AUSTRALIAN INSTITUTE OF MARINE SCIENCE

Concept Design & Capital Estimate

Reef Restoration and Adaption Programme

15th February 2019

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SYNOPSIS

This Conceptual Design was developed in close co-operation with staff at the Australian Institute of Marine Science (AIMS) research facilities at Cape Ferguson, near Townsville. They are the leading scientific authority on the Great Barrier Reef (GBR) and are pioneering research in their renowned SeaSim research aquaria on possible solutions for prevention of the ongoing destruction of the corals by the forces of nature. Their work is particularly focussed on developing methods of biological support of the Reef corals to better withstand the ravages of coral bleaching caused by global warming and other atmospheric and marine effects. To this end they continue to research and develop systems for breeding and growing new forms of Reef coral species in controlled conditions that concisely replicate those that are emerging over the 2500 kilometre length of the GBR.

The purpose of the Conceptual Design is to build on the staff knowledge and facilities at SeaSim and to provide engineering concepts for the systems necessary at scale to grow and deploy new corals over the Reef, such that, to begin with, areas of greatest interest and popularity can be restored and can prosper under the rapidly changing environmental conditions of the 21st century.

A base case model concept is being developed to achieve three million healthy corals per year[1] (average 100,000 per day), employing as far as practical automated industrial production and deployment methods, based on existing systems where available, at sufficient scale to meet the required objective (Mead. D. 2018). The model is based on the objectives and data shown in the Basis of Design (BoD).

[1] Survival to the end of one year.

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PROJECT 301012-02454 - REEF RESTORATION & ADAPTION PROGRAMME

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1. INTRODUCTION

The RRAP has the objective to develop techniques that can be applied at sufficient scale to have a whole (or at least major parts) of GBR impact (Mead. D. 2018). The objective being to preserve high value "function" across as much of the system as possible. At a conceptual level the program is targeting to develop a suite of tools that:

1. Protect key ecological functions and economic and social values of the GBR;
2. Are logistically feasible to deploy at scale;
3. Are at a price point that it is affordable to deploy across entire reef scapes impacting a sufficient percentage of the GBR to retain core functional values.
4. Can be uplifted and deployed by the private sector to stimulate a Reef Restoration industry sector.

The program acknowledges that climate change mitigation is the highest priority, the closer the trajectory can be held to the Paris Climate Agreement the lesser the need for new interventions, and the increased likelihood that these interventions would be successful. Additionally, that traditional management methods, including water quality improvements and Crown of Thorns Starfish control will be vital.

It is expected that the investment case presented at the end of the concept design phase will read along the lines of:

- Forecast of increasing sea surface temperatures (+ ocean acidification and storms), leading to:
  - Projections of mass coral bleaching risk (as probability and severity), leading to;
    - Predicted consequences for Functional Reef State, leading to;
      - Predicted consequences reef Values, however if you;
- Invest in an R&D program of $x to develop abc Intervention Concepts (additional management options), then invest $y to deploy at Scale ABC, then;
  - New Functional State and Functional Value occurs, therefore;
    - Investing in $x + $y retains the difference in reef Functional Value (do nothing vs invest)
    - Stimulates the development of a new industry sector that can be exported globally

This study will be utilised to assess feasibility, development requirements and risk and future development costs for one of the intervention types being assessed under the program.

1.1 Background

A key are that the RRAP is seeking to assess is the viability of developing a large scale capability to re-seed reefs with corals. Corals are a primary underpinning product of both efforts to restore degraded areas, and efforts to improve bleaching resistance via increasing the rate of system adaptation (Mead. D. 2018). Irrespective of how the improved resistance to bleaching events is achieved. (assisted gene flow, selective breading, hybridisation, synthetic biology etc), larvae (Figure 1-3) from brood stock will require delivery to required locations at required numbers into appropriately prepared areas and substrates. The distributed corals need not be adults, they could be larvae, what will be important is that the method will need to deliver a certainty quantity that reach sexual maturity at the lowest possible cost (Mead. D. 2018).

There are three fundamental base case options available:

1. Direct larval dispersal (Figure 1-2- left)
2. Larval recruits on distribution device (Device Distribution) (Figure 1-1)
3. Juvenile corals (Figure 1-2- right)

For the base case engineering design, larval recruits on a distribution device is the method selected for this study (Figure 1-1).

Figure 1-1: (left) Close-up of SECORE's settlement substrates[2] that self-stabilize on the reef; mid) A diver with a tray of Seeding Units that are going be out planted onto a reef in the waters of Curaçao; right) Close-up of a SECORE Seeding Unit with golf ball corals (*Favia fragum)* growing on it[3] (SECORE INTERNATIONAL 2018)

Figure 1-2: (left) Larval collection. (right) Juvenile corals for deployment (diveSSI 2018, Hays. B 2018)

[2] First generation SECORE devices, made of concrete.

[3] http://www.secore.org/site/newsroom/article/sowing-corals-a-new-approach-paves-the-way-for-large-scale-coral-reef-restoration.159.html?IS4SSN=20802152&IS4BOOT=1525168733986

Figure 1-3: Capital Larval Creation (Russell. M 2017)

Figure 1-4: Reef egg-sperm bundles, or gametes (Alexandrea. P 2018)

1.2 Partners

The Conceptual Design is being developed in close co-operation with staff at the Australian Institute of Marine Science (AIMS) research facilities at Cape Ferguson, near Townsville. They are the leading scientific authority on the Great Barrier Reef (GBR) and are pioneering research in their renowned SeaSim research aquaria on possible solutions for improving resilience of coral reefs, in response to climate change and cumulative stressors. Their work is particularly focussed on developing methods of biological support of the Reef corals to better withstand the ravages of coral bleaching caused by global warming and other atmospheric and marine effects. To this end they continue to research and develop systems for breeding and growing new forms of Reef coral species in controlled conditions that concisely replicate those that are emerging over the 2500 kilometre length of the GBR.

To provide a base case coral scaling and delivery concept design at a Class 5 estimate level (±50%) that will be utilised to:

1. Quantify a "worst case" future deployment cost range for use in the Phase 2 investment case.
2. Determine the R&D requirements to further develop and test the base case concept during Phase 2.
3. As a production cost (techno-economic) model to enable identification of where future concept variations and/or "breakthroughs" will have the most impact.
4. As a base case model to compare alternative options against.

1.3 Concept Design

The Concept Design and Estimate described in this report are developed in conjunction with AIMS for the prospective large scale production and deployment of coral larval recruits suitable for placement on the Reef, in accordance with the Basis of Design (BoD), Section 1.1, item 2): Larval recruits on distribution device (Device Distribution) and generally as illustrated below in Figure 1-1.

The Base Case Facility is designed for the production and deployment on the Reef of 13 million corals in each of four annual cycles of 91 days. This is based on table 2.2 and Case Study 1 from the BoD and summarised in Table 1-1.

Table 1-1: Numbers required at each stage

Life stage	Days post spawn	Number of corals
Fertilisation	1	1,213,928,332
Larvae	2	1,092,535,499
Larvae to settle	5	983,281,949
Settlement	6	884,953,754
Choco tiles	20	159,291,676
Deployment	60	53,097,225
1 year	365	35,295,220
Corals reaching sexual reproduction	1500	3,000,000

For the purpose of preparation of the Concept Design and compilation of Capex and Opex Estimate the process layout in the on-shore hatchery facilities is based on the flow sheets for the AIMS SEASIM research facilities[4]. It is noted that these facilities and their associated breeding and aquaculture processes are constantly being refined and improved, primarily for the purpose of research. Therefore the actual large scale production processes that may be developed during the subsequent R&D Phase could be significantly different to those shown in this report. However it is considered that the layouts and associated cost estimates and contingencies provided herewith

[4] the facility is modelled and sized around the detailed knowledge AIMS have of the life cycle of the corals of the genus Acropora.

represent a realistic upper bound of potential costs, at to-day's prices, for construction and operation of the projects.

1.4 Design Objectives

The primary objective is to provide a Base Case coral production and delivery concept designs and a Class 5 (+ 50%) Capex and Opex estimate for a single facility. These will be used in the overall Concept Feasibility Study:

1. To quantify a "worst case" future deployment cost range for use in the Investment Case studies;
2. To determine the R&D requirements to further develop and test the Base Case concept during Phase 2;
3. As a production cost (techno-economic) model to enable identification of where future concept variations and/or "breakthroughs" will have the most impact;
4. Against which to compare alternative conceptual options.

1.5 Production Model

Like most manufacturing processes, it is not cost feasible to only have a single production run per year. One option we modelled during the Basis of Design development, is that we have coral larvae available more than once per year. Two fundamental production models assessed:

- Multiple sequential cycles each year, ultimately settling on four by 3-month cycles. The implication being that three of the cohorts would need to be spawned out of season and then then the recruits cycled back to the current temperate/light profiles prior to departing the facility for deployment
- A single annual breeding cycle in combination with the recruits micro-fragged every 3 months with a progressive deployment through-out the year, the cycle then repeating the next year. The micro frags being deployed of similar size to the 30 to 90 day recruits from option 1

Modelling indicated that the methods would provide similar output numbers for the same sized facility and that both need to be further investigated and developed going forward. For design and costing purposes the multiple sequential cycle option was selected.

1.6 Design Cases

The design concept and estimates were originally intended to be developed for two cases, based on year-round spawning (i.e. four quarters) as described below. However, it was subsequently decided by AIMS that the Distributed Case would not be developed in this report, but is included for future reference if required during Phase 2 R&D.:

Base Case

This is a single facility that would produce and deploy corals from one central location on shore. This is the principal case, upon which the concepts and estimates for the technologies and methodologies for production and deployment are based.

Project management, co-ordination and control would be based at this site.

Distributed Case

In this case production and deployment are based in three regional locations on shore, with the combined total throughput the same as for the Base Case. It was originally thought the case study described in the BoD of 100,000 juvenile corals per day (as survivors at the end of 1 year) could be split over 3 sites. It is currently thought that this would serve only the Central section of the reef, centered on Townsville, as shown in Figure 3-1. Therefore, the Distributed Case is not addressed in the following Sections of the report.

Overall project management, co-ordination and control would be centred on one of the three sites.

This Case would have been used in the overall Concept Feasibility Study for comparison with the Base Case.

In both cases the on-shore facilities are largely autonomous, supported by central services functions. For deployment to the Reef the marine resources could be shared between the distributed locations, depending on Reef deployment sites and their sizes, and on scheduling requirements for seasonal and weather conditions.

1.7 Automation and Innovation

Processes that can benefit the most from automation are usually those that are time critical and the most labour intensive. For this project these processes occur at the commencement of production in the on shore hatchery and at the deployment of juvenile corals offshore, on the Reef. Other lesser benefits can also be realised on some of the intermediate processes, such as packing for delivery of juvenile corals to the docks that in aggregate could lead to comprehensive automation of the whole process, resulting in significantly reduced human intervention.

Some of these potential opportunities are explained and tabulated in this report for research and development in Phase 2 of the RRAP Program.

The following items of Automation are considered necessary:

1. Fertilisation tanks management and transfer to Larval Rearing tanks (onshore)
2. CHOCO board placement in Settlement tanks, removal of settled boards and transfer to Transport tanks (onshore)
3. Life support system during transport
4. CHOCO board breaking and erection on deployment device (offshore)
5. Field deployment of the assembled deployment devices (offshore)

1.8 Concept Design

The following Sections detail the Input Data and how it has been developed into the Concept Design and Cost Estimates for the Base Case.

1.9 Value Engineering

During the concept design phase, a review was carried out of the key drivers for the physical/biological/engineering inputs and any key issues that need to be accommodated (the BoD document). Options were also identified for any alternative approaches to the design which may enhance economical performance and execution benefits. These options are shown in .

1.10 General

This document presents the Concept Design for the Reef Restoration and Adaption Program for the Aquaculture Program. The facility will provide a reliable/alternative source of corals that will have a material impact on any restoration efforts on the Great Barrier Reef. The capacity of the facility, together with the deployment offshore, is designed to produce and deploy 36 million healthy corals annually.

Some studies critical to development will be completed by mid-2019 when RRAP delivers the results of this study to the Australian Government.

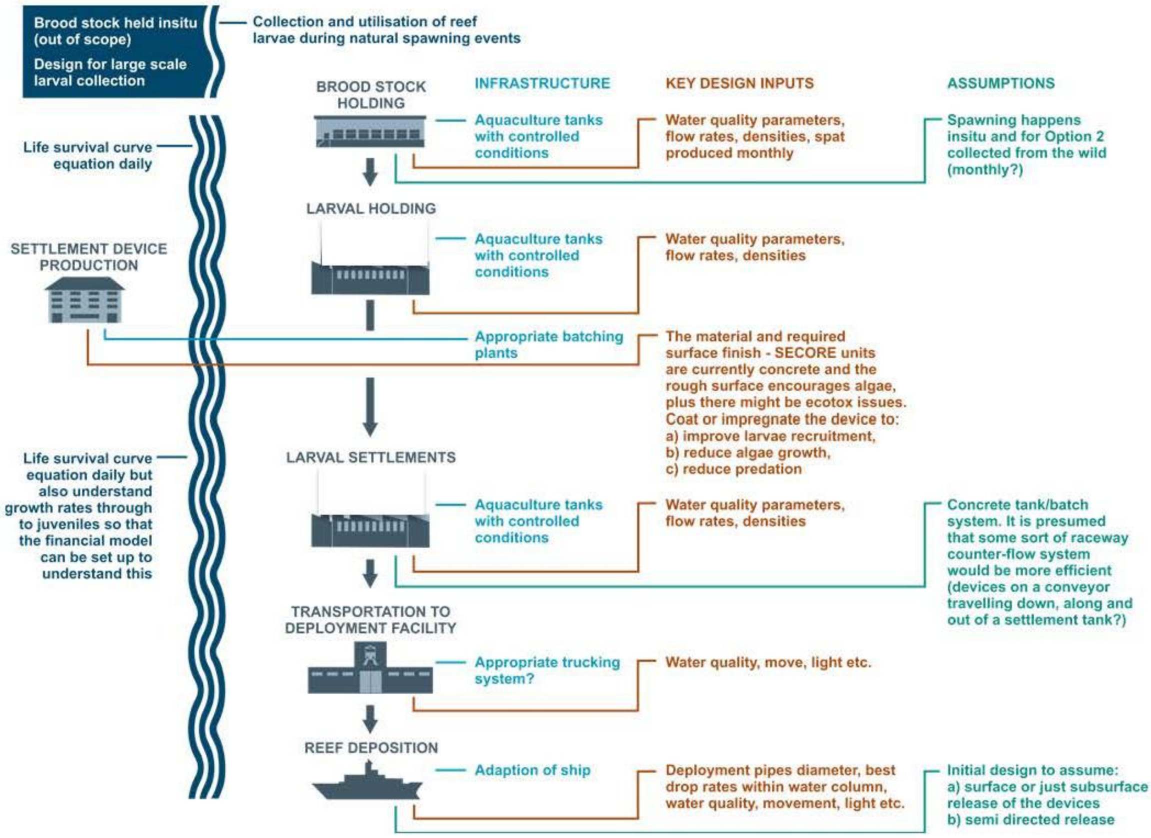


Figure 1-5: Concept inputs

2. INPUTS GENERAL

Detailed input data for the Concept Design and Estimate is provided in the BoD, sections 2 to 9. The following extracts from the BoD summarise the basic physical data upon which the conceptual layouts for the onshore hatcheries and the offshore deployment vessel fleet are based.

2.1 Biological Inputs

This Concept design focused on faster growing corals in the first instance. The genus for modelling was Acopra. SEASIM data has been used based on successful spawning over numerous years for the survival rates from spawning to settlement, which is considered higher (survival rates) than the natural or aquaria produced spawn in the literature. This has resulted in two equations as detailed in the Basis of Design Section 2.3.1. It is accepted that further design work would be required to facilitate slower growing corals where a micro fragmentation and coating approach may be needed in order to achieve acceptable survival rates.

Broodstock development and management of genetic diversity is assumed to be managed separately to this design, however it was assumed that a minimum of 50 colonies would be held for genetic diversity[5]. Based on the broodstock tank numbers (105) detailed in Table 3-1 of the Basis of Design, with a stocking density of 24 corals per tank, gives 2,520 coral colonies in each facility, far in excess of the desired colonies to maintain genetic diversity, even if used for multiple species.

2.2 Deployment Device

At the outset it was envisaged a SECORE type deployment device would be utilised (Figure 1-1). During the development of the BoD it became evident for the number of required corals, the pure volume of packing these wet with attached corals, along with the automation preference a different deployment concept was required.

A device proposed by Andrea Severanti (AIMS) was adopted which had the recruits on a board (aka CHOCO Tile) and this separate from a deployment device (erected offshore). Under this scenario the settlement media (CHCO Tile) was placed on the floor of the settlement race way tanks with 100% coverage (Figure 4-8). The larvae are then pumped to a raceway system to settle on the CHOCO Tiles (made up of smaller CHOCO boards, similar to a chocolate bar) included at the bottom within the raceway systems (BoD Figure 7-1). The benefits of this was the media could be removed as a full sheet (Figure 4-13) and packed in Offshore Transportation Tank (Figure 5-2) and only erected into a deployment devices offshore (Figure 5-4).

Modelling of this approach showed significant less volume had to be transported as the deployment device could be dry packed for transportation and only the CHOCO Board had to be in Offshore Transportation Tank with a packing density suitable for survival (Table 2-1).

[5]Minimum number of colonies per species = 50 (divided by spawning events) i.e. 12.5 if 4 events per year.

Table 2-1: Erected Device

Choco tiles (3x) litres	0.00353
Deployment Structure (dry) litres	0.15
Packing factor % (for circulation)	500
Volume (litres)	0.89
number of devices per m3:	1127
number of devices per crate wet:	6716
Total deck space m2 reqd for all deployment devices	11782

2.3 Process Flow Diagram

The flow diagram is taken from the BoD Section 2.2 and is shown in Figure 2-1 below. This is the basis for the adopted process layout and, because of the large number of corals required for each quarterly cycle, the production is split into six identical Process Facilities or buildings.

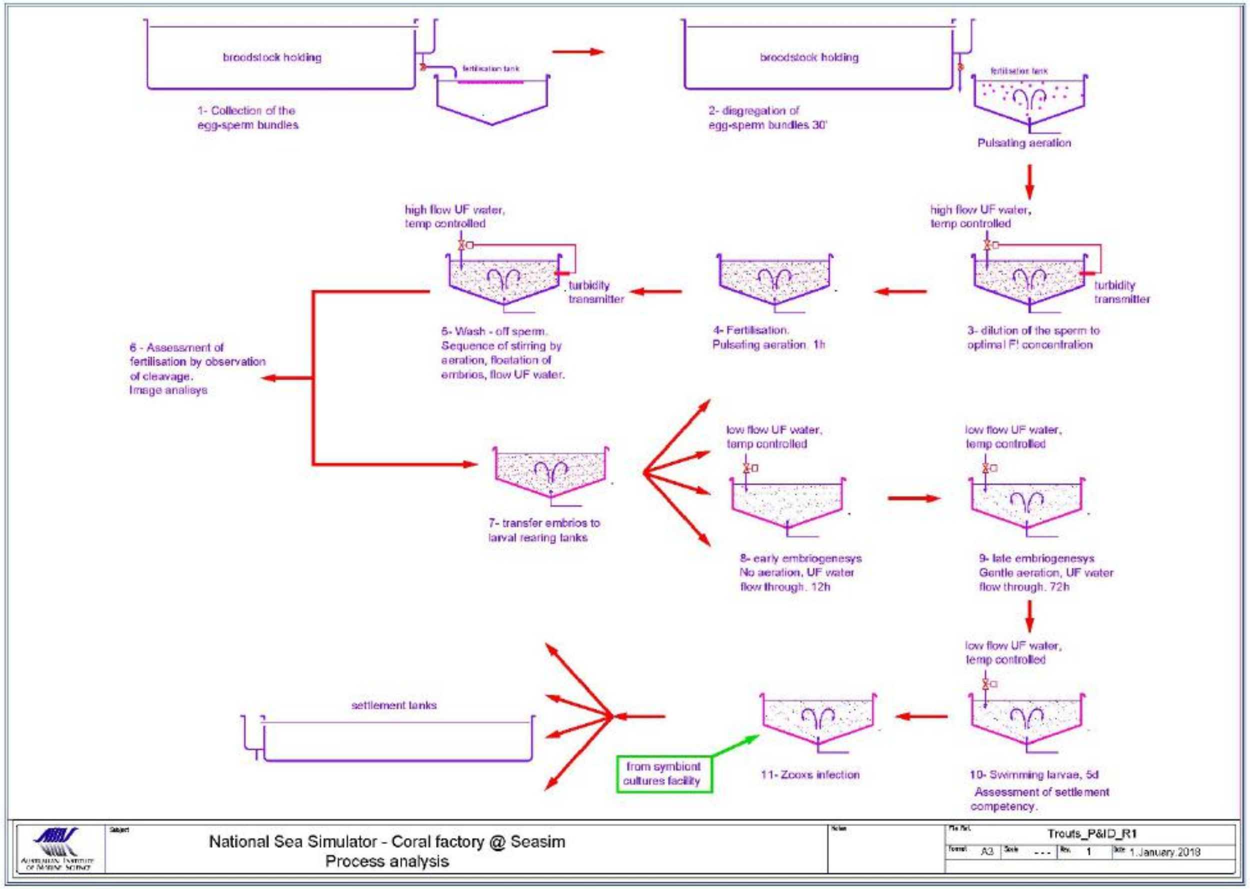


Figure 2-1: Process flow diagram of the production process for coral recruits of a typical species of Acropora.

2.4 Process Tank Sizes and Numbers

Table 2-1 Process Tank Details summarises the tank internal sizes and nominal total minimum numbers of tanks per cycle, as shown in the BoD Sections 3, 4, 5 and 7. The numbers may be rounded up, to suit the adopted number of production lines.

The footprints of each tank that are adopted for the purpose of determining the arrangement of the process layouts are shown in Section 4.3.1 of this report.

Table 2-2: Process Tank Details (internal dimensions) [6]

Tank	Length mm	Width (diam) mm	Footprint area M2	Number of tanks	Total floor area all tanks M2.
Broodstock	3900	1900	7.41	104	771
Fertilisation*	3200	2500	8.00	208	416
Larval	1800	2200	3.96	910	3,605
Settlement	3850	2090	8.05	1383	11,126

Note: Spawning takes place almost simultaneously in all tanks over a short period. On average at least 2 fertilisation tanks are required to accept stock from each of the Broodstock tanks at any one time. The number of Fertilisation tanks assumes that 50% of the stock will spawn at more or less the same time.

[6] At this stage Fertilisation and Larval tanks are cylindrical

The Broodstock tanks are permanently in use, holding one species each. Therefore, the minimum number required will be 104.

The fertilisation, larval and settlement tanks will be re-used for each successive cycle.

2.5 Transport Tank Sizes and Numbers

Table 2-3 summarises the tank internal sizes as shown in the BoD Section 8. The number of tanks required depends on the transport and shipping trip cycle requirements and will vary according to where on the Reef the juvenile corals will be deployed.

Table 2-3: Transport Tank Details (internal dimensions)

Tank	Number	Volume litres	Length mm	Width/diam. mm	Depth mm
Transport	15	4000	3200	1200	1000

Note that the dimensions of the Transport tanks are adjusted form those shown in the BoD to match the configuration of the settlement media in the settlement tanks.

The tanks will be re-used throughout each cycle.

2.6 Estimating

Summaries of the Capital and Operational cost estimates, to an overall accuracy of +/-50%, are contained in Section 6, together with explanation of the procedures adopted in their compilation. The total cost per deployed Device is also shown, with and without Amortisation.

Detailed information on the process equipment is provided in the relevant sections of the BoD.

3. SITE LOCATION

The Distributed Case described below was subsequently deleted from the scope of this study but is included in the report for future reference if required during Phase 2 R&D.

Because of the diversity and length of the Reef, it is envisaged that in practice production could be split and sited in three separate dispersed locations, such as Townsville, Cairns/Port Douglas and Rockhampton, with two Process Facilities at each hatchery. The benefits or otherwise for Distributed production facilities will be addressed in the financial modelling. The precise number of facilities and trains and their geographical locations will be determined later during Phase 2 of the RRAP.

The locations and distances that are assumed for the Concept Design and Estimate are shown relative to the Reef in Figure 3-1 and are summarised below:

Base Case

Location: Townsville (Bowling Green Bay)

Indicative road distances for transport of juvenile corals to the existing loading docks are as follows:

- At Townsville: 55km (this report)
- Between Townsville and Port Douglas: 420 km
- Between Townsville and Rockhampton: 725 km

Distributed Case

Three Locations are selected to account for geographic differences encountered on the Reef, as follows:

- Cairns/Port Douglas
- Townsville
- Rockhampton

Road distance to the local existing loading docks: 50km

It is assumed that transport of juvenile corals from the Base Case at Townsville will be by road to docks at Port Douglas and Rockhampton. This assumption facilitates comparison with the distributed hatcheries at these locations. In practice, for either the Base Case or the Distributed Case, loading of deployment vessels might be at existing or new docks that are closer to the deployment sites, should this prove to be a more cost-effective use of road transport and deployment vessels. No further consideration .

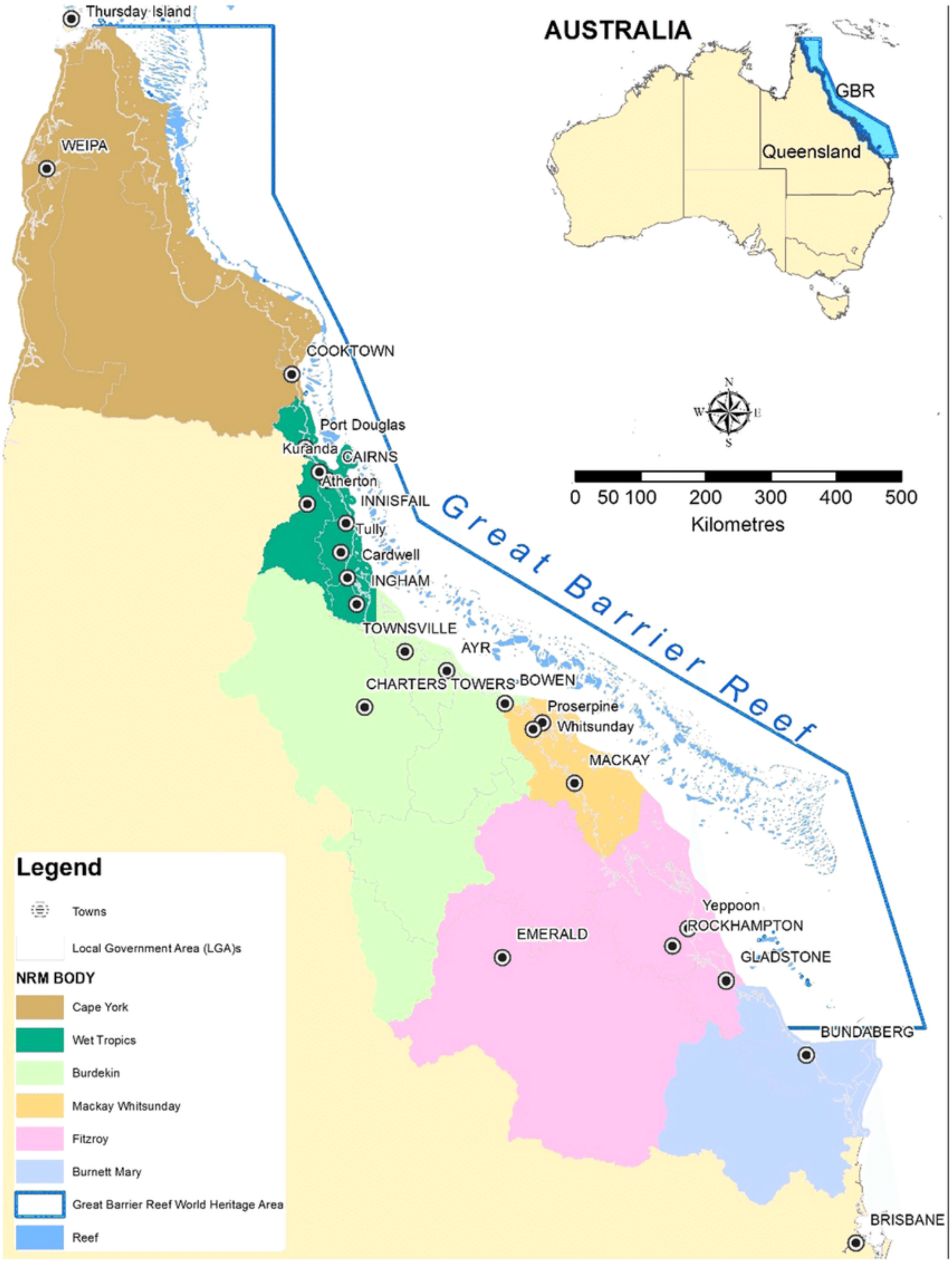


Figure 3-1: Locations of Onshore Facilities (Cairns, Townsville, Rockhampton) Relative to the GBR (Marshall. N, Bohensky. E et al. 2016)

The Base Case facility is proposed to be located in the Bowling Green Bay (east of Cleveland Bay), immediately east of Townsville, Australia. A chart of the onshore/offshore area is shown in Figure 3-2 and Figure 3-3 respectively and represented by the tear dop.

Figure 3-2: Cape Ferguson, about 50 km east from Townsville's CBD (tear drop)

Figure 3-3: Nearshore bathymetry near the proposed facility (tear drop)

4. ONSHORE FACILITIES

The following sections describe the overall site layout, including the production support facilities and services. This is followed by high level descriptions of the proposed process facilities, including packing and loading of juvenile corals for transport by road to the deployment loading dock. The decriptions are supported by concept sketches as illustrated[7].

4.1 Base Case Site Layout. Reference Figure 4-10 - SK0001

A large area is required to accommodate the number of tanks necessary to meet the target deployment rate of new corals on the Reef. Studies indicated that production would require several similar facilities of manageable size, as discussed in Section 4.3, and an optimum number of six Process Buildings was adopted for the purpose of Concept Design and Estimate. The six facilities would operate autonomously, independently of each other, which would allow progressive project implementation and, for the purpose of this report, facilitate adaption of the concept layout for the Distributed Case, with two Process Buildings at each site (later deleted from the scope of the report).

The number of buildings and the building floor dimensions of 104m x 76m were primary consideration in developing the concept design of the site layout, together with the following considerations of process, process support and administration requirements:

4.1.1 Civil Works

- Adequate roads, maneuvering areas and access to Transport Tank loading areas for ISO container transport vehicles, possibly with trailers;
- Adequate areas for staff parking, alongside service buildings and process buildings;
- Adequate areas for contingency space that might be required, both during Phase 2 development and as a result of early production experience;
- Seawater supply, filtration and storage;
- Services reticulation and fire protection;
- Surface water drainage;
- Area and street lighting
- Site Security;

[7] For details of tank dimensions and other information required for execution (not repeated in this document), reference should be made to the current revision of the BoD. Some illustrations of existing SeaSim facilities have been copied from the BoD and are included in the sections below to provide context to the process descriptions.

- Adequate areas for landscaping as a green industrial area.

4.1.2 Process

- Each of the six facilities to function autonomously;
- Alignment north – south on the short axis of the Process Buildings, to maximize sun exposure for the Settlement tanks..

4.1.3 Process Support Services

- Security and redundancy of process water supply, electrical power supply, IT and waste process water services;
- Two interconnected process seawater storage lagoons and intake works, pump house, filtration house, buffer storage tanks and reticulation;
- Fresh (and fire) water buffer storage and reticulation;
- Two process building waste water and storm water ocean outfalls or infiltration basins;
- A process services centre to support the six production facilities, including central workshops and bulk stores;

4.1.4 Support Buildings

- Administration;
- Cafeteria and conference;
- Process services centre;
- Training and education;
- Interpretive centre and tourism;
- Fire station and clinic;
- Security and gatehouse;
- Building services;
- Comms and IT.

The resulting site layout measures approximately 816m long by 458m wide, about 38 hectares, excluding the seawater gravity intake works and the process waste and surface water outfalls. The site generally is given a slight fall from south to north, to reflect the change in floor levels within the process buildings and to assist with surface water drainage.

4.2 Distributed Case Layout

This layout has not been considered in this study but generally could comprise two process trains of the 6 presented, together with appropriately scaled support facilities and services.

4.3 Production Facilities[8]

4.3.1 Process Building Layout

Each of the six Process Buildings (six in the Base Case and two each in the Distributed locations) is a self-contained factory with a capacity to produce one sixth of the annual requirement of juvenile corals, ready for transport to a dock for deployment on the Reef. Broodstock tanks are provided to supply one year's production, whilst the Fertilization, Larval Rearing and Settlement tanks are re-used for each quarterly cycle.

A key driver for determining the required size of the building is the number and size of the process tanks and their associated footprints, which include allowance for minimum 800m wide footways and adjacent life support systems. The footprints used in determining the process layout for each building are shown below in Table 4-1 which summarises the dimensions of the footprint of each tank and the total minimum floor area required for each tank.

Table 4-1: Tank Footprints and Floor Areas.

Tank	Length mm	Width (diam) mm	Footprint area M2	Number of tanks	Total floor area all tanks M2.
Broodstock	3900	1900	7.41	104	771
Fertilisation*	1400 (diameter)		8.00	208	416
Larval	1400 (diameter)		3.96	910	3,605
Settlement	3850	2090	8.05	1383	11,126

Note*: The original concept envisaged mobile Fertilisation Tanks, as shown in the Process Flow Sheet. However, for the purpose of the Concept Design and in discussion with AIMS this was subsequently changed to two fixed tanks for each Broodstock tank.

Each building comprises three steel portal frames that span north-south. All floors are concrete and production floors are sealed with industrial grade epoxy coating.

[8] Reference Figure 4-11 and Figure 4-12, SK0002 and SK0003

The production floors are on two levels, as shown, and there are two raised suspended floors at the south end, supporting the Broodstock tanks and Fertilisation tanks. Floors levels are shown in Table 4-2.

Table 4-2: Process Facility Floor Levels

Area	Floor Level mBD[9]
Settlement and Packing	0.0m
Larval Rearing	+1.5
Fertilisation	+3.5
Broodstock Holding	+4.0

The southern portal is enclosed and houses the Broodstock, Fertilisation and Larval tanks. The Broodstock area is partitioned into four discrete areas that can each be independently climate controlled, whilst the Fertilisation and Larval areas are all contained in a single climate controlled area. Access between sections is provided through PVC strip doors. The southern half of the roof comprises translucent sheeting with remotely controlled retractable shade cloths. The southern half of the roof is sheeted and supports solar pv panels that supplement the grid power supply.

The central portal covers the Settlement tanks and has translucent roofing, together with internal adjustable shade cloth blinds. The sides are open and along each side of the process area there are office, laboratory, amenities and process service demountables, together with wide access ways that are ramped at the step in floor level between the Larval and the Settlement tanks.

The northern portal also has translucent roofing and covers the Transport tank storage, packing and road transport loading area. The sides are open and along each side are office, workshop and stores demountables.

Sliding door access is provided at both sides of the building, for Broodstock delivery. Wide sliding access doors are provided at the northern end for container vehicles that carry the juvenile coral Transport tanks to and from the marine loading dock. Personnel and emergency access is provided at the southern end of the building.

All waste process and flushing water is directed and collected in grated deck drains in the Process Areas. These are connected by underground dedicated drainage pipework to the disposal system.

Security is provided by internal and external CCTV and card entry facilities.

[9] Note: BD is Building Datum

4.3.2 Process and Production

Overall Layout of Process

Each of the six Process Facilities operates independently of the others. Therefore if production is interrupted in one facility, the others are not affected. Independent facilities also are sectioned in modules, and the facilities are segregated, reduces the risk of parasites or diseases to spread to the whole production.

The basic flow diagram upon which the process layout is based is in accordance with the BoD Section 2.2 and as shown above in Section 2.1,

The layout is based on gravity transfer between the four stages of the process:

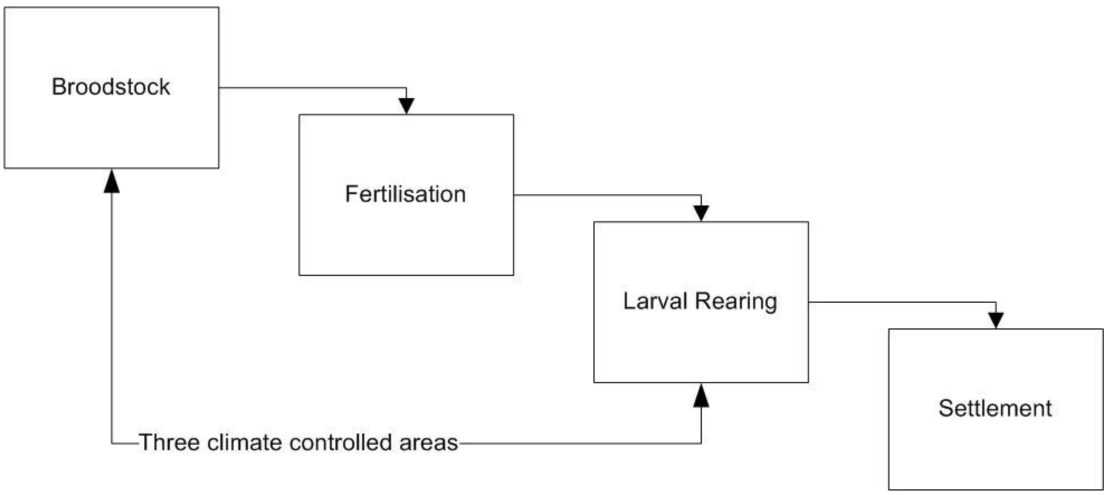


Figure 4-1: A typical production line sequence

Figure 4-1 & Figure 4-2 are explained as follows:

There are 20 production trains located in parallel across the building, covering a width of approximately 89 metres.

Broodstock is delivered in transport tanks and transferred as required to any of 20 Broodstock Holding tanks which are located at the high level on the Broodstock Platform. After spawning, which typically happens few hours after sunset, the floating gametes bundles are skimmed off the Broodstock tanks into the adjacent Fertilisation tanks on the Fertilisation Platform. Newly fertilised embryos are transferred to the Larval Rearing tanks.

The lines of Larval tanks align with 20 lines of six pairs of Settlement tanks, to which Larvae are transferred as required by gravity through a pipework system. Typical cross sections through the process lines are shown in Figure 4-12.

After several days (typically 5 to 8 for Acropora sp.) in the larval tanks the larvae are free swimming and competent to settle. Then the larvae are transferred by gravity to the Settlement tanks, where the settlement substrate is positioned to maximise the settlement surfaces. The settlement happens over few hours on the appropriate substrate.

It follows full metamorphosis and the controlled infection with symbiont zooxanthellae.

The following 3 weeks are considered the minimum time interval necessary for the early growth and optimization of the survivorship rates.

After this time the larvae are in batches transferred by a robotised transfer system to the deployment Transport tanks in the Packing Area, where the tanks are placed in skeletal ISO containers that are then loaded onto road transport for delivery to the marine loading dock.

Process Equipment

Process trains are grouped in four discrete Modules of five 5 trains each. For the Broodstock and Fertilisation tank areas the process equipment is located on the ground floor, directly below the tank areas. For the Larval and Settlement areas the equipment for both is located between the respective areas

Functions such as the central supply to all modules of ultra-filtered chilled and hot water, low pressure air etc, distribution boards, process control and logging are also located below the Broodstock and Fertilisation platforms at the south end of the Process Facility. LPG for water heating is stored nearby in pods, outside the south end of the Process Facilities

Based on the experience at SEASIM, the key process functions in each of the modules are all duplicated on a duty and stand-by basis. Wherever practical, piping and cables are run overhead on racks and the floor kept clear for ease of cleaning. All the tanks are custom-made moulded fibreglass, similar to those at SEASIM. The majority of process pipework is uPVC, including fittings.

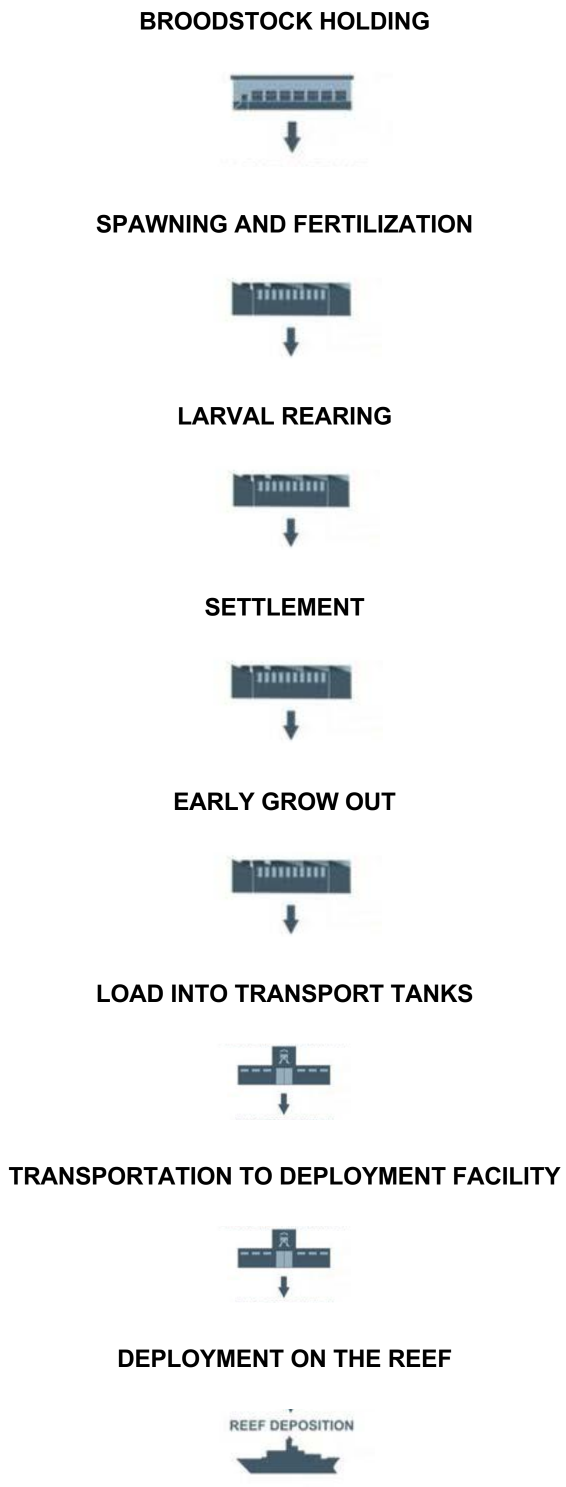


Figure 4-2: Production Sequence

As in the existing SEASIM facility, the artificial lighting, tank water conditioning, circulation and replacement are managed by a pre-programmed control system. This system also manages and controls all process monitoring and data logging functions. The control centre is located at the south end of the building, beneath the Broodstock Platform.

4.3.2.1. Broodstock Holding Tanks.

Broodstock is sourced externally from other RRAP projects and is delivered in specially equipped transport tanks at the Broodstock Reception Entrance. These tanks are unloaded by battery warehouse stacker and raised to the high level Broodstock Platform, where they are then moved manually by trolley along the platform to the designated Holding tanks, for manual transfer of the stock.

2.8 m long Broodstock tanks are located in parallel across the building on stands, with 3 metre wide walkways between; a 900mm wide walkway is provided at the south ends of the tanks, for transfer of the delivered stock transport tanks. Once the broodstock is sourced, either from the wild of from other selection process the involves other area of RRAP, is held long term, and used year after year in the production facility. Tanks are assumed to be similar to those already in use at SEASIM, as shown in Figure 4-3.

Figure 4-3: Typical Broodstock Holding Tanks

The Broodstock tanks are designed to allow efficient skimming of the surface for quick and effective harvest of the egg-sperm bundles at the time of spawning. The skimmed gametes are delivered to the Fertilisation tanks. Refer to the concept shown in Figure 4-4.

Natural lighting is provided as described above, supplemented by suspended controlled overhead artificial lighting as required and depending on the time of year of spawning.

4.3.2.2. Automation of the Broodstock Processes

The development of sensor system to replace human intervention in the observation of the spawning and skimming activities and timing of transfer to the Fertilisation tanks is still in the early stages of research and could prove problematic in the automation of this activity within the required timeframe.

However such a system could be retro-fitted and integrated into the control system, including integration with the fertilisation process and transfer to the Larval rearing tanks, at a later date.

4.3.2.3. Fertilisation Tanks

The 924 litre Fertilisation tanks hold the spawned stock for up to two hours prior to transfer of the fertilised stock to the Larval Rearing tanks. Two tanks are required at each Broodstock tank and are located at the lower fertilisation platform level to allow gravity transfer from the Broodstock tanks, over the directional chute. Each tank is connected to an insulated and circulated supply of temperature controlled and ultrafiltered seawater, and to a low pressure air supply. Stock density measurement and control is assumed to continue with the present manual system, however automation of these functions by the use of suitable turbidity sensors is a probable development prospect.

Consideration was given to the use of mobile fertilisation tanks to deliver spawned stock to selected Larval tanks in any of the 20 production trains, which might be distant from the Broodstock tanks. However this concept was deferred for further possible research and development and the present system of manual transfer by bucket has been retained. A carousel system that traverses across the 20 production lines is envisaged, to assist with movement of buckets to the selected Larval tanks, as shown in Figure 4-4.

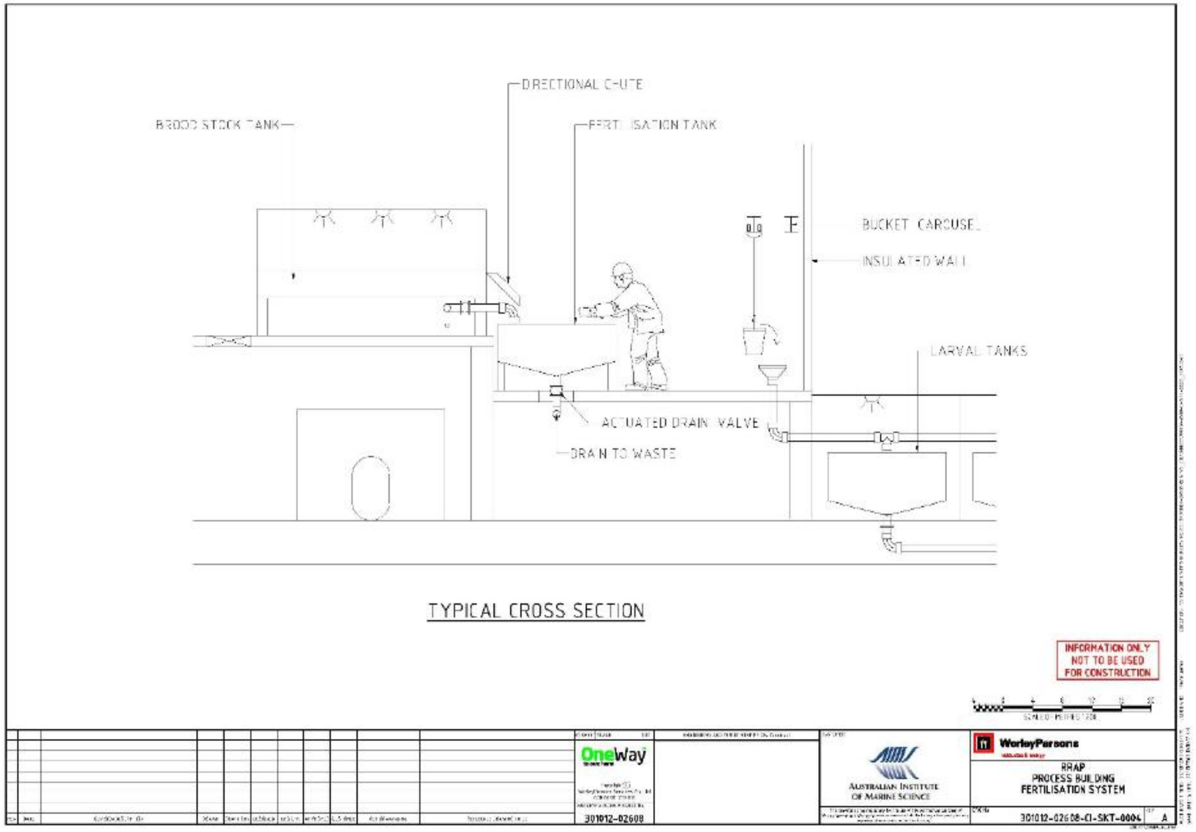


Figure 4-4: Conceptual Fertilisation Tank.

4.3.2.4. Automation of the Fertilisation Tanks Processes

Prospective automation includes sensing and controlling the required stocking density, sperm density during fertilization and dissolved oxygen concentration as well as other water quality parameters during the fertilization process.

Sequences of agitation, rest and rinse in UF water will deliver 2-4 cells embryos ready to be transferred to the larval rearing tanks. levels in the tanks. Pre-programming of transfer of spawned stock to the selected Larval tanks might also be considered, as part of automated execution of the transfer process.

4.3.2.5. Larval Rearing Tanks

The larval tanks will hold the larvae from broadcast spawners for several days, until they are competent to settle. Settlement assays will be conducted by operator, with possibility to automate the procees at later stage.

When the larvae are competent to settle they are transferred to the settlement tanks by actuating a sequence of automatic valves.

The 910 litre tanks are mounted on stands and grouped in four pairs at each production line, generally as shown in Figure 4-5 below and Figure 4-11. Spawned stock is transferred from the Fertilisation tanks by buckets, which are manually emptied into a funnel at the selected production train. Tanks are filled from the funnel through a central header pipe with branches to each tank. Remotely actuated valves, three for each pair of tanks, are manually selected to fill the required Larval tank. .

Figure 4-5: 70 litres larval rearing tanks in SeaSim. See Figure Appendix A-9-4 for 500 litres tanks for stock cultures. The proposed larval tanks are designed around the same principles, with 1400mm diameter, and 900 litres volume.

Tanks are emptied through valved branches to a central header pipe that transfers larvae by gravity to the Settlement tanks. Remotely actuated valves, one per tank, are manually selected to empty the Larval tank and to fill the required Settlement tank. The supply and drain header pipes can be flushed to waste if necessary.

As for the Fertilisation tanks, stocking density measurement and control is assumed to continue with the present manual system. However automation of dilution and stock density control by the use of suitable turbidity sensors is a probable development prospect.

4.3.2.6. Automation of the Larval Rearing Tanks Processes

The development of sensor system to replace human intervention in the observation of the larva and timing of transfer to the Settlement tanks is still in the early stages of research and could prove problematic in the automation of this activity within the required timeframe. However such a system is believed to be feasible and could be retro-fitted and integrated into the control system at a later date.

Pre-programming of transfer of stock to the selected Settlement tanks might also be considered, as part of automated execution of the transfer process.

4.3.2.7. Settlement and Transport Tanks

The 3.2m long Settlement tanks hold the “newly settled corals”, or the “coral recruits” for up to 84 days. The tanks are mounted on stands and are grouped in six pairs at each of the 20 production lines, generally as shown in Figure 4-11. A typical settling tank installation is shown in Figure 4-6 below. Tanks are filled from the Larval Rearing tanks through the central header pipe with valved branches to each tank. Remotely actuated valves, three for each pair of tanks, are manually pre-programmed to fill the required destination tank from each Larval Rearing tank. The supply header pipes can be flushed to waste if necessary.

Conditioned seawater is continually circulated and changed up to five times per day. When the settlement process is complete and media has been removed, tanks are emptied through valved branches to a central header pipe that discharges to waste. Remotely actuated valves, one per tank, are manually selected to empty the selected tank.

Figure 4-6: AIMS Townsville, SeaSim Open Plan External, showing holding and rearing tanks under translucent roofing.

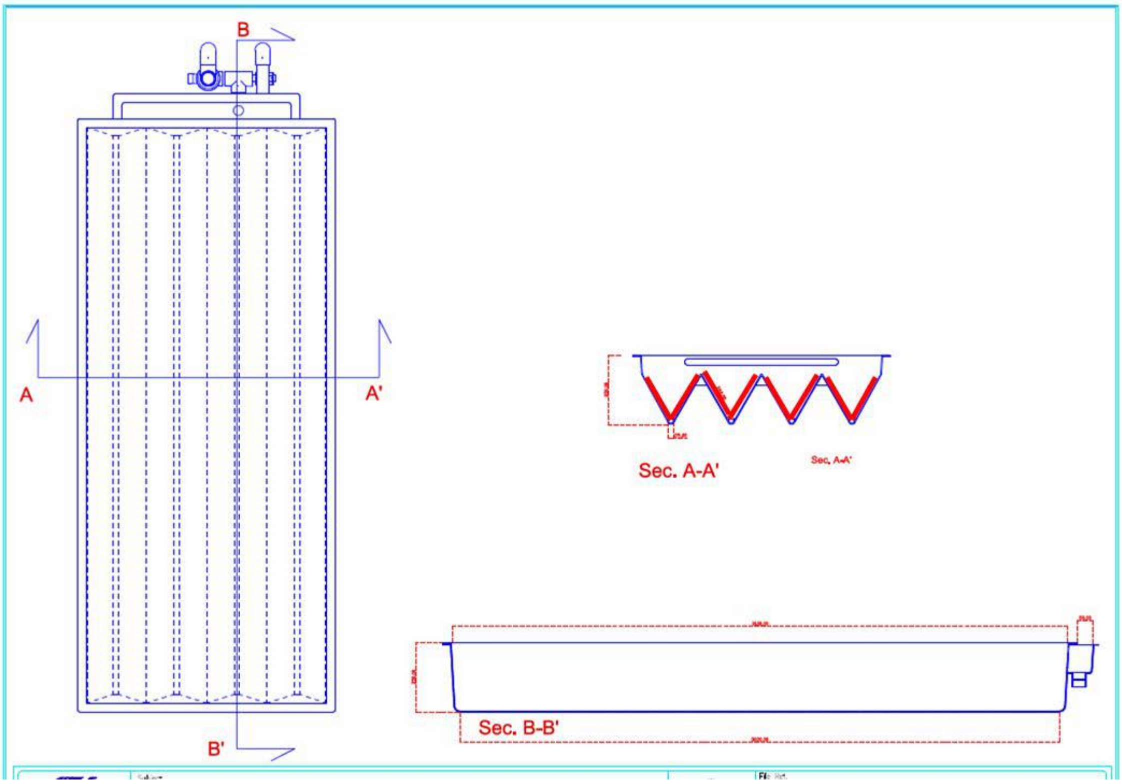


Figure 4-7: Settlement Tank.

The configuration of tanks and boards is based on a concept proposed by AIMS. Each tank contains 80 CHOCO boards, each comprising 400 tiles. The boards are hinged together along their long edges in eight rows of 10 boards to facilitate removal from the tank, as shown in Figure 4-8. The 80 boards of settled juvenile corals are removed in one operation by a robot Cartesian picker mounted on a carrier that transfers them to a Transport tank at the end of the production line. A seawater misting system mounted on the picker ensures that the juvenile corals are kept wet during transfer to the Transport tank. A typical industrial Cartesian picker arrangement is shown in Figure 4-9 below and a conceptual diagram of the proposed system is shown in Figure 4-13. A single mobile picker moves between production trains and has the capacity to transfer all the quarterly production of Choco boards into the Transport tanks. In practice it may prove feasible for a single picker to service the packing area in more than one Process Facility.

The CHOCO picker is designed also to install a set of new boards into the Settlement tanks at the commencement of each quarterly spawning cycle. The Choco board material must be compatible with coral settlement and field deployment, depending on the material selected, the mass of a set of boards for one tank could range between 200 and 700kg.

Prior to transfer of the CHOCO boards, the receiving Transport tank is filled with conditioned seawater and is connected to a dedicated life support package that remains with the tank until it is delivered to the Deployment Vessel offshore.

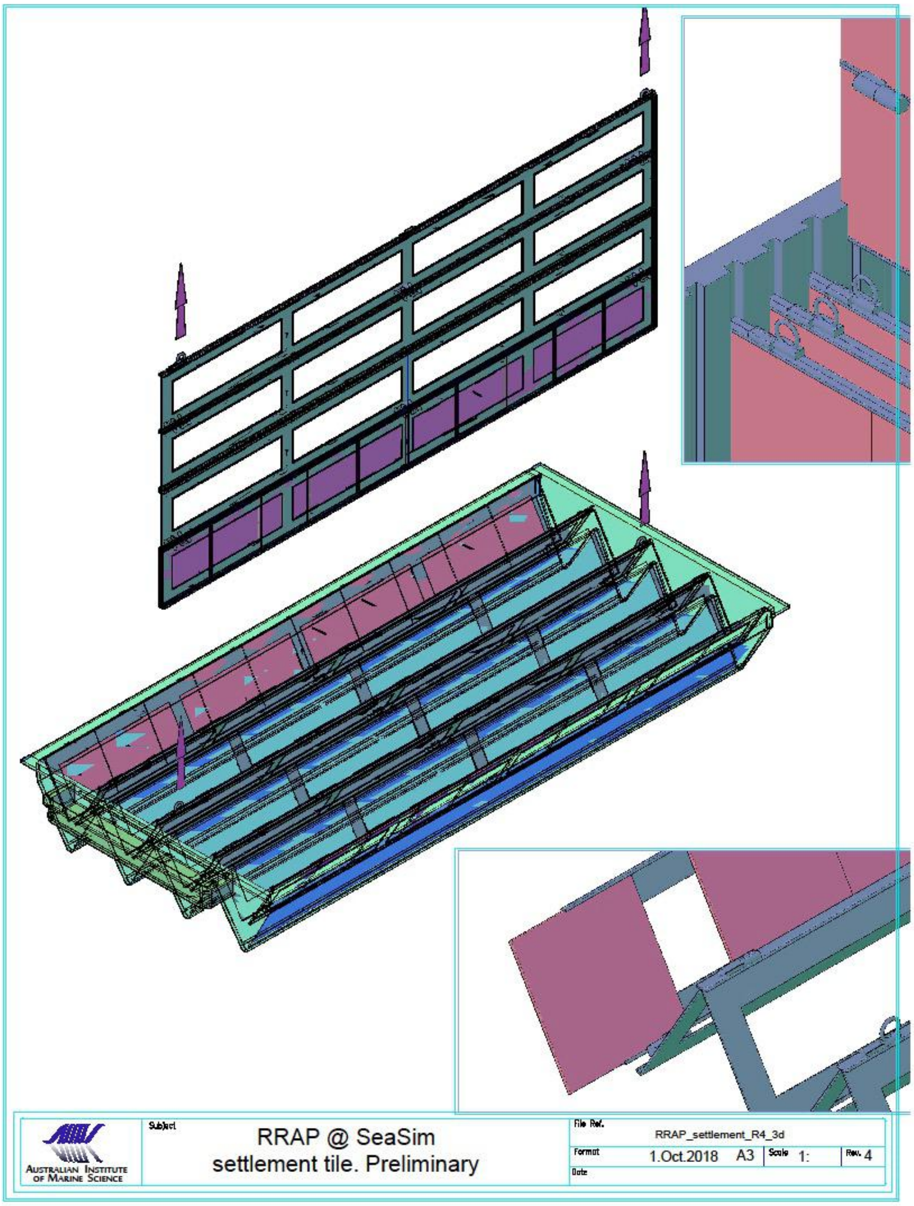


Figure 4-8: Choco Board Arrangement

A typical fibreglass marine organism transport tank is shown in the BoD Figures 8-1 and 8-2. However the tank shape required for the proposed settlement and transfer system is longer and deeper, with a transport mass of tank and contents in the order of six tonnes. In addition, transparent sides and top wil be required in order to ensure the juvenile corals on the closely packed CHOCO boards receive adequate light during transport. An example of a clear-sided tank is shown in Figure 4-14. Each tank contains sufficient CHOCO boards for about one day's deployment on the Reef, based on the system described above.

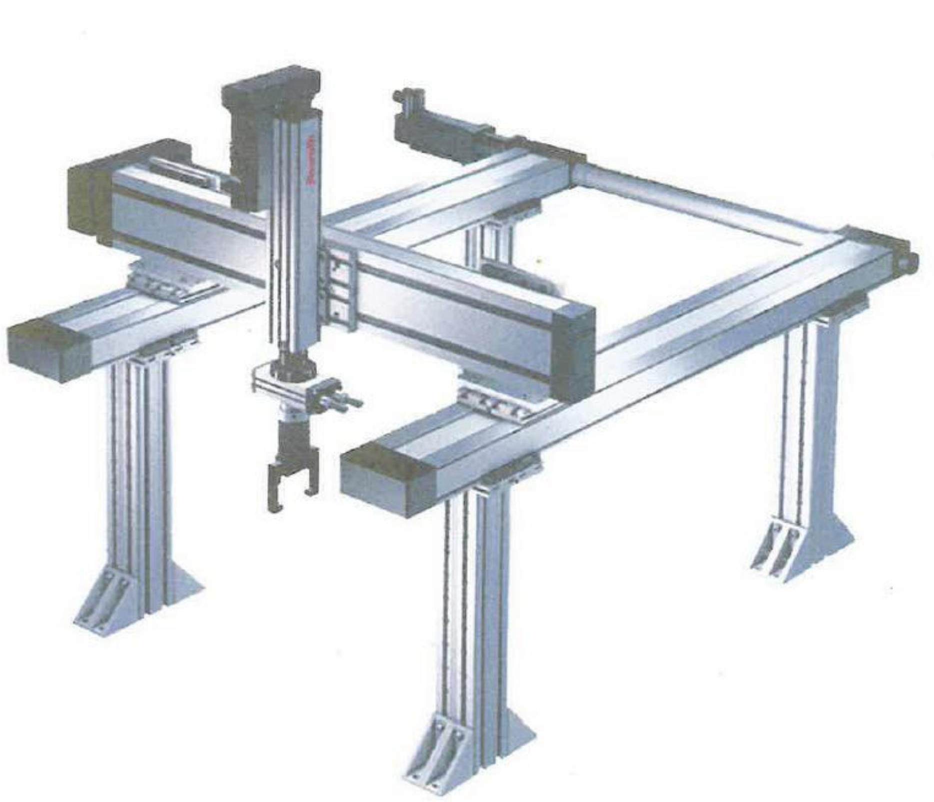


Figure 4-9: Typical Cartesian Picker Arrangement

4.3.2.8. Automation of the Settlement and Transport Tanks Processes

There appear to be two opportunities for automation of the settling and transfer process:

- Underwater sensing of the development of the juvenile corals on the CHOCO boards to signal readiness for transfer;
- Prototyping, trialling and proving the system for transferring settled CHOCO boards to the Transfer tanks, either as conceptualised above or by another system. Based on the current state of the technologies it is considered that the above are two of the simpler processes that could be researched and developed as one integrated system, so that incoming larvae, once they are settled and matured sufficiently, can be automatically transferred as quickly as possible to the Transport tanks. This would minimise time lost in the short survival time of the corals during transfer to the Reef.

It is noted that this process is the first part of the overall deployment system, which must be developed and integrated as a whole, including placement on the Reef. Such a system will include consideration of:

- Dimensions and shapes of the Settlement and Transport tanks to meet the requirements of the settled CHOCO board picking, packing, loading, life support, road and sea transport and unpacking on the Deployment vessel;
- Compatibility of the CHOCO board configuration (or other equivalent system) with the unpacking and assembly of the settled corals to the Deployment Device (assuming this is to be undertaken offshore and not in the onshore Hatchery);
- Minimisation of disturbance to the corals during transport;
- Adequacy of life support systems to ensure survival of the corals in transit.

The prototype development of the complete system must include consideration of offshore deployment:

- Attachment of corals to the Deployment Device offshore,

with particular attention to:

- Unit cost of Device Deployment, and
- Risk associated with system functional reliability and coral survivability.

4.3.2.9. Loading Transport Tanks

Transport tanks are handled by forklift with spread forks in the Packing and Loading area at the north end of the Process Facility. Full tanks with their life support system are loaded for road transport into either a special drop-side container or special enclosed vehicle. Containers are handled by reach stacker, which could possibly also double as the fork lift for tank handling.

The type of transport container depends on climatic conditions, both on shore and offshore. In this respect it is expected that the life support systems will require power and an onboard chiller, especially if long road-haul and/or sea distances are entailed.

A buffer storage area for empty tanks and containers is provided, to deal with fluctuations of overall trip times between the Hatchery and the Deployment sites.

4.3.2.10. Automation of the Tank Loading Processes

As with any intermodal transport process, discrete event simulation will be required as a basis for rationalising and optimising the overall system. This project is a classic case where such simulation can bring together all the diverse requirements of transporting a climate- and time-sensitive cargo.

In this respect the need, benefit and opportunity or otherwise for automation of the loading of Transport Tanks and associated processes, such as management of buffer storage, will become apparent as an outcome of the simulation. The technology of automated freight handling systems is well advanced and its application to the requirement of the handling of Transport tanks will be mainly a matter of selecting an appropriate system.

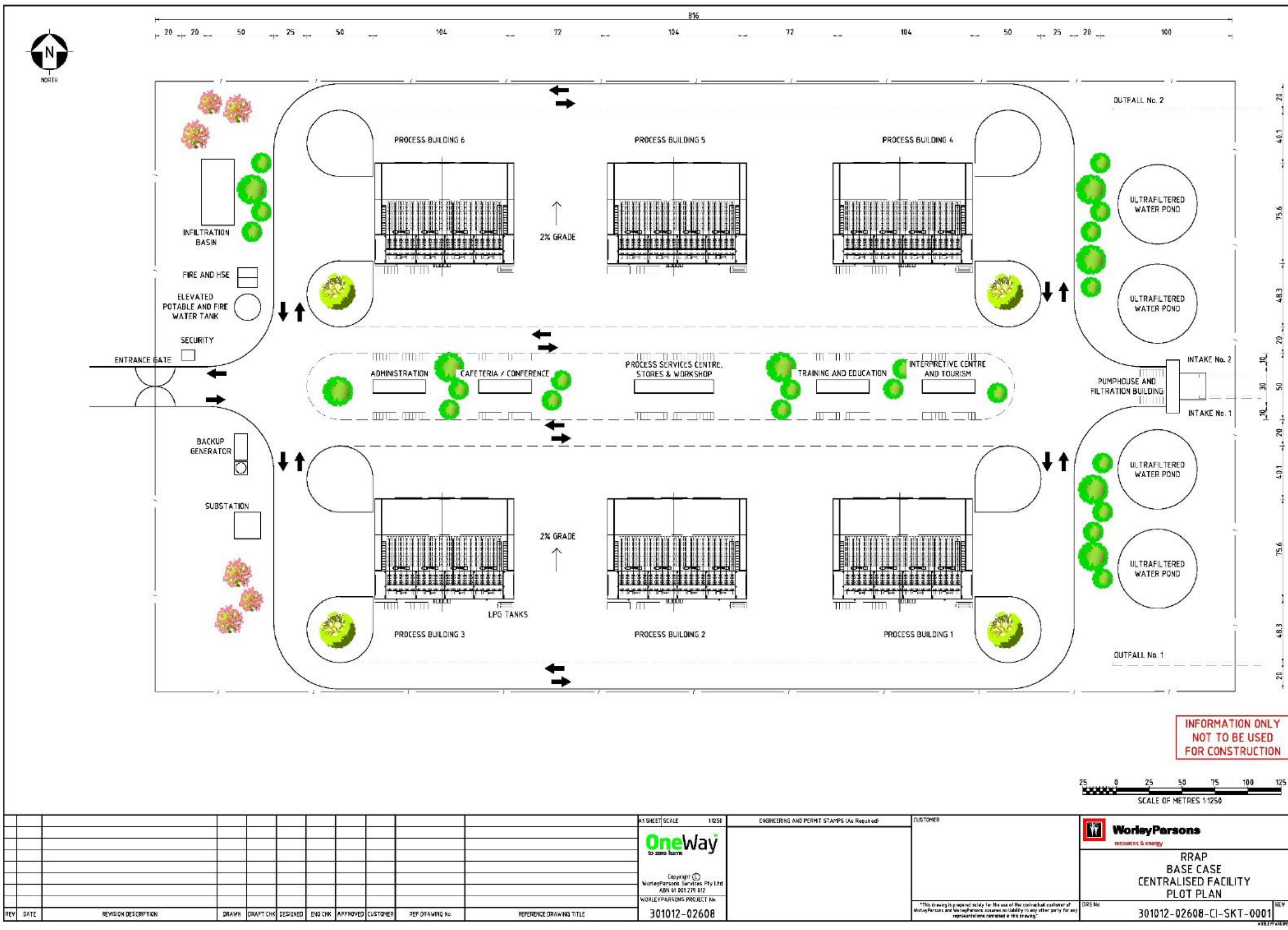


Figure 4-10: Base Case Site layout

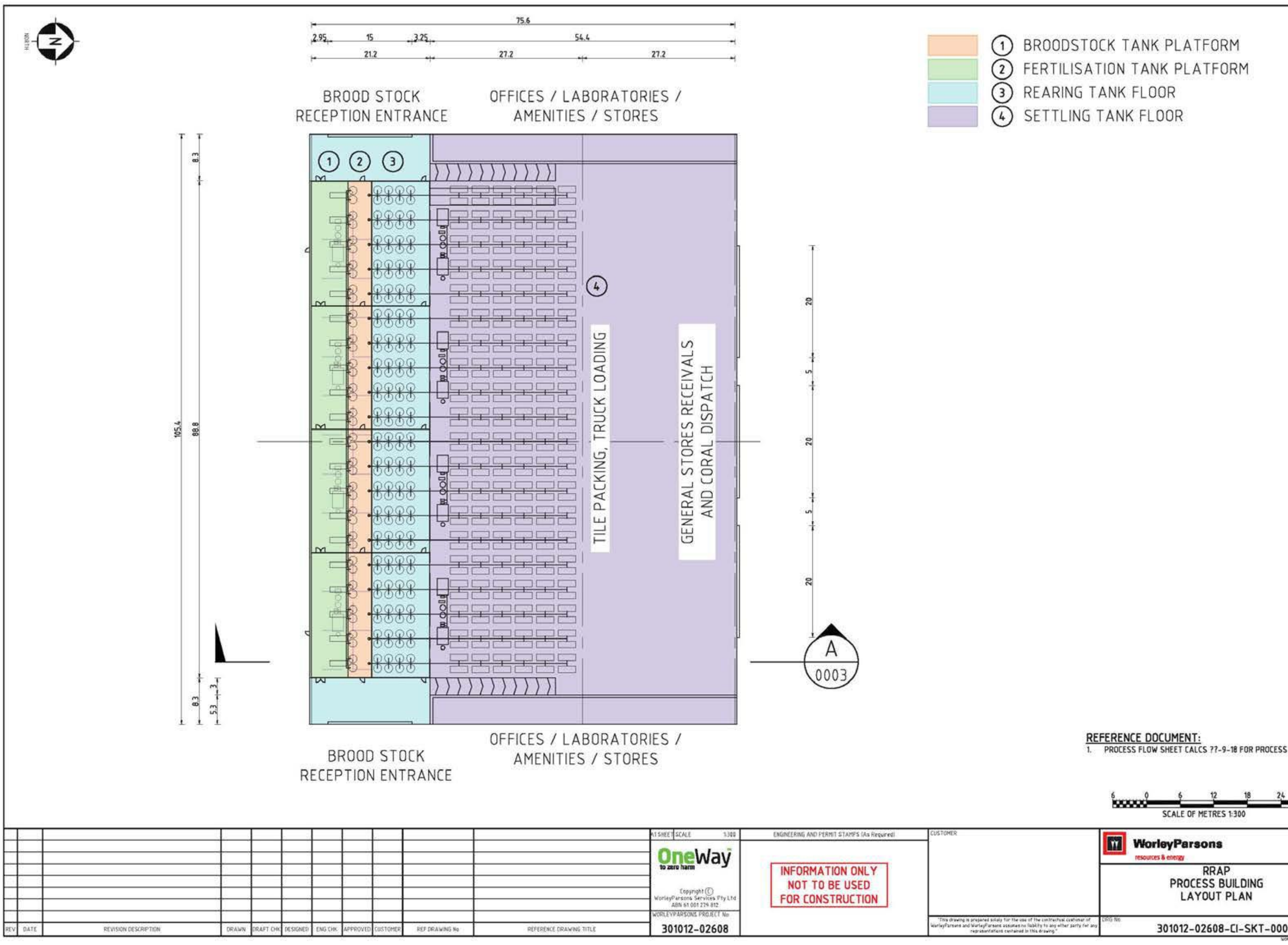


Figure 4-11: Process Building Layout Plan

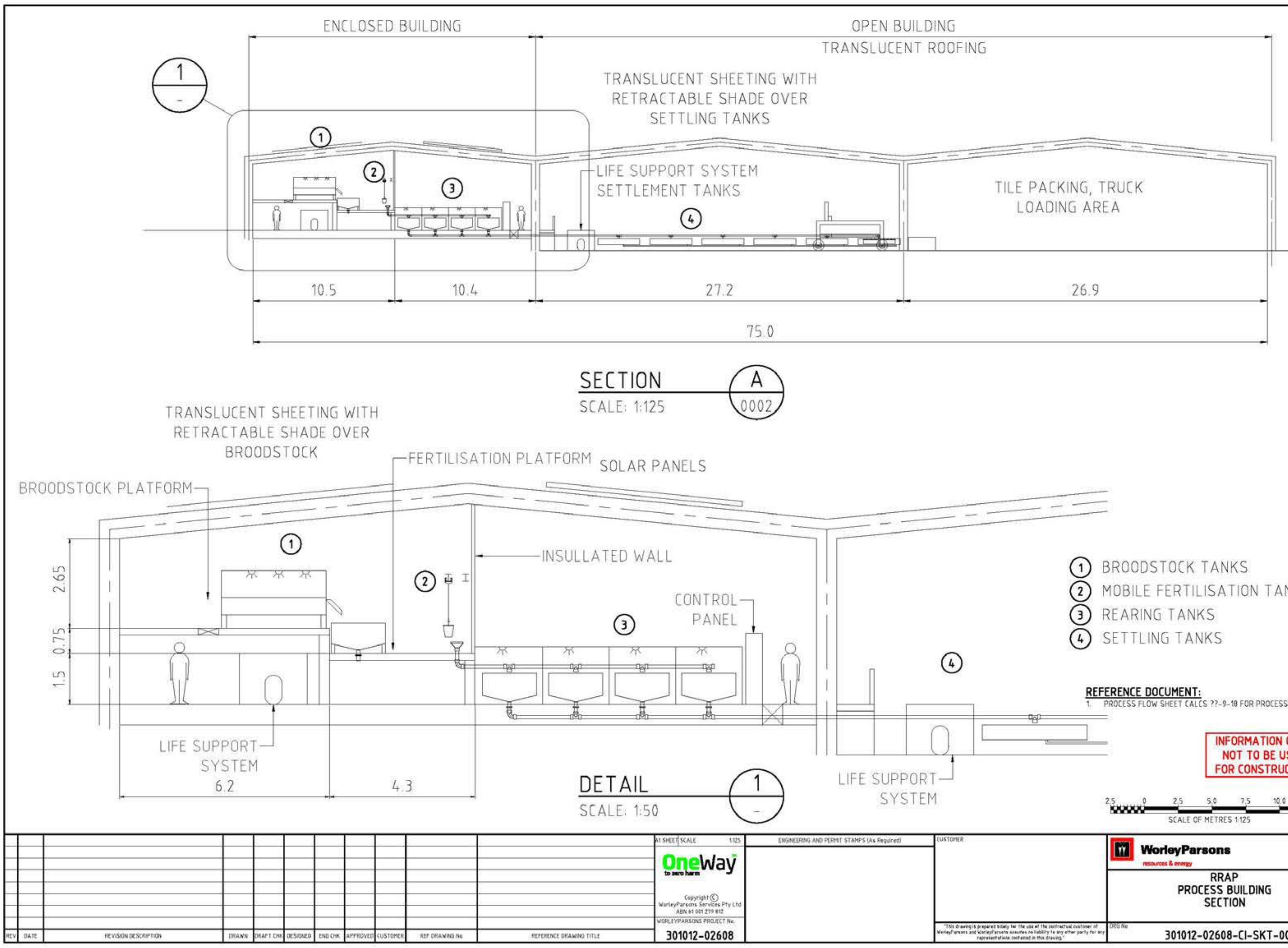


Figure 4-12: Facility Cross Section

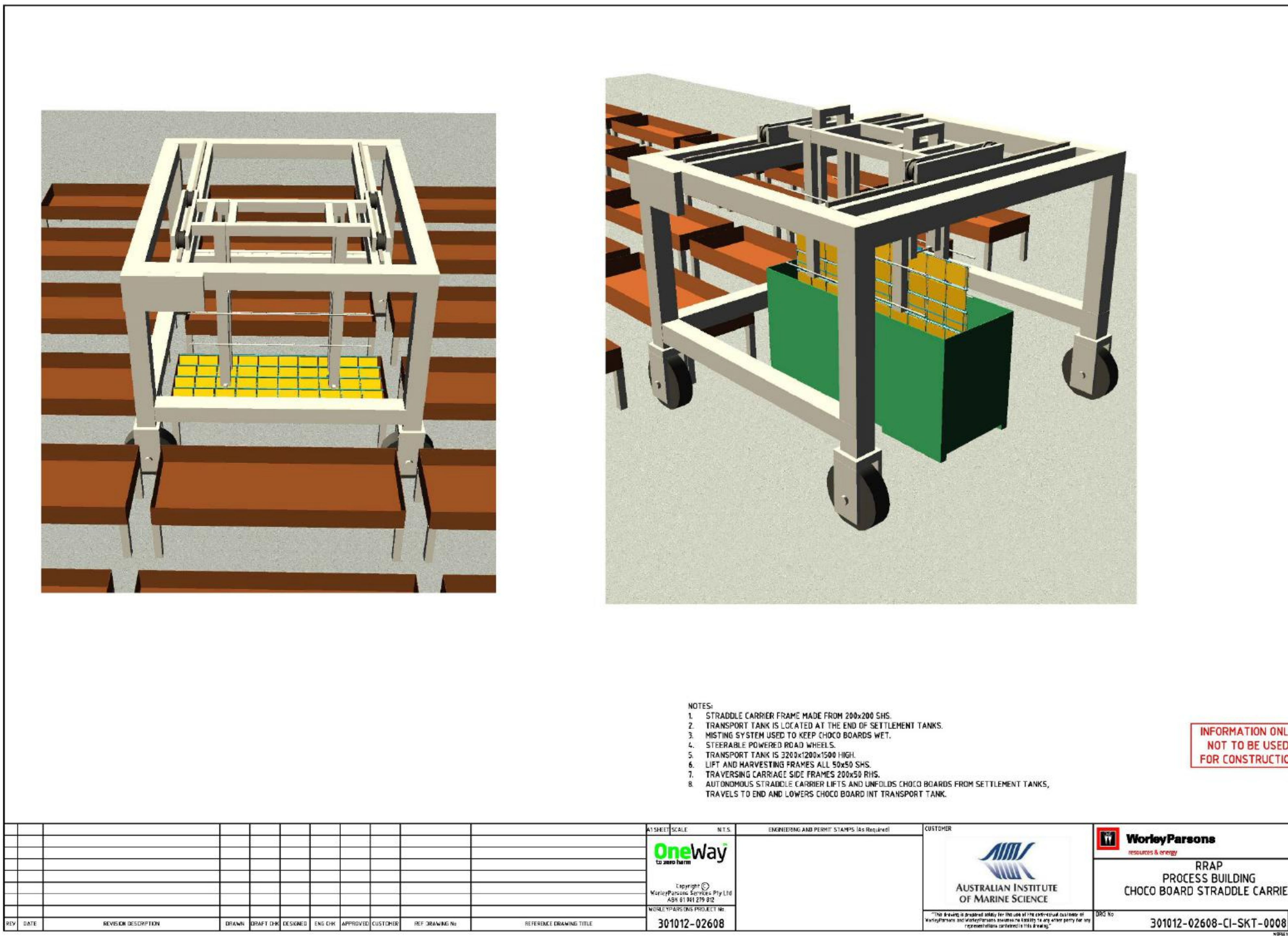


Figure 4-13: Settlement Tank Picker

4.4 TRANSPORT TO DOCK

For the Base Case it is assumed that movement of the Transport Tanks from the Production Facility to the loading Dock will be by haulage contractor on public roads. However if either a Centralised or Distributed Production Facilities can be located at the coast with direct ship access, then movement of the Transport Tanks to the Dock would be effected by, depending on the distance, conveyor or shuttle vehicle.

There are two types of tanks proposed:

1. To house the CHOCO boards (Figure 4-14 - left) – 23 folded boards 3.2m long, 1.25m wide, 1.5 m high – surface area = 4m^2

    a. Made of Perspex

    b. Contain full life support system

2. House the deployment devices (both un-erected onshore and erected offshore) – 2mx 2m, 1.7m high (Figure 4-14 - right, but with clear sides and top to ensure corals receive adequate daylight after Erected Devices have been loaded)

Figure 4-14: Transportation Tank Options (1 left, 2 right)[10]

The Offshore Transport Tanks will require a Life support System during transit between the Hatchery and the Medium Transport vessel. This will require Tanks and the Life Support system to be moved as one package. It is envisaged that the Life Support system will be integrated with the container and be provided with its own power supply.

[10] solid acrylic is extremely heavy (at least 80mm thick for a total weight of 2480kg) and intrinsically too rigid. The preferred path is that the tank is definitely FRP, with PMMA windows if needed.

It will be important to minimise the time in transit between packing the Transport tanks in the Hatchery and deployment of Devices on the Reef. AIMS advise that the maximum coral survival time after loading into Transport tanks is 14 days, but preferably should be no more than 10 days. Under ideal circumstances the Transport tanks will be loaded direct from the road transport to the Medium Transport vessel. However if there is a mis-match in scheduling then there will need to be provision for parking the loaded containers at the dock, including hook-up to a power supply (similar to reefer parking at container terminals).

The road distances from the Base Case at Townsville to the loading docks are assumed to be as follows:

a. Cairns/Port Douglas: 420km

b. Townsville: 50km

c. Rockhampton: 725km

The present study considers only the Base Case operating in the Central area of the reef, adjacent to Townsville. As discussed in Section 3 above, for future studies it is envisaged that transport from the Base Case at Townsville will be by road to docks at Port Douglas and Rockhampton. This assumption facilitates the study comparison with the dispersed hatcheries at these locations. In practice, for either the Base Case or the Distributed Case, loading of Medium Transport vessels might be at docks that are closer to the deployment sites, if this proves to be a more cost effective use of road transport and deployment vessels. All this would be worked out as part of the scheduling of the deployment vessels up and down the Reef.

4.5 CHOCO BOARDS AND DEPLOYMENT DEVICE MANUFACTURER

Originally a threaded device was proposed for the deployment device. Subsequently through discussions with manufacturers it was learned that threading ceramic is possible but difficult. The design was subsequently changed with no thread as shown in Figure 4-15 and Figure 4-16.

Technical Ceramics Australia[11] quoted lots of 5,000 pieces and 100,000 pieces. The quote was only a preliminary estimate of $6.00 each for a lot of 5000 and about half that price for 100,000 off.

As the Deployment Device and CHOCO boards were set to make up to 50% of the cost (using the Australian supplier at 100,000 units), cheaper alternative had to be found either through self-manufacturer or offshore production. WorleyParsons engaged its offshore procurement center to source suitable quotes and the results are detailed in Table 4-4. The content varied in the quote as detailed in Table 4-3, however whilst in general the physical properties were not considered material to the products usability, the density could be explored during detailed design considering the 100% heavier zirconia material. The alumina also absorbed moisture which may be beneficial if advanced materials are to be impregnated on the surface i.e. to discourage algal growth or encourage settlement.

[11] http://www.technicalceramics.com.au/

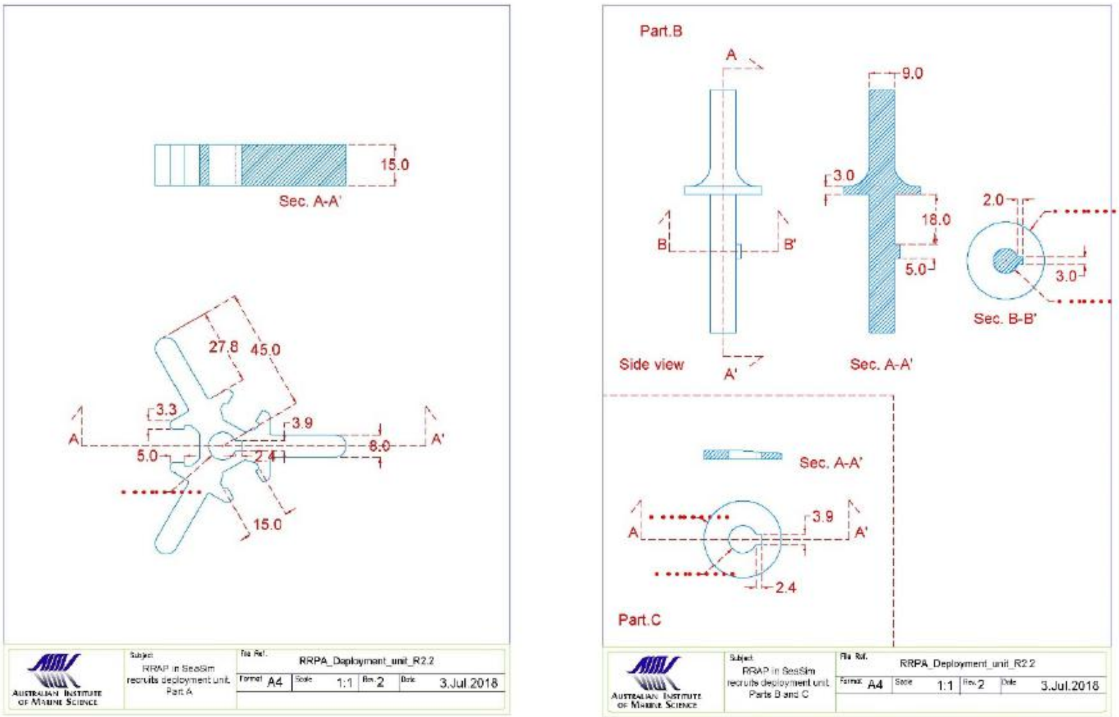


Figure 4-15: Part A B and C respectively of the deployment device

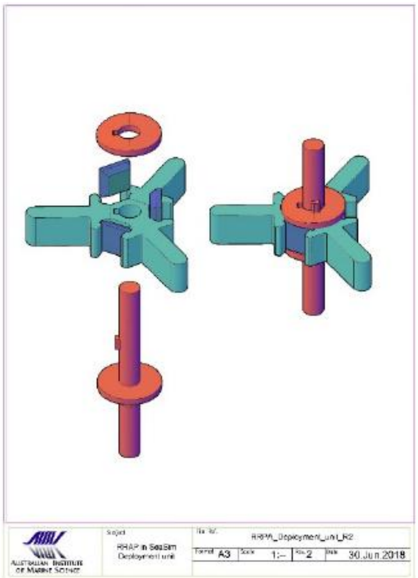


Figure 4-16: 3D view of erected Deployment Device – see the slotted CHOCO boards in blue

Table 4-3: Ceramic Properties

Material		Alumina						Zirconia
Properties	Units	99.99%	99.70%	99.50%	99%	97%	95%	ZrO2
		Al2O3	Al2O3	Al2O3	Al2O3	Al2O3	Al2O3	
Color	——	White	Ivory	Ivory	Ivory	White	White	White, Black, Blue
Permeability	——	Gas-tight	Gas-tight	Gas-tight	Gas-tight	Gas-tight	Gas-tight	Gas-tight
Density	g/cm³	3.95	3.94	3.9	3.8	3.75	3.7	5.9-6.0
Straightness	%	1	1	1	1	1	1	1
Hardness	Mohs Scale	9	9	9	9	8.9	8.8	8.8
Water Absorption	%	≤0.2	≤0.2	≤0.2	≤0.2	≤0.2	≤0.2	0
Bending Strength (Typical 20℃)	Mpa	375	375	370	340	320	304	1200
Compressive Strength (Typical 20℃)	Mpa	2300	2300	2300	2210	2100	1910	2500
Max Working Temperature	℃	1750	1750	1750	1700	1650	1500	1050
Coefficient of Thermal Expansion (25℃ to 800℃)	10-6/℃	8	7.8	7.8	7.7	7.6	7.5	10
Fracture Toughness	MPa *m1/2	4.4	4.3	4.3	4.2	4	3.8	10
Dielectric Strength (5mmThickness)	AC-kv/mm	9	8.7	8.7	8.7	8.5	8.3	9
Dielectric Loss (25ºC@1MHz)	——	< 0.0001	< 0.0001	< 0.0001	0.0001	0.0002	0.0002	0.001
Dielectric Constant	25º C@1MHz	9.8	9.7	9.7	9.5	9.3	9.2	29
Electrical Resistivity (25℃)	Ω*mm/m	14	14	14	14	14	14	12
Thermal Conductivity (25℃)	W/m·K	30	30	30	29	27.5	25	2.5

Table 4-4: Ceramic Manufacturers Quote Summary

Quotation	Xinhua County Yi Bo Cera	Yixing Hengyuan Ceramic	Lianyungang Toho Ceramic	Shenzhen Jiamei Photoel	STA Refractory (Zhengzh)	Yixing K.F Ceramic Manu	Jiangsu Mingbaisheng Re	Dongguar
Product name	ceramic device	Customized high purity alumina ceramic parts	Alumina Material ceramic alumina	Factory OEM Customized Laser Cutting zirconia ceramic parts	95 alumina ceramic nozzle	Alumina Material ceramic alumina	Heat Resistance Insulator Ceramic 99 Purity Aluminium Ceramic Parts	Factory cu Material c ceramic til device
Unit price	USD 0.01/Pieces	USD 1/Pieces	USD 0.1/Pieces	USD 0.98/Pieces	USD 0.5/Pieces	USD 0.28/Pieces	USD 4/Pieces	USD 0.5/F
Min. order quality	10000 Pieces	10000 Pieces	10000 Pieces	10 Pieces	10000 Pieces	10000 Pieces	10 Pieces	10000 Pie
Payment terms	T/T	T/T	T/T	T/T	T/T	T/T	T/T	T/T
Quotation valid time	2018-11-03	2018-11-03	2018-11-03	2018-11-03	2018-11-03	2018-11-03	2018-11-03	2018-11-0
Product description	as per customer's drawings	as per customer's drawings	as per customer's drawings	as per customer's drawings	as per customer's drawings	as per customer's drawings	as per customer's drawings	as per cus
Business type	Manufacturer, Trading Company	Trading Company	Trading Company	Manufacturer, Trading Company	Manufacturer, Trading Company	Manufacturer, Trading Company	Manufacturer, Trading Company	Manufactu Company
Main products	ceramic discs, metallization ceramics, spice grinder ceramics, piezoelectrical ceramics, new energy ceramics	ceramics, fireproofing material, purple clay products, thermal insulation material, hardware	Ceramic tube pipe rolller, Alumina ceramic, Zirconia Ceramic, SIC Steatite Mullite Cordierite, Irregular ceramic	laser cutting service, laser cutting parts, laser making service, cutting services, oem services	muffle furnace, tube furnace, box furnace, chamber furnace, high temperature furnace	Cordierite porcelains, Steatite ceramics, zirconium oxide ceramics, electric ceramics, precision ceramics	alumina ceramic plates, alumina ceramic rods, alumina ceramic tubes, alumina ceramic crucibles, alumina ceramic rings	Industrial Zirconia, A Parts
Main market	Mid East, Eastern Europe, Western Europe, Domestic Market, South Asia, North America	Eastern Europe, North America, Mid East, Western Europe, South America, Eastern Asia, Southeast Asia	Oceania, South Asia, Southern Europe, South America, Africa, Eastern Asia, Western Europe, Southeast Asia, Northern Europe, Central America, Mid East, Eastern Europe, Domestic Market, North America	Mid East, Eastern Europe, South America, Africa, Southeast Asia, Eastern Asia, Northern Europe, North America		Northern Europe, Mid East, South America, Southeast Asia, Southern Europe, Eastern Europe, Western Europe, Central America, Eastern Asia, Domestic Market	Domestic Market, Mid East, Western Europe, South Asia, Eastern Asia, South America, Eastern Europe, Southeast Asia	Mid East, Asia, Sout Europe, S Western E Europe, S Eastern A America, I Domestic

5. OFFSHORE DEPLOYMENT

For Deployment, the activities described below cover the whole of the Deployment operations, which serve all six Process Trains in the central Base Case Facility.

5.1 LOAD TO MEDIUM TRANSPORT VESSELS

The purpose of the Medium Transport is to be stationed at the Reef and provide a continuous supply of Restoration Materials to the Deployment Vessels. This will maximise the time available for deployment of new corals.

Two Medium Transport Vessels (Figure 5-1) are required to maintain a continuous supply of materials and consumables over the 60 day deployment window. Each cycle comprises 2 days for loading and sailing and 8 days on site to supply the Deployment Vessels. (as per BoD – Back and Forth Barges – Table 8-7) The trip cycle time is constrained by the expected survival time of corals whilst in transit

Unassembled two-piece Devices are transported off shore in crates, for erection of Tiles on the Medium Transport Vessel. In addition to the Devices, each Medium Transport will house the following Tanks.

- Onshore Transport Tanks
    - Each device will have 3 CHOCO tiles (see Figure 4-16)
    - Each quarter 13,274,306 Devices will be deployed over a period of 60 days, which equates to 221,238 devices per day;
    - Therefore 39,822,918 CHOCO Tiles (at 3 per Device) need to be transported offshore per deployment window;
    - An Onshore Transport Tank, filled with conditioned seawater, holds 23 rows of 80 CHOCO boards, each with 400 boards, which equates to 736,000 tiles per Onshore Transport Tank;
    - Approximately 15 Onshore Transport Tanks are required per quarter to be transported, returned empty and refilled for the next replenishment trip by the Medium Transport Vessels;
    - Two Medium Transport vessels are required to maintain a continuous supply of Choco boards.
- Offshore Transport Tanks
    - Erected Devices are loaded to the Deployment Vessels in Offshore Transport Tanks that are filled with conditioned seawater;
    - Each Offshore Transport Tank holds 6716 Erected Devices;
    - Approximately 36 Offshore Transport Tanks are required per quarter to be loaded to six Deployment Vessels, returned empty and refilled for the next day's deployment;

- The average Deployment rate (devices per hour) is 3600 or 1 per second, continuously for 12 hours per day;

Figure 5-1: Proposed Medium Transport Vessels (Back and Forth Barges)

Table 5-1: Medium Transport Vessel Particulars

Draft particulars:	Back and Forth Barges
Classification:	Coastal for GBR
Type:	Medium Barge
Function:	Coral deployment
Positioning:	GPS
Crew accommodation:	~30
Speed cruising laden (knots):	6
Range (km):	<500
Duration (days):	<60
Open deck area (m^2):	600

Staff for 24 hour ops	11

1. The following activities 24/7.
    a. Deployment Devices will be erected 24 hours day;
    b. Transportation Tanks with fully erected devices (6 Offshore Transportation Tanks per Deployment Vessel) will be loaded daily (3 trips daily);
    c. Each Offshore Deployment Tank will contain 6,716 devices (13,432 per vessel – based on 2 tanks per Deployment Vessel floor space);
    d. Devices are deployed at 3600 units per hour (1 per second – see Figure 5-5) - Deployment vessels work 12 hours and are replenished day and night;
    e. The Medium Transport Vessel will refuel Deployment Vessels and undertake maintenance during night operations.
2. To operate for the specified duration between replenishments at the Dock, anywhere on the Reef.
3. To act as a warehouse at the Reef, to handle, store and re-position:
    a. Unassembled Devices;
    b. Onshore Transport Tanks with settled CHOCO boards under controlled conditions;
    c. Erected Deployment Devices placed in Deployment Tanks under controlled conditions;
    d. Consumables required for Deployment operations and on-board crew hotel operations.
4. To prepare Devices by automated processes for deployment under controlled atmospheric conditions that will:
    a. Remove folded CHOCO boards from seawater-filled Transport Tanks and prepare for attachment to Deployment Devices;
    b. Attach Tiles from the CHOCO boards to the Deployment Devices;
    c. Pack Erected Devices into seawater-filled Deployment Tanks.
5. To provide hotel and medical facilities for Deployment Vessel Crews;
6. To be self-sufficient for cargo loading at the Dock and for cargo re-positioning on board and for loading and unloading the Deployment Vessel fleet at sea;
7. To be the administrative and communications hub for the Deployment Area;
8. To provide safe mooring and/or berthing for the entire fleet of Deployment Vessels.

The Medium Transport Vessels will be:

1. Of shallow draft design suitable for stationing close to the Reef in order to minimise travel distances for replenishment trips by the Deployment Vessels.

2. Be able to maintain station at or nearby the Reef at any geographical location without damaging the Reef.

5.2 TRANSFER AT SEA AND DEPLOY TO REEF

This operation will be undertaken by specialist crews using purpose-designed Deployment Vessels (Small Utility Vessel in CAPEX/OPEX).

Besides normal ship management, communication and navigation systems, the functions of the Deployment Vessels will be as follows:

2. To operate for the specified duration, including replenishments by the Medium Transport Vessel, anywhere on the Reef.
3. To deploy Devices to the Reef 12 hours per day, 7 days per week, comprising the following activities on day shift:
    a. Receive loaded Deployment Tanks from the Medium Transport Vessel, each tank containing 6716 Erected Devices;
    b. Sail to the Deployment site on the Reef;
    c. To dynamically position the Deployment Vessel in accordance with a pre-determined site-specific Deployment Plan;
    d. Unload Erected Devices under controlled atmospheric conditions from the Deployment Tanks by an automated process;
    e. To transfer Devices from the Deployment Tanks to the Offshore Device Deployer by an automated system;
    f. To deploy Devices to the Reef at the rate of 3600 per hour using the Offshore Device Deployer;
    g. return to the Medium Transport Vessel twice per day to replenish stock of Devices, and ;
    h. Return to the Medium Transport Vessel at night.
4. To receive Deployment Tanks and consumables from the Medium Transport Vessel, either alongside and/or at a docking station.
5. To deploy Devices to the Reef using the Offshore Device Deployer.

The Deployment Vessels will be:

a. Of shallow draft design suitable for operation at the Reef in all water depths at any site, with reasonable tidal constraints, as necessary.
b. Equipped with a DP1 Dynamic Positioning system.
c. Able to maintain station without damaging the Reef;
d. Equipped with daytime hotel and ablution facilities for the crew;

6. All Deployment Vessels will be serviced overnight by the Medium Transport Vessel and prepared for the next day's deployment activities, including the following:
    a. Unload the empty Deployment Tanks and store;
    b. Remove waste;
    c. Refuel the vessels including routine maintenance;
    d. Clean the vessel and replenish consumables;
7. Vessel crew will rest overnight on the Medium Transport Vessel.

5.3 OFFSHORE AUTOMATION

5.3.1 CHOCO board breaking and erection on deployment device (offshore)

The purpose of the Offshore Erection Device is to be stationed on the Medium Transport Vessel and provide a continuous supply of Restoration Materials to the Deployment Vessels. This will maximise the time available for deployment of new corals and will operate 24 x7. There will be one main operating Offshore Erection Device) and 1 backup device per Medium Transport Vessel.

By erecting offshore, the corals can be packed in the Hatchery into Onshore Deployment Tanks and transported to the Medium Supply Vessel to await assembly on the Devices. Trade off studies were undertaken as part of the BoD to land on this concept (Section 8.7 of BoD) (Figure 5-2). The Transport Tanks will require a Life support System during transit between the Hatchery and the Medium Transport vessel. This will require Tanks and the Life Support system to be moved as one package. It is envisaged that the Life Support system will be integrated with the container and be provided with its own power supply.

There are two types of tanks that will be used as detailed in Section 4.4 and Figure 4-14

The following attributes were considered:

- Onshore Transportation Tanks are 3.2m Long, 1.25m wide and 1.5m high and house both the CHOCO boards (Figure 5-2)
- Offshore Transport tanks for deployment devices are 2mx2m by 1.7 m high and house deployment devices both un-erected and erected (Figure 5-3). They will also contain life support system.
- The CHOCO boards are stacked vertically (Figure 5-2).

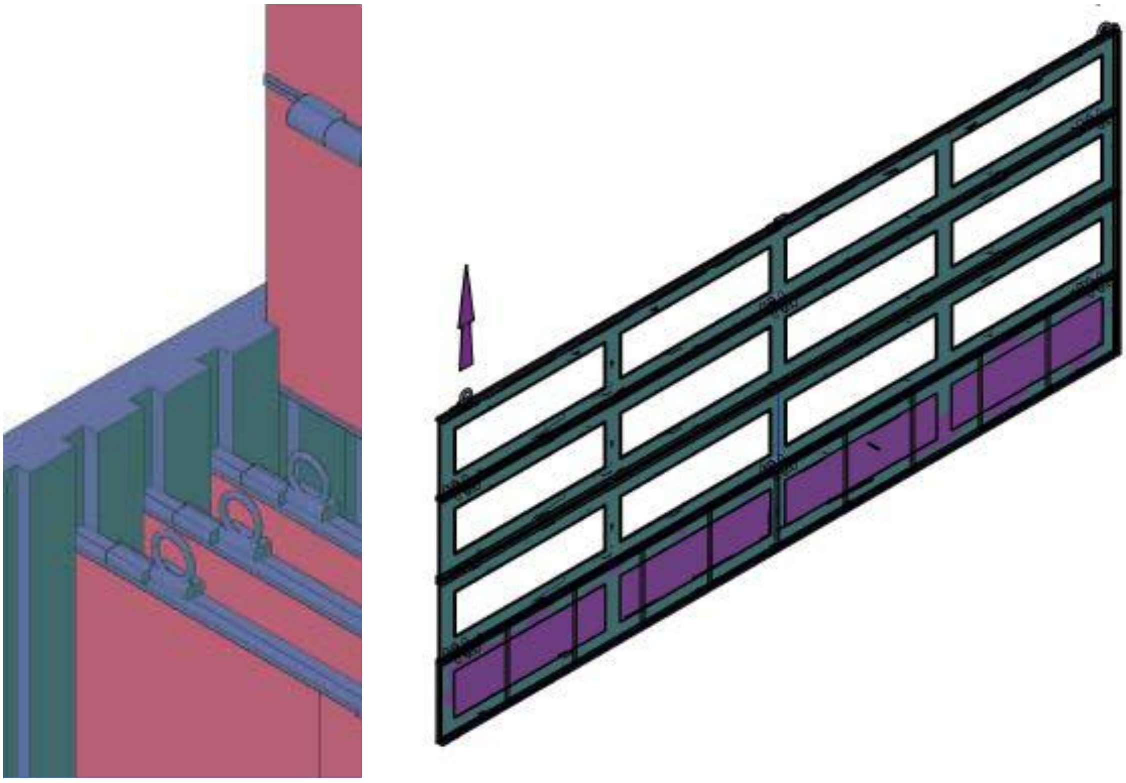


Figure 5-2: CHOCO Boards being stacked into an Onshore Transportation Tank (see also Figure 4-14 (left)

Figure 5-3: Offshore Transportation Tank

- On the Medium Transport Vessel deployment area, on one side is a Transport Tank with CHOCO boards stacked. On the other side is a crate with dry stacked Deployment Devices.
- A robotic arm collects one CHOCO board and 1 Deployment Device and a punch punches three CHOCO tiles from the main CHOCO board (i.e. each CHOCO tile is shown by the breaking lines in the drawing and each CHOCO board is 280mm x 280mm.

- The automation facility attaches the three sub CHOCO tiles to the Deployment Device and puts it on a conveyor in which it lands into the Offshore Transportation Tank.

Conceptually this is illustrated in Figure 5-4. The steps are illustrated in the concept design Figure 5-6 to Figure 5-8.

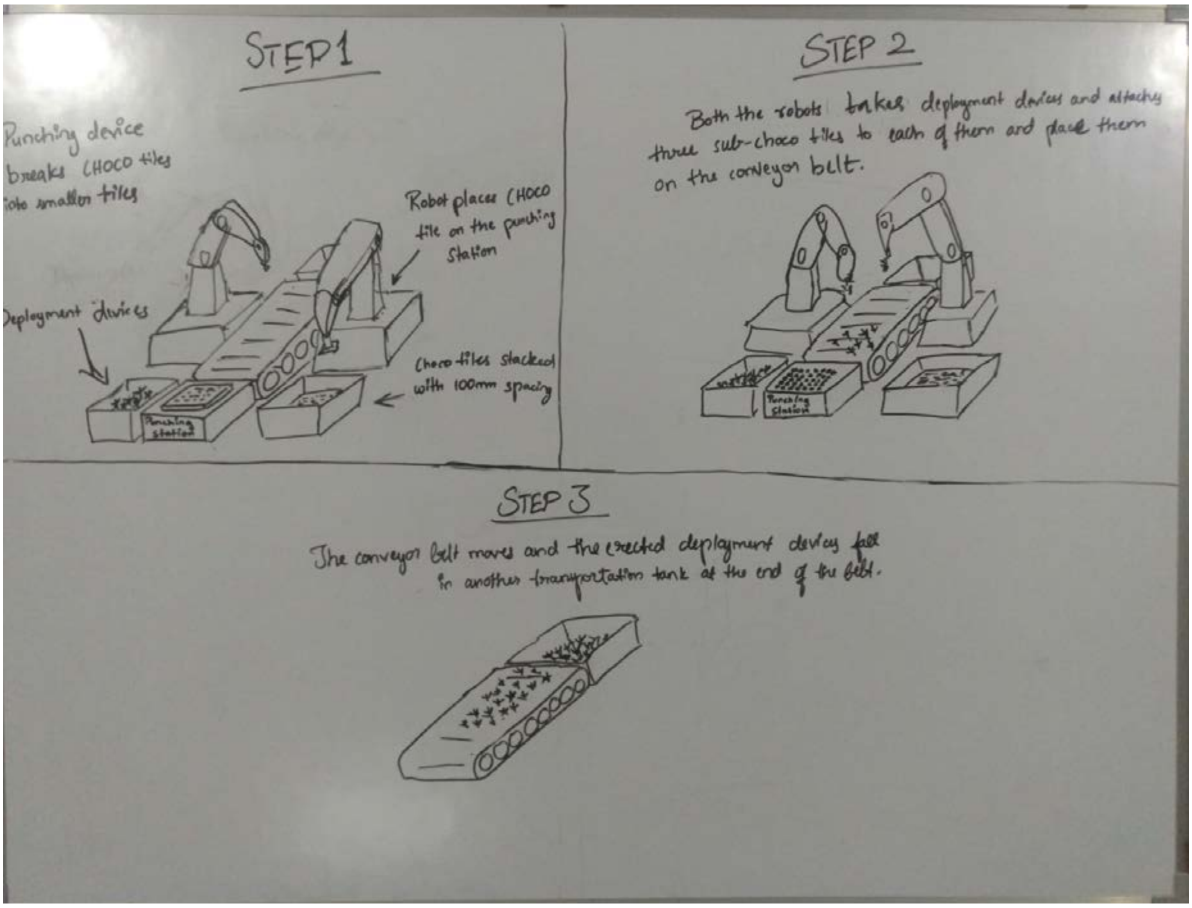


Figure 5-4: Offshore Erection Device

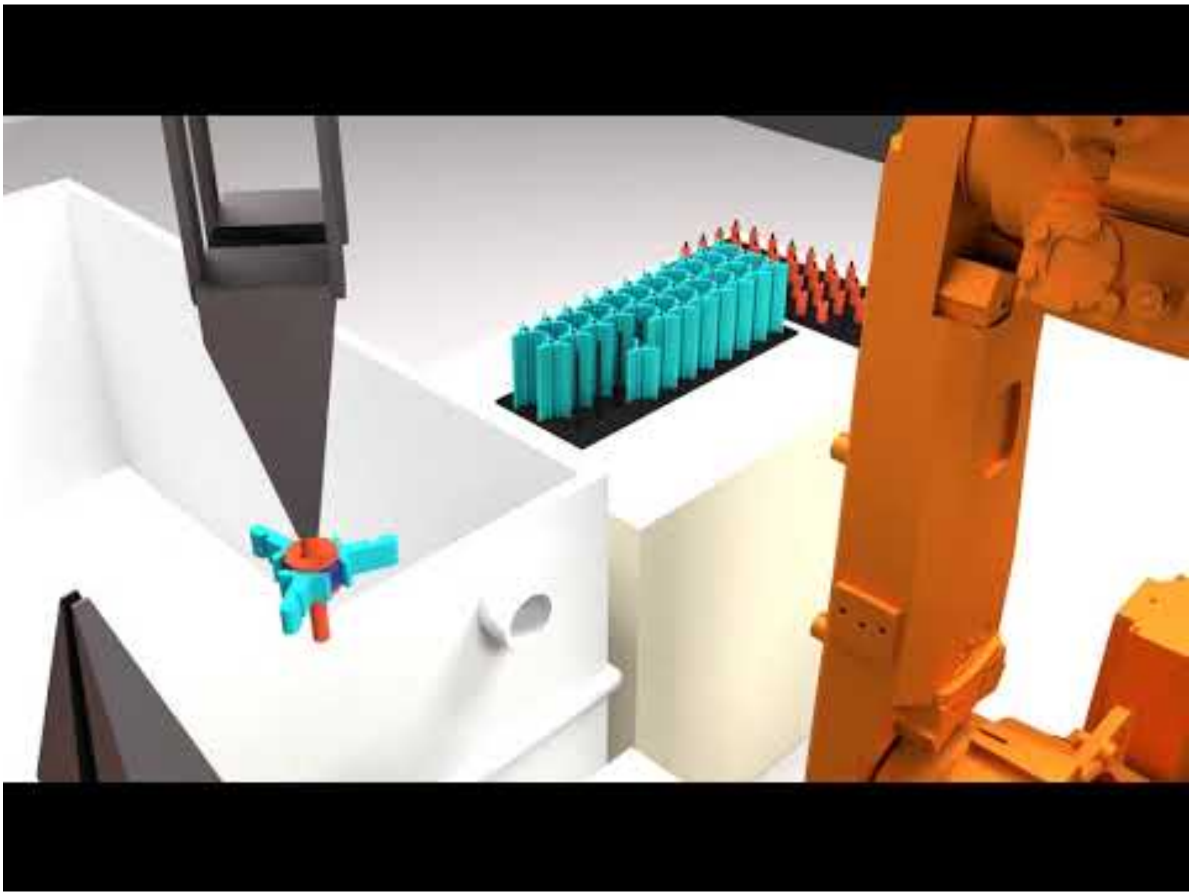
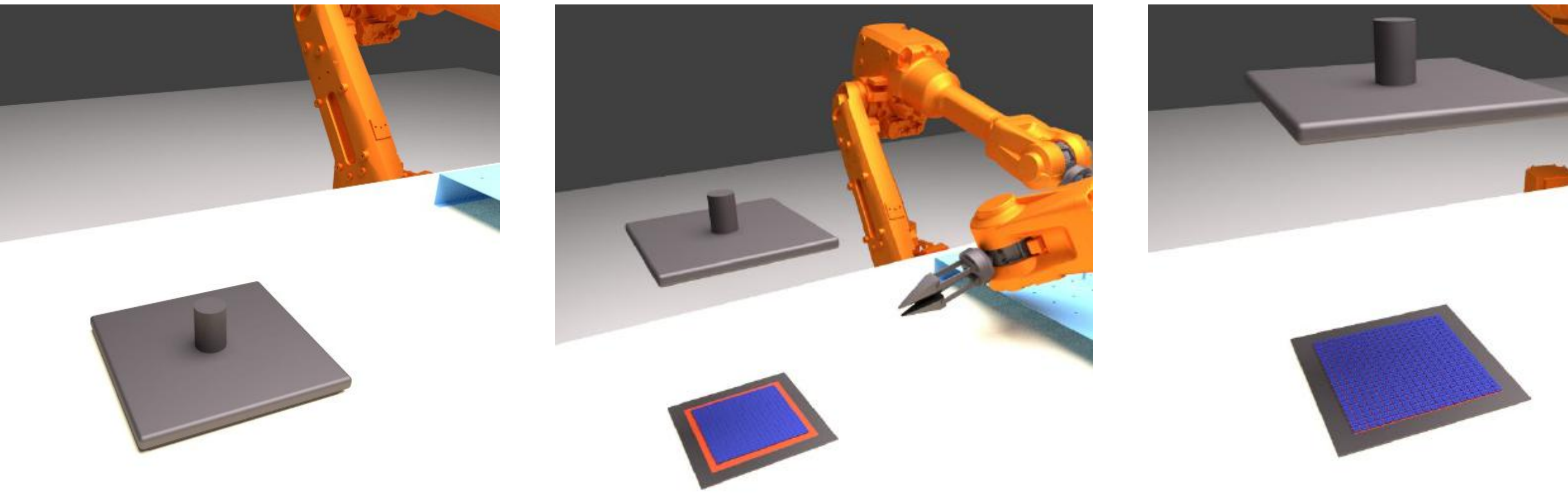
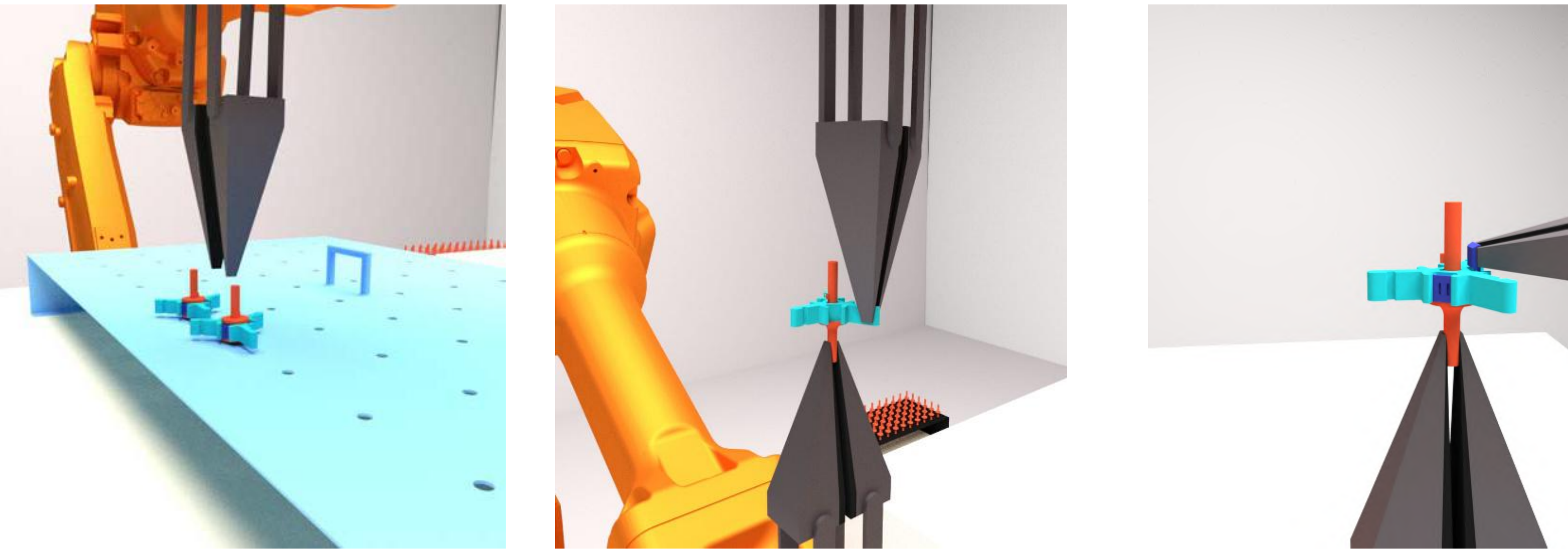


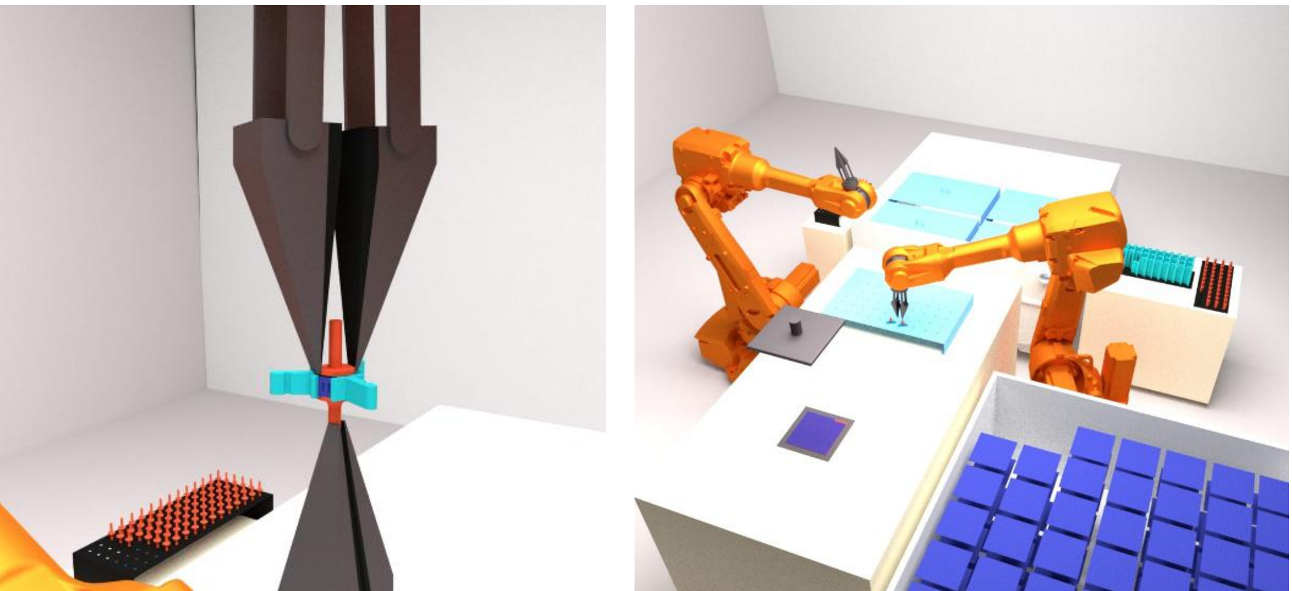
Figure 5-5: Offshore Erection Device (https://www.youtube.com/watch?v=2eJfTsW9w8A)



re 5-6: Punching Station



re 5-7: Assembly



5.3.2 Deployment Device Deployment (offshore)

Small manoeuvrable shallow draft deployment vessels are required in order to deploy corals. Deployment needs to be diverless and ideally from the surface[12].

The purpose of the Deployment Device Deployer (Appendix B – Unmanned Subsea Surveyor – Trade name) is to be stationed on the Deployment Vessel (Table 5-2) at the Reef and provide a continuous supply of deployment Devices to the seabed (when instructed) at the rate of approximately 10 per square meter (100 days per hectare or 1.67 quarters[13]). Key attributes include:

- Retractable from the water for vessel maneuverability/transport.
- Telescope a delivery pipe close to the bottom to deploy, max water depth is 15m
- Contain a camera on the end.

WorleyParsons has used existing technology to survey coral health before which meets the required attributes, namely the Unmanned Subsea Surveyor[14].

As costs, serviceability and usage were well understood and it met the design brief it has been adopted for the deployment kit. Specifications are listed in Appendix D.

Table 5-2: Deployment Vessel Particulars

Draft particulars:	Deploy Little boats
Classification:	Coastal for GBR
Type:	Shallow draft workboat
Function:	Coral deployment
Positioning:	GPS
Crew accommodation:	0
Speed cruising laden (knots):	10
Range (km):	<50
Duration (days):	<1
Open deck area:	8
Staff for12 hour ops	2

[12] Divers are simply impractical and would result in severe (orders of magnitude) restrictions to deployment rates, while subsurface (automated) “planting” delivery systems would be complex to develop (very low current TRL), expensive and environmental conditions constrained (likely to be limited to low current/calm conditions).

[13] Or 1 per second

[14] www.unmannedsubseasurveyor.com

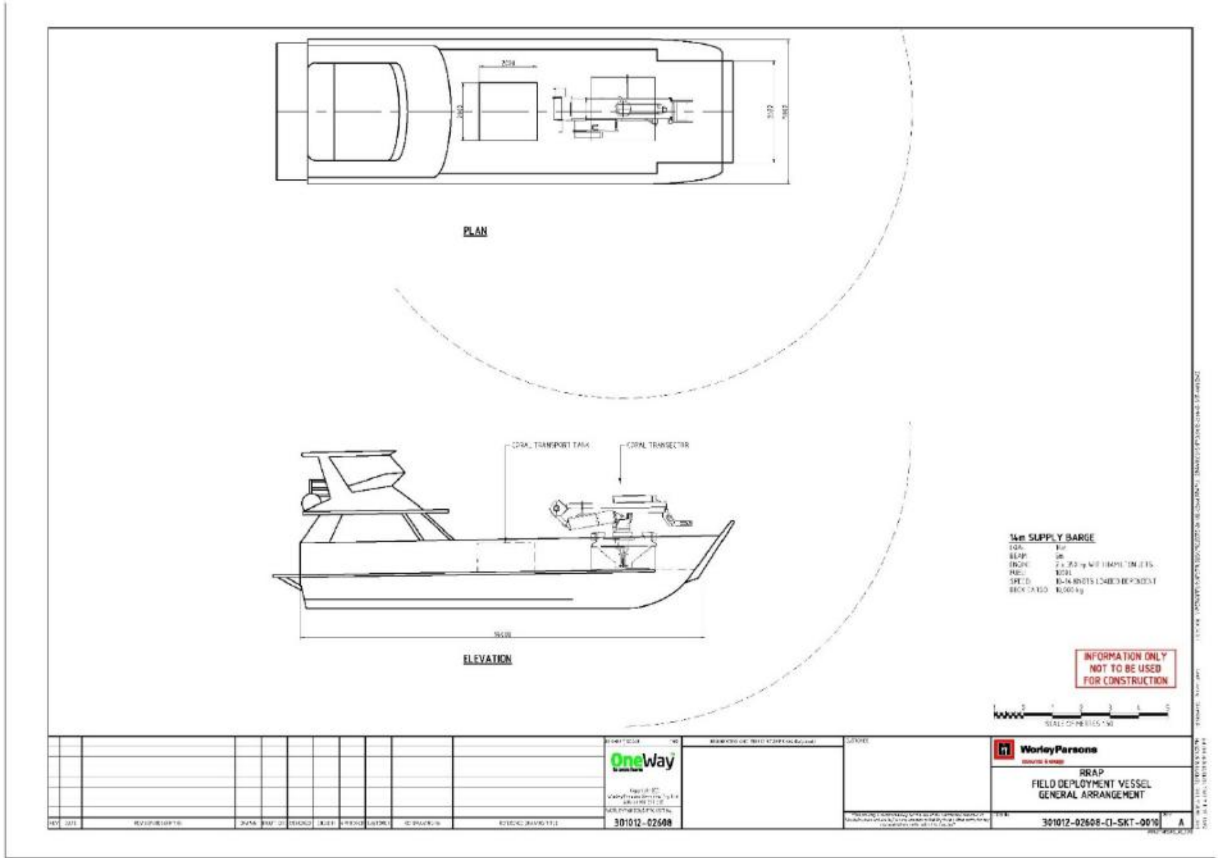


Figure 5-9: Proposed Deployment Barge and Deployment Concept

6. COST ESTIMATE

Estimates have been prepared for the Base Case Hatchery and Deployment, for both Capex and Opex. Overall accuracy is considered to be +/-50% in accordance with AACE Class 5 requirements. The basis of development of the capital operational cost estimates is described in this Section.

6.1 General Clarifications

The following clarifications and assumptions have been applied in preparation of the cost estimates:

- Estimate base date is October 2018;
- Sustaining capital is shown as a single line item;
- Contingency is shown as a single line item;
- Forward escalation for 5 years up to the date of contract award is shown as a single line item;
- The estimates are expressed in Australian Dollars (AUD);
- Battery limit between the Hatchery and Deployment estimates is assumed to be at the departure of the loaded road transport vehicles from the Process Facilities' loading bays.

6.2 Estimate Exclusions

The following items are excluded from the Capex and Opex estimates:

- Site purchase/land costs;
- Owners Costs;
- All costs outside of the estimating scopes;
- Taxes and duties;
- Sunk cost (e.g. cost for current site works, cost for this and previous studies);
- Costs to undertake the next study phases, up to FID;
- Working capital, and
- Abandonment cost at the end of facility life.

Exclusions specific to Hatchery and Deployment estimates are shown under their respective Sections.

6.3 Contracting Strategy

The estimates are based on an EPCM execution methodology. The EPCM contractor will undertake the engineering and manage the procurement, construction and commissioning of the Hatchery. He will also engineer and manage the specification, procurement, commissioning and delivery of the Deployment vessels and equipment, which will be designed by the selected suppliers. EPCM costs have been calculated as 12% of the overall installed costs for the Hatchery and for the Deployment vessels and equipment.

6.4 Sustaining Capital

Sustaining capital expenditure is applied to all capital expenditures at a rate of 2.5 percent per annum and is shown as a line item in the OPEX estimates.

6.5 Contingency and Accuracy

Contingency is an allowance added to cover for project execution unknowns, risks and uncertainties. As a consequence, contingency is added to the base estimate to allow for items such as incomplete project definition, estimate omissions and other “unknown unknowns”.

The contingency to be added to the base estimate is defined as:

> *“An allowance for goods and services which at the current state of project definition cannot be accurately quantified, but which history and experience shows will be necessary to achieve the given project scope”;*

and: *“It is that amount required to bring the base estimate to a 50/50 estimate”;*

that is, where there is an equal chance of overrunning and underrunning the estimate within its accuracy range.

For this estimate the contingency allowance of 25% of the total direct and indirect cost has been included as a line item in both the Capex and the Opex estimates.

It is anticipated that the accuracy of this estimate scope is within -50/+50% given that the maturity of the engineering deliverables and basis used in developing the cost estimate typically meets the requirements of AACE Class 5.

6.6 Escalation

Escalation beyond the base date has been calculated from the estimate as 9%, assuming contract award in 5 years’ time, and has been included as a line item in both the Capex and the Opex estimates

6.7 Estimate Summaries for the Base Case

Estimated costs, including contingency and escalation, are summarised in the following sections for the Capex and Opex for the Hatchery and Deployment, both separately and combined.

Amortised capital costs are included in the Deployment Operational summaries and the annual cost per Device is shown, both with and without Capex amortisation.

6.8 Hatchery Capital Cost

The capital cost summary by area for the Hatchery is shown in Table 6-1. Sensitivities were run on the m2 rate applied for the Process Facility Building (Figure 6-1). For the base case $4,500m2 was adopted.

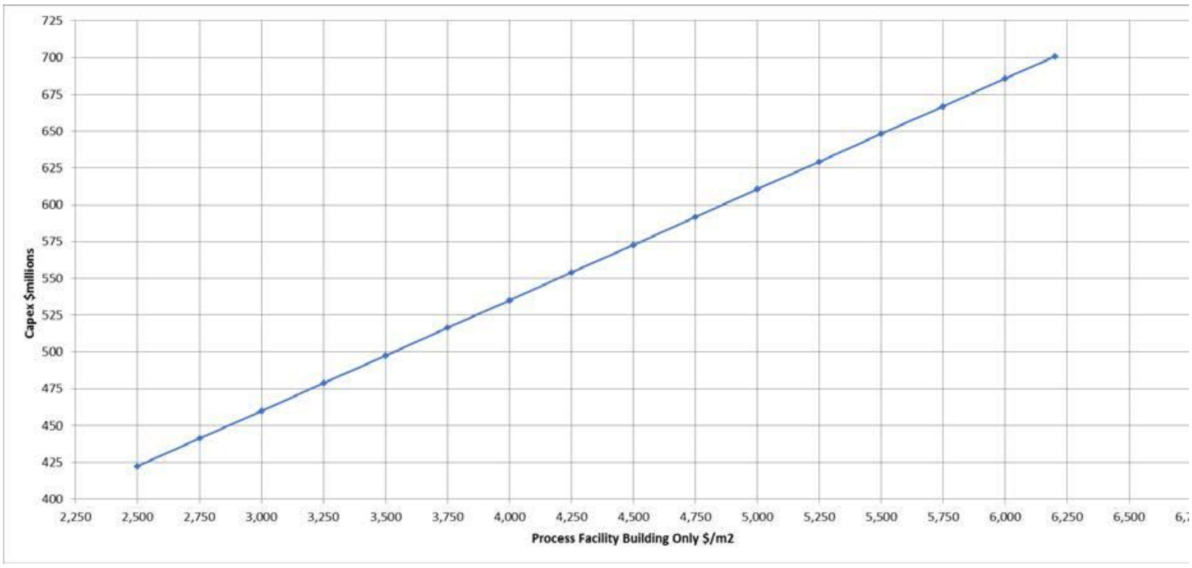


Figure 6-1: Sensitivity Analysis Process Facility Building

Table 6-1: Capital Cost Estimate Summary by Area for Hatchery.

Description	Total (AUD)	% of Total
Site preparation, Earthworks & Services	13,196,972	2.9%
Below ground services	8,987,067	2.0%
Support Buildings	20,774,958	4.6%
Process Facilities	235,314,150	52.0%
Total Direct Costs	**278,273,146**	**61.5%**
Indirect Costs	13,817,292	3.1%
EPCM	40,198,853	8.9%
Owners Costs	Excluded	
Contingency 25%	83,072,323	18.3%
Escalation (5 years)	37,382,545	8.3%
Total Hatchery Capital Cost	**452,744,158**	**100.0%**

6.9 Deployment Capital Cost

The capital cost summary for procurement of the Deployment vessels and equipment is shown in Table 6-2 below:

Table 6-2: Capital Cost Estimate for Purchase of Deployment Vessels and Equipment.

Description	Total (AUD)	% of Total
Medium Transport	30,000,000	51.3%
Small Utility Vessel	3,500,000	6.0%
Deployment Device Putter Together	2,400,000	4.1%
Coral Deployer	7,000,000	12.0%
Total Direct Costs	42,900,000	73.4%
Indirect Costs		0.0%
EPCM		0.0%
Owners Costs	Excluded	
Contingency 25%	10,725,000	18.3%
Escalation (5 years)	4,826,250	8.3%
Total Deployment Capital Cost	**58,451,250**	100.0%

6.10 Total Capital Cost for Base Case.

The total capital cost for the Base Case is shown in Table 6-3 below.

Table 6-3: Total Capital Cost Estimate for the Base Case

Description	Total (AUD)	% of Total
Hatchery	278,273,146	54.4%
Deployment	42,900,000	8.4%
Total Direct Costs	321,173,146	62.8%
Indirect Costs	13,817,292	2.7%
EPCM	40,198,853	7.9%
Owners Costs	Excluded	0.0%
Contingency 25%	93,797,323	18.3%
Escalation (5 years)	42,208,795	8.3%
Total	**511,195,408**	**100.0%**

6.11 Hatchery Operational Cost

The summary of the annual operational costs for the Hatchery is shown in Table 6-4 below.

Table 6-4: Operational Cost Estimate Summary for Hatchery

Description	Total (AUD)	% of Total
Manpower	23,592,711	27.2%
Energy	488,058	0.6%
Consumables	915,004	1.1%
Maintenance	11,469,244	13.2%
Mobile Equipment	147,500	0.2%
Subcontract Services	481,726	0.6%
Sustaining Capital	9,928,172	11.5%
Total Direct Costs	47,022,415	54.3%
Indirect Costs	2,213,226	2.6%
Owners Costs	Excluded	0.0%
Amortisation	14,346,137	16.6%
Contingency 25%	15,895,445	18.3%
Escalation (5 years)	7,152,950	8.3%
Total Hatchery Operational Cost	**86,630,173**	100.0%
Cost per Device including Amortisation	1.92	
Cost per Device without Amortisation	1.53	

6.12 Deployment Operational Cost

The summary of the annual operational costs for Deployment is shown in Table 6-5 below.

Table 6-5: Deployment Operational Cost Summary

Description	Total (AUD)	% of Total
Medium Transport	7,132,800	29.9%
Small Utility Vessel	3,067,776	12.9%
Deployment Devices	3,000,000	12.6%
Berthing costs	320,000	1.3%
Licensing	24,000	0.1%
Base case - Trucks (ex Hatchery to Townsville)	8,112	0.0%
Deployment Device Putter Together	240,000	1.0%
Coral Deployer	700,000	2.9%

Sustaining Capital	1,072,500	4.5%
Total Direct Costs	15,565,188	65.3%
Indirect Costs	214,500	0.9%
Owners Costs	Excluded	
Amortisation	1,716,000	7.2%
Contingency 25%	4,373,922	18.3%
Escalation (5 years)	1,968,265	8.3%
Total Deployment Operational Cost	**23,837,875**	100.0%
Cost per Device including Amortisation	**0.48**	
Cost per Device without Amortisation	**0.43**	

6.13 Total Operational Cost for Base Case

The Total operational cost summary for Deployment is shown in Table 6-6 below.

Table 6-6: Total Operational Cost Estimate for the Base Case

Description	Total (AUD)	% of Total
Hatchery	37,094,243	33.6%
Deployment	14,492,688	13.1%
Sustaining Capital	11,000,672	10.0%
Total Direct Costs	62,587,603	56.7%
Indirect Costs	2,427,726	2.2%
Owners Costs	Excluded	
Amortisation	16,062,137	14.5%
Contingency 25%	20,269,367	18.3%
Escalation (5 years)	9,121,215	8.3%
Total	**110,468,048**	100.0%
Cost per Device including Amortisation	3.03	
Cost per Device without Amortisation	2.43	

6.14 Capital Cost Estimate for the Hatchery

This estimate is for the Base Case Hatchery only. The scope of the estimate includes the following:

- Site preparation, earthworks and services;
- Below ground services;

- Support Buildings;
- Process Facilities (six identical)

6.14.1 Clarifications and Assumptions

The following clarifications and assumptions have been applied in preparation of the capital cost estimate:

- The cost of site or land purchases are not included in the estimate, this is assumed to be part of the client's external costing;
- The contractor's distributable factor also contains the profit and margins provision;
- A SEASIM type process system has been assumed.

6.14.2 Exclusions

The following items are excluded from the Capex estimate:

- Site purchase/land costs;
- Off-site handling;
- Rock excavation;
- OPEX.

6.14.3 Estimating Basis

Quantities

A large portion of the quantities used in the estimate have been provided by WorleyParsons' engineering in the form of high level material take-off sheets (MTOs). These include information received in consultation with AIMS on the aquaculture processes that are envisaged at this conceptual design phase. The following facilities are supported by engineering quantities:

- All site preparation works;
- Support Buildings;
- Process Facilities

Estimating has calculated some of the quantities, generally as described below:

- Where there were obvious items required such as clearing a right of way;
- Applied estimating techniques such as Lang factors to allow for cost for items not supported by quantities at this stage of the study;
- Factored from other studies for similar facilities;
- Design and MTO allowances have been calculated as an overall growth allowance.

Pricing

Recent historical rates have been applied and factored to reflect the pricing list for this study. Lang factors have been applied to the equipment procurement cost to obtain the cost for installation, freight and handling. Contractor's distributable/indirects (including profit margins) are calculated on an overall percentage basis.

6.15 Capital Cost Estimate for Deployment

This estimate covers the purchase, delivery to the project home anchorage and commissioning of Deployment vessels and associated equipment.

6.15.1 Clarifications and Assumptions

The following clarifications and assumptions have been applied in preparation of the Deployment cost estimate:

- All vessels are assumed to be registered in Queensland in compliance with. Class 4C;
- Vessels CAPEX and OPEX were provided by the Clients team namely QUT.

6.15.2 Exclusions

The following items are excluded from the capital cost estimate:

- All recurring costs related to operations offshore;
- Costs related to construction and/improvements of loading dock facilities, if any;
- Capital cost related to provision of road transport (assumed to be by haulage contractors)
- OPEX.

6.15.3 Estimating Basis

Quantity

The number of vessels and their supported equipment is based on an analysis of vessel trip times, an assumed Device deployment rate per Deployment vessel and the expected survival time for juvenile corals in transit after leaving the Hatchery.

Pricing

Prices for vessels are based on the costs available in the public domain for similar vessels.

The price for the Deployment Device Putter Together is based on similar equipment that is used on packing lines in other industries.

The price for the Coral Deployer equipment is based on similar equipment owned by WorleyParsons

6.16 Operational Cost for Hatchery

6.16.1 Clarifications and Assumptions

The following clarifications and assumptions have been applied in preparation of the Operational cost estimate:

- A burden of 22% is applied to basic wages.

6.16.2 Exclusions

The following items are excluded from the Operational cost estimate:

- Sustaining capital expenditure

6.16.3 Estimating Basis

Manpower

All staff permanently employed in the six Process Facilities and in support roles, are as shown in the Staff Organisation Chart in Figure 6-2 below. For the Process Facilities this is based on advice provided by AIMS and takes account of normal rostering. Additional casual staff are recruited during the four spawning seasons and are assumed to be on two twelve-hour shifts. Numbers of support staff are based on an assessed requirement.

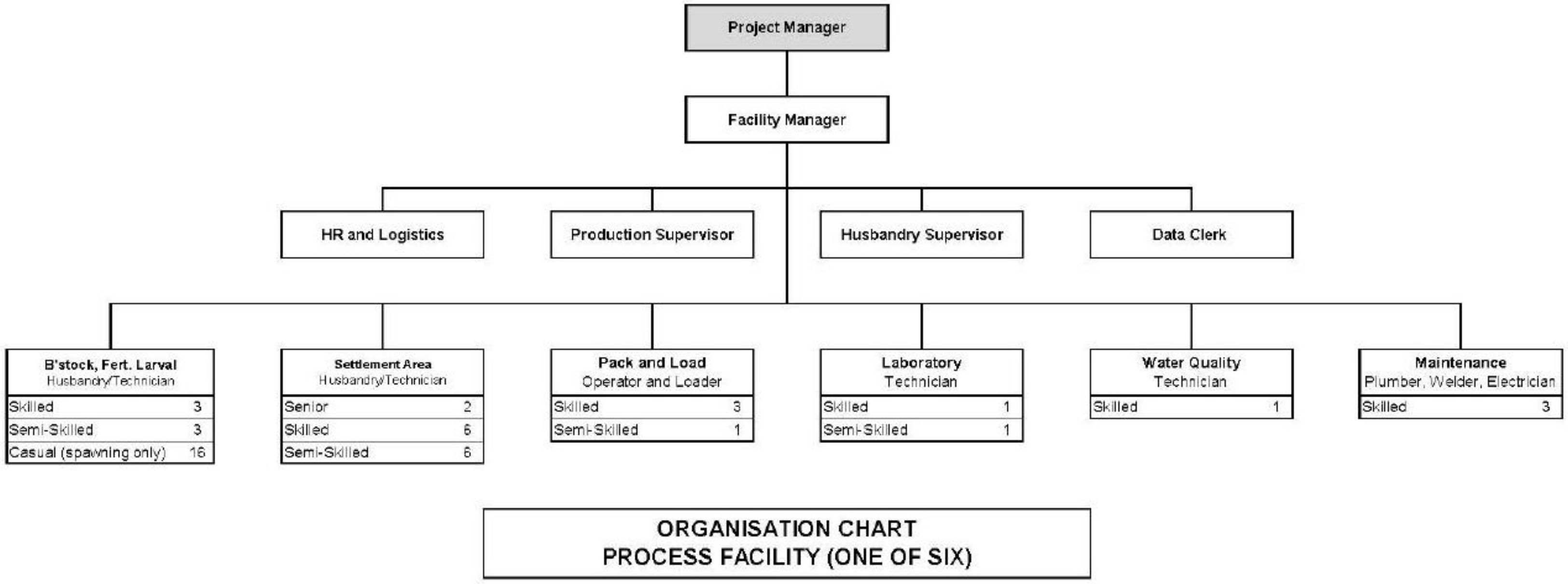


Figure 6-2: Organisational Process Facility

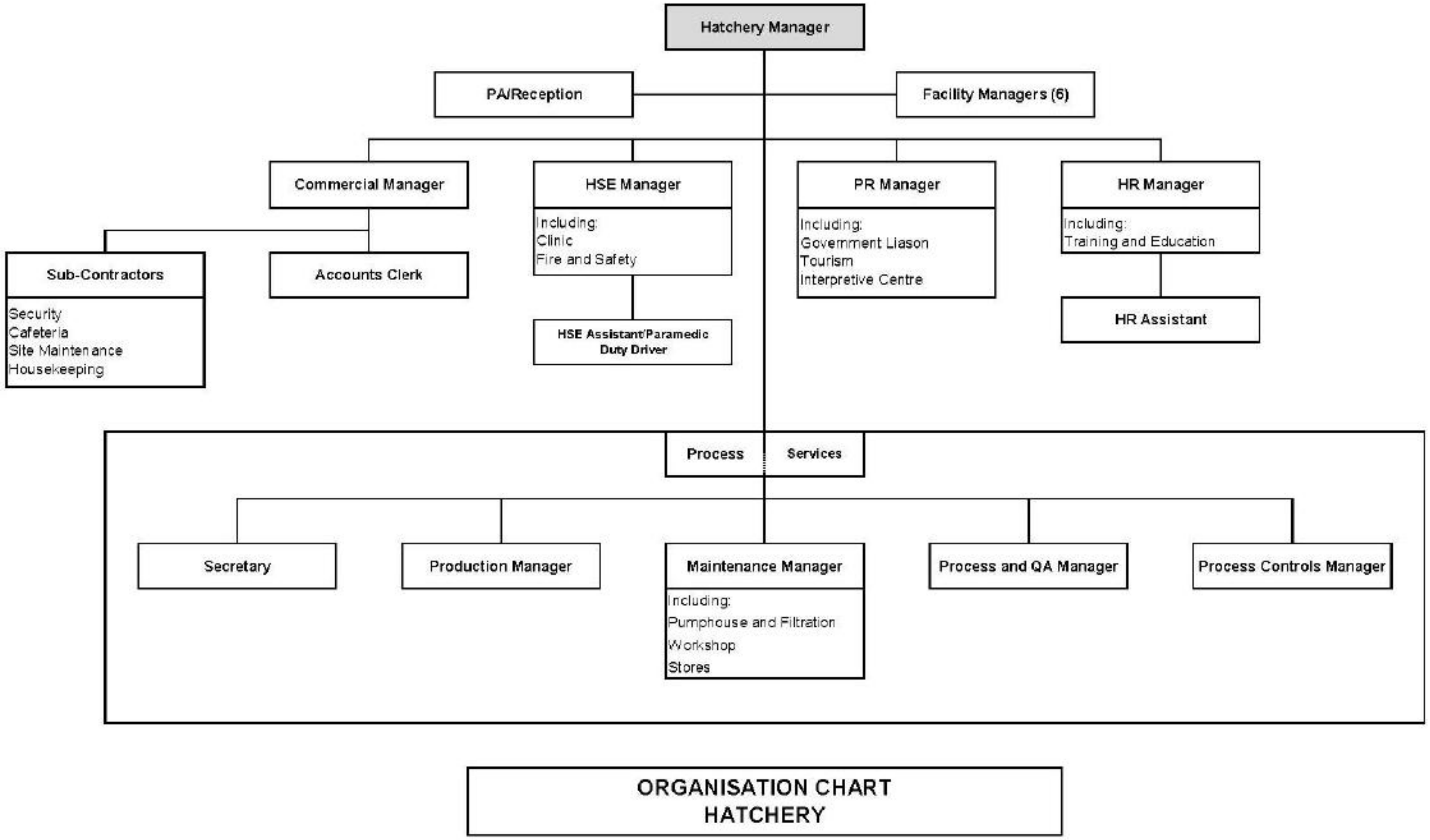


Figure 6-3: Project & Hatchery Organisational Chart

Sub-Contract Services

This item covers security and housekeeping and is based on assessed normal industrial requirements and labour rates. Security is assumed to operate 24/7.

Energy

This item covers annual consumption of gas and electricity, based on rates provided by AIMS, as follows:

- LPG: 72 cents per litre;
- Electricity: 17 cents per kWh.:.

Process Facilities

Consumption of LPG and electricity for the process trains and support systems in each Process Facility is based on information provided by AIMS.

Estimated electricity consumption for HVAC in the Broodstock, Fertilisation and Larval areas is based on estimated installed kW and estimated time of operation.

Estimates for general power, lighting and air conditioning are based on specific percentages of the building areas, depending on their function.

Site Works

Electricity consumption for the seawater pumping and filtration system is based on installed kW and estimated annual running time, including peak demand during the four spawning periods.

Power consumption for the Support Buildings is based on specific percentages of the building areas and estimated operating times.

Power consumption for area lighting is based on installed kilowatts and estimated running time

Maintenance

All estimates of maintenance costs of fixed and mobile assets are based on specific percentages of the capital cost of each asset when new and include all labour, plant and materials.

Consumables

This item covers all process and operational materials that are not otherwise covered in the Maintenance estimates.

Process Facilities

The price for CHOCO boards is based on a quotation out of China.

The estimated cost of general consumables for the process trains and general expenses, including administration, is based on a percentage of manpower costs.

Site Works and Seawater Supply

Consumables associated with the daily running of Support Buildings are based on a percentage of manpower costs.

For the filtration system the estimated costs of dosing chemicals and filter membranes are based on industry norms and equipment running times.

6.17 Operational Cost for Deployment.

6.17.1 Clarifications and Assumptions

The following clarifications and assumptions have been applied in preparation of the Deployment cost estimate:

- All vessels are assumed to be registered in Queensland in compliance with. Class 4C
- Only initial operations in the Central area (ref Figure 4-1) of the Reef have been considered in the estimate. Potential operations out of Townsville in the North and Far North, where the majority of damage has occurred to date, would require additional Supply Vessels and road transport.
- Supply vessels are loaded and unloaded at the Port of Townsville.
- The Base Case site is assumed to be located near to SEASIM, 55km from the port.
- The unit price for Devices is assumed to include delivery to the Hatchery in crates.
- A burden of 22% is applied to basic wages.

6.17.2 Exclusions

The following items are excluded from the Operational estimate:

- Operations in the Far North, North and the South areas of the Reef. (ref. Figure 4-1).
- Delays at the port affecting Supply Vessel schedules;
- Sustaining capital expenditure

6.17.3 Estimating Basis

Operational costs are calculated on the following basis':

6.17.4 Vessel Running Costs

These cover the Supply and Deployment vessels and are based on information provided by AIMS. The rates include labour, maintenance and fuel and are applied to operations for four periods of 60 days each per year.

Crewing numbers are as shown in the Deployment Staff Organisation Chart in Figure 8.11.3.1 below., including allowances for rostering.

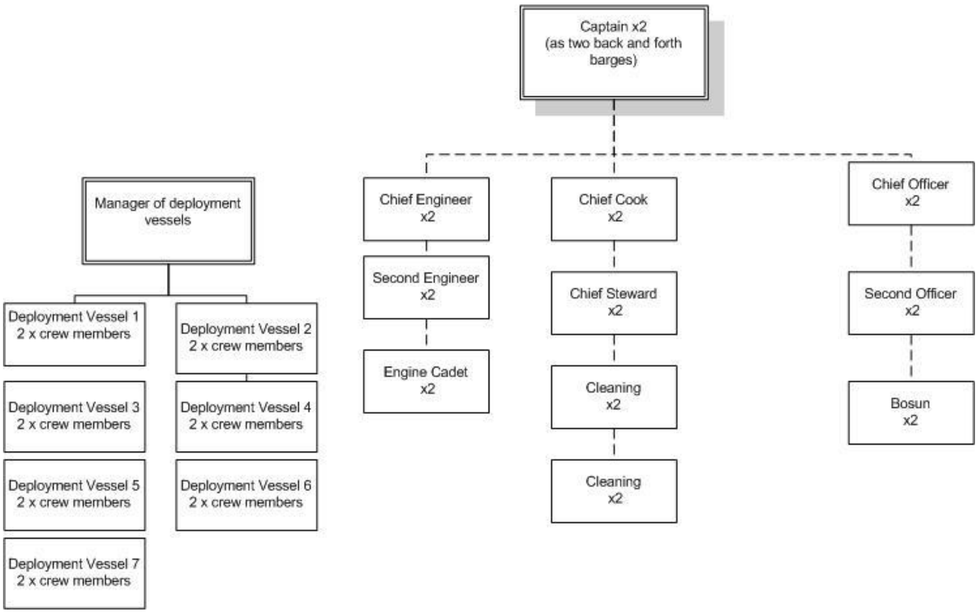


Figure 6-4: Organisational Chart for Deployment

6.17.5 Onshore Road Transport

There are approximately 30 Medium Transport Vessel trips per 240 days. Based on a 8-day Deployment of Devices per trip and a container holding two Transport Tanks or Device crates, then there will be a total of 567 road trips per 240 days. A road trip is assumed to be 50km between the Hatchery and the Port of Townsville.

Deployment Device Putter Together and Deployer

The maintenance costs are estimated at 10% per annum pro rata 240 operational days.

The cost of Devices is based on a quote from China and is assumed to include delivery to the Hatchery.

Berthing, Certificate of Survey and Crew Licensing

Berthing costs are based on Port of Townsville wharfage charges.

Survey and crew licence estimates are based on statutory requirements.

7. OUTTURN COSTING ASSESSMENT

Currently, there are positive and negative impacts of aquaculture on biodiversity conservation.

This study looked at mass coral production using the well-defined *product* and lean manufacturing, with wholesale switch to autonomous systems where practical. The study's objective was to annually deliver 30 million healthy juveniles to the reef. The study incorporated economic considerations to build large-scale coral nurseries.

So far, restoration has been carried out only on scales of tens of square meters to several hectares. Large-scale nurseries and transplantation could potentially change this constraint and enable interventions to occur at whole of reef levels. In this research, mass production of coral, for at-scale reef restoration in the Great Barrier Reef, Australia was investigated (Mellor, Mead et al. 2018).

To compare our cost per healthy deployed coral (as a device) (Figure 1-1), and to commercially profitable aquaculture ventures, a comparison of the various aquaculture species was undertaken (Table 7-1).

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Table 7-1: Outturn Costing Assessment

Species or Species Group	Tonnes per hectare	Costs Per hectare (AUD)	Costs per Tonne	Average Size of saleable product (kg)	How many X in each tonne	Cost per saleable product (AUD)	Crops per year	proxy calc
Barramundi (Queensland Government 2016c)	3.3 (Queensland Government 2016c)	$52,000 (Queensland Government 2016c)	$15,600	0.5 (Queensland Government 2016b)	31,200	$0.50	2 (Queensland Government 2016b)	$15,000,000
Shrimp (Queensland Government 2016c)	12.8 (CSIRO 2017)	$150,000 (Queensland Government 2016a)	$11,718	0.03 (Queensland Government 2018a)	390,625	$0.03	3 (Queensland Government 2018a)	$900,000
Freshwater - Fin fish farm i.e. silver perch (Queensland Government 2016c)	7 (Queensland Government 2016c)	$100,000 (Queensland Government 2016c)	$14,285.71	0.5 (Queensland Government 2016c)	28,571	$0.50	2 (Queensland Government 2016c)	$15,000,000
Redclaw (Queensland	5000 (Queensland	$86,750 (Queensland	$17.35	0.05 (Queensland	347	$0.05	1	$1,500,000

Species or Species Group	Tonnes per hectare	Costs Per hectare (AUD)	Costs per Tonne	Average Size of saleable product (kg)	How many X in each tonne	Cost per saleable product (AUD)	Crops per year	proxy calc
Government 2016c)	Government 2018b)	Government 2016c)		Government 2018b)				
Catfish	16.3 (Beibei. Jia, Sophie. St-Hilaire et al. 2016)	$101,310 (Beibei. Jia, Sophie. St-Hilaire et al. 2016)	$6,215.34	1.1 (WorldWide Aquaculture 2015)	5,650	$1.10	0.3 (WorldWide Aquaculture 2015)	$33,000,000
Tilapia	20 (Southwest Aquaponics and Fish Hatchery 2016)	$14,474 (N. I. Toma, M. Mohiuddin et al. 2015)	$723.70	0.45	1,608	$0.45 (Southwest Aquaponics and Fish Hatchery 2016)	0.75 (Southwest Aquaponics and Fish Hatchery 2016)	$13,500,000
Abalone	200 (M. Heasman and Savva 2007)	$60,000	$60,000 (S. Dakis 2016)	0.1 (Ocean Grown Abalone 2017)	600,000	$0.10	0.25 (M. Heasman and Savva 2007)	$3,000,000

8. GENERAL INFORMATION

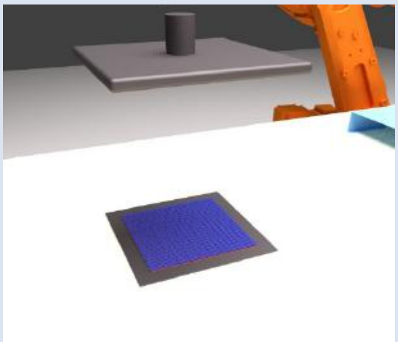
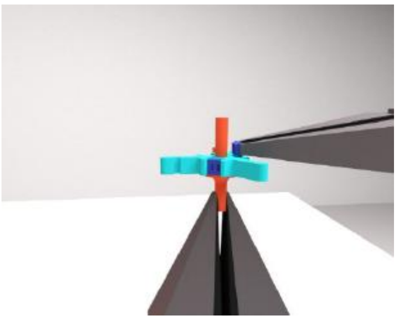
8.1 Abbreviations

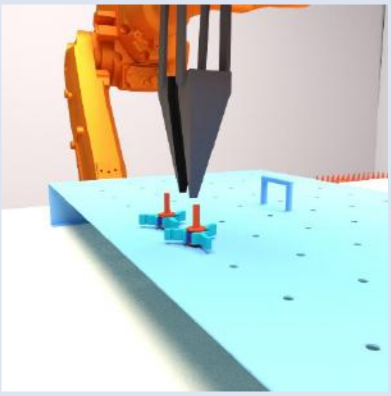
Key abbreviations for this project are as follows:

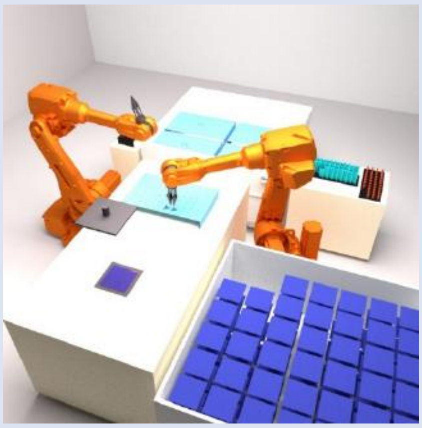
Acronym	Definition	Page first appeared
AHD	Australian Height Datum	63
AIMS	Australian Institute of Marine Sciences	14
ARI	The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.	67
CHOCO	Name given to settlement boards	19
CSIRO	The Commonwealth Scientific and Industrial Research Organisation	14
GBR	Great Barrier Reef	11
HAT	Highest Astronomical Tide	68
LAT	Lowest Astronomical Tide	68
MSL	Mean Sea Level	68
NSW	New South Wales	1
PAR	Photosynthetic Active Radiation	36
PMMA	Poly(methyl methacrylate)	36
PSU	Practical Salinity Units	36
RRAP	Reef Restoration and Adaption Programme	11
SCU	Southern Cross University	14
SEASIM	The Australian Institute of Marine Science's National Sea Simulator	10

SECORE	SECORE (SExual COral REproduction) is an international non-profit organization focused on coral reef conservation. They also have a bespoke deployment device as referred to in this document.	7
TRL	Technology Readiness Levels	52
TSS	Total Suspended Solids	36

8.2 Key Terms

Term	**Meaning**	**Picture**
CHOCO Board	PCB type waxed material with pre designed “snapped points”	
CHOCO Tile	The smaller sub unit of the above	

Term	Meaning	Picture
Deployment Device	The device deployed to the reef to meet the objective of the study	
Medium Transport Vessels	Medium Transport is to be stationed at the Reef and provide a continuous supply of Restoration Materials to the Deployment Vessels	
Deployment Vessels	This operation will be undertaken by specialist crews using purpose-designed Deployment Vessels (Small Utility Vessel in CAPEX/OPEX)	
Offshore Transportation Tank	For the Base Case it is assumed that movement of the Transport Tanks from the Production Facility to the loading Dock will be by haulage contractor on public roads. There are two types of tanks proposed.	

Term	Meaning	Picture
Offshore Erection Device	The purpose of the Offshore Erection Device is to be stationed on the Medium Transport Vessel and provide a continuous supply of Restoration Materials to the Deployment Vessels.	
Deployment Device Deployer (Appendix B – Unmanned Subsea Surveyor – Trade name)	The purpose of the Deployment Device Deployer is to be stationed on the Deployment Vessel	

8.3 Financial Model Manipulations

The following functionality has been built into the financial model to see various relationships:

- SLIDER 1 – SPAWNING EVENTS PER YEAR WILL BE MANIPULATED IN THE FINANCIAL MODEL
- SLIDER 2 - FOR MANIPULATION OF THE FINANCIAL MODEL A COMBINED EQUATION WAS ADOPTED USING ALL THE DATA POINTS MODELLED AS DETAILED IN TABLE 2 2.
- SLIDER 3 – LARVAE INPUTTED INTO THE SYSTEM AT MONTH 2 AND GROWN OUT INSITU FOR THE NEXT 12 MONTHS.
- SLIDER 4 – DEPLOYMENT RATE
- SLIDER 5 – DEPLOYMENT DAYS

The model is a separate deliverable for AIMS to be able to manipulate sensitivities.

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Appendix A - Photos of SEASIM Facility

Figure Appendix A-9-1: Broodstock Holding Tank

Figure Appendix A-9-2: Indoor Mesocosm System

Figure Appendix A-9-3: Larval Rearing (70L)

Figure Appendix A-9-4: Larval Rearing (70L+500L)

Figure Appendix A-9-5: Open Plan External General

Figure Appendix A-9-6: Open Plan External Systems

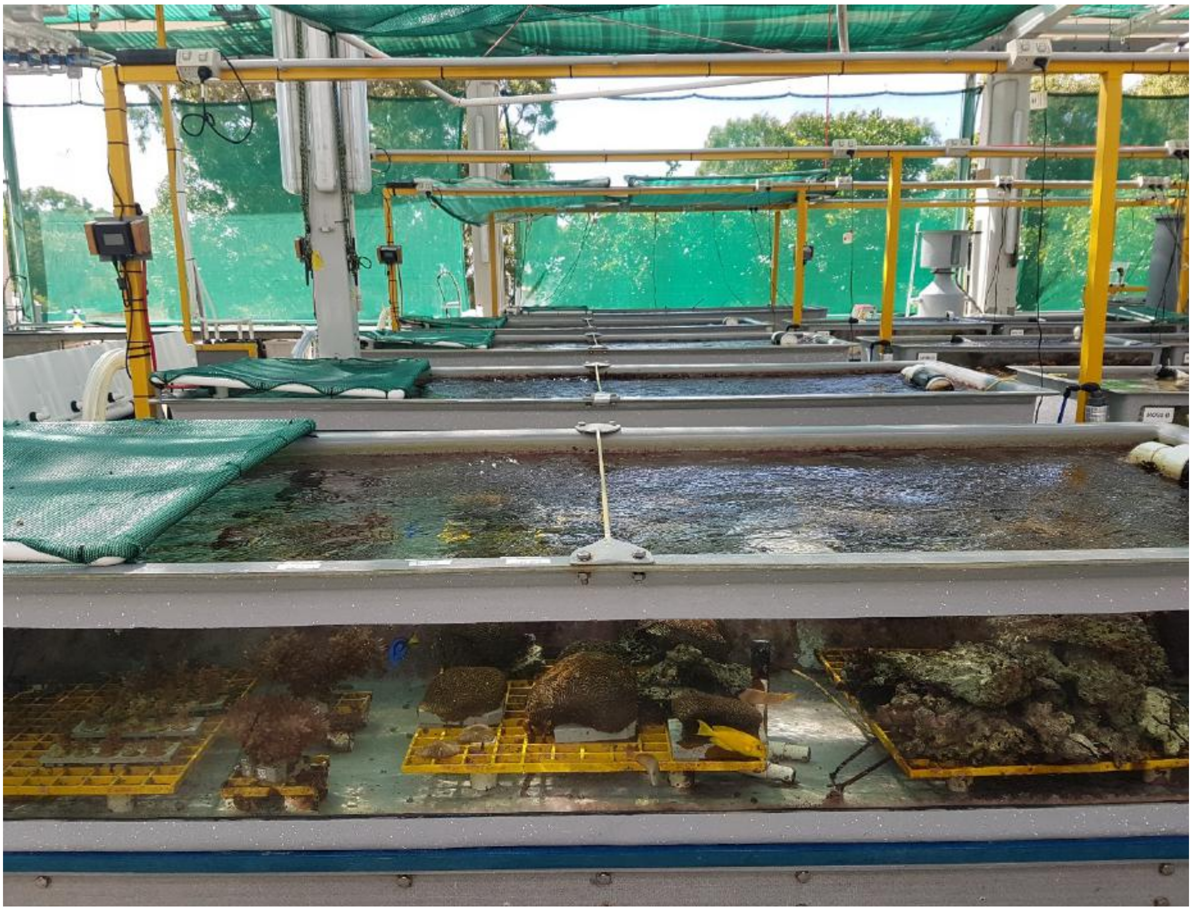


Figure Appendix A-9-7: Open Plan External Holding

Figure Appendix A-9-8: Open Plan External Internal (1)

Figure Appendix A-9-9: Open Plan External Internal (2)

Figure Appendix -A-9-10: Spat Grow Out Room

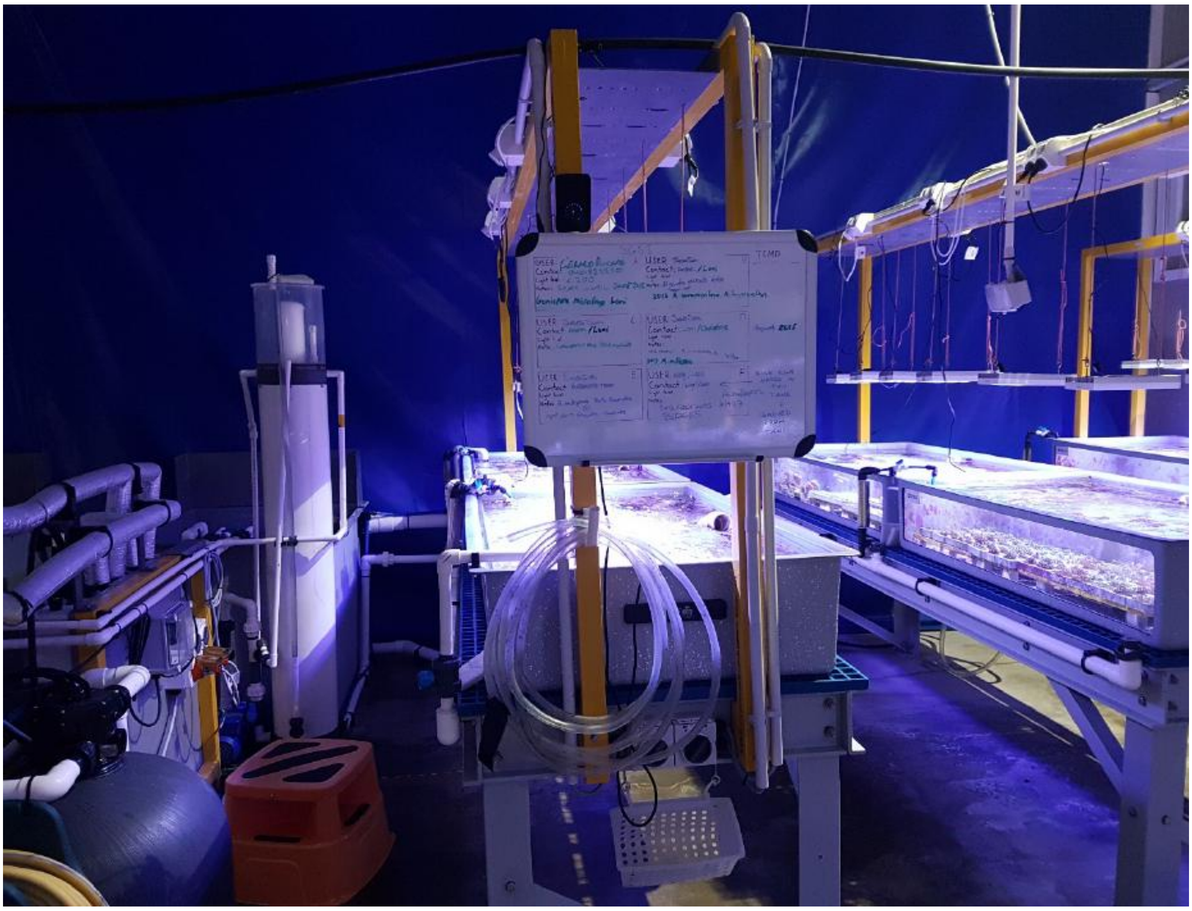
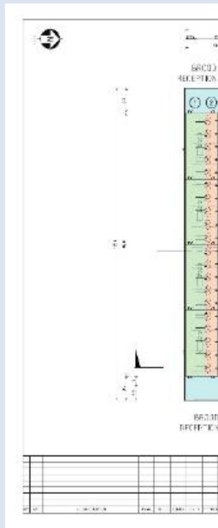
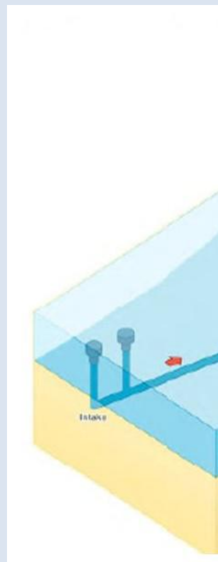
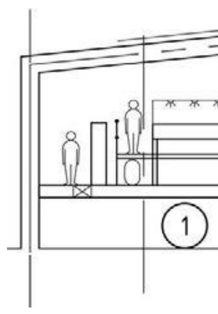


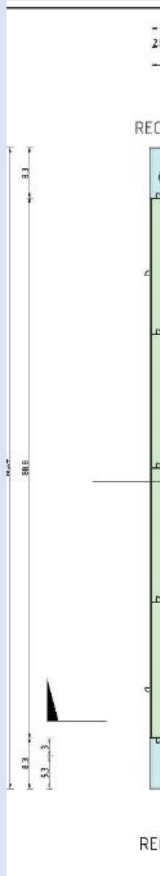
Figure Appendix A-9-11: Spat Grow Out System

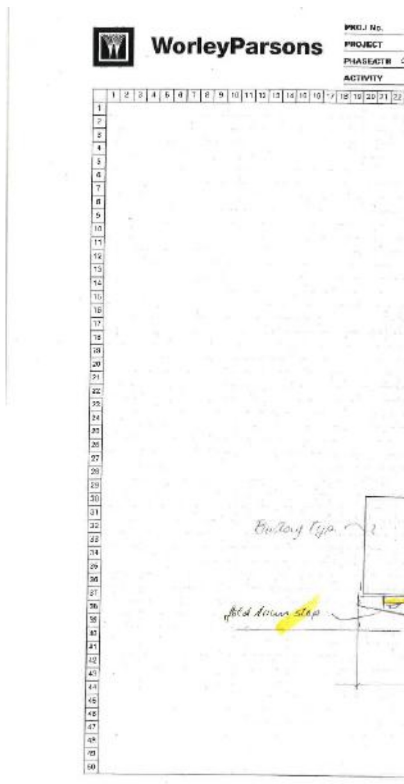
Appendix B - Unmanned Subsea Surveyor

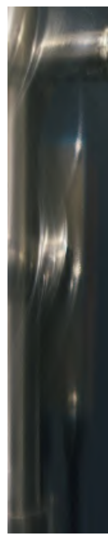
Appendix C - Value Engineering

Table 9-1: Value add opportunities

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
1	INNOVATION	Process Facilities	Hatcheries of manageable size	Autonomous production units reduce impact of an outage. Reduces risk of species cross contamination Allows for prototyping and managed production ramp -up Replicable at Distributed locations	
2	INNOVATION	Site Layout	Two independent seawater supply and filtration systems that can be cross-connected.	Redundancy of supply. Ease of maintenance.	
3	INNOVATION	Coral production lines	Concept of discrete production lines in groups of five in a Module	Each Module is autonomous Easy to manage and control.	
4	INNOVATION	Coral production lines	Gravity transfer between the four stages	No need for pumping	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
4	INNOVATION	Coral production lines	Four discrete modules of 5 Larval and Settlement trains.	Improved redundancy. Facilitates process management and control Reduces risk of cross contamination	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
5	INNOVATION	Fertilisation	Bucket carousel	Provides flexibility of management of intense activity during spawning periods Allows distribution of fertilised larvae to selected production train, without complicated and extensive transfer plumbing.	
6	INNOVATION	Broodstock tank loading	Wide access ways for delivery of incoming stock by forklift	Minimises possible delays in transfer. Allows delivery tanks to be quickly placed alongside Broodstock tanks for transfer of stock to Broodstaock tanks	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
7	INNOVATION	Production lines	Pre-programmed transfer valves between Fertilisation, Larval Rearing and Settlement tanks.	Allows for central pre-planning and control of tank usage and allocation of species.	
8	INNOVATION	Production Lines	Modularise train components in two lines per SKT0002 and 0003 for assembly in factory conditions, including pumps, plumbing,, electrics and instrumentation. Modules would be transported to site on standard-width vehicles, placed in position and services connected between modules with plug-in connectors	Assembly in standardised production line conditions Improved quality management Minimised site labour Ease of assembly on site Ease of disassembly if required, for replacement of change of layout.	
9	INNOVATION	Deployment Device (potential innovation for R&D)	Identify cheaper material, production and handling for Deployment Device	Reduces large component of daily cost. (average 100,000 Devices per day)	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
10	INNOVATION	Marine Transport	With the focus on reducing environmental impacts as well as the offshore workforce for the deployment, it was considered if autonomous surface vehicles could be used.	Environmental and cost benefits	
11	INNOVATION	Deployment	Electric Small Utility Vessels (for coral deployment)	Vessels charged overnight from LNG fuelled Transport vessel	
12	INNOVATION	Deployment	LNG fuelled Medium Transport vessels (for coral and Device supply to sites)	Compared with an equivalent diesel fuelled engine, running on LNG emits around 90 percent less NO2 emissions, 99 percent less particulate matter, and up to 15 percent less CO2 – rising to 95 percent less CO2 when using biomethane,	
13	INNOVATION	Deployment	Autonomous coral seabed mapping	Accuracy and reduced cost	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
14	INNOVATION	Deployment	Autonomous deployment using dynamic positioning	Use digitised seabed mapping data to control xyz positioning and movement of Deployment Vessel and Device delivery to seabed.	
15	INNOVATION	Broodstock	Either eliminate or mechanise the transfer of delivered broodstock to the Broodstock tanks	Either use the same tanks for broodstock transport and holding to save cost and human intervention, or assist the human intervention by mechanisation.	
16	AUTOMATION	Broodstock	Movement of the delivered transport tanks to the selected Broodstock tanks	May save labour. Improved efficiency of pre-planned activities	
17	AUTOMATION	Broodstock	Development of sensor system to replace human intervention in the observation of the spawning and skimming activities and timing of transfer to the Fertilisation tanks	Depending on reliability of system, could reduce the intensity of human input and activity during the critical spawning period.	
18	AUTOMATION	Fertilisation	Manually pre-programmed automation of the transfer of the propagules from the Fertilization tanks to the Larval tanks	May save labour. Improved efficiency of pre-planned activities	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
19	AUTOMATION	Fertilisation	Control of the fertilisation density and programming of valves to direct the flow to the selected Larval tank(s).	May save labour. Improved efficiency of pre-planned activities.	
20	AUTOMATION	Larval rearing	Sensor system to replace human intervention in the observation of the larva and timing of transfer to the Settlement tanks	May save labour. Improved efficiency of pre-planned activities	
21	AUTOMATION	Settlement	Placement of Choco boards	Reduces the amount of human input	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
22	AUTOMATION	Settlement	Underwater sensing of the development of the juvenile corals to signal readiness for transfer	Reduces the amount of human input	
23	AUTOMATION	Settlement	Transfer of settled media to the Transport tanks	Reduces the amount of human input	
24	AUTOMATION	Loading Transport tanks	Handling and loading Transport tanks	Reduces the amount of human input	
25	AUTOMATION	Loading Transport tanks	Integration of deployment plans and actual events with Device supply logistics	Minimise human involvement leading to more effective and efficient implementation	

Item	Innovation/Automation	Location	Opportunity	Benefit	Pictures – general idea thinking
CHOCO boards/deployment device	INNOVATION	Deployment	Investigating density of zircon verse alumina ceramics	100% denser and adsorbs moisture	
MICRO-FRAGGING	INNOVATION	Settlement Tanks	Fracking gives slightly increased numbers to out of season spawning	Automatic fracking unit to traverse tank splitting settled corals