UniQuest

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Clayton Utz

Subject

Provision of expert advice in relation to a report provided by WMAwater

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Author's Declaration

This report has been prepared in accordance with UniQuest's Quality Management System, which is compliant with AS/NZS ISO 9000:2000.

The work and opinions expressed in this report are those of the Author.

Signed by Emeritus Professor Colin Apelt

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Gary Heyden – General Manager
UniQuest Signatory

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1. INTRODUCTION

Clayton Utz, advising Brisbane City Council with reference to the Queensland Floods Commission of Enquiry (The Commission), asked UniQuest Pty Ltd to engage Professor Apelt to provide expert advice in relation to a report prepared by WMAwater for The Commission with the title, „*BRISBANE RIVER 2011 FLOOD EVENT – FLOOD FREQUENCY ANALYSIS FINAL REPORT SEPTEMBER 2011'* .

As part of this advice, Clayton Utz requested that Professor Apelt prepare a list of the enquiries and investigations that, in his view, ought to be completed prior to any determination of the Q100 flood line following the January 2011 event.

This report consists of three main parts:

- The material of the first part, Section 2, provides the response by Professor Apelt to the request for a list of the enquiries and investigations that, in his view, ought to be completed prior to any determination of the Q100 flood line following the January 2011 event.
- The second part, Section 3, provides a summary of the methodology used in the WMAwater report for arriving at the estimate of 1% AEP flood flow and levels together with discussion of this methodology.
- In the third part, Section 4, some particular parts of the WMAwater report are discussed in more detail.

2. REVIEW RESPONSE - PART 1; DETERMINATION OF THE Q100 FLOOD LINE

The following material has been prepared in response to the request by Clayton Utz for Professor Apelt to prepare a list of the enquiries and investigations that, in his view, ought to be completed prior to any determination of the Q100 flood line following the January 2011 event. This work has been carried out in a limited time frame and without the opportunity for discussion with colleagues. Consequently, it is not guaranteed to be a final or complete list and it must not be taken as the detailed specification of work to be done.

2.1 Data required

All the data from the January 2011 flood event for the whole of the Brisbane River system catchment must be gathered, checked and assessed for accuracy: – rainfall; all flood levels, not just peak levels; all flood flows, not just peak flows; Moreton Bay tidal data; catchment conditions prior to the event. This will require all sources to share freely the data they have so that an archive can be created of all data including information about accuracy and plausible bounds. This archive must be accessible to all, without restriction.

An accurate digital terrain model must be generated for all areas likely to be flooded in extreme flood events. This will require

(i) Topographic survey of areas above dry weather water level

(ii) Bathymetric (stream bed and banks below water level) survey for the whole of the Brisbane River from the “mouth”, including the parts of Moreton Bay that can influence river heights during extreme flood events, up to Wivenhoe Dam and for the major tributaries.

Sediment characteristics must be measured for the same extent of the system for which the bathymetric survey data is required.

2.2 Analyses required - Generation of the best possible homogeneous data set for Flood Frequency Analysis (FFA) for pre-dams conditions

The generation of the best possible homogeneous data set for Flood Frequency Analysis (FFA) for pre-dams conditions requires the assessment of:

(i) how changes to the Brisbane River, especially those downstream from the Port Office Gauge, have affected flood levels;

(ii) the peak flow of each flood.

- A much more detailed analysis will be required than those that have been done to date.
- It will be necessary to develop appropriate hydrodynamic models of the Brisbane River to simulate the conditions that existed at the times of historic floods and to use them in conjunction with appropriate hydrologic models to produce estimates of flood flows consistent with the recorded / reported rainfalls and flood levels for each event.
- The models should then be used to produce estimates of the flood levels for the River system in its present state but excluding the Wivenhoe and Somerset Dams.
- Because the data available is limited in detail and accuracy it will be necessary to generate „best estimates' and „plausible bounds' for each historic flood event.
- The estimates of flood flows produced by this process can then be used for FFA.
- The FFA should be done with the „best estimates' and repeated using the two sets of „plausible upper bounds' and „plausible lower bounds'.
- The estimates of flood levels for the River system in its present state should be used to produce or extend rating curves for key locations.
- The rating curves should show the curve corresponding to the „best estimate' and also the „plausible upper bound' and „plausible lower bound'.

2.3 Analyses required - Generation of estimates for post-dams conditions

The effects of morphological (river bed level and cross section) changes due to sediment erosion and deposition during flood events must be studied for a range of flood magnitudes to determine what effects they can have on flood levels.

The model for simulating the expected operation and effects of Wivenhoe and Somerset Dams on flood flows, and associated data, should be independently peer reviewed.

The design hydrology must be determined for a range of Annual Exceedance Probabilities (AEPs), not just for 1% AEP. A Monte Carlo or similar type analysis will be required.

This analysis must take into account the observed variability:
(i) in temporal and spatial patterns of rainfall and the associated variability in relative timings of inflows from the dams and downstream tributaries;
(ii) in the correlations between event occurrences;
(iii) in losses; and
(iv) in reservoir drawdown.

An appropriate hydrodynamic model must be used to estimate the flood levels along the Brisbane River for the flood events that have been determined for the range of AEPs. When this is being done the effects of tidal variation on flood levels in the estuarine zone must be taken into account. This will require a Monte Carlo type analysis to examine the joint probabilities of flow rates and sea levels in Moreton Bay caused by tidal action and storm surge.

2.4 Comment

Section 2.3 calls for analysis of a range of AEPs, not just of the1% AEP. It is acknowledged that the full set is not required for „determination of the Q100 flood line'.

Nevertheless it is essential for a complete Flood Risk Management analysis for the area of Brisbane and for the whole of the Brisbane River system affected by flooding from the Brisbane River and its tributaries to be carried out.

It is essential to move from the "Q100 mentality" and to adopt a risk management approach in line with National Flood Risk Advisory Group (NFRAG) and other relevant guidelines. The risk management approach will require a detailed assessment of the benefits and costs of a full range of flood mitigation options for the full range of Annual Exceedance Probability flood events.

It will be most efficient for the full set of analyses to be done at the same time, rather than in a „piecemeal' approach.

3. REVIEW RESPONSE - PART 2; METHODOLOGY USED IN WMAwater REPORT FOR ARRIVING AT THE ESTIMATE OF 1% AEP FLOOD FLOW AND LEVELS

This part of the report provides a summary of the methodology used in the WMAwater report *„BRISBANE RIVER 2011 FLOOD EVENT – FLOOD FREQUENCY ANALYSIS FINAL REPORT SEPTEMBER 2011'* for arriving at the estimate of 1% AEP flood flow and levels together with discussion of this methodology.

Comments by Professor Apelt on some aspects of the report are presented below. Where References are cited the number of the Reference is that used in the WMAwater report named above. Unless stated otherwise, Figure numbers, etc are those from that report. Wherever anything in what follows is attributed to "the author", this refers to Professor Apelt.

3.1 Summary of methodology used in report for arriving at the estimate of 1% AEP flood flow and levels

- A rating curve is developed at the Port Office/City Gauge (see Note a).
- A Flood Frequency Analysis is done for the Port Office/City Gauge for the No Dams case to give an estimate of 13000m^3/s for the 1% AEP flood at the Port Office/City Gauge for the No Dams case (see Note b).
- A plot of peak flows at the Port Office/City Gauge versus peak flows for the No Dams case is constructed, Figure 3 (see Note c).
- The „relationship' in this plot is used directly to derive the estimate of the 1% AEP flood at the Port Office/City Gauge, 9500 m^3/s, as a ratio of the 1% AEP flood at the Port Office/City Gauge for the No Dams case (see Note d).
- A flood profile is calculated, starting from a level of 4.32 m AHD at Port Office/City Gauge to produce a profile of 1% AEP flood levels. The profile is produced after adjusting the MIKE 11 model results to match the observed data when it was used to reproduce the 2011 data (see Note e).

3.2 Notes and comments on the methodology for arriving at the estimate of 1% AEP flood and levels

a. This involves estimates of what the levels of historic floods would have been in the river in its present state, allowing for effects from lowering of the bar and of dredging along the river.
   i. The effect of bar lowering is estimated at 0.4 m and this is applied to ***all*** floods.

ii. The effect of river dredging is estimated at 1.52 m and this is applied to ***all*** floods.
iii. For cases where both „corrections are to be applied they are simply added for ***all*** floods.

Briefing material provided to the Independent Review Panel (by BCC officers from City Design) during its work in 2003 included the assessment of evidence on effects of the dredging of the river; "This suggests that small floods reduced by 1.52 m but little effect on large floods". It is noted here that the description „river dredging' does not encompass all of the changes – river training and reclamation of some tidal flats were involved also.

These estimates are taken directly from Reference 17 except for differences in two cases (detailed below in section 4.1). They are gross approximations. Further, their magnitudes are open to question; the briefing of the Review Panel included the advice that Bureau of Meteorology (BoM) provided a chart relating Moggill Alert to Brisbane City Alert "to show that the adjustment of pre-dredging levels should only be by 0.6 m rather than 1.8 m assumed in the December 1999 review" with the comment "This raises the estimate of the 1893 flood and all nineteenth century floods above those assumed in December 1999." The author quotes this comment, not to endorse the inferences about the magnitude of the nineteenth century floods, but solely to emphasise the point that, to his knowledge, there has never been a clear consensus about these matters.

The Independent Review Panel was briefed in 2003 on the uncertainties associated with any attempt to establish a rating curve for the Port Office site. It was obvious that it would not be possible to investigate this matter with sufficient thoroughness to establish a best estimate of a rating curve and its error bounds for the Port Office in the time available - approximately five weeks. In fact, there was insufficient time even to assess whether a rating curve **could** be developed that would be sufficiently reliable for the purpose of flood frequency analysis (FFA). In these circumstances, the Panel accepted the decision by Sinclair Knight Merz (SKM) to use the combined record from the gauges at Savages Crossing, Lowood and Vernor, referred to as "Savages Crossing" as the key site for FFA (Reference 20, para 4.2).

In further discussion of this matter in Section 4.1 the author's comments on paragraphs 148 and 149 of the WMAwater report warn that substantial margins of uncertainty about the rating curve at the Port Office may persist even after the extensive investigations have been completed, such that it may remain insufficiently reliable for use as the key site for FFA.

There have been several attempts to produce a rating curve for the Port Office/City Gauge for the No Dams case. There is no real consensus. As just one example, in an email to Ken Morris of Brisbane City Council dated 12 August 2003, Peter Baddiley of BoM provided a rating curve that is linear.

The writer acknowledges that persons involved in discussions about these matters in 2003 may have „moved on' from the views they held then. Nevertheless, the fact remains that most of the material used to produce the rating curve at the Port Office used in the WMAwater report (Figure 8), continues to have substantial uncertainties.

b. The results of the FFA are not greatly different from those from previous studies.
   i. The SKM study of 2003 estimated Q100 pre-dams at the Port Office/City Gauge to be in the range from 11000 to 13000 m^3/s and adopted 12000 m^3/s.
   ii. WMA gives results in Table 10 produced with GEV and LP3. As the number of larger floods omitted from the FFA increases, the results from GEV give progressively smaller estimates for Q100 (as would seem reasonable) whereas three of the estimates of Q100 from LP3 are virtually the same and the one for the case when five of the largest seven floods are omitted is the largest of all at 16610 m^3/s. This is counter-intuitive. This suggests that the GEV estimates should be preferred, not averaged with LP3 estimates. If the estimate for Q100 is based on GEV alone it becomes 12130 m^3/s.
   iii. The similarity in the estimates of Q100 produced by all of these FFAs gives little ground for comfort because they all suffer from the fact that most of the data are estimates of flows of uncertain accuracy, especially in the cases of most of the large floods.

c. It is not clear how Figure 3 was created. The plotted points are somewhat scattered. The data point identified as „SKM 2011' presumably was produced with the faulty Version 1 of MIKE11 since the only references for 2011 listed for SKM are No 35 (24 June 2011) and No 36 (11 March 2011), whereas the review that led to the production of the improved Version 2 of MIKE11 was carried out between 27 June and 5 July 2011 as described in the WMAwater report *'Review of Hydraulic Modelling Final Report 28 July 2011'*.

   The author is not convinced by the approach adopted to produce the data points in Figures 2 and 3 for the January 2011 flood event. In paragraph 64 of the report it is stated that "the 2011 event has a peak inflow of 11000 m^3/s (WMA) and 11150 m^3/s (Seqwater) and a peak discharge of 7500 m^3/s (giving a reduction of 32-35%).” This completely overlooks the complexity of the event in that there were two peak inflows approximately 29 hours apart.

- The first peak inflow was **10095** m^3/s at 08:00 on 10 January.
  At that time the outflow was 1944 m^3/s; it increased slowly to 2087 m^3/s at 15:00; then more rapidly to 2695 m^3/s at 20:00; then slowly to 2753 m^3/s at 08:00 on 11 January; it then increased rapidly to 7464 m^3/s as the second peak inflow arrived.
- The minimum inflow between the peaks was 3594 m^3/s at 02:00 on 11 January
  At that time the outflow was **2721** m^3/s, the dam level was 73.35 m AHD and the storage was 1,977,862 ML or 169.8% of FSV. The storage at FSL of 67.00 m AHD is 1,165,000 ML.
- From all of this one could argue that the attenuation of the first peak was 73.1%, corresponding to the peak outflow being 26.9% of peak inflow i.e. **2721/10095.** Even if one uses the initial objective of limiting outflow to 4000 m^3/s the attenuation would have been 60%, corresponding to the peak outflow being 40% of peak inflow.
- The second peak inflow was **11561** m^3/s at 13:00 on 11 January. The peak outflow rose to **7464** m^3/s by 19:00 on the 11th. This gives an attenuation of 35.4%, corresponding to peak outflow being 64.6% of peak inflow. (WMA has 32-35%). But the dam was at 170% of FSV at the start of this second peak inflow.
  The author does not consider that it is appropriate to use this figure of approximately 35% in isolation, ignoring the complexity of the event, as somehow representative of the attenuating effects of the dam. It is particularly of concern that no account appears to have been taken of the fact that a large proportion of the flood storage compartment was already used up when the second inflow peak began to arrive.

  Note: the figures used in the above discussion are taken from the Seqwater Report (Reference 26).

d. The 1% AEP peak flow at the Port Office/City Gauge is estimated by using directly the result calculated by SKM 2011 (see comment above in Note c). This gives for the Port Office/City Gauge a post-dams peak flow of 9500 m^3/s versus a pre-dams peak of 13000 m^3/s. So 9500 m^3/s is adopted for the 1% AEP peak flow at the Port Office/City Gauge. The author has severe reservations about this „conclusion’. The WMAwater report justifies this choice in paragraph 132 with “Using Figure 3 without applying any weight to the 2011 event a value of 9000 m^3/s is obtained as the post dam (Wivenhoe and Somerset dams) flow. The 2011 data provides the only real data point on the performance of the dam and suggests a post dam flow of 10000 m^3/s using WMAwater's estimate and 9500 m^3/s using SKM's estimate. On the basis of these three datasets a post dam flow of 9500 m^3/s was adopted."

If, for example one were to adopt 12130 m^3/s as the pre-dams 1% AEP peak flow at the Port Office/City Gauge and use the "estimation line" in Figure 3, the estimate of the post-dams 1% AEP peak flow becomes approximately 8300 m^3/s.

But, the author has a fundamental difficulty with the application of one specific result for a particular event (that may or may not be „typical') to convert a value obtained by statistical analysis to give another value and to treat that derived value as having statistical significance. There seems to some problem in the logic of that process. Further, it ignores the fact that the event from which the conversion multiplier is taken was unusual in that the inflow to Wivenhoe was double peaked. This is discussed further below. It also makes no allowance for the different combinations of flows from Wivenhoe and from the tributaries downstream from the dam.

The author considers that it is not appropriate to use one specific flood event as the basis for the estimate of the attenuation achieved by the dams that is to be incorporated in the estimate of the 1% AEP post-dams peak flow. The 1% AEP post-dams peak flow is a statistical, design concept and all the variable elements that contribute to its estimation, including the attenuation of the flood peak by the dams, must be estimated by statistical processes. In brief outline, these processes should include hydrological modelling of the whole Brisbane River catchment for a number of synthetically generated 1% AEP design storm events for the pre-dams case to produce inflow hydrographs at the site of Wivenhoe Dam, in addition to the pre-dam flood hydrographs at the Port Office. The inflow hydrographs at the dam site should be run through a dam operations simulation model to generate outflow hydrographs from Wivenhoe Dam for the post-dams case. These outflow hydrographs then provide the post-dams input from Wivenhoe Dam to the hydrological model of the Brisbane River catchment downstream from the dam to produce post-dams flood hydrographs at the Port Office. The end result of this modelling will be a set of estimates of pairs of 1% AEP design flood peaks for pre-dams and post-dams conditions at several locations along the Brisbane River, including at the Port Office. The best estimate of the pre-dams and post-dams 1% AEP design flood peaks will be determined from this set of „pairs'. (It is stressed that this brief outline must not be taken as a complete specification of the work required to produce the 1% AEP design flood estimate; it is given as an indicative outline only.)

e. It is not clear how the level of 4.32 m AHD was arrived at. No detail is given on how the MIKE 11 model results were "adjusted". The resulting profile in Figure 13 looks less plausible than the „non-conforming' one produced by MIKE 11 without adjustment (see Figure 12). The profile in Figure 13 has been made to conform to figures for peak flood levels given in the Joint Flood Taskforce Report (Reference 27). However, it was stated clearly in that report that the levels were "subject to final verification". When the JFTF report was being produced, the author and another member of the Taskforce shared concerns they had about the accuracy of the flood levels given in Reference 27 for the stretch of the river from the West End Ferry to Seventeen Mile Rocks, because they seemed inconsistent with the rest of the flood profile. At the time, this was the only information available to the Taskforce and it was not feasible to have it checked during the three weeks between the first meeting of the Taskforce and the deadline for completion of the Report (8th March 2011). Floodwise Property Reports for the locations of these flood levels, downloaded in September 2011 from the BCC website, indicate that the current best estimates of many of these levels are lower than those given in Reference 27.

4. REVIEW RESPONSE - PART 3; EXTRACTS FROM WMAwater REPORT WITH COMMENTS ADDED

The numbering of paragraphs in the following is that used in the cited report. The text of each numbered paragraph is that in the Report. The Comments added are by Professor Apelt, referred to as "the author".

4.1 Matters of substance

91 Depending on the size of a particular event, rating curves can be sensitive to overbank conditions and topography. Often a change in slope is seen in the rating curve as flow enters the overbank. Future work utilising 2D hydrodynamic modelling to develop rating curves specific to a point in time needs to ensure that overbank topography is representative of the time of the event in question.

Comment This comment suggests that the writer of the WMAwater report believes that more investigation is needed to produce the best possible estimate of the rating curve at the Port Office.

92 If a 2D model is developed it should use high resolution survey data (LiDAR) for current conditions. To model earlier events it would be necessary to draw upon a range of data sets including aerial photography, ortho-photo maps, 1873 and 1974 survey details.

Comment As for paragraph 91.

99 The recorded stage for the 1893 flood event was 8.35 m AHD, however it is necessary to adjust this height for current conditions. Reference 17 adjusted all the recorded stages from 1864 to 1917 by 1.52m (5 feet) except for the 1893 event and assumed the discharge of this event was 14 600 m^3/s. *Table 10.2 of Reference 17* presents 5 estimates of flow ranging from 11 300 to 16 990 m^3/s for the 1893 event. Two of these estimates are based on velocity measurements taken during the event at Indooroopilly and Victoria Bridges (16 990 m^3/s and 14 600 m^3/s respectively). Reference 3 (Part 3, Section 2) details problems associated with reverse flow on the inside bend making measuring flow at Indooroopilly Bridge difficult during the 1930's and 1950's. Reference 18 modelled the 1893 event using cross sections from 1873 and estimated the peak flow at 11 600 m^3/s. (Italics added)

Comment There is no Table 10.2 in Reference 17, or in Reference 18.

119 For floods prior to 1917 the 1.52m dredging adjustment was used and for those prior to 1864 the 0.4m bar adjustment was also used. This is the same approach as used in Reference 17 other than the dredging adjustment has been applied to all events (including 1841 and 1893). For smaller events the flow adjustment used in Reference 17 was also used. For larger events the high flow rating derived as part of the current study was used (refer to Section 6.3.2).

Comment The blanket reductions applied to all flows are gross approximations. It will be necessary to develop appropriate hydrodynamic models of the Brisbane River to simulate the conditions that existed at the times of historic floods and to use them in conjunction with appropriate hydrologic models to produce estimates of flood flows consistent with the recorded/ reported rainfalls and flood levels for each event. The models should then be used to produce estimates of the flood levels for the River system in its present state but excluding the Wivenhoe and Somerset Dams. Because the data available is limited in detail and accuracy it will be necessary to generate „best estimates' and „plausible bounds' for each historic flood event. The estimates of flood flows produced by this process can then be used for FFA.

120 Adjustments were made to the 1974 event to account for Somerset dam and to the 2011 event to account for both dams. Every attempt was made to make adjustments in a consistent and non contradictory manner. The adopted high flow estimates are presented in Table 7 below. It is noteworthy that the 1841, the second 1893 event and the 2011 event are essentially the same size.

Table 7: Homogeneous Data Set of Flood Levels for the Brisbane River

Event	**Recorded Level (i.e. As measured during the event) (mAHD)**	**Adjusted Level (mAHD)***	***Adjusted Level (mAHD) <u>Ref 17</u>***	**Pre Dam Current Conditions Height (mAHD)**	**Pre Dam Current Conditions Flow (m3/s)**	**Pre Dam Current Conditions *Flow (m3/s) <u>Ref 17</u>***
1893(a)	8.35(1)	6.83(1)	***8.35(1)***	6.83	13700	***14600***
1893(b)	8.09	6.57		6.57	12600	
1841	8.43(2)	6.51(2)	***8.03(2)***	6.51	12500	***14100***
2011	4.27	4.27		6.40	12400	
1974	5.45	5.45	***5.45***	5.50	11300	***10364***
1844	7.03	5.11	***5.11***	5.11	10400	***8924***
1890	5.33	3.81	***3.81***	3.81	8100	***6972***
1898	5.02	3.50	***3.45***	3.50	7500	***8500***

* Includes 1.52 m prior to 1917 and an additional 0.4 m adjustment for prior to 1864

<u>**Comment**</u> The two columns with entries in ***bold italics*** have been added to the Table 7 from the WMAwater Report by the author to include the corresponding data from Reference 17 for comparison. The differences between levels for 1893(a) and 1841 are explained in notes (1) and (2) below. Insufficient discussion is provided in the Report to support preference for the flow rates adopted over those from Reference 17.

Note (1) No adjustment was applied in Reference 17. The lower level adopted in the WMAwater Report results from a lowering by 1.52 m to account for dredging.

Note (2) Reference 17 lowered the level by 0.4 m to account for bar excavation but no adjustment was made for dredging. The further lowering is to account for dredging.

The differences between the entries in the original Table 7 of the WMAwater report and those in the extra two columns added by the author provide detailed illustration of the uncertainties associated with the rating curve at the Port Office, that has been discussed above in Section 3.2, Note a.

127 Results from the 4 flood frequency analyses undertaken at the Port Office gauge are shown in Table 10 (for both GEV and LP3 distributions).

Table 10: Comparison of Q100 Estimates for Considered Approaches

Data set/ Case	*Comments*	Q100 (m^3/s)		
		GEV	LP3	*Mean*
1841-2011[a]	***Includes all large floods***	12 130	13 730	***12 930***
1841-2010[a]	***Omits one large flood (3rd)***	11 740	13 900	***12 820***
1908-2011[b]	***Omits five of seven largest floods***	10 740	16 610	***13675***
1908-2010[b]	***Omits six of seven largest floods***	9 510	13 900	***11705***

[a] 141 censored flows lower than 2,000 m^3/s

[b] 90 censored flows lower than 2,000 m^3/s

Comment The two columns with entries in ***bold italics*** have been added by the author to the Table 10 from the Report.

128 Conducting the flood frequency analysis without the 2011 event changes the average of the GEV and LP3 estimates by only 95 m^3/s.

Comment The GEV estimate is reduced as more and more of the larger floods are omitted (as would seem reasonable). However, the LP3 gives the largest estimate for the case when five of the seven larger floods are omitted. This is counter-intuitive and it casts doubt on the LP3 estimates. This suggests that the GEV estimates should be preferred, and not averaged with LP3 estimates. If the estimate for Q100 is based on GEV alone it becomes 12130 m^3/s. However, the relatively small differences between estimates for Q100 are not really important here because the estimates of the individual flood flows have such uncertain accuracy, especially in the case of most of the larger floods. The similarity in the estimates of Q100 produced by all of these FFAs gives little ground for comfort because they all are based on data of such uncertain accuracy.

141 The Mike 11 Model (Version 2) developed by SKM for Seqwater as described in Reference 38 (and Version 1 described in Reference 35) was calibrated by SKM to Moggill, Jindalee and the Port Office. It was intended to use this model to fit a flood surface between Moggill and the Port Office for a peak post dam design flow of 9500 m^3/s. *When this model was compared to observed flood height data in the 2011 Joint Taskforce report (Reference 27, Table 3) problems were found with the fit (Figure 12)*. While the model fitted well at Moggill, Jindalee and the Port Office the fit was slightly low between Moggill and Jindalee and up to 1.8m low between Jindalee and the Port Office. This problem demonstrates the need for organisations to consider all agencies data when calibrating models. The Mike 11 model was therefore unsuitable to be used in profile generation. (Italics added)

Comment A note at Table 3 of Reference 27 states explicitly that the Jan 2011 levels given are "subject to final verification". The resulting profile in Figure 13 looks less plausible than the „non-conforming' one produced by MIKE 11 without adjustment (see Figure 12). The profile in Figure 13 has been made to conform to figures for peak flood levels given in the Joint Flood Taskforce Report (Ref 27). Floodwise Property Reports for the locations of these flood levels, downloaded in September 2011 from the BCC website, indicate that the current best estimates of many of these levels are lower than those given in Reference 27.

142 As part of the prescribed work scope The Commission required profile information on peak flood levels between Moggill and the Brisbane River mouth for the 2011 event and 1% AEP. January 2011 levels at each location were estimated *by adjusting the Mike 11 model results to match the observed data from 2011 Joint Taskforce (Reference 27).* From this, approximate flood levels at the points of interest identified by The Commission were determined. The same process was adopted for the 1% AEP flood levels using a peak post dam flow of 9500 m^3/s. These profiles are presented on Figure 13 and summarised in Table 13. (Italics added)

Comment No information is given about the nature of these adjustments.

148 A detailed study needs to be undertaken *to improve the rating relationship at the Port Office gauge.* This study needs to draw upon all the information held by Council and State Government. The rating information held by different organisations also needs to be consolidated and objectively reviewed. (Italics added)

149 The study needs to contain the following components:

- Development of a suitable industry standard 2D hydrodynamic model of the lower reaches of the Brisbane River. This model needs to be suitable for assessing historical changes to the river bathymetry and needs to have a run time that is practical for detailed calibration and assessment of changes,
- A detailed search of all data sources on the bathymetry of Brisbane River needs to be undertaken. This study needs to produce best estimate maps of the bathymetry at different times during Brisbane's development. A current survey of the bathymetry also

needs to be undertaken and the current morphological behaviour of the river needs to be understood,

- Astronomical tide need to be calculated for the flood events that occurred prior to the regular recording of tides,
- Where sufficient tidal and meteorological information is available the storm surge component at the river mouth needs to be estimated for each historical event,
- The methodology that has been developed under Research Project 18 of Australian Rainfall and Runoff for the calculation of the joint probability of river flooding and elevated ocean levels, should be applied to the lower reaches of Brisbane River so that flood risk can be properly quantified, and
- The sensitivity of flood levels to elevated ocean levels from climate change needs to determined.

Following the completion of the above tasks a revised flood frequency analysis should be carried out using the current best practice. This analysis should explore the use of a regional flood frequency approach.

Comment The statements and recommendations in paragraphs 148 and 149 are agreed with fully. Further, these paragraphs constitute implicit acknowledgement that the estimate of Q100 in the report is not a final figure to be adopted.

The author considers that extensive investigations of the kind discussed above and elsewhere throughout this report will be essential to improve the estimates of the magnitudes of the peak flows of historic floods to reduce the uncertainty of the results produced by flood frequency analysis.

The author would recommend against the use of any of the several extant versions of the rating curve at the Port Office. It needs to be recognised, however, that substantial margins of uncertainty about the rating curve at the Port Office may persist even after the extensive investigations have been completed. If that should turn out to be the case, the author would support use of "Savages Crossing" as the key site for flood frequency analysis.

4.2 Lesser matters of interpretation etc

63 "Figure 2 compares peak inflow and outflow for Wivenhoe dam from a number of sources for occasions when the dam is full. Also plotted on the graph is the 1:1 line (*or 50% reduction in flow by the dam as recommended by the 2003 Review Panel (Reference 20)*).While there is considerable scatter amongst the data points the graph shows below an inflow of 6000 - 8000 m3/s the attenuation is quite high while around 12000 m^3/s the attenuation is quite low. It is not unexpected that there would be some scatter as two floods could have a similar peak inflow and very different volumes and hydrograph shapes. There is however a reasonable correlation of volume and peak flow. For peak outflows up to 4000 m^3/s (max discharge allowed at Moggill under W3) the discharge is very dependent on the flow occurring in the Lockyer and Bremer Systems." (Italics added)

65 Figure 3 to 5 depict pre and post dam flow at Port Office, Moggill and Savages Crossing. The 50% reduction line*, as adopted by the 2003 Review Panel* is also shown. (Italics added)

<u>Comment</u> The 2003 Review Panel made no *recommendation* for a 50% reduction, nor did it adopt it. It noted that for the period 1890 to 2000 the DNRM model simulation of dam operations had indicated that it should be possible to operate the dams to reduce peak flood flow rates by about 60% on average and that it indicated a January 1974 flood attenuation of nearly 50%. (Reference 20, p15). The panel did not have access to the DNRM model and it recommended that it should be peer reviewed. (Reference 20, p23).

The work done in 2003 by SKM as consultants to BCC included hydrological modelling of the Brisbane River catchment for a number of synthetically generated design storm events (in this case 1% AEP design CRC FORGE rainfall events). In addition, hydrologic modelling was done using typical "real" event" spatial rainfall distributions with 1% AEP design CRC FORGE rainfall. The modelling of the pre-dams case produced inflow hydrographs at the site of Wivenhoe Dam in addition to the pre-dam flood hydrographs at the Port Office. The inflow hydrographs at the dam site were run through the DNRM dam operations model to generate outflow hydrographs from Wivenhoe Dam for the post-dams case. These outflow hydrographs provided the post-dams input from Wivenhoe Dam to the hydrological model of the Brisbane River catchment downstream from the dam that produced the post-dams flood hydrographs at the Port Office. The end result of this modelling was a substantial set of estimates of pairs of pre-dams and post-dams flood peaks at several locations along the Brisbane River, including at the Port Office. All had been calculated as 1% AEP design flood events. The Review Panel exercised its judgement to determine from this set of estimates the best estimate for the 1% AEP design flood flow at the Port Office. The fact that this turned out to be approximately 50% of the pre-dams flood flow is a consequence of the fact that most of the estimates of pairs of pre-dams and post-dams flood peaks were related approximately in this way. This ratio was applies only to the 1% AEP flood events considered in the SKM study. It was an **outcome** of the study, not an input to it. It cannot be applied to substantially different flood events.

Whatever ratio may be appropriate as the estimate of the attenuation for the 1% AEP design flood peak inflow to Wivenhoe Dam, it is fundamentally incorrect to use that ratio as applying to all magnitudes of inflow peaks, as is implied by the straight line plotted in Figure 2 of the WMAwater report. In fact, the magnitude of the **inflow volume** is of much greater significance than is the peak inflow rate. For floods with an inflow volume less than the flood storage compartment available, 100% attenuation can be achieved if so desired, regardless of the magnitude of the peak inflow rate. As the flood inflow volume becomes larger than the flood storage compartment available, the amount of attenuation of the peak flow that can be achieved will reduce but it will also depend on the dam operation strategy. For very rare flood events that are very much larger than that for which the dam was designed, the amount of attenuation will be very much reduced, though there will always be some attenuation because of storage volume resulting from rising flood levels upstream from the dam.

80 It would appear that this level was still not adopted as a planning level and SKM were commissioned by Council to prepare two further reports which were issued on 8th and 28th August 2003 to an Independent Review Panel (Reference 20)...... It is noted that the 2003 Review Panel terms of reference includes the following statement "*Even if the Q100 changes from 6800 m^3/s, it is likely that the Development Control Level will remain the same as is currently used in the Brisbane City Plan.*"

<u>Comment</u> The 2003 Review Panel was not influenced in any way by the quoted statement.

82 SKM re-calibrated the 1998 Mike 11 hydraulic model to determine 1% AEP (100 year ARI) flood levels in a report from February 2004 (Reference 22). Although the December 2003 report had later found Q100 to be 6500 m^3/s, the 2003 Review Panel recommended Q100 flow of 6000 m^3/s at the Port Office gauge be used to giving a Q100 flood level at the Brisbane Port Office of 3.16 m AHD.

Comment The meaning of this paragraph is unclear. The Review Panel report (Reference 20) was issued in September 2003. Further, the Q100 level in that report is 3.3 m AHD, not 3.16 m AHD. The Review Panel saw a draft version of an SKM report with the same title as the December 2003 report (Reference 21). That draft was dated 28 August 2003 and it proposed the best estimates for the Q100 flow and levels at the Port Office as 6500 and 3.51 m AHD, respectively. The Review Panel cited this draft report in the List of References in Section 6 of its report (Reference 20). The contents of the draft SKM report were taken into account by the Review Panel when it formulated its considered judgements concerning the best estimates of the Q100 flow and level at the Port Office, aware that they differed from those proposed in the draft report. This is described in Section 4.8 of Reference 20.

5. CONCLUSION

Many of the matters discussed in this report are quite complex. The appropriate way to clarify many of the issues raised would be in thorough discussion and review with colleagues. Because of the very short time frame available, it has been necessary for the author to formulate the material presented in this report without any opportunity for discussion with colleagues or for lengthy review. With the benefit of sufficient time for such discussion and review of the issues in depth, the author's views on some matters may evolve somewhat.

EMERITUS PROFESSOR COLIN J. APELT

Colin Apelt is Emeritus Professor and Honorary Research Consultant in the Department of Civil Engineering at The University of Queensland. He was appointed Professor of Civil Engineering in 1979 and served as Head of Department from 1982 to 1994. After retirement from full time academic staff in 1996, he was appointed Professorial Research Fellow until the end of 1999.

His research fields are in:
Computational Hydraulics applied to floods and tidal flows, to sediment transport and water quality in estuaries and marinas, to waves, and to transients in pipelines;
Experimental Fluid Mechanics applied to efficient passage of flood flows through waterways; to turbulence and energy losses in natural streams and engineered waterways; to flows past bluff bodies with relevance for flood and debris loads on bridges and for wind engineering; and to wave forces on berthing structures;
Computational Fluid Mechanics applied to flows in open channels and to bluff body flows;
He has substantial interests in all aspects of dredging and arranged four specialist courses on dredging in Brisbane since 1987.

He has acted as specialist consultant on hydraulic design of many major projects involving spillways, energy dissipators, bridges, culverts and flood mitigation works; and on computer modelling of flood and tidal flows in design and/or flood plain planning studies associated with many river and estuary systems in Queensland and New South Wales.

Since 1995 he has acted as specialist consultant in several major flood plain planning studies for the Brisbane River system and the Nerang River System. Those include;

- Member of Independent Review Board established to review the response of Brisbane City Council to the January 2011 flood event.
- Chair, Joint Flood Taskforce established to investigate the January 2011 flood event and to recommend interim standards and development guidelines to manage redevelopment of flood affected areas and new development activity within the Brisbane River floodplain for BCC. (2011)
- Review of Hydrodynamic Modelling for Tamar River & North Esk River Flood Study for Launceston City Council. (2008)
- Chair, Lord Mayor's Taskforce on Suburban Flooding, for BCC. (2005)
- Review of Brisbane River Flood Study for BCC as member of Independent Review Panel (R. Mein, C.J.Apelt, J Macintosh, E Weinmann) (2003)
- Review of Floodplain Hydraulic Modelling Methodology for Gold Coast City Council (with R Tomlinson). (2001)
- Review of Safety Analysis of Wivenhoe, Somerset and North Pine Dams (with Eric Lesleighter (SMEC)). (1992-1995)

The details of these and of other recent consultancies are given below.

Academic Qualifications
1952 BE(HonsI) in Civil Engineering, The University of Queensland.
1957 DPhil (Oxon), Fluid Dynamics and Numerical Analysis, Oxford University.

Professional Affiliations
Fellow of The Institution of Engineers Australia
Chartered Professional Engineer (retd)

Prizes and Awards

1952	University of Queensland Medal.
1954	Rhodes Scholar for Queensland.
1965	R.W.Chapman Medal of The IEAust.
1966	Fulbright Fellow, Senior Research Fellow Category.
1969	National Science Foundation Senior Foreign Scientist Fellowship Award.
1985	The Hawken Address, Queensland Division of The IEAust.
2001	Second Henderson Orator.
2011	Inducted into Engineers Australia National Committee on Water Engineering Hall of Fame.

Professional Experience

1951(Dec)-1954(Jul)	Design Engineer, Queensland Irrigation Commission.
1957(Jun)-1958(Nov)	Postdoctoral Research Fellow in Engineering Science, Oxford Univ.
1958(Dec)-1964(Dec)	Senior Lecturer in Civil Engineering, University of Queensland.
1965(Jan)-1979(Sep)	Reader in Civil Engineering, University of Queensland.
1966(Feb)-1966(Sep)	Research Associate, Maths Department, MIT.
1969(Feb)-1970(Jan)	Visiting Professor, Dept of Civil Engineering, Colorado State Univ. and Visiting Scientist, Nat. Centre for Atmos. Res.,Boulder, Colorado.
1977(Jan)-1977(Dec)	Visiting Professor, Civil Engineering, Univ. Canterbury, Christchurch.
1979(Sep)-1996(Jul)	Professor of Civil Engineering, University of Queensland.
1982(Jan)-1994(Apr)	Head of Department of Civil Engineering, Univ. of Queensland.
1996(Jul)-1999(Oct)	Emeritus Professor and Professorial Research Fellow, Dept of Civil Engineering, Univ. of Queensland.
1999(Oct)-Present	Emeritus Professor and Honorary Research Consultant, Dept of Civil Engineering, University of Queensland.

Competitive Research Grants

1972-1981	ARGC	$68,300
1981-1987	MST/AMSTAC	$143,200
1985-1990	ARC	$106,200
1985-1988	ARRB	$20,000
1993-1995	NCHRP(USA)	$60,300
1995	MARINAS	$53,400
1997-1998	CRC-TOURISM	$29,000
1998-1999	CRC-TOURISM	$110,000
1999- 2000	CRC-TOURISM	$120,000

Supervision of Postgraduate Research

PhD: 16 completed; MEngSc: 17 completed.

Publications Summary

2 Books; 91 refereed papers; 24 Commissioned Technical Reports; 2 Technical Movies; 1 Technical Video; 33 unrefereed papers and research reports.

Consultancies since 1990 (Current Consultancies not listed for reasons of Privacy)

Tweed River Entrance Sand Bypassing; Re-Assessment of Long Term Average Sand Transport Rate for Tweed River Sand Bypassing. C.J.Apelt as Independent Expert, UniQuest Project No 16066 for BMT WBM Pty Ltd Brisbane, 08/01/09 - 11/03/10.

Flagging of flood hazard areas, *Review of Methodology to Flag Flood Affected Areas in City Plan* 19/12/08 (4 pp) by C.J.Apelt and *Review of Final Methodology to Flag Flood Affected Areas in City Plan* 07/08/09 (5 pp) by C.J.Apelt, UniQuest Project Nos 15790 and 15790.02 for Brisbane City Council, 11/12/08 - 07/08/09.

Review of Hydrodynamic Modelling for Tamar River & North Esk River Flood Study 10/07/08 (47 pp) C.J.Apelt, UniQuest Project 15489 for Launceston City Council, 03/06/08 - 09/07/08.

NORTH BANK Task Force (Chair), *North Bank Flooding and Tidal Impacts Prepared by North Bank Task Force for Brisbane City Council 2 June 2008* (18 pp), UniQuest Project 15467 for Brisbane City Council, 23/04/08 - 02/06/08.

North South Bypass Tunnel Review of MPB memorandum Tite/Jordan of 19 December 2007 16/04/08 (11 pp), UniQuest Project 15304 for Brisbane City Council, 11/03/08 - 15/04/08.

North South Bypass Tunnel *Review of Estimates of Q100 flood levels in Breakfast Creek for pre-NSBT and post-NSBT conditions* 01/11/07 (43 pp), Peer Review by C.J.Apelt, UniQuest Project 15073 for Brisbane City Council, 27/09/07 - 01/11/07.

Peer Review Report: The Lord Mayor's Taskforce on Suburban Flooding 17/01/07 (47 pp), Peer Review of Progress in implementation of recommendations of the LMTF by C.J.Apelt, UniQuest Project 14442.02 for Brisbane City Council, 23/11/06 - 15/01/07.

Independent peer review of Hydrodynamic Modelling for Notional Seaway Project Draft EIS 01/08/06 (8 pp), Peer Review of Hydrodynamic Modelling GC Seaway by C.J.Apelt, UniQuest Project 14453 for GHD, 04/07/06 - 26/07/06.

Appraisal of extra heavy duty drainage grate with performance guidelines linked to AS3996 1992 04/07/06 (19 pp), Appraisal of Heavy Duty Drainage Grates by C.J.Apelt, UniQuest Project 114225 for Gatic Milne, 08/03/06 - 04/07/06.

Lord Mayor's Taskforce on Suburban Flooding (Chair), S*trategies to reduce the effect of significant rain events on areas of Brisbane prone to flooding* August 2005 (61 pp) UniQuest Project for Brisbane City Council, Feb/05 - Sep/05.

Assessment of the relative merits of the Max Q Stormwater Inlet design for use by the Brisbane City Council. Oct/04 (34 pp) C.J.Apelt, UniQuest Project 13384 for Brisbane City Council, Aug /04 – Oct/04.

Expert Peer Review for Gold Coast City Council of planning and design work by the Griffith Centre for Coastal Management (GCCM) in connection with Palm Beach Protection Strategy and the Palm Beach Artificial Reef 20/07/04 (80 pp) C.J.Apelt, UniQuest Project 13158, 19/02/04 – 25/08/04.

Review of Brisbane River Flood Study 03/09/03 (27 pp) R. Mein, C.J.Apelt, J Macintosh, E Weinmann, Independent Review Panel to Brisbane City Council, July/03 – Sep/03.

M.R.Marshall v Department of Transport. Review of Physical Model Studies of Eudlo Creek at Bruce Highway Crossing Taking Account of Matters Raised in Max Winders & Associates Report, 8 July 2002 09/01/03 (46 pp) C.J.Apelt, UniQuest Project 12459 for Crown Law (Qld) Department of Justice

& Attorney-General, 18/05/02 – 16/12/02.

A Review of Floodplain Hydraulic Modelling Methodology Aug/01 (37pp) C.J.Apelt and R Tomlinson, prepared for Gold Coast City Council, UniQuest Project 11855 for Griffith University Centre for Coastal Management (GCCM), Oct/00 – Oct/01.

Namibia Tender – Bucket Wheel Design Review 09/05/01 (2 pp), Review of Design of Bucket Wheel for Dredge for extracting Diamonds Namibia by C.J.Apelt for Neumann Equipment Pty Ltd Currumbin, 27/04/01 - 09/05/01.

Cadia Hill Gold Mine NSW Pit Diversion Channel Library Search on Expansions in Open Channels 14/03/01 (8 pp), Library Search on Expansions in Open Channels for Cadia Hill Gold Mine Pit Diversion Channel by C.J.Apelt for Gilbert and Associates Pty Ltd Brisbane, 09/02/01 – 14/03/01.

Barcoo Outlet Project Review of Hydraulic Aspects 21/08/00 (7 pp) C.J.Apelt, Review of Hydraulic Design of Barcoo Outlet Piped System with Venturi for Connell Wagner Pty Ltd Brisbane, 11/08/00 - 21/08/00.

Cadia Hill Gold Mine NSW Cadia Hill Pit Diversion Channel Review of Hydraulics Aspects 09/06/00 (5 pp), Review of Hydraulics Cadia Hill Gold Mine Pit Diversion Channel by C.J.Apelt for Gilbert and Associates Pty Ltd Brisbane, 01/06/00 - 09/06/00.

Technical Review for Queensland Department of Primary Industries of Dredging and Spoil Disposal Report on Dredging of South Channel of Burrum River 29/01/00 (10 pp), Technical Review of Report prepared by Cardno and Davies for Hervey Bay City Council by C.J.Apelt
for Queensland Department of Primary Industries, 03/12/99 - 29/01/00.

Bridge over Cattle Creek at Gargett Hydraulic and Sedimentation Issues 1997 (42 pp) C.J.Apelt for Main Roads Dept, Mackay District.

Review with Eric Lesleighter (SMEC) of Safety Analysis of Wivenhoe, Somerset and North Pine Dams presented in six Interim Reports on review of 'Consultancy Work by Queensland Water Resources Commission "Brisbane River and Pine River Flood Studies"'
UniQuest Project 320407 for South East Queensland Water Board, 01/12/92 - 08/03/95.

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Lennox Bridge for Upper Parramatta River Catchment Trust, 02/07/91 - 20/08/91.

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Report on Proposed Townsville Commonwealth Offices: Assessment of Ground Level Wind Environment – Contract No. CNC 924 04/09/89 (4 pp), C.J.Apelt, UniQuest Project 3032461 for Australian Construction Services, 23/08/89 - 04/09/89.

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05/05/89 (12 pp) C.W. Letchford, L.T. Isaacs, C.J. Apelt, Assessment of environmental wind conditions at Riverside Centre Stage I, Brisbane (Desk Study), UniQuest Project 3032004 for Civil and Civic Pty Ltd, 14/03/89 - 05/05/89.

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C. J. Apelt as Review Consultant to Macdonald Wagner Pty Ltd for creation and calibration of mathematical flood model of Barron River for Cairns Port Authority, 10/08/87 - 10/06/88.

Review of processes in Great Sandy Strait contributing to the dynamics of beach zone
Fraser Island – Great Sandy Strait Appraisal of Beach and Near Shore Processes in Vicinity of North White Cliffs 15/03/89 (4pp) C.J.Apelt and M. R. Gourlay for Philip G Breene & Associates, 15/12/87 - 15/03/88.

Review of EIS Flooding and Drainage Report Settlement Shores Final Stage EIS Flooding and Drainage Report – Your Ref. 931/9 23/04/86 (6 pp) C.J.Apelt for Cardno & Davies Australia Pty Ltd, 07/12/85 - 29/04/86.

Supervision of Postgraduate Research

PhD: 16 completed; MEngSc: 17 completed.

Publications Summary

2 Books; 91 refereed papers; 24 Commissioned Technical Reports; 2 Technical Movies; 1 Technical Video; 33 unrefereed papers and research reports.

Books

Thom, A & APELT, C.J. 1961, “Field Computations in Engineering and Physics”, D Van Nostrand, London and N.Y.

APELT, C.J. 1963, “Some Studies in Fluid Flow at Low Reynolds Numbers”, Micromethods Ltd, East Yardley Yorkshire.

Publication Details Since 1985

Papers in refereed Journals

Jempson, M.A. & APELT, C.J. 2005, Discussion of “Hydrodynamic loading on river bridges” by Stefano Malavasi and Alberto Guadagnini, Journal of Hydraulic Engineering ASCE, 131, pp 621-622.

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Morris, P.H., Lockington, D.A. & APELT, C.J. 2000, “Correlations for mine tailings consolidation parameters”, International Journal of Surface Mining, Reclamation and Environment, 14, pp 171-182.

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West, G.S. & APELT, C.J. 1997, "Fluctuating lift and drag forces on finite lengths of a circular cylinder in the subcritical Reynolds number range", *Journal of Fluids and Structures*, 11(2), pp 135-158.

APELT, C.J. & West, G.S. 1996, "Comparison of two methods for direct measurement of sectional fluctuating lift on a circular cylinder", *Experiments in Fluids,* 20(3), pp 232-233.

APELT, C.J. 1995, Discussion of "Design procedure and performance of minimum energy designed culvert", *Australian Civil Engineering Transactions,* CE 37, 3, p.266.

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Fox, T.A. & APELT, C.J. 1993, "Flow-induced loading of cantilevered circular cylinders in a low-turbulence uniform flow. Part 3: Fluctuating loads with aspect ratios 4 to 25", *Journal of Fluids and Structures*, 7(4), pp 375-386.

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APELT, C.J. & Ryall, G.L. 1992, "Modelling the sedimentary processes in real estuaries", *Transactions of IEAust*, CE34(1), pp 1-7.

Paterson, D.A. & APELT, C.J. 1990, "Simulation of flow past a cube in a turbulent boundary layer", *Journal of Wind Engineering and Industrial Aerodynamics*, 35, pp 149-176.

Johnson, T. & APELT, C.J. 1990, "Performance of minimum energy structure outlets near maximum expansion rates", *Transactions of IEAust*, CE31(4), pp 163-168.

Paterson, D.A. & APELT, C.J. 1989, "Simulation of wind flow around three-dimensional buildings", *Building Environment*, 24, pp 39-50.

APELT, C.J. & Piorewicz, J. 1987, " Laboratory studies of breaking wave forces acting on vertical cylinders in shallow water", *Coastal Engineering*, 11, pp 263-282.

Paterson, D.A. & APELT, C.J. 1986, "Computation of wind flows over three-dimensional buildings", *Journal of Wind Engineering and Industrial Aerodynamics*, 24, pp 193-213.

APELT, C.J. & Richter, N.J. 1985, "Modelling Barrier Reef tides in the Mackay region" *Transactions IEAust*, CE27, pp 166-173.

Papers in refereed Conference Proceedings

APELT, C.J. & Xie Qi 2011, "Measurements of the Turbulent Velocity Field in a Non-Uniform Open Channel"

Proceedings of the 34th IAHR World Congress, Brisbane, 26 June–1July 2011.

Jempson, M.A., Maxwell, N. & APELT, C.J. 2004, “Application of CFC modelling to free surface flow around bluff bodies – a case study using a bridge superstructure” Proceedings, 8th National Conference on Hydraulics in Water Engineering, Surfers Paradise, 13 – 16 July 2004, Engineers Australia, Canberra.

APELT, C.J. 2001, "What has Fluid Mechanics got to do with it?", *the Second Henderson Oration*, in *The State of Hydraulics* (6th Conference on Hydraulics in Civil Engineering, "The State of Hydraulics", Hobart, 28 - 30 Nov 2001), ed Michael Wallis, The Institution of Engineers, Australia, 11 National Circuit, Barton A.C.T., pp 25 -38.

APELT, C.J. & Voisey, C.J. 2001, "Recent Dredging Projects in Sensitive Areas in Queensland" in *Coasts & Ports 2001* (Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference and The 8th Australsian Port and Harbour Conference, Gold Coast Qld, 25 -28 Sept 2001), ed Rodger Tomlinson, The Institution of Engineers, Australia, 11 National Circuit, Barton A.C.T., pp 32 -37.

Nielsen, C. & APELT, C.J. 2001, "The Application of Wave Induced Forces to a Two Dimensional Finite Element Long Wave Hydrodynamic Model" in *Coasts & Ports 2001* (Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference and The 8th Australsian Port and Harbour Conference, Gold Coast Qld, 25 -28 Sept 2001), ed Rodger Tomlinson, The Institution of Engineers, Australia, 11 National Circuit, Barton A.C.T., pp 296- 303.

Heape, D. & APELT, C.J. 2001, "Pollution Estimation in Harbours - a Case Study" in *Coasts & Ports 2001* (Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference and The 8th Australsian Port and Harbour Conference, Gold Coast Qld, 25 -28 Sept 2001), ed Rodger Tomlinson, The Institution of Engineers, Australia, 11 National Circuit, Barton A.C.T., pp 423 - 428.

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