Department of **Water and Environmental Regulation**
Department of **Primary Industries and Regional Development**

GOVERNMENT OF
WESTERN AUSTRALIA

Reconnecting Toby Inlet: options for increasing water circulation in Toby Inlet to improve water quality

A Revitalising Geographe Waterways project

Revitalising Geographe Waterways

VASSE taskFORCE

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Department of Water and Environmental Regulation

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Report no. 80

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Department of Water and Environmental Regulation
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7000
Facsimile +61 8 6364 7001
National Relay Service 13 36 77
www.dwer.wa.gov.au

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Reference details

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Summary

The Reconnecting Toby Inlet study was undertaken by the Department of Water and Environmental Regulation (DWER) as part of the Revitalising Geographe Waterways program, which aims to improve the water quality, waterway health and management of Geographe waterways. The study was initiated in response to interest from various stakeholders in options to improve water quality in the Toby Inlet by increasing tidal flushing and/or increasing inflows from the catchment. A hydrodynamic model was used to examine the management scenarios proposed by the community, local government and interested agencies.

Key findings from the Reconnecting Toby Inlet study include:

- Keeping the Toby Inlet mouth open resulted in 72% of the inlet being regularly flushed by tidal movement, which was considerably more than maintaining the opening at Station Gully (36%).
- The water exchange from Station Gully drain is limited by the shallow, narrow channel between Station Gully and Toby Inlet, therefore increasing the culvert capacity at Station Gully is likely to do little to improve the water exchange between the waterbodies.
- Artificially opening the Toby Inlet mouth to a sill elevation of less than -0.15 mAHD may cause the inlet to drain on low tides, leaving individual pools that may become warm and de-oxygenated – potentially harming aquatic biota.
- Maintaining a single cut to the Toby Inlet provides significant flushing of most of the inlet, however poor circulation remains in the upper inlet (upstream of the Quindalup boat ramp). A second cut would improve circulation in the upper inlet, however it is likely that seawater ingress would occur upstream of Caves Road Bridge – potentially damaging the freshwater wetland ecology in the area.
- Sediment removal in the inlet was shown to have minimal impact on increasing circulation, although removal of sediment to improve aesthetics and water quality may still be warranted.
- Options for increasing summer flows from the catchment are limited as there are no large regulated storages in the catchment. Analysis of current water storage in the catchment (Dunsborough Lakes and small catchment dams) showed volumes were orders of magnitude less than what was required to maintain summer flows.
- Concentrations of nutrients in Station Gully are higher than those in the Toby Inlet and therefore diverting flows from Station Gully would increase nutrient concentrations in the inlet. Flow velocities were also inadequate to improve sediment scouring.

Based on this study’s key findings, the recommendations are that:

- The Toby Inlet mouth is kept open year-round (with a minimum sill elevation of -0.15 mAHD).

- The sill elevation of the Toby Inlet mouth does not fall below -0.15 mAHD, either by maintenance operations, or during natural erosional processes, between the months of October to June.
- The culvert between Station Gully and Toby Inlet remains open (to maintain some tidal circulation in the lower inlet should the Toby Inlet mouth close over temporarily).
- If tidal flushing of the upper inlet is desired, the feasibility of a second cut should be further investigated. If a second cut is investigated, it would require a minimum sill elevation of -0.15 mAHD. If the option of a second cut were pursued, the potential risk of saltwater ingress on the local ecology upstream of Caves Road Bridge would need to be further investigated.

1 Introduction

Revitalising Geographe Waterways is a Western Australian Government initiative to improve the water quality, waterway health and management of Geographe waterways. The program is delivered through partnerships and is overseen by the Vasse Taskforce. The taskforce has representation from state and local government, water service providers and catchment groups. It provides direction and support to the lead agencies responsible for delivering projects, addresses broader issues, and reports to the community on the outcomes of activities designed to improve waterway health. The four-year program will focus on improving water quality across five key water assets – Geographe Bay catchment, Vasse-Wonnerup wetlands, Lower Vasse River, Toby Inlet and rural drainage networks.

Evaluating the technical options to address public concern about the long-term poor water quality in Toby Inlet is an important part of the Revitalising Geographe Waterways initiative. This report summarises key findings of the Reconnecting Toby Inlet study, which will be used to inform the *Toby Inlet water management plan* being developed by the City of Busselton.

An estuary circulation model was developed to examine a range of management scenarios to improve water quality in the inlet (primarily through increased summer water circulation) proposed by the community, local government and interested agencies.

1.1 Background

Toby Inlet is located east of Dunsborough in the south-west of Western Australia (Figure 1). The inlet has ecological and social significance, providing habitat for fish and migratory birds as well as a recreational area for residents and tourists.

The region has a long history of clearing and drainage modification to enable productive farming. As a result, the system's hydrology has been altered from its natural state with consequences for Toby Inlet's water quality and ecological health.

Before drain modification, Toby Inlet was one of the only waterways that connected the catchment to Geographe Bay, with the Carbunup River originally flowing through Toby Inlet to the sea. A channel was excavated from the sea to the wetland chain south of Toby Inlet in the 1800s, which altered the flow and direction of the river. This drain (colloquially referred to as Molloy's ditch) effectively changed the entire wetland structure to the west, undoubtedly impacting on Toby Inlet as well (Pen 1997). The wetlands' hydrology was further modified by the rural drainage program (1920s), which involved the upper reaches of Station, Annie and Mary brooks being re-directed into a single, straightened drain (referred to as Station Gully drain, but also known locally as Annie Brook drain), and by the upgrade of Quindalup Siding Road (1950s). All culverts were removed beneath the road, effectively dividing one wetland into two separate waterbodies. The flow of water on the road's east side was directed to the east into Molloy's ditch, while water on the west side continued to flow to Toby Inlet. Nutrients from urban development surrounding the inlet have also negatively affected inlet health. Algal blooms, de-oxygenation and nuisance odours are a regular occurrence during summer – damaging the ecological function of Toby Inlet and hindering its use for recreation.

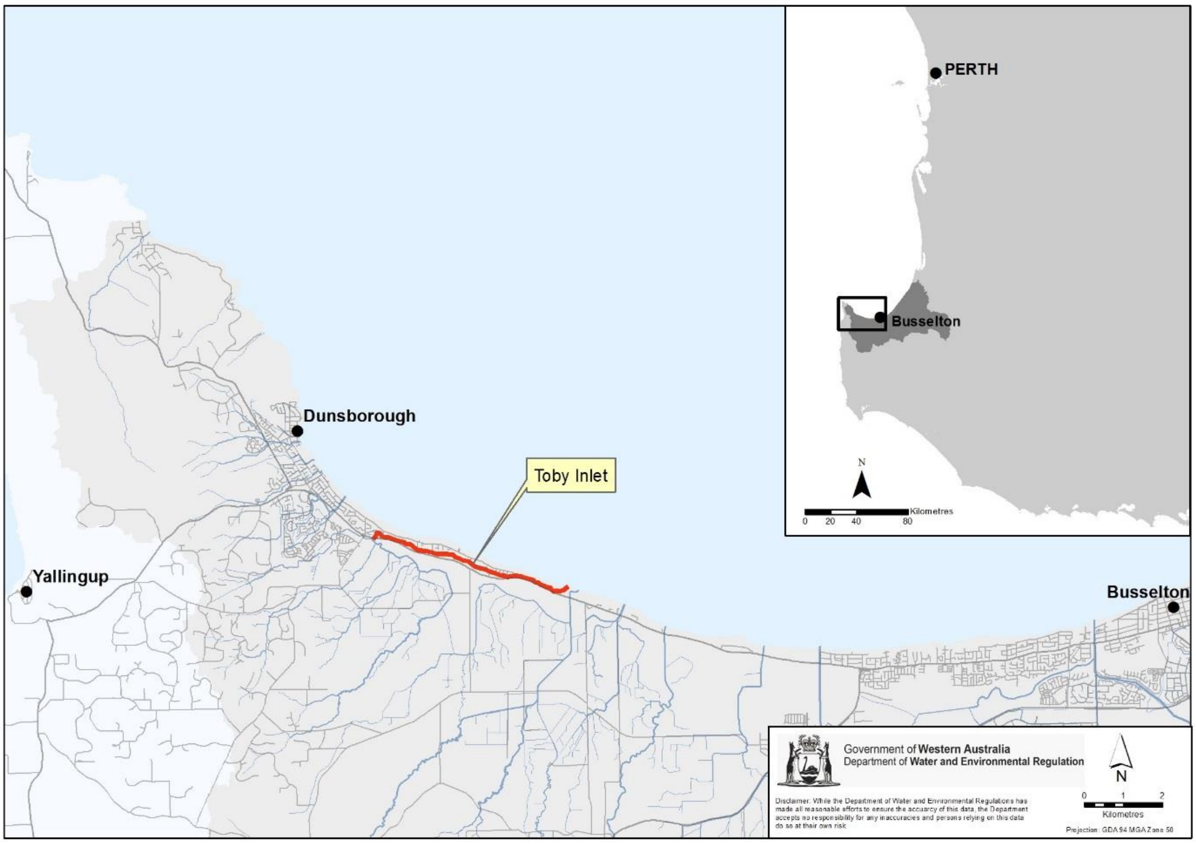


Figure 1 Location of Toby Inlet

The inlet has been the focus of a series of studies and reports. The *Toby Inlet aquatic study* (Streamtec 1997) sampled the inlet's macroinvertebrate fauna and water chemistry and provided a baseline biological survey. The report recommended a restoration program for the riparian zone to maintain the system's ecological health, the continuation of nutrient monitoring, and the mapping of land use data into a geographic information system (GIS) to target subcatchments for nutrient removal. This report was accompanied by terrestrial fauna (Hart, Simpson and Associates Pty Ltd 1997) and flora studies in 1997.

In 1999 the *Toby Inlet ocean entrance management study* (MP Rogers and Associates 1999) was undertaken with the objective of understanding the inlet's dominant hydrodynamic processes and developing a management plan to promote the long-term health of the inlet's ecosystem. The report detailed relevant historical information, which included:

- In the early 1900s the Toby Inlet entrance came out a few hundred metres east of the Radisson Hotel site. At this time, the 'deadwater' was active and part of the main body of Toby Inlet.
- The Shire of Busselton opened the entrance to Toby Inlet on three or four occasions before 1999.
- A combined entrance to Toby Inlet and Station Gully drain was excavated by the shire in 1996 and remained open until 1999 (and migrated 600 m eastwards).

- In the 1970s the Public Works Department maintained two separate entrances. These entrances were made perpendicular to the shoreline and usually closed within a year.

The 1999 study recommended that the culvert between Station Gully drain and the inlet remain open for water quality purposes; that detailed bathymetric information on the western ‘deadwater’ (i.e. the channel between Toby Inlet and Station Gully drain) be collected (if a proper assessment of the benefits of removing or replacing the existing causeway were required); that an entrance between the ocean and the inlet be kept open to result in a healthier functioning ecosystem; and that the riparian zone be replanted. The study also stated that from a cost and functionality point of view, maintaining a combined entrance to both Toby Inlet and Station Gully would be the best management option, and that for proper management of the ocean entrance, a responsible organisation (and funding model) needed to be determined for ocean entrance excavation works.

The *Toby Inlet management plan* (Clay 2005) was published six years later, with a particular focus on the management of foreshore and vegetation habitats and fauna communities, water quality and land use issues. One of the plan’s recommended actions was to “establish a protocol under the appropriate authority to ensure the opening for Toby Inlet ocean entrance is addressed and maintained”.

The *Toby Inlet, Dunsborough – acid sulphate soil investigation* (ENV 2007) used six shallow auger holes to 1 m depth over a 1.5 km section of the inlet (the upper inlet only, starting at Caves Road). The study showed that acid sulfate soils, including monosulfidic black ooze (MBO), were present in the channel. The report stated that the recorded sulfur, total metal concentrations and the presence of MBO indicated there was potential for substantial impact on the aquatic ecosystems within and beyond the inlet if the sediments were disturbed. It recommended that any requirement for such disturbance should be predicated on further investigation to better understand the risk and constrain the potential for impacts, and that such works would need to be carried out under an approved management plan.

The *Vasse-Wonnerup wetlands and Geographe Bay water quality improvement plan* (WQIP), developed by the Department of Water (2010), outlined a number of actions and priorities to protect the waterways in the Geographe catchment from nutrient pollution. Within the Toby Inlet catchment, implementation of the WQIP involved a range of activities including rural soil testing and nutrient mapping, establishment of riparian vegetation (on both private and public land), urban fertiliser education and auditing through the Bay OK program, the establishment of a nutrient monitoring site for Toby Inlet inflows, and an infill sewerage program to replace septic tanks along the inlet.

1.2 Project objectives

The Reconnecting Toby Inlet Study investigated scenarios to improve water quality by:

1. Increasing flushing of the inlet

   This could be achieved by increasing tidal flushing (by manipulating the mouth of the inlet) or by inflow flushing (by increasing the inflows of water through the inlet) or

2. Reducing nutrients in the inlet

   This could be achieved through dilution of flows or though sediment scouring.

The study also considered potential risks from changes in salinity and water levels throughout the inlet resulting from the different management scenarios.

To achieve the study's objectives, a hydrodynamic model was constructed and calibrated to simulate water and salinity movement in Toby Inlet.

The model investigated a suite of management actions (scenarios) that were determined through community and project stakeholder workshops led by the City of Busselton. The model was used to determine residence time, salinity concentrations and water levels that resulted from each of the scenarios. The following scenarios were assessed:

- Maintaining an open cut in the sandbar at Station Gully drain
- Maintaining an open cut in the sandbar at Toby Inlet
- Modifying the culvert connecting Toby Inlet to Station Gully drain
- Introducing a second cut partway along the inlet
- Excavating the mouth of the inlet to make it deeper and wider
- Removing sediment from the upper and lower reaches of the inlet
- Increasing the inflow to the inlet by:
  - a) Releasing water from upstream dam storages
  - b) Re-directing water from Station Gully drain to the Toby Inlet catchment.

The potential increase in circulation (a direct output of the model) and assessment of potential environmental risks have been provided for each scenario. Risks assessed include the potential for the estuary to drain to very low levels and form isolated pools (potentially stranding fauna in low oxygen conditions), and the potential for saltwater incursion upstream of the Caves Road Bridge, which could adversely affect farmland or vegetation that has adapted to freshwater conditions.

2 Conceptual model

To effectively model the Toby Inlet, a standard systematic modelling approach was adopted involving three steps:

1. Development of a conceptual model
2. Construction and calibration of a hydrodynamic model
3. Simulation of predictive scenarios.

A conceptual model's primary objective is to convey the fundamental principles and basic functionality of the system which it represents. For Toby Inlet, this included a physical description of the system and a qualitative description of the processes driving the changes in water level and salinity, both spatially and temporally.

The catchment surrounding Toby Inlet covers an area of 33 km^2 and receives around 800 mm of annual rainfall. The sandbar at the inlet mouth routinely opens and closes depending on streamflow and the weather conditions that drive longshore drift on the foreshore of Geographe Bay. Adjacent to the inlet opening is the mouth of Station Gully drain, a rural arterial drain which, similarly, routinely opens and closes depending on longshore drift and flow conditions. The inlet is connected to the drain via a gated culvert that allows water exchange between Toby Inlet and Station Gully depending on water levels in the respective waterbodies. A conceptual diagram showing the interaction between Toby Inlet, Station Gully drain, Geographe Bay and the upstream catchment is shown in Figure 2.

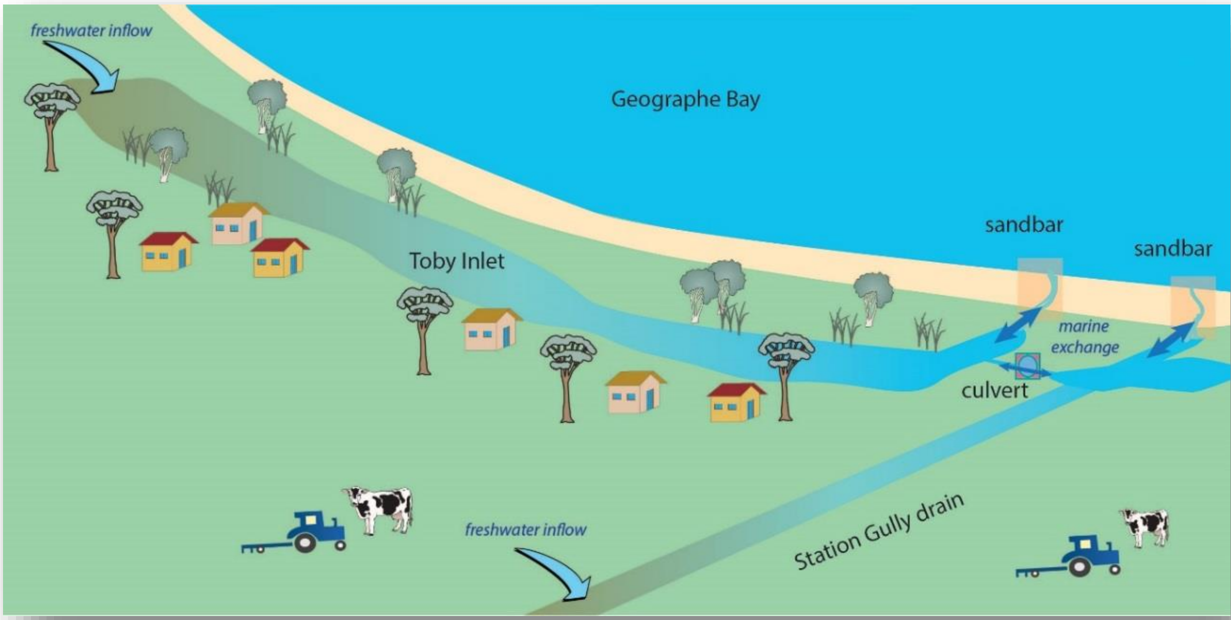


Figure 2 Toby Inlet conceptual diagram

Land use within the catchment is a combination of agriculture, lifestyle blocks, urban residential and native vegetation. The upstream catchment and waterways contributing to Toby Inlet and Station Gully drain, with associated land uses, are shown in Figure 3.

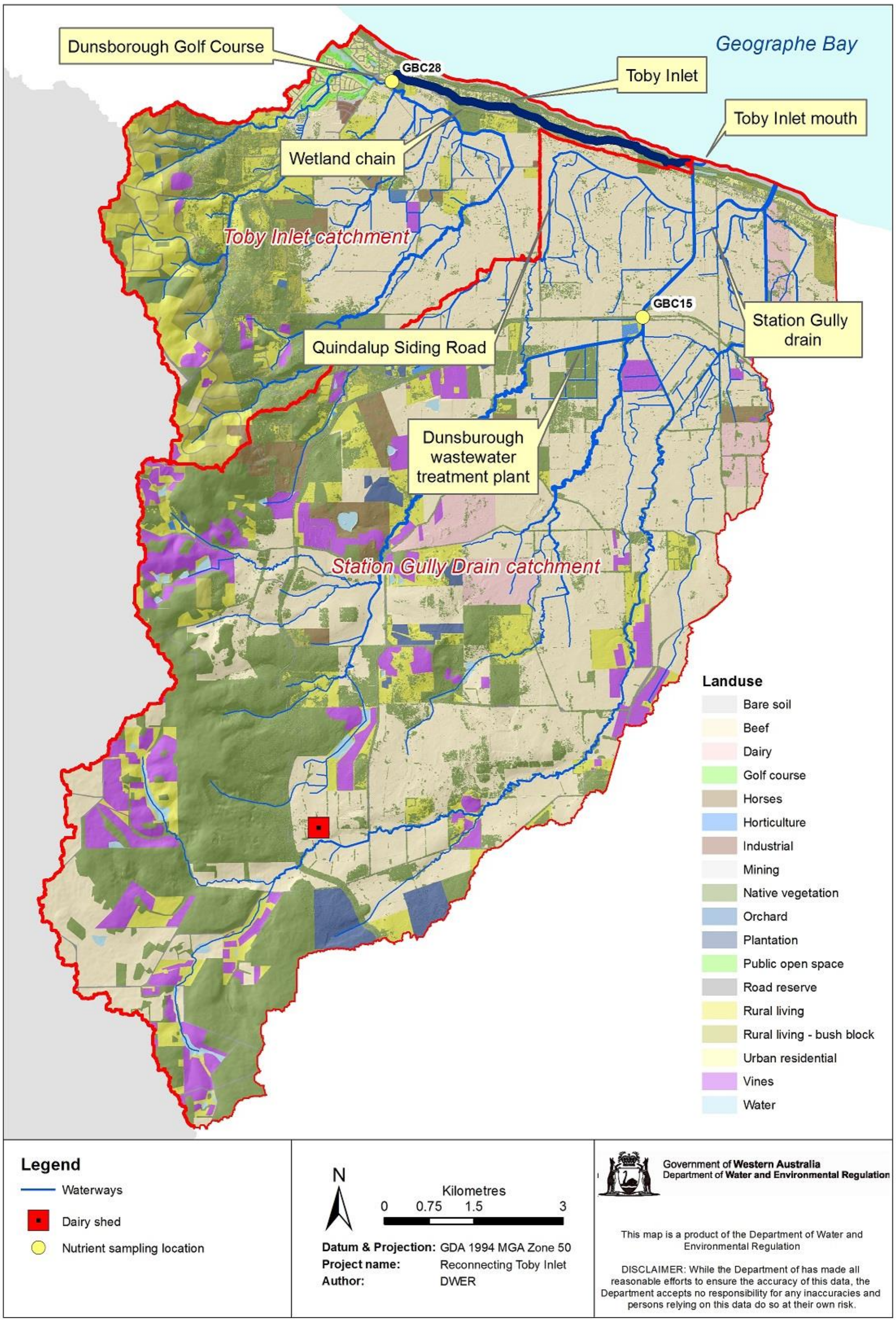


Figure 3 Toby Inlet and Station Gully catchment, hydrology and land use

Toby Inlet receives freshwater inflows from rainfall-runoff in the catchment, as well as saline, tidally driven, ocean water from Geographe Bay.

Freshwater inflow is highly seasonal. Most inflows discharge to a wetland system south of Toby Inlet and the Bussell Highway. These wetlands are low-lying and have a very low gradient; as such, the movement of water into Toby Inlet through Caves Road Bridge occurs at a very low velocity. Other freshwater inflows are via a culvert in the Commonage Road roundabout, which drains a significant portion of the Dunsborough Lakes golf course development. These flows, containing sediment and nutrients, provide flow and govern water levels at the upstream end of Toby Inlet, particularly in winter and spring. When the inlet mouth is open to the ocean, the tidal forces and the elevation of the invert of the mouth (referred to as the sill) govern water level at the inlet's downstream end.

Atmospheric conditions also affect Toby Inlet. Wind forcing may have significant impacts both on mixing and water levels. Other parameters affecting water temperature include air temperature, humidity, short wave solar radiation and cloud cover. Groundwater inflows into the inlet are assumed to be minimal (minor impact on inlet hydrodynamics) and are not explicitly modelled (nevertheless these inflows may affect summer nutrient concentrations, but nutrient dynamic modelling is outside the Toby Inlet hydrodynamic model's scope).

The gated culvert that connects Toby Inlet to Station Gully drain allows movement between the two waterbodies depending on their respective water levels. Water movement throughout the inlet is a function of tide, streamflow, wind and depth at the respective sandbar openings.

Water movement in Toby Inlet is strongly dependent on sandbar morphology. Modelling sand transport was not the focus of this study due to the highly dynamic and unpredictable nature of the system generating a broad range of potential scenarios for given inputs, which would make any modelling approach highly uncertain, and unlikely to be useful for asset managers. The approach used for modelling was to control the depth and width of the sandbar in the model to run different scenarios for analysing the resulting inlet hydrodynamics.

Bathymetric data collection

Toby Inlet's bathymetry is an important driver for water and salt movement in the inlet. It is also important to understand the level at which the inlet will dry, or form isolated pools. As detailed bathymetric data was not available before this study, the collection and processing of bathymetric data for Toby Inlet was undertaken by DWER. An M9 HydroSurveyor was used to collect raw water depth data for the inlet. Water depth was converted to bed elevation in mAHD using the gauged water level at the time of the survey. Water level was assumed to be static for the duration of the survey. Raw survey points were combined with DWER's 2008 terrestrial LiDAR dataset to interpolate a continuous digital elevation model for the river bed and banks. A discretised spline interpolation method was used to produce the final 1 m resolution grid.

The M9 HydroSurveyor operated in both real-time kinematic (RTK) and differential GPS mode during the survey. Horizontal accuracy is estimated as ± 1.0m. Vertical accuracy is influenced by horizontal accuracy, water level fluctuations and point cloud density. There was also uncertainty related to the vertical datum of the gauge board used for the bathymetric survey.

The data capture and interpolation method was consistent across the extent of the dataset. The dataset was complete along the linear extent of Toby Inlet within the survey area. The mouth of the inlet and the upstream area near the Caves Road Bridge could not be surveyed due to shallow depth. The resulting model bathymetry is shown in Figure 4. A metadata statement for the bathymetric data is provided in Appendix A.

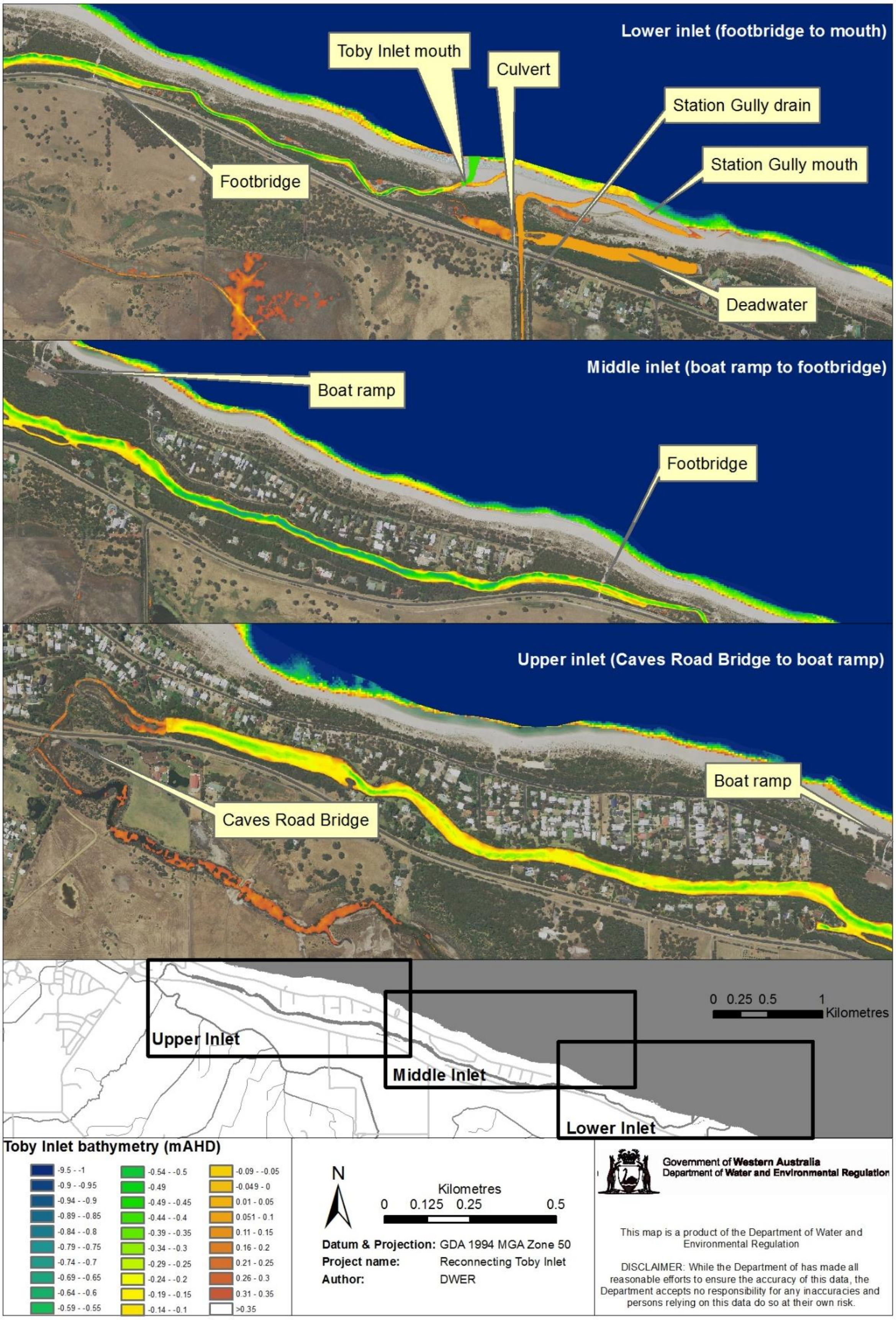


Figure 4 Toby Inlet bathymetry

3 Hydrodynamic model construction

Model construction involves the conversion of the conceptual model to a quantitative, numerical framework. It involves the selection and application of:

- the appropriate software and numerical method
- model domain and dimension
- spatial and temporal discretisation
- boundary conditions.

Each of these topics is described below.

3.1 Software and numerical method

TUFLOW-FV (build version 2015.01.001) was selected as the engine to model inlet hydrodynamics in Toby Inlet. TUFLOW-FV is a finite volume numeric model engine which solves three-dimensional Non-Linear Shallow Water Equations (NLSWE) on a ‘flexible’ mesh comprising finite volume (triangular) and rectilinear (quadrilateral) cells. The flexible mesh allows for higher resolution in areas of greater interest or complexity and coarser resolution in homogeneous zones, leading to superior computational efficiency and hence shorter run times.

TUFLOW-FV also contains an advection-dispersion module which enables both salinity and temperature to be modelled. Using this module, a conservative tracer is introduced to the inlet to calculate the time taken for the tracer to be reduced to one third of its original concentration, which is a common measure to estimate circulation and flushing times within estuaries (BMT WBM 2013, BMT WBM 2014; Monsen et al. 2002). This is also known as the e-folding residence time. The e-folding time is a key model output to compare the inlet flushing extent of each of the modelled scenarios.

3.2 Model domain and dimension

The model domain covers the entire length of Toby Inlet downstream of the Caves Road Bridge and a 3 km radius of ocean extending out into Geographe Bay to adequately capture near-shore processes and flushing extent. The extent of the modelling domain is shown in Figure 5. A two-dimensional modelling approach (in the horizontal plane) was deemed most appropriate for Toby Inlet, where shallow depth throughout the entire inlet means that vertical mixing is likely under most conditions. A two-dimensional approach is much faster to set up, calibrate and run simulations when compared with a three-dimensional approach, and was deemed the most appropriate solution, taking into consideration the inlet’s dynamics and the study’s objectives.

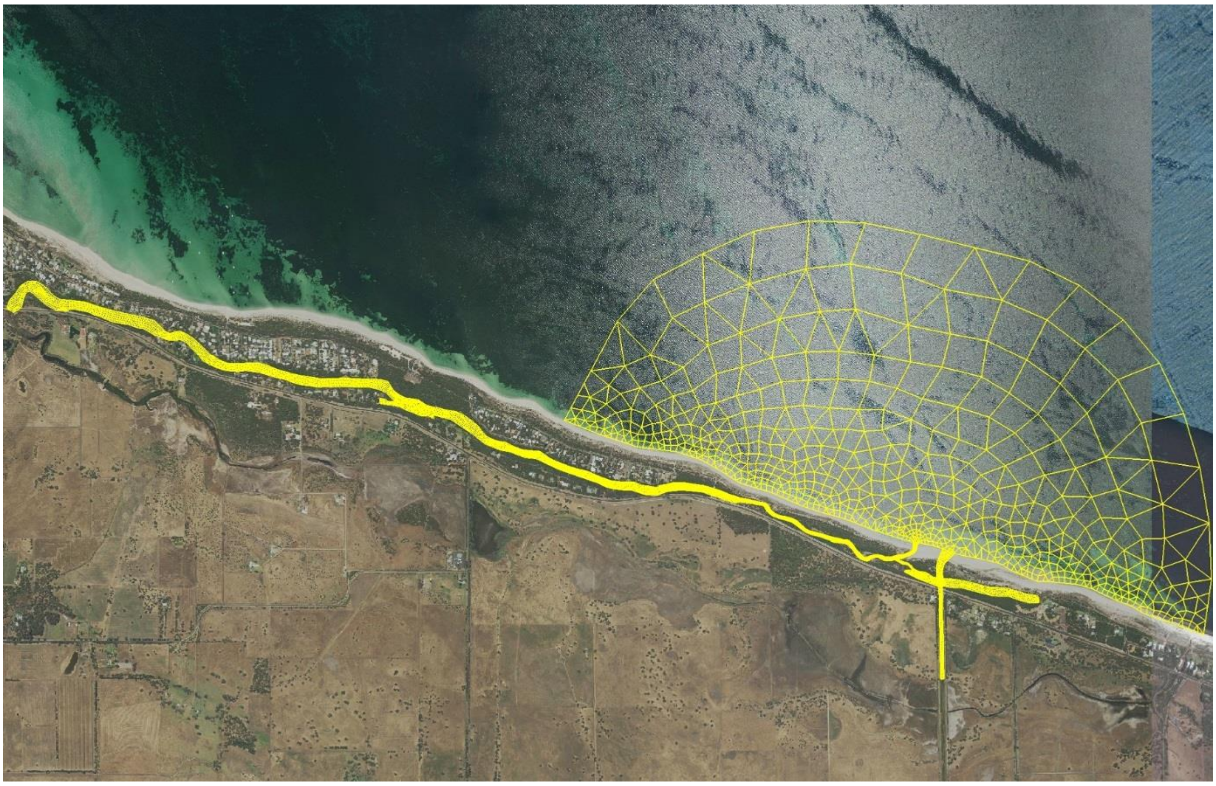


Figure 5 Toby Inlet hydrodynamic model grid and domain

3.3 Spatial discretisation

A two-dimensional flexible mesh was developed using the program SMS11.2 by Aquaveo (Aquaveo 2011). The model domain covered by the mesh is shown in Figure 6 with key landmarks highlighted for frame of reference. Mesh development statistics are shown in Table 1. Higher mesh resolution was used throughout the main channels to capture the inlet bathymetry in detail, while courser mesh was used around the relatively homogeneous coastal boundary.

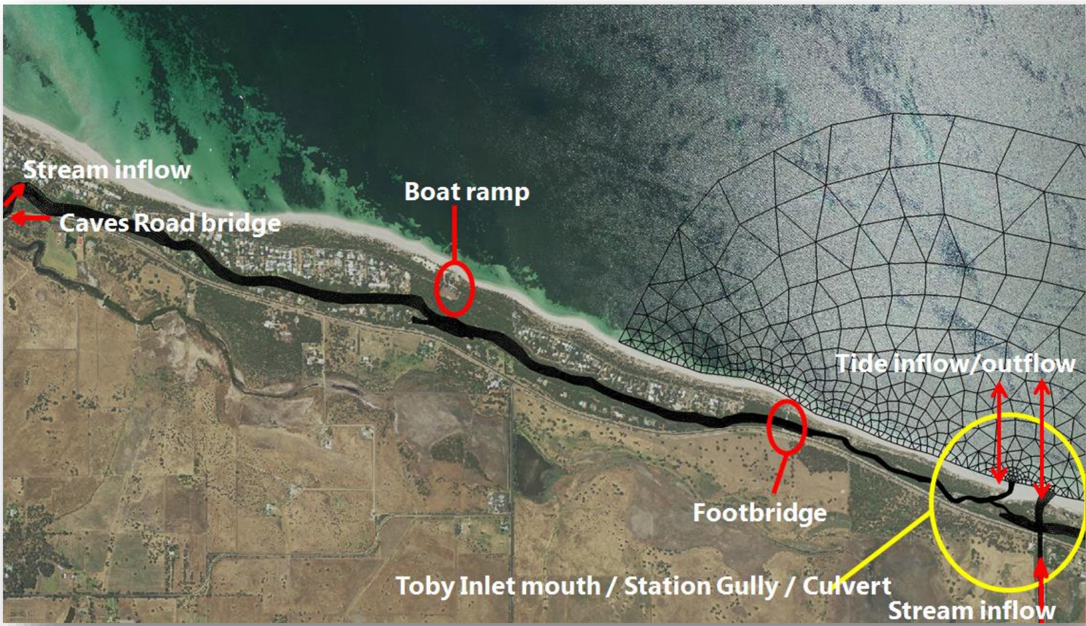


Figure 6 Toby Inlet model mesh and domain with significant features

Table 1 Toby Inlet mesh statistics

Statistic	Value
Maximum element front width	74
Maximum node half band width	116
Number of elements	6883
Number of nodes	7453
Minimum Z value	-7.1
Maximum Z value	3.36
Element type	Linear
Number of triangular elements	913
Number of quadrilateral elements	5970

3.4 Inflow boundary

Inflow to the Toby Inlet catchment model was taken from the Geographe Bay hydrological and nutrient model, and is described in detail in the accompanying catchment modelling report (Department of Water and Environmental Regulation, in press). Key elements of this model, with regard to the Toby Inlet catchment, are described below.

Toby Inlet and Station Gully catchment details

The catchment of Toby Inlet spans from Quindalup Siding Road towards Dunsborough Lakes and extends inland up to the Leeuwin-Naturaliste Ridge. Much of the catchment has been cleared for agriculture and rural and urban residential development. Quindalup Siding Road, which does not contain any culverts for water exchange, forms a distinctive boundary for the northern coastal plain section of the Toby Inlet catchment.

Station Gully drain takes inflow from the modified drainage system, and includes the upstream catchments of Station, Annie and Mary brooks, as well as downstream runoff from wetlands east of Quindalup Siding Road (Figure 3).

Data description and statistics

There are no gauged streams in the Toby Inlet catchment and consequently flows are modelled using data from an adjacent catchment. The closest gauging station is located 4 km from the Toby Inlet mouth, at the lower end of the Carbunup River. Calibrated parameters for the catchment model from this gauging station were used for Toby Inlet and Station Gully drain catchments to estimate flow. The total catchment area of Toby Inlet is approximately 32 km^2 and adjacent Station Gully drain is 110 km^2. There are no major water supply dams on the catchment.

Catchment modelling software

The modelling framework eWater Source was used to develop a daily rainfall-runoff model for the Geographe Bay catchment (using the LASCAM rainfall-runoff plugin, Hall 2011). Toby Inlet was part of the Dunsborough catchment model consisting of 65 subcatchments, five major tributaries and a total of 15 outlet nodes.

Flow seasonality

Flows in Toby Inlet and adjacent Station Gully are highly seasonal: nearly all flow occurs in winter and spring. Due to a significantly larger catchment area, Station Gully drain discharges more than three times the flow of Toby Inlet. However, during the low-rainfall months of summer and early autumn there is effectively no flow in either of the streams. Figure 7 demonstrates the seasonality of flows in both catchments for the period 2010–15.

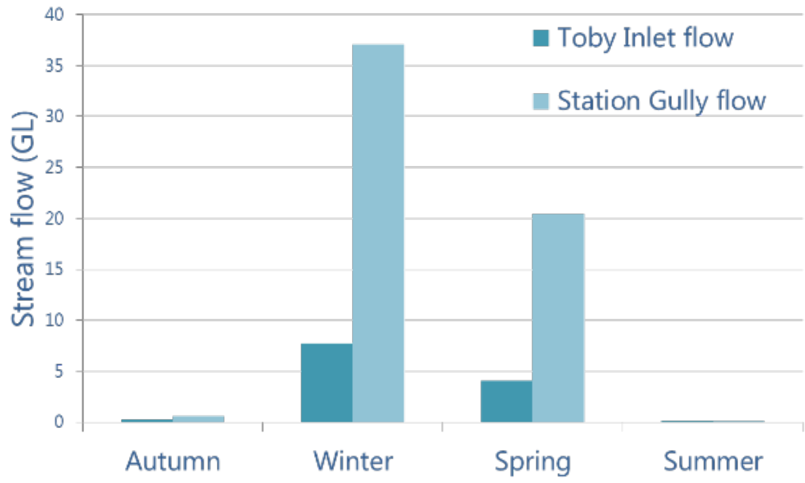


Figure 7 Average seasonal flows in Toby Inlet and Station Gully (2010–15)

Stream inflows to Toby Inlet enter the model domain at the Caves Road Bridge, while inflows to Station Gully drain enter upstream of the culvert. The flows were taken directly from the catchment model and input as a daily time-series. Stream inflows are near-fresh with a salinity concentration of 0.729 ppt (taken from DWER monitoring results).

3.5 Other boundary conditions

Boundary conditions applied to the model include those applied across polyline ‘node strings’ at the edge of the model domain and those applied globally across all nodes within the model domain.

The node string boundary conditions of stream inflow and tide are shown in Figure 6. The tidal boundary is applied across an arc several kilometres offshore centred at the mouths of both Toby Inlet and Station Gully. This allows the model to smoothly resolve hydrodynamics around the inlet and drain mouths. Water level data was taken from the Department of Transport’s Port Geographe tidal station and updated in the model at one-hour intervals. Salinity is assumed to be constant at 35 ppt in accordance with Bureau of Meteorology (BoM) sea surface data.

Global boundary conditions are local meteorological conditions affecting both water level and salinity dispersion. The data was collected from the BoM climate data station at Cape Naturaliste Lighthouse (BoM reference: 09519) located about 18 km from Toby Inlet. The model inputs (at an hourly time-step) are wind speed and direction, rainfall, cloud cover, incoming shortwave solar radiation and relative humidity. Shortwave radiation was converted from a daily total incoming solar radiation to instantaneous incoming solar radiation at an hourly time-step using equations derived by Jean Meeus in *Astronomical algorithms* (Meeus 1999) and used by the National Oceanic and Atmospheric Administration of the United States.

4 Model calibration

4.1 Monitoring data

Continuous monitoring data was collected from two sites within the inlet for three months – 1 October 2015 to 31 December 2015 – using Hydrolab DS5X sondes for the purposes of model calibration. Water depth, salinity and temperature data were collected at 15-minute intervals. Data were quality controlled and errant data removed or corrected as required. Figure 8 shows the location of the monitoring probes TIUP1 and TILOW2 within Toby Inlet.

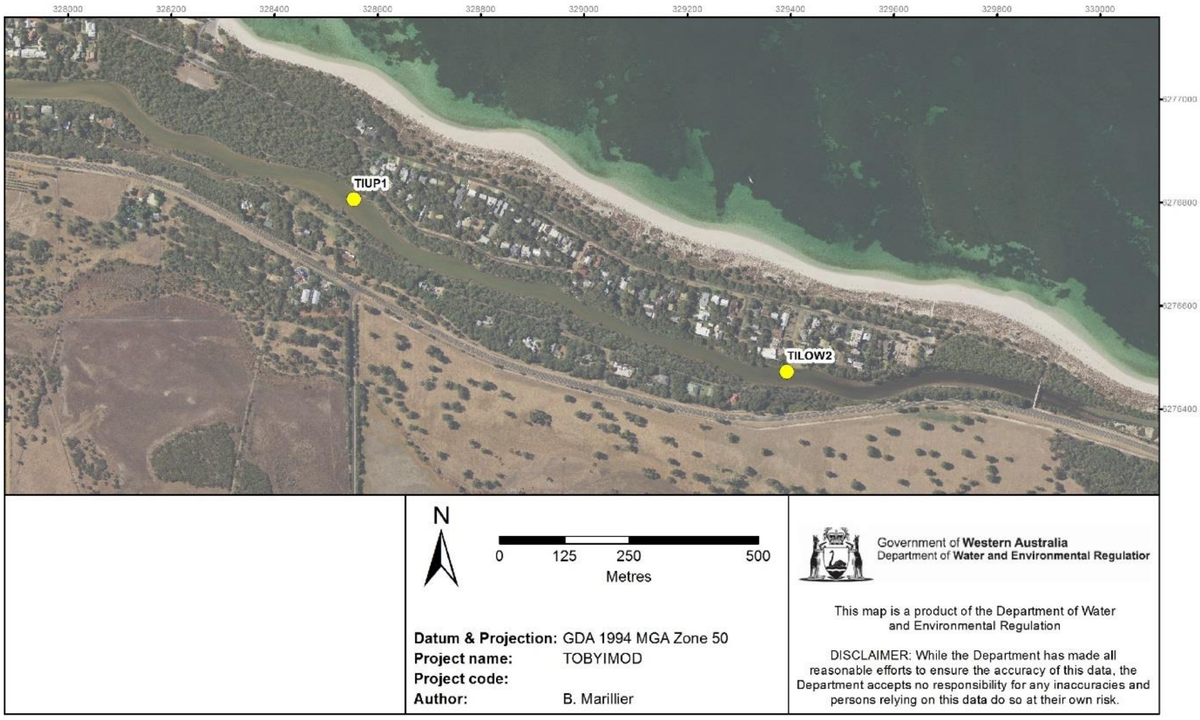


Figure 8 Toby Inlet monitoring probe locations

4.2 Calibration strategy

After a three-month warm-up period, the model was run to simulate conditions from October 2015 through to the end of December 2015. This period corresponded to that of the continuous data collected during monitoring. The model was successfully calibrated to water level and salinity, as described below.

Initial conditions and model warm-up

A warm-up time in a numerical model is the time that the simulation will run before starting to collect results. This allows the water levels, flows and salinity concentrations (and other aspects in the simulation) to develop into conditions that are typical of the system. The model was initialised on 1 June 2014 and simulated for one month to allow the model to warm up. The initial conditions water level was 0.2 mAHD, salinity was 20 ppt and temperature was 15°C. The model sufficiently warmed up after one month of simulation due to the high stream inflow quickly flushing the inlet.

Model simulations were then run for three-month periods using a ‘hot start’ two-dimensional initial condition taken from the previous model simulation. For example, the initial conditions for the simulation period 1 July 2014 to 1 October 2014 were taken from the final time-step of the warmed-up model run from 1 June 2014 to 1 July 2014.

Parameterisation

The hydrodynamic model used a two-dimensional configuration of TUFLOW-FV with particular configuration and parameterisation as follows:

- Smagorinsky model to estimate horizontal turbulent mixing
- Manning’s bottom drag model
- Density coupled with both salinity and temperature
- Scalar mixing model
- Global horizontal eddy viscosity = 0.2

4.3 Calibration results and discussion

Water level calibration

It became evident during water level calibration that the model was sensitive to the height of the opening at the sandbar (referred to as the sill elevation). While the sandbar was surveyed before the monitoring, it was clear the mouth’s shape had changed during the monitoring period and thus corrections to the model mesh needed to be applied. The sandbar used in the final calibrated model is shown in Figure 9 and has a sill elevation of -0.15 mAHD at a width of approximately 15 m.

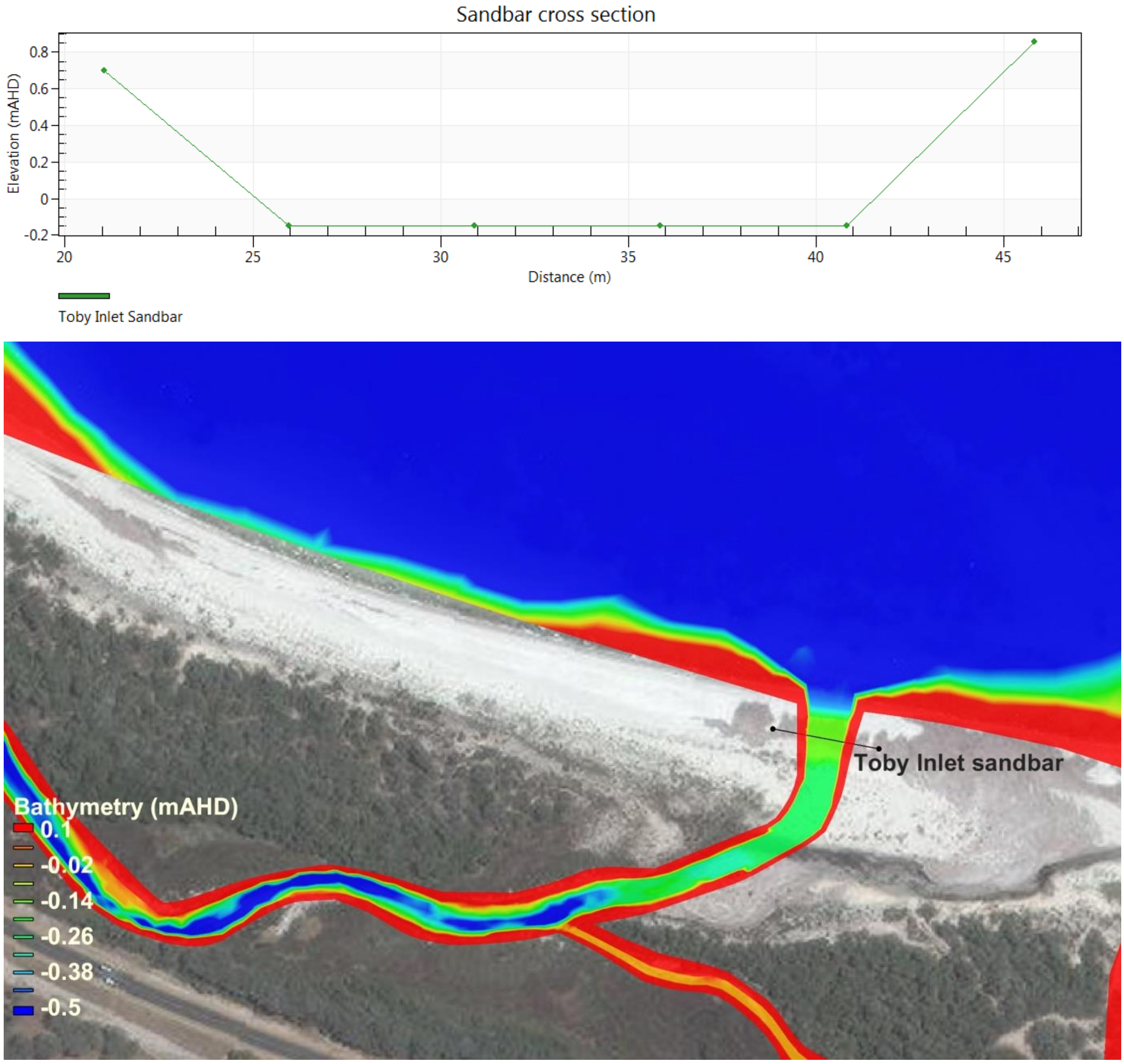


Figure 9 Toby Inlet sandbar location and cross-section used for simulations

Figure 9 shows the calibration results for water level at the monitoring probe location in the month of October. The differences in observed and modelled water level in the model calibration are likely to be a result of the variability in tide data which drive water level hydrodynamics between Port Geographe and Toby Inlet, as well as variability in the sandbar sill level at the outlet. In particular, the sand bar level sets a lower 'limit' to the inlet water level (where the sandbar level is greater than the low tide level). This is because the inlet level will fall with the dropping tide until it reaches the sill elevation, which will maintain a level within the inlet. Sill elevation is likely to be an important factor when managing Toby Inlet.

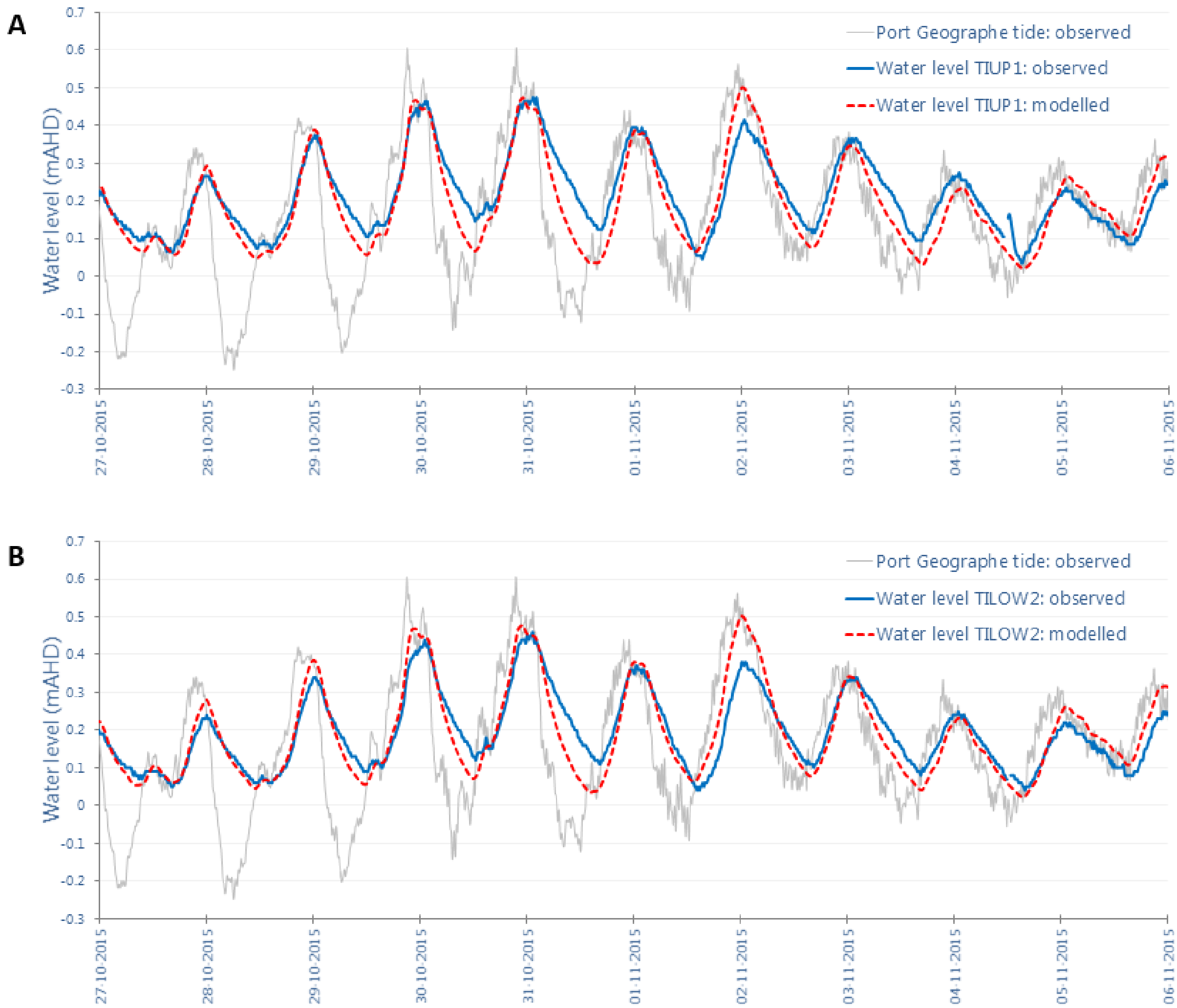


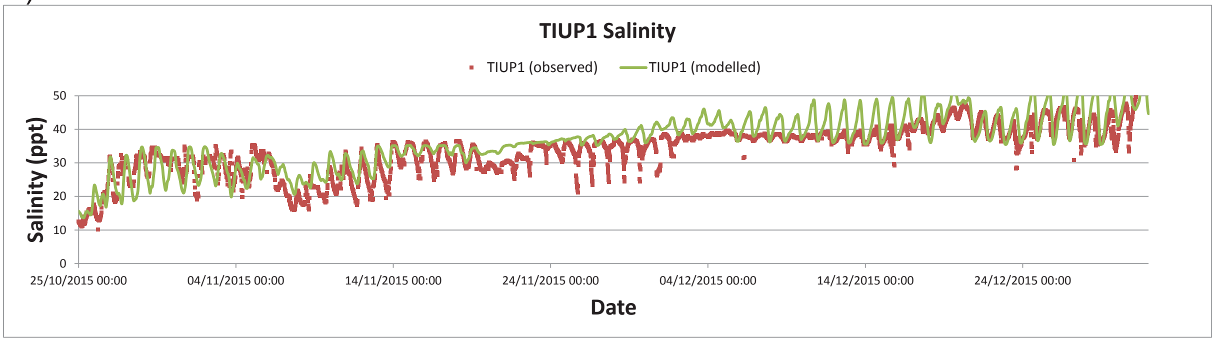
Figure 10 Model calibration for water level at monitoring locations TIUP1 (A) and TILOW2 (B), both showing water level at tidal station

Salinity calibration

The period of continuous salinity monitoring corresponds to a period of transition within the inlet changing from brackish (salinity at around 5–15 ppt) through to a hyper-saline system with salinity values reaching 45 ppt. The model was able to replicate the timing and magnitude of this change well; however, some modifications to the hydrology were required. Modelled flows into Toby Inlet for the period of late September and early October were assumed to be slightly overestimated (based on the calibration at Lennox Vineyard, 610015 – see Department of Water and Environmental Regulation, in press).

Using unmodified modelled flows the model calibrated poorly, with modelled salinity concentrations significantly lower than at monitoring sites. Monitoring data suggested lower freshwater inflows during this time as the data indicated the inlet had salinity concentrations around 10 ppt. Reducing the flows by a factor of 5 for this period was sufficient for the model to calibrate well, as shown in Figure 10. Use of the hydrodynamic model to infer modified inflows can be justified by the fact that no local monitoring data were available for Toby Inlet, and that the Toby Inlet catchment has quite different rainfall-runoff characteristics when compared with the Carbunup River, from which the inflow parameters were derived (i.e. most catchment inflows for Toby Inlet flow to a large wetland chain before discharging to the inlet, whereas the Carbunup inflows are through a relatively narrow channel to the ocean).

A)



B)

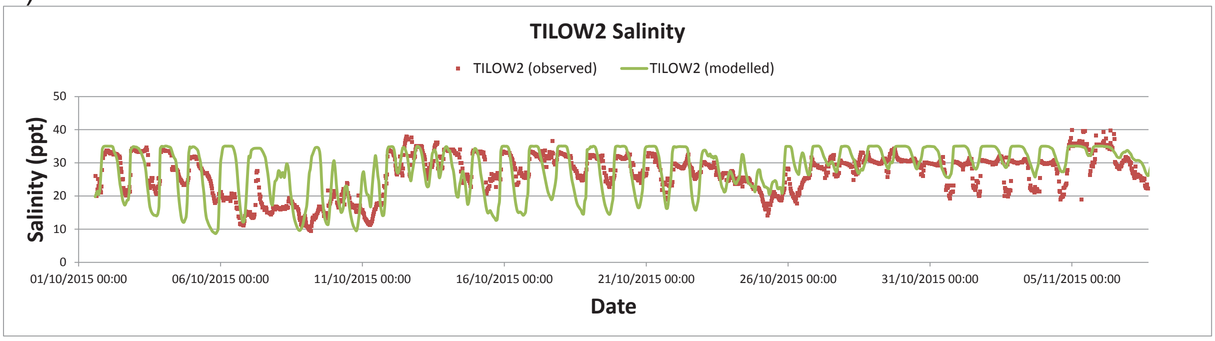


Figure 10 Model calibration for salinity at monitoring locations TIUP1 A) and TILOW2 B) both showing water level at the tidal station

Table 2 shows the calibration statistics for the water level and salinity at monitoring probe locations TIUP1 and TIOW2.

Table 2 Calibration periods and statistics for all monitoring locations

Location	Parameter	Period	No. points	NSE (hourly)	R^2 -	R -	RMSE (m)	Mean error (m)	Mean absolute error (m)
TIUP1	Water level	1/10/15 - 31/12/15	2034	0.50	0.66	0.81	0.08	-0.04	0.06
TIUP1	Salinity	1/10/15 - 31/12/15	2173	0.62	0.62	0.79	7.42	-0.37	5.22
TIOW2	Water level	1/10/15 - 18/11/15	911	0.42	0.77	0.88	0.07	-0.04	0.06
TIOW2	Salinity	1/10/15 - 18/11/15	823	0.62	0.55	0.74	5.51	-2.20	4.37

5 Management scenarios

The Toby Inlet working group – which included members of the Vasse Taskforce, City of Busselton, Department of Water (now DWER), Water Corporation, Busselton Water and the community – developed a suite of potential management actions for improving water quality in the inlet. A list of 10 modelling scenarios were put forward, each of which fell into one of two categories:

1. Those that involved manipulation of the ocean outlet of the Toby Inlet and Station Gully drain, in order to increase seawater circulation (or 'tidal flushing') in the inlet, and
2. Those that were designed to increase catchment inflows ('inflow flushing') and/or sediment movement and to improve nutrient concentrations.

The following scenarios involved manipulation of the ocean outlet:

- **Scenario 1:** Keep the Toby Inlet and Station Gully sandbars open
- **Scenario 2:** Keep the Toby Inlet sandbar open and Station Gully closed
- **Scenario 3:** Maintain a single opening at Station Gully (i.e. Station Gully maintained open whilst Toby Inlet is closed, but the culvert between Station Gully and Toby Inlet open to exchange water between the ocean and Toby Inlet)
- **Scenario 4:** Increase the size and number of culverts that exchange water between Station Gully and Toby Inlet
- **Scenario 5:** Widen and deepen the channel and sill at the lower end of the inlet
- **Scenario 6:** Introduce a second cut to the inlet
- **Scenario 7:** Shift Station Gully mouth to its previous location in front of Wyndham Resort and reconnect Toby Inlet to have a single combined inlet mouth.
- **Scenario 8:** Remove sediment from the lower and upper reaches of Toby Inlet

Each of these were developed as scenarios for the Toby Inlet model (apart from Scenario 7, which had results inferred from previous scenarios). Each scenario was then assessed based on the following criteria:

- **Increase in circulation (residence time):** The residence time is the amount of time a droplet of water remains in the inlet, and was derived from model results using the e-folding method. The month of January 2015 was used as a starting point for residence time conditions, as there were no catchment inflows and the system was tidally driven. These are the conditions in which water quality issues become apparent. Any section of the inlet was considered to have good circulation if the residence time was less than one week.

- **Potential risks:** This assessment is semi-qualitative, and it relies on the outputs of the models or numerical analysis of the scenarios to flag whether the scenario could potentially give rise to an environmental risk. Risks that were assessed included the potential migration of salt water upstream of the Caves Road Bridge – damaging the ecology of the freshwater-adapted fauna and vegetation in that area, and the potential for water levels to fall to the extent that the estuary formed isolated pools – stranding fauna in low-oxygen conditions. **Error! Reference source not found.** shows the isolated pools that occur below -0.4 mAHD. Isolation of larger species such as fish (e.g. black bream) would occur at water levels higher than -0.4 mAHD, given they require some depth of water between pools to swim in.

Two scenarios were developed with the purpose of potentially increasing catchment inflows. These aimed to increase summer flows to the inlet and/or to scour sediment and dilute nutrient concentrations to improve the water quality in the inlet:

- **Scenario 9:** Introduce a culvert underneath Quindalup Siding Road and divert flow from Station Gully drain through the wetland chain to Toby Inlet
- **Scenario 10:** Increase summer flows from water stored in small dams throughout the catchment including Dunsborough Lakes

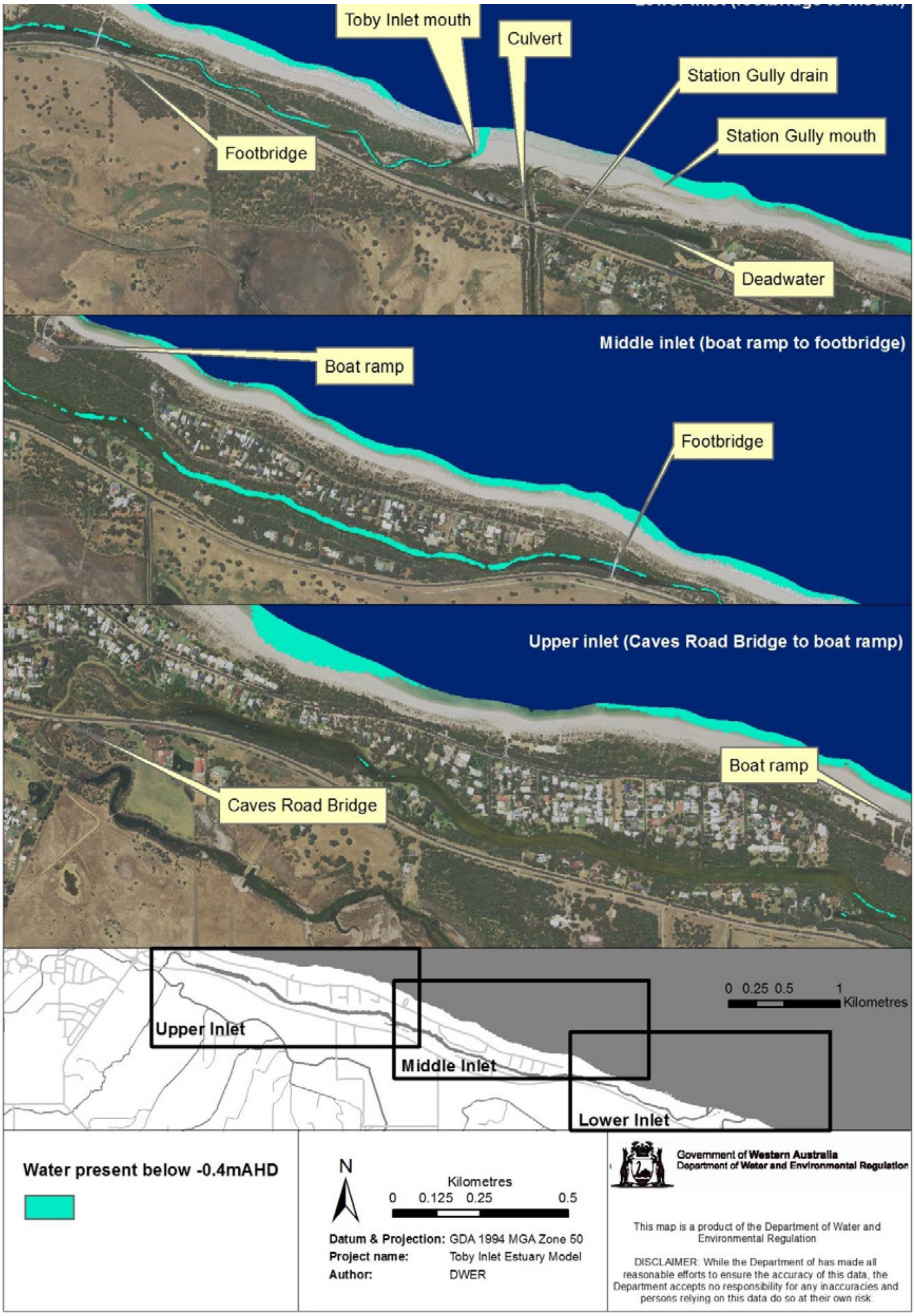


Figure 11 Waterbodies (isolated pools) below -0.4 mAHD in Toby Inlet

5.1 Scenario results: manipulation of outlets

Scenario 1: Keep the Toby Inlet and Station Gully sandbars open

Extent of predicted regular tidal circulation: 72% of the inlet

Minimum predicted water level: -0.05 mAHD

Potential risks: low (at sill elevation of -0.15 mAHD)

Tidal flushing will occur when the Toby Inlet and Station Gully sandbars are artificially or naturally kept open throughout the winter. When both sandbars are open, regular tidal flushing was predicted to extend to 3.6 km of the inlet (72% of the inlet). The residence time of the inlet water for Scenario 1 is shown in Figure 12.

The potential risks are 'low' if the sill elevation is managed at -0.15 mAHD. Minimum water levels are predicted to be -0.05m, where the inlet is one continuous body of water with depth greater than 0.2 m to provide fish passage, and significant saltwater incursion upstream of Caves Road Bridge is unlikely.

Figure 12 Residence time for Toby Inlet in January, Scenario 1 (Toby Inlet and Station Gully sandbars both open)

Scenario 2: Keep the Toby Inlet sandbar open and Station Gully closed

Extent of predicted regular tidal circulation: 72% of the inlet

Minimum predicted water level: -0.05 mAHD

Potential risks: low (with sill elevation of -0.15 mAHD)

There was a negligible difference to the extent of tidal flushing when only the Toby Inlet sandbar was kept open, compared with when both the Toby Inlet and Station Gully sandbars were kept open. This is likely to be due to the limited water exchange that occurs through the culvert and the narrow channel that connects Toby Inlet to Station Gully.

Similar to Scenario 1, the potential risks are considered ‘low’ if the sill elevation at the Toby Inlet mouth is managed at -0.15 mAHD. Both scenarios 1 and 2 show that maintaining an open mouth provides significant flushing of the inlet, however poor circulation remains in the upper inlet (upstream of the boat ramp).

Scenario 3: Maintain a single opening at Station Gully

Extent of predicted regular tidal circulation: 36% of the inlet

Minimum predicted water level: 0.14 mAHD

Potential risks: low

Maintaining a single mouth opening at Station Gully was predicted to result in a significantly lesser extent of tidal flushing of the inlet compared with maintaining the mouth open at Toby Inlet (about half the flushing extent).

The potential risks were set to ‘low’ as the shallow, narrow channel that joins Toby Inlet and Station Gully will be the limiting factor for the lower level of the inlet and is greater than 0.1 mAHD, so even if the Station Gully sill elevation of the outlet channel is extremely deep, the inlet will not fall to a depth lower than the base of the channel between Toby Inlet and the Station Gully drain (0.1 mAHD). Therefore, the minimum predicted water level in the inlet for this scenario was 0.14 m. Saltwater incursion upstream of Caves Road Bridge was also unlikely in this scenario.

Figure 13 shows the residence time of the inlet water for Scenario 3, and Figure 14 shows the narrow and shallow channel between Toby Inlet and Station Gully drain (referred to as the ‘western deadwater’ in a previous report (MP Rogers and Associates 1999).

Figure 13 Residence time for Toby Inlet in January, Scenario 3 (single opening at Station Gully)

Figure 14 The shallow and narrow waterbody adjoining Toby Inlet and Station Gully

Scenario 4: Increase the size and number of culverts that exchange water between Station Gully and Toby Inlet

Extent of predicted regular tidal circulation: 36–44% of the inlet

Minimum predicted water level: 0.13–0.14 mAHD

Potential risks: low

Increasing the number of culverts or completely removing culverts between Station Gully and Toby Inlet resulted in only minor increases in tidal flushing. Scenario 4 simulated a series of scenarios which involved the addition of four, 10 and 20 culverts, and a scenario that removed the culverts completely. These scenarios estimated a minor increase in tidal flushing of the inlet, with regular tidal flushing extent of between 1.8 km (i.e. no change) and 2.2 km (for the scenario where culverts were removed completely). The highest level of tidal flushing occurred when the culverts were removed completely (Figure 15). The water exchange from Station Gully drain is limited by the shallow, narrow channel between Station Gully and Toby Inlet, therefore increasing the culvert capacity at Station Gully resulted in only minor increases in tidal flushing. Details of this channel’s bathymetry are shown in Figure 16. Potential risks were set to ‘low’, and risks were similar to those in Scenario 3.

Figure 15 Residence time for Toby Inlet in January, Scenario 4 (culvert removed)

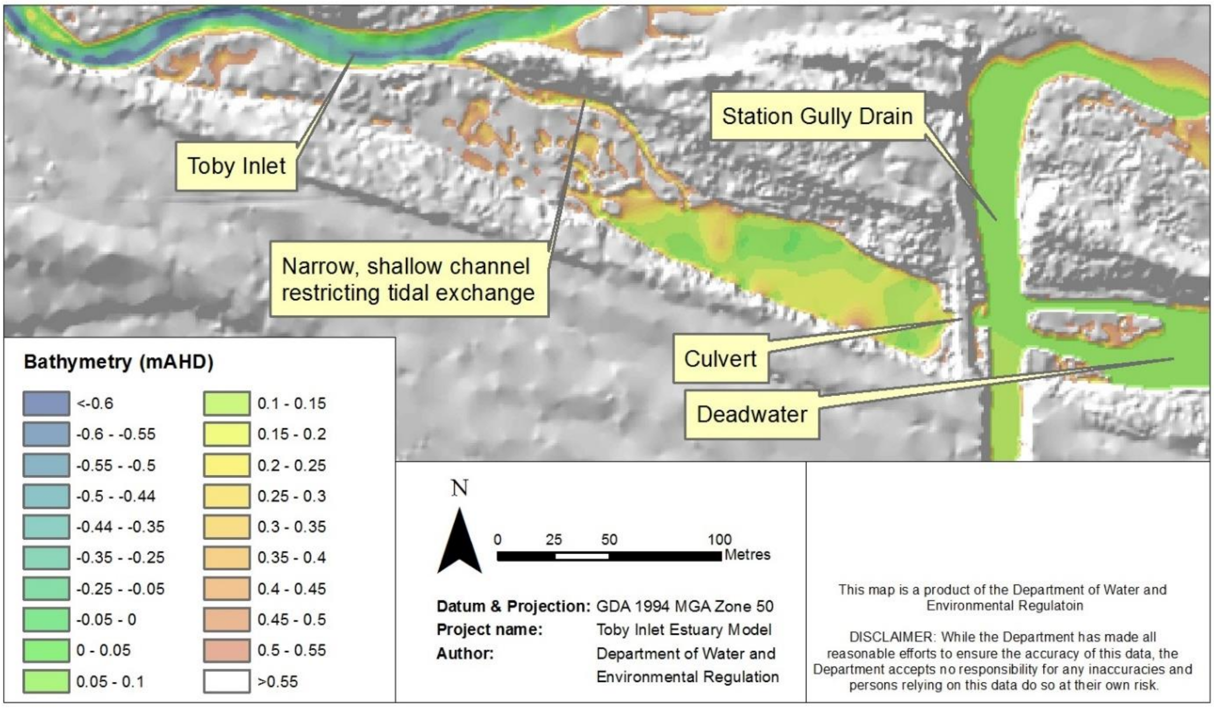


Figure 16 Detailed bathymetry between Toby Inlet and Station Gully drain

Scenario 5: Widen and deepen the channel at the lower end of the inlet

Extent of predicted regular tidal circulation: 84% of the inlet

Minimum predicted water level: -0.18 mAHD

Potential risks: high

In this scenario, the lower extent of the Toby Inlet channel and the mouth of the inlet was dredged to -0.5 mAHD, with a minimum channel width of 10 m (the simulated width being similar to the width of the cut during 2015). This was predicted to significantly improve tidal flushing, with 4.2 km (84% of the inlet) predicted to have improved circulation in this scenario (Figure 17). However, this scenario also results in significantly lower water levels in the inlet, particularly during low tides (Figure 18)

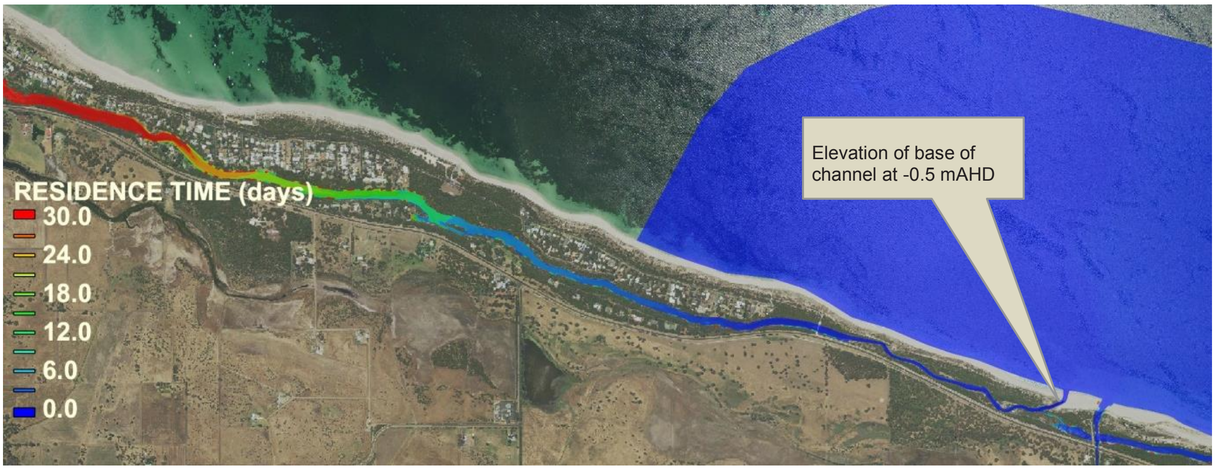


Figure 17 Residence time for Toby Inlet in January, Scenario 5 (mouth and sill excavated to -0.5 mAHD)

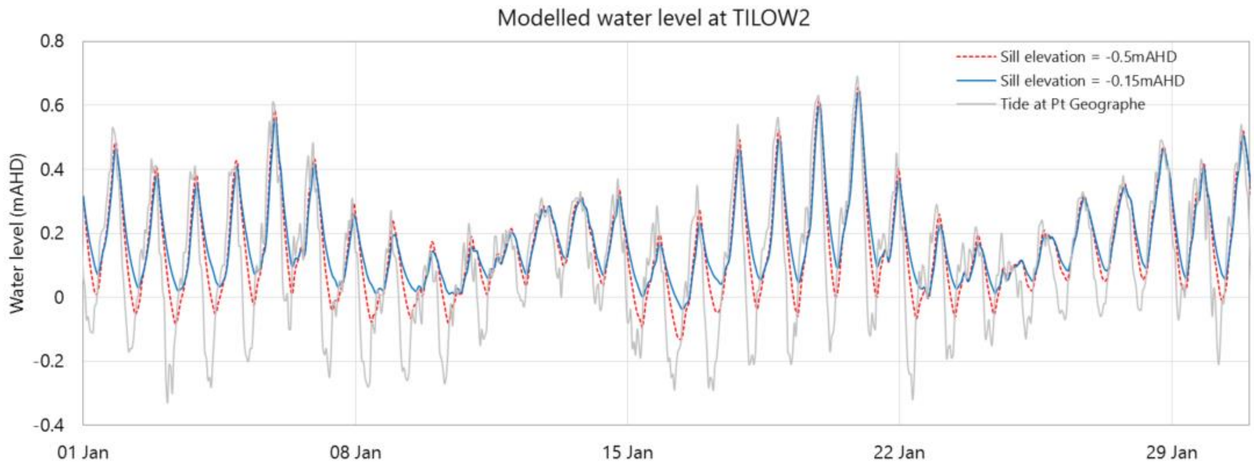


Figure 18 Predicted January water levels at TILOW2 for sill elevation of -0.5 mAHD (Scenario 5) and sill elevation of -0.15 mAHD (Scenario 2)

The minimum predicted water level was -0.18 mAHD (compared with -0.05 mAHD for scenarios 1 and 2). The potential risks were set to 'high' for this scenario, as significant risks were associated with the lowering of the minimum water level in Toby Inlet, including the potential:

- stranding of fauna in isolated pools during low tide (the March 2014 fish kill has been attributed to low water levels in the inlet)
- exposure of sediments (many of which will react with oxygen to produce acid)
- community backlash due to extremely low water levels.

Scenario 6: Introduce a second cut to the inlet

Extent of predicted regular tidal circulation: 84% of the inlet

Minimum predicted water level: -0.14 m

Potential risks: high

An additional cut was modelled assuming the sill elevation and width of the second cut were identical to the mouth (-0.15 mAHD and 15 m width), and that the cut was 600 m upstream of the mouth of Toby Inlet (in the narrowest section between the ocean and the inlet). The model predicted that tidal flushing would increase to 4.2 km (84%) of the inlet (Figure 19). This increase was exactly the distance between the mouth and the new cut. It is likely that tidal flushing of the inlet would occur 3.6 km upstream of a cut, regardless of where it is located (assuming a sill elevation of -0.15 m and width of 15 m). This means that a second cut that is more than 1.4 km east of the current mouth of Toby Inlet could regularly tidally flush the entire inlet. If a second cut were developed close to the boat ramp (where there are no dwellings between the inlet and the ocean), it is likely that regular tidal flushing would extend beyond the Caves Road Bridge. This could potentially introduce the risk of pushing salt water into the area's wetland system that has adapted to freshwater conditions. Because of this, further ecological studies are recommended to investigate the salt tolerance of this system if the second cut option were to be explored.

In addition, a second cut with sill elevation of -0.15 mAHD was predicted to drop minimum water levels (for the summer of 2015) from -0.05 m to -0.14 m. This is because the inlet can drain more efficiently in low tides, and will drain to a level much closer to the sill elevation. At -0.14 mAHD the inlet is a continuous waterbody, and there is likely to be enough depth for fauna to move between pools; however, if this scenario were pursued, further analysis of the sill elevation would be required to ensure fauna were not stranded at low tides. For these reasons, the potential risks were set to 'high' for this scenario.

This scenario would also require significant construction works, approvals and associated costs (including significant earthworks and bridge/culvert construction on Geographe Bay Road).

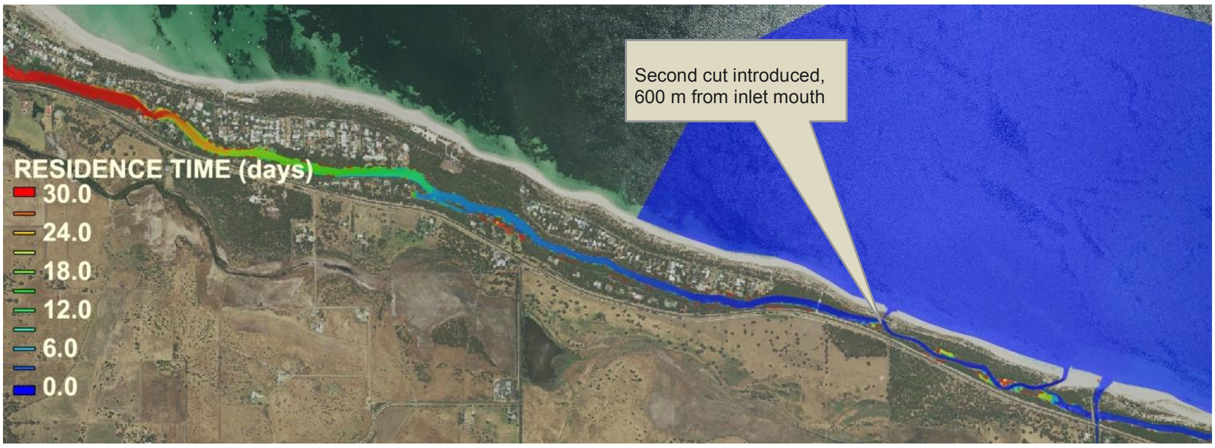


Figure 19 Residence time for Toby Inlet in January, Scenario 6 (introduction of a second cut)

Scenario 7: Shift Station Gully mouth to its previous location in front of Wyndham Resort and reconnect Toby Inlet to have a single combined inlet mouth

Extent of predicted regular tidal circulation: 36% of the inlet

Minimum predicted water level: 0.14 mAHD

Potential risks: low

This scenario was not modelled, but was inferred to have similar results to Scenario 4 – given an inlet mouth at Wyndham Resort would provide a very similar level of tidal flushing to a mouth at Station Gully (Figure 20). As explained in Scenario 4, tidal flushing is restricted by the narrow and relatively shallow channel between Station Gully and Toby Inlet. This action would effectively move the maximum flushing distance in the inlet further downstream and not improve the current situation when Toby Inlet is open.

It is possible that a mouth at this ‘deadwater’ could return some aesthetic value to the waterways in front of the Wyndham Resort. However, the water levels in the ‘deadwater’ would still depend on tide levels (and sill elevation of this mouth), particularly in summer when streamflows are negligible and mud and silt may be exposed during low tides. The tolerance of the ecology of the ‘deadwater’ to a return to saline conditions would also need to be considered if this solution were pursued.

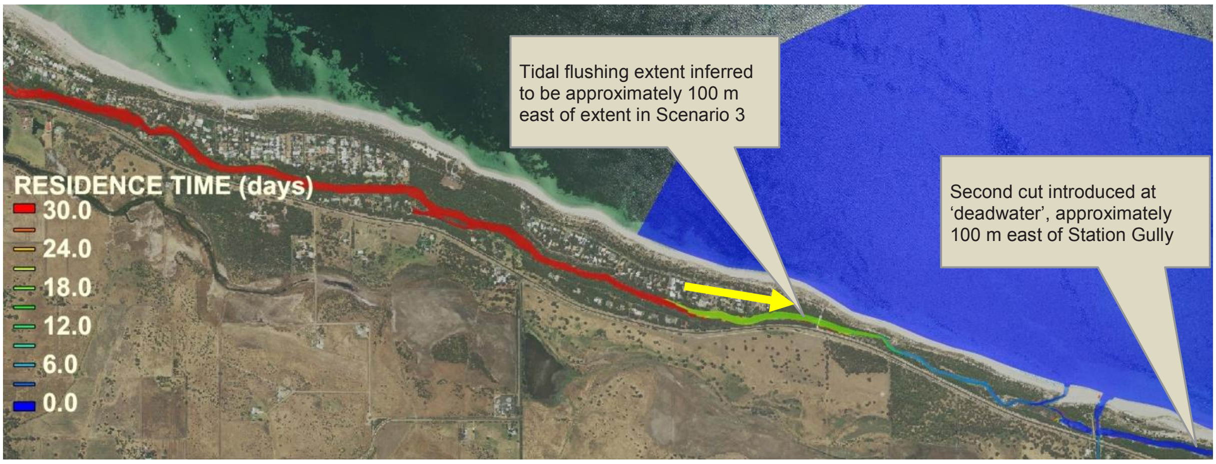


Figure 20 Residence time for Toby Inlet in January, Scenario 3 (single mouth at Toby Inlet and Station Gully), showing inferred results for Scenario 7

Scenario 8: Remove sediment from the upper and lower reaches of Toby Inlet

Extent of predicted regular tidal circulation: 74% of the inlet

Minimum predicted water level: -0.08 mAHD

Potential risks: low

This scenario was simulated by lowering the bathymetry to a level of -0.5 mAHD at the lower and upper reach of the inlet (Figure 21) equivalent to removing about 300 mm of sediment. The model predicted a minor increase in circulation in the estuary (about 100 m extra regularly tidally flushed length of inlet), due to a more efficient movement of water through the inlet. As this change is so small, it is unlikely that removing sediment would be a priority if increasing circulation in the estuary were the only objective. However, other reasons for removing sediment may be pertinent (e.g. improving aesthetics and water quality) and thus the removal of sediment may still be warranted. Potential risks associated with the inlet falling to very low water levels or saltwater incursion upstream of the Caves Road Bridge are 'low' for this scenario. Any additional risks of removing sediment have not been considered in this study.

Figure 21 Residence time for Toby Inlet in January, Scenario 9 (sediment removal)

Table 3 summarises each of the scenarios that involved manipulation of the ocean outlet of Toby Inlet.

Table 3 Summary of the scenarios involving manipulation of the outlets for Toby Inlet and Station Gully to improve seawater circulation

Scenario no.	Description	Toby Inlet sandbar	Toby Inlet sill elevation (mAHD)	Station Gully sandbar	Mixing zone km from mouth *(% of estuary)*	Min water level in Inlet (mAHD)	Other risks		Comment
							Estuary falling to low levels creating isolated pools	*Saltwater incursion upstream of Caves Road Bridge*	
0	Do nothing - estuary mouth closes naturally over summer	closed	-	closed	0 km *(0%)*	not assessed	Low	Low	No seawater mixing for the entire length of Toby Inlet
1	Keep Toby Inlet and Station Gully sandbars open	open	-0.15	open	3.6 km *(72%)*	-0.05	Low	Low	Low potential risks if sill elevation at mouth is managed at -0.15mAHD.
2	Keep Toby Inlet sandbar open and Station Gully sandbar closed	open	-0.15	closed	3.6 km *(72%)*	-0.05	Low	Low	Station Gully sandbar maintenance does not affect length of mixed zone when Toby Inlet is open. Low potential risks if sill is managed at -0.15mAHD
3	Maintain a single mouth at Station Gully Drain	closed	-	open	1.8 km *(36%)*	0.14	Low	Low	Station Gully outlet provides limited mixing for Toby Inlet. Scenario 4 was desgined to test if the culvert was the limiting factor.
4	Increase the size and number of culverts that exchange water between Station Gully and Toby Inlet	closed	-	open	1.8-2.2 km *(36-44%)*	0.13	Low	Low	Increasing number of culverts does little to increase the water exchange thorugh Station Gully. The limitation is the narrow, shallow channel between Toby Inlet and Station Gully
5	Widen and deepen the channel at the lower end of the estuary, and the estuary mouth	open	-0.50	open	4.2 km *(84%)*	-0.18	High	Med	Risks associated with minimum water level falling and leaving a very low estuary at low tide. Mixing zone is increased
6	Introduce a second cut to the estuary (600m upstream of estuary mouth)	open	-0.15	open	4.2 km *(84%)*	-0.14	Low	High	Mixed zone is increased by the distance between the cut and mouth. New bridge/road on Geographe Bay Road required, significant earthworks. Risks associated with minimum water levels.
7	Shift Station Gully mouth to its previous location in front of Windham Resort	open	-0.15	open	~1.8 km *(36%)*	0.14	Low	Low	Not modelled, can infer results from Scenario 2 and 4, as the channel between Station Gully and Toby Inlet will be the limiting factor
8	Remove sediment from the lower and upper reaches of the estuary	open	-0.15	closed	3.7 km *(74%)*	-0.08	Low	Low	Further sediment studies to determine depth and distribution of sediments, as well as disposal mechanisms would be recommended.

5.2 Scenario results: manipulation of catchment inflows

Scenario 9: Introduce a culvert underneath Quindalup Siding Road and divert flow from Station Gully drain through wetlands

This scenario was assessed by considering three proposed functions to improve water quality in Toby Inlet:

1. Increasing summer flows to the inlet
2. Introducing cleaner inflows to dilute nutrient concentrations in the inlet
3. Increasing sediment scouring in winter months due to higher flow velocities

Quantitative analysis of the catchment inflows and nutrient concentrations were used to answer proposals 1 and 2 and qualitative analysis, based on scouring relationships in the Lower Vasse River, were used to address proposal 3.

Increasing summer flows to the inlet: Hydrological modelling shows there is almost no flow in Station Gully drain and Toby Inlet during summer and autumn (see Figure 7) – therefore changes in summer and autumn flows that would result from this diversion would be negligible (for this reason, the scenario was not modelled with the Toby Inlet hydrodynamic model).

Introducing cleaner inflows to dilute nutrient concentrations: Analysis of average nutrient concentrations in Toby Inlet and Station Gully, for 2014–16, show that both nitrogen and phosphorus concentrations are higher in Station Gully (Figure 22). It would therefore be undesirable to introduce more flow from Station Gully to Toby Inlet to attempt to perform a dilution function. The locations of the catchment sampling points are shown in Figure 3.

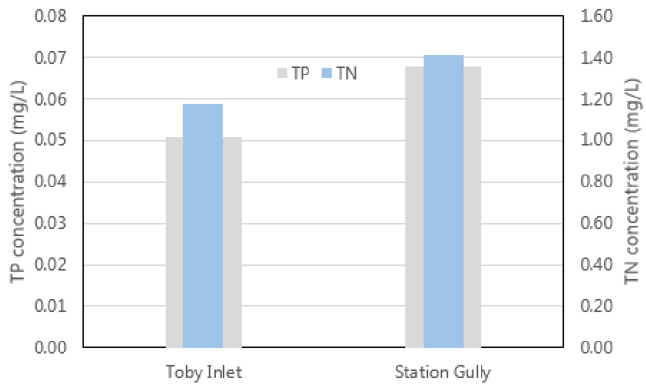


Figure 22 Concentrations of total phosphorus (TP) and total nitrogen (TP) in Toby Inlet and Station Gully inflows

Increase sediment scouring in winter months due to higher flow velocities: Flows in Station Gully are approximately three times greater than Toby Inlet due to its significantly larger catchment area. As the extent of the model did not cover the wetland system south of the Bussell Highway (upstream of Caves Road Bridge), the model cannot quantify the increase in flow velocity entering Toby Inlet if Station Gully flows are diverted to it, as this region is outside of the hydrodynamic model domain. However, analysis of the topography shows the entire wetland system to be close to 0 mAHD. While the flow volume may be high, the flow velocities are likely to remain lower than minimum scouring velocities due to the very flat slope of the inlet and the wetland system upstream of the inlet. Similar studies on the Lower Vasse River that analysed shear stress and potential sediment movement showed flow was unlikely to reach the velocities required to scour sediment in this flat landscape.

Significant risks are associated with the diversion of flows from Station Gully, including the introduction of a high flood risk for properties along Toby Inlet during winter. This could, however, be minimised if adequate flood studies and an appropriately sized culvert diversion along the Station Gully drain were implemented, so that a high-flow bypass could continue down Station Gully. The increase in winter and spring nutrient concentrations would also pose a risk to Toby Inlet, and could lead to more regular or extreme algal blooms.

Significant flood studies, approvals (through the drain asset manager), infrastructure costs and earthworks would be required to undertake this action.

Scenario 10: Increase summer flows from water stored in dams throughout the catchment including Dunsborough Lakes

Releasing water from small upstream dams in the Toby Inlet catchment to the inlet during summer to reduce residence times (referred to as inflow flushing) was explored using some simple flow calculations to determine whether this volume of water was worth considering for further analysis with the hydrodynamic model.

An estimate of the total amount of water held in the lower section of Dunsborough Lakes connected to the inlet is 100 ML. The amount of water required to flush the upper third of the inlet in one week was calculated using an average cross-section area of 15 m^2. Only the upper third of the estuary was considered, as this is the area that is poorly circulated when the Toby Inlet mouth is kept open. About 440 ML of water was required to flush the upper third of the estuary within a week. This is significantly more than the amount available from upstream users. There are likely to be major practical issues to implement this scenario, as the dam owners are unlikely to consent to the use of their water for this purpose.

A summary of the scenarios that involve modification of catchment flows to potentially improve water quality by inflow flushing, dilution and/or sediment scouring are shown in Table 4.

Both scenarios are unlikely to improve water quality in the Toby Inlet during the summer because they would neither significantly circulate the inlet by way of inflow flushing, further dilute the nutrient concentrations of the wet season inflows, nor scour sediment from the inlet.

Additionally, significant potential risks and practical difficulties are associated with applying each of these scenarios.

Table 4 Summary of scenarios involving modification of catchment inflows

Scenario No.	Description	Improved sediment scouring	Improved Spring nutrient concentration in Toby Inlet	Improved summer flows	Likelihood of improving water quality	Likelihood of increasing summer estuary flushing	Comment
9	Introduce a culvert underneath Quindalup Siding Road and divert flow from Station Gully Drain through wetland	unlikely to be significant	No (likely worse)	No	Low	Low	Nutrient concentration higher in Station Gully inflows than Toby Inlet inflows. Flow velocities from flat wetland system unlikely to be high enough to scour sediment - however this was outside of the scope of the model. Summer flows will be unchanged, as there is no summer flow in Station Gully. Flood risks would need to be managed.
10	Increase summer flows from water stored in dams throughout the catchment including Dunsborough Lakes	No	No (unchanged)	Not signifcant	Low	Low	Significantly more water than the 100ML available would be required to adequately reduce residence time. Convincing dam owners and operators to release water would be likely to be difficult.

6 Discussion

This project modelled 10 scenarios to improve water quality in the Toby Inlet by increasing tidal flushing and increasing inflows from the catchment. Of these scenarios, the most favourable was to keep the Toby Inlet sandbar open at a sill elevation height of -0.15 mAHD – resulting in an estimated tidal flushing of 72% of the inlet (Scenario 1). Keeping a permanent entrance to the ocean from the inlet was also a key recommendation of the *Toby Inlet ocean entrance management study* (MP Rogers and Associates 1999).

The 1999 study also stated that from a cost and functionality point of view, maintaining a combined entrance to both Toby Inlet and Station Gully was the best management option. Modelling undertaken in the current study did not, however, support this recommendation – with modelling outputs estimating no additional tidal flushing with the combined opening of the Toby Inlet and Station Gully sandbars. The reason for the different recommendations arising from the two studies is because the 1999 study did not have access to bathymetric data or a hydrodynamic model: it therefore assumed that water exchange through a single mouth at Station Gully would be greater than water exchange through the Toby Inlet mouth.

Detailed bathymetry undertaken to support the current study (a key recommendation of the 1999 study) identified that water exchange from Station Gully drain is limited by the shallow, narrow channel between Station Gully and Toby Inlet, not the culvert. Increasing the culvert capacity at Station Gully or keeping the Station Gully mouth open is therefore predicted to have little impact on improving the water exchange between the two waterbodies. The two studies did, however, both recommend that the culvert between Station Gully and Toby Inlet remain permanently open to provide some flushing of the lower inlet if the Toby Inlet mouth temporarily closed and Station Gully mouth remained open.

Other recommendations from the 1999 study, namely planting of the riparian zone and identifying a responsible management organisation, have either been addressed by the Toby Inlet Catchment Group through substantial plantings or are being addressed through the Revitalising Geographe Waterways Long-term Governance Project.

A key aspect of the recommendation for keeping the Toby Inlet sandbar open was the condition of not allowing the sill height to drop below -0.15 mAHD. The sill elevation is the minimum invert level of the drain between the ocean and the main body of Toby Inlet. This is the level that governs the lower level of the inlet during low tide periods. If the mouth is artificially opened (e.g. by an excavator), and the drain is lower than -0.15 mAHD, it is possible the waterbody could fall to a very low level in low tide conditions, resulting in the inlet becoming a series of isolated pools. This could potentially strand fish or other fauna. If this happens in low oxygen conditions (e.g. at night-time when plants and algae respire and photosynthesis is not occurring), it can result in suffocation.

It is likely that this situation occurred in March 2014, with the resulting significant fish kill. Analysis of the conditions after the fish kill showed that the sandbar and culvert were open and the overnight tide was very low. An assessment of the fish kill found that water quality conditions at the time were good and therefore the likely cause was stranding of fish in isolated pools due to the low tides. Analysis of the bathymetry shows that an isolated pool of water is likely to occur at the footbridge in low tide conditions (Figure 11): it is likely that this is where the fish were stranded at low tide. This incident highlights the importance of appropriate management of the sill elevation at the Toby Inlet mouth.

An appropriate minimum sill elevation of -0.15 m was used in the modelling of most scenarios. At this elevation, Toby Inlet would still be one continuous body of water in low tide conditions, allowing fauna to escape to other regions of the inlet, should a particular section become low in oxygen. The only scenario modelled with sill elevation of -0.5 mAHD (Scenario 5) resulted in significant risks associated with the falling water level in low tide conditions.

Sediment removal

The removal of sediment in the Toby Inlet is a commonly discussed topic at community and stakeholder meetings. Sediment removal investigations were recommended in the *Toby Inlet management plan* (Clay 2005) and subsequent acid sulfate soils investigations were undertaken (ENV 2007).

This study found that removing sediment from the inlet channel and upper reaches of the estuary would result in a minor increase in circulation in the estuary (about 100 m extra regularly tidally flushed length of inlet). This would be due to a more efficient movement of water through the inlet. But as this change would be so small, it is unlikely that removing sediment would be a priority if increasing tidal flushing in the estuary were the only objective. However, other reasons may arise for removing sediment that would improve water quality (e.g. to limit the release of nutrients in anoxic conditions or to improve the habitat for benthic fauna and flora). For these reasons, removal of sediment to improve aesthetics and water quality may still be warranted. If removal of sediments is desired, further investigations are recommended (including acid-producing characteristics of the sediments, disposal mechanisms, and likely ecological consequences).

Sewerage infill program

A major project to improve water quality in the Toby Inlet under the Revitalising Geographe Waterways program is the Toby Inlet Infill Sewerage Project being undertaken by the Water Corporation. This project will provide connection to deep sewerage to about 150 residents in the Quindalup area in the upstream portion of Toby Inlet, between Elmore Street and Robbies Place (Figure 23).

This region corresponds with the poorly flushed area of the inlet, when the mouth of Toby Inlet is kept open (Scenario 1), and reiterates the importance of deep sewerage connection to these lots. There are several urban lots east of the Quindalup boat ramp that are not going to be connected to deep sewerage as part of the Water Corporation infill program. This part of the inlet is predicted to be regularly tidally flushed when the Toby Inlet mouth is kept open, however it would be poorly flushed if only the Station Gully drain mouth were kept open (Figure 13). It is desirable to flush this part of the inlet during the summer for water quality improvement, when summer-time septic leachate is likely to pollute the inlet. This provides further support for keeping the Toby Inlet mouth open during summer.

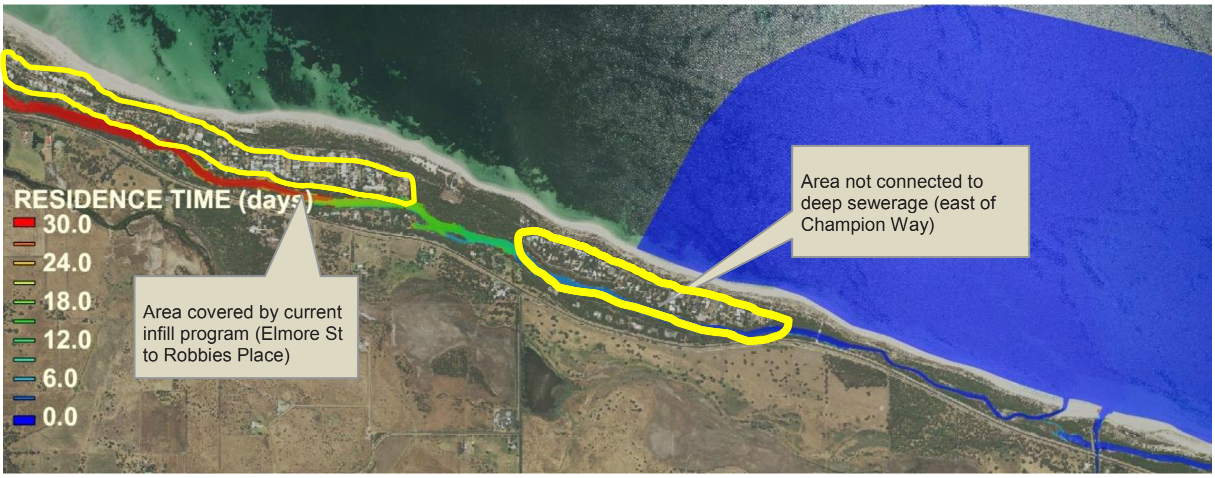


Figure 23 Residence time for Scenario 2 (Toby Inlet mouth opened) in January, and properties to be connected to deep sewerage or to remain on septic

7 Conclusions and recommendations

This Revitalising Geographe Waterways study was initiated in response to interest from various stakeholders in options to improve water quality in the Toby Inlet by increasing tidal flushing and/or increasing inflows from the catchment. A two-dimensional hydrodynamic model of the Toby Inlet was used to examine the management scenarios proposed by the community, local government and interested agencies.

The model was constructed and calibrated for both water level and salinity throughout the inlet using the program TUFLOW FV, a finite volume numeric model engine which solves three-dimensional Non-Linear Shallow Water Equations (NLSWE) on a ‘flexible’ mesh. The program SMS 12.1 was used to construct the mesh and interpret the results of model simulations. The model was successfully calibrated to water level and salinity at two monitoring locations in the body of the inlet, which collected continuous monitoring data during a three-month period.

The stakeholder consultation process resulted in the development of 10 modelling scenarios, which were broadly divided into two categories:

Those that involved manipulation of the ocean outlet of the Toby Inlet and Station Gully drain, in order to increase seawater circulation (or ‘tidal flushing’) in the inlet, and

Those that were designed to increase catchment inflows (‘inflow flushing’) and/or sediment movement and to improve nutrient concentrations.

Keeping the Toby Inlet mouth open resulted in 72% of the inlet being regularly flushed by tidal movement, which was considerably more than maintaining the opening at Station Gully (36%). The water exchange from Station Gully drain is limited by the shallow, narrow channel between Station Gully and Toby Inlet, therefore increasing the culvert capacity at Station Gully is likely to do little to improve the water exchange between the waterbodies.

This study recommends that the Toby Inlet mouth be kept open. This recommendation is contrary to a key recommendation in the *Toby Inlet ocean entrance management study* (MP Rogers and Associates 1999), that a single cut be maintained at the mouth of the Station Gully drain. The 1999 study did not have access to detailed bathymetric data or a hydrodynamic model: it therefore assumed that water exchange through a single mouth at Station Gully would be greater than water exchange through the Toby Inlet mouth. The Toby Inlet hydrodynamic model (which incorporated the new bathymetric data) showed that this is not the case.

If the Toby Inlet mouth is artificially opened, management of the sill elevation is very important. If the mouth is artificially opened (e.g. by an excavator), and the drain is lower than -0.15 mAHD, the waterbody could fall to a very low level in low tide conditions, resulting in the inlet becoming a series of isolated pools. This situation could potentially strand fish or other fauna, and was the likely reason for the March 2014 fish kill. A sill elevation of -0.15 m would maintain an adequate level of water in the inlet.

Maintaining an opening at Toby Inlet would provide significant flushing of most of the inlet, however poor circulation would remain in the upper inlet (upstream of the Quindalup boat ramp). A second cut would be likely to improve tidal flushing of the upper inlet: the modelling indicated that tidal flushing would occur 3.6 km upstream of the location of the cut. However, depending on its location, a second cut could result in seawater ingress upstream of Caves Road Bridge, and potentially damage the freshwater wetland ecology in the area. This would need to be investigated if the option of a second cut were pursued.

Removing sediment from the inlet channel and the upper reaches of the estuary was predicted to result in a minor increase in circulation in the estuary (about 100 m extra regularly tidally flushed length of inlet). This is due to a more efficient movement of water through the inlet. As this change is so small, it is unlikely that removing sediment would be a priority if increasing circulation in the estuary were the only objective. However, other reasons for removing sediment may be pertinent (e.g. to limit the release of nutrients in anoxic conditions or to improve the habitat for benthic fauna and flora) and thus the removal of sediment may still be warranted.

Scenarios involving the manipulation of inflows to Toby Inlet were limited, given that no large regulated storages are located in the catchment, and only two scenarios were developed. The first was the diversion of drainage flow from Station Gully drain through the wetlands south of Toby Inlet, which would eventually flow beneath Caves Road Bridge and into the inlet; and the second was the release of water from small upstream dams (including Dunsborough Lakes) during summer.

Analysis of the diversion of Station Gully flows indicated that nutrient concentrations in Station Gully drain were higher than Toby Inlet inflows, so water quality improvements due to dilution were not likely. Flow velocities were unlikely to be large enough to improve sediment scouring, and the lack of summer flows meant that summer flushing was unlikely to improve. Analysis of the water available from upstream storages showed volumes were substantially less than what was required to provide the flow rates needed for water quality improvements. Water quality in Toby Inlet is unlikely to improve under inflow management scenarios.

7.1 Recommendations

Based on this study's key findings, the recommendations are that:

The Toby Inlet mouth is kept open year-round (with a minimum sill elevation of -0.15 mAHD).

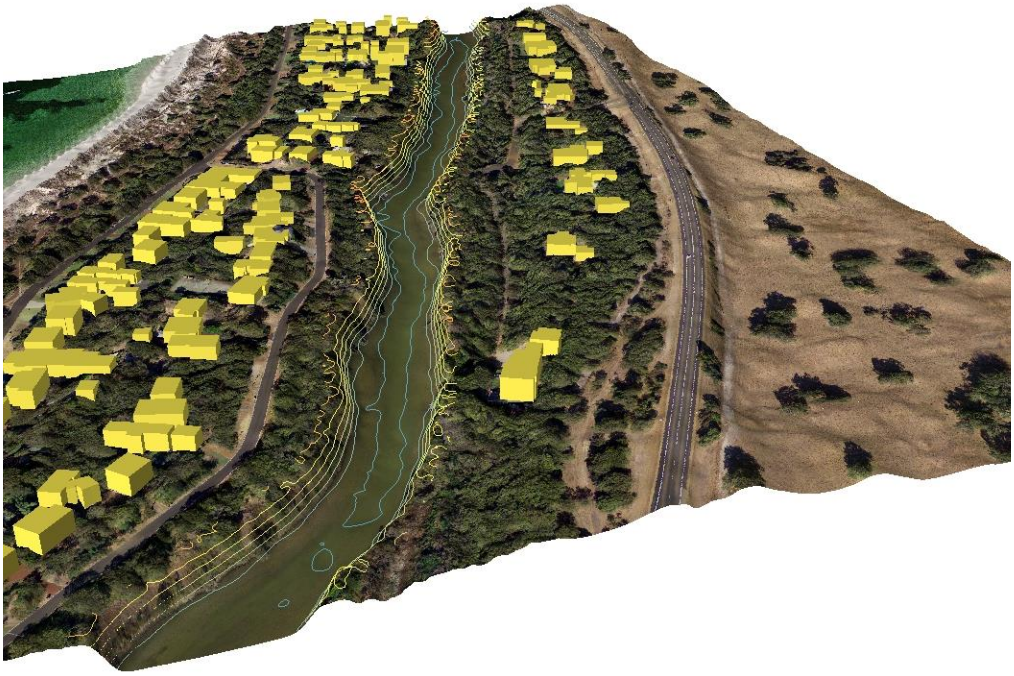
The sill elevation of the Toby Inlet mouth does not fall below -0.15 mAHD, either by maintenance operations, or during natural erosional processes, between the months of October and June.

The culvert between Station Gully and Toby Inlet remains open (to maintain some tidal circulation in the lower inlet should the Toby Inlet mouth close over temporarily).

If tidal flushing of the upper inlet is desired, the feasibility of a second cut should be further investigated. If a second cut is investigated, it would require a minimum sill elevation of -0.15 mAHD. If the option of a second cut were pursued, the potential risk of saltwater ingress on the local ecology upstream of Caves Road Bridge would need to be further investigated.

Appendix A – Bathymetric survey metadata

Toby Inlet bathymetric survey July 2015



DEPARTMENT OF WATER (DoW)

Metadata Statement

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CITATION INFORMATION

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DATASET TITLE:

Toby Inlet bathymetry

CUSTODIAN:

Department of Water (DoW).

JURISDICTION:

Western Australia.

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TEXTUAL DESCRIPTION

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ABSTRACT:

River bed bathymetric survey of the Toby Inlet from below Caves road to the outlet near Station Gully drain. Bathymetry was collected using an M9 HydroSurveyor, integrated with terrestrial LiDAR and interpolated to a regular grid at 1m resolution.

ANZLIC SEARCH WORDS:

MARINE Estuaries, WATER Hydrology

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SPATIAL EXTENT

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GEOGRAPHIC EXTENT: Western Australia

GEOGRAPHIC BOUNDING BOX:

(all coordinate values expressed in Decimal Degrees)

North Bounding Latitude: 6277473

South Bounding Latitude: 6276048

East Bounding Longitude: 326382

West Bounding Longitude: 330948

The bounding box encloses the maximum extents of the dataset. There may be voids or gaps within the bounding box, depending on the defined coverage of the dataset.

HORIZONTAL COORDINATE SYSTEM:

```
Projected System. Map Grid of Australia Zone 50

GEODETIC MODEL:
Geocentric Datum of Australia 1994.

VERTICAL COORDINATE SYSTEM:
Australian Height Datum (1971)
===========================================================================
========================
 DATA CURRENCY & STATUS
========================

BEGINNING DATE:
24 JUNE 2015

ENDING DATE:
24 JUNE 2015

PROGRESS:
 Complete

UPDATE FREQUENCY:
 Not-planned

METADATA DATE:
21/07/2015

ADDITIONAL METADATA:
============================================================================
==============
 DATA STORAGE
==============
STORED DATA FORMAT:
ESRI grid
ESRI point shapefile (point cloud)

AVAILABLE FORMAT TYPE:
ESRI grid
ESRI point shapefile (point cloud)

ACCESS CONSTRAINTS:
Dataset is available to all, based on a license agreement.
============================================================================

==============
```

DATA QUALITY

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LINEAGE:

An M9 HydroSurveyor was used to collect raw water depth data for the Lower Vasse River. Water depth was converted to bed elevation in mAHD using the gauged water level at the time of survey. Water level was assumed to be static for the duration of the survey. Raw survey points were combined with the Department of Water 2008 terrestrial LiDAR dataset to interpolate a continuous digital elevation model for the river bed and banks. A discretised spline interpolation method was used to produce the final 1m resolution grid.

Updates:

Date of update (NA)

Note planned.

POSITIONAL ACCURACY:

Horizontal accuracy: the M9 HydroSurveyor operated in both RTK and DGPS mode during the survey. Horizontal accuracy estimated as +- 1.0m.

Vertical accuracy: influenced by horizontal accuracy, water level fluctuations, and point cloud density. There was uncertainty related to the vertical datum of the gauge board used for the bathymetric survey. The approximate datum of the gauge board was estimated to using an RTK GPS system as mAHD +- 0.2m. Including the datum uncertainty and variation in water surface elevation during the survey vertical accuracy is estimated at +- 0.4m in locations covered by the survey point cloud, and +- 0.7m at interpolated locations.

ATTRIBUTE ACCURACY:

NA

LOGICAL CONSISTENCY:

Data capture and interpolation method was consistent across the extent of the dataset.

COMPLETENESS:

Dataset is complete along the linear extent of Toby Inlet within the survey area. Outlet of estuary and upstream near the Caves road bridge was unable to be surveyed due to shallow depth.

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CONTACT INFORMATION

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CUSTODIAN:

-- CONTACT ORGANISATION: Department of Water

-- CONTACT POSITION: Water Science Branch

-- POSTAL ADDRESS: PO Box K822, Perth, Western Australia

-- LOCALITY: Perth

-- STATE: Western Australia

-- COUNTRY: Australia

-- POSTCODE: 6000

-- TELEPHONE: 6364 6587

-- FACSIMILE: na

-- EMAIL ADDRESS: na

SPATIAL CUSTODIAN:

-- CONTACT ORGANISATION: Department of Water

-- CONTACT POSITION: Manager Spatial Services, Water Information Branch

-- POSTAL ADDRESS: PO Box K822, Perth, Western Australia

-- LOCALITY: Perth

-- STATE: Western Australia

-- COUNTRY: Australia

-- POSTCODE: 6000

-- TELEPHONE: 6364 6587

-- FACSIMILE: na

-- EMAIL ADDRESS: na

DATA EXCHANGE CUSTODIAN:

-- CONTACT ORGANISATION: Department of Water

-- CONTACT POSITION: GIS Officer

-- POSTAL ADDRESS: The Atrium Building, 168 St Georges Terrace, Perth

-- LOCALITY: Perth

-- STATE: Western Australia

-- COUNTRY: Australia

-- POSTCODE: 6000

-- TELEPHONE: (08) 6364 7498

-- FACSIMILE: (08) 6364 7601

-- EMAIL ADDRESS: spatial.data@water.wa.gov.au

Appendix B – e-folding time output

Both sandbars open, culvert open

Station Gully closed, Toby Inlet open, culvert open

Toby Inlet closed, Station Gully open, culvert open

Toby Inlet closed, Station Gully open, increased to four culverts open

Toby Inlet closed, Station Gully open, culvert removed

Toby Inlet closed, Station Gully open, culvert open, extra cut

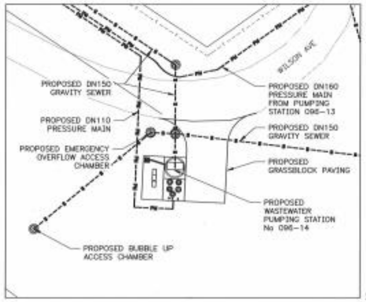
Toby Inlet open, Station Gully open, culvert open, lower section dredged to -0.5 mAHD

Toby Inlet open, Station Gully open, culvert open, sediment removed

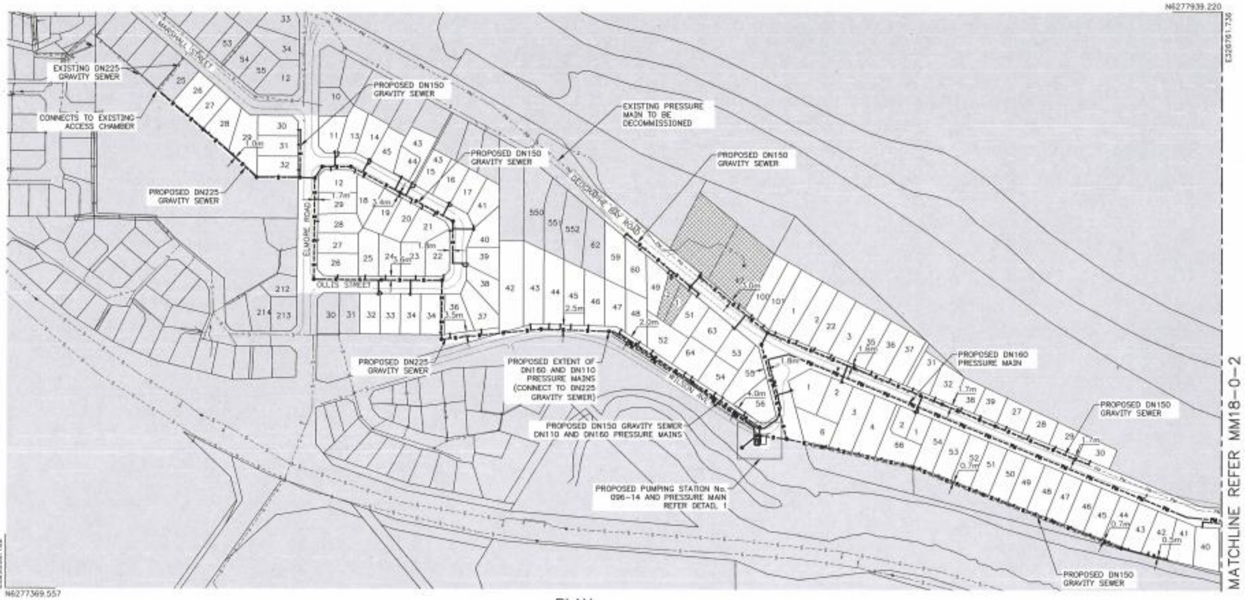
Appendix C – Infill sewerage details

DUNSBOROUGH WASTEWATER

NOTICE OF PROPOSAL TO CONSTRUCT INFILL SEWERAGE AREAS DUNSBOROUGH 5C AND 9A, PUMPING STATIONS AND PRESSURE MAINS - SHEET 1 OF 2



DETAIL 1
SCALE (2)



PLAN
SCALE (1)

To provide for the disposal of wastewater in Dunsborough the Water Corporation proposes to construct:

- Below ground sewers of up to 225mm diameter and associated Access Chambers
- Two wastewater pumping stations
- Below ground 110mm and 160mm diameter sewer pressure mains

The location of proposed works are shown on the plans.

Further information may be obtained by contacting the Project Manager James Gee on (08) 9420 2961.

Objections to the proposed works will be considered if lodged in writing to the Project Manager at Water Corporation, P.O. Box 100, Leederville 6902, before the close of business 21 calendar days from the date on the attached letter.

LEGEND

- PROPOSED GRAVITY SEWER MAIN WITH ACCESS CHAMBER AND LOT CONNECTION
- PROPOSED DN90 PRESSURE MAIN
- LOT NUMBERS — 272
- ALIGNMENT OFFSET FROM PROPERTY BOUNDARY — 4.0m
- EXISTING GRAVITY SEWER MAIN WITH ACCESS CHAMBER
- AREA TO BE SEWERED SHOWN NOT SHADED
- SEWERED BY PRIVATE PUMPING SYSTEM
- NOT SEWERED AS PART OF PROPOSAL

(1) SCALE 1:2000 — 50 40 30 20 10 0 50 100 m
(2) SCALE 1:250 — 5 4 3 2 1 0 5 10 15 m

ISSUE	DATE	CKD	REVISION	DRN	REC	APPD

DESIGN SURVEY	VERTICAL DATUM AHD	DES CALC R. JONES
	COORDINATE SYS MGA94-50	DES CHD G. WILSONACH
ASCON SURVEY	DES REF	DRN G. GRIFFITHS
		Q.C. CHD C. CARNEVALI

NORTH POINT

JACOBS | WorleyParsons resources & energy

RECOMMENDED 24/01/17 — CONSULTANT PROJECT MANAGER
APPROVED 24/1/17 — CONSULTANT PROJECT DIRECTOR

WATER CORPORATION

DUNSBOROUGH WASTEWATER
RETICULATION AREAS 5C AND 9A
PREREQUISITES TO WORKS
NOTICE OF PROPOSAL - GENERAL WORKS - SHEET 1 OF 2

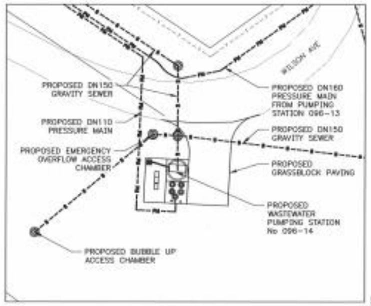
FILE JT1 2016 01487 V01 | PLAN | CAD | ISSUE
PROJECT CS01882 | MM18-0-1 | A | MF

ORIGINAL SHEET SIZE A1

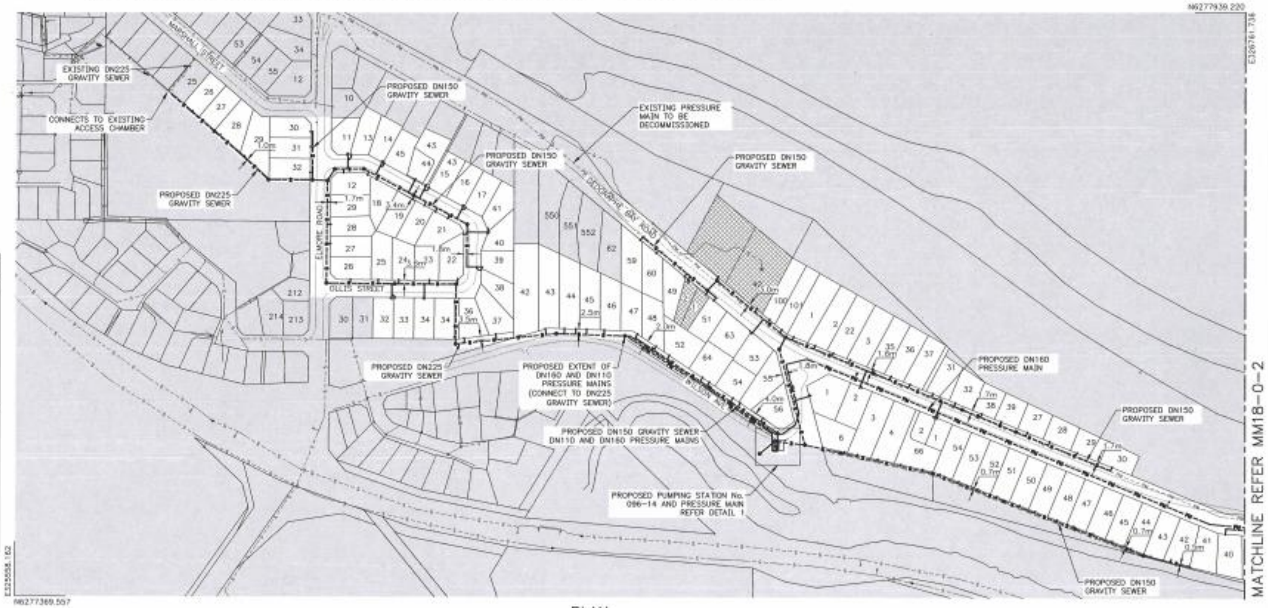
USERS\GGRIFFITHS\APPDATA\LOCAL\PROJECTWISE\WATERCORP_WP_JV_PROJECTS\DMS04748\MM18-000-001 09/01/2017

DUNSBOROUGH WASTEWATER

NOTICE OF PROPOSAL TO CONSTRUCT INFILL SEWERAGE AREAS DUNSBOROUGH 5C AND 9A, PUMPING STATIONS AND PRESSURE MAINS - SHEET 1 OF 2



DETAIL 1
SCALE (2)



PLAN
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LEGEND

PROPOSED GRAVITY SEWER MAIN WITH ACCESS CHAMBER AND LOT CONNECTION	
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LOT NUMBERS	272
ALIGNMENT OFFSET FROM PROPERTY BOUNDARY	4.0m
EXISTING GRAVITY SEWER MAIN WITH ACCESS CHAMBER	
AREA TO BE SEWERED SHOWN NOT SHADED	
SEWERED BY PRIVATE PUMPING SYSTEM	
NOT SEWERED AS PART OF PROPOSAL	

(1) SCALE 1:2000 (2) SCALE 1:250

JACOBS WorleyParsons WATER CORPORATION

RECOMMENDED 24/01/17 CONSULTANT PROJECT MANAGER
APPROVED 24/1/17 CONSULTANT PROJECT DIRECTOR

DUNSBOROUGH WASTEWATER
RETICULATION AREAS 5C AND 9A
PREREQUISITES TO WORKS
NOTICE OF PROPOSAL - GENERAL WORKS - SHEET 1 OF 2

FILE JT1 2016 01487 V01 PROJECT CS01882

MM18-0-1 ISSUE A A1

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Department of Water and Environmental Regulation
168 St Georges Terrace Perth Western Australia 6000
Phone: 08 6364 7000 Fax: 08 6364 7001
National Relay Service 13 36 77
dwer.wa.gov.au

188 50 0418