# Review of Expert Hydrology Report

## 10th January 2011 Grantham Flood

Grantham Flood Commission of Inquiry

Review

13th August 2015

# Review of Expert Hydrology Report

## 10th January 2011 Grantham Flood

Prepared for Grantham Flood Commission of Inquiry

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Stefan Szylkarski
Director
Signed by: Stefan Paul Szylkarski

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# APPENDICES

# 1 Summary of Conclusions

1. I was commissioned by the Grantham Floods Commission of Inquiry (GFCoI) to review the expert hydrology report prepared by Dr John Macintosh of Water Solutions Pty Ltd. The expert hydrology report was prepared for the GFCoI and documents the work carried out to investigate the circumstances and contributing factors of the flooding behaviour at Grantham for the 10th January 2011 flood event.

2. The objectives of my review were to:

   - Assess whether the issues I raised in my review of SKM's previous modelling carried out for the Queensland Floods Commission of Inquiry had been addressed within the current study; and
   - Provide my opinion and interpretation of the results presented in the expert hydrology report.

3. This review and my opinion are based on the findings presented in the expert hydrology report produced by Dr John Macintosh, a review of the flood modelling animations and the geotechnical report produced by Mr David Starr.

4. I am satisfied that an appropriate investigation has been carried out to develop an understanding of the flood behaviour for the 10th January 2011 flood event. The report is sufficient to support me forming an opinion on the causes of the flood, the likely flood behaviour and the potential range of contributions from manmade or natural features within the floodplain.

5. The expert hydrology report has identified and revised a number of critical hydrological and hydraulic conditions from those that have been previously documented. The report has applied engineering principles and modelling to assess the likely and potential behaviour of the flood during the event. There has been an extensive effort to correlate the model results with the eye witness accounts and photographic evidence which provides a level of transparency which I can use to assess the reliability of the model. This new work has provided the basis for resolving the inconsistencies identified in my previous review of the SKM modelling report including:

   a. The magnitude and timing of the flood hydrographs from the Lockyer Creek at Helidon, Ma Ma Creek and Flagstone Creeks which represent the boundary conditions of the model;
   b. The influence of downstream modelled water level conditions;
   c. The approximate and likely time of commencement of failure of the Western Levee;
   d. The possible rates of failure of the Western Levee during the flood;
   e. The initial water level conditions in the quarry pit prior to the flood commencing; and
   f. The likely pre quarry conditions that existed before the excavation of the quarry pit.

6. Most importantly, the expert hydrology report provides a plausible explanation to key observations from multiple eye witness accounts in Grantham during the flood. Eye witness accounts (Paragraph 98, Ref/4/) have described noticeable change in flow directions during the onset of flooding and the observation of several waves or surges during the onset of the flood. It is clear from the latest modelling that Grantham is initially flooded by backwaters from Sandy Creek breaking out of the bank followed by a second flood flow breakout from Lockyer Creek to the South West of Grantham. This flood breakout from the South West, crosses Gatton-Helidon Road and then commences to rapidly inundate the town. A third and larger breakout flow from Lockyer Creek then comes from the West of Grantham immediately adjacent to Quarry Access Road. This third breakout flood flow arrives in Grantham between 5 to 10 minutes after the arrival of the South-West breakout. There is evidence in the modelling to show that there may have been a sudden and dramatic change in flow direction through Grantham and some residents in the West of Grantham may have also experienced complete reversal of the flow direction. This behaviour of the flooding is due to the unique and natural configuration of the

floodplain and the behaviour is shown to occur irrespective of the existence of the quarry. The quarry does not therefore alter this specific aspect of the flooding behaviour that has been the basis for some of the observations that are recorded.

7. Based on my review of the modelling work presented in the expert hydrology report I have formed the following opinion in relation to the contribution to flooding due to the existence of the quarry:

   a. The flooding of Grantham in 2011 was unprecedented and was a rapidly developing and extremely hazardous natural event which would have occurred irrespective of the existence of the quarry. This opinion is consistent with my previous findings from the review of the SKM modelling by Dr Philip Jordan (Ref /3/).
   b. The existence of the quarry had the potential to influence flooding behaviour in Grantham in the 10th January 2011 flood event. The existence of the quarry and the breaches of the Western Levee influenced both the energy state of the water in the Lockyer Creek floodplain, and the paths that the floodwaters followed prior and subsequent to the breaches to the Western Levee.
   c. The contribution to the flooding of Grantham from the existence of the quarry is most likely:
      - a delay in the onset of flooding flows from the South-Western and Western Overbank breakouts and their arrival at Grantham (by approximately 3 minutes); and
      - a slight increase in the rate at which flood flows breakout, from Western and South Western Overbank breakouts such that the time from their commencement to the peak (about 30minutes) is about 3 minutes shorter than in the pre-quarry conditions. This is due to the peak flood flows at the breakout occurring at the same time as in the pre-quarry case but commencing at a time approximately 3 minutes later.
   d. Due to the model responses demonstrated by the Worst Case scenarios, the possibility of a slightly higher contribution of up to 5% more flow to the South Western breakout flows, from a more rapid slip failure, cannot be completely eliminated.
   e. The modelling results indicate that the flood intensity exceeded an extreme condition of $2m^2/s$ at all locations that were assessed for all scenarios presented under the Most Likely and Worst Case conditions. Therefore the existence of the quarry does not have a material impact on the flood intensity which is used to assess the damage or hazard caused by the flooding for the 10th January 2011 flood event.

8. In considering the combination of scenarios described above I am of the opinion that the contribution to flooding is most likely a delay in the onset of flooding flows arriving at the South-Western and Western Overbank breakouts and a subsequent increase in the rate of rise of flood flows as assumed by the "Most Likely" scenario. However due to the responses demonstrated by the worst case scenarios the possibility of a contribution to the flood breakout flows from a more rapid slip failure at alternative times cannot be completely eliminated.

9. Based on the analysis in the expert hydrology report, I have concluded that the existence of the quarry is likely to have had a contribution to the flooding of Grantham however the contribution was not sufficient to materially change the flood intensity that would have been experienced in Grantham prior to the existence of the quarry.

10. On the basis of the expert hydrology report, I believe that the matters I have previously raised (Ref /1/) have been investigated to a level that is sufficient to provide an explanation and an understanding of the flood event at Grantham on the 10th January 2011.

# 2 Introduction

11. The impact of the Grantham quarry on flooding was first raised as a concern by the local residents during the Queensland Flood Commission of Inquiry (QFCoI) which took place between January 2011 and March 2012. The QFCoI commissioned Sinclair Knight Merz (SKM) to investigate the impact of the quarry on flooding, during the 10th January 2011 flood event, using hydraulic modelling. SKM later produced a report setting out the results of that investigation (Dr Phillip Jordan (Ref /3/). The QFCoI relied upon Dr Jordan's report in making its findings in March 2012. In the three years since the final report from the QFCoI was released, there have been continuing concerns from local residents that their observations and recollections of the events of that day were not consistent with the results of the hydraulic modelling carried out and reported by Dr Jordan.

12. In late 2014, DHI were commissioned by The Australian newspaper (Nationwide News Pty Ltd) to carry out an independent review of the modelling report by Dr Jordan and his assessed impact of the Grantham quarry on flooding behaviour during the flood event that occurred on the 10th January 2011 in the Lockyer Creek. I was responsible for carrying out the review and preparing a report containing the results of that review (Ref /1/). My report highlighted a number of inconsistencies between Dr Jordan's report (as well as the underlying modelling) and some of the observations in eye witness accounts. I also identified a number of specific issues that warranted further investigation to support the findings in Dr Jordan's report. These included:

    a. Confirming the extent of the Western Levee breach failure length;
    b. Selection of a suitable model and resolution capable of simulating the behaviour of short period waves;
    c. Completing and documenting a model calibration and correlation to eye witness accounts;
    d. Carrying out and documenting the sensitivity analysis to critical assumptions relating to the Western Levee failure mechanisms.

13. The Grantham Floods Commission of Inquiry (GFCoI) was subsequently initiated by the Queensland Government to investigate the Grantham flood event with specific terms of reference to investigate:

    a. the flooding of the Lockyer Creek between Helidon and Grantham on 10 January 2011, with specific reference to any natural or man-made features of the landscape which could have altered or contributed to the flooding;
    b. whether the existence or breach of the Grantham quarry caused or contributed to the flooding of Grantham;
    c. whether the existence or breach of the Grantham quarry had a material impact on the damage caused by the flooding at Grantham;
    d. whether the breach of the Grantham quarry had implications for evacuation of Grantham;
    e. how these matters were first investigated and how eyewitness accounts were dealt with, particularly by State Government agencies and Emergency Services.

14. DHI Water and Environment Pty Ltd (DHI) were commissioned by the GFCoI in July 2015 to review the expert hydrology report prepared by Dr John Macintosh of Water Solutions Pty Ltd (Ref /4/). I was responsible for carrying out the review and preparing this report.

# 3 Scope of Review

15. The scope for this report was to review the expert hydrology report completed by Dr John Macintosh and the animation files representing Dr Macintosh's modelling. In doing so, I was also required to consider the report of the geotechnical investigations carried out by Mr David Starr (Ref /2/).

16. The objectives of the review were to:

- Assess whether the issues I raised in my review of the previous modelling carried out by SKM have been addressed within the current expert hydrology report; and
- Provide my opinion and interpretation of the results presented in the expert hydrology report.

# 4 Review of Expert Hydrology Report

## 4.1 Model Review

17. I have reviewed the modelling in the expert hydrology report in relation to the following key modelling issues:

a. Model Selection;
b. Modelling of the Western Levee walls;
c. Boundary Conditions; and
d. Calibration and validation.

### 4.1.1 Model Selection

18. The expert hydrology report is based on the application of a TUFLOW finite difference based hydraulic model with a 10m grid resolution, which is the same type of model that was previously applied by SKM.

19. The expert hydrology report demonstrates that the sensitivity of the model to a higher resolution 5 metre grid has been investigated (Section 12.6, Ref/3/). The report concludes that the model sensitivity to the higher resolution grid does not extend beyond the quarry pit and is therefore not significant. I am of the opinion that this is a suitable sensitivity analysis to test the applicability of the model resolution.

20. The TUFLOW model and resolution is suitable for modelling the behaviour of the flood generally across the floodplains of the Lockyer Creek as well as the influence of the quarry on the distribution of flood flows around and through the quarry. Whilst the TUFLOW model is a standard approach for flood modelling it is important to note that the model is based on a specific two dimensional finite difference numerical scheme. These schemes cannot simulate steep fronted waves, similar to the movement of a breaking wave on a beach shoreline. I note that some of the eye witnesses have observed waves travelling across the floodplain during the onset of flooding and that may have appeared as "breaking waves".

21. In my previous report, I expressed a preference for an alternative model that can capture steep fronted wave behaviours in order to address the observations of eye witnesses of waves during the 10th January 2011 flood event. Whilst I would have preferred the use of this alternative model, I do not believe that the results of this study are invalidated by the use of a TUFLOW

model type. This is because the calibration of the model has demonstrated sufficiently that the timing of the arrival of the flood waves in Grantham is well aligned to the eye witness accounts. However, it is important to understand this model limitation to capture the behaviour of these waves when interpreting the model results.

### 4.1.2 Modelling of Quarry and Western Levee

22. An analysis of the quarry terrain for pre and post flood conditions has been carried out. I am satisfied that an acceptable representation of the Western Levee to the quarry has been developed in the model that represents the full extent of the various breaches of the Western Levee.

23. The expert hydrology report includes sensitivity testing using alternative failure mechanisms to investigate the significance of uncertainty in the timing of the failure and the speed of the failure.

24. We will never know the exact mechanism by which the Western Levee actually failed based on the evidence presented in the expert hydrology report. It would not be reasonable to test an exhaustive list of every possible combination of factors that could lead to the Western Levee failure. The correct engineering approach is to develop an envelope of possibilities that incorporate the range of possible scenarios and then interpret the model results from the envelope of model results. Three failure rates have been assumed (Section 10.4, Ref /4/) which I consider to be an appropriate range of failure rates to test in the model.

25. Pre-quarry topography in the modelling has also been developed based on investigations carried out by Mr David Starr (Ref /2/). The pre-quarry terrain is important because the pre-quarry conditions are used to assess the relative contribution to flooding from quarry breach scenarios. The expert hydrology report and my review rely on Mr David Starr's opinion as to the pre-quarry topographic surface.

### 4.1.3 Boundary Conditions

26. The expert hydrology report has revised both the upstream inflow model boundary conditions and the downstream water level boundary conditions.

27. The upstream inflow boundary condition to the model is based on the measured water levels at the Helidon gauging station and has been converted to a discharge hydrograph. This approach represents the most reliable means of estimating the timing and volume of inflows. The revised boundary inflow condition at Helidon has more flow volume (approximately 30% more) and a slightly higher peak flow discharge (approximately 500$m^3$/s more) than was previously estimated in the modelling for Dr Jordan's report.

28. The downstream boundary condition was developed using a rating curve derived from the floodplain characteristics, and resolves the previous concerns I had in relation to backwater influence within the model.

29. I am satisfied that the model boundary conditions are acceptable for the current study and represent the best estimate currently available.

### 4.1.4 Calibration and Validation

30. The expert hydrology report includes a comprehensive calibration and validation of the model, which has taken due cognisance of the measured peak flood heights, eye-witness accounts of the flood progression, photographs and videos of the flood event.

31. Modelled peak flood water levels have been validated against water level survey records from the event (Figures 12.8a and 12.8b, Ref/4/). The validation against these observed levels is

within acceptable ranges for the water levels within the town of Grantham and in the immediate vicinity of the quarry. This water level validation also provides implicit validation of the Lockyer Creek hydrograph applied at the upstream boundary, and the two additional tributary inflow hydrographs for Ma Ma Creek and Flagstone Creek.

32. However, I note there are a number of water levels records upstream of the quarry in the Carpendale area where the peak water levels predicted by the model diverge substantially. (Ref/4/ Figure 12.8b). Potential issues with the measurement for these levels has been identified and they are therefore considered unreliable records against which to calibrate. Despite there being uncertainty in relation to the accuracy of these flood marks, they are located away from the area of interest. My opinion is that the model can be considered to be sufficiently calibrated, and applied to assess the behaviour of flooding between the quarry and Grantham.

33. The model validation has included a detailed analysis of the timing of the flood inundation and corroboration with the eyewitness accounts. The timing of eyewitness accounts that have been authenticated by phone records and other time stamped methods (such as a photographs and video) show good correlation with the modelling results. I can therefore be confident that the flood model is able to reproduce the sequence of events observed during the flood.

## 4.2 Sensitivity and Scenario Analysis

34. The expert hydrology report includes a range of sensitivity simulations that can be reviewed to assess the possible changes in the behaviour of the flood to assumptions that are made in relation to the conditions of the quarry during the flood event. The primary assumptions include:

   a. Timing of the failure of the Western Levee;
   b. Speed of the Western Levee failure;
   c. Extent of the Western Levee failure; and
   d. The initial water level conditions in the quarry pit prior to the flood.

35. The timing of the failure is a key assumption. Dr Jordan’s modelling for the QFCoI assumed a failure time of 3:10pm (Ref /3/). The expert hydrology report includes a “most likely” scenario (Section 10.5, Ref /4/) which indicates that the Western Levee most likely commenced failure at 3:25pm (Table B.2, Appendix B, Ref /4/) in the North West corner of the quarry, with subsequent failure of the different sections of the Western Levee along the Western side of the quarry at 3:45pm and 3:56pm. The timing of the initiation of failure is based on an assumption that the Western Levee would fail when water levels upstream of the quarry reached specific trigger levels associated with overtopping of the wall which would initiate erosion of the Levee. I consider the “most likely” scenario to be a reasonable assumption for the Western Levee failure sequence with the understanding that there are alternative potential failure mechanisms with a similar likelihood that could produce different responses from the system.

36. The speed of the failure of the Western Levee wall for the “most likely” scenario has been tested for three failure rates of 5 seconds (effectively instantaneous), 10 minutes and 1 hour (Paragraph 343, Ref /4/). I consider this to be a suitable range of failure rates for the purposes of testing the sensitivity of flood behaviour to the assumed failure rate.

37. In addition to the “most likely” scenario, a range of “worst case” scenarios have been tested with assumed instantaneous failure of the full length of Western Levee at a single point in time. The assumed times of initiation of these “worst case” failure scenarios range between 3:13pm and 4:16pm (Table 10.2, Ref /4/). These failure times represent the envelope of times that are possible given the timing of the flood hydrograph at Helidon. In my view, these scenarios can be used to assess the potential maximum response of the flood behaviour to alternative failure responses.

38. The expert hydrology report has expressed an opinion that slip failure is unlikely to have occurred (Paragraph 208, Ref/4/). However it has not been established conclusively that a rapid slip failure did not occur on at least part of the Western Levee. If the Western Levee becomes inundated due to overtopping flows, then the toe of the wall could be eroded from flow turbulence and the conditions for a potential slip failure are present. I consider this to be consistent with the description of the required conditions for slip failure (Paragraph 208, Ref /4/). I therefore consider that it is feasible that the failure of the Western Levee could have occurred as a combination of failure conditions involving top down erosion based failure of the main breach and a more rapid slip failure of section of Levee 4 and Levee 5 (Figure B.18, Ref/4/).

39. To take into account the full range of potential outcomes from a failure of the Western Levee it is necessary to consider not only the Most Likely scenario but also the Worst Case scenarios. This is because there is a possibility that the actual failure of the Western Levee has occurred as a combination of both slip and top down erosion based failures and potentially at one of the alternative trigger times considered in the Worst Case scenario simulations.

40. The sensitivity of the model outcomes to the initial water level conditions in the quarry pit have been tested for two conditions of 116 mAHD and 120 mAHD (Figure 12.6, Ref /4/). The results of this sensitivity are shown to be important as they have an effect on the timing of the flood flows contributing to flooding in Grantham (Figure 12.7, Ref /4/). When the water levels is changed from 120mAHD to 116mAHD for the Most Likely scenario it is shown to delay the onset of flooding breakout flows by about 5 minutes (in the 116 mAHD condition) whilst also increasing the rate of rise of the flood breakout flows. This behaviour is due to the lower initial water level in the pit providing for additional storage space in the pit, for the flood waters to be stored, after the Western Levee fails.

41. We will never know the true extent, speed and timing of the failure of the Western Levee, however the range of scenarios postulated provides a basis for assessing the relative sensitivity of the flooding behaviour to the primary assumptions of how the Western Levee might have failed. When reviewing the entire set of model sensitivity simulations I am able to form an opinion on the different types of flood behaviour that could physically occur within this range of uncertainty.

# 5 Interpretation of the Modelling Results

## 5.1 Flooding Behaviour

42. The expert hydrology report has identified three key flood breakout flows from Lockyer Creek that are responsible for flooding Grantham during the 10th January 2011 flood event. These are as follows:

    a. The first breakout occurs due to flood waters from Lockyer Creek beginning to back flow up Sandy Creek and then slowly inundating the eastern and low lying areas close to Sandy Creek at 3:25pm (Figure 9.3a Ref/4/);
    b. the second breakout occurs in Lockyer Creek to the South West of Grantham at 3:40pm (Figure 9.2b, Ref/4/) and flows towards Western Grantham across the floodplain arriving at 3:55pm (Figure 9.2 c, Ref/4/);and
    c. the third breakout flow originates near Quarry Access Road at 3:35pm (Figure 9.1g Ref /4/), West of Grantham and then flows towards Western Grantham arriving at 4:10pm. (Figure 9.2f, Ref/4/).

43. I consider that the two flood breakout flows from the West and South-West of Grantham are the most important for creating the hazardous flood conditions that occurred on that day. A review of the flood modelling animations (Table 9.1, Ref /4/) shows that the flood flows arrive at different times in the Western Grantham as follows:

    a. The South-West breakout flow crosses the Gatton-Helidon Road at Western Grantham at approximately 3:55pm and begins to inundate Western areas of Grantham (Figure 9.2c, Ref/4/). This flooding produces flows that are generally moving in a north to north east direction. Some of this flood flow is also shown to move slightly in a North Westerly direction as it spreads out towards the Western end of Grantham and also to the East as it is blocked by the presence of the railway embankment; and
    b. Subsequently, the Western Overbank breakout flow arrives at approximately 4:10pm (Figure 9.2f, Ref/4/) at the Gatton-Helidon Road on the Western side of Grantham. The flood discharge from the West is greater than the South Western flood flows and produces a strong West to East flow direction and combines with the flood flows from the South West to produce a high intensity flood flow from West to East through Grantham.

44. This flooding behaviour provides a plausible explanation to key observations from eye witness accounts in Grantham during the flood (Paragraph 98, Ref/4/). The eye witnesses' accounts in several instances describe the sudden change in flow direction during the onset of flooding and the observation of several waves or surges during the onset of the flood. There is evidence in the model results shown in the animations that there was a sudden and dramatic change in flow direction as the various flood breakout flows pass through Grantham.

45. The behaviour of the sequencing of the flood flows from the South West and Western breakouts occurred due to the unique and natural configuration of the Western and South-Western Overbank breakout locations. A review of the model scenarios for the "No Quarry" case as well as all the quarry failure scenarios shows the same sequence of flooding occurring from the breakouts; initially from the South West and then from the West. The quarry does not therefore alter this specific aspect of the flooding behaviour that has been the basis for many of the observations that are recorded.

## 5.2 Conceptual Model Interpretation

46. My interpretation of hydraulic flood modelling results is on the basis of a conceptual understanding of the physics of water movement in the system. Hydraulic model simulations

forecast the possible movements of water based on the physical process that governs how water moves. The interpretation of the influence of the quarry on the flood flow can be conceptualised as shown in Figure 1.

47. This conceptual diagram illustrates the influence that the quarry or a similar obstruction to flow can have on the energy state in the floodplain. In the case of Grantham, the influence of the Western Levee upstream of the quarry is to slow the approaching flood flows and temporarily store the kinetic energy of the water in the form of increased water levels as the water is impounded. During impoundment, the flows and therefore energy levels downstream of the quarry are temporarily reduced.

48. Following the breach of the Western Levee the water stored upstream of the quarry will be released, but starting from a higher energy state and carrying greater energy than if the Western Levee had not been present. As the flood travels through the breaches to the Western Levee and spills into the quarry much of the additional energy stored will be dissipated, primarily as turbulence within the flow. Some of the stored energy may also pass through the quarry and continue downstream. The hydraulic model simulates this physical behaviour in fine detail, and the model is used to determine to what extent this additional flow energy can influence the hydraulics downstream towards Grantham. The additional energy available to the flow is expressed as slightly higher flow rates, flow depths and flow velocities in the hydraulic models. It is important to note that the hydraulic models do not simulate the physical system exactly but provide the ability to understand the general response of a system to the flood flows. It is therefore important that the model results are interpreted are not necessarily relied upon as being exact.

49. In addition to influencing the energy state of the flow, the presence of the Western Levee and the quarry pit can also change the flow paths by which the flood travels. The influence of the quarry breach is to provide an additional flow path by which water can travel downstream through the quarry pit towards the Lockyer Creek as opposed to having to travel around the quarry.

## 5.3 Hydraulic Model Interpretation

50. I have interpreted the modelling results to assess the contribution of the quarry and Western Levee failure to the flood behaviour in Grantham. It is important to understand that it is not possible to be certain as to the exact contribution of the quarry to the flooding in Grantham due to the range of unknown conditions at the time of the flood, the exact conditions of the floodplain prior to the existence of the quarry and the scientific limitations for any modelling to perfectly recreate every aspect of the flooding behaviour.

51. The modelling tool has been used to predict the potential flooding outcomes from a range of hypothesised scenarios and conditions ranging from most likely to worst case and including the no quarry case. It is likely that none of these scenarios represent the exact manner in which the Western Levee failed but they represent a range of possible system behaviours. I have therefore interpreted the modelling results as representing the envelope of possible outcomes from the range of conditions that have been simulated. I then used engineering judgement to form an opinion based on a combination of the model results and the conceptual model of the system to estimate the likely contribution to flooding in Grantham.

52. I have interpreted the contribution to flooding of Grantham based on the metric of "discharge" at the three downstream reporting locations presented in the expert hydrology report (Figure 10.4, Ref/4/) as the Western Overbank, the South-Western Overbank and Lockyer Creek. I consider discharge to be the most appropriate measure as it is a consistent and reliable representation of the physical volume of flood waters that arrive in Grantham over time. Any changes to the physical flow volume arriving in Grantham can be used as a reliable assessment of the relative contribution to the flooding of Grantham.

53. I have interpreted the contribution to the damage and hazard from flooding in Grantham on the basis of the depth and intensity graphs at the key locations provided in the expert hydrology report (Figure 10.5, Ref/4/). The depth and flood intensity metric is a single point measure that is taken at a specific location. The depth and flood intensity is highly variable across the flood plain and throughout Grantham. Depending on the locations chosen you will get highly variable results. It is therefore a good measure for estimating damage and hazard from a flood at a specific location but it is not a consistent measure to estimate the overall contribution to flooding of Grantham. For this reason it is important to assess the damage and hazard for the flood at a range of locations, (such as those chosen by Dr Macintosh) and to also make an assessment of the modelling from the entire animation of the scenarios.

54. Based on the methodology for interpretation above, I have assessed the potential contributions to flooding in Grantham, due to the existence of the quarry using the results in the expert hydrology report in Figure 10.10, Figure 10.17, Figure 12.6 (Ref/4/) as follows:

a. The Most Likely scenario results (Figure 10.10, Ref/4/) indicate that under all the evaluated conditions the Overbank breakout flood flows from the South West and the West, that travel into the town of Grantham, are delayed by about 3 minutes when compared to the pre-quarry conditions. The Western Overbank breakout is also reduced slightly in maximum flow rate, by about 5% when compared to the pre-quarry conditions. However, the onset of flooding occurs at a slightly faster rate. The rate of increase in flood flows at the breakouts occurs about 3 minutes faster over the first 30 minutes of the breakout. This is due to the flood peak flows at the breakout occurring at the same time as in the pre-quarry case but starting at a time approximately 3 minutes later;

b. The Worst Case scenario (Figure 10.17, Ref/4/) for Trigger 126.4mAHD demonstrates the upper limit of possible contributions to flood breakout flows that can be created with the model. The results show that the Western Overbank breakout flow can be no more than ~25% greater and the South-Western Overbank breakout can be no more than ~15% greater than the pre-quarry breakout flows. This represents the upper limit that can be created artificially in the model and represents an upper bound which cannot be exceeded. I agree with the expert hydrology report that this is an unrealistic scenario and cannot be considered as a possible outcome;

c. The Worst Case scenario (Figure 10.17, Ref/4/) for the lower Trigger level of 124.5mAHD demonstrates the possible contributions to flood breakout flows that could be created with a Western Levee slip type failure that is slightly later in time (3:35pm) than what is considered in the Most Likely 5-second failure scenario (failure at 3:25pm). The results show that the Western Overbank breakout flows are no greater than pre quarry flows and the South Western Overbank no more than 5% greater than pre-quarry flows. This scenario provides the basis for understanding the response of the flow contribution to a complete catastrophic slip failure when the upstream water level is beginning to overtop the Western Levee and the quarry pit is close to full at the time of failure. I agree that this is unrealistic scenario in terms of the raising of the Western Levee wall and cannot be considered a possible outcome for that reason;

d. In considering the combination of scenarios described above I am of the opinion that the contribution to flooding is most likely a delay in the onset of flooding flows arriving at the South-Western and Western Overbank breakouts and a subsequent increase in the rate of rise of flood flows by about 3 minutes faster than what might have otherwise occurred in the pre-quarry conditions. However due to the responses demonstrated by the worst case scenarios the possibility of a contribution of up to 5% more flow to the South Western breakout flows from a more rapid slip failure cannot be completely eliminated.

55. I have also assessed the potential changes to flood hazard and damage based on the interpretation of the modelling results of flood intensity as shown in (Figure 10.11, 10.18, Ref/4/). The modelling results indicate that the flood intensity exceeded an extreme condition (I consider

this to be values in excess of 2 $m^2/s$) at all locations that were assessed for all scenarios presented.

56. So whilst I cannot eliminate the possibility that the quarry had a contribution to flooding this indicates that the flood intensity in the extreme condition regardless of the existence of the quarry.

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# FIGURES

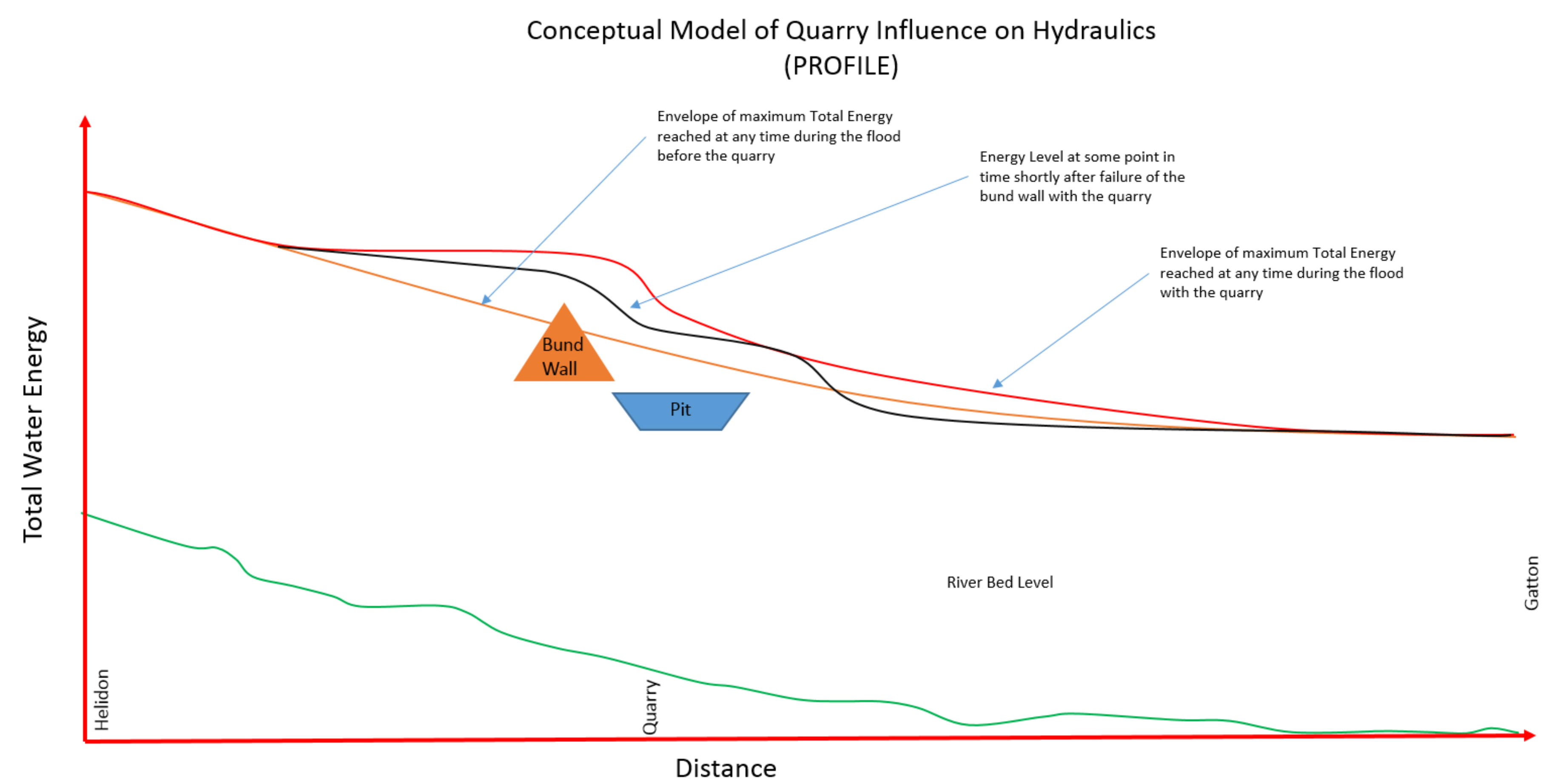


Figure 1 Conceptual Model of Flow Energy

# APPENDIX A - CV

Stefan Szylkarski

# CURRICULUM VITAE

**Name:** **STEFAN P. SZYLKARSKI B.E.(HONS), M.ENG.SC,. M.I.E.AUST., RPEQ**

**Date of Birth:** 21 December 1969

**Nationality:** Australian

Qualifications:

M. Eng. Sc., (Water), University of NSW, 1996
B.E. (Hons) Civil, University of Queensland, 1991
Registered Professional Engineer Queensland

Memberships

Institution of Engineers Australia
Australian Water Association
International Mine Water Association
International Association of Hydrogeologist

Positions:

| | |
|---|---|
| DHI 2015 | Director (South Africa, New Zealand) |
| DHI 2014 | Director (Peru) |
| DHI 2012 | Vice President – Mining |
| DHI 2008 – 2012 | Managing Director (Australia) |
| DHI 2007 | Director (Australia) |
| DHI 2000 – 2006 | State Manager (Queensland Australia) |
| DHI 1999 – 2000 | Senior Engineer (San Francisco, CA USA) |
| DHI 1997 – 1999 | River Hydraulics Engineer (Copenhagen, Denmark) |
| DHI 1992 – 1997 | Lawson and Treloar Pty Ltd (Sydney, Australia) |

Career Overview

Stefan is a Civil Engineer with over twenty three years of experience within the water and environmental engineering disciplines. He graduated from the University of Queensland in Civil Engineering and practiced as a consultant in Sydney before joining DHI's Copenhagen Office in 1997. In the subsequent years he worked for DHI in the Asia region and the US before returning to Australia in 2000 to start up an Australian operation for DHI as the regional manager in Brisbane. He subsequently managed the Australian operations as Managing Director from 2007 to 2012 and was appointed to the global role of Vice President in Mining in 2013. In 2014 he setup DHI's Peru office as the founding director and in 2015 was appointed to the boards of DHI's Southern Hemisphere offices including New Zealand, Australia and South Africa. He is currently the Group Business Cluster director for the South Hemisphere region.

Stefan's experience includes engineering and modelling in the fields of hydraulics and hydrology, flood and surface water drainage, piped water supply system planning, piped waste water planning, mine water balance, water quality modelling, ecological and environmental modelling assessments. His technical specialisation is in the application of models to water planning issues and the application of real time software systems to operational water management issues in rivers, urban, mining and marine water environments.

He has managed and worked extensively within teams of multidisciplinary engineers and scientists in the fields of engineering, biogeochemistry, hydrogeology, ecology and information technology to deliver solutions to complex water management challenges in a wide variety of industries.

**EXPERIENCE:**

**2014** **Universal Water Operating Platform, QGC Pty Ltd, Queensland Australia.** Project Director. Development of conceptual approach and successful tendering for a $3million software system to manage water operations for Coal Seam Gas produced waters. The project was part of a larger corporate software implementation being implemented by Accenture. Provided coordination of multidisciplinary teams both internally and externally and included software and hydraulic model developments and monitoring of project direction.

**2014** **Coeur d'Alene River, Washington State, USA.** Project Director. Two dimensional morphological modelling to assess the future transport of mine tailings that have been discharged to the River over 100 years ago.

**2013** **Tenke Fungurume Mine Hydrological Modelling- Freeport McMohran, Democratic Republic of Congo.** Project Director. Development of conceptual approach and review of project direction.

**2011** **Colton Mine Mary River Discharge Dispersion Analysis, New Hope, Queensland Australia.** Project Director. Development of conceptual approach and numerical model to assess the impact of mine water discharges to the Mary River.

**2011** **Nyidinghu High Resolution Groundwater Modelling, Fortescue Metals Group, Western Australia.** Project Director. Development of high resolution groundwater models to assess the impact of mine dewatering and re-injection of dual density ground water systems.

**2011** **Nattai Catchment Hydrological Modelling. Sydney Catchment Authority.** Project Director. Development of an integrated distributed and physics based hydrological model to assess catchment yield for the Sydney water supply catchment. Coordination of multidisciplinary team and monitoring of project direction.

**2011** **Cavel Ridge Mine Discharge Conditions Analysis, BHP Mitsubishi Alliance, QLD Australia** Project Director. Development of conceptual approach and numerical model to assess the impact of mine water discharges to a local waterway during high flow flood periods.

**2011** **Computer Aided River Management System Implementation (CARM), State Water, NSW.** Project Director. Development of conceptual approach and successful tendering for a $5million decision support software system to manage water deliveries in the Murrumbidgee River System. The project involved development of a corporate software implementation to provide hydrologists with hydraulic modelling based forecast systems and water ordering optimisation tools. Provided coordination of multidisciplinary teams both internally and externally and included software development, hydraulic and hydrologic model developments and monitoring of project direction.

**2010** **Flood Effects on Dampier to Bunbury Natural Gas Pipeline River Crossings, DBNGP Pty Ltd, Western Australia.** Project Director. Development of conceptual approach and review of project direction. Development of a two dimensional adaptive mesh morphological model to assess the migration of Fortescue River and the associated risks to the buried gas pipeline crossing.

**2009** **Gold Coast Seaway Smart Release Project, Gold Coast Water, Australia.** Project Director. Development of conceptual approach, coordination of multidisciplinary team and monitoring of project direction. Involved the development of a real time decision support system to optimise release times of treated waste water through the Gold Coast Seaway so as to minimise environmental risks.

2007 **Daly River Surface Water and Groundwater Interaction Study.** Project Director. Mike 11 (1D) hydraulic modelling of Daly River flow including rainfall/runoff calibration. The Mike 11 model was coupled with a groundwater model (FeFlow) to simulate the GW-SW interaction and assess based flows in the dry season.

2006 **Gateway Upgrade Project, AECOM, Queensland Australia.** Modelling Advisor to the Leighton Abi Group Joint Venture. Review and advice on flood modelling, river hydraulics and navigation issues associated with bridge and road embankment.

2005 **Brisbane Airport New Parallel Runway Project, Preliminary Design. AECOM, Queensland, Australia.** Project Manager. Flood modelling using a regional scale 1D-2D coupled hydraulic model to assess the flooding and drainage impacts of land reclamation for the development of a second runway at Brisbane Airport.

2004 **Maroochy River Floodplain Model Development, Department of Main Road, Queensland Australia.** Technical Reviewer. Review and advise on flood model development.

2003 **Port of Brisbane Vessel Interaction Study, Port of Brisbane, Queensland, Australia.** Project Manager. Data Collection and analysis of vessel interactions due to pressure wave disturbances within the Port of Brisbane. Physical modelling was carried out in order to identify behaviour and mitigation measures.

2003 **Pimpama River Estuary Ecological Study, SKM, Brisbane Australia.** Project Manager of numerical modelling activities involving multidisciplinary modelling groups including hydraulics, ecological and bio-chemistry. The modelling activities were a critical component of an Environmental Impact Assessment for future recycled water releases to the Pimpama Estuary. The study involved extensive data collection, mapping over an 18month period to develop a scenario assessment model for ecological response of sea-grass beds within the Pimpama and South Morten Bay area.

2003 **Burdekin Storm Surge Study, AECOM, Queensland Australia.** Project Manager for the development of a cyclone storm surge model for the Burdekin region on the North Queensland coastline. The study involved the application of a two dimensional model system for the prediction of surge inundation under a range of tidal, wave, atmospheric and wind conditions. The model was calibrated to historical events and used to predict a range of impacts under various design conditions. The study outputs formed the basis for a storm surge risk assessment study being carried out by AECOM for the Burdekin Shire Council.

2003 **Northern New Territories Drainage Improvement Study, Maunsell, Hong Kong.** Hydraulic Engineer. Modelling of master plan drainage options and analysis for the Northern New Territories development areas of Hong Kong.

2003 **Storm Water Drainage Master Plan, South Hong Kong Island, Hong Kong, Maunsell, Hong Kong.** Hydraulic Engineer. Modelling of master plan drainage options and analysis for South Hong Kong Island development areas.

2003 **Townsville Flood Study, Maunsell, Queensland Australia**. Senior Hydraulic Engineer. Development of 1D-2D coupled hydrodynamic modelling.

2002 **Trinity Inlet Tidal Inundation and Flushing Study, Department of Natural Resources, Queensland, Australia.** Project Manager- This project involved the development and calibration of a 1D and 2D coupled model covering the East Trinity wetland area adjacent to the city of Cairns. The model was used to assess the flushing efficiency and inundation extents for a wetland restoration project of the East Trinity area that was affected by poor water quality from exposed acid sulphate soils.

**2002** **Brisbane City Sewer Modelling – Overflow Abatement Planning, Brisbane Water, Queensland Australia.** Project Manager. The project involved the development and calibration of dry weather flow sewer models for the complete Brisbane City Council sewer system. The modelling project was resourced with a modelling team made up of engineers and GIS specialists. The models were calibrated to over 300 flow gauges and 300 pump stations servicing a population of over 800,000. The models represent a strategic development for Brisbane Waters overflow abatement project.

**2002** **Townsville Flood Study, AECOM, Queensland Australia.** Senior Hydraulic Engineer. Supervised the development and calibration of a two-dimensional flood model of the City of Townville. The model was used for the assessment of local drainage and flood behaviour in the City and the evaluation of mitigation options.

**2002** **Green Bridge Hydraulic Impacts Assessment, City Design, Brisbane City Council.** Hydraulic Engineer. Development and validation of a 3D hydraulic model of the St Lucia Reach of the Brisbane River. Assessment of the impacts to peak water level and flow distribution for a range of bridge alignment and pier options.

**2002** **Sparkes Hill Water Supply Master Plan Modelling, Brisbane Water, Queensland, Australia.** Project Manager:- Stefan supervised the development and calibration of a water supply model for the Sparkes Hill pressure zones in Brisbane. The project involved the development and calibration of a MIKENET model that was used to assess future infrastructure requirements within the pressure zone in order to meet Brisbane Water standards of service.

**2002** **Manly and Roles Hill Water Supply Master Plan Modelling, Brisbane Water, Queensland, Australia.** Project Manager:- Stefan supervised the development and calibration of a water supply model for the Manly and Roles Hill pressure zones in Brisbane. The project involved the development and calibration of a MIKENET model that was used to assess future infrastructure requirements within the pressure zone in order to meet Brisbane Water standards of service.

**2001** **South Pine River Catchment Management Plan, John Wilson and Partners, Queensland Australia.** Senior Engineer. Development of 1D-2D coupled hydraulic models for assessment of flooding impacts from long term catchment land use plans

**2001** **Mooloolah River Flood Study, Department of Main Roads, Queensland Australia.** Senior Engineer. Development of 1D-2D coupled hydraulic models for assessment of flooding impacts from the development of embankments for highway augmentations.

**2001** **Bulimba Creek Trunk Sewer Augmentation Study, Brisbane Water Queensland, Australia**
Hydraulic Engineer. Sewerage system modelling and planning

**2001** **Cubberla Creek Sewer Augmentation Study, Brisbane Water Queensland, Australia**
Hydraulic Engineer. Sewerage system modelling and planning

**2001** **Gold Coast Water Infrastructure Charges Planning, Gold Coast Water Queensland, Australia.** Hydraulic Engineer. Provided sewer modelling advise and managed the development of software applications for the analysis of sewer system and infrastructure charges as part of the Infrastructure Charges Planning study of the Gold Coast region.

**2001** **Wide Bay Water Sewer and Collection System Model Development, Queensland, Australia.**
Hydraulic Engineer. Sewerage system modelling and planning

**2001** **Barkly Highway Upgrade – Flood Impact Study on the Buckley and Johnson Rivers, Department of Main Road, Queensland, Australia.** Modelling Advisor. Development and Calibration of 2 dimensional models of the floodplain to assess proposed road upgrades and realignments. The project involved significant training and technology transfer of modelling systems to the Department of Main Road staff.

**2001** **Bulimba Creek Flood Study, Port Access Road upgrade. Parsons Brinkerhoff, Queensland Australia.** Modelling Advisor and technical review of the development and calibration of the Bulimba Creek flood model for assessment of the flooding impact from a major upgrade to the Brisbane Port Access Road upgrade.

**2000** **River Murray Loch No 5 Navigational and Hydraulic Assessment., URS, South Australia.** Hydraulic Engineer. Assessment of hydraulic conditions under various flow conditions for Lock & Weir No. 5 on the River Murray. An hydraulic model was used to assess the cross current velocities and eddies that develop during a range of flow conditions.

**1999** **Alafia River Watershed Modelling, Florida, USA.** Hydraulic Engineer. Environmental flows assessment for brine release from desalination plant and the analysis of annual hydrodynamic and water quality cycles of the Alafia River at the site to assess the siting of the water intake structure for the plant.

**1999** **Napa Sonoma Salt Marsh Restoration, The Nature Conservancy, California, USA.** Hydraulic Engineer. Evaluation of management and restoration alternatives of abandoned hyper saline salt production ponds. The ponds formed part of a reclaimed wetland-marsh complex adjacent to the Napa River and Sonoma Creeks. The area is an important habitat of endangered aquatic fowl populations. A model of the marsh and tidal slough channels was developed as a coupled MIKE11 and MIKE21 for hydro-dynamic and transport-dispersion processes.

**1999** **Yangtze River Flood Analysis, Dongting Lakes, China.** Hydraulic Engineer. Development and calibration of MIKE11 model for the Yangtze River at Dongting Lakes. The model was used to assess impact on flooding and forecast predictions resulting from dyke collapse and flooding of relief areas.

**1999** **Little Pudding River Flood Study, Marion County, Oregon, USA.** Hydraulic Engineer. Flood inundation and flood mapping

**1998** **Northern New Territories – Drainage Master Plan, Hong Kong.** Hydraulic Engineer. Assessment of flooding impacts using MIKE 11 HD and MIKE 11 GIS. Development of flood plain management options for drainage master plan requirements. Development of automated flood plain mapping system.

**1998** **Windmill Power Generation, Lillgrund Øresund Hydraulic Impact and Sediment Plume Analysis, Copenhagen., Denmark.** Hydraulic Engineer. Assessment of flow blocking potential from the construction of 37 Wind Power Generator foundation piers in the Øresund. The study involved the use of a fully three-dimensional model (MIKE 3) to assess the reduction in flow and salinity.

**1997** **Modélisation prospective de la Loire Estuarine, Nantes, France.** Hydraulic Engineer. Predictive modelling of the Loire estuary to determine the long-term evolution of water quality, morphology and hydraulic behaviour. The study involved the use of a one-dimensional hydrodynamic model (MIKE 11) coupled with water quality, cohesive sediment and morphology models.

**1997** **Aussen-Alster Hydrodynamic Study, Hamburg, Germany.** Hydraulic Engineer. Assessment of flushing characteristics of the Aussen-Alster, a small fresh water lake draining from Hamburg City to the Elbe River. The study involved the use of one- and two-dimensional models to investigate flushing times and pollutant loading from catchment inflow and combined sewer flows.

**1997** **Hamburg Harbour Cooling Water Outlet Assessment, Hamburg, Germany.**
Assessment of thermal impacts from a cooling water outlet in the Elbe River, Hamburg. The study involved the use of coupled one- and two-dimensional models.

**1997** **Songkhla Lakes Water Supply and Quality Study, Songkhla, Thailand.** Hydraulic Engineer. Analysis of irrigation demands from Songkhla Lake in Southern Thailand. The study involved the assessment of proposed irrigation demands and their impacts on the long-term salinity water quality characteristics in Songkhla Lake.

**1997** **Project Manager – Clarence Regional Water Supply Scheme, Grafton NSW, Australia.** Hydraulic and water quality modelling of the Clarence River and tributaries to assess the potential environmental impact of the proposed regional water supply scheme on the aquatic ecology.

**1997** **Project Manager – Hunter River MIKE 11 Model Mapping.** A series of interfacing applications were developed to enable the Hunter River MIKE 11 model to be imported for display and query within the MapInfo mapping software system.

**1997** **Spring Street Flood Study, Sydney, Australia.** Hydraulic Engineer. Development and calibration of extensive urban drainage models using the MOUSE software system to assess flooding impacts for land use planning.

**1997** **Bonnie Doon Flood Study, Sydney, Australia.** Hydraulic Engineer. Development and calibration of extensive urban drainage models using the MOUSE software system to assess flooding impacts for land use planning.

**1996** **Nepean River Flood Study at Penrith - Western Sydney NSW, Australia.** Hydraulic Engineer. Two-dimensional flood modelling of the Nepean River floodplain using MIKE 21. Data processing, model terrain generation land-use mapping and floodplain characteristics were completed using GIS for incorporation into the hydraulic model. Post processing of model results was undertaken with the GIS for hazard identification.

**1996** **Shoalhaven City Water Supply Augmentation Scheme EIS - Nowra NSW, Australia.** Hydraulic Engineer. Hydraulic investigations were carried out to determine the impacts of environmental flows and off take releases from dam storages. Environmental indicators were identified and quantified using numerical modelling and data collection. Flora, fauna and morphological states impacted by the changes to flow environments were identified.

**1996** **Georges River Water Quality Assessment, Sydney, Australia.** Hydraulic Engineer. Eutrophication and Bacterial Fate modelling (MIKE 11 EU) of the Georges River Estuary to evaluate the ecological and human health risk of alternative sewage treatment and sewer infrastructure development strategies.

**1996** **Lake Illawarra and Port Kembla Water Quality Study, Wollongong, Australia.** Hydraulic Engineer. Bacterial fate modelling of sewer overflows and urban runoff into Lake Illawarra and Port Kembla using 2D hydraulic and water quality models. Aqualm modelling for predicted catchment runoff water quantity and quality.

**1996** **BHPP, Eastern Gas Pipeline, Australia.** Hydraulic Engineer. Analysis of hydrologic conditions and environmental impacts for a potential major gas pipeline construction project. The project involved the mapping of over 300 stream crossings using the Arc/View GIS. Data management undertaken using the Access relational data base.

**1996** **Straits of Johor Hydrologic Investigations, Singapore. Hydraulic Engineer.** Analysis of rainfall and evaporation data. Development of a NAM hydrological model for the prediction of long term runoff hydrographs in water quality studies.

**1996** **Sepang Marina Development, Malaysia. Hydraulic Engineer.** Nitrogen and phosphorous transport dispersion modelling for proposed marina development using the one- dimensional model - MIKE 11. Model development, estimation of export loads and catchment runoff.

**1996** **Puteri Marina Development, Malaysia,** Hydraulic Engineer. Nitrogen and phosphorous transport dispersion modelling for proposed marina development using the one-dimensional model- MIKE 11. Model development, estimation of export loads and catchment runoff.

**1995** **Emu Plains Flood Study, Western Sydney NSW, Australia. Hydraulic Engineer.** Hydraulic Engineer. Two-dimensional flood modelling of the Emu Plains floodplain using MIKE 21. Data processing and model terrain generation was completed using GIS. Land-use and floodplain characteristics were mapped using GIS for incorporation into the model. Post processing of model results was undertaken with the GIS for hazard identification.

**1995** **Ingleside Warriewood Water Cycle Management Study, Northern Beaches, Sydney, Australia.** Project Engineer. Application of MIKE 11 and RAFTS-XP models to study the impacts of a proposed urban release area on water quantity and quality.

**1995** **Newcastle City Council (NCC), Flood Management Mapping, Australia**. Project Engineer. A polygon data layer was developed to identify all regions within the council with flood related issues. This data layer was incorporated into the council MAP/INFO GIS to allow immediate identification at the customer service desk. The project involved the development of a terrain model of NCC and the estimation of extreme flood extents using GIS techniques and modelling systems.

**1995** **Development of an Integrated Quality Quantity Management Model (IQQM).** Project Engineer. Conceptualisation, development and application of a groundwater/surface water interaction module for flow and salinity as part of the IQQM project undertaken by the NSW Department of Water Resources.

**1995** **Floodplain Assessment, Narrabeen Creek, Sydney NSW, Australia.** Project Engineer. An assessment of flooding behaviour under existing and post development conditions was carried out to determine the impacts of proposed channel improvements and detention basin designs on flood extents.

**1995** **Narara Floodplain Management Study, Gosford, Central Coast NSW, Australia**. Project Engineer. Conversion of HEC-2 and CELLS models to MIKE 11 with verification of final model to published results. Modelling of design and PMF events to evaluate alternative flood mitigation options. Presentation of flooding results and extents using GIS.

**1994** **Tuggerah Lakes Flood Study and Flood Forecast System, Central Coast, NSW, Australia. Hydraulic Engineer.** Project Engineer. Development and calibration of MIKE 11 flood forecast and flood study models as part of an integrated flood warning system for Tuggerah, Munmorah and Budgewoi Lakes.

**1994** **Throsby Creek/Newcastle CBD Flood Investigations, Newcastle, NSW, Australia.** Project Engineer. The project involved the development of one- and two- dimensional models using MIKE 11 and MIKE 21 to determine existing flood behaviour. GIS was used to allow for a seamless presentation of results environ-mental conditions constraints. Damages assessment, hazard identification, optimal flood management solutions and flood evacuation route selection were carried out as a pilot project using a GIS.

**1994** **Honeysuckle Development Urban Drainage Study, Newcastle, NSW, Australia.** Project Engineer. Development of a MIKE 11 UD (Urban Drainage) model of the Newcastle CBD to evaluate flood mitigation options proposed for the honeysuckle re-development. Rainfall-runoff modelling of the catchment was completed using RAFTS-XP with results interfaced to the MIKE 11 model for hydraulic simulation. Presentation and mapping of results using GIS.

**1993** **Hexham Swamp Inundation Study, Lower Hunter Valley, NSW, Australia.** Project Engineer. Development and application of MIKE 21 model to aid the estimation of flood inundation areas. Application of MIKE 11 and MIKE 21 models for salinity investigations.

**1993** **Moruya River Floodplain Management Study, Moruya, South Coast, NSW, Australia.** Project Engineer. Conversion of Rubicon model to MIKE 11 and verification of results. Modelling of design and PMF events to evaluate alternative flood mitigation options.

**1993** **Ironbark Creek, Total Catchment Management Model Newcastle, NSW, Australia.** Project Engineer. Hydrological rainfall runoff models were developed using RAFTS to generate catchment flows. Linkages of hydraulic modelling systems to GIS were developed to allow for a seamless presentation of simulation results and environmental conditions and constraints. A spatial decision support system (SDSS) was developed around the GIS to support, damages assessment, hazard identification, optimal flood management solutions.

**1993** **Minnamurra River (Rocklow Creek), Flood Study, Kiama, South Coast, NSW, Australia.** Project Engineer. Application of MIKE 11 & RORB to proposed development on Rocklow Creek to determine effects of floodplain filling.

**1993** **Hawkesbury River Floodplain Management Study, Western Sydney, NSW, Australia.** Project Engineer. Conversion of Rubicon model to MIKE 11 and re-calibration & verification to ensure compatibility between models. Modelling of design and PMF events and interpretation of model results.

**1993** **Wind Wave Modelling of Port Phillip Bay and Corio Bay using MIKE 21, Melbourne, VIC, Australia.** Project Engineer. Modelling and analysis of sediment transport processes in Corio Bay.

**1992** **Satwave Software Development. Project Engineer.** Processing of remotely sensed wave data collected by Satellite Altimetry to a usable data base form on a PC media base. Development of interface software to read, analyse and plot the records from the wave data base.