Great Lakes Costal Hazard Study

Appendix G – Entrance Stability Analysis

For: Great Lakes Council

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PREPARATION, REVIEW AND AUTHORISATION

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1	22/08/2012	M. Glatz	C. Adamantidis	D. Messiter

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SMEC Australia Pty Ltd
PO Box 1346, Newcastle NSW 2300

Tel: **02 4925 9621**

Fax: **02 4925 3888**

Email: **Dan.Messiter@smec.com**

www.smec.com

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1 ENTRANCE STABILITY ANALYSIS

As part of the overall coastal processes assessment for Great Lakes, the long term stability of Wallis Lake Entrance has been studied herein using an Escoffier analysis, to predict future changes to the tidal regime and changes to tidal currents and bank stability within the entrance reaches of Wallis Lake.

The cross-sectional stability of a tidal inlet has been first analysed by Escoffier in 1940. Escoffier's theory analysed the permanency of the stability of the entrance depending on its size and the maximum current speed at the entrance. The relationship between cross-sectional area and maximum velocity is illustrated in Figure G.1. When the maximum velocity is equal to the equilibrium velocity, the cross-sectional area is in equilibrium and the entrance is stable. When the maximum velocity is lower than the equilibrium velocity, the current is not strong enough to move the sediments carried into the inlet by littoral drift and the sediments will be deposited into the entrance reducing the cross-sectional area. When the maximum velocity is higher than the equilibrium velocity, the sediment transport capacity of the inlet currents will be larger than the volume of sediment carried into the inlet entrance by littoral drift and the entrance will therefore erode and the cross-sectional area will increase. From this and Figure G.1, it can be observed that:

- if the cross-sectional area A is lower than A1 (A<A1), the sediments will deposit into the entrance and the entrance will close;

- if A1 < A < Ae, the entrance will erode until A = Ae;

- if A > Ae, the sediments will be deposited into the inlet entrance and the entrance cross-sectional area will reduce until A = Ae;

- if A = A1, the equilibrium is unstable as if there is any storm depositing or removing some sediment from the entrance, the entrance would either close or widen to reach the equilibrium area Ae; and

- if A = Ae, the equilibrium is stable as if a storm deposit or remove some sediments from the entrance it will recover to reach A = Ae.

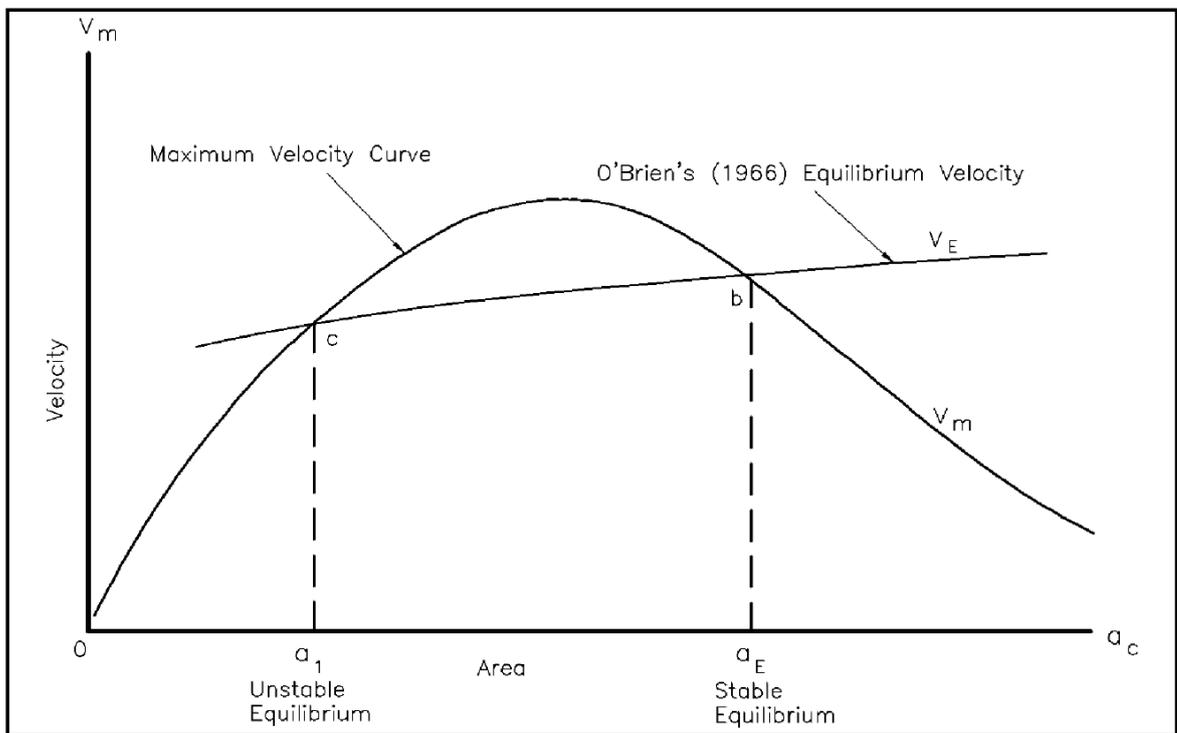The entrance is stable for A > A1.

Figure G.1:   Escoffier (1940) curve, maximum and equilibrium velocities versus inlet cross-sectional area
(C.E.M., Chap. II-6)

However, the equilibrium cross-sectional area may be subject to long term changes. O'Briens (1966) determined a relationship between cross-sectional area and tidal prism. Assuming a maximum velocity $u_i = \hat{u}_i \sin(wt)$ with w the angular frequency of the tide and t the time, it follows:

$$\Omega_i = \frac{A_i \hat{u}_i T}{\pi}$$

with Ω_i =   Tidal Prism of the estuary

A_i =   Cross-sectional area of the inlet entrance

T =   Tidal period

This formula is usually presented as:

$$A = C\Omega^n$$

with C and n free parameters. These parameters can be obtained by analysing the correlation between the tidal prism and the cross-sectional area of several estuaries located within the same region. This correlation has been undertaken along Australia's East Coast by BMT WBM (2008) as shown on the graph in Figure G.2.
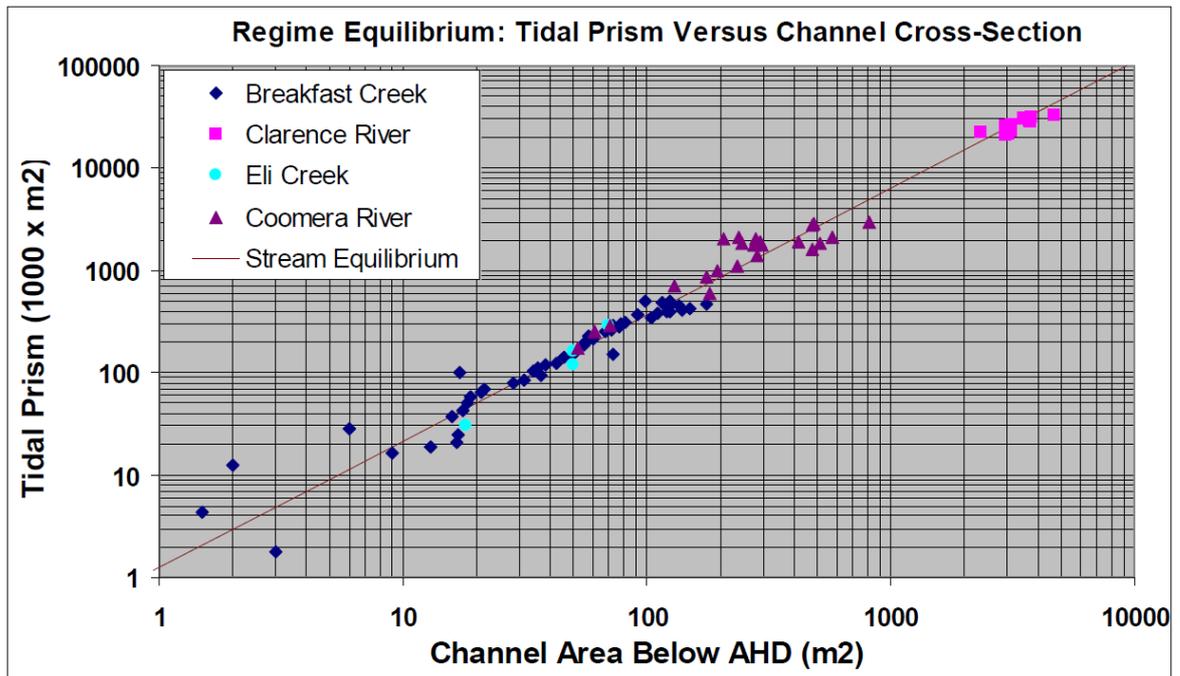
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Figure G.2: *Regime equilibrium relationship for tidal estuaries along Australia's East Coast (BMT WBM, 2008)*

From this graph, the relationship derived was identified as:

$$A = 3.1 \times 10^{-3} \Omega^{0.81}$$

This cross-sectional area–tidal prism relationship was used for Wallis Lake at Forster.

The stability of Wallis Lake entrance was studied at Forster. The analysis of the entrance stability was undertaken using the Channel Equilibrium Area (CEA) model created by the Coastal Inlets Research Program (CIRP) from the U.S. Army Corps of Engineering. This model allows the determination of the Escoffier curve and therefore the estimation the entrance channel equilibrium area based on the channel and entrance characteristics, the tidal prism and the tidal parameters. The parameters used in the calculation are as follow:

- Fundamental Ocean Tide Amplitude: this value is one half of the tide range and the spring tide or M2 tidal constituent amplitude is typically used (i.e. around 0.65m for Wallis Lake)

- Ocean Overtide Amplitude: M4 tidal constituent amplitude (estimated to be 0.0447)

- Tidal Period (i.e. 12.42 hrs for semidiurnal tides)

- Tidal Mean Basin Surface Area: surface of the lake and estuary (estimated to be around 83,800,000m^2)

- Hydraulic Radius: average depth of the channel (i.e. 5.2 m at the entrance)

- Channel Width: Width of the minimum cross sectional area (i.e. around 100 m at Wallis Lake)

- Channel Length (i.e. around 500m at Wallis Lake)

- Channel Area (i.e. around 520m^2 for Wallis Lake)

- Entrance Loss Coefficient K$_{en}$: value from 0.05 for a relatively streamlined inlet, to 0.25, for an inlet with dual jetties (i.e. 0.25 here)

- Exit Loss Coefficient K_{ex}: a value of 1.0 for the exit loss coefficient describes a relatively deep bay and complete loss of kinetic head. Smaller values may be tried during calibration (a value of 1.0 was assumed in the calculation)

- Manning's Coefficient (*n* value): This bed resistance parameter may have typical values between 0.025 and 0.050 for inlets (a value of 0.04 was used in the calculation)

Results of the calibration are provided in Figure G.3. These results were compared with existing water level data from the Office of Environment and Heritage (OEH) measured on 28 March 1998. The tidal measurements are provided in Figure G.4. Comparison of Figures C.12 and C.13 shows that the tidal amplitude and phase are matching the measurement. The ocean tide is validated. However, the measured water level for the lake is higher than the modelled water level. This may be explained by the fact that the model only takes into account the tide level while the measured water level is subject to freshwater inflows from the estuary and barometric setup as well as tidal setup due to friction through the entrance channel that would increase the level. From the Bureau of Meteorology (BoM) website, some rainfall were observed around the dates of the tidal measurement with 7 mm, 15.6 mm and 0.4 mm on March 26th, 27th and 28th 1998 respectively (http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_display_type=dailyDataFile&p_stn_num=060013&p_startYear=1998&statType=Rainfall+of+....&p_nccObsCode=136).

The Escoffier Curve resulting from the model is illustrated in Figure G.5. From this figure, it is observed that the existing current velocities are larger than the equilibrium velocities. Therefore, the entrance will tend to increase its cross-sectional area to reach the area A_2. Thus, continuing future scour of the bottom of the entrance can be expected until the cross sectional area reaches a new stable equilibrium. Associated with this scour will be an increase in tidal range within the lake (thus increasing potential for inundation of the lake foreshore as well as changes to foreshore ecology) and potential for erosion of foreshores inside the estuary. Increasing tidal ranges have already been observed in Wallis Lake, which are consistent with the predictions of the stability analysis presented here (Nielsen and Gordon, 2007).
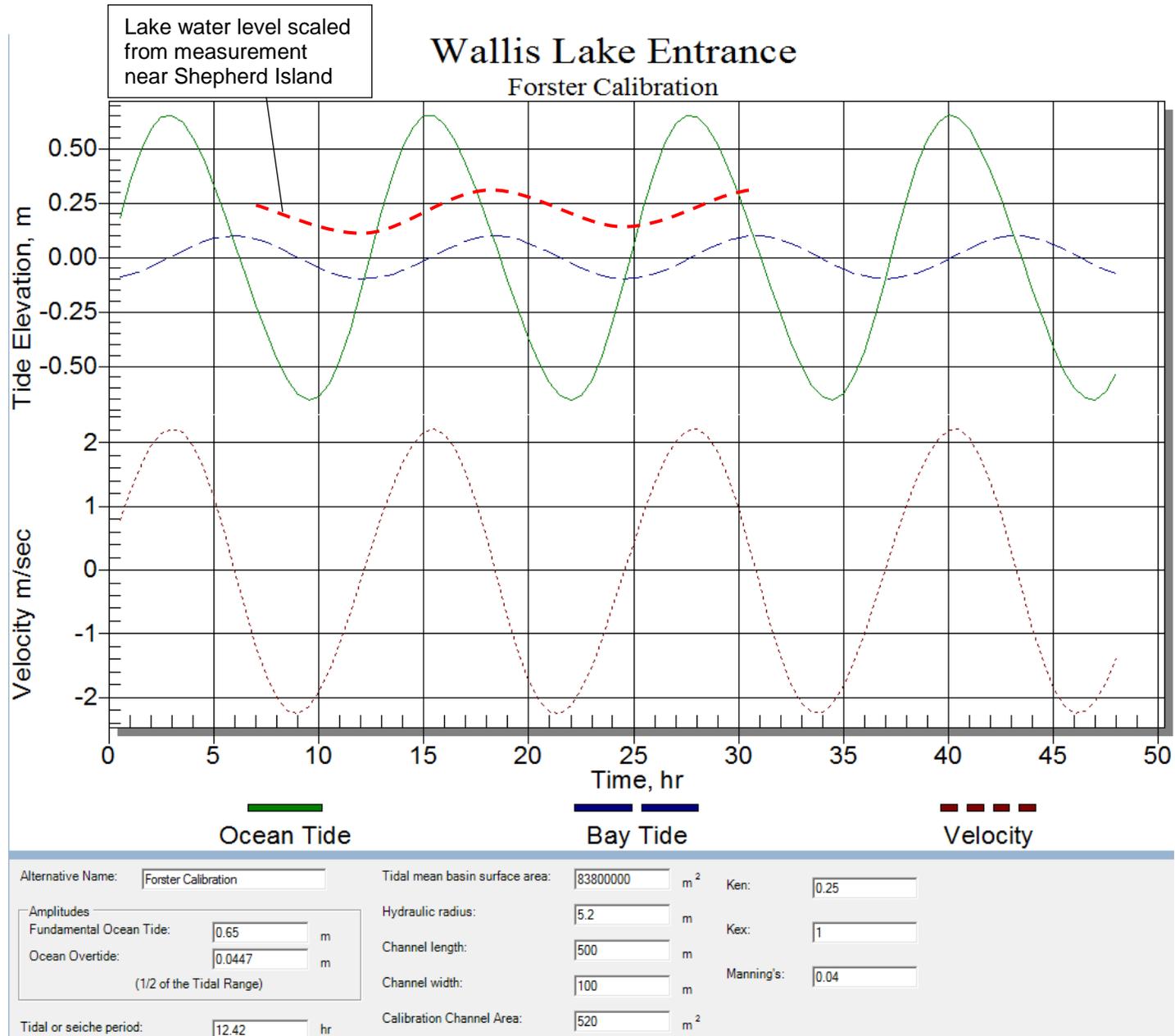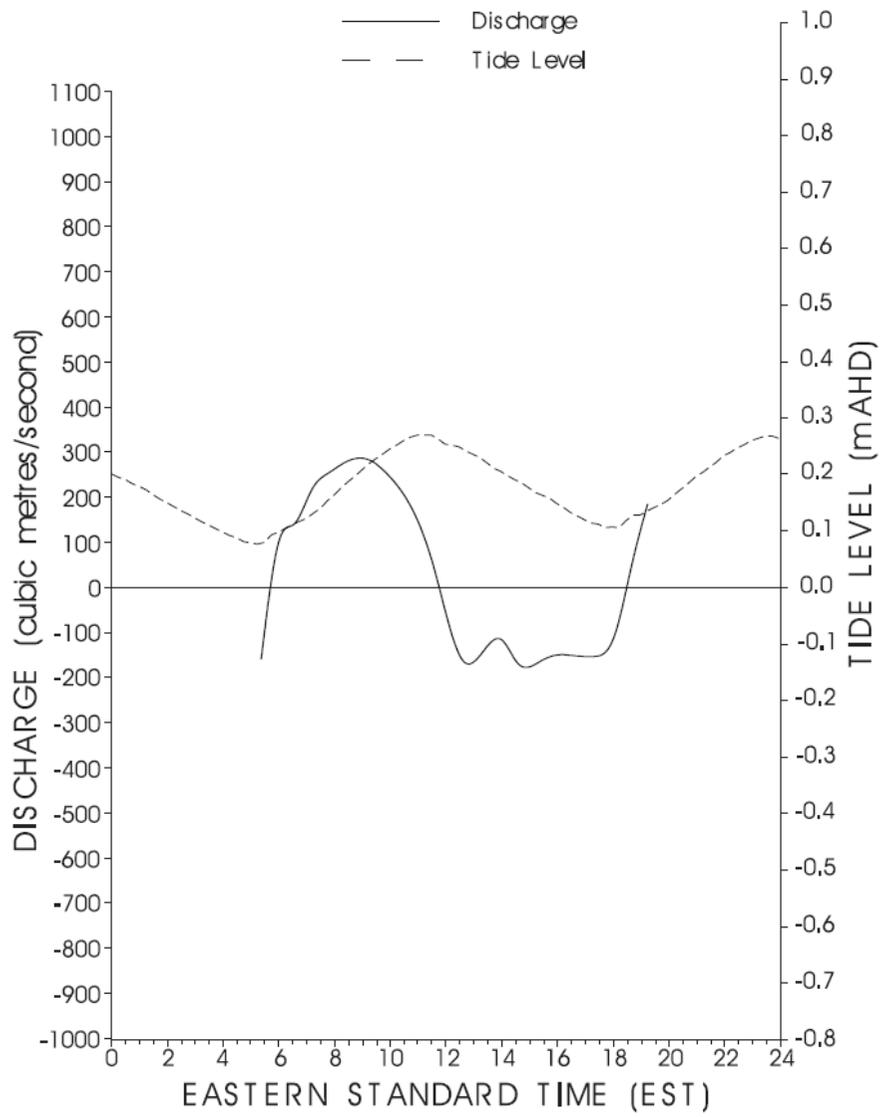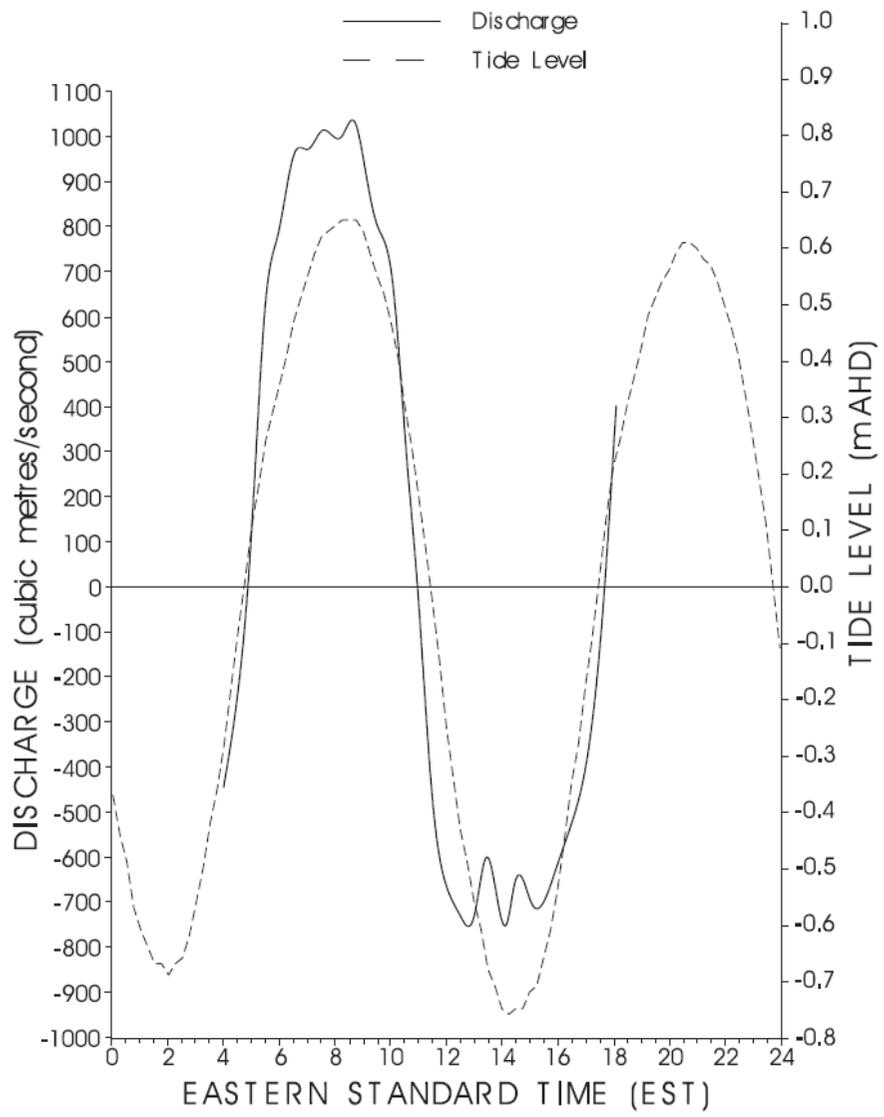
Figure G.3:   Calibration of CEA model

Figure G.4: Water level at Wallis Lake measured on 28 March 1998
Left – Ocean Water Level at Wallis Lake Entrance (http://www.dnr.nsw.gov.au/estuaries/inventory/data/tidal/pdfs/tidaldata-21a.pdf)
Right – Lake Water Level near Shepherd Island (http://www.dnr.nsw.gov.au/estuaries/inventory/data/tidal/pdfs/tidaldata-21b.pdf)
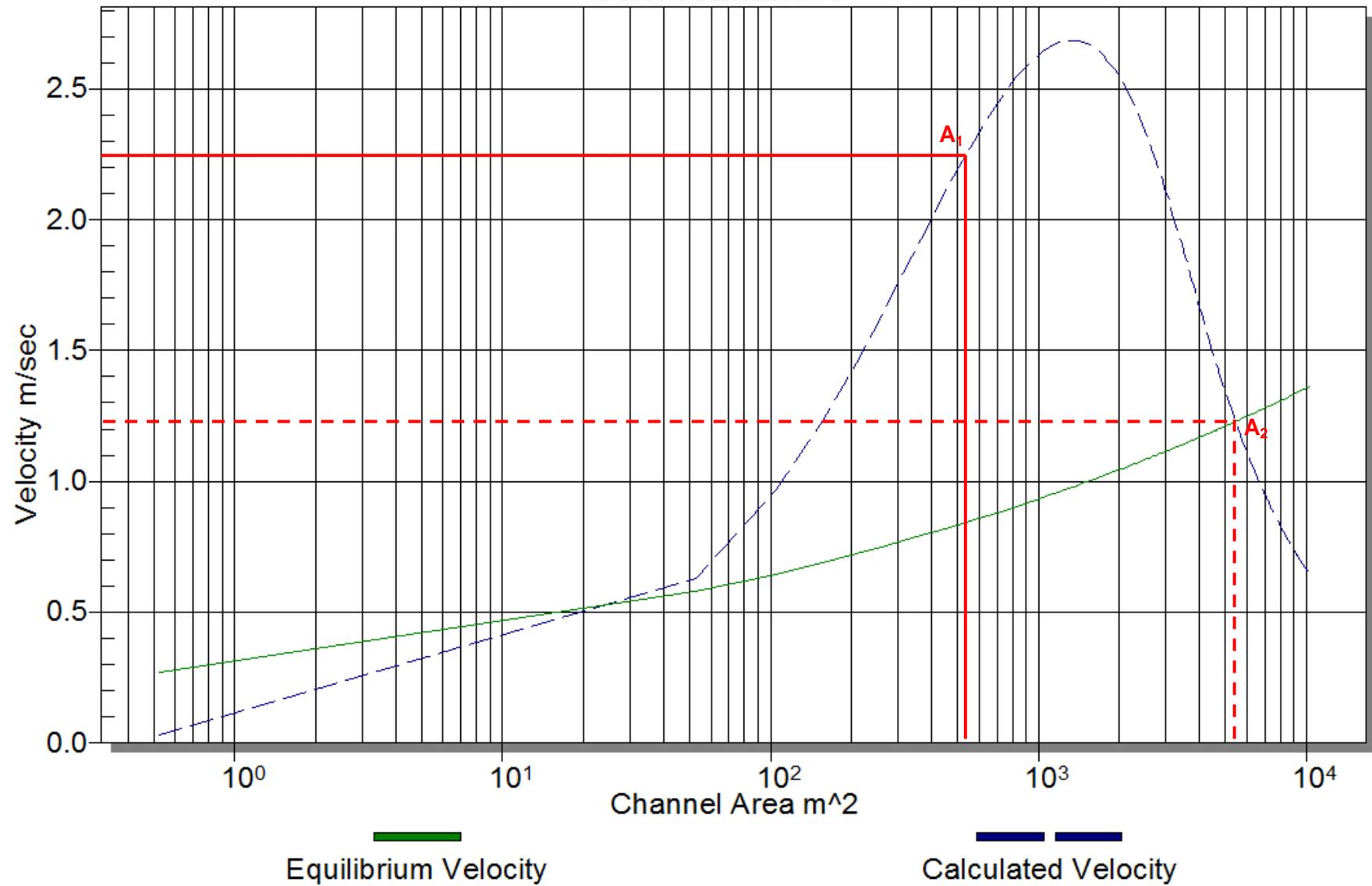
Figure G.5: *Escoffier Curve from CEA model (the solid red line and A_1 represent the existing conditions while the dashed red line and A_2 represent the equilibrium conditions)*

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