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Management Options for Improving Flows of the Shoalhaven River at Shoalhaven Heads

WRL Technical Report 2015/19
November 2015

By W C Glamore, J E Ruprecht and D S Rayner

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1. Introduction

The Shoalhaven River entrance at Shoalhaven Heads (Figure 1.1) has been an area of considerable interest and debate for many years. The creation of Berry's Canal in 1822 provided a direct link between the Shoalhaven River and Crookhaven Heads. Since then erosion and dredging has expanded the canal and it is now large enough to efficiently convey the entire Shoalhaven River base flow.

As it has evolved and enlarged over time, Berry's Canal has become the preferential flow path for the Shoalhaven River. This is largely due to a reduced wave climate at Crookhaven Heads. When the Shoalhaven River entrance has been historically opened by flood events, the prevailing wave and tidal conditions cause the entrance to infill and eventually close. Long periods of closure have led to local community concerns that the Shoalhaven Heads entrance will become an estuarine backwater with poor water quality and increased sedimentation. Local residents have voiced concerns that the existing state of the entrance limits tourist opportunities such as fishing, boating and swimming, and also impacts the local oyster industry, with associated impacts on the local economy.

The Shoalhaven Heads Estuary Taskforce, an advisory committee of Shoalhaven City Council (SCC), was created in response to the above concerns with the aim to investigate potential remediation options. SCC and the NSW Government acknowledged the concerns of the community at Shoalhaven Heads and allocated funding to investigate potential remediation options (this study).

This study was designed to identify and investigate options that may increase water circulation in the estuary at Shoalhaven Heads and prevent the area becoming a shoaled backwater. While previous studies have focused on entrance engineering options at Shoalhaven Heads (Posford et al., 1977; Public Works, 1984; Nittim and Cox, 1986), this study provides the opportunity to focus on water quality issues, while considering research and technological improvements over the past 30 years.

Stakeholder consultation was a key part of the study. The Shoalhaven Heads community, SCC experts, the Shoalhaven Heads Estuary Taskforce and relevant government agencies were consulted on their views working towards a sustainable solution. It is important to note that this study primarily collated existing data sources rather than undertaking site specific field measurements.

The main tasks in this study included:

1. Undertaking a comprehensive literature review;
2. Discussing issues with the relevant working groups;
3. Conducting preliminary investigation of options based on Working Group discussions, community consultation and literature review;
4. Assessing the feasibility of identified potential options;
5. Preparing and distributing educational material; and
6. Facilitating community consultation via two public meetings.

This report addresses points 1, 3 and 4 above. Points 2, 5 and 6 were undertaken as part of this study and details are provided on relevant working group and public meetings outcomes. To address these tasks the report is divided into the following sections:

Section 2 provides a literature review of available information;
Section 3 details community and working group engagements and outcomes;
Section 4 discusses identified concerns;
Section 5 assesses management options identified and tested in the study; and
Section 6 provides recommendations regarding the feasibility of the assessed options.

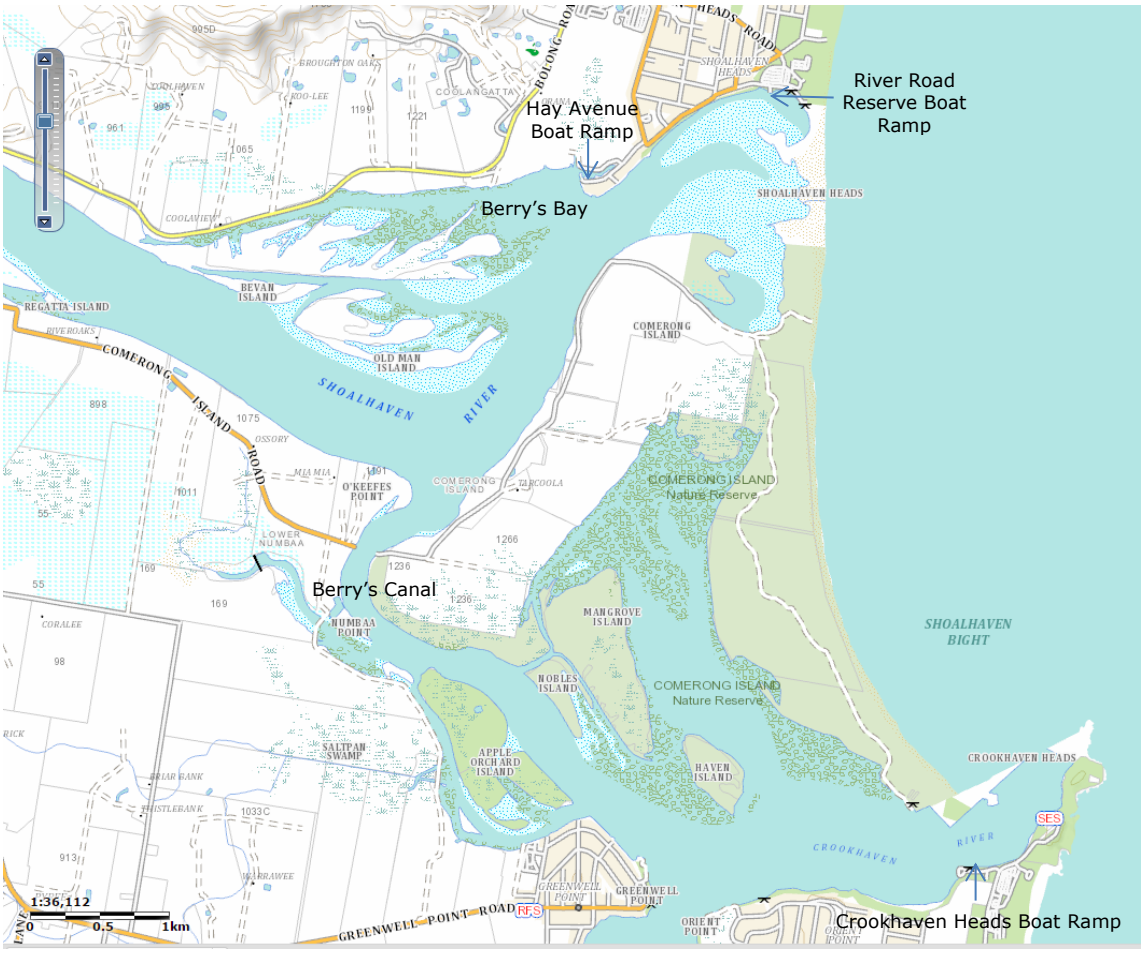


Figure 1.1 Study Domain with Key Sites Identified (Map Source: Six Maps)

2. Background Information

The evolving nature of the entrance at Shoalhaven Heads has been an ongoing issue for the local Shoalhaven community for many decades. News articles dating back to 1936 (Shoalhaven News and South Coast Districts Advertiser, 1936) indicate that the local community (then known as 'Jerry Bailey') wished to have the entrance manually opened annually. As is commonly stated by the community, failure to regularly open the entrance can have significant economic ramifications locally.

A primary task of this study is to complete a literature review focused on the history of research, projects and plans developed for the Shoalhaven Heads and Berry's Canal area. As such, a large number of reports were collated and reviewed for this study. A compendia of the reports has been developed and categorised into the following general areas:

Geomorphology: Wright, 1976; Public Works, 1982; Williams, 1988; Public Works, 1988; Umitsu et al., 2001; Paterson Britton and Partners, 2003; Webb McKeown and Associates, 2004; Young et al., 2007; Thompson, 2012; Caravalho and Woodroffe, 2013; and Gordon, 2013.

Estuarine Health: Chafer, 1998; Healthy Rivers Commission, 1999; Department of Environment and Climate Change, 2011; Office of Environment and Heritage, 2011; Shoalhaven River Oysters, 2012; and Nash and Rubio, 2014;

Flooding Impacts: Webb McKeown and Associates, 1987; Webb McKeown and Associates, 1988; Public Works, 1988; Public Works, 1990a and 1990b; ; Webb McKeown and Associates, 2008; Webb McKeown and Associates, 2011; Cardno, 2012a and 2012b;.

Estuarine Dynamics and Climate Change: Miller et al., 2006; MHL, 2012; WMA Water, 2011; and Glamore and Rayner, 2014;

Entrance Studies: Posford et al., 1977; Brown et al., 1978; Public Works, 1984; and Nittim and Cox, 1986.

Estuarine Policy and Plans: Webb McKeown and Associates, 2006; Shoalhaven City Council, 2006; Department of Natural Resources, 2006; Umwelt, 2008; and Shoalhaven City Council, 2008.

This literature review focused on the entrance studies/plans that related to circulation in the Shoalhaven Heads region. For a broader background the reader is directed to previous studies including the Shoalhaven River Entrance Management Plan (SCC, 2006), the Healthy Rivers Commission of New South Wales Independent Inquiry into the Shoalhaven River System (1999), Thompson's recent collation of information on Berry's Canal (2012) and various flooding reports (Public Works, 1990; Webb McKeown and Associates, 2008; 2011). The review provided below is detailed in chronological order. A full bibliography of all reports reviewed is provided in Section 7.

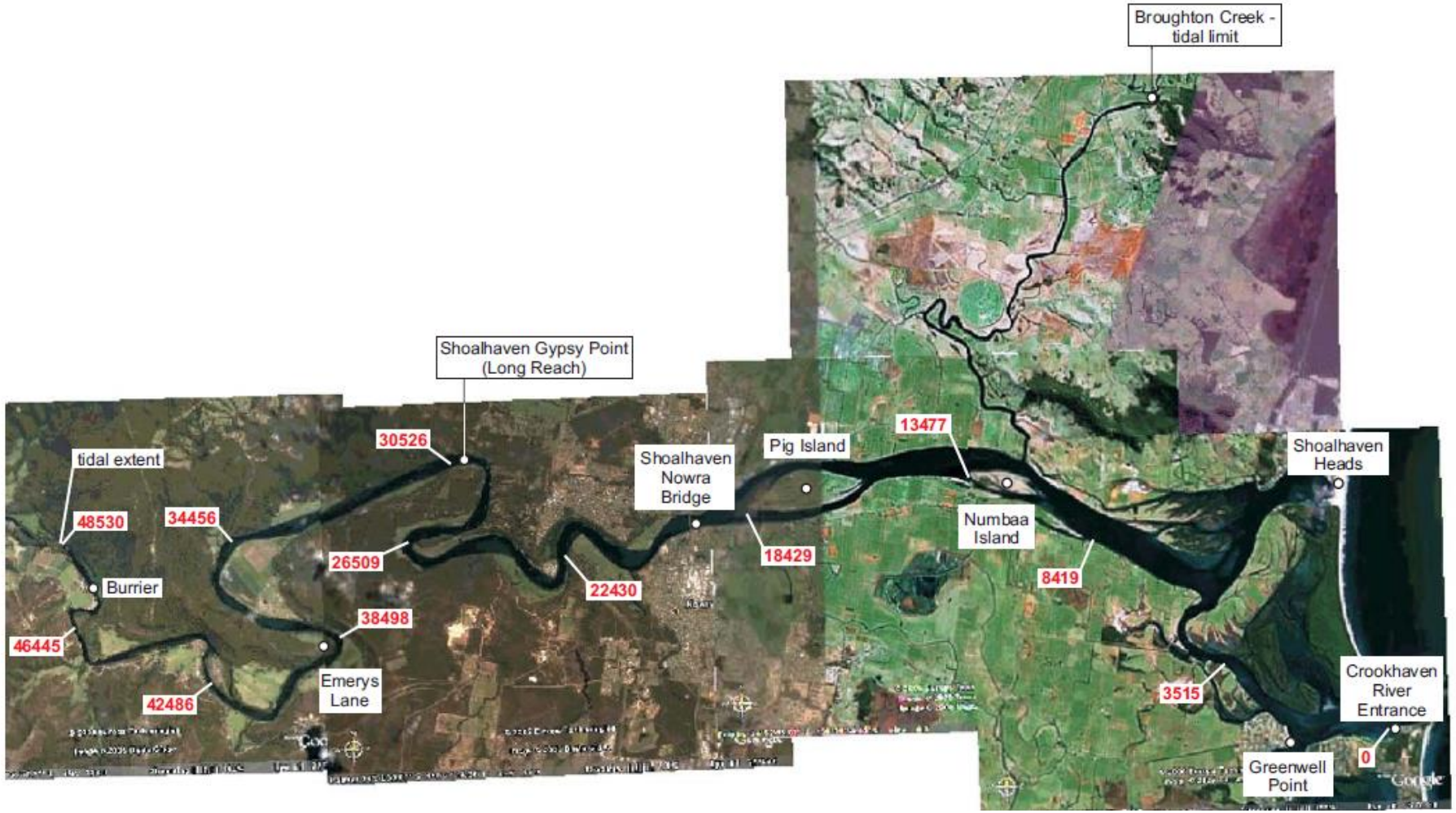


Figure 2.1 Shoalhaven River Estuary (with chainage from Crookhaven River mouth) as per Miller et al. 2006

2.1 General Background

With catchment size of 7,500 km^2, the Shoalhaven River is the 4th largest river in NSW and the largest south of Sydney (Figure 2.1). The river is an example of a mature stage, wave dominated estuary (Roy and Thom, 1981). This implies that the broad floodplain of the lower river has infilled to form a channelized river. Over geological timeframes the mouth of the Shoalhaven River has migrated significantly between the existing Crookhaven River entrance in the south and Mount Coolangatta in the north.

In 1797, George Bass was the first to report on the Shoalhaven River entrance, which appeared closed at the time of his inspection. In October 1818, John Oxley was also unable to enter the Shoalhaven River entrance with a small vessel, the 'Emmeline'. In January and June of 1822, when Alexander Berry arrived to the region, the Shoalhaven River entrance had significant sandy berms (or shoals) which limited navigation. Upon settling in the region, in July 1822, Berry sent three men to construct a canal (approximately 209 yards long and 18 feet wide), which formed Comerong Island, and allowed the Shoalhaven River to discharge via Crookhaven Heads. Several years later dredging and erosion opened up the river to steamships on the coastal trade via the Crookhaven River. Over the past 200 years, Berry's Canal has continued to evolve and expand and has been the subject of various studies (e.g. Public Works, 1988; Chafer, 1998; and Thompson, 2012).

The expansion of Berry's Canal has altered flushing conditions within the lower and upper sections of the Shoalhaven River estuary. Research undertaken by Thompson (2012) indicated that the canal is now sufficiently enlarged to permit daily base flows from the Shoalhaven River, although sections of the canal will continue to erode and enlarge due to floods and natural re-alignment. Miller et al. (2006) demonstrated that tidal flushing via Berry's Canal now provides adequate flow conveyance to ensure that salinity concentrations upstream of O'Keefe's Point are largely unchanged regardless of the condition of the Shoalhaven Heads entrance (i.e. open or closed). In combination, this suggests that flushing and salinity conditions for the upstream reaches of the estuary (upstream of O'Keefe's Point) and downstream within the Crookhaven River have now reached a dynamic equilibrium.

The enlargement of Berry's Canal has also reduced the volume of water discharged via the Shoalhaven Head's entrance. Studies by Posford et al. (1976) indicated that wave set-up at the open Shoalhaven Heads entrance from 2-3 m offshore waves is sufficient to divert 40% of the Shoalhaven Heads ebb tide flow volume down Berry's Canal. This suggests that the Crookhaven Heads entrance is the preferential flow path under most offshore conditions as it is sheltered from the prevailing southeast and southerly wave attack and is not similarly influenced by wave set-up.

The reduced volume of water discharging from the Shoalhaven River estuary via Shoalhaven Heads also has implications on the closing dynamics of the Shoalhaven Heads entrance. After opening during large floods, the area inside the entrance can act as a sump to littoral transport in the region. Asymmetry in the tidal signal, as well as higher suspended sediment concentrations due to ocean wave action, allows more sediment to be transported into the river entrance than is flushed out with each tide. This ensures that there is a regular supply of sand available to close the entrance unless floodwaters regularly return to scour the channel.

2.2 Previous Technical Assessments

In response to these 'natural' processes, there has been ongoing concern that the Shoalhaven Heads region would become a shoaled backwater. Between 1976 and 1986, three major reports were undertaken to examine the entrance area. These scientific reports largely focused on the feasibility of an artificial entrance at Shoalhaven Heads to maintain an open entrance either permanently or for extended periods. A brief summary of those reports is provided below.

Posford et al. (1977) is the most comprehensive study of the Shoalhaven River entrance. This report provides a field and desktop assessment of the tidal, shoaling, entrance and offshore dynamics of the region and provides calculations to confirm conceptual models of hydrodynamics in the vicinity of the entrance. This report details the impact of Berry's Canal on the flushing of the Shoalhaven River entrance and highlights the importance of wave setup on diverting flows via the Crookhaven River. This information is then used to test various permanent entrance option designs.

Posford et al. (1977) noted that it is possible to construct a permanent river entrance at Shoalhaven Heads, although it would be very costly to construct a navigable design. The most favourable non-navigable scheme recommended was a series of eight (8) groynes (the first pair 200m in length and the remaining 160 m long). This design would be enhanced by the closure (either through weirs or a canal lock) of Berry's Canal at considerable additional costs and flood implications. In 1975, an order of estimate capital costs or the groyne design (not including the land connection) was $2 million. Posford et al. (1977) also examined the costs/benefits of a permanent entrance to local tourism and the fishing/oyster farming industries and found limited appreciable benefit from maintaining an open entrance.

Following major floods in 1978, the Shoalhaven River entrance gradually shoaled until it closed in 1981. In 1984, Public Works completed the Shoalhaven River Entrance Management Study. This study examined shorter term options (versus the long term options identified in Posford et al., 1977) to encourage entrance opening during flood events. The long term effects of a permanently closed entrance were noted as:

- *"More frequent flooding of the low-lying areas south of the Shoalhaven River will occur,*
- *Waterway between Berry's Canal and Shoalhaven Heads is likely to become a backwater not subject to regular tidal flushing,*
- *Major floods could lead to further substantial erosion along Berry's Canal,*
- *Bed load sediment during floods will eventually have to be discharged through the Crookhaven entrance, with attendant siltation problems for the lower Crookhaven system."*

Public Works (1984) was the first to propose an artificial low point (or notch) in the entrance dunes to facilitate the discharge of flood waters. A notch of 2 m AHD with a width of 5 m was suggested. The implementation of the notch design was shown to reduce flooding at Shoalhaven Heads by 0.7 m for the 1978 flood (note that this setup varies with each event). Dune reshaping and preferred areas to construct the notch were also described. It is worth noting that numerous assumptions were made in calculating the scour behaviour of the notch during the passage of a flood.

In response to further public pressure, Nittim and Cox (1986) examined the effects of closing Berry's Canal. Despite historic reports to the contrary, this report used other similar rivers to suggest that the Shoalhaven River would remain open if the canal was closed. The costs to

undertake this work were estimated at $20.4 million at August 1986 rates. Based on discussions with the local community it was agreed that the canal should not be closed, the notch should be visible, the sand dunes should be revegetated and that dredging is required at Shoalhaven Heads. The concept of a pilot channel leading to the notch was also addressed and shown to only have a slight effect on scour dynamics as the water level in the bay is the controlling factor. The recommended work programme included revegetating the sand dune but maintaining a 750 m wide bare section to allow for breakout in a major flood (the August 1974 storm produced a 600 m wide break). The dune revegetation efforts by the local community between 1988 and 1990 are detailed by Aber and Kesby (1991).

2.3 Flood Studies

A flood event in 1988 caused the highest flood level recorded at Shoalhaven Heads (Aber and Kesby, 1991). In August 1990, another large flood was experienced, equivalent to a 1:30 Annual Exceedance Probability (AEP) event. In 1990, the Lower Shoalhaven River Flood Study was completed (Public Works, 1990a). This study used computer models to predict flood behaviour based on Council's existing entrance strategy allowing a berm to be maintained at 2 m Australian Height Datum (AHD) which subsequently scoured during the flood.

The results from this flood study indicated that the Shoalhaven Heads entrance had a significant influence on flood behaviour in the lower estuary and these impacts can extend up to Pig Island. The flood modelling indicated that the width of the entrance had minimal impact to the scour volume of the entrance, whereas a greater difference between the flood level immediately inside the entrance and the ocean level produced the largest entrance scour volume. The flood results also detailed the influence of an open entrance for a simulated flood event with a 0.75 m difference at Shoalhaven Heads, a 0.4 m difference at Greenwell Point but only a 0.014 m reduction at Nowra Bridge (Public Works, 1990a).

The Lower Shoalhaven River Flood Risk Study (Webb, McKeown & Associates, 2008a) examined the risks associated with the predicted flood levels. This study highlighted the role of the entrance condition on the flood risk and noted that the 1:10 (AEP) design scenario results in the potential flooding of some 116 properties, with 390 buildings inundated above floor levels at Shoalhaven Heads. Importantly, this study assumed the entrance was closed at the start of the flood but was allowed to scour with the passage of floodwaters.

The recommendations from the Lower Shoalhaven River Flood Risk Study included the development of a formalised flood management policy that details a decision making process and action plan, incorporating the range of issues associated with the entrance conditions. This policy is emphasised as an interim solution, until the residual flood problem can be addressed through long-term measures such as house raising, development controls or rezoning. The management plan recommendation was subsequently formalised as an action in the Lower Shoalhaven River Floodplain Risk Management Plan (Webb, McKeown & Associates, 2008b) as:

> *"Finalise and implement Council's Shoalhaven River Entrance Management Plan for Flood Mitigation. The Plan must be reviewed every two years or immediately after every opening."*

2.4 Towards an Entrance Management Plan

In 1999, the Healthy River's Commission (HRC) of NSW led an independent inquiry into the Shoalhaven River (HRC, 1999). The inquiry was set up to help Government and the community

make informed choices about ecological, social and commercial goals for the river. The report recommended "*the integrated management of the estuarine waterway, its interaction with ocean processes and its interaction with land uses and processes operating on the floodplain*." Various actions were identified to better integrate water quality concerns across the floodplain, including addressing acid sulphate soil drainage in the lower estuary.

The HRC (1999) also detailed the considerations of the community and the science associated with Berry's Canal and the Shoalhaven Heads. The report detailed the pros/cons of a permanent entrance including the cyclical nature of the entrance in relation to the Southern Oscillation Index and the increase in biodiversity when the entrance has been closed for periods exceeding one year (Chafer, 1998).

Overall the HRC's report promoted catchment wide initiatives to improve water quality and better river management. The HRC (1999) report provided strong conclusions on the following topics:

- **Entrance Opening:** Maintaining a permanent opening is not feasible in the high wave energy environment and the establishment of a permanent opening should not be pursued or further investigated.
- **Habitat:** Natural variations in the entrance (i.e. open vs closed) provides the best conditions for fisheries over the long term.
- **Dune maintenance**: The dry notch policy at 2 m AHD should be continued and the Dunecare program, albeit temporary and localised, should be encouraged.
- **Dredging:** Dredging activities to the Shoalhaven Heads boat ramp to be considered on a cost to benefit ratio, including the ways in which their costs and benefits would be shared among those directly affected and the broader community.
- **Documentation:** Linkages between entrance closure and water quality in the Shoalhaven Heads region should be investigated and documented to assist the assessment of longer-term management decisions of the area.
- **Berry's Canal:** Neither rock revetments or closure of the canal should be pursued.

The plan also states that opening of the entrance in times of large oceanic storms may result in increased flooding.

In 2006, the previous work on estuarine process, entrance dynamics, flooding and river health culminated in the adoption of the Shoalhaven River Entrance Management Plan for Flood Mitigation (SCC, 2006). This plan describes procedures for undertaking entrance management, pre-conditions to satisfy prior to artificially opening the entrance, state agencies roles and responsibilities, and steps to follow in the event of an emergency opening of the entrance. The report provides useful background details on flooding impacts, previous entrance openings and the role of the entrance in mitigating flood risks by reducing peak flood levels by between 0.4 – 0.6 m (increasing with the size of the flood event).

Within the plan there are detailed specifications for the dry notch including:

- The maintenance of a 50 m wide channel with a 400 m wide non-vegetated area;
- A maximum berm height of 2 m AHD, and;
- The location of the entrance should be as far south as is reasonable.

The SCC (2006) plan is designed to formalise Council procedures in relation to flood response. As such, the plan is not designed to address ecological or water quality purposes. However, the

plan does provide a review of environment factors (REF) prepared in accordance with the requirements of the Environmental Planning and Assessment Act (1979). The REF (SCC, 2009) assesses the impacts of artificially opening the river and of maintaining the dry notch. The REF and plan also state that any mechanical excavation should be undertaken to minimise impact to the shorebird breeding season (October to March).

Importantly, the plan details modelling results that indicate the extent of flood impact if the preferred scour width (400 m) is not maintained. Detailed action triggers and water level indicators are outlined in the plan.

The SCC (2006) plan also notes that flooding of the Broughton Creek region is not directly adopted within the triggers. As such, if there is a large amount of rain in the Broughton Creek catchment it may be possible that water levels at Shoalhaven Heads could exceed 2 m AHD before Nowra Bridge levels reach 3 m AHD (water level triggers). A flood study of Broughton Creek is recommended within SCC (2006) and is to be included in future updated plans.

The SCC (2006) plan is recommended to be reviewed at regular intervals. These include after each event, at no less than 5 year intervals and as soon as the Lower Shoalhaven River Floodplain Risk Management Plan is completed. The plan also supports the recommendations from the HRC (1999) report regarding water quality monitoring to clarify linkages between entrance closure and water quality in the vicinity of Shoalhaven Heads.

2.5 Estuarine Ecohealth

Since the adoption of the SCC (2006) plan, research and technical reports in the lower Shoalhaven River estuary have focused primarily on water quality concerns and geomorphology. With regards to water quality, Miller et al. (2006) examined the salinity dynamics of the estuary under various flow regimes. This report found that the lower estuary salinity dynamics are largely unaffected by pumping upstream of Tallowa Dam and that Berry's Canal has sufficient conveyance so that salinity concentrations (and thereby tidal flushing) upstream of O'Keefe's Point are largely unaffected by the Shoalhaven Heads entrance condition. This suggests that any water quality issues related to flushing in the lower estuary would be isolated to the bays in the vicinity of Shoalhaven Heads. Glamore et al. (2014) expanded on this modelling and through detailed field work examined acid sulphate soil priorities across the lower estuary. Glamore et al. (2014), as well as other recent estuary wide studies, examined climate change impacts on the floodplain.

To support the recommendations with HRC (1999) and the estuary management plan, SCC (2008), OEH (2012) provided an estuary ecosystem health report card for the region. This work used turbidity and Chlorophyll-a as indicators (collected monthly) as well as estuarine vegetation change over time to assess ecosystem health. These indicators align with the NSW Monitoring, Evaluation and Reporting Program. Chlorophyll-a is used as an indicator of nutrients derived from catchment runoff, whereas turbidity is a measure of suspended sediments. Locations for monitoring were selected within the lower Shoalhaven River estuary including within Shoalhaven Heads. Report card results from within Shoalhaven Heads area indicate that both turbidity and Chlorophyll-a received a 'B' rating, implying a 'good' estuarine health score.

Other water quality data suggests variable results, dependent on the location within the Shoalhaven Heads region. In relation to oysters, Nash and Rubio (2014) highlight the variable nature of water quality and the high faecal coliform numbers associated with the Berry's Bay area (versus other areas in the lower estuary). The Shoalhaven River Oysters Inc. (2012) also

highlight these variable results and notes the entrance opening as a 'low level' risk due to its influence on water quality. Further detailed analysis of water quality data is provided in Section 4.1.

Recent geomorphological reports have primarily focused on the expansion of Berry's canal and its influence on riverbank erosion and tidal hydraulics. Following the seminal work by Public Works (1988), Chafer (1998) examined the influence of geomorphology (and entrance dynamics) on bird populations with time. Thompson (2012) reviewed and updated the cross-sectional areas of Berry's Canal and suggested that a decrease in the rate of erosion indicates that Berry's Canal is adjusting towards a dynamic equilibrium. Caravalho and Woodroffe (2013) used remote sensing data to examine spatial and temporal variations in Berry's Canal and at the entrance to estimate depositional/erosional processes and entrance dynamics. Additional research findings by Caravalho related to offshore sediment transport and estuarine dynamics is anticipated and should be incorporated within future estimates (pers comms, R. Caravalho).

2.6 Summary

This review of background literature provides the following conclusions:

- The modified system has been the subject of concern to the local community at Shoalhaven Heads for more than 80 years.
- Previous technical studies have largely focused on:
    - methods for ensuring an open entrance (and thereby oceanic water quality conditions);
    - the dynamics of Berry's Canal, and;
    - concerns with water quality within the entire estuary (particularly acid sulphate soils).
- Detailed management studies examining the entrance have concluded that large engineering works to maintain a permanent entrance are not justified on a cost-benefit analysis and that the existing plan that maintains a notch at 2 m AHD (400 m wide) should be supported as a temporary measure.
- Flood studies for the area (conducted in 1990) highlight the importance of the entrance management plan recommendations in reducing flood risk to the community.

The following sections of this report combine the previous knowledge from previous reports with community/stakeholder feedback and available process understanding to assess current issues and test management options.

3. Community and Working Group Engagement

The focus of this study is to review updated information on water quality within the Shoalhaven Heads region and assess options for improving circulation (and thereby water quality). This approach relies on the veracity and robustness of previous knowledge and datasets and, importantly, integrates this information with feedback from the local community and state agencies. Therefore, engagement with the local community and key stakeholders is an integral component of the study.

Two main approaches were adopted to engage with the local community: (i) ongoing and extensive discussions with the Shoalhaven Heads Estuary Taskforce who are representatives from the community. This included attendance at multiple Taskforce meetings; and (ii) direct engagement with the community via a 'Community Science' day held at Shoalhaven Heads. Representatives from state agencies were also directly contacted and written details sought on relevant agency perspectives. Note that further engagement with the local community will be conducted following submission of this report to assist in disseminating and explaining the report findings.

The engagement process is important as it guides the overall approach to the study and enables exchange of scientific knowledge and information between the study team and the local community in relation to water quality processes and the role of the entrance. Details on engagement measures are detailed below.

3.1 Community Science Field Day

A community science field day was held in Shoalhaven Heads, at the River Road Reserve boat ramp, on May 23rd 2015. The event was promoted by various means. Event flyers were distributed across the community, radio interviews were held, information was posted to the SCC and UNSW's websites and articles were written for the local newspapers. Members from SCC and the Shoalhaven Heads Estuary Taskforce played a key role in distributing information and providing logistical assistance during the event.

During the event various scientific displays and experiments were conducted to engage with the local community.

- Firstly, over 400 tagged oranges were released from four (4) GPS marked locations within the bay at various times. These oranges were subsequently collected throughout the day and the retrieved location marked on a large map. These locations were then discussed to highlight flow paths, timings and dynamics. A picture of the final map with noted locations is provided in Figure 3.1**.**
- Secondly, an unmanned aerial vehicle (UAV or drone) was flown twice during the event. GPS location markers (tiles) were distributed on-ground with the help of the local community to calibrate the flight data. The flights were conducted at high and low tide using visual and near infrared spectra cameras. The data from the flights was processed onsite and shown to community participants to highlight the topographic features of the area. Results from the UAV flights are provided in Figure 3.2**.**
- Thirdly, a physical demonstration model of the lower Shoalhaven River estuary was purpose built for the event. This model was used to highlight the inter-connectivity between the Crookhaven River, Berry's Canal, Shoalhaven River, Shoalhaven Heads and the upper estuary. The model played a key role in engaging with the local community, discussing options for adjusting flow distributions in the Shoalhaven Heads area and

providing training on the important estuarine/coastal processes. A picture of the demonstration model is provided in Figure 3.3.

- Finally, various other models were provided to engage with the local community. This included a physical wave model that highlighted the role of waves in fostering sediment transport, live numerical model animations demonstrating saline dynamics in the estuary and various handouts on estuarine process and the overall study aims.

Figure 3.1 Location of Oranges Retrieved During Community Science Day

Feedback from the community was gathered on the day through a survey distributed to attendees. More than 100 surveys were completed on the day, with additional surveys being subsequently completed by community members. Details of the results of the surveys is provided in Section 3.2 below.

Feedback from the Community Science Day was very favourable. Overall there was strong support for the project's approach and an appreciation for the demonstration models. Newspaper articles after the event stated that "*Children and adults walked away with a greater understanding of the local environment*" (South Coast Register, May 27th 2015).

In addition to the Community Science Day, Dr William Glamore (Project Director) attended three Shoalhaven Estuary Taskforce Meetings at SCC. At the project inception meeting (25th March 2015), Dr Glamore outlined the project's approach and proposed methodology. At the second meeting (22nd July 2015), Dr Glamore presented the study's initial findings, recommendations and next steps. The third meeting (23rd September 2015) was held in response to a flood event in the lower catchment and the response of SCC in enacting the entrance management plan. A final meeting will be held upon the submission of the draft report to disseminate report findings.

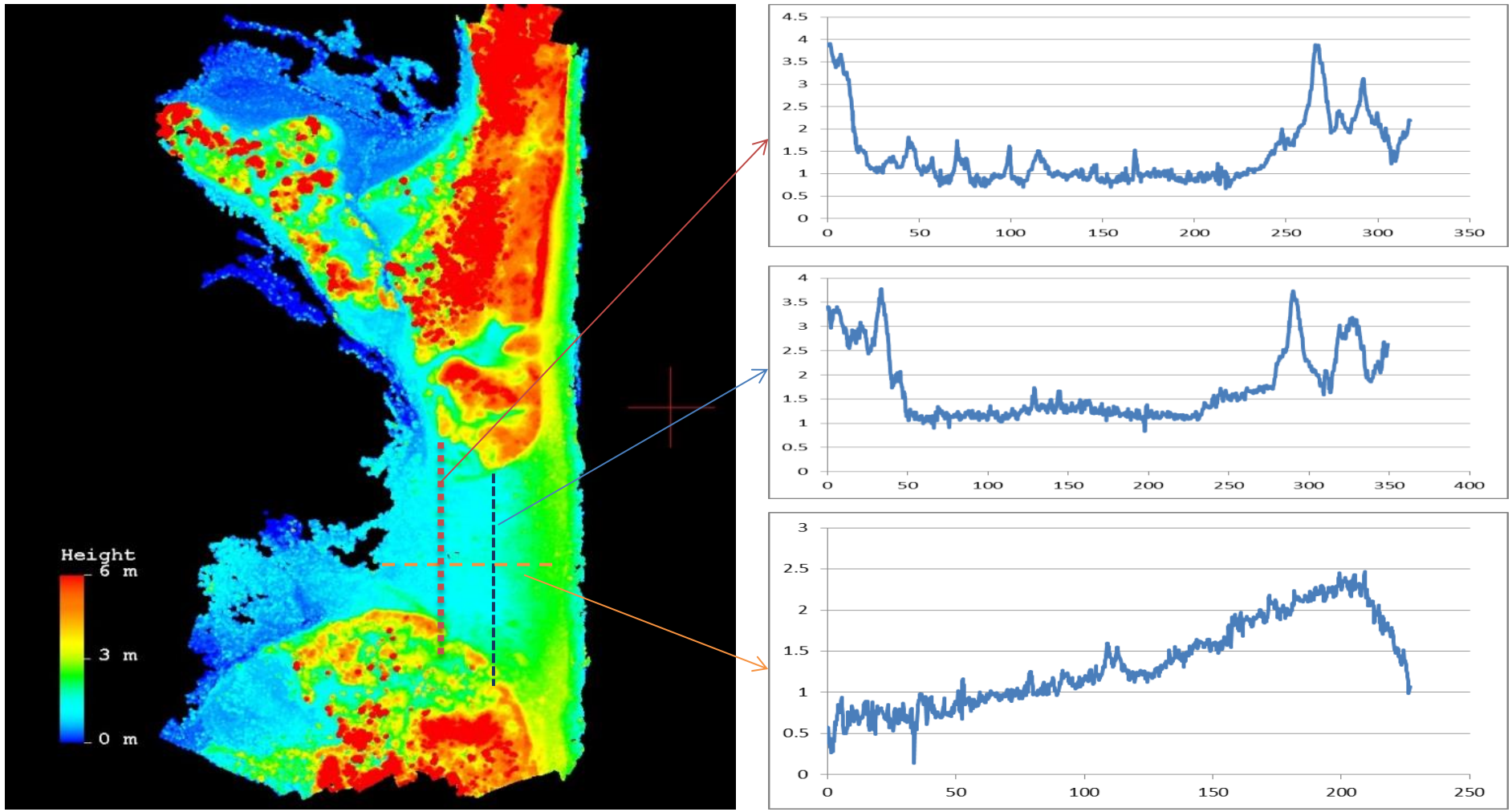


Figure 3.2 Topographic Survey Results from UAV flight at Shoalhaven Heads

Figure 3.3 Display of the Shoalhaven River Estuary Model

3.2 Community Science Survey Results

A ten (10) question survey was distributed to attendees during the Community Science Day. A copy of the survey is provided in Appendix A. The aim of the survey was to better understand the interests, desires and background knowledge of the local community. The results of the survey are provided in Figures 3.4-3.15 below.

Results from the 111 surveys completed can be summarised as follows:

- The community has a long history in the area, with a significant proportion living in the region for more than 20 years. Locals undertake a variety of activities both in (sailing, kayaking, swimming) and around (walking, bird watching) the waterway.
- More than two thirds of those surveyed have a 'high concern' for the local environment including recreational/amenity and environmental values.
- There have been many changes noted over time but the main concerns are focused around water quality and sedimentation. Future concerns are also related to water quality, siltation and circulation in the bay with an underlying concern for the ecosystem services (fishing, boating, tourism, recreation) the waterway provides.
- More than 50% rate their understanding of the local circulation as low to moderate.
- At least 50% of respondents rate their interest in further training/education as high.
- Approximately one third of all respondents noted increased entrance openings (or maintenance of permanent open entrance) as their preferred future management option. Other options included actions related to improved water quality management and decreased sedimentation. Ten percent (10%) of those surveyed identified evidence-based decision making as their preferred management action.

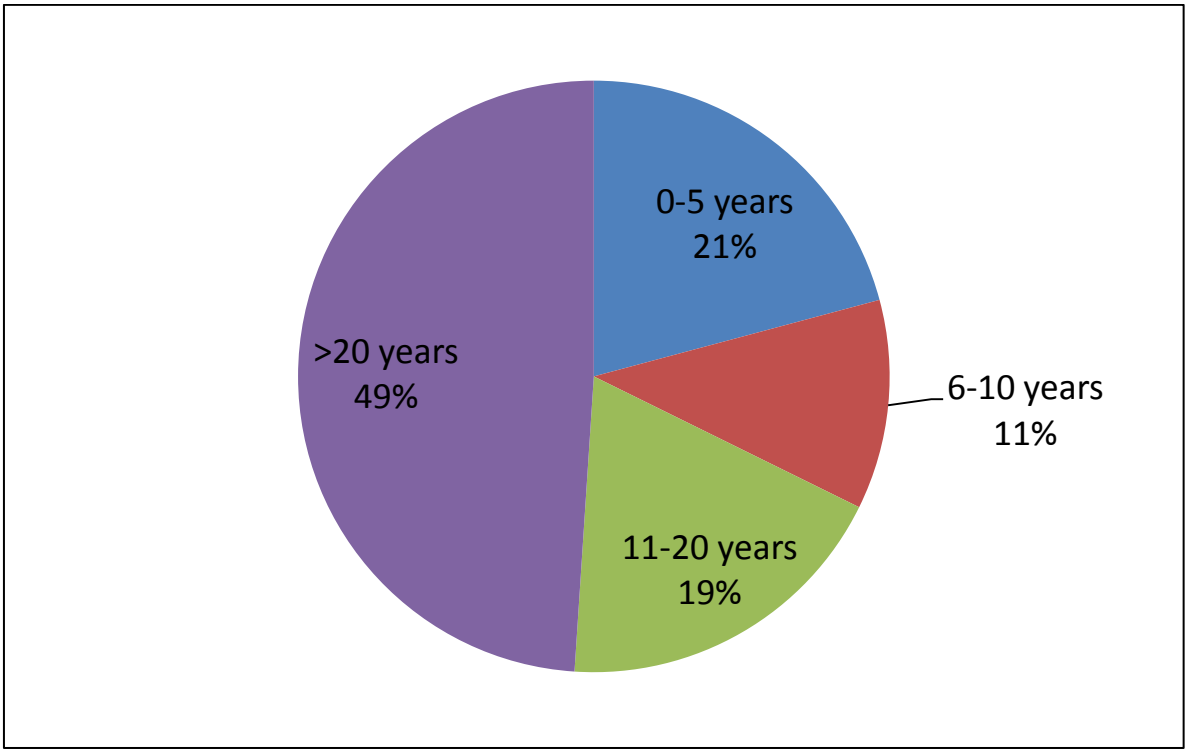


Figure 3.4 Length of Time in Shoalhaven Area

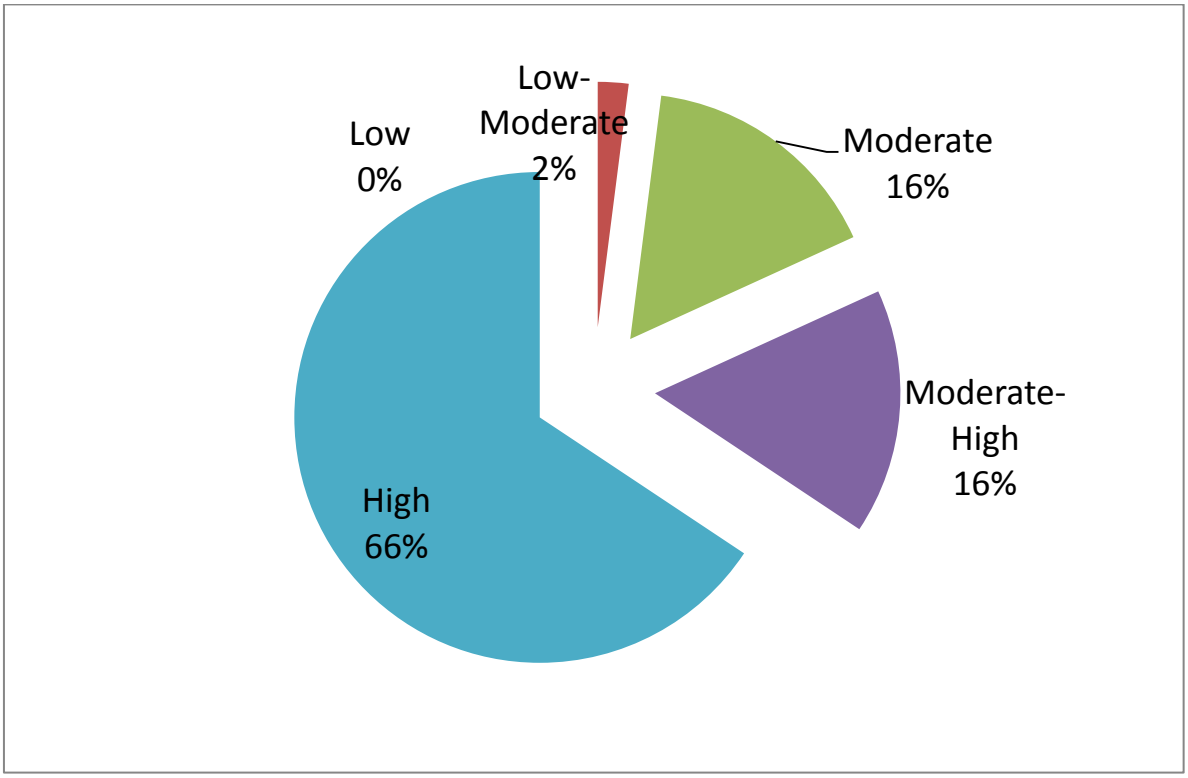


Figure 3.5 Level of Overall Concern/Interest

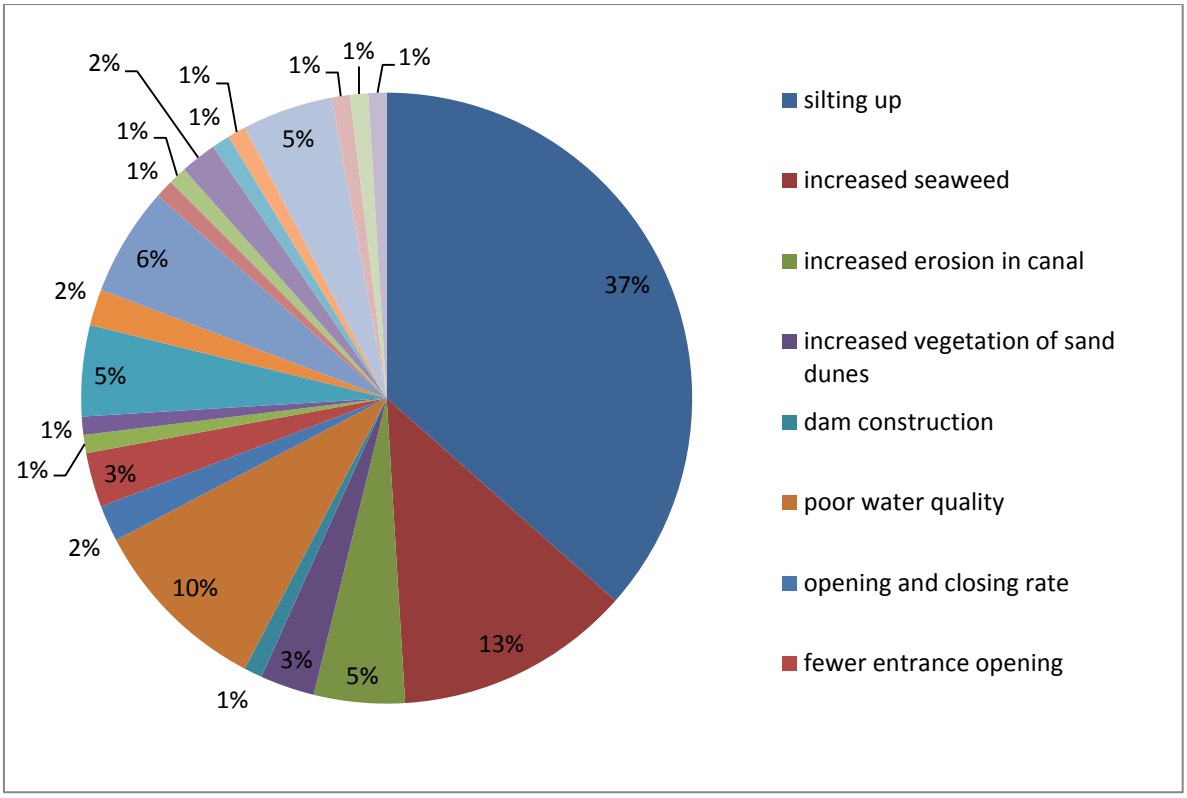


Figure 3.6 Major Changes Noted in the Estuary

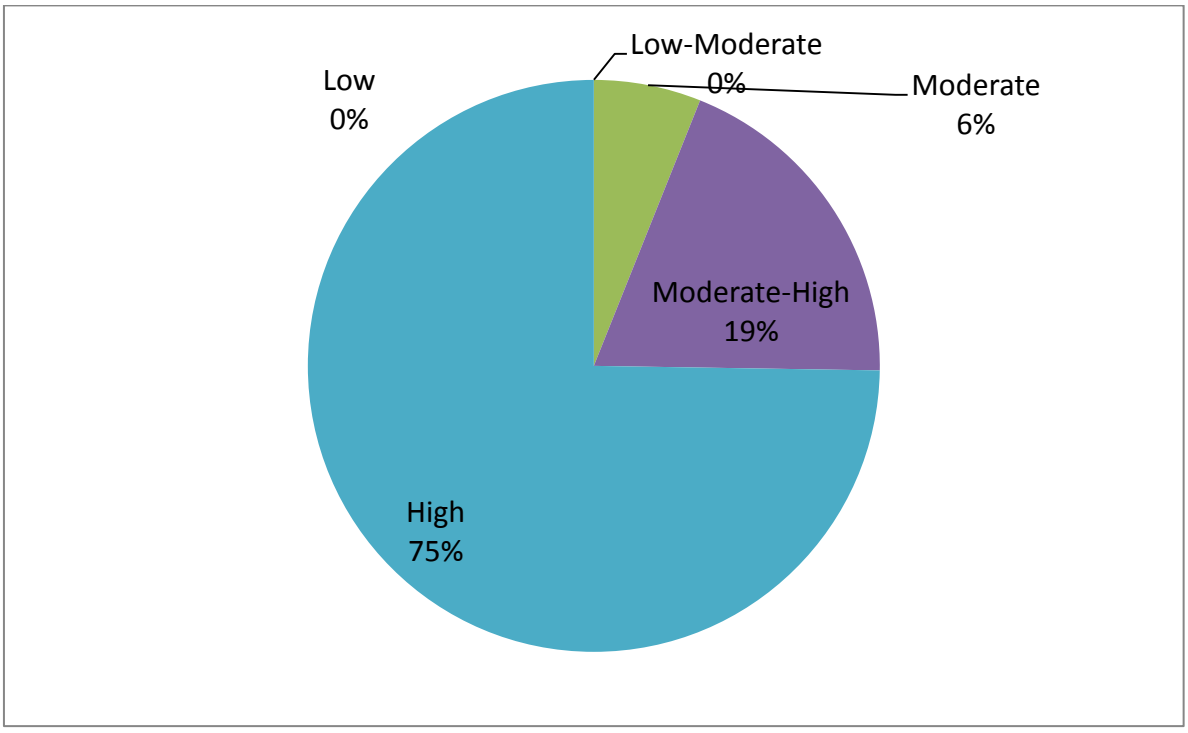


Figure 3.7 Importance of Recreational and Amenity Value

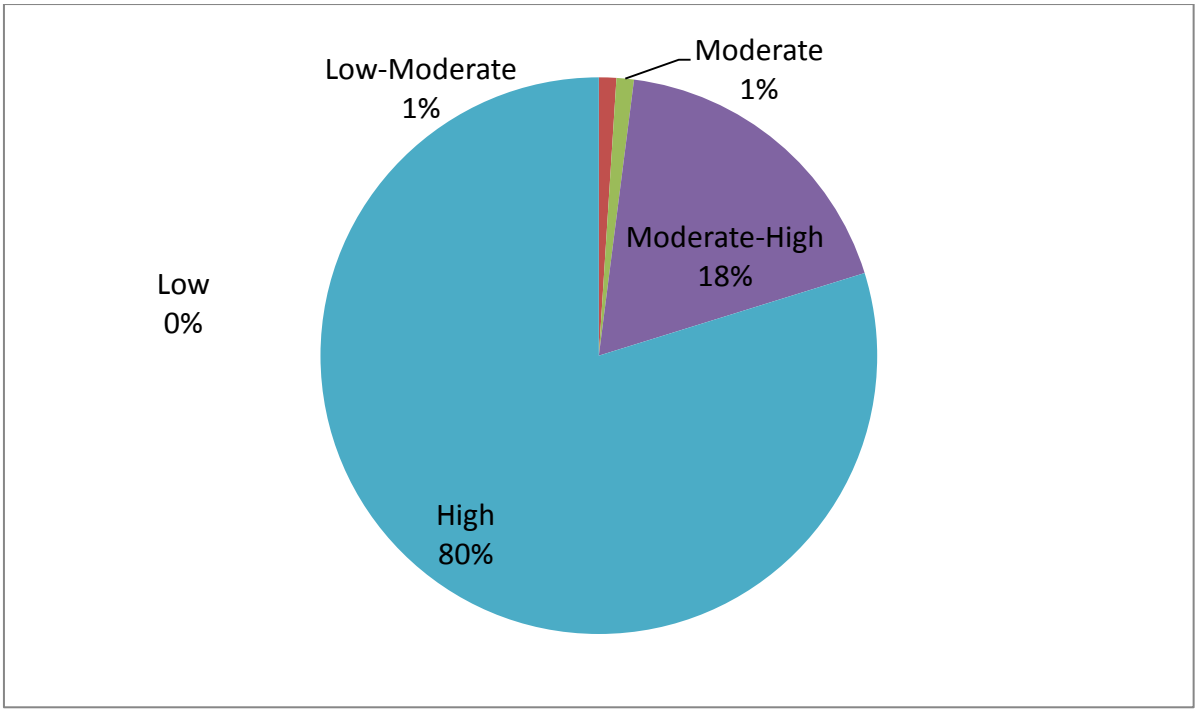


Figure 3.8 Importance of Environmental Value

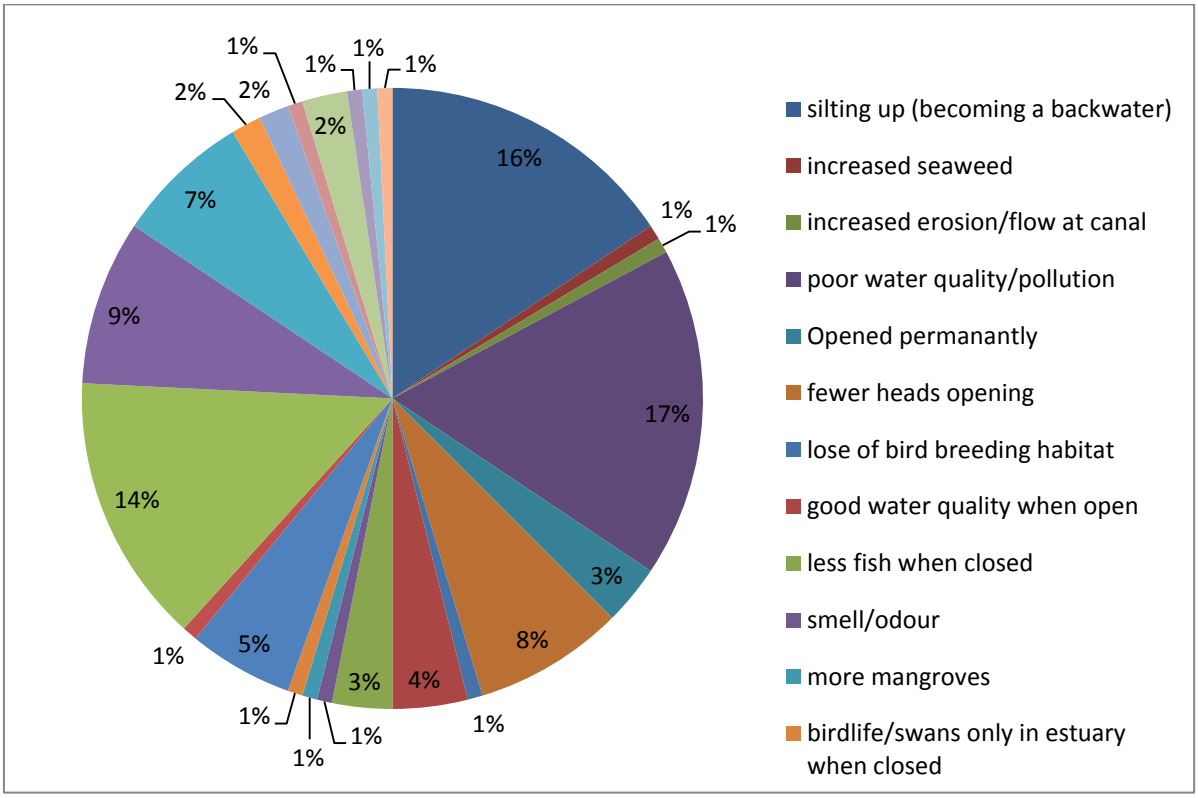


Figure 3.9 Biggest Concern for the Shoalhaven Heads and Estuary

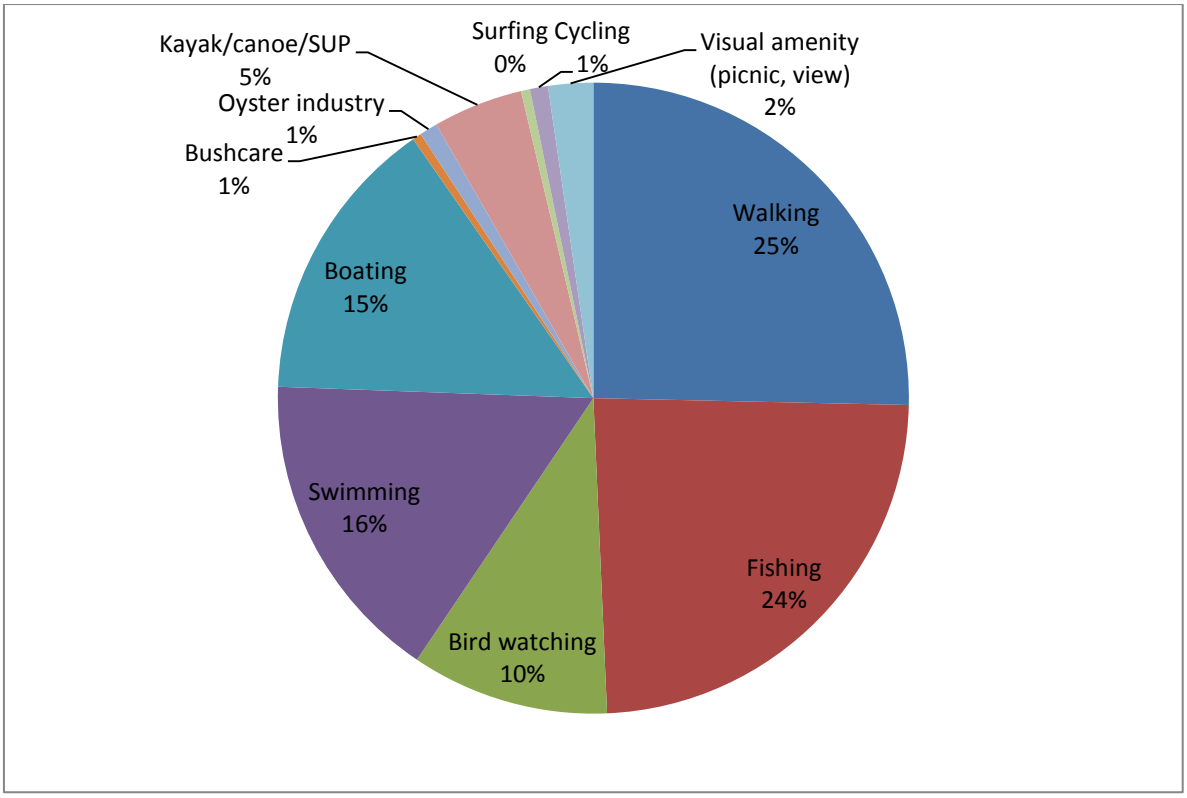


Figure 3.10 Most Common Activity in the Shoalhaven River Estuary

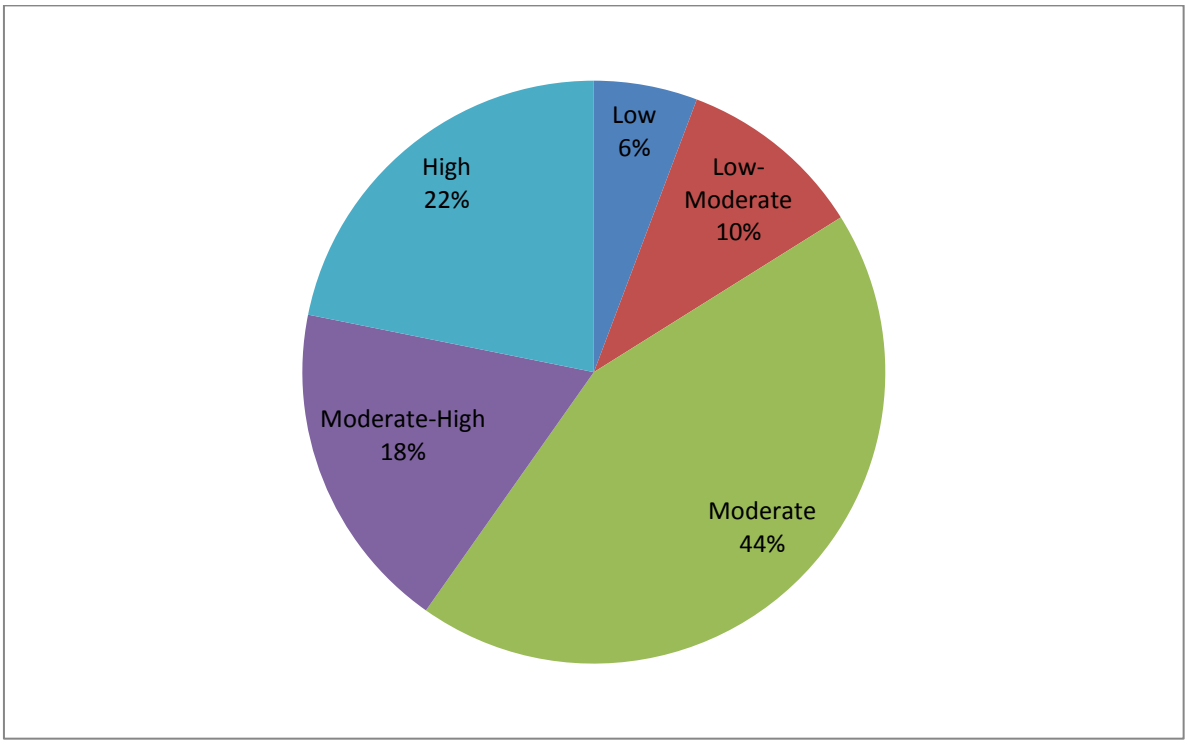


Figure 3.11 General Understanding of How Shoalhaven River Estuary Flows to Sea

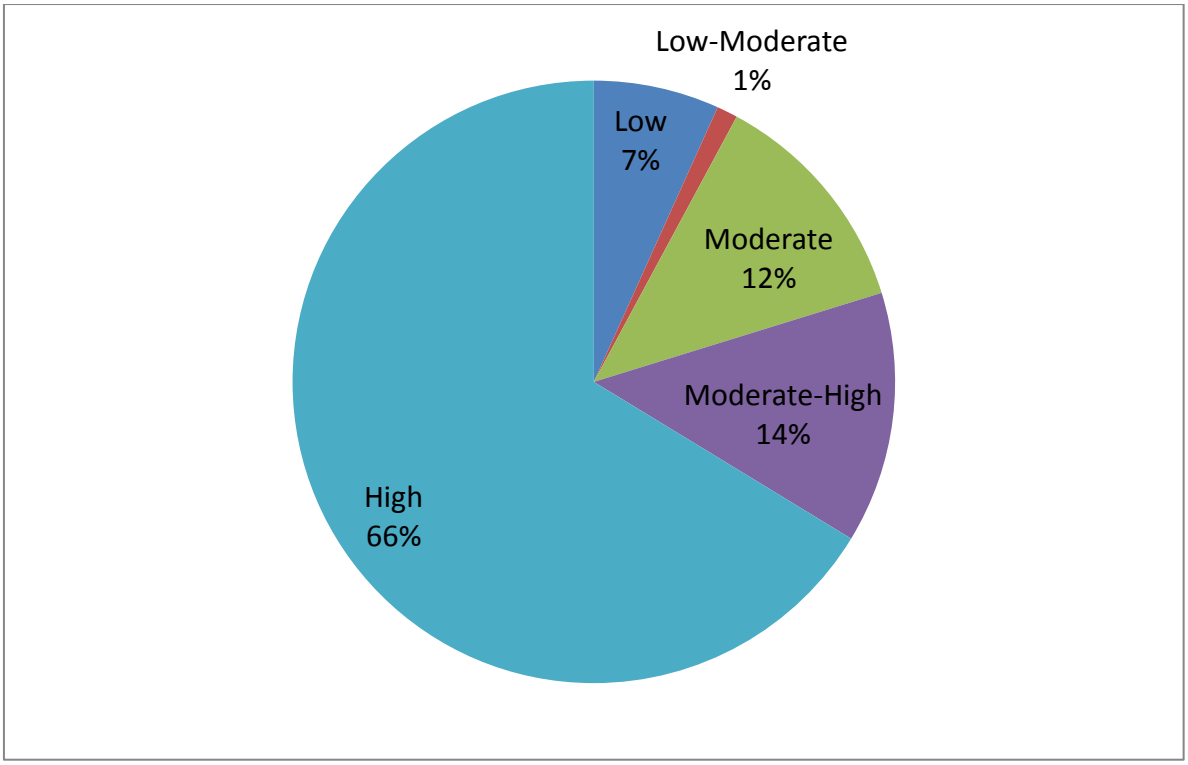


Figure 3.12 Importance of Maintaining Existing Environment and Amenity in Estuary

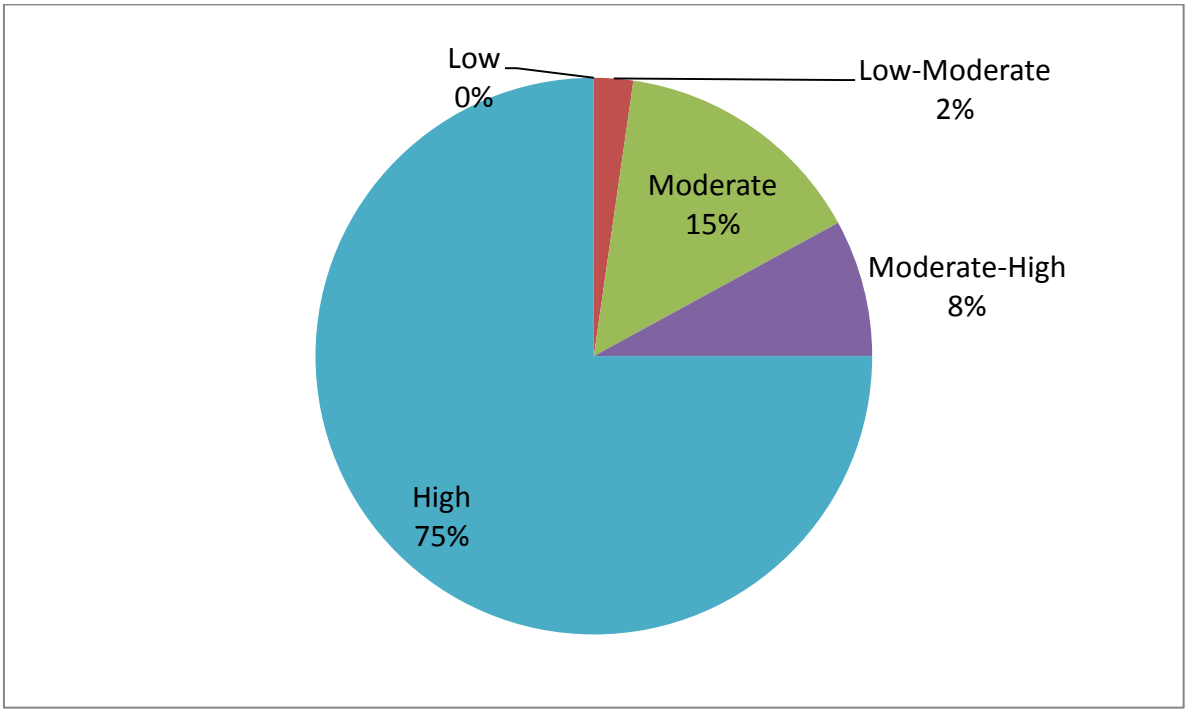


Figure 3.13 Importance to Improve Amenity and Recreational Values of Estuary

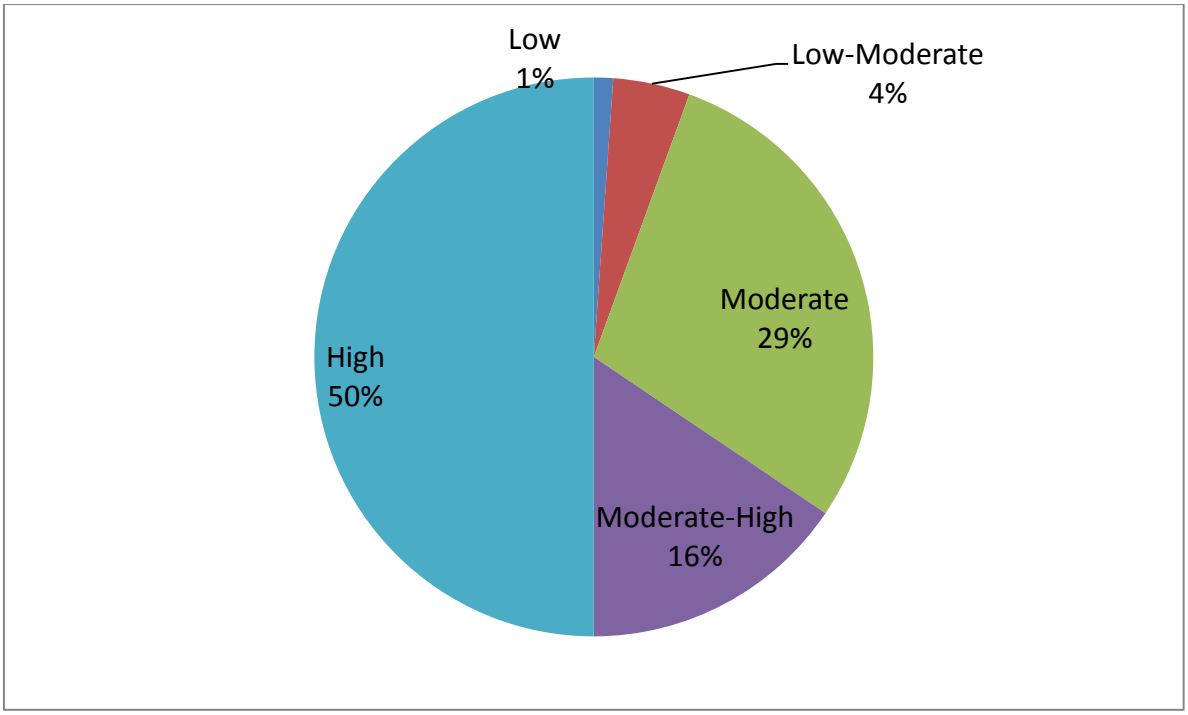


Figure 3.14 Interest in Environmental Training and Education

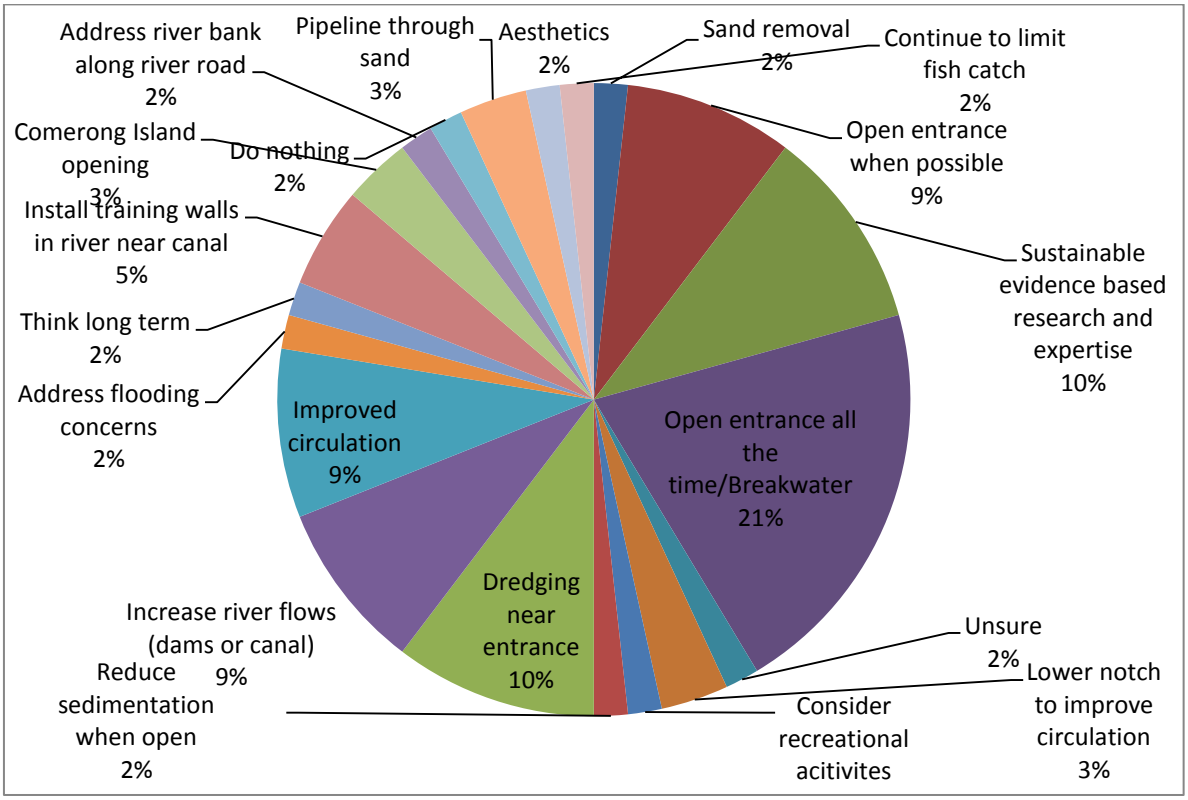


Figure 3.15 Future Management Actions

Survey results were used to focus the options addressed within the study. An assessment of the options assessed is detailed in Section 5.

3.3 State Agency Positions on Shoalhaven Heads Entrance

As part of this study, various state agencies were contacted and a request lodged to update their position on the Shoalhaven Head's entrance. Agencies contacted included the NSW Department of Primary Industries – Fisheries (DPI Fisheries), the NSW Office of Environment and Heritage (OEH) and the NSW Crown Lands Department (Crown Lands).

Position statements were previously noted within ordinary meeting minutes of the Shoalhaven River Natural Resource and Floodplain Management Committee on Wednesday, August 24th 2011. These position statements were provided to each state agency for assessment and revision.

The following position for DPI Fisheries as per the meeting minutes from 2011 is:

> • *Any proposals for artificial opening of ICOLLs must seek the approval or concurrence of I&I NSW under the Fisheries Management Act 1994;*
>
> • *The Department supports minimal interference with ICOLL entrance barriers and advocates natural processes being allowed to operate to the greatest extent possible;*
>
> • *The Department does not support the artificial opening of an ICOLL unless the proponent (i.e. Council or other agency) can demonstrate that the social, environmental and economic benefits greatly outweigh any potential adverse impacts; and*
>
> • *The Department supports using estuary management plans and environmental assessment processes to analyse the issues relating to opening a particular ICOLL, and to develop an entrance management plan or entrance management policy. Proposals for artificial openings which are to be carried out according to a formulated entrance management plan or policy are more likely to be approved by I&I NSW.*

The following position for Crown Lands as per the meeting minutes from 2011 is:

> *The entrance at Shoalhaven Heads is Crown Land. A proposal for a permanent entrance opening will require land owner approval. Crown Lands indicated that a request for land owner approval will need to be endorsed by Council's policy position accompanied by an environmental impact assessment of the proposed activities. Crown Lands indicated that it endorses the existing Entrance Management Plan as it is based on a State Government endorsed process.*
>
> *It is considered highly unlikely that proposals for permanent entrance opening would receive support from State Government Agencies, given this would be contrary to the Entrance Management Policy they have endorsed.*

Both Crown Lands and DPI Fisheries wished to maintain these positions. In contrast, OEH provided a new submission to update their position. The full submission is provided in Appendix B of this report. The previous statement for OEH included:

> *The Office of Environment and Heritage calls for Entrance Management Policy to be informed by Estuary and Flood Risk Management Study and Plans and community*

consultation. The process followed by Council so far is in line with OEH's position. Any amendment to the existing policy will need to follow a similar process.

In summary, OEH's updated response states that '*management options were thoroughly considered through the Estuary and Floodplain Management Planning process and the resultant plans are an appropriate guide for management decisions*'. The response also states that '*I am not aware of information that identifies a significant threat to public health or water quality deterioration in the lower Shoalhaven River estuary. To the contrary, completed estuary health report cards by Shoalhaven City Council undertaken with financial and technical assistance from the OEH indicate the Shoalhaven River's estuary health is good…*'.

4. Identified Concerns

Upon reviewing the available literature and engaging with relevant stakeholders, three (3) main areas of concern were identified. These can be summarised as below:

> **Water Quality:** There is general concern that poor water quality impacts aesthetics, fishing and recreational activities and causes odours. There is concern that poor water quality would also impact tourism and the oyster industry. Overall, a significant concern is that water quality issues are increasing.
>
> **Circulation:** There is general concern that the area is becoming a stagnant backwater full of mangroves. The lack of circulation is perceived to have a negative impact on water quality.
>
> **Sedimentation:** There is a general concern that the bay is silting up, thereby impacting boating and waterway amenities. The siltation is perceived to have an impact on flooding. There is also widespread concern that the Berry's Canal erosion is increasing and that the entrance will no longer open (or function as it previously did), especially during flooding periods.

This section examines the above concerns and uses available data to determine if the concerns are supported by evidence. Where suitable information was not available, numerical modelling or analytical calculations were undertaken.

4.1 Water Quality

The desire for targeted water quality data has been highlighted in many previous studies (Posford et al., 1977; Nittin and Cox, 1986; HRC, 1999). For this study, available water quality data was analysed from recent studies and assessed against known parameters or trigger levels. No additional sampling was undertaken for the study. The primary data sources available to the project included:

- Water quality monitoring undertaken by SCC (and publically available on the SCC website);
- Oyster monitoring data compiled by Dr Ana Rubio and available via the Oyster Portal (http://www.oysterinformationportal.net.au/); and
- Results from the Ecohealth assessment undertaken by SCC with assistance from OEH.

As mentioned previously, the Ecohealth assessment involves the collection of time transient datasets on Chlorophyll-a and turbidity at predetermined locations. For this assessment, samples were collected by SCC at various locations ranging from upstream of Nowra Bridge to Broughton Creek to Shoalhaven Heads and within the Crookhaven River estuary. The most relevant location for this study was at the River Road Reserve boat ramp. At this location the data was statistically summarised and the site was given a B rating for Chlorophyll-a and a B rating for turbidity. These ratings indicate 'good' water quality for an estuary. A map of the Ecohealth assessment results for the entire estuary is provided in Figure 4.1. It is worth noting that no specific analyses were provided for the Berry's Bay area. Further details on the study can be found within SCC (2011).

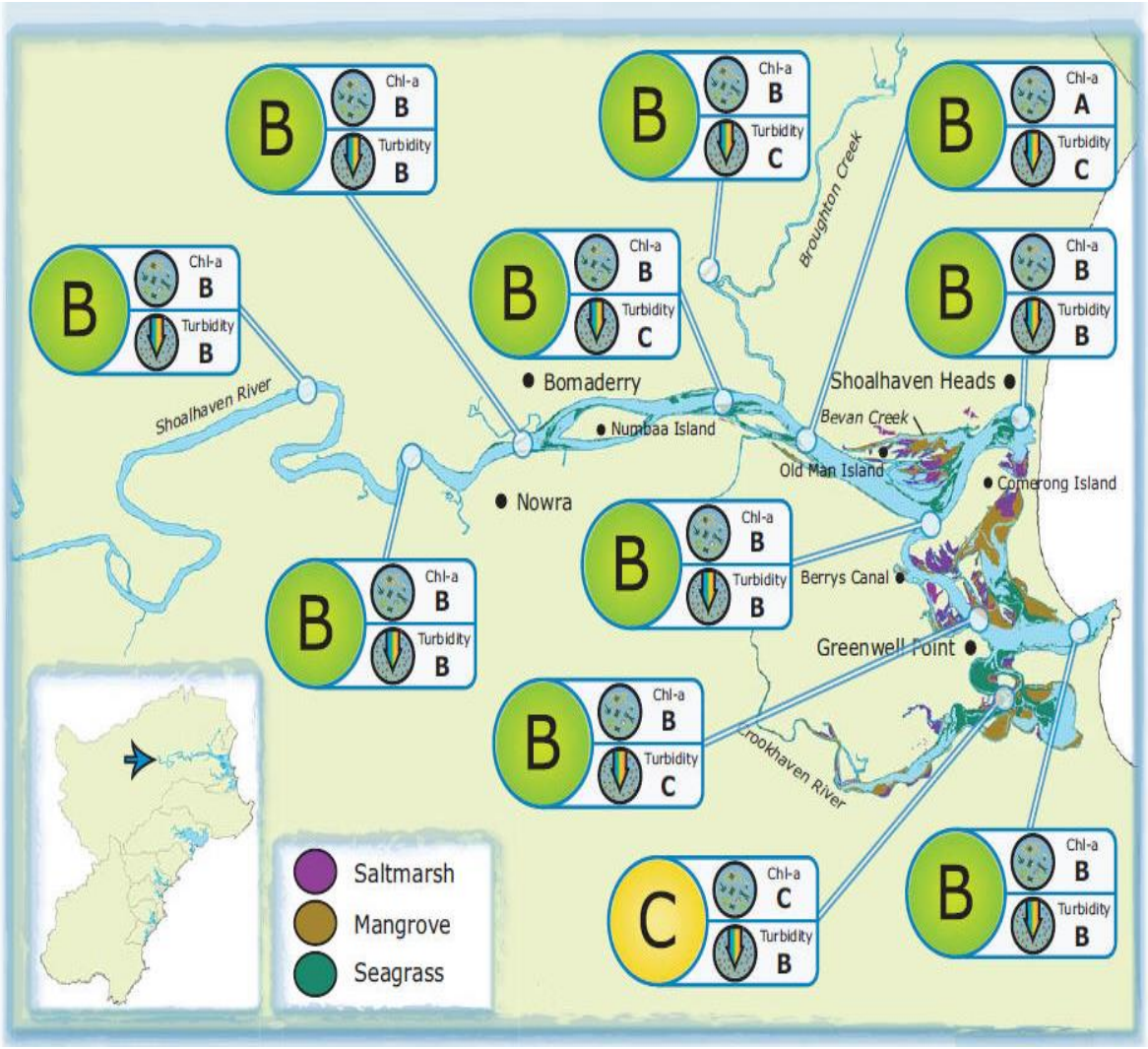


Figure 4.1 EcoHealth Risk Assessment Report Card (after SCC, 2011)

Water quality monitoring results are also available via the Aqua data website operated by SCC (http://webreports.esdat.net/SCC). Data reports available within the vicinity of the Shoalhaven Heads are limited to two sites namely, the River Road Reserve Boat Ramp and the Hay Avenue Boat Ramp (at the mouth of Berry's Bay). The available data varies in its temporal extent and many of the parameters have not been reported beyond 2013. Available parameters within the Aqua Data database include:

- Temperature
- Dissolved Oxygen
- Faecal Coliforms
- Total Suspended Solids
- Enterococci
- pH
- Phosphorus
- Nitrogen (total, total oxidised, Kjeldahl Nitrogen, Ammonia)
- Salinity/Electrical Conductivity
- Chlorophyll-a

- Turbidity
- Total Dissolved Solids
- Secchi Disk

For the purpose of this investigation, salinity, dissolved oxygen and faecal coliforms are discussed because they are considered indicators of overall water quality.

4.1.1 Salinity

Figure 4.2 shows that salinity concentrations across the estuary vary with time. The data records depicted in Figure 4.2 suggest that salinity concentrations at the River Road Reserve Boat Ramp fluctuate in line with the salinity concentrations immediately upstream of Berry's Canal and correlate well with salinity concentrations at Crookhaven Heads (although salinity at Crookhaven Heads is typically higher than the River Road Reserve boat ramp). These results align with the tidal flushing and salinity simulations/measurements described by Miller et al. (2006), indicating that salinity concentrations respond to catchment inflows and tidal forcing.

Salinity concentration data from the Aqua Data website is available from September 1992 to October 2013. Using the available salinity data, the median concentration at the River Road Reserve was 39,485 uS/cm. The median concentration for the Hay Avenue site was 43,950 uS/cm. The average difference between the River Road Reserve Boat Ramp and Crookhaven River Heads site was 10,500 uS/cm suggesting that salinity concentrations within the Shoalhaven Heads area are reduced by freshwater inflows. During periods of freshwater inflows this is particularly apparent, as noted throughout 2011-2012 when significant rainfall was recorded across the catchment but the Shoalhaven Heads entrance remained closed.

The salinity conditions as recorded at Hay Avenue and the River Road Reserve Boat Ramp indicate that the water within the Shoalhaven Heads area is typical of estuarine conditions near the mouth of a large river. The salinity conditions fluctuate between brackish (1000 to 45,000 uS/cm or 0.5 to 30 ppt) and marine regimes (the salinity of the ocean is approximately 55,000 uS/cm or 35 ppt). During times when the Shoalhaven Heads entrance is closed, there are extended periods of brackish conditions coinciding with wet periods and increased salinities during dry times. It is worth noting that the brackish conditions extend throughout the lower Crookhaven River estuary.

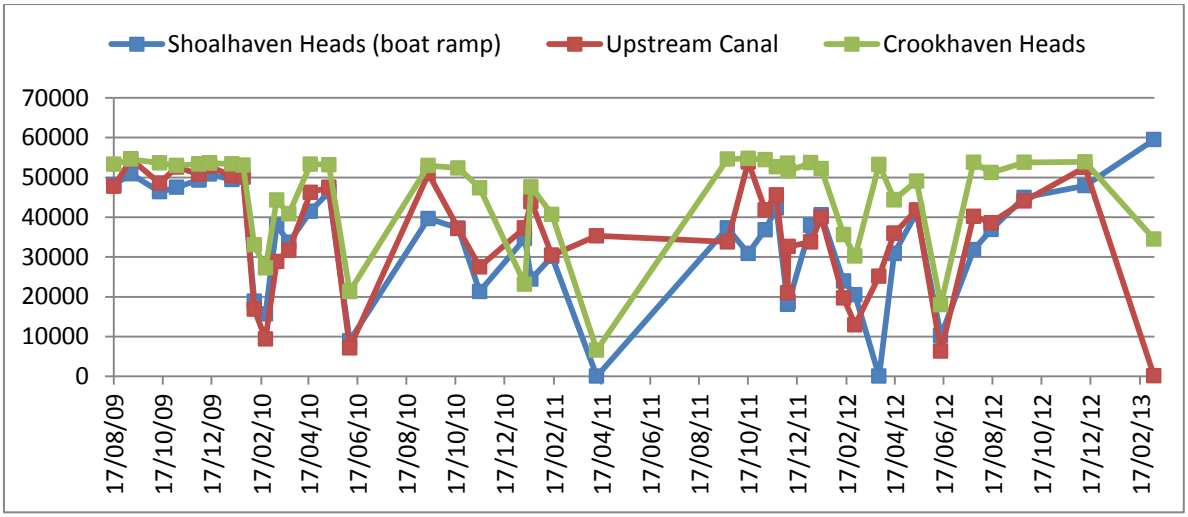


Figure 4.2 Salinity Concentrations within Shoalhaven River Estuary

From an ecological perspective the salinity conditions experienced are within natural fluctuations. There are no salinity triggers or guidelines for estuaries and therefore no determination as to whether an exceedance value is triggered by altering salinity. However, for oyster harvest areas salinity is an important variable.

As per the NSW Food Authority, there are six (6) areas in the Shoalhaven River estuary for harvesting of oysters (Figure 4.3). Berry's Bay is the main harvest area within the Shoalhaven Heads region with the other areas located further downstream. The Australian Shellfish Quality Assurance Program classifies Berry's Bay as 'Conditionally Restricted', recognising that there are some local issues with water quality, but at levels low enough to be removed via depuration. The conditions for the Berry's Bay site are based on rainfall (greater than 40 mm in 48 hours) and salinity (less than 18 ppt or approximately 30,000 uS/cm).

Figure 4.2 indicates that salinity is often below 30,000 uS/cm following rainfall. Salinity conditions at Crookhaven Heads also fall below this trigger value but recover quicker. Indeed, the only time when salinity concentrations are higher at Shoalhaven Heads versus Crookhaven Heads is when the entrance was opened following a manual entrance opening in early 2013. As such, the oyster industry at Berry's Bay prefers a sustained open entrance at Shoalhaven Heads as it ensures elevated salinity concentrations and a quicker return to salinity concentrations above 30,000 uS/cm after rainfall (pers comm, J. Zealand).

4.1.2 Dissolved Oxygen

Dissolved oxygen (in % saturation) is the measure of the amount of oxygen in the water and is used to define living conditions for aerobic aquatic organisms. ANZECC (2000) guidelines recommend 80 – 110 % dissolved saturation for estuarine waterways. Dissolved oxygen levels at the River Road Reserve Boat Ramp, Hay Avenue and offshore of Crookhaven Heads Boat Ramp are provided in Figure 4.4. Note that the measurements for the three sites are not over the same time period.

Dissolved oxygen concentrations are shown to vary across the lower estuary. Measurements at the River Road Reserve Boat Ramp depict a variable system with median concentrations of 90 % saturation. In contrast, median values at Hay Avenue and Crookhaven Heads are lower with 84

% saturation and 87 % saturation, respectively. Numerous measurements below 80% saturation appear to coincide with catchment wide rainfall events when nutrients or low dissolved oxygen inflows can be discharged into the system.

Low dissolved oxygen measurements in the lower Shoalhaven River estuary have been previously linked to acid sulphate soil discharges from impacted floodplain drainages. Glamore (2014) and Glamore et al. (2014) recorded significant 'black water' discharges, with corresponding low dissolved oxygen concentrations, discharging into Broughton Creek from agricultural drains in the weeks following rainfall events. In these circumstances, low dissolved oxygen levels can occur due to dissolved oxygen consumption from iron reactions or due to oxygen consumption from prolonged inundation of floodplain vegetation. This water can then be discharged downstream with the tide and transported into the Shoalhaven Heads region. Similar events have been noted throughout acid sulfate soil estuaries in NSW including the Hunter River, Richmond River, Wilson River, Clarence River, Macleay River and Manning River estuaries.

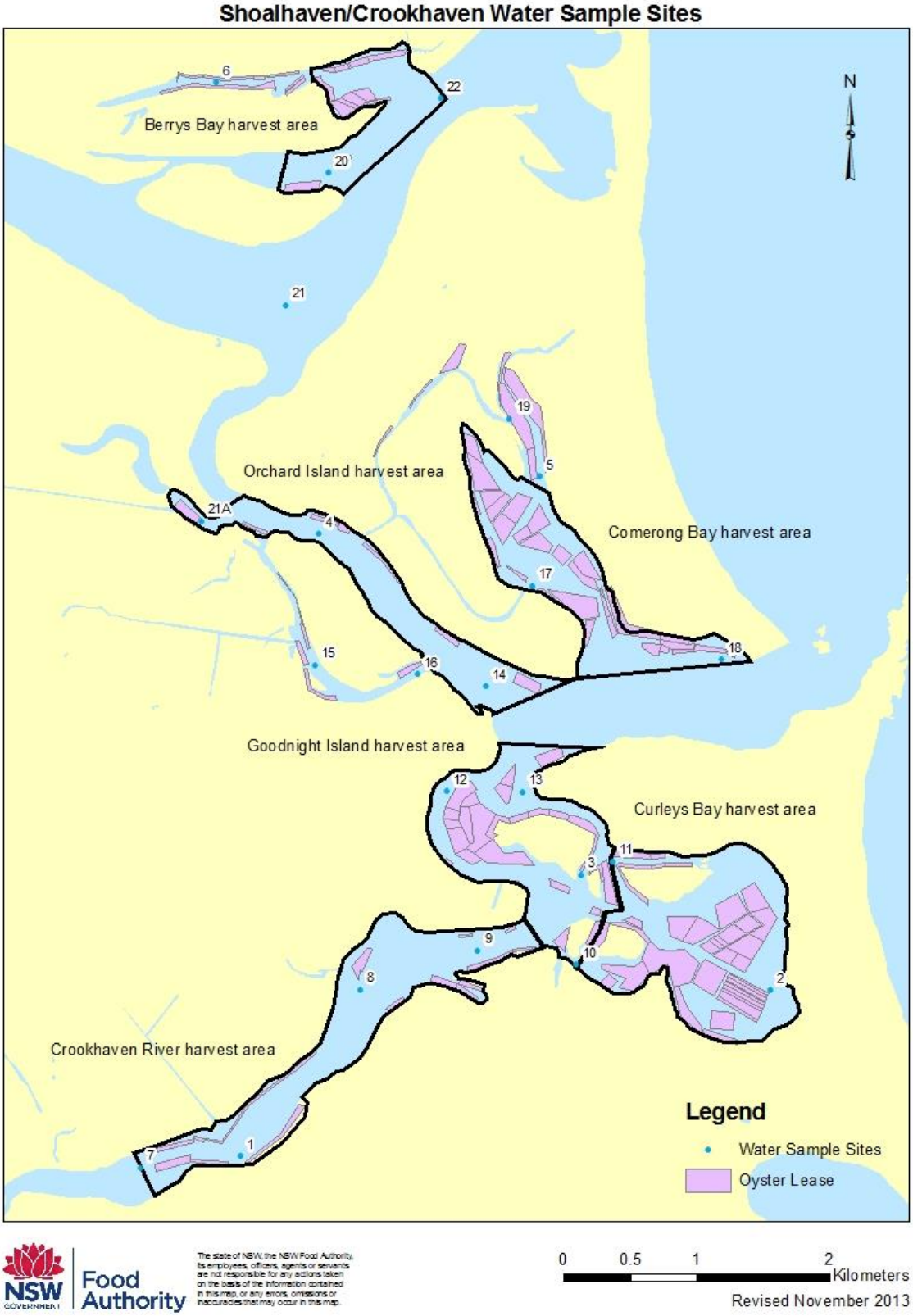
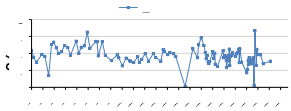
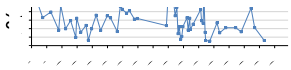


Figure 4.3 Harvest Areas in the Shoalhaven River (from Shoalhaven River Oysters, 2012)



(a)



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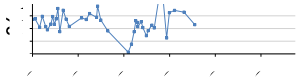


(c)

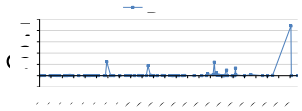
Figure 4.4 Dissolved Oxygen Conditions at the River Road Reserve Boat Ramp (a), Hay Avenue (b) and Offshore of Crookhaven Heads Boat Ramp (c). Note varying time periods between sites. Source: SCC Aqua Data.

4.1.3 Faecal Coliforms

Faecal coliform counts are used to provide an indicator of the presence of faecal material from warm blooded animals. For primary contact recreation (e.g. swimming), the ANZECC (2000) guidelines recommend faecal coliform counts of less than 150/per 200 mL (with 4 out of 5 samples <600/100 mL; minimum of 5 samples taken at regular intervals not exceeding one

month). For shellfish the median faecal coliform concentration should not exceed 14 MPN/100mL (not CFU); with no more than 10% of the samples exceeding 43 MPN/100 mL. Faecal coliform counts at the River Road Reserve Boat Ramp, Hay Avenue and offshore of Crookhaven Heads Boat Ramp are provided in Figure 4.5. Note that the measurements for the three sites are not over the same time period.

(a)



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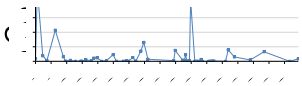

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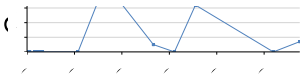
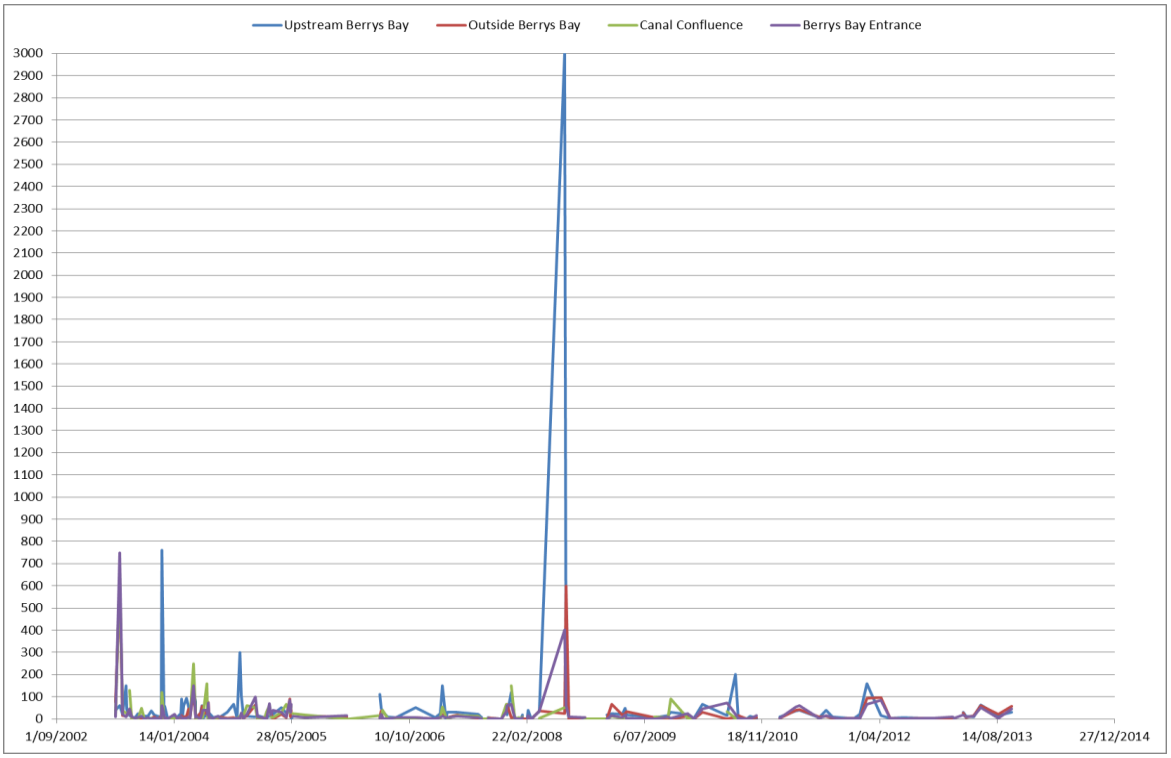


Figure 4.5 Faecal Coliform Records at the River Road Reserve Boat Ramp (a), Hay Avenue (b) and Offshore of Crookhaven Heads Boat Ramp (c). Note varying time periods between sites. Source: SCC Aqua Data.

Faecal coliform counts within the vicinity of Shoalhaven Heads are shown to be typically within acceptable levels with individual measurements occasionally exceeding triggers values. As noted in the guidelines, individual readings may exceed the trigger but subsequent samples (4 out of 5) at the River Road Reserve Boat Ramp and Hay Avenue return below trigger concentrations. Generally, faecal coliform triggers are exceeded at Hay Avenue more frequently than at the River Road Reserve site suggesting the source is further upstream. However, the source is difficult to ascertain as occasional high measurements in estuaries can be associated with septic tank discharges, stormwater overflows or agricultural runoff (faecal coliform counts do not distinguish between human and other warm blooded sources e.g. cattle).

Additional data collected by Food Safe Authority (2013) suggests that faecal coliform counts are highest within the upstream reaches of Berry's Bay. As per Figure 4.6, concentration values in exceedance of the trigger values were measured during multiple sampling runs between 2004 and 2013. This suggests that a source of faecal coliform contamination may be evident within Berry's Bay and further studies are recommended.



4.1.4 Water Quality Summary

Based on the limited data set available to the study, the overall condition of the Shoalhaven Heads estuary has been depicted. The data suggests that the water quality within the vicinity of the Shoalhaven Heads entrance is in fair to good condition with episodic exceedance of trigger values. The data is typical of estuaries throughout NSW and is shown to fluctuate with rainfall events, indicating broad acre diffuse source concerns. While the data is limited to prior to 2013, there does not appear to be a negative trend with time in the available data.

4.2 Flow Circulation

The hypothesis of this study's brief is that flows within the Shoalhaven Heads area can be improved to benefit water quality and the overall ecosystem. Well flushed estuaries are intrinsically more robust than poorly flushed estuaries (Wolanski, 2007). Flow circulation within the Shoalhaven Heads area was assessed using a series of analytical calculations and modelling scenarios. This section provides a summary of these findings.

Calculations were undertaken to determine the maximum possible tidal exchange and tidal exchange during a spring tide. A study area encompassing Shoalhaven Heads and Berry's Bay (Figure 4.6) was selected and using available bathymetry data, the entire water volume was calculated at approximately 4,000,000 m^3. By developing a stage-volume relationship it was then possible to determine the maximum tidal volume that could be potentially exchanged.

For the area denoted in Figure 4.6, between Indian Spring Low Water (-0.54 m AHD) and the Highest Astronomical Tide (0.89 m AHD) the tidal volume that could be potentially exchanged is approximately 2,000,000 m^3 (or 50% of the total volume). For a spring tide with a low tide of -0.3 m AHD and a high tide of 0.5 m AHD (tidal range of 0.8 m) the total potential volumetric exchange is approximately 1,000,000 m^3 (or 25% of the total volume). This indicates that a large proportion of the water volume within the Shoalhaven Heads region is available for tidal exchange. This does not suggest that with every spring tide 25% of the water is completely exchanged but it does imply that there is significant tidal exchange regularly.

The residence time of water in an estuary is another key physical variable determining the health of an estuary. One method to calculate residence times, and provide a qualitative understanding of the estuary, is via a tidally averaged box model. In this approach the residence time (T) is defined as:

$$T = 0.23(MSTR)^{-0.4} (T_L)^{1.2} \qquad \text{(Uncles et al., 2002)}$$

Where: T is the residence time in days,
MSTR is the mean spring tidal range in m, and
T_L is the distance from the mouth to the tidal limit.

By applying this equation with local data, the residence times within Shoalhaven Heads can be calculated. These results suggest that when the entrance is closed the residence time is approximately three (3) days. In contrast, when the entrance is open the residence time reduces to 0.2 days. While this implies a significant reduction in residence time depends on entrance condition, from an environmental perspective a residence time of 3 days is not an ecological concern for water quality. Further, this suggests that the site is not a poorly flushed backwater but, instead, a flushed estuarine side channel. However, from the oyster's industries position reduced residence times with an open entrance would ensure quicker flushing of any pollutants and a faster return to marine conditions after rainfall events.

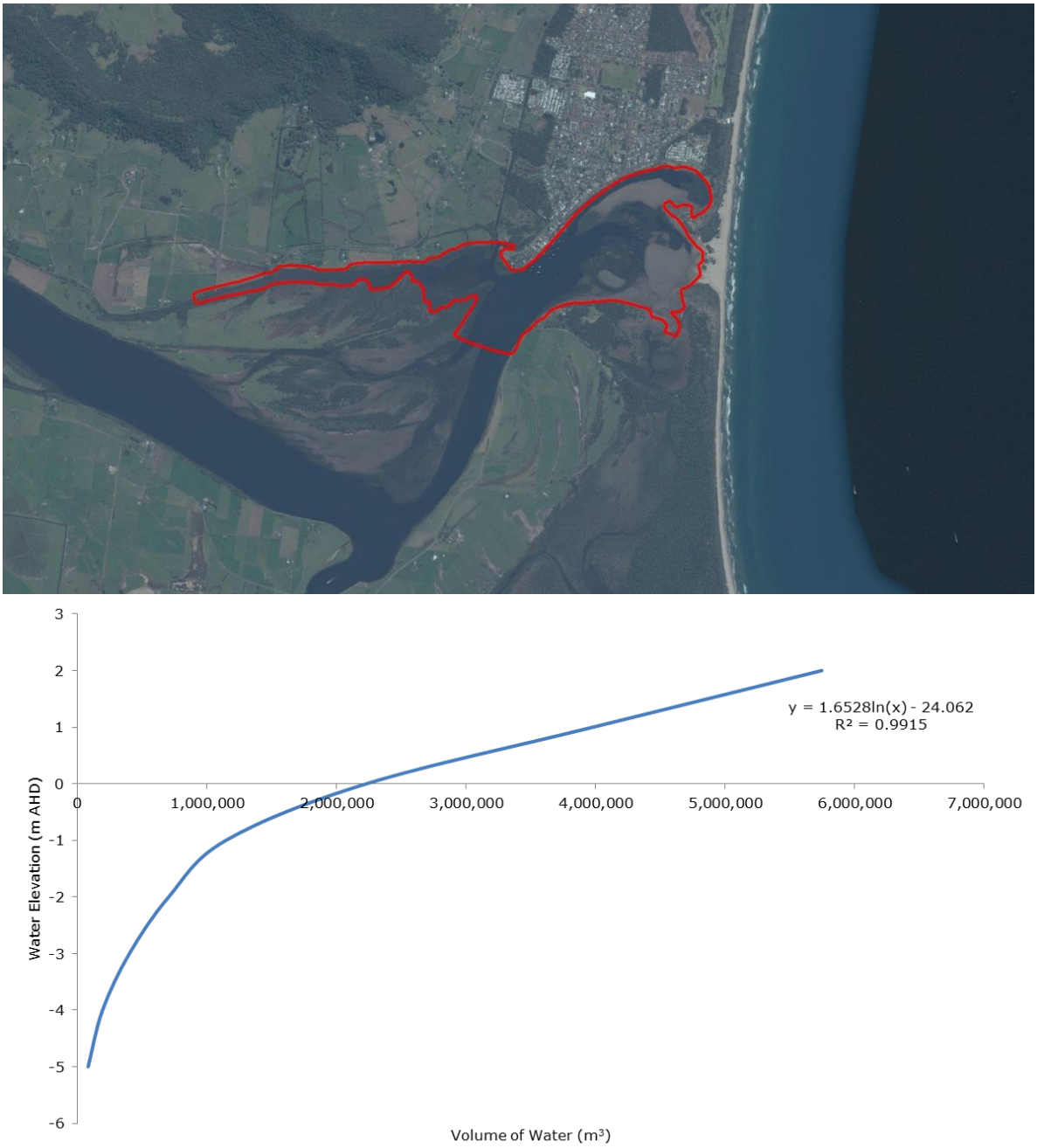


Figure 4.6 Stage-Volume Relationship for Shoalhaven Heads area (denoted in red)

In addition to tidally driven circulation, wind forced circulation would play an important role in the Shoalhaven Heads embayment area. Predominant northeast winds in the summer and southeast winds in the winter have sufficiently long fetches in the embayment to drive water circulation fostering water turnover and decreasing any vertical stratification caused by solar radiation. This additional wind driven circulation would increase mixing and overall circulation in the embayment area.

Additional information on circulation was developed through numerical modelling of the lower estuary. These results, including model outputs, are discussed as part of the engineering options assessment in Section 5.

In summary, tidal flushing of the waterbody at Shoalhaven Heads is sufficient to maintain normal estuarine water quality processes. The majority of the shallow, tidal area is likely well flushed, although deeper pockets (potentially created from previous dredging works) may remain stagnant for extended periods. The residence time estimates align with the water quality data and reflect the nature of the observed short term poor water quality events and subsequent water quality recovery.

4.3 Sedimentation/Erosion

One of the main public concerns within the Shoalhaven Heads area is that the bay is becoming shallower and the rate of infilling is increasing. This infilling is seen to have a negative impact on boating and waterway amenities. Concurrently, there is a concern that Berry's Canal erosion is continuing. This report section compiles existing data to qualitatively assess sedimentation processes in the Shoalhaven Heads embayment. Information on Berry's Canal was previously highlighted in the literature review in Section 2.

Historical aerial images are available to examine geomorphic conditions adjacent to Shoalhaven Heads over time (Figures 4.7 and 4.8). These pictures have been compiled previously including by Chafer (1998) to examine entrance geomorphology versus bird habitat and by SCC (2006) as part of the entrance management policy. Additional images have been added to illustrate recent events.

The aerial imagery highlights the cyclical processes influencing sedimentation within the waterway. During flood events the entrance is opened (or opens naturally) and due to the water level differential between the flood level and the ocean level, scours sands from the entrance and bay. The magnitude of the flood, the frequency of follow-up rainfall events and the antecedent sediment conditions have a significant influence on the volume of sand discharged to the ocean. Previous estimates by Posford et al (1977) suggest that up to 200,000 m^3 of sediment can be discharged from the bay into the ocean during a flood. Due to the limited longshore sediment transport potential of the prevailing wave conditions, the discharged sediment is available to be re-entrained within the entrance. This process is enhanced by the flood tide dominance of the tidal signal, which has a net transport landwards, and the elevated concentrations of suspended sediments due to the breaking wave energy. The reader is recommended to consult Wright (1976) for various schematics of the processes described above.

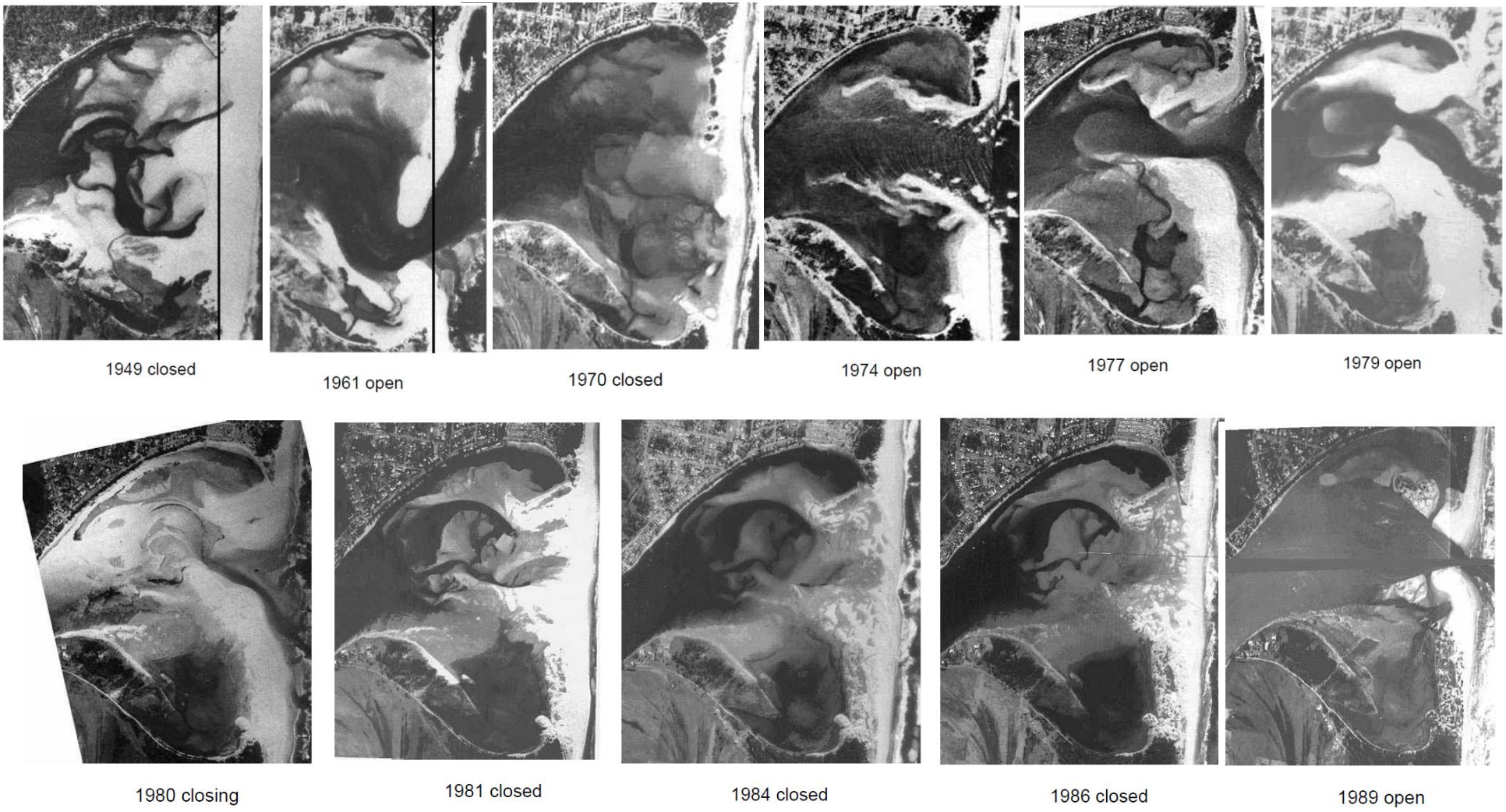


Figure 4.7 Historic Aerial Images of Shoalhaven Heads (1949 - 1989)

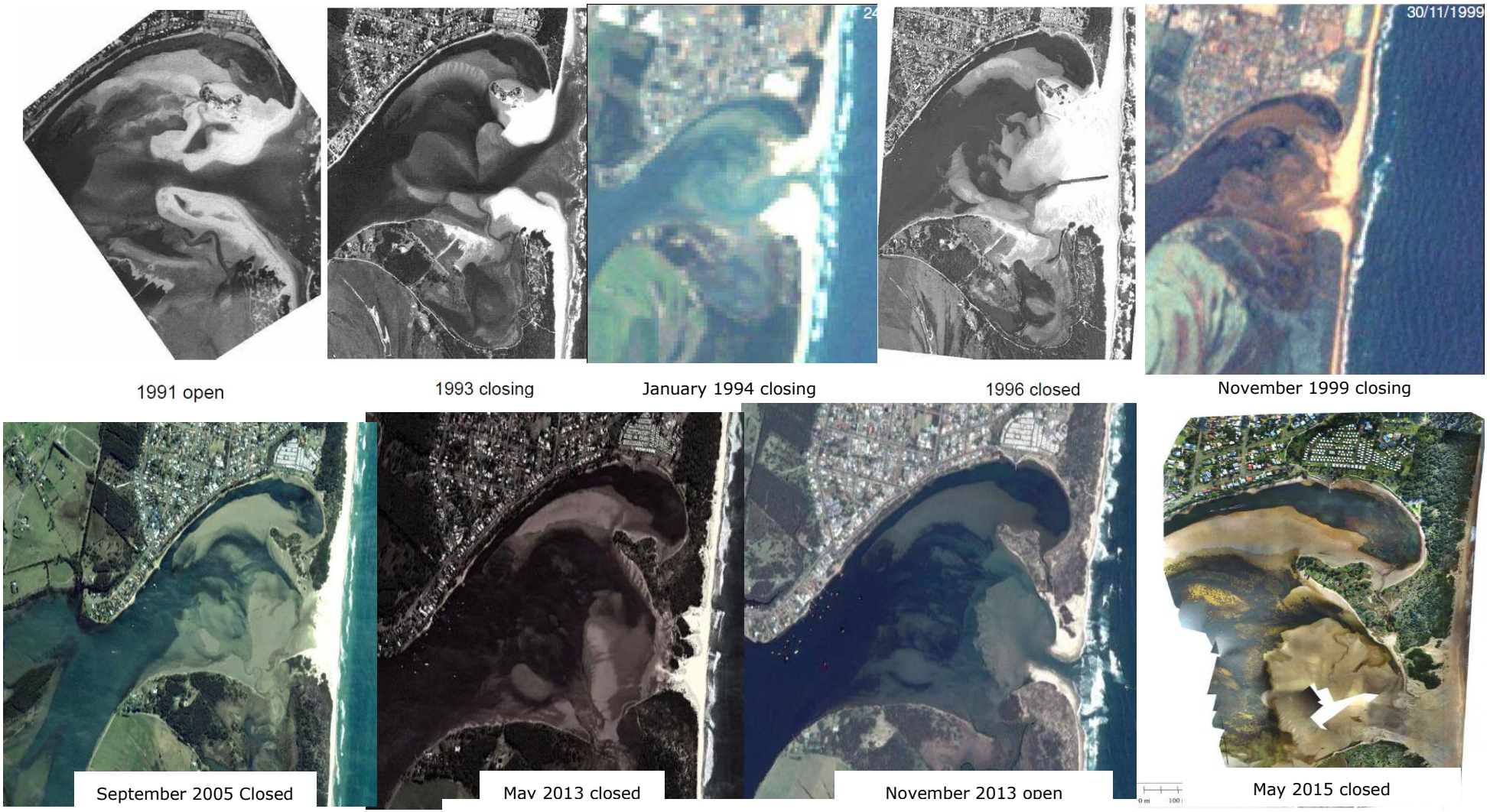


Figure 4.8 Historic Aerial Images of Shoalhaven Heads (1991 - 2015)

The formation of a flood tide delta is evident in several of the historic aerial images. Depending on the entrance dynamics and the antecedent conditions, the flood tide delta can lead to significant volumes of sand being deposited within the bay. Large sand deposits are apparent in the aerial imagery from 1949, 1981, 1996, 2005 and 2015. However, in subsequent images the sand deposits have been removed from the estuary by the preceding flood event.

Additional information comparing bathymetry profiles against recent data should be available upon completion of this study (pers comm, R. Caravalho). It is recommended that this information is reviewed to determine areas with enhanced sedimentation rates. Following recent floods in August 2015, surveys were also undertaken of the area immediately seaward of the entrance. This information should also be assessed to quantify settlement zones and bar formation as well as available sediment for re-entrainment.

The other significant item worth noting in the aerial imagery is the extent of the dune vegetation. Prior to 1999 very little dune vegetation is observed in the imagery. However, dune care initiatives mentioned previously fostered the spread of vegetation from Shoalhaven Heads in a southerly direction. Indeed, by May 2015 the remaining bare dune areas were limited to approximately 200 m in width (half of the design scour area as per SCC 2006). While the increased vegetation limits wind-driven sand transport, previously noted as a concern by Posford et al. (1977), the reduced entrance cross-section has been shown to increase flood heights at Shoalhaven Heads. The influence of beach width and vegetation using contemporary flood modelling techniques is discussed further in Section 6.

4.3.1 Flood Frequency Implications

Flood frequency is also worth discussion as the frequency of large floods has a significant impact on the entrance morphology. An estimate of historic flood heights at Nowra is provided in Table 4.1. This list shows that since 1998 there have only been two floods exceeding the entrance flood trigger. Interestingly both of these floods (2013 and 2015) have been localised Broughton Creek floods, which do not provide the same flood dynamics as large upper catchment floods which typically have larger flow volumes.

An examination of flood records indicates that historically the area was more prone to large floods. Between 1860 to 1900 the region was subject to ten (10) large floods, notably the largest floods on record. Between 1900 to 1940 another eight (8) floods were recorded. Between 1940 and 1980 the area received 13 large floods, including four (4) large floods between 1974 and 1978. However, in the past 40 years the area has only been subject to six (6) storms, with only two (2) moderate events in the past 16 years. This suggests that local community members who have lived in the area since the 1970's would recall a significantly different system than the one currently present onsite. Nonetheless, the likelihood of a large, significant flood remains and the associated risk and impacts should not be discounted.

In summary, the area appears to undergo cyclical sediment infilling and scouring patterns related to the catchment flood dynamics. Historical aerial imagery indicates that greater levels of sedimentation were previously evident onsite and that these sediments were removed by preceding flood events. There is limited information to suggest that this pattern has been altered by natural or artificial processes. However, a review of flood frequencies suggests that reduced flooding over the past 16-24 years may have curtailed the cyclical scour-infilling dynamics. This is further complicated by the expansion of dune vegetation towards the entrance and the expansion of Berry's Canal to a quasi-equilibrium state.

Table 4.1 Historic Flood Events on the Shoalhaven River Estuary (adopted from SCC, 2006)

Month and Year of Flood	Estimated Flood Height at Nowra (m AHD)	Month and Year of Flood	Estimated Flood Height at Nowra (m AHD)
February 1860	5.7	June 1949	4.0
June 1864	5.2	February 1956	4.6
April 1867	5.0	October 1959	4.7
June 1867	5.1	March 1961	4.2
March 1870	5.5	November 1961	3.4
April 1870	6.5	June 1964	3.5
May 1871	4.5	August 1974	4.9
February 1873	6.2	June 1975	4.9
June 1891	5.3	October 1976	4.1
February 1898	5.0	March 1978	5.3
July 1900	4.4	April 1988	4.8
July 1904	3.7	August 1990	4.3
January 1911	3.6	June 1991	4.0
October 1916	5.3	August 1998	3.44
December 1920	4.2	October 1999	3.5
July 1922	4.2	June 2013	3.75
11 May 1925	5.4	August 2015	3.97
27 May 1925	4.4		

5. Management Options

Following the review of background information, engagement with stakeholders, and an assessment of onsite data/processes, management options were developed and assessed. The options were formulated to respond to community concerns and enhance circulation within the vicinity of Shoalhaven Heads. A memorandum was supplied to SCC and the Shoalhaven Heads Estuary Taskforce on 23rd June 2015 outlining this approach and finalising these options.

The options proposed for investigation included:

1. Decreased cross-sectional area of Berry's Canal;
2. Increased circulation at Shoalhaven Heads via oceanic transfer pipes;
3. Increased estuary wide circulation via a channel on the eastern side of Comerong Island;
4. Targeted dredging works within Shoalhaven Heads to improve circulation; and
5. Assessment of a permanent entrance.

The rationale for each option is detailed below.

Decreased cross-sectional area of Berry's Canal: Several options have been suggested in previous studies and via community feedback to 'restore' Berry's Canal by reducing the overall cross sectional area. This has included decreased entrance configurations via training walls at the upstream boundary or decreased conveyance via targeted infilling or locks. The objective of these works is to encourage increased circulation at Shoalhaven Heads and potentially to keep the entrance open for a longer period following an opening event.

To test the effectiveness of this option, the numerical model from Glamore et al (2014) was refined to better simulate flows around Berry's Canal and tested with 30% and 50% reduced capacity. Spring and neap tides were then simulated in the estuary. Model results examined tidal exchange and circulation at Shoalhaven Heads in comparison to the existing scenario and the potential influence of the altered canal dimensions on sustaining an entrance opening.

Increased circulation at Shoalhaven Heads via oceanic transfer pipes: Local stakeholders have suggested that poor circulation of marine water is a major concern within Shoalhaven Heads. Increased circulation has the potential to improve local amenity and provide conditions similar to an open entrance. To this end, analytical calculations were undertaken to determine the volume of marine water that can be discharged to Shoalhaven Heads from the ocean each tide. Results were subsequently used to assess the implications of any increased tidal exchange on the overall tidal exchange within the bay.

Increased estuary-wide circulation via a channel on the eastern side of Comerong Island: An alternative method suggested for increasing circulation at Shoalhaven Heads is to establish a channel on the eastern side of Comerong Island; linking Shoalhaven Heads with the Comerong Island Nature Reserve. Tidal data suggests that increased circulation may occur if these systems are linked. To test this theory, two (2) channel sizes were tested within the numerical model and the implications to tidal exchange within the estuary calculated.

Targeted dredging works within Shoalhaven Heads to improve circulation: The largest change noticed by survey respondents (38%) is the silting of the Shoalhaven Heads region and potential implications on water quality. While the rate of siltation cannot be manipulated without extensive catchment wide measures, targeted dredging and excavation works may improve circulation and mixing. Alterations to the model bathymetry were made to represent the

proposed dredging and model-tested to determine if subsequent improvements to circulation in this area have the potential to increase local water quality.

A description of the results for each option is provided below.

5.1 Decreased Cross-Sectional Area of Berry's Canal

Numerical simulations were undertaken using a 2-Dimensional hydrodynamic computer model of the lower Shoalhaven River estuary to test the influence of decreasing the cross-sectional area of Berry's Canal on tidal flow regimes. The model was previously calibrated as per Miller et al. (2006) and Glamore et al. (2014). The model was used to simulate existing conditions including water levels, velocities and tidal flushing dynamics. Results of these 'baseline' simulations, depicting resident flushing times during base flow conditions, are provided in Figure 5.1. These tests were undertaken with a conservative (i.e. no decay) tracer concentration of 100 arbitary units initially distributed across the entire estuary. The oceanic boundary concentration was set to 0 arbitrary units. In this manner, tidal (i.e. oceanic) flushing rates (in percentages) could be quickly calculated.

The results from the baseline model simulations provide an indication of the existing tidal flushing throughout the estuary. Figure 5.1 shows that after 2 days of tidal flushing the Shoalhaven Heads region is unchanged. After 3 days of tidal exchange the area has been 30% flushed and following 8 days of tidal exchange, via Crookhaven Heads, the area is approximately 70% flushed. Following 15 days of tidal exchange, the area is shown to be 80% flushed but it requires another nearly 15 days of tidal exchange to reach 90% flushing. These results provide a useful baseline estimate to compare tidal flushing characteristics under various engineered options.

Simulations with a decreased cross sectional area for Berry's Canal were subsequently assessed. Three alternative scenarios were tested including a 30% reduction in canal cross-sectional area, a 50% reduction in canal cross-sectional area and the construction of a constriction from O'Keefe's Point towards Shoalhaven Heads to reduce the cross-sectional area. For these scenarios the model was retested and compared against the baseline scenario to assess tidal flushing dynamics and implications within Berry's Canal.

The results from the updated modelling scenarios suggest that the reductions in cross sectional area have a limited effect on tidal flushing in the Shoalhaven Heads area and result in higher velocities within Berry's Canal. Within the restricted canal scenarios the velocities within the canal increased correspondingly to the percent restricted but did not significantly alter tidal flushing within the estuary. For the scenario with a restricted entrance at O'Keefe's Point, a large eddy was formed in the vicinity of the entrance and velocities significantly increased through the entrance, however there was no appreciable effect on circulation within Shoalhaven Heads. Animations of the hydrodynamic results are provided as electronic video files with this report.

The results from this management option suggest that decreasing the cross sectional area of Berry's Canal will not appreciably alter circulation within Shoalhaven Heads and would likely result in increased velocities and subsequent erosion. To this point unless significant and costly erosion control measures were installed, the channel would likely scour to the existing cross-sectional area. A decreased cross sectional area would also have a significant influence on upstream flood levels and would need to be tested in any future flood study assessments.

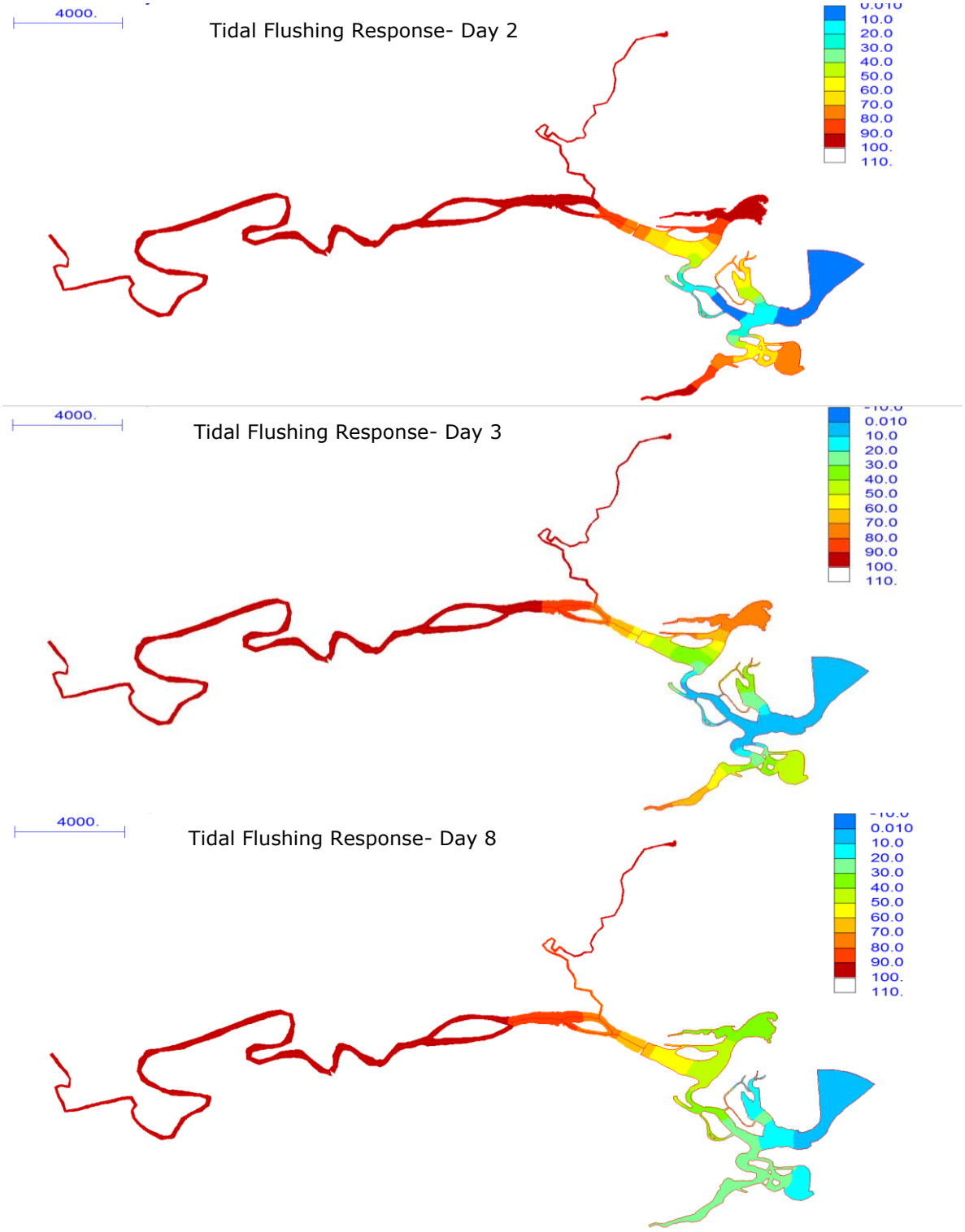


Figure 5.1. Tidal Flushing Results For Baseline Scenarios at 2, 3, 8, 15 and 29 Days

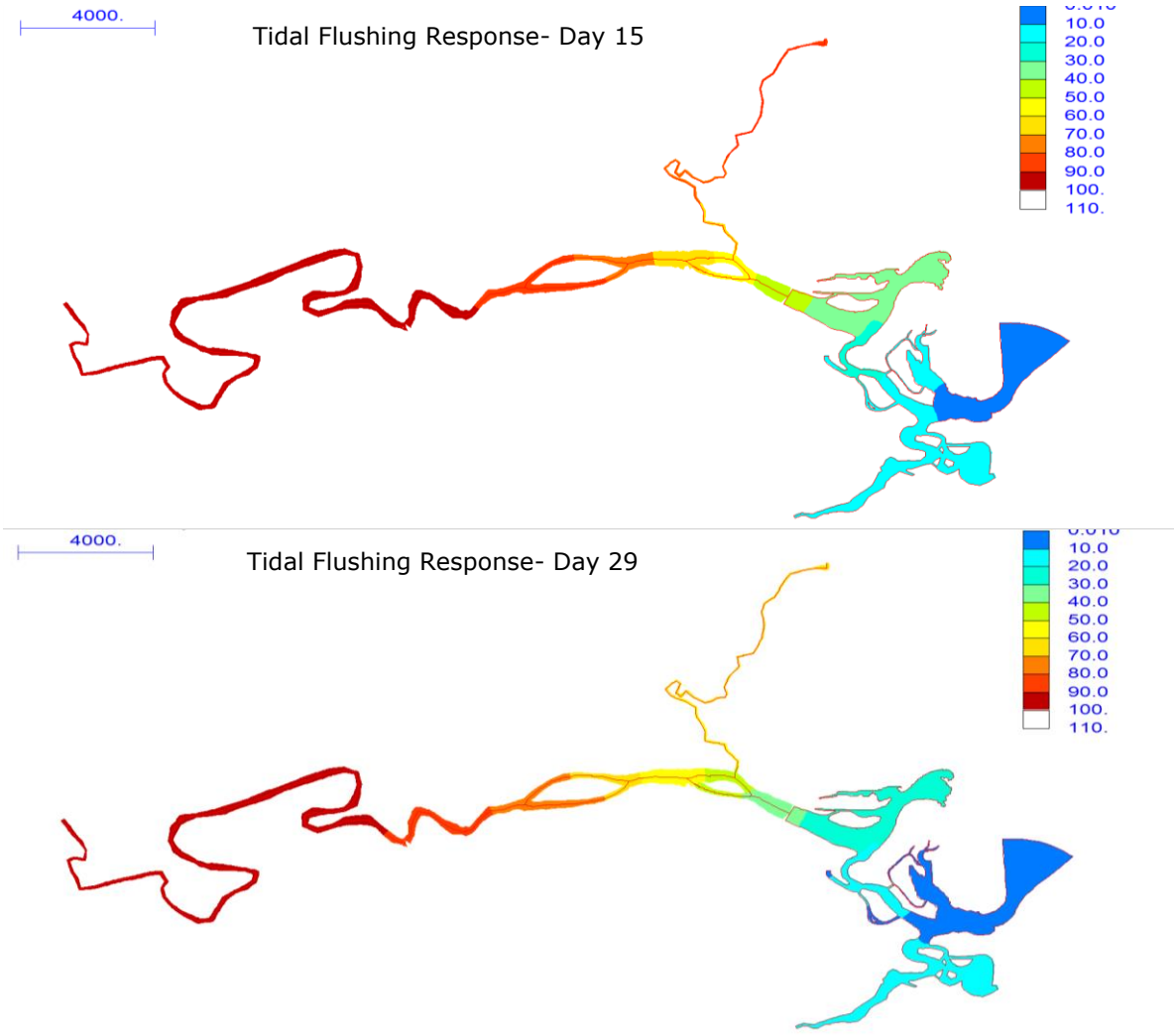


Figure 5.2 (cont'd). Tidal Flushing Results For Baseline Scenarios at 2, 3, 8, 15 and 29 Days

5.2 Increased Circulation at Shoalhaven Heads via Oceanic Transfer Pipes

In theory, oceanic pipes could utilise the tidal lag between Shoalhaven Heads (when the entrance is closed) and the ocean to transfer marine water into the bay and hence, increase circulation. This is particularly appealing to the community as local feedback suggests that the community desires marine conditions within Shoalhaven Heads (versus the existing estuarine conditions). To test this option, a series of analytical equations for pipe flow were developed using real tidal levels. The tidal signal adopted is illustrated in Figure 5.2.

The results from the analytical assessment suggest that the transfer pipes would not provide sufficient exchange to influence circulation. Assuming two (2) 0.9 m diameter pipes could be effectively installed to transfer water without excessive marine growth or sediment clogging the pipes, the maximum volume provided is approximately 8000 m^3. As discussed earlier, the stage-volume relationship for the bay suggests that regular tidal exchange within the system is approximately 1,000,000 m^3. Therefore under a best case flushing scenario, the pipes are likely to only influence 0.8 % of the daily tidal exchange. As such, this option does not warrant further consideration.

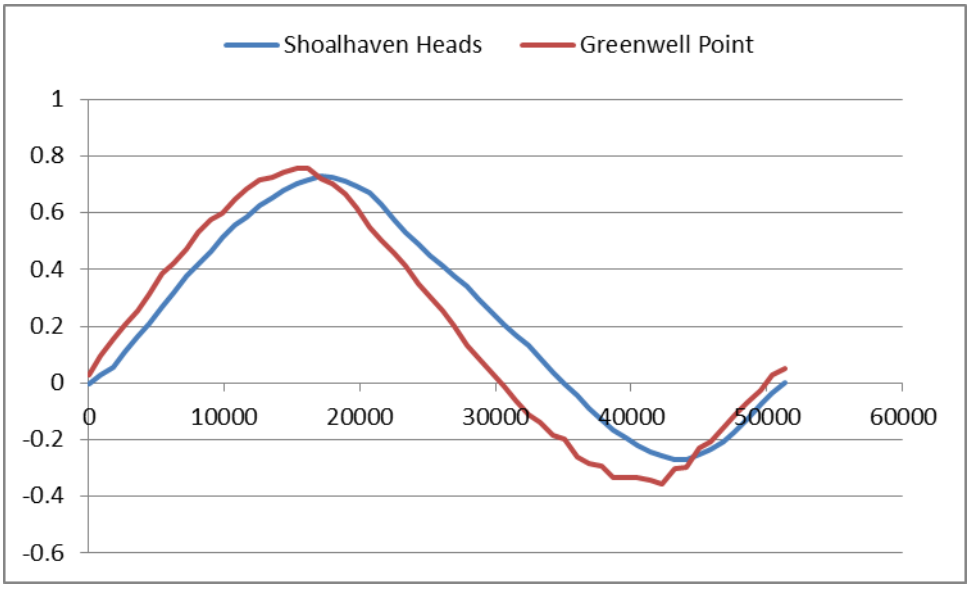


Figure 5.3. Tidal Heights Used to Calculate Potential Tidal Exchange

5.3 Increased Circulation via an Excavated Channel on the Eastern Side of Comerong Island

For this option an excavated 10 m and 40 m wide channel on the eastern side of Comerong Island was considered to potentially improve circulation within the Shoalhaven Heads waterway. The 10 m channel was initially simulated with a depth of 0 m AHD as it is assumed that the presence of acid sulphate soils may limit deeper excavations. Following this scenario, a 40 m wide channel was simulated with a depth to -1.5 m AHD to estimate the maximum flushing potential. The results for the 40 m wide channel simulations are shown below as they provide the greatest potential influence on circulation.

The flushing results for the 40 m wide channel are shown in relation to the baseline results discussed earlier. Days 2, 8 and 29 are highlighted in Figure 5.3 to illustrate the overall impact from the large excavated channel. These results indicate that any impact from the channel would be minimal and largely localised to the area immediately surrounding where the channel enters the bay at Shoalhaven Heads. Interestingly the excavated channel does slightly reduce flushing rates in the Comerong Bay Harvest Area, which would be an undesired effect for local oyster growers. The channel may also influence bird habitat on/adjacent to Comerong Bay. Therefore since the channel provides limited circulation benefits and has various potential concerns, it is not recommended to be pursued further.

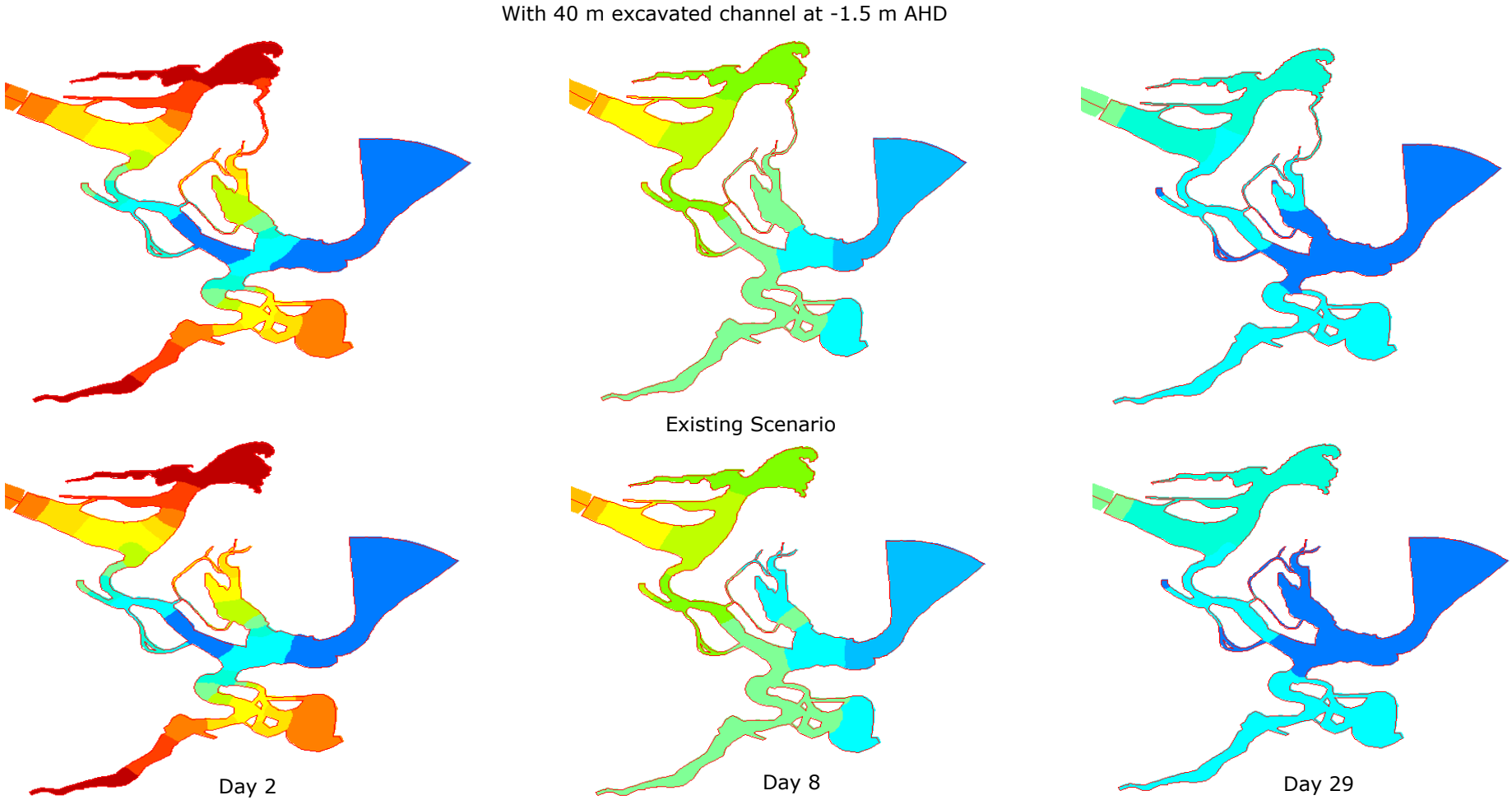


Figure 5.4. Tidal Flushing Simulation Results with (top row) and without (bottom row) a Channel Linking Comerong and Shoalhaven Heads.

5.4 Targeted Dredging Works within Shoalhaven Heads

Due to the extensive flood tidal delta that forms when the entrance is open, entrance dredging and local sand placement has not been extensively modelled for this study. An analysis of a similar strategy at Farquhar Entrance on the Manning River suggests that ongoing annual costs would range from $250,000 to $400,000 per annum, with additional initial capital costs. Of particular importance is that there is no location identified within the Shoalhaven Heads region for onsite dredge disposal that would be suitable for environmental or flood mitigation purposes.

Onsite disposal of dredged materials to maintain an open entrance, without significant entrance engineering works, would most likely result in the infilling of the estuary at a higher rate than currently occurs as the dredge operations would move the sediment further within the system. Preliminary discussions with Crown Lands dredging experts suggests that there are no existing locations in NSW where dredge spoils from a bay are continually disposed on an open coastline. Other large sand transport operations, such as the Tweed River sand bypass, have significant capital and operational fees (approximately $8M/annum) and are more suited to systems with significant longshore sand transport.

Any further assessment of dredging and local sand placement would require concept designs, relevant approvals, a review of environmental factors and associated surveys. Potentially an Environmental Impact Statement would be required due to the presence of migratory wading birds in the region and related matters of national environmental significance. If approved the detailed design, including environmental management plans and plant mobilisation, establishment, demobilisation and site restoration works would need to be considered. It is worth noting that these management costs can typically exceed $600,000. These costs do not include the costs to dredge, load/haul and/or place sand locally.

Recent cost estimates, as shown in Table 5.1 and provided by SCC, are based on similar local sites elsewhere.

Table 5.1 Recent Dredging and Load-Haul Cost Estimates

Operation	Costs/m^3
Dredging and local sand placement	$10-15
Load-Haul 3 km and place sand	$15
Load-Haul 20 km and place sand	$20
Load-Haul 35 km and place sand	$35

Targeted dredging works within Shoalhaven Heads were assessed analytically to determine if they could be undertaken to enhance circulation within the waterway. This is only feasible if the works could be undertaken to expand the tidal prism (via dredging in the depths influenced by the tidal range). Dredging at deeper depths (below the tidal range) will not influence circulation as this water is not regularly exchanged.

Numerical modelling results suggest that additional dredging to expand the tidal prism and, thereby increase circulation, would have a negligible effect on tidal flushing rates. This is because Berry's Canal is already highly efficient and the tidal flushing rates within the vicinity of Shoalhaven Heads sufficiently low. Further, as discussed previously, approximately 50% of the available storage is already within the tidal range and relatively small additions in volume, as generated by dredging, would have limited impact.

5.5 Assessment of a Permanent Entrance

The primary aim of this option is to examine concept designs for improving circulation within the waterbody adjacent to Shoalhaven Heads. For this assessment the entrances examined by Posford et al (1977) were re-assessed to determine if contemporary techniques would significantly alter methods or designs. As noted in the brief, our review of the entrance options was based on expert professional advice. Significant additional field campaigns and numerical/physical modelling would be necessary to undertake a detailed design of any preferred entrance option.

The preferred option recommended by Posford et al. (1977) is a series of groynes either side of the entrance. This option, as depicted in Figure 5.4, has four (4) pair of groynes with the first pair 200 m in length and the remaining 160 m long. The groyne field is spaced at 200 m intervals and the entrance width is 750 m (based on the flushing width of the 1974 floods). The rock volume is estimated at 46,000 m^3 and the groynes would be aligned to the predominant wave attack directions. The entrance, costed at $2M in July 1975, is designed as a non-navigable scheme. Detailed information on the groyne design and performance is provided in Posford et al. (1977).

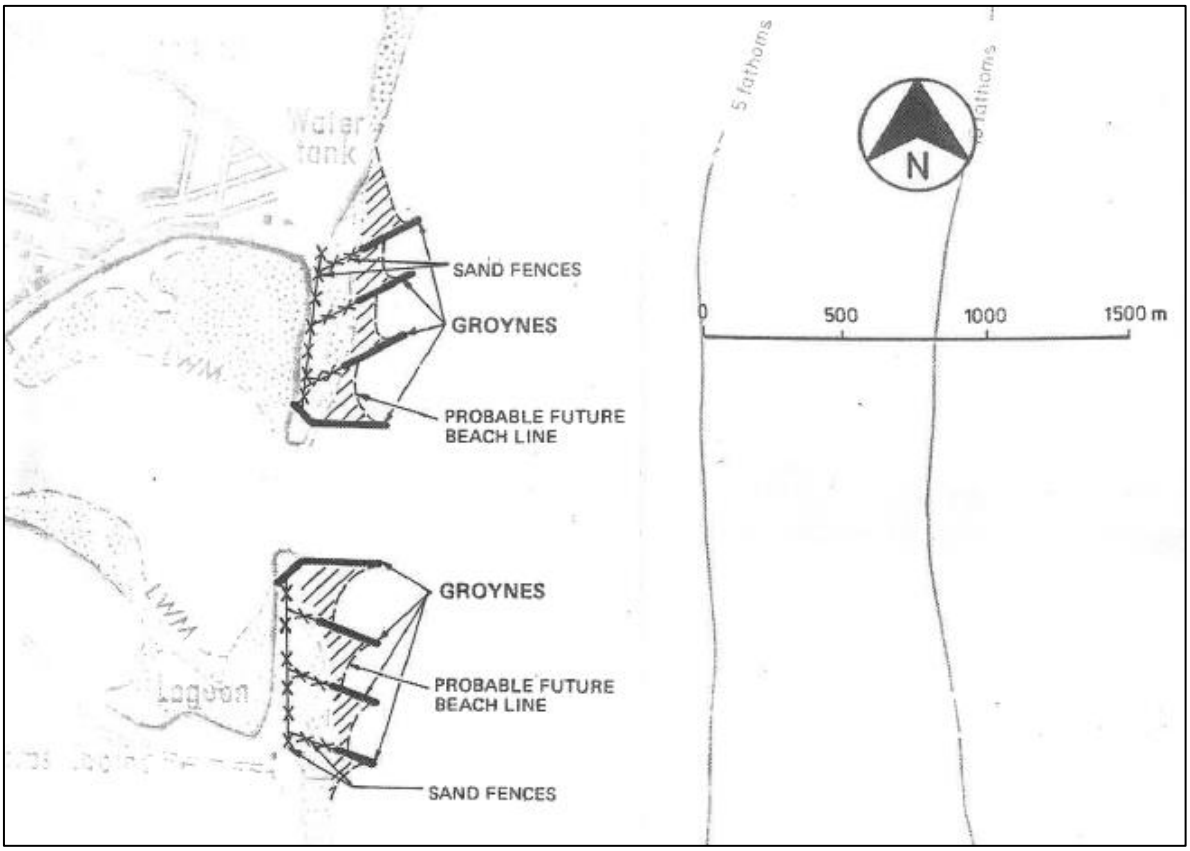


Figure 5.5. Preferred Groyne Design as per Posford et al. (1977)

It is important to note the groyne design has a defined design life of approximately 10 years. Posford et al. (1977) estimated that two groyne fields would have sand stabilisation areas of

approximately 500,000 m^3, which allows for 50% sand bypassing. Posford et al. (1977) note that '*it is probable that the entrance will remain open without closing the canal'.*

While existing monitoring suggests that the waterbody upstream of the entrance has a good ecological health, a permanent entrance is the only likely management option that would effectively increase circulation within the Shoalhaven Heads area. Previous research by Miller et al. (2006) suggests that the tidal flushing impact would be limited to the Shoalhaven Heads area, although this would depend on the entrance design. The primary beneficiary of this work would be the oyster harvest areas within Berry's Bay which would benefit from higher and more consistent salinity readings and increased tidal flushing. A maintained open entrance would also ensure that large catchment flooding risks are minimised, although it may potentially increase inundation hazards from coastal storm events.

Several studies have noted the potential hazards associated with a permanent entrance at Shoalhaven Heads. Of particular concern is the volume of sediment that could be entrained within the entrance under wave induced transport. This sediment has the potential to be transported towards Berry's Canal and eventually become deposited within the Crookhaven River estuary. As such, any detailed design of the entrance should aim to reduce the flood tide dominance and thereby, eliminate the formation of the reverse delta. Detailed sediment transport process studies would have to be undertaken to assess these complex flow dynamics.

HRC (1999) also note that there are several unknown issues that are likely to eventuate due to the altering of the environmental system. These issues are unlikely to be direct mechanisms but instead a function of various repercussions due to the physical modifications. As mentioned previously, it is for this reason that HRC (1999) recommend that no further consideration is given to a permanent entrance at Shoalhaven Heads.

Notwithstanding, a review of the coastal engineering methods in Posford et al. (1977) suggests that the methods undertaken are sound and that there is no new information relating to sediment transport or coastal dynamics that would significantly alter the designs. Further there is no additional local information that would change the ratings relating to the preferred opening scheme. Recent methods have, however, allowed for possible alternatives in construction techniques.

An alternative to the traditional rock groynes is the use of geotubes or geo-containers. These 'soft' engineering methods are constructed using geofabric material sewn together to form a tube and then filled (either onsite using local sands or offsite and hauled to site). The placement and size of the units is designed based on local conditions including wave attack. The primary advantages of sand filled geo-containers is that (i) they provide a soft engineering solution, (ii) they are often seen to improve amenity, and (iii) they can be used as temporary or emergency structures that can be removed. Importantly, modern geo-container coastal structures are designed using more stringent design criteria than historic 'temporary' sand bag solutions.

A comparative cost analysis to rock is difficult to provide as costs are typically reliant on the rock size, water depth and the locally available quarries (and haulage rates). Importantly, while geo-container structures may be initially slightly less expensive (10-25%), they require more ongoing maintenance as the individual bags are subject to shifting and may need to be re-placed. The geotubes are also subject to vandalism but puncture and abrasion resistant fabrics are available. A commercial product that has been used in coastal settings is elcorock (www.elcorock.com.au).

An example of a site similar to Shoalhaven Heads where geo-containers have been successfully used is at the Maroochydore (Queensland) Main Beach, near the Maroochy River entrance. Installed in 2001, as shown in Figure 5.5, this site used 2.5 m^3 vandal deterrent geotextile containers as open coast groynes. Geofabrics Australia Pty Ltd suggest a 25-year minimum design life for these style of bags. It is worth noting that similar size geo-containers were recommended as per the Currarong Beach Erosion Design Study (SMEC, 2011).

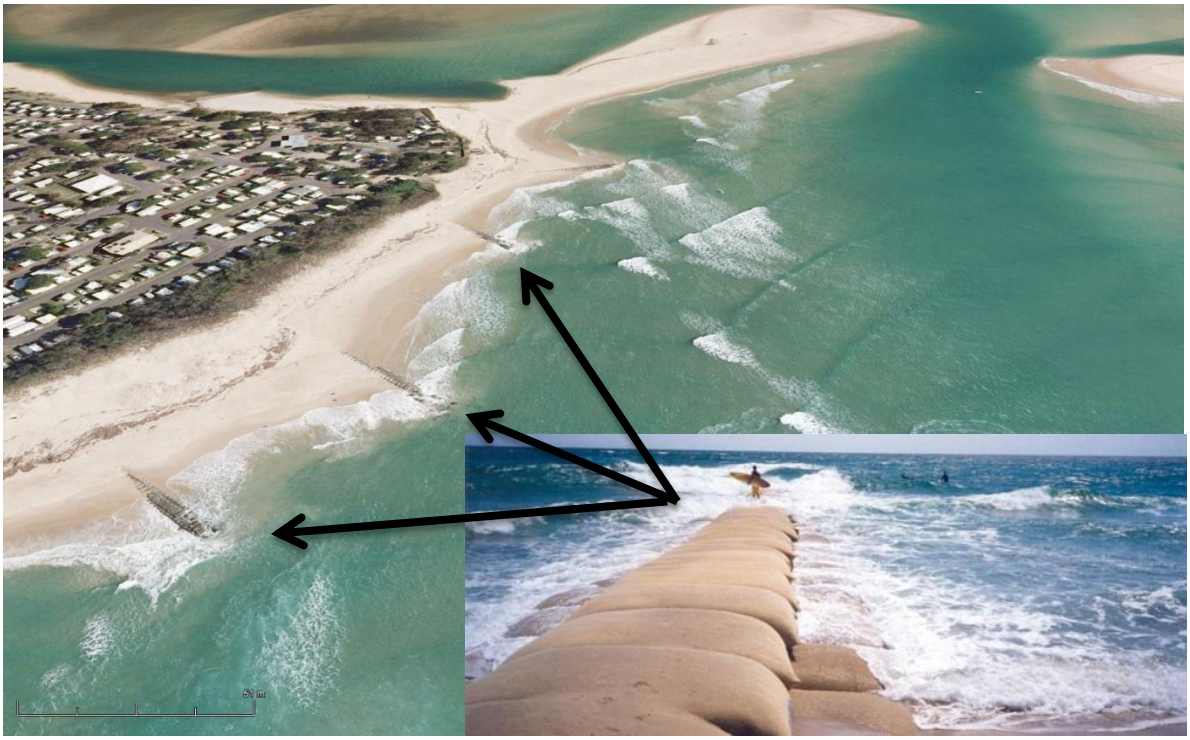


Figure 5.6. Maroochydore Geocontainer Groyne Design

An indicative assessment was undertaken to update costs associated with construction of a traditional rock groyne structure. The costs were based on the volume of rock required and recent estimates for groyne designs at coastal locations NSW. No attempt to estimate costs for a geo-container design has been undertaken as there are no similar sites in NSW to replicate.

Coghlan et al. (2013) and Carley et al. (2015) provide recent reviews of costs for groynes in NSW. Both of these reports note that the most significant factor influencing construction costs is the water depth of the structure. Coghlan et al. (2013) reviewed all groyne structures in northern NSW and undertook cost assessments for two designs in northern NSW (at Kirra and Kingscliff Beach). Based on 2014 cost estimates, Coghlan et al. (2013) calculated per linear metre costs ranging between $27,000 to $39,000. Importantly, both of these structures were at -3.0 m AHD, similar to the main 200 m long groynes specified by Posford et al. (1977). For a 200 m groyne design this equates to approximately $7,000,000 in capital costs per groyne (at $35,000/linear m). Note that Posford et al. (1977) recommended two (2) 200 m groyne.

Carley et al. (2015) recently conducted an extensive review of costs and funding schemes for coastal structures at Byron Bay. Based on a depth of -2.0 m AHD, Carley et al. (2015) estimated a per linear metre cost of approximately $25,000 and an overall cost of approximately $3,000,000/groyne. Carley et al. (2015) also budgeted approximately $1,000,000 in design, investigation and approvals.

Based on the original Posford et al. (1977) design these recent cost estimates suggest that the groyne field at Shoalhaven Heads would cost approximately $33,000,000. Note that this does not include costs associated with dredging the channel or assessing impacts to the upper estuary. Details on funding sources available in NSW to support coastal works are outlined in Carley et al. (2015). Importantly no single funding source is available for this level of associated investment.

6. Summary and Recommendations

This report details the previous studies, community feedback, identified concerns and potential engineered management options for increasing flow circulation at Shoalhaven Heads.

In summary, the findings indicate that:

- From an ecosystem health perspective the Shoalhaven Heads area is presently in 'good' condition. The area is more representative of estuarine, rather than marine, conditions. Measurements of poor water quality are generally sporadic in nature and appear related to runoff events following rainfall. Historical measurements from the Berry's Bay oyster harvest area, particularly the upstream area, have particularly concerning faecal coliform issues which are worthy of further investigations and remedial actions. Acid sulphate soils, and related low dissolved oxygen concentrations, have also been noted throughout the Broughton Creek catchment. The estuarine nature of the system is of particular concern to the oyster industry operating in Berry's Bay.

- Analytical calculations, water quality results and numerical modelling simulations suggest that the Shoalhaven Heads system is typically well flushed. Tidal flushing estimates indicate that the embayed area around Shoalhaven Heads is 50% exchanged in 2-8 days. The areas furthest upstream of the Berry's Bay oyster harvest area may have reduced flushing times. The existing flushing times (when the estuary is closed) are associated with the efficient tidal exchange by Berry's Canal.

- Sedimentation within the bay is an ongoing concern to the local community, however, available data suggests that this is a natural process. Infilling occurs after the entrance has been opened and continues until the entrance closes to the ocean. This is largely due to the flood (incoming) dominated tidal cycle and the entrainment of sediment within the wave zone. Once closed, estuarine processes dominate but the sediment is typically removed following large floods. The reduced frequency of floods over the past 25 years has resulted in estuarine conditions prevailing. Wind-driven sediment transport has likely been reduced by increased dune vegetation, however the current discharge width of the dune opening defined by the present vegetation extent is less than the recommended widths as per the adopted entrance management plan.

- Engineered management options, (including oceanic transfer pipes, modifications to Berry's Canal, an excavated channel to the east of Comerong Island and shallow dredging) to increase the circulation within the Shoalhaven Heads region have been shown to be largely ineffective. This is because Berry's Canal is already a highly efficient channel for ocean tidal exchange and the existing water residence times in Shoalhaven Heads are low. The only means for further reducing the residence times and increasing tidal flushing are via a constructed entrance. A review of previous entrance options suggests that the previously preferred design, including a groyne field, is feasible but requires detailed design studies to confirm efficacy and to ensure that no unanticipated adverse effects would be generated from the entrance construction. Updated costs estimates and possible alternative construction materials are previously discussed.

Recommendations from this study include:

- A catchment wide approach to water quality is encouraged to address acid sulphate soils discharges, point source contamination issues, nutrient concerns and riverbank

erosion/sediment transport. This recommendation aligns with HRC (1999) and the Estuary Management Plan (2008) recommendations.

- The Shoalhaven River flood study should be reviewed and updated to incorporate modern computational methods. Originally completed in 1990, the flood study for the region could be improved to address:
    - Refined entrance design levels, opening dynamics and dredging effects;
    - The role of Berry's Canal as the preferential flow path during moderate to large floods in light of the expansion of the canal and the implications to discharge at the Shoalhaven Heads entrance;
    - Implications of Broughton Creek flooding levels and alternative triggers for localised floods;
    - Concerns with vegetation encroachment at the entrance and infilling dynamics of the bay;
    - Climate change implications.

- An educational program is recommended to highlight that the water quality within and around Shoalhaven Heads is of good quality, that circulation is sufficient, and that the estuary undergoes cyclical processes naturally opening and closing the entrance. The education campaign should also ensure that the community is prepared for future flood events, understand the broad acre acid sulphate soil concerns in the estuary and acknowledge the temporary nature of the shoals within the bay.

- Significant efforts should be made to address water quality issues affecting the oyster industry at Berry's Bay. A catchment approach is recommended to identify pollutant sources, undertake corrective measures and improve response measures to floods and fresh water events. The numerical model developed for this study could be used to further refine salinity and rainfall values currently used as the 'conditionally restricted' or 'closed' triggers. These triggers should align with the variable nature of the estuary.

It is worth noting that this study focused on circulation and related water quality concerns within the Shoalhaven Heads estuary. Recommendations from this report are therefore aimed at physical and eco-health related outcomes for the waterway. Broader economic or social implications of any preferred management strategy may require additional considerations. The reader is directed to NSW Department of Planning and Environment (2014) for a growth and infrastructure plan for the region.

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Appendix A: Draft Survey – Improving Flows to the Shoalhaven River at Shoalhaven Heads

Improving Flows to the Shoalhaven River at Shoalhaven Heads

Community Survey

This survey has been designed to gain community feedback and local expertise on the lower Shoalhaven River estuary and Shoalhaven Heads entrance areas. The outcomes of the survey will be used to improve waterway management. Your information is completely private but you may elect for us to contact you with further details.

1. How long have you lived in (or been visiting) the Shoalhaven Heads area?

- ○ 0-5 years
- ○ 6-10 years
- ○ 11-20 years
- ○ greater than 20 years

2. Rate your overall concern/interest in the Shoalhaven River estuary and Shoalhaven Heads entrance.

Low concern		Moderate Concern		High Concern
○	○	○	○	○

3. Have you personally noticed any major changes in Shoalhaven Heads entrance or estuary? If so, please detail.

4. Rate the importance of the recreational and amenity value of the Shoalhaven Heads estuary.

Low importance		Moderate importance		High importance
○	○	○	○	○

5. Rate the importance of the environmental value of the Shoalhaven Heads estuary.

Low importance		Moderate importance		High importance
○	○	○	○	○

6. What are your biggest concerns for the Shoalhaven Heads entrance and waterway?

7. What is your most common activity in the Shoalhaven River estuary or Shoalhaven Heads entrance area? (Walking, fishing, bird watching, swimming, boating, etc)

8. Rate your level of understanding on how the Shoalhaven River estuary flows to the sea?

Limited understanding		Moderate understanding		Strong understanding
○	○	○	○	○

9. How important is it for you to maintain the existing environment and amenity at Shoalhaven Heads estuary?

Limited importance		Somewhat important		Very important
○	○	○	○	○

10. How important is it to you to improve the amenity and recreational values of the Shoalhaven Heads estuary?

Limited importance		Somewhat important		Very important
○	○	○	○	○

Other (please specify any improvements)

11. Rate your interest in local environmental training and education on the Shoalhaven River estuary and entrance.

Not interested		Somewhat interested		Very interested
○	○	○	○	○

12. Please provide any thoughts on the future management of the Shoalhaven Heads estuary and entrance area.

13. Address (if interested in further information)

Name

Address

City/Town

State/Province

ZIP/Postal Code

Email Address

Phone Number

Appendix A2 - South Coast Register May 27, 2015

Riverside experiment reveals region's environment

SHOALHAVEN Heads locals and visitors were treated to a day of educational fun at the Community Science Field Day at the River Road Reserve boat ramp.

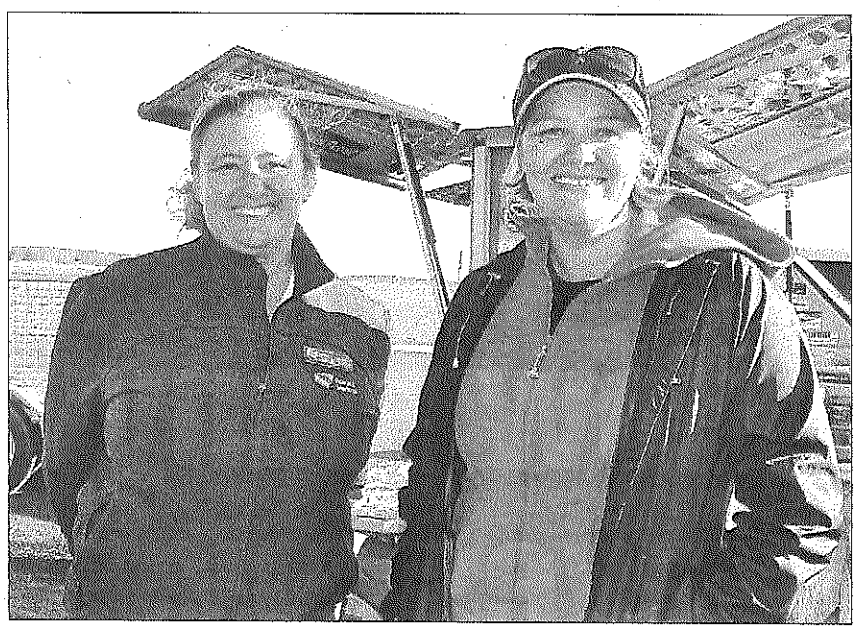
Experts from University of NSW Water Research Laboratory, Dr William Glamore, Dr Kristen Splinter and Chris Drummond, were just a few of the active and knowledgeable people showcasing animations of the region.

An interactive demonstration model of the area was on display as well as a presentation of an unmanned aerial vehicle taking flight.

Experts and viewers were able to discuss the Shoalhaven river estuary.

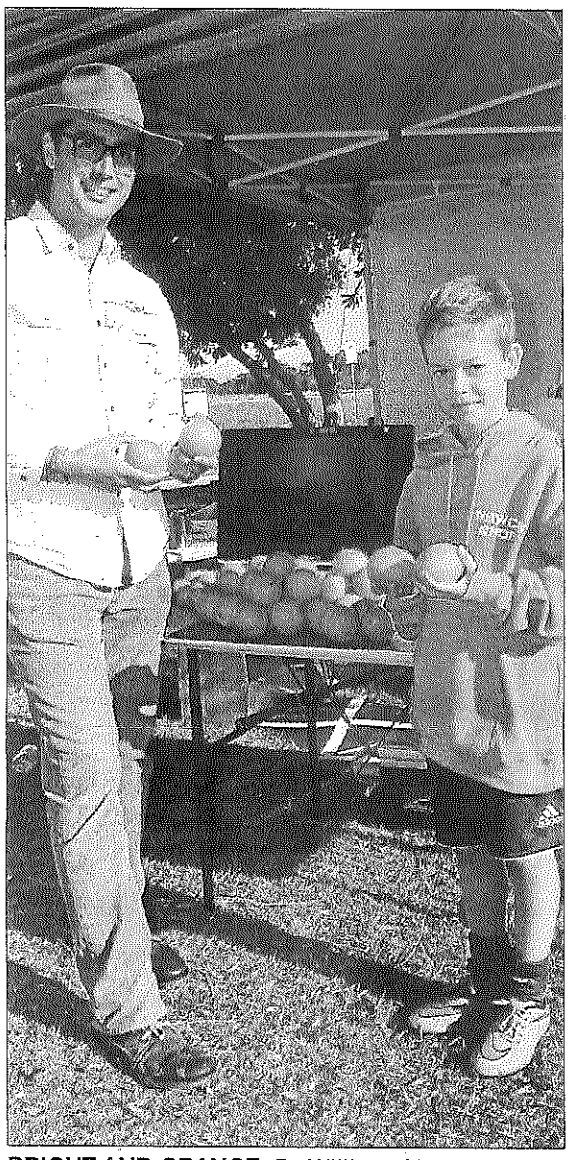
Hundreds of oranges were released into the Shoalhaven River and tracked to study river flows.

Children and adults walked away with a greater understanding of the local environment.



SCIENCE DAY: Danielle Martin from RMS and Jessica Zealand from Shoalhaven Heads at the Community Science Field Day.

FLYING HIGH: Chris Drummond from UNSW Water Research Laboratory with the unmanned aerial vehicle at the Community Science Field Day at Shoalhaven Heads.



BRIGHT AND ORANGE: Dr William Glamore and Danny Ghetti at the Community Science Field Day at Shoalhaven Heads.

KEEN LEARNERS: Dr Kristen Splinter with Kay and Dan Rochford from Shoalhaven Heads at the Community Science Field Day.

Appendix B: DOC15-300467 - NSW OEH correspondence to W Glamore - Shoalhaven Heads Entrance Task Force

NSW GOVERNMENT | Office of Environment & Heritage

Date: 6 August 2015
Our reference: DOC15/300467
Contact: John Bucinskas
4224 4153

William Glamore
Principal Research Fellow
UNSW Water Research Laboratory
E-mail: w.glamore@wrl.nsw.edu.au

Dear Dr Glamore

Thank you for your email dated 16 July 2015 seeking the Office of Environment and Heritage (OEH) position on Shoalhaven Heads and any potential changes to the existing entrance management plan. OEH has worked with Shoalhaven City Council and the community to consider options for the management of the lower Shoalhaven River for many years, and we are happy to continue to provide technical advice in relation to this matter.

The management of the Shoalhaven River entrance should be informed by best available information as contained in Estuary and Floodplain Risk Management Plans prepared and adopted by council in consultation with the community and in accordance with relevant government policies, guidelines, manuals and programs. Permanent artificial opening of the entrance was considered as a management option but not recommended in the above plans. I understand that other agencies, prior independent enquiries by the Healthy Rivers Commission, and the NSW Aquatic Habitat Management and Fish Conservation Policy also do not support a permanent artificial entrance opening.

I am not aware of information that identifies a significant threat to public health or water quality deterioration in the lower Shoalhaven River estuary. To the contrary, completed estuary health report cards by Shoalhaven City Council undertaken with financial and technical assistance from the OEH indicate the Shoalhaven River's estuary health is good, with the Shoalhaven Heads monitoring site achieving good chlorophyll a and turbidity results in addition to seagrass coverage increases which is a positive health indicator for the estuary.

Flooding continues to present risk to the Shoalhaven Heads residents. Council has prepared and adopted the Lower Shoalhaven River Floodplain Risk Management Study & Plan (2008) which identifies a suite of options to reduce this risk. Council has also prepared the "Shoalhaven River Entrance Management Plan for Flood Mitigation" to manage existing flood risk. These documents highlight that entrance opening 'should only be considered an interim measure until the residual flood problems can be properly addressed through other more appropriate long term measures'.

Your email referred to an extract of the minutes from an ordinary meeting of the Shoalhaven River Natural Resource and Floodplain Management Committee on 24 August 2011, in which Council interpreted OEH's position in relation to identifying management options for the Shoalhaven Heads entrance:

> *The Office of Environment and Heritage calls for Entrance Management Policy to be informed by Estuary and Flood Risk Management Study and Plans and community consultation. The process*

followed by Council so far is in line with OEH's position. Any amendment to the existing policy will need to follow a similar process.

In response to your request to confirm whether this remains our position, as stated above our view is that management options were thoroughly considered through the Estuary and Floodplain Management Planning process and the resultant plans are an appropriate guide for management decisions. As OEH is not represented on the Shoalhaven Heads Estuary Taskforce and I am not aware of recent proposals arising from the Taskforce, we cannot confirm whether they are consistent with this approach.

The OEH remains available to provide council with technical and financial support through the Flood, Coast and Estuary Management Programs to support council in the management of the Lower Shoalhaven River estuary and its floodplain. Should you have any further enquiries, please contact John Bucinskas, A/ Senior Team Leader, Water, Floodplains and Coast, Illawarra & SE Regions on 4224 4153 or via e-mail john.bucinskas@environment.nsw.gov.au.

Yours sincerely

Gabrielle Pietrini
Regional Manager, Illawarra

Appendix C: Memo - WRL to NSW OEH - Desktop Analysis of Various Options for the Channel on the North Side of Old Man Island in the Shoalhaven River Estuary

To: Ms. Isabelle Ghetti **Date:** Wednesday 23rd March 2016
From: Will Glamore **Ref:** WRL Memo 20160323_v2.doc
Subject: Desktop Analysis of Various Options for the Channel on the North Side of Old Man Island in the Shoalhaven River Estuary.

Introduction

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia has recently completed an investigation entitled, *Management Options for Improving Flows of the Shoalhaven River at Shoalhaven Heads* (WRL Technical Report 2015/19). Numerical modelling was undertaken as part of the study to investigate management options that may increase water circulation in the estuary at Shoalhaven Heads and prevent the area becoming a shoaled backwater. Subsequent to the findings of the study, The Shoalhaven Heads Estuary Taskforce, an advisory committee of Shoalhaven City Council (SCC), requested additional desktop analysis of management options for the channel on the north side of Old Man Island in the Shoalhaven River estuary, to further investigate the potential for improving flows at Shoalhaven Heads. The options proposed for investigation included:

1. Shoalhaven Heads entrance opened and existing conditions in the channel on the north side of Old Man Island;
2. Shoalhaven Heads entrance opened and the channel on the north side of Old Man Island dredged to -2.0 m AHD, with the existing channel width maintained (approximately 80 m); and
3. Shoalhaven Heads entrance opened, the channel on the north side of Old Man Island dredged to -5.0 m AHD and widened to approximately twice the width of the existing channel.

Numerical simulations were undertaken using a calibrated, 2-Dimensional hydrodynamic computer model of the lower Shoalhaven River estuary to assess the implications of the options proposed. The model was used to simulate changes to hydrodynamic conditions based on the proposed options, including water levels, velocities, and tidal flushing dynamics. A summary of the model scenarios is provided in Table 1. The ocean boundary salinity was set to 35.0 ppt, and ocean boundary water levels were selected from a representative year of tidal record at Crookhaven Heads. It is worth noting that the options proposed were investigated without considering wave action and sediment dynamics at the ocean entrances, which would be likely to have other significant impacts.

Table 1. Model Scenarios

Scenario	Management Option for Shoalhaven Heads Entrance	Management Option for Northern Channel
Case 0	Closed.	Existing Conditions (Avg. Width = 80 m, Avg. Bottom Elevation = - 1.0 m AHD)
Case 1	Open (Entrance Width = 400 m, Avg. Bottom Elevation = - 5.0 m AHD)	Existing Conditions (Avg. Width = 80 m, Avg. Bottom Elevation = - 1.0 m AHD)
Case 2	Open (Entrance Width = 400 m, Avg. Bottom Elevation = - 5.0 m AHD)	Modified Conditions 1 (Avg. Width = 80 m, Avg. Bottom Elevation = - 2.0 m AHD)
Case 3	Open (Entrance Width = 400 m, Avg. Bottom Elevation = - 5.0 m AHD)	Modified Conditions 2 (Avg. Width = 200 m, Avg. Bottom Elevation = - 5.0 m AHD)

Water level, velocity, discharge, and salinity data was extracted at several locations of interest in the Shoalhaven River estuary, including the Northern Channel (i.e. the channel on the north side of Old Man Island), Berry's Bay, Shoalhaven Heads, and the River Road Reserve Boat Ramp, and Crookhaven Heads, as shown in Figure 1.

Predicted Salinity Concentrations

Predictions of annual salinity concentrations at these locations, including the median, minimum, maximum, and 10th percentile and 90th percentile values, are provided in Figure 2. Analysis of the results from the numerical simulations of the proposed options has shown that there is no significant statistical difference in salinity concentrations at the locations of interest in the Shoalhaven River estuary. In particular, comparing the results from Cases 1 and 2 at Berry's Bay showed that there was limited increase in annual median salinity concentrations at Shoalhaven Heads (<1% increase) as a result of dredging the channel on the north side of Old Man Island. It is worth noting that for an open entrance at Shoalhaven Heads (Cases 1 – 3), annual median salinity concentrations increased by approximately 20% at Berry's Bay (compared to when the entrance was closed in Case 0), as shown in Figure 3. However, regardless of the changes made to the channel on the north side of Old Man Island, predicted annual salinity concentrations in the Shoalhaven River estuary were dominated by opening the Shoalhaven River entrance.

Predicted Velocity

Analysis of the predicted velocities in the channel on the north side of Old Man Island for the proposed options showed that there was a 26% increase in the channel velocities between Cases 1 and 2 as a result of dredging the Northern Channel, and a further 25% increase in the channel velocities between Cases 1 and 3 by significantly widening and dredging the Northern Channel. However, it is worth noting that in all cases, the median velocity in the Northern Channel is below 0.6 m/s, which is typically the minimum channel velocity required to move bed sediment and maintain an open channel.

Predicted Flows

Predicted changes to flows and circulation patterns were assessed at the discharge lines shown in Figure 1. Analysis of the numerical simulations showed that dredging the channel on the north side of Old Man Island (Case 2) does not significantly impact flows at Shoalhaven Heads. For example, a comparison between predicted flows at Discharge Lines 3 and 4 (Figure 1) showed that the Northern Channel (Discharge Line 3) conveyed approximately 10% of the discharge in the Shoalhaven River. However, for Case 3, a comparison between predicted flows at Discharge Lines 3 and 4 (Figure 1) showed that the Northern Channel (Discharge Line 3) conveyed approximately 43% of the discharge in the Shoalhaven River. As expected, the effect of significantly increasing the conveyance in the Northern Channel by widening and dredging (Case 3) resulted in a significant increase in flow in the Northern Channel and at Shoalhaven Heads. Note that the same outcome could be achieved by increasing the conveyance (via dredging) of the main arm of the Shoalhaven River.

Summary

In summary, various management options to modify the channel on the north side of Old Man Island in the Shoalhaven River estuary have been considered, and the resulting impact on salinity concentrations and river flows at Shoalhaven Heads assessed. Results of the numerical simulations of the proposed options showed that salinity throughout the Shoalhaven River estuary, including Berry's Bay and the River Road Reserve Boat Ramp, is dominated by opening the Shoalhaven Heads entrance, and not impacted by modifying the channel on the north side of Old Man Island. In addition, the numerical simulations confirmed that dredging the channel on the north side of Old Man Island (Case 2), does not significantly impact flows at Shoalhaven Heads (<5% increase). While Case 3 indicated that increasing the conveyance of the channel on the north side of Old Man Island has the potential to significantly increase flows at Shoalhaven Heads (by approximately 27%), the same outcome could be achieved by increasing the conveyance (via dredging) of the main arm of the Shoalhaven River. Note that to achieve the outcome of increased conveyance in either the Northern Channel or the main arm of the Shoalhaven River, significant engineering works would be required, in addition to an open entrance at Shoalhaven Heads. As such, based on these findings, WRL would not recommend any further evaluation of opening up the channel on the north side of Old Man Island to improve flows at Shoalhaven Heads.

Figure 1. Location Figure Showing Data Extraction Points

Case 1: Shoalhaven Heads Entrance Open + Existing Conditions in Channel North of Old Man Island
Case 2: Case 1 + Channel North of Old Man Island Dredged to - 2.0 m AHD + Existing Width
Case 3: Case 1 + Channel North of Old Man Island is 2x Wider than Case 2 and Dredged to -5.0 m AHD

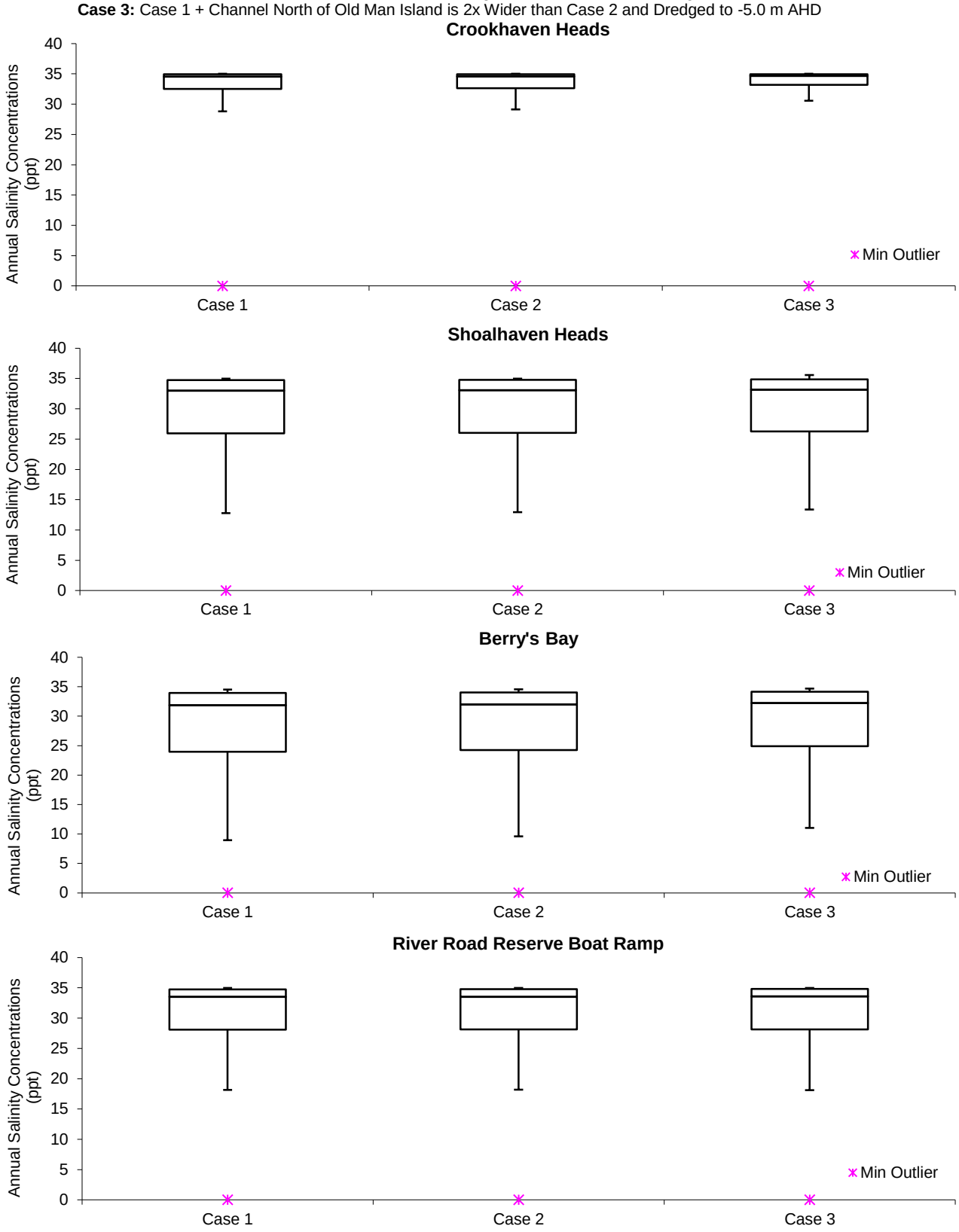


Figure 2. Statistical Analysis (Minimum, Maximum, Median, 10th Percentile, 90th Percentile) of Predicted Annual Salinity Concentrations at Key Locations in the Shoalhaven River Estuary and Crookhaven Heads for the Options Proposed

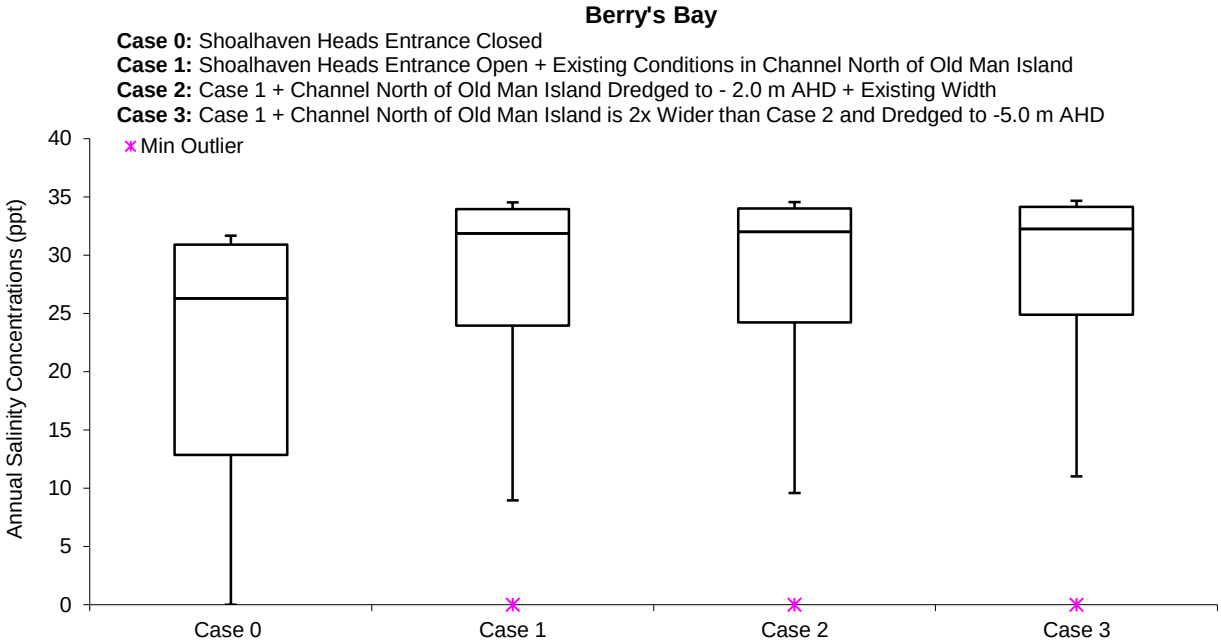


Figure 3. Statistical Analysis (Minimum, Maximum, Median, 10th Percentile, 90th Percentile) of Predicted Annual Salinity Concentrations at Berry's Bay in the Shoalhaven River Estuary for the Options Proposed, and Compared to a Closed Shoalhaven Heads Entrance