4. Results from targeted ecotoxicological studies that test the susceptibility of juvenile greenlip abalone to impacts from elevated levels of suspended sediments and establish an operational NOEC for this species in South Australia.

Collectively these four lines of assessment demonstrate that:

1. Abalone are more resilient to suspended sediments than other aquaculture species that have been investigated.
2. Abalone in general (including the greenlip abalone) are highly resilient to impacts from suspended sediments at the concentrations likely to be experienced from the construction and operation of the Kangaroo Island Seaport.
3. The levels of suspended sediments that are likely to be experienced at Smith Bay, as a result of the construction and operation of the KI Seaport, are below the ambient values for the Yumbah Narrawong farm in Victoria. Given that the Narrawong farm has been in operation for 17 years this finding provides a very robust test of the long-term impacts of suspended sediments on greenlip abalone in an aquaculture setting.
4. In the ecotoxicology studies juvenile greenlip abalone were unaffected by a 24-h exposure to suspended sediments at a concentration of 250 mg/L. This value has been adjusted down by a factor of ten to produce a conservative NOEC (No Observable Effect Concentration) of 25 mg/L which is assumed to represent a Total Suspended Sediment (TSS) concentration at which there are no chronic or acute impacts from exposure.

On the basis of these findings it is concluded that the construction and operation of the Kangaroo Island Seaport will not have any measurable impact on water quality that would impact on the performance of the Yumbah Smith Bay abalone farm.

4.2.2.2. Overview of the impact of suspended sediments on abalone

In broad terms the scientific literature considers:

- Physical burial and smothering of wild abalone (e.g. Marshall and McQuaid 1989; Sainsbury 1982) and the loss of attachment due to surface occlusion (Chew *et al.* 2013);
- Impacts of suspended sediments on larval development and survival (e.g. Lee 2015; Chung *et al.* 1993; Phillips and Shima 2006);
- Impacts of suspended sediments on the physiology and survival of juvenile, sub-adult and adult abalone (e.g.; Sainsbury 1982, Yoon and Park 2011, Chew *et al.* 2013);
- Possible mechanisms for impacts from suspended sediment (Marshall and McQuaid 1989; Chung *et al.* 1993).

In the wild *Haliotis* (abalone) populations are vulnerable to both direct and indirect effects from sedimentation processes (Chew *et al.* 2013) and these effects include lethal, sublethal and behavioural responses (Newcombe and Macdonald 1991). By and large most of the documented impacts occur during the larval and early juvenile (post-metamorphosis) phases of the abalone life history and there are few published papers detailing impacts on sub-adult through to adult animals.

The paucity of papers detailing negative effects of suspended sediments on sub-adult through to adult animals is likely because such impacts rarely occur in the natural environment. Most southern

Australian abalone species (with the exception of *H. cyclobates*), live in environments where they are frequently exposed to high levels of suspended sediments (see e.g. Figure H-7, Figure H-8).

Figure H-7: Image grab from film showing wild harvest of greenlip abalone (Abalone Wars S2, Discovery Channel) near Port Lincoln. Note the massive amount of sediment that is being suspended due to wave action across the habitat (blurring on both left and right-hand side of the image is due to sediments suspended in the water column). This image is taken from the habitat in which the diver is harvesting wild abalone and illustrates that in their natural environment abalone are frequently exposed to very high sediment loads in the water column.

Figure H-8: Images of greenlip abalone growing in an in-sea aquaculture setting (left; source: fis.com from Ocean Grown Abalone) and in a natural habitat (right; source: Victorian Department of Economic Development 2015) . Note that the animal is naturally exposed to very high sediment levels as evidenced by the sediment accumulation on the shell and characteristics of the substratum.

Shepherd (1973) describes the habitat, feeding behaviour, food and ecological relationships with predators across five species of abalone that occur in South Australia, noting that:

1. *Haliotis cyclobates* occur in calm water communities within seagrass and razorfish communities and feed on drift or perhaps through browsing.
2. *Haliotis laevigata* (greenlip abalone - grown at Yumbah on Kangaroo Island) naturally live on exposed sublittoral reefs where they trap drift algae as well as graze on attached plants.
3. *Haliotis rubra* (blacklip abalone – which may be grown at Yumbah) prefer caves in calm to rough water environments and feed on either drift algae or graze/browse the attached community depending on habitat.
4. *Haliotis roei* live in sublittoral narrow crevices in rough water locations and nocturnally graze on the surrounding reef algal community.
5. *Haliotis scalaris* are found in boulder fields and crevices and are similar in feeding behaviour to *H. ruber* (red abalone).

Both the greenlip abalone *Haliotis laevigata* (i.e. the species grown at Smith Bay) and the blacklip abalone *Haliotis rubra* (i.e. a species that may be grown at Smith Bay) live on exposed coastal reef systems. Greenlip abalone typically inhabit low-profile reefs and boulders, often adjacent to the sand line, where sediment resuspension due to wave action is a regular feature of the natural environment. Such locations offer a higher probability of encounters with drift macroalgae on which abalone feed (Shepherd 1973; Wells and Keesing 1989 in Wood and Buxton 1996) but importantly such environments are also routinely subjected to high levels of suspended sediments as material is entrained into the water column through wave action (see for example Figure H-7).

Blacklip abalone occupy similar geographic areas to greenlips although not extending as far to the west. They generally adopt a more cryptic lifestyle inhabiting rock crevices and other areas with less direct exposure to water flow but nevertheless are routinely subjected to suspended sediments by virtue of the proximity to the exposed sand areas in the adjacent environment.

Importantly, Shepherd (1973) did **not** infer that abalone of any of the above species were sensitive to suspended sediments (although it might be inferred that *H. cyclobates* would have a lower tolerance). Furthermore, it is reasonable to infer from their habitat preferences (Figure H-8) that both *H. laevigata* and *H. rubra* would be resilient to quite high levels of suspended sediments given that these are a common feature of the habitat in which the animals live.

While there has been very little work on the impacts of suspended sediments on *Haliotis laevigata* or *Haliotis rubra* there have been studies on other species with broadly similar morphologies to these two Australian species. Tissot (1992) suggested that abalone could be divided into 4 broad groups based on shell sculpture (morphology) and further that within these groups the animals could also be differentiated based on the drag coefficient of the shell. This approach allows a comparison of the form and function of abalone of different species and provides a basis for drawing comparisons from the work that has been done elsewhere with the Australian species of interest.

H. laevigata has similarities in terms of shell sculpture to two other species (Figure H-9), *H. iris* and *H. cracherodii*, both of which have been studied more extensively. Importantly, the work by Tissot (1992) has also highlighted that in the context of drag coefficients, *H. laevigata* is somewhat exceptional being highly adapted (low drag coefficient) to the higher water flows characteristic of the more wave exposed environments; an environment where it would be frequently exposed to concomitantly higher loads of suspended sediments. This issue is developed further in the following discussion.

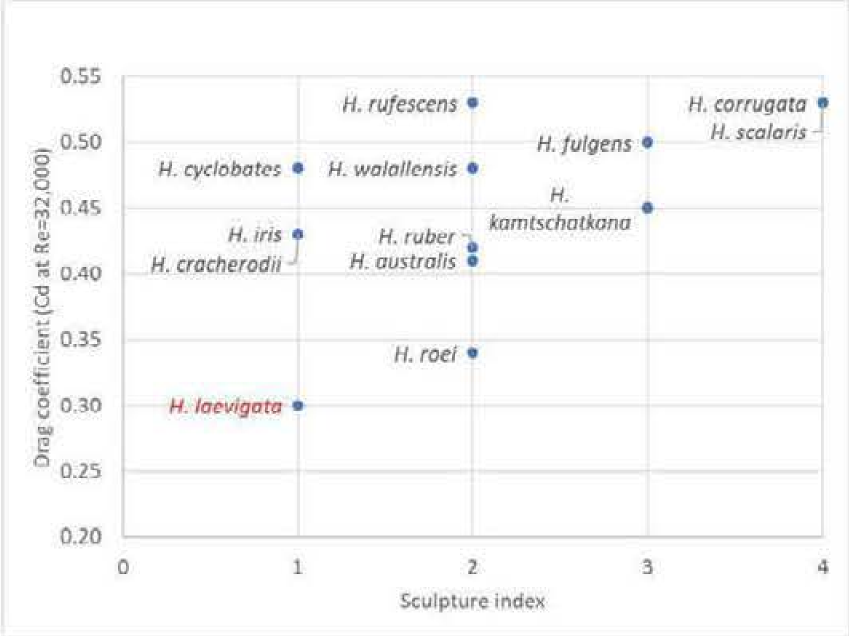

Figure H-9: Comparison of abalone species based on shell sculpture index and drag coefficients based on data and descriptions in Tissot (1992). Drag coefficients were not obtained for *H. rubra*, *H. diversicolor* (both sculpture index 2) or *H. discus* (sculpture index 3).

4.2.2.3. Direct burial and smothering impacts

Work on *H. iris* has demonstrated that suspended sediments may increase mortality of abalone larvae as well as inhibit larval settlement (Phillips and Shima 2006, Onitsuka *et al.* 2008). Sediments are also known to impact on crustose coralline algal communities and thereby reduce habitat suitability (Aguirre and McNaught 2010).

Sainsbury (1982) investigated the effects of sediments on an unfished (wild) population of *Haliotis iris* in Peraki Bay (New Zealand), in terms of population size and structure, growth, recruitment, mortality and reproduction. He concluded that a "major cause [of mortality]" was burial due to the movement of large volumes of benthic sediments that resulted in changes in sediment depths by up to 1 m. Sainsbury (1982) did not make any inferences as to the effect of suspended sediments on larvae or recruits.

This mortality was exacerbated by abalone behaviour whereby animals gravitated towards the sediment-boulder interface where they were closer to a higher abundance of the drift algae that they feed upon. Consequently, when the sediment levels suddenly increased (e.g. due to storm activity or other sediment transport processes), these animals were at higher risk of being buried while surviving abalone would likely move higher on their boulders.

In this sort of environment, sediment movement is not associated with material being suspended in the water column and then settling out over the top of animals. The physical process of burial is primarily driven by a phenomenon called bed-flow transport which involves the movement of sediment grains along the seabed through a combination of rolling, sliding and saltation (or hopping; Einstein 1950, Staudta *et al.* 2017). Such processes only operate under high current flow conditions when water moves over a **sandy substratum.** Such environments are typical of abalone habitats on exposed coasts where abalone live on low profile reefs or in boulder habitats adjacent to, or intermixed with, sandy areas; as such these processes simply cannot operate within an abalone farm where the substratum is **concrete**[10].

The work by Sainsbury (1982) was conducted on juvenile abalone not the sub-adults which live on the raceways of an abalone farm (noting that on an abalone farm juvenile abalone are held in nursery tanks where they live on vertical plates and are able to migrate away from the bottom of the tanks where sediments naturally deposit).

The finding that *H. iris* have little tolerance for sediment burial, has some support from a study by Marshall and McQuaid (1989) comparing tolerance to sand inundation in the pulmonate limpet *Siphonaria capensis* when compared to the prosobranch *Patella granularis* (noting that abalone are also prosobranchs i.e. in the molluscan Subclass Prosobranchia). Marshall and McQuaid (1989) found that the pulmonate survived total coverage with sand for considerably longer periods than the prosobranch.

McShane (1992) undertook a review of what was known about the early life history of abalone with a focus on *Haliotis rubra* (the Australian blacklip abalone). That review referred to the previous work on susceptibility to sediments by Sainsbury (1982).

In addition to burial, Tegner and Butler (1989) and Cox (1962; cited in Shepherd and Breen 1992) indicate that storms can cause abalone death through crushing from dislodged boulders, freshwater runoff and deposition (resulting in burial) by silt and debris. Burial does not constitute a viable cause of mortality for farmed abalone where the volume of sand in the water is limited to no more than a few tens (rather than thousands) of milligrams per litre.

4.2.2.4. Impacts of suspended sediments on larval development and survival

Phillips and Shima (2006) undertook an experimental study that simulated chronic and acute influences of terrestrial runoff to determine the effects on larval development, survival and settlement of a sea urchin (*Eveshinus chloroticus*) and the paua abalone (*Haliotis iris*) in New Zealand. Their study had several key results concerning the larvae of both species:

1. Abalone larvae appeared to be more sensitive to sediment stress when compared to those of the sea urchin;
2. Abalone larvae experienced mortality across all sediment concentrations with higher concentrations being more influential;
3. Short term exposure to sediments was more influential on younger larvae; and
4. Effects of sediments on abalone larvae were prolonged even after removal of the stress.

It is important to note that Phillips and Shima (2006) examined the **larval** phase of the target species which comprised animals that were typically less than 72-96 hours old. As detailed previously (section 3.4.2) farmed larvae are encouraged to settle on conditioned plastic sheets and reared within tanks of <u>filtered</u> (< 10 μm) and UV sterilized seawater. While there is little argument that suspended sediments are detrimental to abalone larvae (or at least to those of *Haliotis iris*), there is no practical relevance of the Phillips and Shima (2006) study in the context of abalone aquaculture. Abalone larvae in a hatchery setting, are protected from exposure to sediments by a filtration system.

In addition, most abalone farms only spawn abalone on a few days during any year (generally around the October or November period) and any analysis of the implied risk needs to take account of the highly episodic nature of spawning and larval settlement in abalone farming systems. This is

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[10] While an argument could be made that water flowing over the raceways might hold a quantity of suspended sediments the resultant deposition rates could never reach the levels required to achieve burial.

not a year-round vulnerability and can therefore be managed simply by coordinating between activities that may generate suspended sediments and the particular needs during spawning and the few days after larval settlement and metamorphosis.

4.2.2.5. Review of reported impacts of suspended sediments on post-larval abalone

Abalone have evolved to live in an environment where, in order to feed and grow, they need to be able to deal with the associated suspension of sand and other forms of detritus (see e.g. Melville-Smith *et al.* 2017).

It is evident from the very nature of their environment that abalone must be adapted to suspended sediments simply because they rely upon drift algae, suspended in the water column, as their principal source of food. The very processes, wave action and current flow, that break off algae and then suspend and transport them to abalone, also suspend and transport sediments. In essence, if there were no sediments suspended in their environment then there would also be significant limits on the food available for them eat.

While there are few studies that specifically address the impacts of suspended sediments on post-larval abalone, those papers that do address the issue all conclude that abalone are robust in terms of their ability to deal with high levels of suspended sediments (Table H-7) which is expected given this fundamental link between suspended sediments and food availability.

Table H-7: Summary of studies comparing effects of suspended sediments on various abalone (and other) species.

Species[11]	Treatments	Period	Finding	Source
Haliotis discus hannai	TSS at: 0, 1,000, 1,500 and 2,000 mg/L	96 h	No effect on mortality. Decrease in glycogen content over 1,500 mg/L	Lee 2008
Haliotis diversicolor	TSS at: 100, 200, 300, 400 mg/L	96 h	No effect on mortality, weaker motility at higher concentrations	Wang 2007
Haliotis discus	TSS (silt and clay): 50 mg/L	48 h	No effect on mortality	Chung *et al.* 1993
Haliotis discus	TSS (silt and clay): 50 mg/L	72 h 96 h	0-1.25% mortality 0-7.5% mortality	Chung *et al.* 1993
Haliotis discus	TSS (silt and clay): 1000 mg/L	96 h	up to 82.5% mortality	Chung *et al.* 1993
Haliotis discus hannai	TSS at: 250, 500, 1,000, 2,000 & 4,000 mg/L	7 d	LOEC[12] = 500 mg/L, Lc50[13]=1,888 mg/L	Yoon and Park 2011
Tigriopus japonicas (copepod)	TSS at: 250, 500, 1,000, 2,000 & 4,000 mg/L	7 d	LOEC = 31 mg/L, Lc50=61 mg/L	Yoon and Park 2011
Paralichthys olivaceus (flounder fry)	TSS at: 250, 500, 1,000, 2,000 & 4,000 mg/L	7 d	LOEC = 125 mg/L, Lc50=157 mg/L	Yoon and Park 2011
Haliotis iris	Synthetic particles 100 mg/L		No significant effect on growth or mortality	Allen *et al.* 2006

11 Animals used in these various experiments were aquaculture bred.

12 LOEC – Lowest Observed Effect Concentration for the experimental protocol.

13 Lc50 – TSS concentration at which 50% mortality occurred.

Chew *et al.* (2013) undertook a field study of the effects of dredge spoil disposal on *H. iris* in the wild. The study found no direct effects on the health or mortality of *H. iris* juveniles (30 mm shell-length) but they did note behavioural changes in that *H. iris* avoided substrata that were covered with sediments by moving from predation refugia beneath cobbles to vertical surfaces on cobble edges. Deposited sediments were also found to inhibit righting response which is a key behaviour in allowing *H. iris* to reattach to the substratum following dislodgement. This study did not use suspended sediments but rather sediments that were deposited onto the substratum.

Lee (2008) exposed *Haliotis discus hannai* to suspended solids with concentrations of 0, 1,000, 1,500 and 2,000 mg/L for 96 hours. Significant decreases in the glycogen content of soft tissues were observed, but only at suspended sediment concentrations over 1,500 mg/L. Even these very high levels of suspended solids had no effect on the mortality of the abalone, and the author noted that abalone could tolerate a high level of suspended solids.

Wang (2007) looked at the effects of different concentrations (100, 200, 300 and 400 mg/L) of suspended sediment on various physiological markers for *Haliotis diversicolor*. There was no mortality within 96 h at those concentrations, although weaker motility was observed at the higher ranges (Wang 2007).

Chung *et al.* (1993) examined the impact of suspended sediments on abalone[14] mortality and respiration at two temperatures for up to 96 hours with varying concentrations of suspended silt and clay. At a concentration of 50 mg/L after 48 hours there was no mortality for either large (40-50 mm shell-length) or small (20-25 mm shell-length) animals. The first mortalities (1.25%) occurred after 72 h of exposure in the small animals held at 20^{0}C; after 96 hours at 50 mg/L mortality was still low (5% and 7.5% for small *Haliotis discus* at 10^{0}C and 20^{0}C respectively; and 2.5% and 0% mortality for large animals at the same temperatures). At very high concentrations (1000 mg/L) mortality was high after 96 hours exposure (up to 82.5% for small abalone at 20^{0}C).

Stringer[15] (2018a) undertook a review of these studies using the criteria developed in Warne (2001) and Warne et al (2015). In that review Stringer (2018a) argued that the work by Yoon and Park (2011) was the most credible in that the "*study design … [gives] … a high level of confidence in the results and the statistical endpoints reported*". Stringer (2018a) went on to conclude (based on the reported results) that the 7-day NOEC[16] for *H. discus* was 250 mg/L and with a 10x acute to chronic conversion factor (as per ANZECC 2000) this would provide an interim guideline for water quality of 25 mg/L.

The Yoon and Park (2011) study looked at the mortality of three marine benthic species, an adult copepod, the Pacific abalone (*Haliotis discus hannai*), and fry of the olive flounder (*Paralichthys olivaceus*). The study concluded that the abalone (which had been raised in an aquaculture setting) were **far less sensitive** to suspended solids than the other species tested, with a lowest observed effect concentration (LOEC) of 500 mg/L compared to 31.3 mg/L for benthic copepods and 156.9 mg/L for flounder fry. The animals used by Yoon and Park (2011) were 10-12 month old sub-adults and they used treatments comprising exposure for 7 days to suspended solids at a range of concentrations (250, 500, 1,000, 2,000 and 4,000 mg/L). The end-point for this study was percent mortality; the resultant 7 day-LC_{50} was 1,888 mg/L.

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[14] Reported as *Nordotis discus* which is a synonym for *Haliotis discus*; see http://www.uniprot.org/taxonomy/36094)

[15] Ian Stringer is the Principal Exotoxicologist at Intertek which operates to NATA (ISO 17025) framework. NATA is the National Association of Testing Authorities.

[16] NOEC – No observable effect concentration for the experimental protocol.

Stringer also noted that Lee (2008) did not see any effects on mortality rate in concentrations up to 2000 mg/L TSS and no sublethal effects even at concentrations of 1500 mg/L TSS.

While noting the results of Chung et al. (1993), Stringer (2018a) concluded that the experimental design used in that study was inadequate and therefore questioned the overall veracity of the data and argued that this largely invalidated their conclusions about the reported LC_{50}.

Interestingly, work by Allen *et al.* (2006) explores the issue of sensitivity to sediments by considering the proposal that abalone actually respond positively to suspended particles in that such particles are likely to be associated with the availability of food in the form of drift algae. They explore the proposal that abalone, in their natural environment, expect to be exposed to suspended particles and hypothesised that this may in fact be **necessary** to promote feeding behaviour. Allen *et al.* (2006) tested this hypothesis using *H. iris* in an aquaculture setting by deliberately exposing animals to suspended particles comprising 2 types of macerated seaweed (*Gracilaria* spp. and *Macrocystis* spp.) and 2 types of synthetic PVC fragments (non-food particles) and a control group (no particles added). The abalone exposed to *Gracilaria* particles showed a positive growth response, but all other treatments showed **no difference to the control**. While the purpose of this experiment was to test the hypothesis that suspended particles might stimulate feeding behaviour, the experiment also acted as a *de facto* test of the effect of abiotic particles (in this case PVC fragments) on abalone growth and mortality. The study concluded that none of the other particulate stimulants had any significant effect on food conversion ratio, water content, protein, lipid and glycogen levels or meat tenderness.

While the synthetic particles used in the experiment (Allen *et al.* 2006) were large by comparison to fine-grained sediments (200-500 µm in length cf 10-60 µm) the concentrations were still quite high (100 mg/L) thus demonstrating that *H. iris* was not impacted by suspended particles of these size classes and concentrations.

The issue of environmentally induced sediment resuspension and the likely impacts of suspended sediments on abalone can also be considered in the context of the evolutionary pressures on abalone shell morphology, and how this may differ between species. It has been argued (Vandepeer 2006) that greenlip abalone require higher water velocities flowing over the shell relative to blacklip abalone. Vandepeer (2006) considered the typical water flow regime for abalone farms in South Australia (as part of a study looking at the likely causes of elevated rates of summer mortality) and noted that while most farms in SA operate with a flow velocity[17] in the order of 5-10 cm/s some species would appear to require substantially higher flow velocities to achieve maximal ventilation of the mantle cavity.

Tissot (1992) investigated the shell morphology as it relates to hydrodynamic drag across the various abalone species and concluded that abalone could be classified into 3 different groups based on shell morphology. Importantly *H. laevigata* was classified with those abalone with oval, arched shells with obscure spiral ribs and tremata[18] that are flush with the upper surface of the shell. This was contrasted with other species in which the ribs are spiral or oblique and that have prominent tremata which are highly elevated (above the surface of the shell). Vandepeer (2006), using the information provided by Tissot (1992), concluded that the two Australian species *H.*

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[17] Noting that our estimates for the Yumbah farm are flow velocities in the order of 3-6 cm/s.

[18] Tremata are the respiratory pores that are found running on the upper-side of the long edge the abalone shell. They promote passive circulation of water through the mantle cavity.

laevigata (greenlip abalone grown at Yumbah) and *H. rubra* (blacklip abalone) were analogs of two species studied by Tissot (1992) *H. cracherodii* and *H. rufescens* respectively (Figure H-10).

The Tissot (1992) study obtained data on the relationship between external water velocity and internal mantle cavity velocity (Figure H-10) and demonstrated that there was a profound quantitative difference in the relationship between over-the-shell water velocity and rate of mantle ventilation. The importance of this finding is that it suggests that *H. laevigata* has evolved in such a way as to **require** a much higher external water flow rate in order to generate a maximal mantle cavity velocity. The likely driver for this is that it has evolved to minimise the hydrodynamic form drag of the shell allowing it to exploit habitats with higher flow velocities (relative to other abalone species). As a consequence the greenlip abalone will have a reduced rate of mantle cavity ventilation under lower water flow velocities characteristic of an aquaculture setting.

This conclusion was further illustrated by Tissot (1992) who documented the drag coefficient (C_D) of abalone shells across the various species. The most notable finding was that the drag coefficient for *H. laevigata* was lower than that for any of the 13 other species investigated (C_D=0.30 at Re=32,000). Tissot (1992) concluded that animals (such as *H. laevigata*) have evolved to exploit open areas in higher-flow environments with moderate-rough exposure levels. Such environments necessarily subject animals to higher suspended sediment loads simply due to the increased hydrodynamic forces experienced.

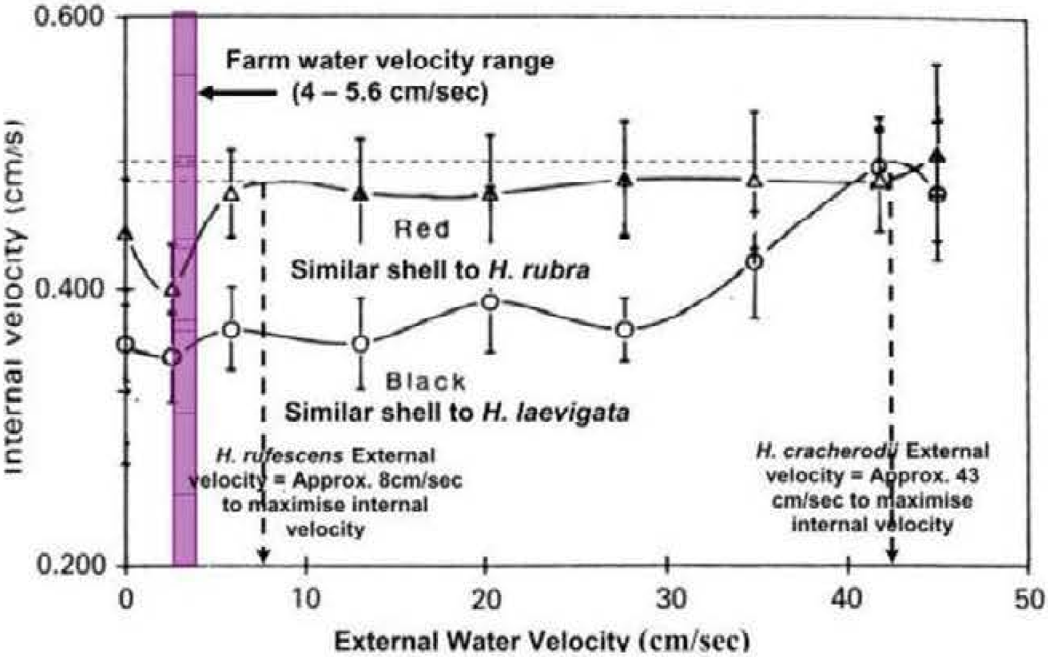

Figure H-10: Induced mantle flow recorded by Tissot (1992) for *H. cracherodii* (an analog for *H. laevigata*) and *H. rufescens* (an analog for *H. rubra*) as related to the shell types of two farmed species (taken from Vandepeer (2006).

In summary, the available evidence suggests that suspended sediments at concentrations less than 50 mg/L for short periods of time (<48 h) represent a very low risk to sub-adult through to adult greenlip abalone. This result is not surprising given that the greenlip abalone has evolved to live on low profile reef systems where it is generally found at the sediment / rock interface, an area that is frequently exposed to very high suspended sediment loads. It would be counter-intuitive that these animals would exhibit such a vulnerability given the nature of their habitat and feeding behaviour which would have strongly selected for animals with resistance to high suspended sediment loads.

Such resilience is likely to be skewed towards the coarser sediment fractions because, in the abalone's natural environment, finer materials would be winnowed out of the system.

4.2.2.6. Data and evidence for impacts of suspended sediment on Yumbah farms

The Yumbah abalone farms, in and of themselves, represent a robust test of the extent to which abalone in an aquaculture setting are vulnerable to suspended sediments. The Smith Bay farm, for example, has been in operation for some 23 years over which time there have been a large number of seasonal storm events (including a one-in-50-year storm in September 2016) all of which would have caused an elevation in suspended sediments in the influent seawater.

While it has been claimed (McShane 2017) that the resuspension of sediments within Smith Bay during storm events is associated with "mass mortality" events on the Yumbah farm, no evidence of such mortalities has ever been provided. McShane (2017) refers to a veterinary report by Dr Richmond Loh (Loh 2017, cited in McShane 2017) but Yumbah has not made that report available to support claims about the association between turbidity and mortality.

Surface layer turbidity levels in Smith Bay routinely reach 5–6 NTU (BMT 2018b) while turbidity within 1 m of the seabed is typically up to 2 times higher. Such values correspond to suspended sediment loads in the range of 10-12 mg/L depending on when and where the measurements were made[19]. Given what we know about other abalone species (Table H-7) and what can be inferred about the biology of the greenlip abalone relative to these other species (e.g. Tissot 1992, Vandepeer 2006) it would seem highly unlikely that the abalone farmed at Smith Bay are indeed susceptible to such events. Furthermore, it seems probable that the land-based abalone farm at Smith Bay would struggle to remain viable if the routine resuspension of coastal sediments during such weather events were to consistently cause mass mortalities.

Although the post-mortem report (Loh 2017) is not publicly available and has not been made available for the EIS, it is entirely probable that the mortalities referred to by McShane (2017) were caused by any number of factors other than suspended sediments. This could include elevated levels of bacteria (e.g. *Vibrio*), which would have a similar pathology, and which have been associated with mortalities on other abalone farms in South Australia (Theil *et al.* 2004). The occurrence of these pathogens in Smith Bay may be associated with rainfall induced flows from Smith Creek, however there are no data to support this contention.

It may be significant in clarifying the claims of mass mortality events made by McShane (2017) that Yumbah has provided no evidence of ever having submitted reports of any such event to the Minister for Agriculture (as per Aquaculture Regulations 3(2) and 13). PIRSA, as the regulatory authority, have advised that they cannot confirm whether they have ever received any such reports from Yumbah.

Notwithstanding these claims in relation to the Smith Bay farm, Yumbah have published detailed information about water quality for their farm at Narrawong in Victoria (Yumbah 2018) and those data are informative in the context of the water quality requirements for abalone aquaculture. The Yumbah documentation comprises a Works Approval Application (Yumbah 2018) seeking approval from the Victorian EPA and Glenelg Shire Council to construct a new abalone farm at Portland in Victoria (to be called Yumbah Nyamat and requiring an investment of some $60 million). The documentation has been prepared to support their case for the development of the

[19] Noting that turbidity is not a direct measure of total suspended sediments but rather a measurement of the extent to which light, travelling through a water sample, is reflected (at an angle of 90°) by particles suspended in the water column. As such the relationship between turbidity and total suspended solids varies with sediment type and depends on a range of issues including the particle size distribution and the shapes of the particles suspended. Direct conversions therefore need to take account of the sources and nature of sediments.

new farm and it provides a comprehensive summary of the farming operation currently at Portland (the Yumbah Narrawong farm) and thus is a relevant source of water quality data that can be compared to water quality data from Kangaroo Island from the perspective of abalone farming requirements.

In outlining their choice of location for the Yumbah Nyamat proposal the company has stated that the site is adjacent to a source of clean oceanic water that they define as "perfect" for the abalone that they are proposing to farm (Yumbah 2018, Page 3). They then summarise the water quality and environmental characteristics of this site with reference to operational water quality data collected for their Narrawong farm over a 17-year period (Yumbah 2018, Appendix G). The Narrawong farm is 6 km along the coast to the east of the proposed new farming site. These data include information on water temperature, salinity, dissolved oxygen levels and suspended sediment loads.

Yumbah (2018, Table 19) state that the ambient TSS loads from the Narrawong farm have ranged from 3.3 mg/L (median value) to 9.4 mg/L (90th percentile) with a maximum observed value of 37 mg/L. The raw data (Yumbah 2018, Appendix G) that form the basis of these estimates can be fitted to a log normal distribution function which allows one to generalise their observations from the sample data set as provided to produce quantitative estimates of the likely long term trends in water quality as defined by TSS (Figure H-11).

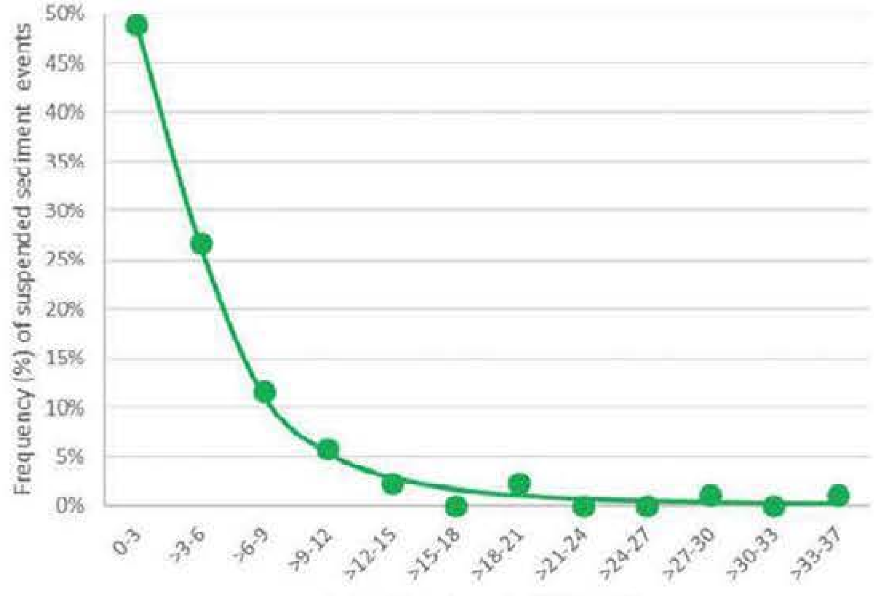

Figure H-11: Graph showing the frequency of suspended sediment events from low intensity (0-3 mg/L) to high intensity (>33-37 mg/L). The green line and points are the bin frequencies for each TSS level derived from Yumbah (2018) Appendix G; the curve is a log normal model fitted to these. The model provides an excellent fit to the data (r^2=0.998).

These data and the associated analysis demonstrate that, over time, one expects to see frequent low turbidity events with some 47% of observations at the 0-3 mg/L level; there are significantly fewer higher turbidity events. Turbidity is below 6 mg/L for 75% of the time and below 15 mg/L for around 95% of the time. Conversely, values will typically exceed 15 mg/L for 5% of the time and thus, such higher turbidity events may occur on 15-20 days per year.

Higher turbidity events are unlikely to be persistent, in that they would not be expected to extend over multiple days, but rather they would peak for a period of some hours during storm and bad weather events before calmer conditions lead to the suspended sediments settling out of the water column.

The data from the Narrawong farm can be compared to monitoring data obtained from Smith Bay. Smith Bay data were obtained using a series of fixed monitoring buoys (including both surface and bottom mounted turbidity sensors) and allow an estimation of ambient TSS loads over the course of a year at the seawater intakes to the Smith Bay farm. The data set comprises in excess of 54,000 records and is thus much more highly resolved over time than the data from Yumbah (2018) which comprised some 86 records over a 17-year period. On this basis one would expect that the Yumbah (2018) data would be more variable as it would likely capture both annual and inter-annual variability. Conversely, the Smith Bay monitoring data has more or less captured turbidity for every 10-minute period over an entire year. Nevertheless, the data do provide the basis for a scope and scale comparison of the water quality (TSS loads) at the two sites (Figure H-12).

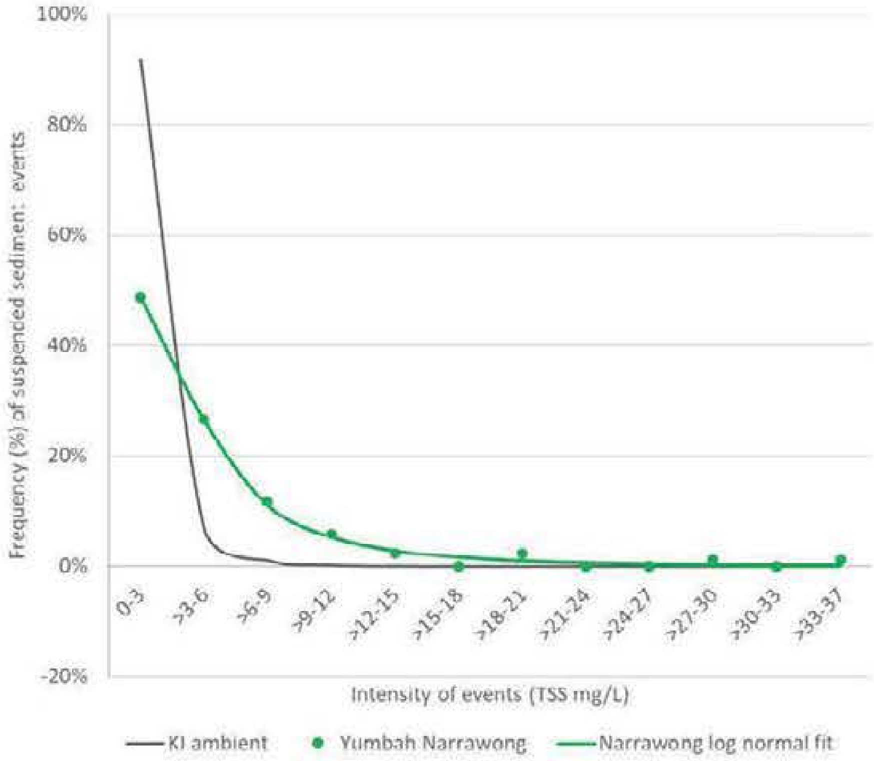

Figure H-12: Comparison of the frequency of turbidity events (TSS mg/L) at Yumbah Kangaroo Island (grey line) and Yumbah Narrawong (green line and points).

The key information to be taken from this comparison is that the Yumbah Narrawong farm would typically see many more events with high levels of Total Suspended Sediments than were seen over the 12-month monitoring period at Smith Bay. At Smith Bay around 98.7% of observations were less than 6 mg/L TSS while at Narrawong only 75% were below this level. On this basis it can be concluded that Narrawong typically experienced around 15-20 days per year (on average) where ambient TSS loads exceeded 15 mg/L while such events would be expected on only 1 day (or less) per year at Smith Bay.

Superficially these results might be taken to mean that the Smith Bay environment is more suitable for abalone farming however this is not the case. Yumbah (2018) have stated that the water at the proposed Victorian farm site is "perfect" for growing abalone hence these differences in suspended sediment loads would not be expected to have any material effect on abalone production. Rather, as with the results from other studies (see above), the data support the conclusion that abalone are insensitive to higher levels of suspended sediments and that the differences between the two sites are not material (at least as far as TSS loads are concerned). Furthermore, these data provide additional evidence that elevated levels of suspended sediments that occur during storm events are not likely to be the cause of elevated mortalities, at least at the levels experienced at the Narrawong farm which would otherwise experience much more frequent and presumably more debilitating mortality events.

Additional data are provided in Yumbah (2018) which adds to our appreciation of the water quality characteristics most notably on temperature profiles for the Narrawong farm. These data and the associated commentary highlight Yumbah's view about the desirability of this location as it largely shields them from the potential impact of elevated temperatures on summer mortality (as discussed above).

Temperature profiles for the location (Figure H-13) indicate that summer temperatures at this site rarely exceed 21°C with winter lows of around 12-14°C. This annual cycle is quite typical of Victorian coastal waters exposed to oceanic influences and is consistent with the ecophysiological preferences of greenlip abalone (see e.g. Vandepeer 2006).

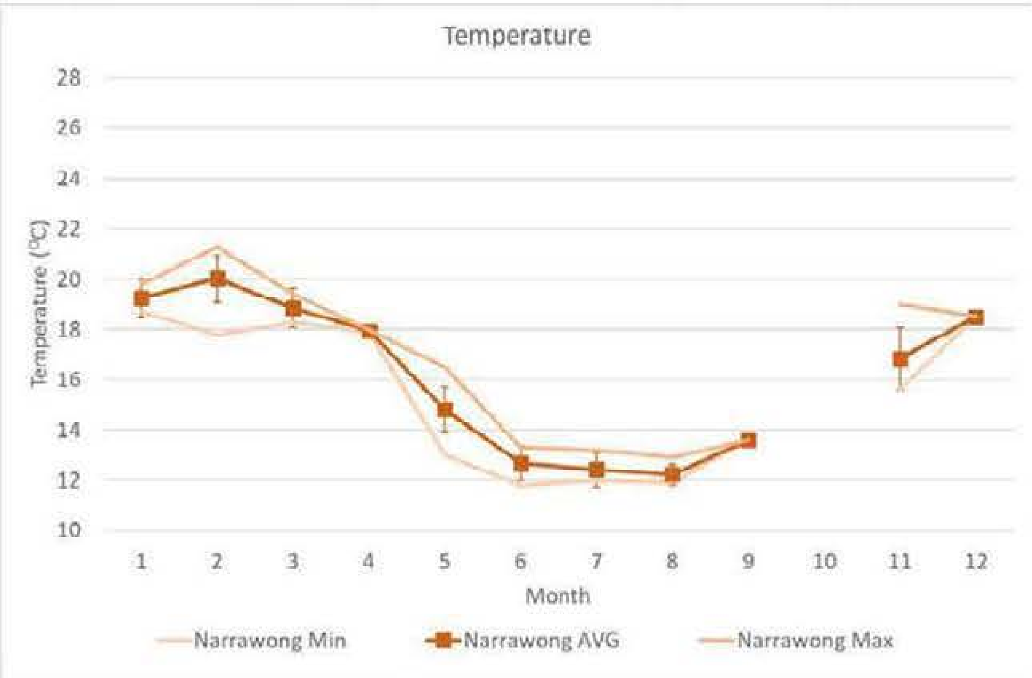

Figure H-13: Water temperatures averaged (by month) across the 17-year period from the Yumbah Narrawong farm (Yumbah 2018). Data show monthly averages with maximum and minimum ranges. For each monthly average the variability is shown using error bars that indicate +/- 1 standard deviation from the mean. In some cases data are not available or have very low variability (e.g. October and April) but this is likely a function of the relative balance of observations across months over the 17 year period rather than any real measure of site variability.

In relation to the new site, Yumbah (2018) state that the data that they have obtained over the preceding summer (presumably the 2017/18 summer) indicates that water temperatures at the new site will be slightly lower and less variable than those for the existing Yumbah Narrawong farm. On this basis they argue that the Yumbah Nyamat site will avoid extreme fluctuations in the summer and winter temperature (Yumbah 2018; P26).

These results contrast strongly with the data from Kangaroo Island (Figure H-14) where sea surface temperatures are consistently higher and, particularly during summer, maximum values are likely to exceed the 22-23 °C threshold that Vandepeer (2006) indicates is likely to cause summer mortalities and reach temperatures as high as 26 °C which will put substantial stresses on the animals.

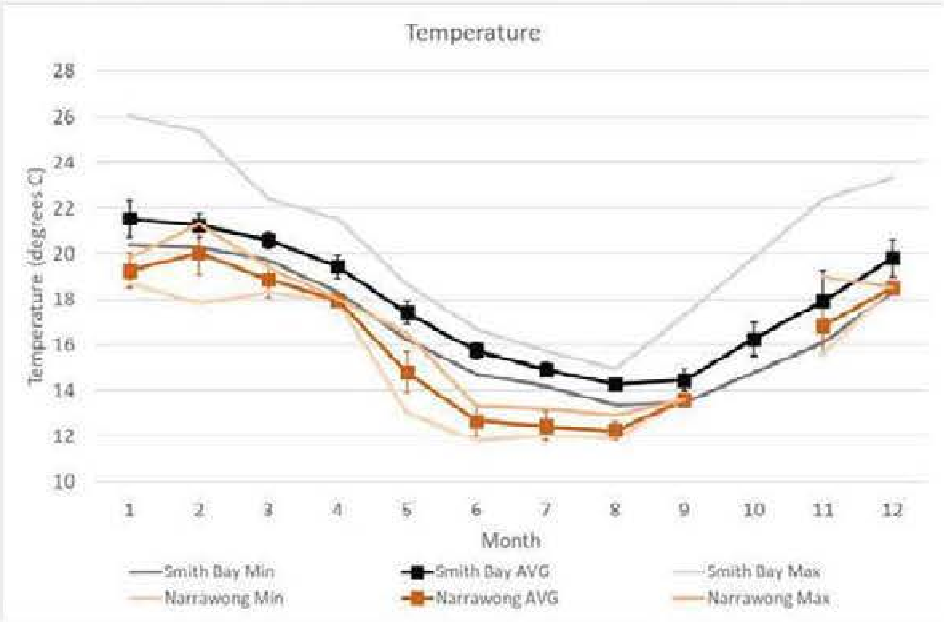

Figure H-14: Comparison of monthly temperature profiles by month between Smith Bay (BMT 2018b) and Narrawong (Yumbah 2018).

The importance of these data to this review is that they provide a basis for comparisons with the ambient water quality data from Smith Bay. Such comparisons are informative as they then provide the basis for consideration of the likely impact of any increases in suspended sediment loads associated with the construction and operation of the Kangaroo Island Seaport facility. Furthermore, they provide the basis for better understanding the risk profile of the Kangaroo Island farm in the context of both the proposed KI Seaport development as well as from the broader risks from climate change where we will see further increases in sea temperature (as well as increases in ocean acidity).

4.2.2.7. Ecotoxicology testing of *Haliotis laevigata*

The preceding sections collectively provide:

1. A comprehensive review of what has been published in the scientific literature about the effects of suspended sediments on abalone, and
2. Data on the water quality characteristics of a successful abalone farm particularly as this relates to ambient suspended sediment loads.

Whereas the scientific literature is limited in that none of the previous studies has looked specifically at the impact of suspended sediments on the greenlip abalone (*Haliotis laevigata*), it can be argued that the water quality data from existing farms provides a very robust test that validates the inferences one can make based on observations on these other species. Notwithstanding, it is desirable to validate these assumptions with practical studies on the target species itself.

To address this issue Environmental Projects commissioned SARDI (Aquatic Sciences) to collect juvenile greenlip abalone from the wild[20] and these animals were then provided to Intertek to be used in a series of targeted ecotoxicology studies. The results of these studies have been published (Stringer 2018b, Stringer 2018c) and are summarised below.

Juvenile animals were used because studies on other species (e.g. Yoon and Park 2011) have shown that this is the most vulnerable phase in the life history.

Juvenile greenlip abalone (average shell length 15-20 mm) were acclimated over a period of 4 days at a temperature of 18 ^{O}C (collection temperature was 16.7^{O}C).

Sediments used in the tests were obtained from Smith Bay but were dried and then sieved through a 64 μm sieve to ensure that the material used for testing comprised only the finer sediment fraction which would both remain in suspension (i.e. not settle out) and has a particle size that is more likely to have an adverse effect on animals exposed to the sediments. These finer sediments are also representative of the fraction that would be transported from the dredging operations to the abalone farm intakes because the coarser, heavier particles, would settle more rapidly and will not remain in suspension long enough to reach the seawater intakes.

The experimental design utilized 32 animals; 4 animals in each of 4 replicate groups across each of 2 treatments an exposure group (16 animals) and a control group (16 animals). The exposure group were exposed for 24 h to suspended sediments at a concentration of 250 mg/L while the control group was placed in the same experimental set up but exposed to normal (0.43 μm filtered) seawater with no additional suspended sediments.

Following the 24 h exposure period animals were subsequently transferred back to the holding tanks and observed for a further 48 h period (Stringer 2018b). No mortalities were observed in either the treatment or control groups.

This result demonstrates that for a 24-h exposure juvenile greenlip abalone have a NOEC of at least 250 mg/L against which a ten times safety factor has been applied to account for acute vs chronic effects. This provides a water quality guideline of 25 mg/L at which neither chronic nor acute effects would be expected.

The same experimental design was used 1 week later to test for effects of exposure to wood dust (Stringer 2018c). The treatment group in this case was exposed for 24 h to 35 mg/L of fine hardwood dust (<63 μm) obtained from *Eucalyptus globulus* (the main hardwood species to be used at Kangaroo Island). No mortalities were observed in either the control or treatment groups which, after employing a ten times safety factor to account for chronic vs acute effects, confirms that animals exposed to wood dust at 3.5 mg/L would not be expected to experience any toxic effects.

An important aspect of the wood dust exposure was that it took over 2 hours for the wood dust to become water logged and go into suspension after which time the water changed colour as tannins and other materials leached from the wood and into the water. Prior to that time the dust simply floated on the surface of the water. This observation is important because the estimated transit time of water down an abalone raceway is less than 1,000 seconds (less than 20 minutes); on this basis alone one can infer that wood dust will float on the surface of the water for the entire period that the water is on the raceway and will then be discharged from the farm without ever causing an effect on water quality for the farmed animals. Notwithstanding, even if the dust did

[20] Environmental Projects initially attempted to purchase animals from an aquaculture farm but no aquaculture farm in Australia was able to supply any animals to support the testing.

leach into the water within the transit period it would not be expected to have a toxic effect on animals at the guideline value of 3.5 mg/L.

4.2.2.8. Summary

All available evidence indicates that greenlip abalone (*Haliotis laevigata*) have a robust capacity to deal with high levels of suspended sediments in their environment. While larval abalone are vulnerable to elevated levels of suspended sediments, such animals are protected in an aquaculture setting through the use of filtered and sterilized water. Such vulnerabilities are not experienced over the remainder of their lives.

There are strong lines of evidence that abalone in general and greenlip abalone in particular have evolved to cope with elevated suspended sediment levels in their natural environment (Tissot 1992). This is further supported by a range of studies that have demonstrated abalone (particularly aquaculture grown animals) are insensitive to quite high levels of suspended sediments with NOEC values likely to be in the range of 250 mg/L or higher (e.g. Yoon and Park 2011, Stringer 2018a). Indeed, it appears that abalone have a substantially higher tolerance to elevated levels of suspended sediments than other aquaculture species (Yoon and Park 2011).

There is also good evidence (Yumbah 2018) that aquaculture abalone thrive in waters where suspended sediments routinely reach 8-10 mg/L and may range as high as 37 mg/L.

These findings are further supported by direct experimental studies that demonstrated that juvenile greenlip abalone were unaffected by a 24-h exposure to 250 mg/L of fine suspended sediments collected from Smith Bay. Given that the end-point for the study was % mortality a ten times safety factor is used to adjust for acute vs chronic effects. On this basis the NOEC value is assumed to be 25 mg/L (Stringer 2018a, Stringer 2018b).

In conclusion it is expected that greenlip abalone farmed by Yumbah on Kangaroo Island would not be expected to show any adverse effects (either in terms of mortality or effects to growth and overall fitness) from levels of suspended sediments that were less than 25 mg/L.

Water quality targets to protect aquaculture of greenlip abalone should therefore be set such that the 50th percentile value for total suspended sediments is 10 mg/L and the 99th percentile is 25 mg/L. While exceeding the simple 10 mg/L threshold recommended by ANZECC (2000) these thresholds are consistent with the literature and the experimental evidence which has shown that abalone are substantially more resilient to elevated suspended sediment loads than other aquaculture species. Furthermore, these values are consistent with the ambient water quality data for Yumbah's Narrawong farm in Victoria where the 99th percentile value is estimated at 22 mg/L (Table H-8).

4.2.3. Impact of suspended sediments on abalone

4.2.3.1. Construction dredging of the access channel and birthing pocket

As detailed above (Section 4.2.1) the impact of dredging on water quality is largely a function of the size of the dredging program, the type of dredging equipment used, the rate at which dredging occurs, and the type of sediment being dredged (Erftemeijer and Lewis 2006).

The potential impact of dredging on suspended sediment loads in Smith Bay was modelled to determine the likely impact of dredging on water quality at the seawater intakes for the Yumbah abalone farm. The modelling was used to analyse an ensemble of different dredging scenarios (BMT 2018a). From the ensemble the Expected (i.e. average) and Worst (i.e. upper bound) levels of the dredge plume were assessed on the basis that the:

1. **Expected case** was developed such that a given percentile comprised the mean level across all simulations. Given the distinct seasonality of the model predictions, summer and winter

averages were assessed separately and the maximum level across both seasons was derived as the 'expected' case.

2. **Worst case** was developed such that for a given percentile, the maximum concentration of all ensemble simulations was taken as the 'worst' level at a given location.

Suspended sediment loads generated through dredging (which included suspended sediments derived from tailwater discharges) were modelled across the entirety of Smith Bay. These predictions were then used in conjunction with data on ambient suspended sediment loads to predict total suspended sediment loads at the Yumbah seawater intakes (including the disused intake associated with licence FT000634).

Suspended sediment loads were modelled over four time periods comprising the summer and winter periods of both 2015 and 2016 respectively. These summer and winter periods were chosen to illustrate the differences between a summer and winter dredging program as well as the likely scale of inter-annual variability from one year to another. In assessing these results from the perspective of the likely impact on water quality at the Yumbah seawater intakes (see below), the worst case for each of the summer and winter periods has been used. Essentially this comprises a worst-case analysis of both the expected and the worst-case assessments presented in BMT (2018a).

In all cases the results have been compared to:

1. The ambient suspended sediment loads at Smith Bay based on the 12-month ambient water quality monitoring program conducted by BMT (2018b) taking account of differences between surface and bottom (1 m from seabed) values.
2. The water quality data for the Yumbah Narrawong abalone farm (Yumbah 2018) which comprise data collected over a 17-year period.

These datasets bracket the range of conditions across which abalone are known to thrive with Yumbah (2018) describing the water quality conditions at the Narrawong location as being "perfect" for the aquaculture production of abalone.

The results from the modelling of suspended and ambient sediment loads demonstrate that, even in the absence of a dredge management plan that would act to stop dredging during higher risk periods, the predicted sediment loads at the Yumbah seawater intakes are generally well below the 10 mg/L threshold (ANZECC 2000) and almost always below the 25 mg/L threshold that has been determined for aquacultured abalone (Section 4.2.2.8, Table H-8).

In only one case (winter dredging for the worst-case assessment) does any predicted value at Smith Bay exceed the ambient water quality conditions that have been observed at the Yumbah Narrawong farm in Victoria. In that case the exceedance is at the 50th percentile value (3.5 mg/L vs 3.3 mg/L). Such an exceedance is trivial in this context as it does not come close to the 10 mg/L ANZECC (2000) water quality guideline for the general protection of waters for aquaculture and as such would not have an adverse impact on abalone.

Table H-8: Comparison of suspended sediment loads under various dredge scenarios. Blue shaded cells indicate values that exceed the 10 mg/L ANZECC (2000) water quality guideline for the protection of aquaculture. Orange shaded cells indicate water quality values that exceed the 25 mg/L NOEC for abalone as per Section 4.2.2 of this report. Yellow shaded cell is the only value where the predicted suspended sediment loads from a Smith Bay dredge scenario exceed the ambient value for Yumbah Narrawong.

Percentile	Smith Bay Ambient Single Year	All intakes at bottom Expected case Summer	Winter	Worst case Summer	Winter	**Narrawong Ambient 17-year average‡**
50th	1	1.5	2.9	1.5	3.5	**3.3**
90th	3.7	4.4	6.2	4.0	8.0	**9.4**
99th	6.3	11.5	15.6	7.7	16.7	**22†**
Max	16.3	14.4	18.7	16.7	26.7	**37**

‡ Data from Yumbah (2018, Table 19).

† Narrawong data is 13.8 for the 95th percentile and this has been interpolated to 22 for the 99th percentile based on a log normal fit to the data.

For most dredging scenarios the 99th percentile values exceed the 10 mg/L threshold ANZECC (2000) but none of these values exceeds either the 22 mg/L value seen for Yumbah Narrawong (Yumbah 2018), nor do they exceed the 25 mg/L NOEC value determined for greenlip abalone (Section 4.2.2).

In only a single instance (winter dredging for the worst-case ensemble) does the maximum value (26.7 mg/L) exceed the 25 mg/L threshold value and even then, this value is below the maximum value observed for Yumbah Narrawong (maximum value of 37 mg/L).

The time of year during which dredging operations are conducted has a substantial influence on suspended sediment loads with summer values being substantially lower than the winter values (Table H-8; typically between half and two thirds the levels). These summer / winter differences are due to an overall shift in water movement patterns (net westward flow in summer vs net eastward flow in winter) which changes the degree of connectivity between the dredge and the seawater intakes for the abalone farm (BMT 2018a). Ambient suspended sediment loads are also lower in summer because there are fewer storm events that cause sediment resuspension (BMT 2018a).

Another perspective on these data is to consider the effect that dredging has on the frequency of suspended sediment events of different intensities. Intensity can be described by the total suspended sediment load at any point in time. The frequency of events of various intensities can be plotted for any given location (as has been done above Section 4.2.2.6). Plots such as that in Figure H-15 illustrate that there is a higher frequency of low intensity events, that is to say that for most of the time suspended sediment loads are relatively low (typically less than 6 mg/L). Sometimes, but much less often, suspended sediment loads increase.

Changes in the frequency of these events can be used as a basis for understanding how the environment changes in response to dredging (Figure H-15). The results from the modelling of dredge plumes in Smith Bay suggests that there will probably be an increase in the frequency of events in the 3-6 mg/L bracket relative to ambient conditions which have a preponderance of events in the 0-3 mg/L bracket. Irrespective, the analysis of the various dredge ensembles demonstrates that the number of moderate intensity events (9-12 mg/L) at Smith Bay will still be lower than the frequency of these events, under natural conditions, at the Yumbah Narrawong farm in Victoria (Figure H-15).

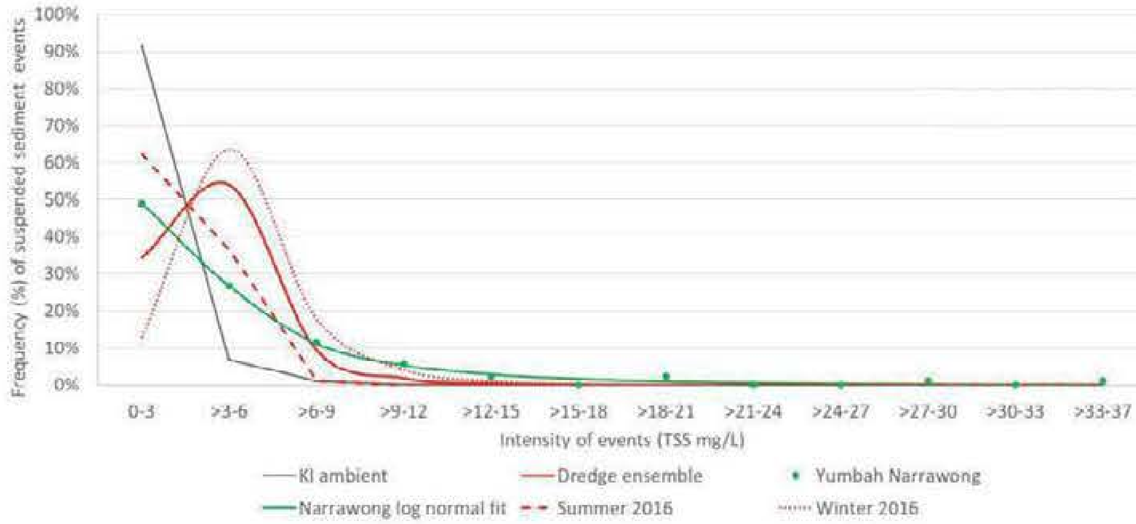

Figure H-15: Expected-case ensemble average (solid red line) for suspended sediment loads (including ambient values and dredge induced sediments). Values shown are averaged across all intakes (data from BMT 2018a). Winter 2016 (red dotted line) has the highest sediment loads, Summer 2015 (red dashed line) has the lowest sediment loads. Green line and dots represent data from Yumbah (2018), grey line is ambient data for Smith Bay.

These results indicate that while the average suspended sediment load will increase there will not be a concomitant increase in risk to abalone aquaculture because the changes are predominantly in the number of low intensity events which do not breach the 10 mg/L water quality threshold.

These estimates of suspended sediment loads do not provide specific predictions on the likely composition of the suspended material in relation to the particle size distribution (PSD). Ambient sediment loads are likely to show changes through time in PSD with coarser particles being found during and immediately after storm induced resuspension events (e.g. periods of rough weather).

The same is not true of the sediment plume generated by dredging operations. At the point of dredging the plume will likely be comprised of the full range of coarse and fine sediment particles but as the suspended material moves further away from the dredging site the coarser particles will settle more rapidly and hence, at a greater distance, the material remaining in suspension will be dominated by the finer size classes of sediment (consistent with those tested in the ecotoxicology studies; Stringer 2018b)

This result is important to the operation of the abalone farm in that it is primarily the coarser sized particles (>64 µm) that settle out onto raceways in abalone farms (Yumbah 2018) and thus increase the need for raceway flushing. In Smith Bay the suspended sediments derived from the dredge plume that are taken up through the seawater intakes will therefore be the finer fraction that will likely remain in suspension and ultimately will flow back out of the farm through the effluent stream. Irrespective, the use of tippers is commonplace and a key role for these is to flush sediments that do settle onto raceways back out into the sea.

This analysis has not taken any account of the protective effect of dredge management controls which would generally be applied to any dredging program. Such controls would be used to shut down dredging operations during periods when there was either a high level of connectivity between the dredge and the seawater intakes (e.g. during dodge tides) or when natural processes acted to increase ambient concentrations above the threshold values (e.g. during storm events or substantial rainfall events). The application of a dredge management plan would provide a further level of protection for aquaculture operations although, based on the predicted levels for suspended sediments under the various scenarios, such additional controls would rarely be needed.

The assumptions underpinning theses analyses are also very conservative and this provides a further level of protection to the farmed abalone and confidence in the conclusions (Table H-9).

Table H-9: Conservative assumptions made in evaluating impacts.

Assumption	Value as determined	Value used for analysis	Rationale
Turbidity to TSS ratio	0.7 – 0.9 mg/L per NTU	1 mg/L per NTU	Makes the assumption that suspended sediment loads are 10-40% higher than they actually are which has the effect of increasing reported suspended sediment loads.
Greenlip abalone NOEC to TSS (Stringer 2018b)	250 mg/L	25 mg/L	Ten times safety factor which has the effect of reducing the level of TSS at which we assume harm may occur to account for acute vs chronic effects and any differences between wild and aquacultured animals.
Greenlip abalone NOEC to wood-dust loading	35 mg/L	3.5 mg/L	Ten times safety factor which has the effect of reducing the level of wood-dust at which we assume harm may occur to account for fatal vs chronic effects.
Time for wood-dust suspension	2 hours till wood dust becomes water logged	Assume it happens immediately	Assumes that wood dust goes into suspension and potential toxins are leached from the wood immediately. Has the effect of substantially magnifying the likely effect of wood dust because the transit time across the raceway is likely to be less than 20 minutes.
Dredging continues continuously other than during programmed maintenance shutdowns or during bad weather			Takes no account of the implementation of a dredge management plan that would operate pro-actively to identify periods when connectivity is higher and thus shut down dredging and reactively to stop dredging when real-time monitoring detected elevations in suspended sediment loads above agreed threshold values.

In summary, while dredging will cause a small increase in suspended sediment loads at the Yumbah seawater intakes, this increase will not drive the total value above key thresholds and thus these sediments would not be expected to impact on the health of aquacultured abalone. Smith Bay has very low ambient sediment levels and therefore any increases will primarily occur off a very low base.

Total suspended sediment loads (ambient plus dredge plume sediments) associated with an appropriately managed capital dredging program would not increase to suspended values to a level that would have an impact on farming systems and would not affect the production of abalone.

4.2.3.2. Maintenance dredging of the access channel and birthing pocket

The need for future maintenance dredging to maintain channel depths is likely to be minimal and infrequent (BMT 2018a, BMT 2018b). The analysis of seabed sheer stress indicated that even with the causeway and floating wharf in place, benthic sheer stresses are still above 0.5 Pa and, as such, silt deposition in access channels is not likely.

Furthermore, maintenance dredging, if it were to be required, would likely be conducted using infrastructure and management arrangements similar to the capital dredging program. The impact of a maintenance dredging program on water quality is therefor likely to have similar dynamics but be much shorter in duration due because maintenance dredging would remove substantially smaller volumes. Consequently, given the findings from the assessment of the capital dredging program, any subsequent maintenance dredging would not be expected to have any adverse effects on water quality that would affect the production of abalone.

4.2.3.3. Sediment suspension during ship operations due to pressure wave propagation and propeller wash

Sediments are likely to be resuspended during shipping operations due to the action of displacement waves and propeller wash, which may be exacerbated by the accumulation of sediments in the dredged basin. These impacts, however, are typically highly localized in both time (during ship operations) and space (along the shipping approach) and would not reflect the sort of resuspension that would typically occur during storm events (BMT 2018a).

Hydrodynamic modelling of sediment concentrations at the abalone farm seawater intakes resulting from shipping operations (BMT 2018a) shows:

- Neither the median nor the 95th percentile maps show any plume that is above the minimum scale limit (0.2 and 1.0 mg/L respectively). This is because the sediment plume occurs over such a short duration that it is not observable for these percentiles.
- The maximum concentration observed in any scenario shows that local plumes in the berth area are ~10 mg/L and that no plumes extend to the Yumbah Intakes.

Therefore, marine vessel operations would not be expected to have any sediment-related adverse effects on water quality that would affect the production of abalone.

4.2.4. Impact of suspended sediments on algal production

Elevated suspended sediment loads in water taken into the farm have the potential to cause a reduction in light transparency of the water body (see e.g. Figure H-16) and hence change the amount and quality of light available to benthic primary producers (particularly to algae grown on the nursery sheets that are used to feed juvenile abalone). This relationship illustrates the expected increase in Kd as turbidity increases although it should be noted that other factors (e.g. the presence of Coloured Dissolved Organic Matter - CDOM) will also impact on attenuation.

BMT (2018b) reports the ambient attenuation in Smith Bay of 0.29 /m and predicts that attenuation associated with dredging may increase at the Yumbah seawater intakes with median values for Kd of 0.32 /m and 95th percentile values of 0.39 /m.

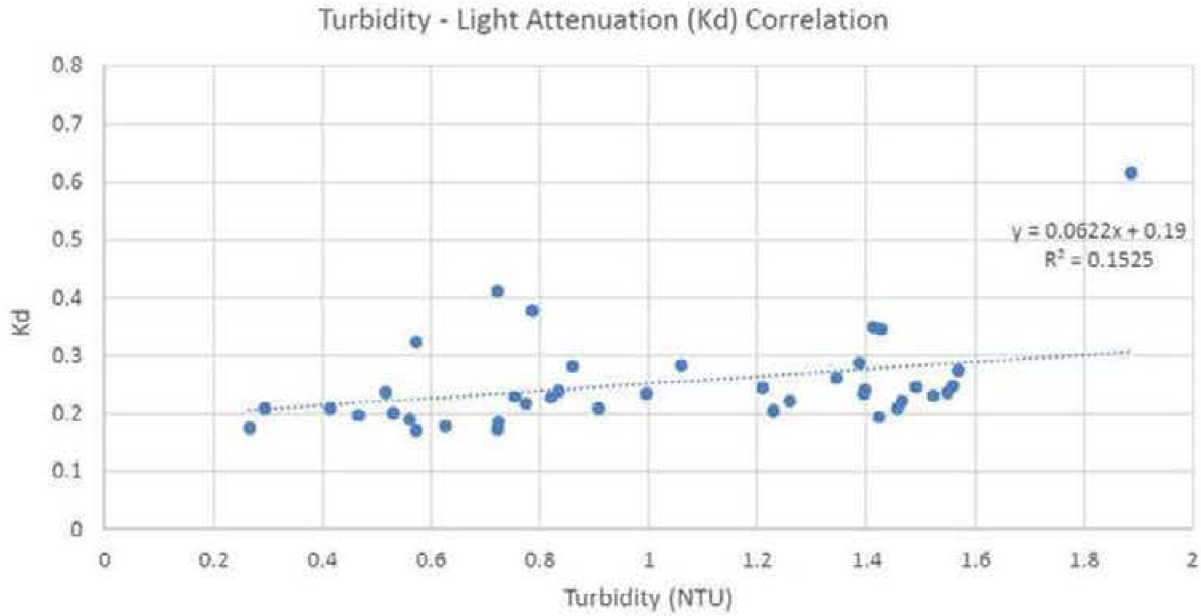

Figure H-16: Relationship between turbidity (horizontal axis) and *in-situ* attenuation (vertical axis) in Smith Bay (taken from Figure 2-30 in BMT 2018b); the correlation is significant p:p=0.011.

4.2.4.1. Evaluation of impacts of suspended sediments on algal production

While it is true that suspended sediments will impact on light transmission through the water column it is highly improbable that such changes will have any material effect on the photosynthetic production of algae on nursery sheets in the Yumbah farming systems. Analysis of the data on the likely level of light attenuation against what we know about the photokinetics of phytomicrobenthos would indicate as follows:

1. Algae exhibit a very high level of plasticity in their adaptation to ambient light environments allowing them to adjust their photosynthetic apparatus to accommodate quite large changes in light field (see e.g. Copertino *et al.* 2006, 2009);
2. Irrespective of the above, the actual changes in light field associated with changes in turbidity at shallow depths are very small; and
3. The only phase of the life cycle dependent upon algae is the nursery phase given that sub-adult and adult animals on the raceways are fed pelleted feeds.

Nursery tanks rely upon light for conditioning of settlement plates (i.e. growing algae on the plates to feed to juvenile abalone) by supporting the photosynthesis and growth of either diatoms (e.g. *Navicula* spp.) or other species of phytomicrobenthos (e.g. *Ulvella* spp.) that will recruit to the nursery plates (Heasman and Savva 2007). These algae then provide food for juvenile abalone while in the nursery phase.

Higher levels of turbidity will affect light transmission through the water column, but such changes are not of sufficient magnitude to actually cause a material change in algal productivity in these aquaculture systems. For example, changes in the turbidity of water in a typical nursery tank (0.5 m deep) from 0.29 /m (typical ambient value) to 0.32 /m and 0.39 /m (50^{th} and 95^{th} percentile values respectively) is predicted (Equation 1) to reduce nett 24 h photosynthetic production of algae in the nursery tank by less than 1.5% and 4.9% respectively.

Equation 1 – Evaluation of $Nett_{24}$ photosynthetic production over a 24-hour period where $I_{t,d}$ is the light intensity at time (t) and depth (d). For the purposes of calculation depth of nursery tanks was assumed to be 0.5 m; Ik, P_{max} and Rd are photokinetic parameters corresponding to sub-saturating light intensity, maximal photosynthesis and dark respiration and were set at Pmax=100%, Rd=-10% and Ik = 0.333*$I_{0.95}$ where $I_{0.95}$ is the sub-saturating light intensity (assumed to be maximum light at solar noon at depth d).

$$Nett_{24} = \int_{t=0}^{t=24} [P_{max} \,.\left(1 - e^{(-I_{t,d}/Ik)}\right) - R_d] \text{ dt}$$

The application of Equation 1 allows a calculation of the percentage change in nett 24 h photosynthetic production for any given value of Kd where $I_{t,d}$ is determined as shown in Equation 2.

Equation 2 – Evaluation of light at time (t) and depth (d) is determined by the surface light intensity $I_{t,0}$ at time (t) attenuated according to the attenuation coefficient Kd (m^{-1}).

$$I_{t,d} = I_{t,0} \,. e^{-Kd.d}$$

These formulae have been well established in the literature (e.g. Kirk 1994, Cheshire *et al.* 1996) and practically applied to estimates of turf algal production (Cheshire *et al.* 1996, Copertino *et al.* 2006, 2009).

An important element of this analysis is that it does not take account of the highly plastic acclimation response of the photokinetic systems in algae that allow for a rapid change (2-3 days) in the photokinetics (Copertino *et al.* 2006, 2009). In practice the actual impact on photosynthetic production is therefore likely to be substantially less than that shown in this analysis.

While sediments in water can change the quantity of light, they can also affect the quality of light (i.e. the spectral composition; Kirk 1994). In large part this is because sediment particles will change the effective optical path length and thereby change the relative absorption of light of different colours. Empirically this has relatively little effect in the context of shallow water bodies. Furthermore, the key algal species used on abalone farms for feeding abalone in the nursery stage have a diverse array of both antenna and reaction centre pigments allowing them to make use of light across the visible spectrum (Falkowski and Raven 1997).

Diatoms contain both Chlorophyll a (principally involved as the reaction centre pigments for PS I and PS II) and Chlorophyll c (Falkowski and Raven 1997) as well as a full suite of accessory light harvesting and photoprotective pigments including carotenoids (e.g. beta carotene) and xanthophylls (e.g. fucoxanthin; see for example Owens and Wold 1986). The Chlorophyll c / fucoxanthin antenna pigment complex, for example, provides light harvesting capacity across the green region of the spectrum.

In a recent review by Kuczynska *et al.* (2015) it was noted that:

> "*Diatoms are organisms of a distinct pigment composition, substantially different from that present in plants. Apart from light-harvesting pigments such as chlorophyll a, chlorophyll c, and fucoxanthin, there is a group of photoprotective carotenoids which includes β-carotene and the xanthophylls, diatoxanthin, diadinoxanthin, violaxanthin, antheraxanthin, and zeaxanthin, which are engaged in the xanthophyll cycle.*"

It is apparent therefore that diatoms growing on the nursery sheets are capable of using light with a wide range of spectral qualities. Similarly, the green algae (e.g. *Ulvella* spp.) also have a rich complex of accessory light harvesting and photoprotective pigments (Falkowski and Raven 1997).

Suspended sediments, at the levels anticipated, would not have a material effect on the photosynthetic production of algae grown in the Yumbah abalone farm. Similarly, there is no evidence that increases in turbidity of the magnitude anticipated will have any material effect on micro-algal and specifically diatom production within Smith Bay itself.

4.2.5. Impact of suspended sediments on farm infrastructure

Elevated suspended sediment loads in seawater taken into the farm have the potential to increase the rate at which filtration systems are loaded and thereby require more frequent back-flushing.

It is probable (and indeed standard practice on abalone farms) that the Yumbah farm uses rapid sand filters to filter the seawater used in the nursery section of the farm (consistent with their design proposal for the Yumbah Nyamat facility; Yumbah, 2018). Sand filters are designed to handle influent flows with elevated levels of particulate material (both organic and inorganic). Influent water is run, under pressure, through a filter bed that removes particulates. Modern filters have in-built pressure sensors on the in-flow and out-flow which measure the pressure differential and automatically switches individual filter units into backflush mode to clean the filters as required; such systems are designed to be low maintenance. Changes in input sediment loads would be likely to cause more frequent back-flushing, but this is unlikely to materially impact on the operating efficiency of the system.

Assuming that Yumbah uses appropriately configured filtration systems, it is unlikely there would be any impact on the operation of such systems and hence mitigation would not be required.

Suspended sediments may also deposit on raceways; most farms manage this through the use of tippers that flush the raceway at regular intervals. Tippers are also used to remove uneaten food and faeces from raceways so provide a multiplicity of benefits to the farming operation.

Most of the additional sediments that come from dredging will comprise the finer fractions (<63 µm) that will not deposit on raceways but rather will remain in suspension and flow out of the farm along with the effluent water. As such this would not impact on the efficiency of existing solid waste handling systems within the farm.

Given that the sediment loads at Smith Bay, even with additional loads from dredging, will be below the ambient levels experienced on other Yumbah farms, it is reasonable to infer that the existing infrastructure (filters and tippers) will adequately deal with these materials with no adverse effects on the farming operation.

4.2.6. Impact of suspended sediments through mobilisation of pollutants and nutrients

No evidence was found for the presence of any pollutants or toxicants, or excessive levels of nutrients within the sediments in Smith Bay (COOE 2017, BMT 2018b). Consequently, there is a very low risk that any such materials would be mobilised during dredging and therefore this would not have any adverse effects on water quality that would impact on the production of abalone at the Smith Bay farm.

4.2.7. Impact of suspended sediments through suspension of anoxic deposits

Sediment coring in Smith Bay revealed a relatively small area where sediments showed evidence of anoxia (COOE 2017). This area is inshore of the dredge footprint and would not be disturbed by dredging. There is therefore a negligible risk that the oxygen content of the seawater adjacent to the dredging operations would be depleted by suspension of such sediments.

Furthermore, even if such sediments were disturbed the associated risk can be quantified using a simple mass-balance model (Table H-10). This model provides an estimate of the volume of water required to meet the oxygen demand of anoxic sediments dredged over a period of 1 hour based on a number of assumptions and data (Table H-10). The model demonstrates that the oxygen demand could be met from a body of water comprising around 22 m^3. Given the rate of mixing of water in and around the dredge this oxygen deficit would be quickly met from the surrounding water body.

Table H-10: Mass balance model providing an estimate of the volume of water required to supply oxygen to meet the demand from suspended anoxic sediments. Note that nitrogen levels in these sediments are low and this does not account for denitrification.

Eqn	Parameter	Estimated value	Units of measure	Source of estimate
1	TOC	4.5	mg/kg	COOE 2017
2	TN	2,850	mg/kg	COOE 2017
3	Oxygen demand	1.067	mg O2/mg TOC	As per 19 (see below)
4	Sediment density	2,400	kg/m^3	Maritime Constructions
5	Dredge rate	250	m^3/h	Maritime Constructions
6	Sediment suspension rate	5%		Maritime Constructions
7	Sediment suspended	30,000	kg/h	Follows 4,5,6
8	TOC suspended	135,000	mg/h	Follows 1,7
9	O_2 requirement	144,000	mg O_2	Follows 3,8
10	Water O_2 saturation	85%	saturation	Conservative (low) estimate
11	Temperature	18	degrees C	Typical for Smith Bay
12	Salinity	35	g/L	Typical for Smith Bay
13	Water O_2 concentration	6.51	mg/L	Follows 10,11,12
14	Water volume required	22.11	m^3	Follows 9,13
15	Cubic dimension	2.81	m	Follows 14
16	Total O_2 in water volume	144,000	mg O_2	As per 9 to balance O_2 consumption by sediment
17	Assume all organic C in the form of $(CH_2O)_n$	30	Molecular weight	Assumption
18	Oxygen	32	Molecular weight	Fundamental principle
19	Oxygen / TOC demand	1.067	mg O_2 / mg C	Follows 17,18

On this basis it is highly improbable that there would be any adverse effects on water quality from the suspension of anoxic sediments that would impact on the production of abalone.

4.2.8. Management and mitigation of impacts from suspended sediments

The results from the extensive *in-situ* data collection program, coupled with the analysis provided through the hydrodynamic modelling, indicate that the suspended sediment loads generated during the capital dredging program and causeway construction, could have an impact on water quality at the Yumbah seawater intakes (BMT 2018a).

The analysis (BMT 2018a) has provided quantitative estimates of how suspended sediment loads, associated with dredging and construction activities, would differ between seasons (summer vs winter), across tidal cycles (neap vs spring tides) and in response to weather events (e.g. during westerly winds). Given that these can generally be predicted in advance (acknowledging that weather can be more variable than forecast) this enables the use of a dredge management system that takes account of the potential differences in risk under the varying seasonal, tidal and weather conditions and thereby provides the basis for pro-actively manages the risk of adverse impacts on water quality at the Yumbah seawater intakes.

This dredge management plan would also include the use of an *in-situ,* real time, turbidity monitoring system, at an appropriate location between the dredging operations and the Yumbah intakes, which would strengthen management controls and allow timely management interventions (e.g. slowing or ceasing dredge operations) should the suspended sediment levels exceed pre-defined criteria.

4.3. Effect of on-land construction and operations on abalone farming

4.3.1. Atmospheric dust deposition – implications for water quality

4.3.1.1. Source of airborne dust

An additional source of sediments that could affect water quality within the Yumbah farm is dust generated by on-shore activities (Winterburn 2017) that is subsequently deposited onto farm infrastructure and potentially into the seawater flowing through the farm. The dust is likely to include silica generated by construction activity on land (46%) and wood dust (54%) released during loading of woodchips onto ships and through the general operation of the facility (Winterburn 2017).

4.3.1.2. Assessment

Quantification of the rates of dust that may be deposited has been undertaken (Winterburn 2017). Winterburn (2017) concluded that the existing operation is likely to experience atmospheric dust deposition at background rates of around 2 g/m^2/month which is equivalent to the typical average rates for coastal and agricultural/pastoral sites in South Australia.

Wind-blown dust would generally be deposited onto the shade-cloth which covers the existing raceway and nursery tank systems. Over time and with wind movement an amount of that dust will likely sift down onto the raceways. While much of the dust, particularly the fine particles, would likely just sit on the surface of the water and then flow out of the farm there is a possibility that some of that dust would become mixed with the water and thereby increase the total suspended sediment loads experienced by abalone.

The atmospheric deposition model used by Winterburn (2017) estimates that dust generated from the construction and operations of the KI Seaport facility would result in an additional deposition of 0.4 g/m^2/month onto the Yumbah farm (at the closest point to the KI Seaport facility). This deposition would be additional to the background resulting in total deposition rates of 2.4 g/m2/month.

If all of this dust were to settle on the shade-cloth covering the farms and then mix with the water flowing through the raceways it would cause an increase in TSS of around 0.03 mg/L (based on an estimate of water velocities and volumes on raceways and assuming that the dust filtered down on a continuous basis). Such an amount is of no significance at all to the health of abalone at any stage of their life-cycle noting that the ANZECC (2000) water quality guideline value for aquaculture protection is 10 mg/L and this value represents 0.3% of the guideline value.

Arguably, the more significant issue is if the dust does not sift down over time but rather builds up on the shade-cloth until such time as a rainfall event washes the material through in a single pulse; the longer the gap between rainfall events, the more intense the pulse of dust.

The potential impact under this scenario was calculated using local rainfall records (Australian Bureau of Meteorology 2018) between 1980 and 2017 and shows that rainfall is seasonally dominated and that longer rainfall free spells tend to occur over summer months. Under such circumstances it is possible to calculate the impact of an accumulated load of dust washing through to the raceways on an episodic basis.

Analysis of the model outputs, assuming a worst-case scenario with additional dust deposition of 0.4 g/m2/month associated with the construction and operation of the KI Seaport facility, shows a very small shift in the intensity of the smaller wash through events (Figure H-17) with a concomitant rise in the slightly higher rate events.

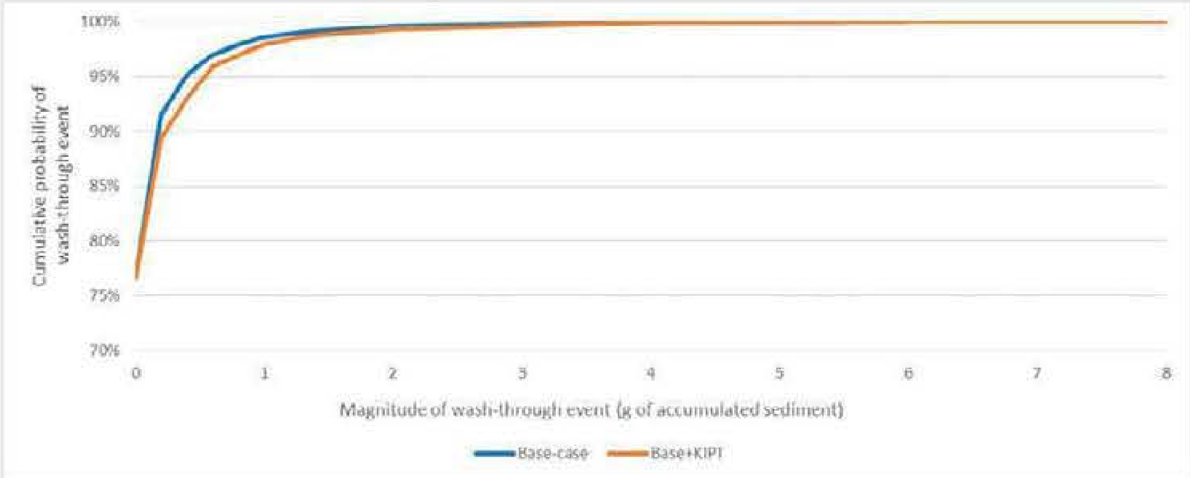

Figure H-17: Dust-wash-through event intensity vs frequency. The blue line represents the background (base-case) and the orange line the background plus the KI Seaport. When only the orange line is visible both lines are equivalent. The horizontal axis represents the dust load in g/m^2 while the vertical axis represents the cumulative probability that the event would occur based on rainfall data for Smith Bay (1980 to 2017; Australian Bureau of Meteorology 2018).

This analysis assumes that all of the sediment is retained on the covering mesh (which is highly improbable but provides for a worst-case scenario) and further assumes that the rainfall is experienced over a period of 1 hour, the water velocity on the raceway is 2.2 cm/s, the water depth is 5 cm.

In any such scenario, the suspended sediment load would be expected to increase as the water flows further down the raceway with more sediment being washed through over the time taken for any volume of water to travel the length of the raceway.

The impact on water quality of this material being washed through onto a raceway can be modelled for the amount of sediment that would accumulate using the 90th and 99th percentile values as reference points (Table H-11). In either case, the additional dust associated with the KI Seaport is estimated to result in an increase of about 20% in the suspended sediment loads on the raceway when compared to the base case (which is based solely on the natural background deposition rates). In the 90th percentile case, the maximum suspended sediment load is not expected to exceed 1.27 mg/L (representing an increase of 0.25 mg/L relative to the base case) and for the 99th percentile case the maximum suspended sediment load is estimated at 8.02 mg/L (1.60 mg/L greater than the base case). Note also that these maximum values occur at the end of the raceway as the water leaves the raceway; most abalone on a raceway would be exposed to something much less (approaching half) this value.

Modelling of the dust sources (Winterburn 2017) indicates that wood-dust accounts for 54% of this additional dust load (i.e. approximately 0.22 g/m^2/month out of the total 0.4 g/m^2/month) originating from the construction and operation of the facility. On this basis, and assuming that all material immediately goes into suspension, the 90th percentile value for the suspended sediment load attributable to the wood-dust fraction would be 0.14 mg/L and the 99th percentile value would be 0.87 mg/L. These latter figures can be compared to the ecotoxicology results (Stringer 2018c) which demonstrated a NOEC for 24-h exposure to wood-dust of 35 mg/L providing a safety factor approaching 40 times to account for chronic vs acute effects.

While the data shown in Table H-11 represent estimates of the increase in the suspended sediment loads, over and above that for the influent water, it needs to be noted that this is an extremely conservative estimate. The fundamental assumption, that all airborne dust deposited on the shade-cloth covering the raceways will remain in place until a rainfall event washes it through, is not likely to be valid. It is highly probable that most of the dust that settles on the shade-cloth will sift through or be blown away very soon after deposition. Hence, given a deposition rate of 2.4 g/m^2/month, the predicted impact on water quality on the raceways would likely be in the order of 0.0069 mg/L against a background rate of 0.0055 mg/L (representing an increase of 0.0014 mg/L due to the KI Seaport).

Similarly, the assumption that all of the dust will move into suspension as it filters down onto the raceways is also highly conservative. The ecotoxicology study (Stringer 2018c) has shown that the wood-dust fraction took around 2 hours to become water logged and go into suspension. Given that the transit time for water on the raceway is likely to be around 925 seconds this means that the bulk of this wood-dust will simply float off the raceway and never make it into suspension. Similarly, it is likely that a substantial proportion of the inorganic dust will similarly be so fine that it will simply sit on the surface of the water and not have any impact on suspended sediment loads *per se*.

Table H-11: Comparison of the worst-case scenario for the wash-through of dust deposited on shade-cloth with the assumption that all material is accumulated for the entire period between rainfall events. The expected increase is 25% over the background (base-case) scenario.

Parameter	Assumed value		Units
Sediment wash-through time	1		Hour
Raceway length	20		m
Flow rate	3		L/s
Seawater velocity	0.022		m/s
Raceway transit time	925		seconds
KI Seaport additional dust	20% of ambient		
Wood-dust as a percent of total KI Seaport dust	54% of additional		
	Background	**Background +KI Seaport**	**Units**
Comparison	90th percentile of accumulation		
Accumulated deposition on shade cloth	0.20	0.25	g/m^2
Average suspended sediment across raceway	0.51	0.64	mg/L
Maximum suspended sediment at end of raceway	1.02	1.27	mg/L
Wood-dust input	0.00	0.14	mg/L
Comparison	99th percentile of accumulation		
Accumulated deposition on shade cloth	1.25	1.56	g/m^2
Average suspended sediment across raceway	3.21	4.01	mg/L
Maximum suspended sediment at end of raceway	6.42	8.02	mg/L
Wood-dust input	0.00	0.87	mg/L

Irrespective of the above, the reality is that whatever the current situation is (i.e. either dust is deposited and accumulates between rainfall events or alternatively it sifts through more or less as it is deposited) the current Yumbah systems are not currently impacted by atmospheric dust deposition so there is no reason to expect, that the small additional amount of dust deposited as a consequence of the KI Seaport will have any material, additional impact on water quality or on the aquaculture production of abalone.

4.3.1.3. Management and mitigation measures for airborne dust

A variety of operational management strategies can be employed to limit dust generation, including the cessation of dust generating activities (both during construction and subsequent operations) when there are strong westerly winds. Similarly, standard dust guards could be engineered around chip conveyors, loaders etc. Dust suppression systems, including water damping, could be used to minimise dust mobilisation particularly around roads and access tracks.

Physical screening can also be used (e.g. shade mesh fences) and strategic vegetation buffers could be established all of which would likely reduce dust suspension (at least from passive wind-blown sources) and would similarly assist with extraneous light transmission (see below).

4.3.2. Extraneous light

4.3.2.1. Sources of extraneous light

Light generated by night-time operations of vehicles and lighting infrastructure erected along the causeway and around the hard-standing area, are all potential sources of light spill that may affect the abalone farm. It should be noted that the abalone farm currently uses a number of large, bright lights around the farm presumably to improve night time security.

4.3.2.2. Abalone tolerance and vulnerability to impacts from extraneous light

A study by Alter *et al.* (2004) investigated the effect of potential stressors (including light exposure) on the early life stages of *H. rubra* and *H. laevigata* hybrids. The work concluded that there was no measurable effect of light vs dark conditions on the oxygen consumption rates (used as a direct index of stress[21]) for these animals. Conversely in a study on *Haliotis discus discus, H. gigantea, H. madaka* and their hybrids it was found that animals kept in the dark showed lower rates of oxygen consumption and ammonia excretion relative to those kept under light. This suggests that animals kept in the dark had reduced metabolic rates compared to those exposed to light. In all cases these are short term experiments but indicate that light *per se* does not impact negatively on the animals and may in fact benefit them. Similarly, in a study on the effect of light regime on abalone growth Periera *et al.* (2007) demonstrated that animals kept in a permanently dark regime did not perform as well as those exposed to light.

The mechanism for light vs dark responses needs to take account of the cryptic nature of the juvenile abalone which tend to hide away in cracks and crevices, rarely coming out into the open where they would be more vulnerable to predation (McGarvey 2006). In part, this can be interpreted as a tendency to move away from light, but reverse photo-taxis provides a mechanism for directing animals into more protected spaces (i.e. it is not a negative response to light *per se*). This behaviour is mimicked when animals are transferred from nursery sheets to the grow-out raceways. Animals that are moved from the relatively protected environment of the vertical nursery sheets (which are closely packed into their holders thus providing a surrogate for the cracks and crevices in rocks) into an open and exposed environment on the flat surface of a concrete raceway have “nowhere to hide”. In such situations, one can observe abalone moving to the edge of the

[21] In this study a drop in the oxygen consumption rates was considered a stress response as it forces the animal to rely more on anaerobic respiration which is energetically more costly.

raceway and jamming themselves into the area where the side walls meet the floor of the raceway which could be perceived as providing protection on at least one side.

Some farms use pieces of electrical conduit or water pipe, screwed into the floor of the raceway (e.g. Figure H-2) and abalone will align themselves along the edge of this appearing to take advantage of the "apparent" safety afforded by having at least one side protected.

In the natural environment greenlip abalone move from being cryptic during their early life phase to feeding more openly when they reach a size of about 40-60 mm in shell length although cryptic behaviour continues across the life-cycle until animals reach around 140 mm in shell length (McGarvey 2006). Larger animals have tougher shells and are more able to resist predation, but this needs to be balanced with actively feeding in the open.

4.3.2.3. Mitigation strategies

Light impacts from wharf operations can be addressed with standard light baffles and other structures to minimize effects on the abalone farm.

4.3.3. Noise and vibration

4.3.3.1. Sources of noise and vibration

Vehicle movements and the use of on-site machinery are all potential sources of noise and vibration. These various sources of noise, associated with the construction and operation of the KI Seaport facility, have been identified, analysed and quantified by Henrys (2018).

4.3.3.2. Assessment of expected noise levels against those modelled for the Yumbah Nyamat abalone farm

Henrys (2018) predicts that noise levels associated with on-land operations of the KI Seaport would be in the order of 40-50 dB on the Yumbah KI farm. Noise levels would dissipate with increasing distance from the KI Seaport facility.

While these levels meet with guideline values, they can also be compared to the likely noise levels on a typical abalone farm. Yumbah (2018) include an extensive report that models the noise levels on and around their proposed new farm near Portland in Victoria (Yumbah Nyamat). Those data are informative as they relate directly to the expected noise levels on their proposed farm and provide a good indication of acceptable noise levels from the context of an abalone aquaculture facility.

The measured background (i.e. pre-existing) noise levels predicted for Yumbah Nyamat are broadly equivalent (although slightly higher) than those at Smith Bay primarily because of more adjacent traffic/residences. The measured noise levels (sound power levels) of noise-generating equipment within the buildings at Yumbah Nyamat would be significant, varying between 70-110 dB (noting that noise levels of greater than 80 dB require hearing protection). Such equipment is however generally housed in bessa-block style buildings separate from the abalone raceways and this would provide significant attenuation. The associated modelling predictions (Yumbah 2018) assume there would be a significant attenuation of noise through the separate building facade, such that noise external to the building (at the nearest receivers) would meet relevant criteria. This would be consistent with the baseline noise measurements from Smith Bay, which don't show a significant impact from the Yumbah KI farming operations.

The noise contours for Yumbah Nyamat (Yumbah 2018) show that noise levels around the abalone raceways are in the order of 40-45 dB generally and up to 50 dB at the tanks nearest to the pump-set buildings and along and between-tank pipelines.

Noise modelling (Henrys 2018) conservatively indicates peak noise levels of up to 50 dB at the Yumbah tanks closest to the KI Seaport facility and decreasing with distance (35 to 45 dB). In practice, taking account of dampening from built infrastructure, KIPT-related noise within the Yumbah farm would be expected to be reduced from the modelled peak of 50 dB and are likely to be inaudible against the background of their own noise-generation (given that noise levels need to be 3dB higher to be detectable).

Irrespective, the data from Yumbah Nyamat demonstrate that design values of 50 dB for noise levels is acceptable for an abalone farming operation (Yumbah 2018).

4.3.3.3. Abalone tolerance and vulnerability to impacts from extraneous noise and vibration

The impact of noise and vibration on abalone is not well understood with no research papers tackling the issue. It is notable that the subtidal marine environment where abalone live is a naturally noisy environment (Fisher-Pool et al. 2016). The wave induced movement of rocks and boulders creates a constant environment of bangs and rumbles along with the sound of marine creatures interacting with the environment (clicking and cracking of shells and pincers etc see e.g. Fisher-Pool *et al*. 2016). Indeed, the amount of noise generated in underwater environments is sufficiently high that researchers have been able to develop underwater ambient noise imaging cameras (Pallayil *et al*. 2016) that utilise ambient noise to create acoustic images.

Little is known about the impact or importance of underwater noise for marine invertebrates although recent work on underwater noise fields has demonstrated that ambient noise generated from reef systems is likely used by some larval fish and invertebrates as a settlement cue (see for example Eggleston *et al*. 2016).

4.3.3.4. Evaluation of impact

Abalone farms are relatively noisy environments; not only is there the constant noise generated by essential machinery including large water pumps, air-blowers, pressurised filters and diesel generators, many farms operate with tippers that create a substantial bang when they drop water onto the raceways (Figure H-2).

Given the predicted noise levels and sound propagation associated with the KI Seaport facility (Henrys 2018) it is considered highly improbable that off-site noises from the KI Seaport will have any material impact, on abalone growth and production, over and above the effects of noise already being generated on the farm itself.

4.3.3.5. Management and mitigation measures for extraneous noise and vibration

It is highly unlikely that noise and vibration would affect the abalone farm and therefore no specific mitigation strategies have been recommended although the use of screening vegetation (to minimise light and dust impacts) would likely help to minimise noise transmission.

4.3.4. Seawater temperature

4.3.4.1. Causes of elevated seawater temperatures

Changes in coastal processes associated with the placement of the causeway perpendicular to the coast has the potential to change the water flow and mixing patterns in the vicinity of the causeway. Such changes could impact on water temperature causing localised areas of warming and cooling.

4.3.4.2. Assessment

Waters in Smith Bay already reach temperatures that are higher than is desirable for land-based abalone farming during the period from late spring, through summer and into autumn (Figure H-

18 but see also Figure H-14). Temperatures are routinely in excess of 21°C and, at least during the year of observations, may reach temperatures in excess of 25°C.

Abalone farms in South Australia all experience high levels of summer mortality (Vandepeer 2006, Doubleday *et al.* 2013), which on some farms reaches or even exceeds 20-25% of farmed stock on days of extreme heat, particularly if these occur during a prolonged period (4-5 days) of heat-wave conditions.

Greenlip abalone have only a modest tolerance to variations in water temperature being competent over the range of 14°C to 23°C with a preference for water around 18°C. Once temperatures exceed 25°C and certainly when they reach 27°C then animal mortality on farms will increase substantially. It is notable that Vandepeer (2006) reports that many farms experience problems when temperatures exceed 21 °C which highlights the very real risks for the Yumbah operation under normal summer operating conditions (Figure H-18) when there are frequent periods where water temperature is elevated.

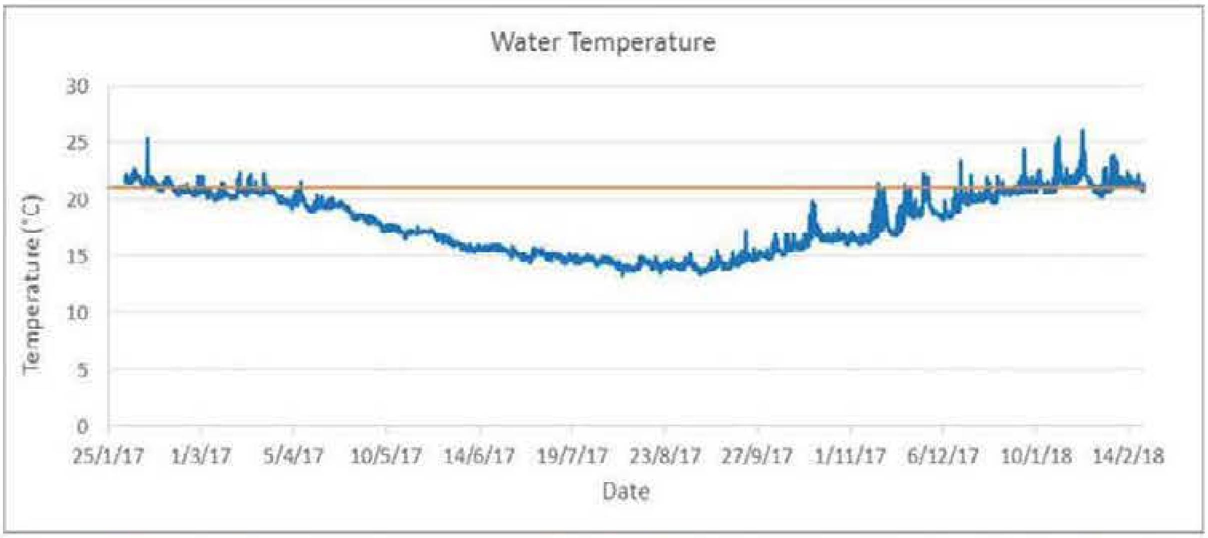

Figure H-18: Plot of surface water temperature for Smith Bay as recorded via the monitoring buoy (after Figure 2-18 in BMT 2018b). The orange line represents the 21°C critical temperature and highlights the existing risks to the Smith Bay operation from elevated temperatures over the summer period (particularly December through to April).

As discussed previously, part of the reason for the increased mortality is that the capacity for water to hold oxygen decreases as temperature increases; at 18°C seawater can typically hold around 7.52 mg/L whereas at 25°C this drops to 6.75 mg/L. Over the length of a raceway, particularly one with a large biomass of adult animals this can cause stress due to oxygen depletion and, with the other impacts of temperature (including increased disease susceptibility), this can lead quite rapidly to the death of animals.

The major causes of increases in water temperature are from periods with low levels of tidal movement (e.g. neap or dodge tides) coupled with prolonged periods of high air temperatures (e.g. days over 35°C). In bays such as Smith Bay, water temperatures can heat up and hence the water that is pumped onto the farms is warmer. Coupled with this, the flow of water through the farm, brings it into contact with pipes and raceways that are absorbing heat, resulting in water temperatures typically 1-2 °C above ambient. Such conditions lead to rapid mortality of abalone and this is often concentrated amongst older, larger, more valuable animals. Some farms have experienced daily mortality levels of 25% of adult stock; such impacts have serious economic consequences.

The abalone industry in South Australia is also faced with a serious issue in that our warming climate with more extended periods of hot weather presents a major threat to the industry (Doubleday *et al.* 2013). Whereas some farms have trialed new technologies such as cooling towers[22], and there are concerted efforts to breed for heat tolerance, these technologies are not proven in a commercial setting.

The more extended and frequent heat waves associated with climate change therefore pose a serious threat to the viability of the abalone industry in South Australia over the coming decades (Doubleday *et al.* 2013). A recent Climate Council publication demonstrates that Adelaide has already experienced (over the period 2000 to 2009) a 30% increase in heatwave days (Steffen *et al.* 2014). Indeed, the data show that the number of heatwave days (when measured against the period 1950-1980) has now almost doubled (from 5 to 9) and the longest heatwave event has increased from 4 to 6 days with the peak heatwave days being 4.3^{O}C hotter. These changes presage serious implications for the abalone aquaculture industry over coming years and are expected to continue and intensify at least until 2050, irrespective of any carbon reduction initiatives, simply due to climate hysteresis.

There remains, therefore, a fundamental risk to the industry that land-based farms in SA may not be able to operate economically within the next 10 - 20 years due to climate change related heatwave conditions.

4.3.4.3. Evaluation of impact of water temperature increases

Hydrodynamic modelling has shown that there is potential for a very small increase (less than 0.1^{O}C) in water temperature around the Yumbah intakes during summer (BMT 2018a, BMT 2018c; see also Figure H-19) and small changes in temperature of coastal waters including an elevation of up to 0.2^{O}C (depth averaged) inshore of the Yumbah Intakes (Figure H-19). Actual changes at the intakes are predicted to be less than 0.1^{O}C which is effectively below the limit of model resolution. This increase is caused by the propensity for water to pool in the lee of the proposed causeway under some tidal conditions.

Even given the vulnerability of coastal abalone operations in South Australia to summer temperature increases, such an impact is not likely to have a material effect on the farming operations over and above the risks currently experienced by operators where excursions in temperature over short time periods (e.g. 1-2 days) can be more than 4 ^{O}C.

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[22] Cooling towers provide a system for both cooling the water and increasing the oxygen content. Water is pumped up and then cascades down over the sides of a small tower (up to 1 m in height): the latent heat of vaporization cools the water, cools the air around the tower and allows the water to take up additional oxygen.

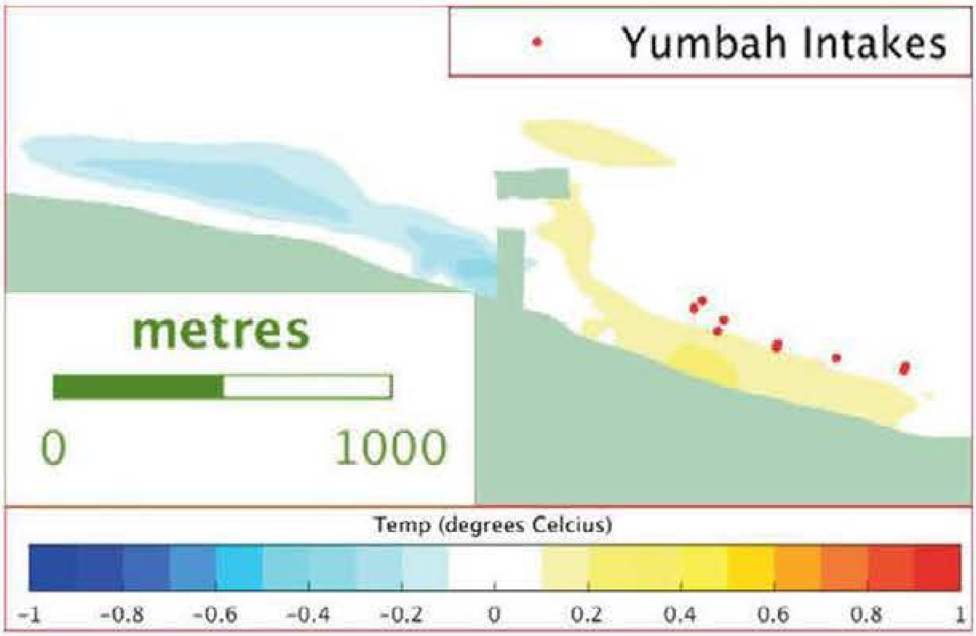

Figure H-19: Predicted maximal depth averaged temperature changes associated with the causeway development. Adapted from Figure 3-10 in BMT (2018c).

4.3.4.4. Management and mitigation measures for elevated seawater temperatures

If considered necessary, an open bypass system could be installed in the near-shore section of the causeway to minimise the interruption to tidal currents. This could comprise either large culverts or a pier section, the size of which would be determined by hydrodynamic modelling. Given the small predicted maximum increase such a measure is not considered essential and it needs to be recognised that the benefit of such a bypass system may be offset by compromising the protective barrier formed by the causeway in relation to effluent from the degraded Smith Creek during rainfall events.

It may be possible to engineer a gated culvert through the causeway that could fulfil a dual function by allowing through-flows during summer thereby managing the risk of temperature increases. The gate could then be closed during other months and thereby facilitate the redirection of Smith Creek discharges further offshore during major flow events (particularly during autumn and winter) thus improving nearshore water quality.

4.3.5. Red tides

4.3.5.1. Assessment

Red tides are caused by blooms of harmful microalgae commonly called dinoflagellates. In South Australia, we have a long history of red-tides in the Port River (Cannon 1990; Cannon 1993). While many dinoflagellate species may cause red-tides the two species associated with red tides in the Port River were *Alexandrium minutum* and *Gymnodinium catenatum*. In the late 1980s through to the early 1990s these algae were known to bloom (reaching cell densities greater than 10^7 cells/L) during dodge tide periods particularly during spring when cool waters with freshwater inflow were associated with high light levels due to clear sunny days. Over recent years, with much better management of waste water inputs and the shutting down of the Penrice Soda plant and the phosphate wharf, these problems have largely abated.

In South Australia, red-tides have not been found much beyond the Port River and they are usually only associated with areas where high levels of inorganic nutrients are being discharged into the system (in Port Adelaide a mixture of waste water disposal from sewage treatment works and industrial inputs including the Penrice ammonia discharges; Cannon 1990, Cannon 1993).

Red-tides have caused fish-kills in the Port River (due to de-oxygenation of the water body) and also presented risks to human consumption from shellfish that have been feeding on red-tide algae with the potential to cause paralytic shellfish poisoning due to the consumption of saxitoxins.

While dinoflagellates are present in almost every marine system in the world, the presence of red-tide species is normally restricted to areas where dinoflagellate blooms can occur; this particularly includes protected/sheltered embayments with high levels of nutrient pollution. Such conditions are not present in Smith Bay (BMT 2018b) where water quality is very good due to the normally low levels of nitrogen and phosphorus.

The risk of red-tide species being introduced via ballast water is real. Such species have been transported around the world in ballast water and most introductions have been to Ports and Harbors. Importantly however, the conditions that would promote such red-tides (elevated nutrients and still waters) are not likely to occur in Smith Bay (BMT 2018a, BMT 2018b).

4.3.5.2. Mitigation strategies

While acknowledging that conditions that would promote red tides are highly unlikely to occur in Smith Bay standard ballast water management practices would be implemented as required for any Port in Australia.

4.4. Beneficial outcomes from the construction of the causeway

The location of the causeway to the east of Smith Creek is likely to mitigate the potentially adverse effects that silt-laden discharges from Smith Creek may have on water quality at the abalone farm seawater intakes, during rainfall events.

Hydrodynamic modelling of storm flows from Smith Creek (Figure H-20) demonstrates that, during ebb tides:

- creek discharges currently flow almost directly past the Yumbah seawater intakes and typically results in suspended sediment loads of 5-10 mg/L above the ambient conditions
- a solid causeway would direct discharges several hundred metres out to sea before being entrained by tidal currents, providing a reduction of up to 50% (2-4 mg/L) in the average concentration of creek water reaching the Yumbah intakes (BMT 2018c).

While these levels of suspended sediment are not likely to be problematical (in and of themselves), they are indicative of the loads of other materials that might be entrained in the runoff including, for example, agricultural chemicals, pathogenic bacteria, nutrients and other terrigenous toxicants. By diverting the bulk of this water offshore, and away from the Yumbah intakes, the potential for this land-based runoff to have an adverse impact on the farming system is substantially lessened.

It should be noted that should there be a requirement to install pass-through sections in the causeway, this could negate the benefit of directing the Smith Creek discharge offshore. The use of a gated culvert could be investigated (see above). Failing this there would be a trade-off between realising the benefit of redirecting the creek discharges against the potential for a very small increase in temperature of the influent water (acknowledging that the abalone industry will face major problems with seawater temperature rises and already have a need to implement technologies to protect themselves from this risk; Doubleday *et al.* 2013).

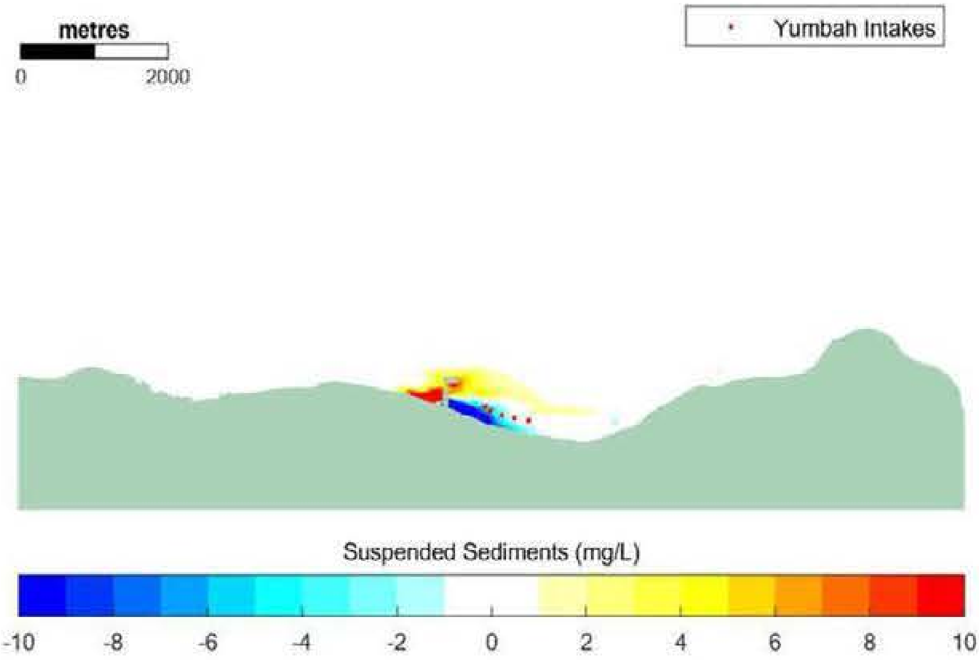

Figure H-20: Changes in suspended sediment loads in the vicinity of the seawater intakes associated with the off-shore diversion of flows from Smith Creek. Taken from Figure 3-11 in BMT (2018c).