Coastal Infrastructures Vulnerability Assessment – Trade-Off between Cost-Time Saving and Accuracy

Hamid Mirfenderesk[1] , Elton Chong[1] , Michael Tonks[1] , Mustafizur Rahman[1] , Ryan Van Doorn[1] , Scott Vis[1] , Motiul Kabir[1] , Steve Cornelious [2]
[1] Gold Coast City Council PO Box 6091 QLD 4702
[2] DHI Water & Enivronmnet

ABSTRACT

Sea level rise means higher exposure of some of the major coastal infrastructure to saltwater. This study provides an estimation of such impacts on the stormwater drainage network for ten subcatchments on the Gold Coast, using hydrodynamic modelling. The paper provides the level of uncertainty of the results if, instead of hydrodynamic modelling, a simple bathtub approach was used for this type of assessment. The study also makes a comparison between sea level rise maps that are developed using the two abovementioned approaches, e.g. modelling and bathtub. This study will provide asset managers and planners with some insight into the scale of the problems arising from sea level rise. It also provides a measure of accuracy of sea level rise maps that are developed using the simple bathtub approach.

INTRODUCTION

The draft Queensland State Coastal Plan prescribes a time horizon-based planning, based on the lifecycle of the assets. The plan also prescribes adoption of enhanced hydrological parameters for planning due to climate change. Using such enhanced design parameters has a number of implications on asset management planning. For instance, assumption of sea level rise means higher exposure of some of the major coastal infrastructure, most notably the stormwater drainage network, to saltwater. This would result in faster deterioration of this type of infrastructure, if not mitigated. Gold Coast City Council requires salt water cover pipes to be used in tidal zones (Gold Coast City Land Development Guideline). This requirement is based on existing industry standard (QUDM, 2007) and is shared by other local authorities across Queensland (The Noosa Plan, Capricorn Municipal Development guideline). Mackay Council Engineering Design guideline, mentions Highest Astronomical Tide (HAT) as the criteria for identifying tidal zone in an area.

Effective asset management planning requires a realistic assessment of saltwater impacts. An accurate assessment of climate change impact on coastal infrastructure generally requires complex modelling and could be both time consuming and expensive. Given other uncertainties associated with climate change, it is not clear whether such investment on developing highly sophisticated models is a prudent exercise, or that the modelling exercise should be substituted by simple methods until we have a better understanding of the impacts of climate change. Simplified methods of climate change impact assessment can potentially be used for planning and asset management purposes, provided that we have some understanding of their level of accuracy.

This study assesses additional exposure of stormwater pipe network to saltwater resulting from sea level rise for ten sub-catchments on the Gold Coast. The study compares a simplified (bathtub approach) and a model-based approach of impact assessment on stormwater pipe network to estimate the level of extra accuracy that can be obtained by using a model-based approach. The study also makes a comparison between inundation maps resulting from the two abovementioned methods, providing an insight into the level of accuracy of bathtub approach in sea level rise mapping.

Study Area

The study area is the Gold Coast City Council local authority located in South East Queensland, Australia. Figure 1 provides the location of the city and its catchments. The figure also shows the location of 10 subcatchments that were modelled for estimating the level of additional exposure of their stormwater pipe network to saltwater arising from sea level rise.

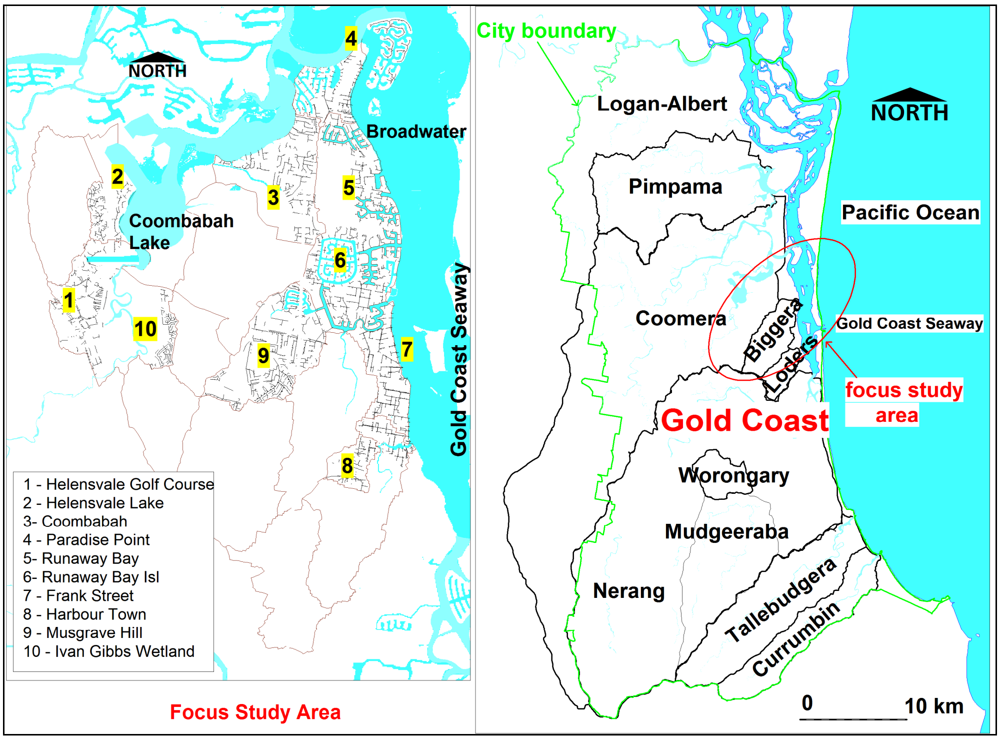


Figure 1 Study area

METHODOLOGY

Bathtub Approach

Bathtub approach is regarded as the most simplified method for sea level rise mapping. In this approach, the dynamic of fluid flow is ignored and inundation modelling is reduced to a simple GIS exercise of mapping all areas below a nominal level as flood-affected areas. This nominal level reflects future sea level due to climate change. In this approach, the Highest Astronomical Tide (HAT) at a standard port in the vicinity of the study area is usually used as the basis for inundation mapping. The impact of sea level rise is estimated by adding the predicted rise, e.g. 80 cm for the 2100 planning horizon, to HAT. Any area within the study area that is below this level is regarded as affected by sea level rise. On this basis, “HAT+sea level rise” is constant across the study area.

Despite its simplified nature, such an exercise may have some merit. It provides a quick and inexpensive method for mapping sea level rise. Once a suitable DTM is prepared, the mapping work can be completed in a few hours for a local authority.

The downside of this approach is the lack of accuracy of the method for a number of reasons, such as:

- Lack of consideration of tide wave dissipation or amplification, as it propagates upstream of estuarine systems,
- Exclusion of hydraulic structures, such as weirs and tide gates that act as barriers against tidal flow; and
- Exclusion of stormwater pipe network, that prohibits tide from flowing through the hydraulically efficient stormwater pipes into areas beyond land barriers that separates coastal zone from lands further away from the coastline.

The first two sources of uncertainties may cause the bathtub approach overestimating the impact of sea level rise; and the third source of uncertainty may cause the bathtub approach underestimating the impact of sea level rise. Planning that is based on bathtub-approach-generated maps can be a source of risk, if an estimate of accuracy of the maps is not calculated and not communicated effectively to users of the data set.

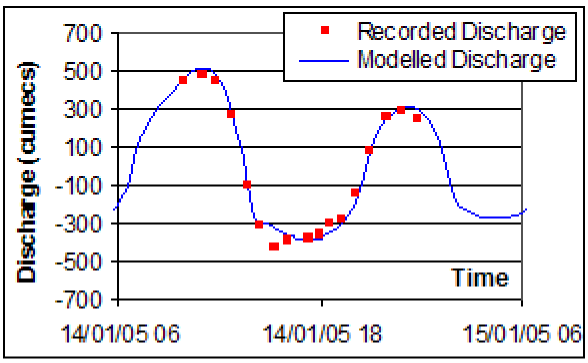
Modelling

This method can address the uncertainties associated with the bathtub approach. In this approach, the tide is simulated using a free surface flow hydrodynamic model of the study area. The impact of sea level rise is estimated by adding the predicted rise to the tide time series at the downstream boundary of the model. Unlike the previous method, in this approach “HAT+sea level rise” is not constant across the study area. Depending on the estuarine characteristics, the tide energy can be amplified or dissipated and accordingly, water level can be increased or reduced (in comparison with the water level at the standard port). Another advantage of this method to bathtub approach is that it provides time series of water level variations at any point of interest. Using this information the length of time and frequency of infrastructure exposure to salt water can be estimated.

This study uses a number of hydrodynamic models that have been developed for the Gold Coast estuarine system over the past few years. To gain an insight into the impact of stormwater pipe network on the results, a coupled pipe-overland-flow model was set up for catchment number 1 in figure 1. DHI MIKE11, MIKEFLOOD and MIKEURBAN were used as software platforms for these models. Some of the catchments such as Tallebudgera, Currumbin and Logan Alrbert, which comprise of a main natural channel, were modelled one-dimensionally using MIKE11. Other catchments, e.g. Nerang, Coomera, Loders and Biggera were modelled two dimensionally, using MIKEFLOOD. The Helensvale Golf Course subcatchment was modelled using MIKEURBAN and included the stormwater pipe network.

Fresh water inflow into the Gold Coast estuarine system is insignificant (compared with tidal discharge) for the most part of the year; and, due to strong mixing processes, the estuaries usually remain well mixed. Random salinity measurement within the study area confirms this and shows that baroclinic contribution to the tidal elevations is negligible, except during heavy rainfalls. On this basis, the models were set up based on a barotropic condition assumption and were driven solely by tide (ignoring freshwater inflow), in a fully dynamic mode. Bottom friction was modelled using Manning’s coefficient. For the purpose of simulating the impact of sea level rise for the planning horizon of 2100, the tide boundary condition of the models were raised 80 cm.

These models were calibrated using a comprehensive data set of water level and current. This dataset was sourced from a number of different previous projects that were commissioned by the Gold Coast City Council during the years between 2004 and 2010 (Mirfenderesk et al, 2005, 2006, 2007, 2010). It included water level measurements for a period between one and six months at 35 stations across the city and current measurements for a period of one full tidal cycle at 14 transects at critical locations across the city. Figure 2 shows a typical calibration result. This figure depicts a comparison between modelled and measured water level and discharge at the mouth of the Coomera River.



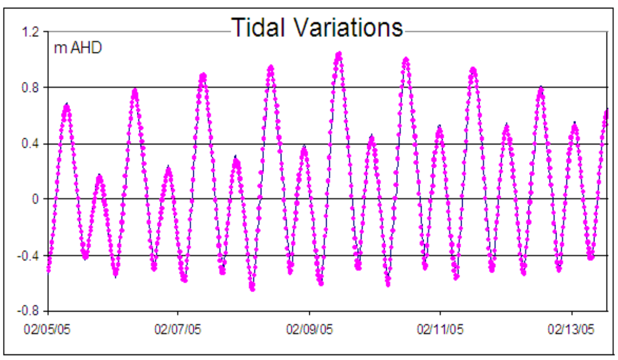


Figure 2 – Calibration results at the Coomera River

Each model was run using the recorded water level variations at the mouth of the Estuary. The first few days of each run was used to establish tidal momentum within the estuary prior to the calibration. Calibration was achieved by adjusting the Manning coefficient ‘n’ for different sections of each model. To this end, the model was run for a number of different values of Mannings ‘n’. The best correlation of the model and the recorded data was obtained using a combination of Manning coefficient between 0.02 and 0.04 for main reaches of the estuaries.

RESULTS

- Table 1 provides the results of the study for the 10 subcatchments shown in Figure 1.
- A comparison between the extent and depth of inundation due to sea level rise, using both modelling and bathtub approaches, was made for the whole city. Figure 2 shows the result of this comparison for the Nerang Catchment.
- Sub-catchment number 1 in figure 1 (Helensvale Golf Course) was modelled in two different ways, free surface flow and nested pipe and free surface flow. The difference between depths of water, obtained from the two abovementioned methods, was approximately 4cm across the catchment.

Table 1 Length of pipelines that are exposed to saltwater

Subcatchment	Total Length (m)	Length of the pipeline that is exposed to saltwater					Difference between bathtub & modelling approach (80cm SLR)
		HAT	HAT + 50cm SLR	HAT+ 80cm SLR	HAT+ 110 cm SLR	Bathtub Approach 195 cm above MSL	
Harbour Town	43200	10220	11420	12060	13170	12470	410
Coombabah	23650	12310	18670	20810	21210	21460	650
Frank Street	27100	20590	22090	22450	22740	22480	30
Helensvale Golf Course	26460	75	1264	2670	3703	3532	862
Helensvale Lake	10370	35	625	1150	1890	1775	625
Ivan Gibbs Wetland	31740	320	1240	1950	3170	2904	954
Musgrave Hill	8870	7420	8160	8870	9880	8870	0
Paradise Point	18550	14600	17080	17550	17944	17680	130
Runaway Bay	17610	15210	17010	17500	17580	17500	0
Runaway Bay Island	19080	12193	15120	16700	17790	17220	520
Total	226600	92973	112679	121710	129077	125891	4181
Additional length that will be subjected to saltwater			19706	28737	36104	32918	4181
Percentage			9%	13%	16%	15%	

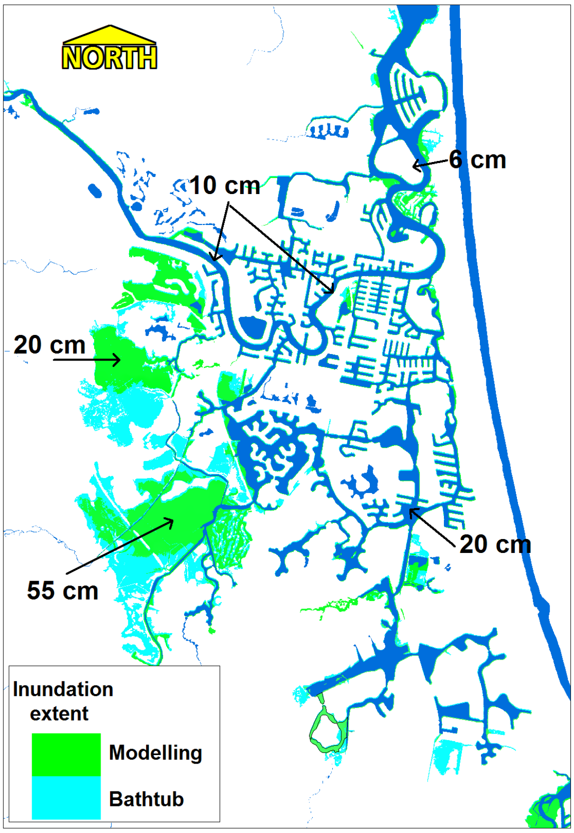


Figure 2 – Difference between maximum water level and extent of inundation, using the bathtub and modelling approaches

DISCUSSION AND CONCLUSION

This study provides an initial estimation of the sea level rise impact on storm water drainage networks in low-lying coastal areas. The results are associated with 10 sub catchments that are located at different distances from the coastline, as shown in Figure 1. The total length of pipeline in these catchments is 261 km. Under the current climate, approximately 93 km of these pipes is within the tidal zone and exposed to saltwater. As shown in table 1, the additional length of pipelines that will be exposed to saltwater, can increase by 9%, 13% and 16% corresponding to 50cm, 80cm and 110cm sea level rise. This corresponds to 20, 29 and 36 kilometres of pipeline that additionally will need saltwater cover. The variation seems to be linear and the magnitude of change in pipe network exposure to saltwater appears to be relatively substantial.

The study shows that the difference between the bathtub and modelling approach in the case of 80 cm sea level rise is about 2% on average, as far as pipe network exposure to saltwater is concerned. The difference varies between 0% at the lower reaches of the estuarine system and 3% at upper reaches of estuarine system. The reason for this difference is that tidal variations at the lower reaches of the estuaries (at the Broadwater) are very similar to that at the Gold Coast Seaway (standard port). Tidal variations at the upper reaches of the estuaries can vary substantially from that at the Gold Coast Seaway, depending on the physical characteristics of the estuary.

The difference between sea level rise maps developed using bathtub and modelling approaches seems to be substantial. Figure 2 shows that this difference is enhanced at the upper reaches of the estuarine system. This could be explained using the same abovementined reasons for pipe network exposure to saltwater.

It appears that there is not a substantial difference between free surface hydrodynamic modelling and couple pipe-free-surface-flow modelling for catchments that are close to receiving waters. This conclusion is based on only one case study; and intuitively seems to be valid only if there is no land barrier against free over land flow. If there is a barrier in place, pipe network will possibly contribute in conveying tide behind the land barriers and exacerbating the impact of sea level rise. This issue needs further investigation by undertaking more case studies.

TAKE HOME MESSAGE

Bathtub approach can be used for sea level rise impact assessment in small catchments that drain stormwater at the lower reaches of the estuarine system. However, it may not be a suitable method in the case of catchments that drain stormwater into the upper reaches of the estuarine system.

ACKNOWLEDGEMENTS

The funding and support for this study is provided by the Gold Coast City Council (GCCC). The authors of the paper would like to thank Ms Gail Mcarthur for editing the manuscript.

REFERENCES

Engineering Design Guidelines Stormwater Drainage Design Planning Scheme Policy No. 15.05 Mackay Council.
http://www.mackay.qld.gov.au/__data/assets/pdf_file/0008/14777/15.05_Stormwater_Drainage_Design_V2.pdf

Gold Coast City Council Land Development Guidelines Policy 11. Section 3, Engineering Infrastructure – Design Requirements.

Linvingstone Shire Council Policy No. D1.23 Guide line for Development Works. Section 5, Stormwater Drainage.
http://www.cmdg.com.au/Links/Livingstone%20Shire%20Council/Development%20Policy%20D1.23/A1.ACOVER.pdf

Queensland Urban Design Manual. Queensland Government, Natural Resources and Water, (2007).

Mirfenderesk, H. ; Tomlinson R ; Hughes. L., (2005), “ Field Data Collection and analysis at the Broadwater, Gold Coast”, 17th Australasian Conference on Coastal and Ocean Engineering, Adelaide, Australia. P477-482.

Mirfenderesk H. and Tomlinson R., (2006) “Tidal Asymmetry in a predominantly Semidiurnal Regime Estuary”, 7th International Conference on Hydro Science, California, USA.

Mirfenderesk, H. and Tomlinson R., (2007) “Impact of Sea Level Rise on Sediment Transport Capacity of Semidiurnal Tidal Regime Estuary”, 18th Australasian Coastal and Ocean Engineering & 11th Australasian Ports and Harbour Conferences. Adelaide, Australia.

Mirfenderesk, H. and Tomlinson R., (2007) “Numerical Modelling of Tidal Dynamic and Water Circulation at the Gold Coast Broadwater, Australia”, Journal of Coastal Research, SI50, p277-281. ISSN 0749.0208.

Mirfenderesk H., Tomlinson R., Hughes. L., (2010), “Analysis of Water Circulation in the Coomera Rive Estuary”, Australian Journal of Water Resources, Vol 14, No. 1, p75-82, ISSN1324-1583

The Noosa Plan - Planning Scheme Policy 5 – Engineering Design Standards – Roads, Drainage and Earthworks.
http://www.sunshinecoast.qld.gov.au/addfiles/documents/noosaplan/policies/psp05_engineering_design_stds_roads.pdf