-axis. Measurements were taken periodically at 60 s intervals within out-flowing header tank (blue circles) and in-flowing water (green circles). Fluorescein concentration within tarpaulin (red circles) represent the mean (\pm one standard error, $n = 3$). Target concentration within the tarpaulin was 0.16-0.26 mg/L (dashed lines).

4. Discussion

4.1 EFFICACY OF DEPLOYMENT

Field trials of the prototype system show that it can be effectively deployed to soft sediment from land and a floating structure. Methods of deployment that increase the ease and efficiency of deployment and are therefore recommended for general use comprise:

- The use of the two-pump system when deploying from land and a floating structure.
- The use of a mechanical hoist and winch for the retrieval of sandbags, when available.
- Inflation of the tarpaulin using the high flow CO305 pump.
- The immediate discharge of the chemicals contained in the header tank into the tarpaulin and subsequent mixing (i.e. method employed in the fourth trial), rather than the gradual introduction of chemicals to the tarpaulin from the header tank (i.e. method employed in trials 1-3).

Deployment from land occurred from a wharf, but could equally have been from a reclamation, jetty or shoreline. Elevation of the header tank above sea-level enabled the system to be deployed with only a single pump, but gravitational flow to the tarpaulin varied greatly with tidal amplitude and required constant vigilance to maintain a static water level within the header tank. Although use of a single pump may be more cost efficient than the two pump system, the rate of flow and delivery of chemical agents was not constant, hence use of a two pump system is recommended.

Deployment of the tarpaulin from land was less efficient than from the vessel, mainly because deployment of the tarpaulin directly below the vessel enabled the sandbags to be dropped directly onto the tarpaulin, whereas sandbags had to be manually deployed from the wharf. While there appears to be little means of improving efficiency of deployment in this regard, retrieval of the sandbags to land and vessel could have been aided greatly by use of mechanical hoists or winches.

Inflation of the tarpaulin with seawater raised the tarpaulin and hose attachments above the sediment, which had the advantage of preventing the entrainment of sediment and ensuring unimpeded flow throughout the encapsulated area. However, it took time to inflate the tarpaulin, which was initially accomplished using the lower flow SV205 pump. This time was subsequently reduced by approximately one third by using the high flow CO305 pump.

Throughout most of the trials (trials 1-3), the gradual release of fluorescein occurred to provide the best indication of the rate of mixing; in the fourth trial all chemical was discharged to the tarpaulin and then mixed at once. Data from the fourth trial indicated that chemical concentration greatly exceeded target (i.e. lethal) concentrations and then decreased, whereas chemical concentrations only moderately exceeded the target concentration when gradually introduced to the tarpaulin (trials 1-3). Chemical concentrations within the tarpaulin are therefore more likely to induce mortality when all chemical within the system is discharged immediately into the tarpaulin.

4.1.2 Efficacy of containment and circulation

Field trials of the prototype system indicate that it can effectively encapsulate, contain and circulate chemicals when deployed to soft sediment from land and floating structures.

Circulation through a single attachment was not effective in mixing the chemical throughout the encapsulated water; the use of multiple attachments, each circulating water throughout different regions of the encapsulated area however effected good circulation. Complete mixing of the chemical occurred in a little under 4 hrs, and when the total system volume had been re-circulated through the system a little more than twice. Establishment of the site, deployment of the system, mixing of the chemical throughout the encapsulated water and retrieval of the system is unlikely to be accomplished effectively in a single working day. Effective treatments are therefore most likely to require that the system remain deployed for more than a day to affect a lethal dose of chemicals to the target organism. However, the ability of the system to remain inflated overnight indicates that the delivery of lethal doses of chemicals to target marine organisms over several days is technically feasible.

Doses of 0.25 % sodium hypochlorite for 30 min are known to completely kill fragments of *Caulerpa taxifolia* in laboratory tests, but lethal doses in the field are likely to require longer treatments to penetrate sediments to reach the rhizoids and maintain an effective concentration under high organic loads (Williams & Schroeder 2004). Similarly, doses of chlorine, copper sulphate and non-oxidising molluscicides require days of treatment to kill bivalve molluscs (Van Benschoten et al. 1993, Bax 1999). Coutts & Forrest (2005) found that treatments of sodium hypochlorite were ineffective at killing the clubbed sea-squirt, *Styela clava*, colonising marina pontoons after exposure of up to 24 h, but treatments of 1% acetic acid resulted in 100 % mortality of the clubbed sea-squirt, *Styela clava*, after exposure periods of as little as 10 min. These field trials were conducted by encapsulating the marinas in tarpaulins with polyethylene plastic, suggesting that glacial acetic acid treatments may be a feasible proposition for application using the present system.

Leakage of chemicals to the surrounding water column would likely dilute to sub-lethal concentrations within a short distance from the tarpaulin, but could still affect non-target species in immediate proximity to the treatment area and particularly at locations with little water movement. While the system was designed to contain the circulating chemical without significant leakage to surrounding water column, some leakage of chemical did occur. The amount of leakage depended largely on how effectively the containment system was deployed with the chemical concentrations in the surrounding water column varying considerably (i.e. 0.1 - 4 % of target concentrations).

Re-inflation of the tarpaulin invariably placed pressure on the containment system, leading to leakage of residual chemicals from previous trials, but in trials with the most effective seal (i.e. trial four) leakage of chemicals to the surrounding water column was between 0.6 % and 4 % of the target concentration. This information facilitates the assessment of environmental risks particular to each response, taking into account the ecotoxicity of the chemical used, treatment parameters (i.e. target concentration, treatment duration), susceptibility of non-target species to the chemical, and local bathymetric and hydrological conditions.

During the field trials, all the encapsulated water and fluorescein was released to the surrounding water column when the system was retrieved from the seabed. This may not be desirable when toxic substances are used for an incursion response. However, it would be possible to reduce any release of toxic chemicals to the wider marine environment by deactivating a chemical contained within the system by adding an appropriate neutraliser to the header tank. For example, sodium thiosulphate could be used to deactivate any residual chlorine after treatments using sodium or calcium hypochlorite. It may also be possible to treat the contained water on site by other means such as filtering it through activated carbon, or removing the encapsulated water to an appropriate treatment facility.

4.2 LOGISTIC AND RESOURCE REQUIREMENTS

Four persons is the minimum number of personnel required to deploy the system from land, including a dive supervisor, two occupational divers, and a scientist. Additional personnel such as a skipper and possibly a deckhand are required for deployment of the system from a vessel. The use of at least one small to moderately sized vessel or barge is required to deploy the system from land because it is necessary to position the pump near sea level. A vessel or small barge moored above the tarpaulin also enables the sandbags to be retrieved more efficiently from the seabed than would otherwise be possible if they were retrieved directly to land.

The logistics of transporting and storing tonnes of chain, sandbags and chemicals is likely to be challenging, particularly at sea or when accessing remote locations. Vessels need enough space to safely hold, deploy and operate the system including room for equipment, personnel, the required amount of chemicals to deliver a lethal dose, and enough oil and fuel to sustain the pumps throughout the treatment period. The safe use and storage of oil, fuel and chemicals in confined spaces, as would occur on a vessel, may not be possible without the use of multiple vessels. The location of the header tank and chemical stores on a separate vessel or land removed from the treatment location may have to be considered.

Many operational and logistic requirements of the deployment of the system directly result from actions required to avoid or mitigate risks to the environment and human health and safety. Many of the hazards identified in health and safety plans for the field trials were associated with conducting heavy manual work from a wharf or vessel, occupational diving and the use of mechanical pumps (i.e. fuel and noise). The use of fluorescein as a chemical surrogate avoided many of the issues surrounding the use of hazardous substances, but such issues will not be avoidable if hazardous chemicals are used in response to a marine incursion.

In such a case, a comprehensive Health and Safety and Environment Plan (HaSEP) would be required, examining all aspects of the operation relating to the procurement, transport, storage, release and disposal of chemicals; occupational diving; the operation of vehicles and vessels; and any other work associated with the deployment, operation and retrieval of the system. Operational and logistic requirements that arise from the HaSEP could include, but would not be limited to:

- Barriers, signage and notification alerting the public or protecting them from potential hazards.
- Personal Protection Equipment (PPE) required for the specific class of hazardous substance being used e.g., overalls, gloves, boots, hoods, safety goggles and respirators.
- Ventilation and air muffs for persons working in close proximity to the pumps.
- First aid facilities to deal with exposure to chemicals e.g., eye wash and shower.
- Sack barrows and mechanical lifting devices.
- Facilities for the separate storage of flammable substances and oxidisers.
- The ability to contain and clean up any uncontrolled release of chemical i.e., spills or leakage from hose attachments.
- Fire fighting equipment.
- Hyperbaric facilities.
- Appropriate documentation and qualifications i.e. Material Safety Data Sheets (MSDS), approved handler and first aid certifications.

Costs of deployment of the system in response to an incursion will be determined largely by the scale of the response. The scale will influence the amount of time, equipment and chemicals required. Field trials indicate that the deployment of 6 x 6 m tarpaulin, steel girders and sandbags, plus treatment of encapsulated water is probably the largest unit area that can be feasibly undertaken on soft sediments. However, the amount of chemical and time required to reach the target concentration could be greatly reduced if the volume of water encapsulated by the system was decreased. This could be accomplished through the deposition of a 5 x 5 m steel rod pyramid onto the tarpaulin, with sandbags placed directly onto its base to seal the periphery in the same manner as was accomplished using box steel girders in the present trials (Fig. 4.1). The four sides of the pyramid would prevent inflation of the tarpaulin and would also enable it to be attached to a rigid structure. This would reduce the internal volume and increase the structural integrity of the system.

Figure 4.1 also presents the deployment of multiple units across a 12 x 12 m tarpaulin. Treatment of an area of approximately 100 m² could be accomplished through two successive treatments each using two 5 x 5 m pyramids (Figure 4.2). The treated areas encapsulated by the tarpaulin would not overlap during the first treatment, and an overlap would be required during the second treatment to ensure that areas of the seabed previously covered by sandbags were effectively treated. However, deployment of the pyramids during the second treatment would require that the pyramid structure interlocks at the corner and could only be accomplished if the vertical rods of the pyramid could be momentarily detached from the base.

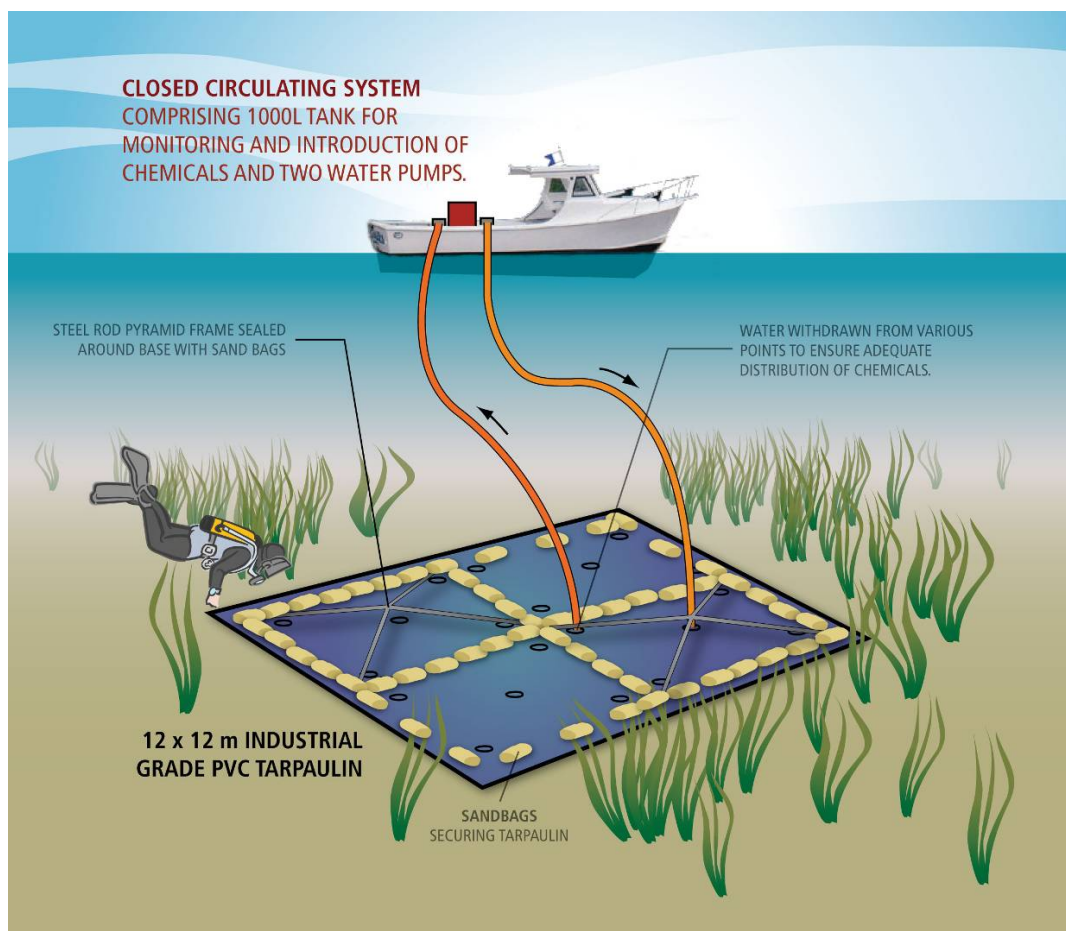


Figure 4.1: Deployment of the system scaled up to a 12 x 12 m area with the addition of a steel rod pyramid to reduce the encapsulated volume of water (not to scale).

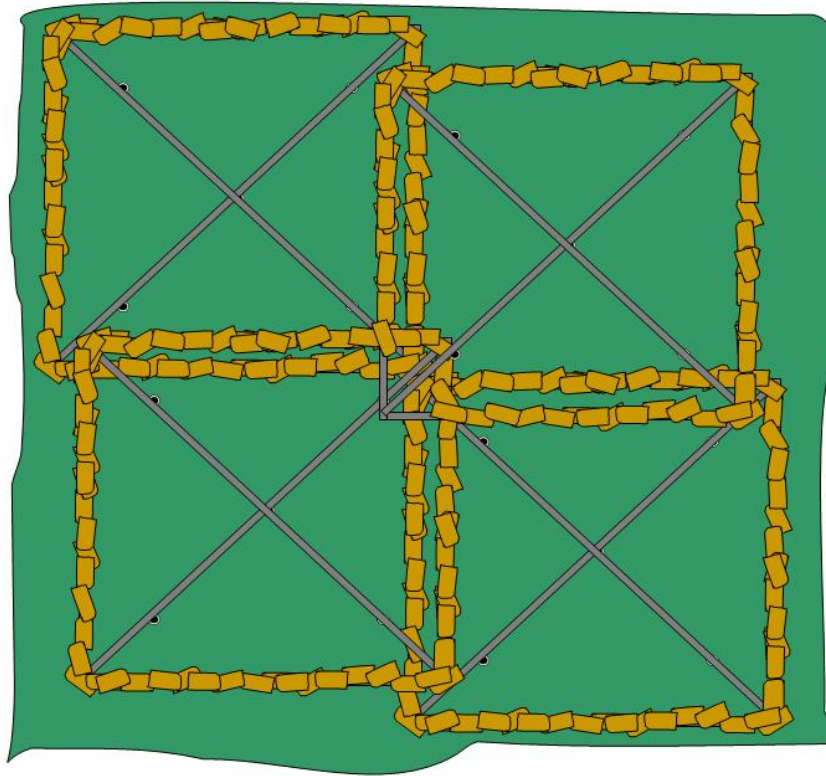


Figure 4.2: Proposed treatment pattern involving the deployment of two non-overlapping 4 x 4 m pyramids at the top left and bottom right, and subsequent deployment of overlapping pyramids to top right and bottom left.

Efficiencies of scale are likely as the pyramids and sandbags could be easily shifted between successive positions on the tarpaulin which will reduce the time required between successive treatments. Retention of the encapsulated waters between successive field trials also indicate that it may be possible to alternately monitor and circulate chemicals within each of the two treatment areas using a single header tank and pump system. However, the modular nature of the system means that the scale of deployment is largely limited by the available resources in terms of time and expense. The entire system could be replicated over a large area if treatments had to occur over a short period, but this would be expensive. The alternative treatment strategy of using one or two systems to systematically treat an area would cost less, but would take longer.

4.3 ECOLOGICAL, SOCIAL AND CULTURAL IMPACTS

Ecological, social and cultural impacts of an incursion response using the system will vary considerably between locations, the chemical used, extent of the treated area and the target taxa; with an assessment of such impacts informing decisions regarding the regulation of incursion response activities under the RMA 1996. Potential impacts of incursion response activities will not be limited to the chemical treatment of the target species, but may also impact on non-target species both within and outside of the containment area. Deployment of the system could also disturb the seabed and the effects of reduced water motion and light within the containment system could impact on species' ability to respire, photosynthesise and feed. The data presented here would better inform any assessment of the environmental,

social and cultural impacts of the deployment and operation of the containment and treatment system.

Unless exempted by the Biosecurity Act 1993¹, activities in the Coastal Marine Area (CMA) will most likely require resource consent before response actions can be undertaken. However, the rules determining what activities are permitted, discretionary or prohibited can vary between regional coastal plans and locations within each region. Immediate consultation with regional authorities, interested and potentially affected parties, and stakeholders would be necessary to facilitate a rapid response to an incursion.

An inert dye was used as a chemical surrogate in these field trials to avoid issues around the social, cultural and environmental impacts of the discharge of chemicals to the marine environment. Sites were also selected outside of sensitive areas such as mataitai, taiapure, marine protected areas or marine protection areas, consideration of which would obviously not be an option during an actual incursion.

4.4 THE USE OF HAZARDOUS SUBSTANCES IN AN INCURSION RESPONSE

The application of effective chemical treatments using the system depends largely on the ability to ensure that all target organisms have been treated with a lethal dose. However, treatment parameters are most often determined in the laboratory and are expressed in terms of a concentration and exposure time (i.e. LD₁₀₀). The concentration of chemical solutions used to calculate lethal doses in the laboratory are necessarily constant and tested in clean water on a limited numbers of subjects. However, the concentration of chemical agents in the field may vary considerably depending on the amount of dissolved organic matter (DOM), dissolved oxygen, suspended sediments, and the treated biomass of target and non target species (Boyd 1996, Kennish 1997, Williams & Schroeder 2004, Coutts & Forrest 2005). It may be necessary to add chemical throughout the treatment process to overcome the loss of chemical due to leakage and degradation.

Biologically inert tracers would still be a valuable means of determining if there are any leaks in the system, and when the system is completely mixed if a direct method of monitoring chemical concentrations was not available, or the chemical concentrations decreased rapidly during treatments. Tracers should, however, be selected that are not affected by the chemical agents used e.g., fluorescence may be significantly reduced at low pH and quenched by halogen anions such as hypochlorite (Flury & Wai 2003). Target organisms could be placed into the header tank and monitored throughout the treatment process to determine when a lethal dose has been delivered.

Potential release of hazardous substances (i.e. chemical agents and pesticides) to the environment is regulated under the Hazardous Substances and New Organisms Act 1996 (HSNO Act 1996), which would preclude the use of chemicals that have not been approved for specific use as a pesticide in the marine environment. However, approval can be sought from the Environmental Risk Management Authority (ERMA) New Zealand to specifically use chemicals for incursion response. Advance applications for the release of a hazardous substance in an emergency can also be made to ERMA New Zealand under section 47 of the HNSO Act 1996. Such approvals allow substances which do not otherwise meet approval requirements to be used for specific emergencies, including the release of chemical agents in an emergency response to a new organism. These mechanisms could be used to gain prior

¹ Biosecurity Act 1993, s7A

approval from ERMA New Zealand for the release of specific chemicals in an incursion response using the containment and treatment system.

4.4 TARGET SPECIES AND OTHER APPLICATIONS

A wide range of taxonomic and functional groups could be treated by the system provided that they can be encapsulated and contained by the system. This would not be suitable for large or highly mobile organisms such as fish and large crabs that are likely to escape from under the tarpaulin during deployment. However, sessile organisms and species with low mobility such as the benthic life history stages of angiosperms, algae, annelids, ascidians, bryozoans, coelenterates, echinoderms and molluscs could be effectively caught and contained by the system. Smaller epibenthic and epiphytic crustaceans, such as small crabs, amphipods, barnacles, isopods and ostracods could also be targeted by the system.

The system would be suitable for the application of non-chemical treatments such as hot and fresh water, but could be constrained by the amount of energy required to attain and maintain lethal temperatures and supply freshwater. However, the feasibility of such applications would be greater if the internal volume of the system is reduced.

Although field trials assessed the efficacy of the system when deployed specifically to marine subtidal soft sediments, it would be possible to apply the system in other environments and to different substrates. Incursions of non-indigenous freshwater species occurring on or in soft sediments, such as *Lagarosiphon major*, could be effectively treated by the system. Chemical treatments could also be delivered to structures that are easily encapsulated by a tarpaulin, such as marina pontoons and floating vessels. The effective treatment of large benthic structures, such as sunken vessels, would depend greatly on the size of the structure and the nature of the underlying substrate.

The efficacy of the system on uneven and hard substrates remains untested, but the establishment of an effective seal about the tarpaulin would appear feasible under such circumstances. However, the deployment to substrates such as rocky reef, cobble and boulder substrates could only be accomplished by using materials that conform more easily to the substrate than steel rod, such as sandbags, chain, sand-filled layflat hosing, and PVC bunds inflated with water.

5. Conclusions

The development, manufacture and testing of a prototype containment system has resulted in a fully operational system capable of delivering chemical treatments for use in response to incursions of NIMS. The system can be effectively deployed from land or vessel to subtidal marine soft sediment substrate and is capable of containing and re-circulating chemical treatments over a 5 x 5 m area to depths of 20 m. It could be easily scaled up to 12 x 12 m and also applied easily to other environments and substrates, such as freshwater, marina pontoons and floating vessels. Field tests of the prototype occurred in a sheltered harbour environment, however, where wave action and currents were minimal; and deployment in strong currents or wave action may be difficult.

The greater technical and operational understanding gained through the field trials mean that it is now feasible to further develop the system and overcome the challenges of deploying the

system on hard, uneven substrates and in more exposed conditions. The present system could be tested on a soft sediment non-indigenous species or indigenous surrogate to determine its efficacy when deployed against a target organism. Further work is also required to assess the risks and hazards the use of chemicals in marine incursion response present to health and safety, and the environment. Prior approvals for the release of chemical treatments using the system would greatly facilitate its immediate use in an incursion response, and likely aid in obtaining the necessary resource consent to undertake activities in the coastal marine area.

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