Disaster Management Tool – Brisbane River 2D GPU Model

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Introduction

The Disaster Management Tool (DMT) is a two-dimensional (2D) Brisbane River hydraulic model that has been developed for the Queensland State Government for disaster management arrangements. The context for development of the DMT was the 2013 flood event, which highlighted a need for interim disaster management outcomes, given the Brisbane River Catchment Flood Study (BRCFS), developed in response to the 2011 flood event and subsequent Queensland Flood Commission of Inquiry (QFCoI, 2012a, 2012b) recommendations is due to be completed in 2016. It follows, that the primary objective of the DMT was to expedite and deliver a set of disaster management maps for Somerset Regional Council (SRC), Ipswich City Council (ICC) and Brisbane City Council (BCC), for a range of notional flood events. This paper will discuss the development and calibration of the DMT, the benefits, model developmental issues and limitations associated with the use of emerging Graphics Processing Unit (GPU) technology, and ultimately how the use of such technology assisted City Projects Office to expedite, and deliver a calibrated, large scale 2D flood model within relatively short timeframes.

Objective of project

The primary objective of the DMT project was to deliver a set of disaster management maps prior to the 2013/2014 wet season. The DMT maps also include information on gauge height relationships, flood flows and timing of the expected flood peak in order to provide 'heads up information' to disaster managers. This objective was met with the completion of *Brisbane River Catchment Flood Study Disaster Management Tool (DMT) Interim Calibration Report* in October 2013 together with associated flood inundation map deliverables.

Since the issue of the Interim Calibration Report (BCC, 2013), additional work and investigations have been undertaken with a view to improving the DMT hydraulic model calibration. Specifically, these investigations and sensitivity analyses have focused on rating curve consistency with the data derived from other agencies, and the BRCFS hydrology phase project, as well as matching the 2011 and 2013 ADCP (Acoustic Doppler Current Profiler) flow gaugings. Within the scope and limitations of the DMT project, these objectives have now been achieved with the development of the DMT Mark (Mk) II hydraulic model. The DMT Mk II hydraulic model utilises a finer grid resolution of 20m for model computations as compared to the DMT MK I hydraulic model used to prepare the Interim Calibration Report (BCC, 2013) which utilised a 30m grid. The final report, mapping deliverables and associated metadata based on the DMT MK II hydraulic model was delivered to Queensland State Government in November 2014 and prior to the 2014/2015 wet season.

Study extents

The overall extent of the DMT is illustrated in Figure 1 and comprises a model area of 5,140 km^2 or approximately 40% of the total Brisbane River catchment (13,500 km^2). Figure 1 also illustrates that the western extent of the DMT hydraulic model is well beyond the boundaries of SRC into the Lockyer Valley Regional Council (LVRC) area. The DMT project hydraulic model area was defined based on the extents of the DTM (Digital Terrain Model), and in conjunction with the Unified River Basin Simulator (URBS, Carroll, 2012) hydrologic model sub-catchment breakdown (Seqwater 2013 and Seqwater 2013a) of the Brisbane River catchment.

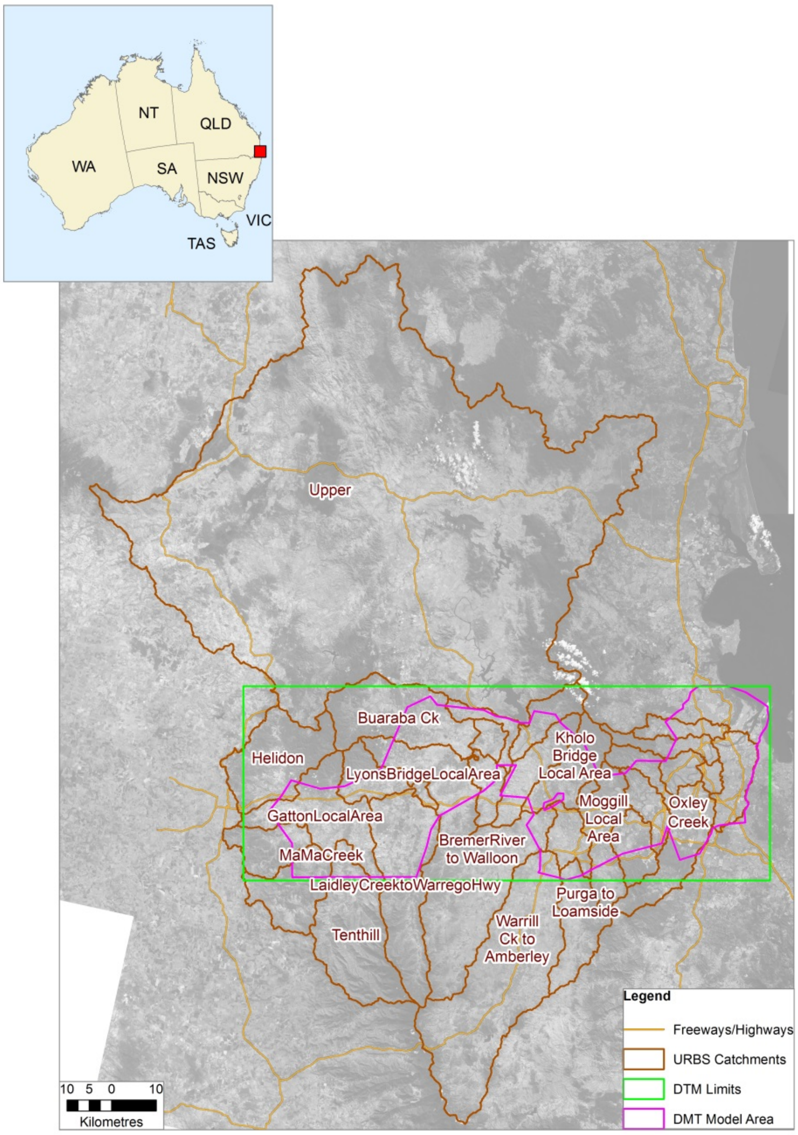

Figure 1: Brisbane River 2D GPU Model Extents

Study data

The primary data inputs for development of the DMT hydraulic model include:

- 10m Digital Elevation Model (DEM) from the Digital Terrain Model (DTM) and Bed Level Sensitivity Analysis (BLSA) project (BCC, 2014a)
- Seqwater (2013a, 2013b, 2013c) URBS model as at May 2013 (containing recorded water level information at key gauges) for five historical flood events; 2011, 2013, 1974, January 29 1893 and February 1893
- Relevant model data from the *Brisbane River Hydraulic Model to Probable Maximum Flood* (2009). An example includes the base hydraulic roughness map used in the DMT.

Essentially the DMT project has updated the original Brisbane River hydraulic model (BCC, 2009) using the latest readily-available data with calibration of the model undertaken against the 1974, 2011, 2013 historical flood events, whilst the two largest 1893 historical floods were used as additional events due to their large magnitude.

Method review

The DMT model has been developed in TUFLOW (2013) GPU (Graphics Processing Unit) software. Findings from the study indicate that the GPU software can undertake simulations 30 times faster than traditional Central Processing Unit (CPU) technology which historically has been used to undertake 2D flood modelling. The use of this software has enabled the original Brisbane River hydraulic model (BCC, 2009) to be extended further west and has allowed a reduction in grid resolution from 30m to 20m for model computations whilst maintaining reasonable model run times. Such outcomes would not have been possible if traditional CPU software technology had been adopted. Some limitations do exist with the software, the most noticeable being that 1D hydraulic structures currently are not able to be modelled with the GPU software. Given the objective of this project is to produce broad scale disaster management maps, this limitation has not significantly impacted the DMT outcomes. It does, however, limit the application and use of the DMT model for other purposes.

The DMT calibration process has been dynamic, inclusive of stakeholder and interagency feedback, and has involved third party technical review for rigour. Further, the process involved interaction with the hydrology phase of the BRCFS in order to achieve consistency of results (rating curves), and a satisfactory calibration outcome for this project. The calibration process has involved numerous sensitivity analyses and investigations, the results of which have been incorporated into the final DMT hydraulic model.

Overall the DMT Mk II hydraulic model produced satisfactory calibration outcomes for the larger flood events of 1974, 2011 and both 1893 events. This is demonstrated by the satisfactory comparison of DMT model outputs with recorded flood inundation extents for these flood events. The acceptable performance of the model for these events can be attributed in part to the good quality survey data available over the floodplains. This has led to a good representation of the flood conveyance and storage characteristics within the floodplain which is critical for good calibration of the large flood events.

The 2013 event being the smallest flood event analysed, is the only event where further calibration investigations are warranted. This is likely to require a joint hydrologic and hydraulic review, noting that such a review is beyond the scope of the DMT project. The calibration process for the 2013 flood event has shown that the DMT model results are very sensitive to changes in the creek and river bathymetry. Consequently, the calibration outcome for smaller events is very much dependent on the quality of survey data that defines the channel bathymetry.

In consultation with stakeholders from the BRCFS Technical Working Group, the 1974 flood event has been used to develop notional flood profiles of varying magnitude for the Lockyer Creek, Bremer River and Brisbane River systems in order to produce a range of notional flood profiles for the purpose of disaster management flood inundation extent mapping. The 1974 flood event was selected as the basis for the notional profile development due it being a single peaking voluminous hydrograph not impacted by dam operations, and so, for the purposes of generating disaster management flood inundation extents from the DMT hydraulic model this approximates steady state flow.

In total, 92 notional profile simulations have been undertaken for the DMT project as follows:

- *36 for Somerset Regional Council (6 x 6 Lockyer Creek/Brisbane River coincident flooding scenarios)*
- *36 for Ipswich City Council (6 x 6 Bremer River/Brisbane River coincident flooding scenarios)*
- *20 for Brisbane City Council (20 notional profiles with varying storm conditions)*
- *20* for SEQ region based on the scenario above [For both BCC and the SEQ region of the 20 simulated only 17 were mapped]

This has resulted in the production of 106 maps for the SEQ region, and an example is shown in Figure 2.

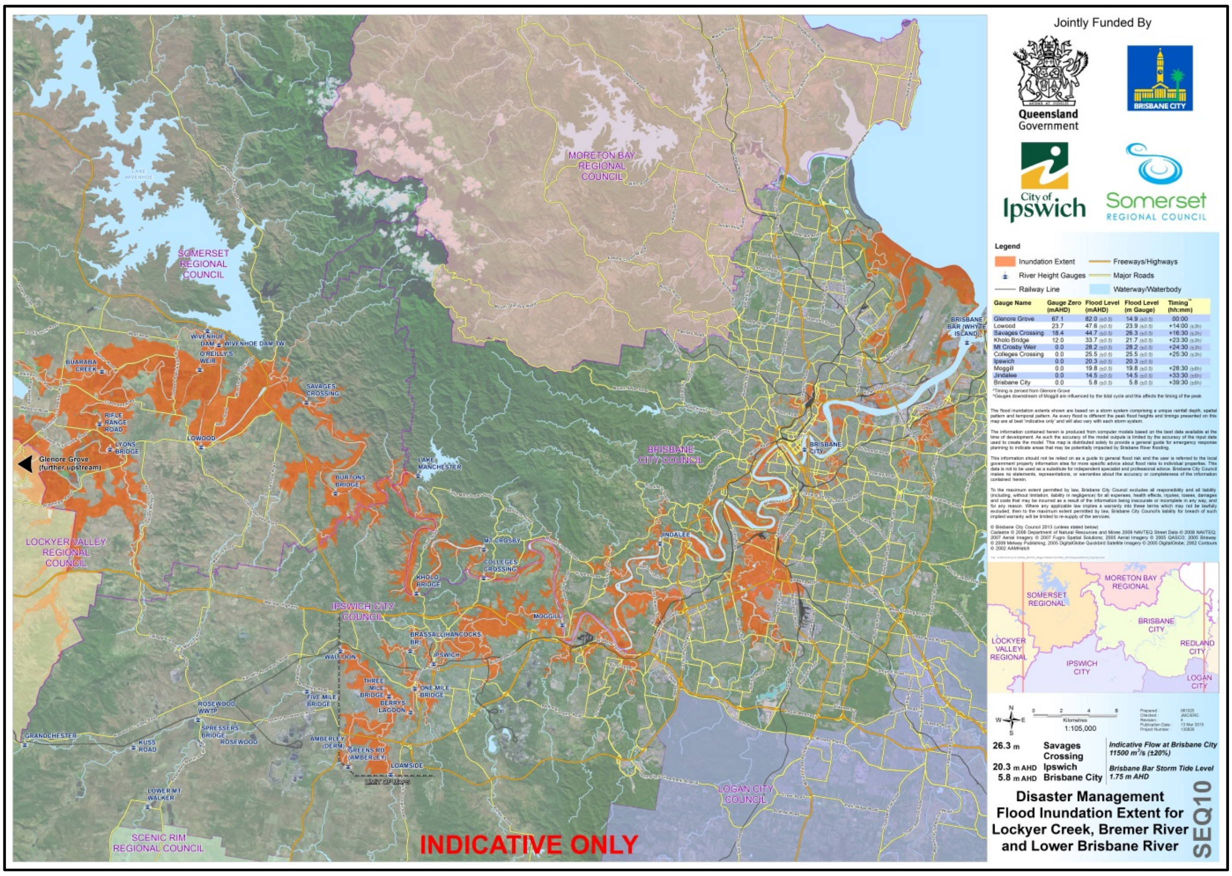

Figure 2: DMT SEQ Regional Output for SRC, ICC and BCC

Digital terrain model (DTM) and bed level sensitivity analysis (BLSA)

The DMT topographic data is based on a DTM which was developed as part of the DTM and BLSA project (BCC, 2014), and preceded development of the DMT model (BCC, 2014b). The extents and data sources utilised in the Digital Terrain Model (DTM) are outlined in more detail in Figure 3. A 10m Digital Elevation Model (DEM) was produced from the DTM, for input into the DMT hydraulic model, however DEM's smaller than 10m down to 1m, can be generated from the DTM if required.

The DTM comprises the latest bathymetric survey data sets from the Port of Brisbane (hydrographic survey corresponding to the tidal extents Brisbane River, mouth to College's Crossing) in conjunction with floodplain ALS (Airborne Laser Scanning) or LiDAR (Light Detection and Ranging Survey) survey data. Due to the size of the geographical area (in excess of 5,000 km^2) a large amount of survey data covering 6 local government areas was collected. The number of ALS points processed in the development of the DTM was approximately 6,415 million (6.4 billion). Despite the large amounts of data collected and processed, there were still some gaps in the available data sets which may be shown to be critical with further, more detailed hydraulic modelling, however the survey gaps are unlikely to influence results within the scope and modelling tolerance of the DMT project.

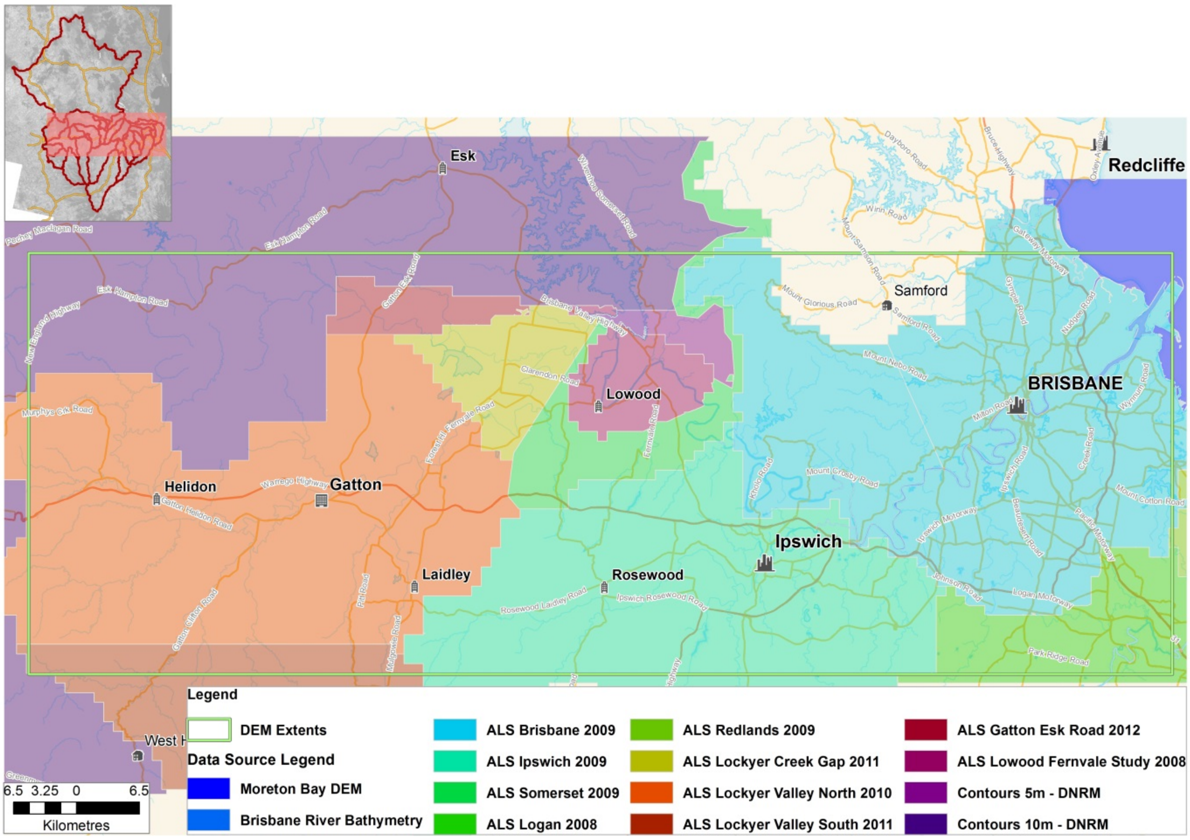

Figure 3: DTM Model

A single DTM developed from the DTM and BLSA project (BCC, 2014) was adopted as the 'Base DTM' for the DMT project. This DTM is based on the latest floodplain LiDAR and bathymetry (post 2011 flood) information and represents the best information available at the time of this study. In order to test this assumption, a BLSA was undertaken from Victoria Bridge to the mouth of the Brisbane River. Figure 4 outlines the extents of the BLSA. The results of the BLSA (BCC, 2014a) are reproduced in Table 1 and Table 2 and have relevance to the DMT project as they provide a guide to the sensitivity of the hydraulic model to changes in model bathymetry, and ultimately how this might translate to the calibration on the DMT model across historical flood events.

The conclusions from the BLSA results, as outlined in Table 1 and Table 2, is that the hydraulic model appears to be relatively insensitive to changes in bathymetry (for large flood events) in the very low reaches of the Brisbane River, with notable impacts being predominantly localised and limited to the Brisbane City Gauge, and to a lesser degree at Jindalee.

Whilst localised bed changes occur (scour and deposition) during each historical flood event, it appears the Brisbane River (as defined by its current geomorphology) appears to be in 'regime'. When a major river is considered 'in regime', large variations in expected flood levels are not expected between comparable flow events as movement in the bed will compensate to even out the flood slope.

The BLSA supports the modelling approach adopted in the DMT project, where a single DTM has been used successfully to assess and calibrate all historical flood events. The only exception is the 15th February 1893 historical flood event, where a bed level adjustment of 1m (for siltation effects) has been required for calibration. The siltation correction adjustment is justified by the historical records of the 1893 floods which suggests that a large of volume of silt was initially deposited by the 29th January 1893, prior to the occurrence of the 15th February 1893 historical flood event which occurred only two weeks later.

Table 1: BLSA – 2011 Flood Event

Scenario (S)	Ipswich	Moggill	Jindalee	Brisbane
Existing	18.91	17.84	12.65	4.42
S1: -4m	18.89 (-0.02)	17.77 (-0.07)	12.43 (-0.22)	3.02 (-1.40)
S2: -2m	18.90 (-0.01)	17.80 (-0.04)	12.50 (-0.15)	3.52 (-0.90)
S3: +2m	18.95 (+0.04)	17.93 (+0.09)	12.94 (+0.29)	5.87 (+1.45)

Table 2: BLSA – February 1893 Flood Event

Scenario (S)	Ipswich	Moggill	Jindalee	Brisbane
Existing	23.43	22.92	17.25	8.17
S1: -4m	23.35 (-0.08)	22.81 (-0.11)	16.85 (-0.40)	5.69 (-2.48)
S2: -2m	22.38 (-0.05)	22.85 (-0.07)	17.00 (-0.25)	6.69 (-1.48)
S3: +2m	23.53 (+0.10)	23.04 (+0.12)	17.62 (+0.37)	9.72 (+1.55)

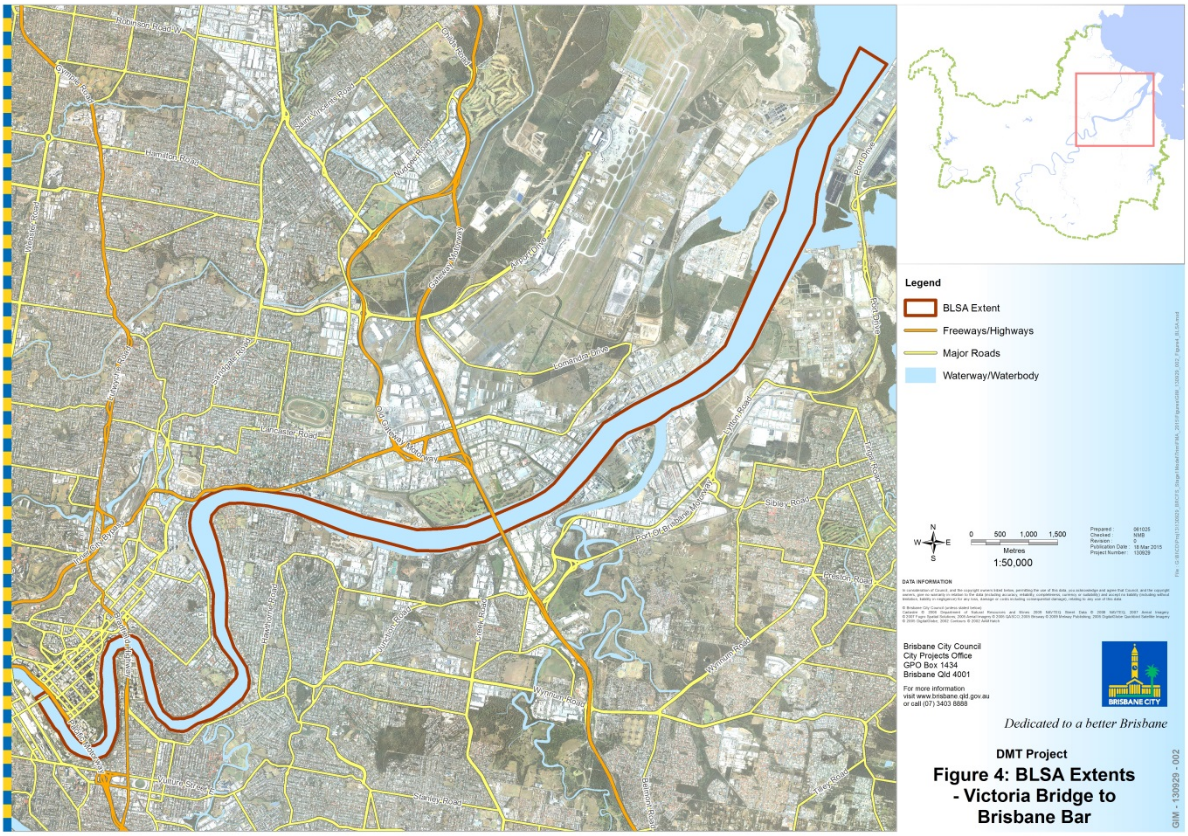

Figure 4: BLSA Extents – Victoria Bridge to Brisbane Bar

Modelling platform

The DMT project was developed using TUFLOW GPU software. The software versions used during the project are outlined in Table 3 and were continuously updated in order to provide better outcomes for the DMT project.

Table 3: TUFLOW GPU Software Versions used for the DMT

Software Version	Date of Use for the DMT Project	Use/Application
2012-05-AE-iSP-w64	28 March to 29 June 2013	Initial Model Development
2013-06-AJ-Dev-iSP-w64	3 July to 14 July 2013	Initial Calibration
2013-07-AA-Dev-iSP-w64	15 July to 3 October 2013	Calibration and Original Productions Runs
2013-09-AK-Dev-iSP-w64	10 October to 11 October 2013	Software Testing/Validation
2013-09-AL-Dev-iSP-w64	14 October to 15 November 2013	R1 - Interim Production Runs (Maps issued to State Oct. 2013)
2013-12-AA-iSP-w64	10 Dec. 2013 to 13 March 2014	Rating Curve Review and Recalibration
2013-12-AB-iSP-w64	13 March to 10 April 2014	Rating Curve Review and Recalibration
2014-04-AF-Dev-iSP-w64	10 April to June 2014	R2 - Final Production Runs (Maps issued to State June 2014 and Final Report November 2014)

Notes: R1 – Revision 1 of Maps, R2 – Revision 2 of Maps (Final product)

The primary reason CPO has adopted the GPU technology, is its ability to run flood models (based on our experience on this project) 30 times faster than the CPU software version (Central Processing Unit). Speed gains of this magnitude effectively translate to overnight calibration run times, as opposed to many days, if a traditional CPU based software model were adopted. This makes the computation of large flood models that contain millions of computational grid points such as the Brisbane River possible, where previously this was just not feasible due to impractical run times.

Software limitations

GPU flood modelling technology is relatively new, only becoming commercially available within Australasia (Australia and New Zealand) in the last 12-18 months. The application and use of GPU technology on the Brisbane River represents a significant technologic advancement in 2D flood modelling for Australasia, with only several other known examples or applications, where the GPU technology has been applied to a comparably sized large catchment (greater than 5,000 km^2).

There been several versions of the software applied to the project, with new features and or improvements being made to these releases of software during the life of the project. The developmental nature of the GPU software has meant there are currently restrictions to available features when compared to the traditional CPU version. The most noticeable limitation is that currently, 1D hydraulic structures are not able to be modelled with the GPU software. This has not largely impacted the DMT, given the scope and objectives of this project is to produce broad scale disaster management maps, however there have been other software limitations experienced which have impacted this project.

For example, the first two GPU software versions applied to this project, had limited functionality with regard to the output of discharge which is obviously necessary for the purposes of model calibration and the determination of rating curves. Further, changing the model grid size was not permissible until the 2013-12-AA release was made available in early December 2013. Also, it is important to highlight that the 2013-12-AA software release, upon detailed of review of results by City Projects Office, was found to produce ‘spikey’ or ‘bouncy’ profile results (localised instabilities) illustrated in Figure 5 for the very high notional flood profiles (generally greater than 11,000 m^3/s at the Brisbane City Gauge).

The spikes were found to be slight instabilities that occurred for a brief period during the simulation when the Nc Courant Criteria was pushed to its limit. The spikes were found to occur in the middle of the river where the water was deepest and fastest (i.e. high Courant number), and their impact did not extend onto the floodplain. Re-running the simulations identified as having experienced instabilities with a 20% reduction in the Nc Courant condition criteria resolved the problem. The instabilities in the GPU software were overcome by the use of a Courant Number condition limiting command, which the 2013-12-AB version automatically contains (compiled into the internal GPU software computations). [The command specifies a Maximum Courant Number of 0.8 which maintains the Nc Courant condition value at 1.6 or less for the GPU Solver criteria, as opposed to 2 previously used in the GPU Fast Solver Mode.]

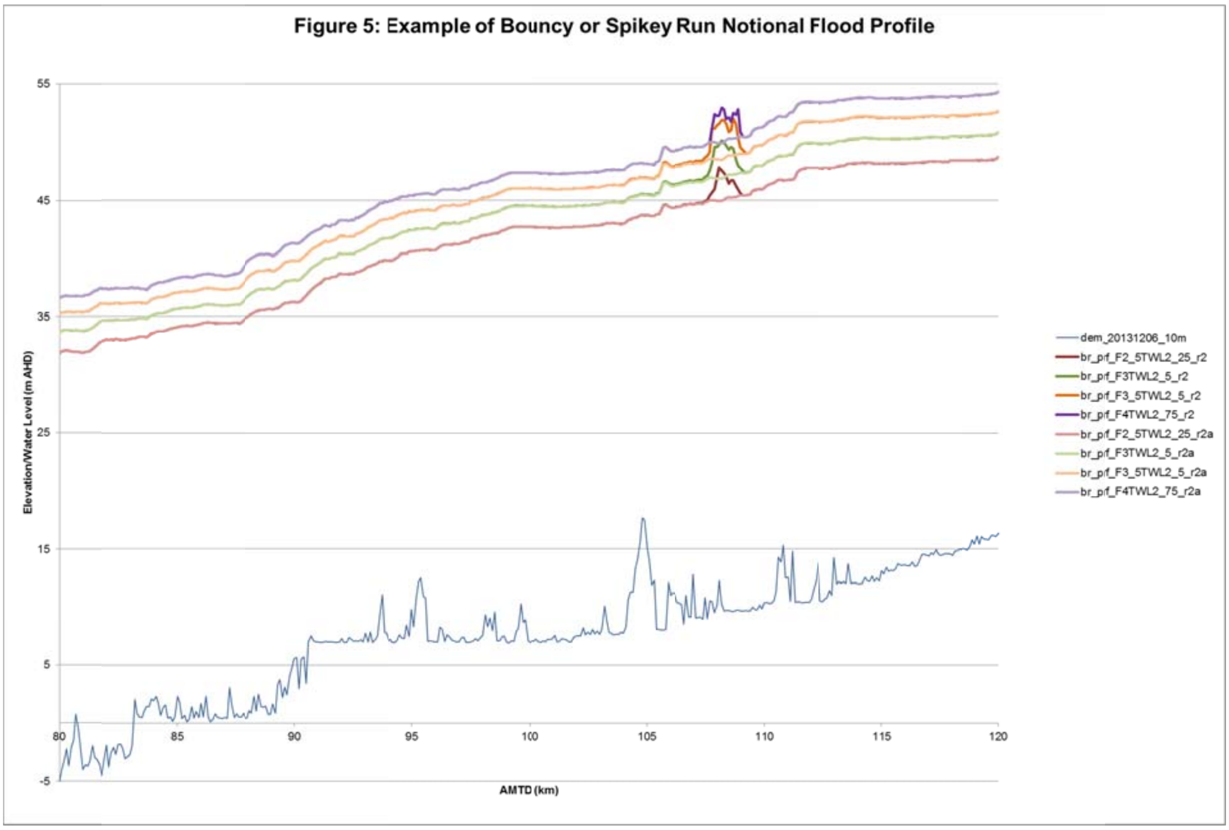

Figure 5: Example GPU Fast Solver Bouncy or Spikey Runs

Benchmarking comparisons

In order to validate the GPU, a benchmarking comparison was undertaken against traditional CPU software using the F2TWL2.25 notional profile. [The F2TWL2.25 represents a flood event approximately 2 times larger than the historical 1974 flood event.] The results of the benchmarking exercise are detailed in Table 4 with the model run time comparison outlined in Table 5. The results indicate a difference in water level attributable to the different software utilised, and that the GPU solver is 26 to 32 times faster than traditional CPU software.

The primary reason for the differences in water level is that the two solution schemes, whilst solving the same equations, are inherently different. The CPU software is a second order semi-implicit (matrix) finite difference solution, whilst the GPU software is an explicit first order spatial finite volume solution. Observations to date from the study indicate that for comparable model set-up, the GPU software produces higher water levels, up to 1m at some locations along the Brisbane River. [Refer TUFLOW 2013-12 Release Notes from TUFLOW.com (2013) for further information on computational differences between CPU and GPU software.]

In addition, a GPU 10m grid simulation was also undertaken (using the same F2TWL2.25 notional profile) to consider the effect of grid resolution on rating curves. The results of 10m grid show little to change to the 20m grid rating curves as detailed in Table 4. The GPU 10m simulation took 54hrs to run (with a Maximum Courant Number of 0.8).

Table 4: Notional Profile (1) – Peak Water Level Benchmarking (BM) Comparisons

[1]	[2]	[3]	[4]	[2]-[3]	[2]-[4]
Gauge	**GPU 20m (m AHD)**	**CPU BM 20m (m AHD)**	**GPU BM 10m (m AHD)**	**GPU 20m – CPU BM 20m**	**GPU20m – GPU BM 10m**
Helidon	138.29	137.97	137.78	0.32	0.51
Gatton Weir	106.34	106.12	106.36	0.22	-0.02
Glenore Grove	82.61	82.73	82.73	-0.12	-0.12
Lyons Bridge	64.42	64.26	64.50	0.16	-0.08
O'Reillys Weir	52.35	51.73	52.04	0.62	0.31
Lowood	51.55	50.72	51.13	0.83	0.42
Savages Crossing	50.50	49.56	50.01	0.94	0.49
Mt Crosby Weir	35.09	34.41	34.70	0.68	0.39
Amberley	29.69	29.69	29.83	0.00	-0.14
Loamside	28.85	28.63	28.67	0.22	0.18
Ipswich	26.70	26.51	26.44	0.19	0.26
Moggill	26.44	26.27	26.24	0.17	0.2
Centenary Bridge	20.50	19.97	19.85	0.53	0.65
Brisbane City	10.51	10.13	9.73	0.38	0.78
Brisbane Bar	2.19	2.23	2.27	-0.04	-0.08

Note: (1) F2TWL2.25GPU Flood Event

Table 5: GPU and CPU- 20m grid - 2D Model Benchmarking Comparisons

Model Simulation. (hrs) Software Version	**Model Computational Time (hrs) and Simulation hrs/Computational hrs Ratio**					
	R2 – CPU 20m grid		**R2 – GPU 20m grid**		**R2A – GPU 20m grid**	
	CPU Comp. Time (hrs)	**Sim/Comp Ratio**	**GPU Comp. Time (hrs)**	**Sim/Comp Ratio**	**GPU Comp. Time (hrs)**	**Sim/Comp Ratio**
F2TWL2.25R2 (192) 2014-04-AF-Dev-iSP-w64	214	0.9	6	32	7.5	26

Notes: R2: Revision 2, R2A: Revision 2 with Maximum Courant Number of 0.8

Hardware

CPO has used a specialist high-end supercomputer to deliver the DMT project for the State. The hardware features are summarised in Table 6 and Table 7.

Table 6: CPU Hardware Features

Machine	RAM	CPU (16 Cores)	Hard Disk Drive	Specialist Features
HPZ820	64 GB	2 x 8-Core Intel Xeon E5-2687W 3.10Ghz 20MB Cache 1600 MHz BUS	7 TB	1125W Power Supply with HP Liquid Cooling

Table 7: GPU Hardware Features

Graphics Card	NVIDIA Driver	GPU RAM	CUDA (1) Cores
Quadro K5000 (GPU 1)	332.50	4 GB	1,536
Tesla K20 Card (GPU 2)	332.50	5 GB	2,496
Tesla K20 Card (GPU 3)	332.50	5 GB	2,496
Titan Z* (*latest NVIDIA graphics card not used in this study)	347.52	12 GB	5,760

Note: (1) Compute Unified Device Architecture (CUDA) is a parallel computing platform and programming model created by NVIDIA and implemented by GPUs that they produce. Using CUDA, the latest NVIDIA GPU's become accessible for computation like CPUs.

It is also worth highlighting the latest NVIDIA Driver (at the time of the study) was used for the final production runs. The NVIDIA driver must be regularly checked for updates, as the latest driver when used in conjunction with the latest GPU software can make a significant improvement to the model run times whilst utilising the same existing hardware. For example, this was evidenced in the R2 productions runs, as outlined in Table 8, where a significant improvement was noted in the post March 2014 model run times when compared to model run times undertaken in December 2013. This effectively translates to a 30% improvement and highlights the speed at which GPU technology is changing and improving.

Table 8: Comparison of GPU Computational Times with different NVIDIA Drivers

Model Simulation (Model Simulation Date)	Simulation. (hrs)	Software Version	NVIDIA Driver Version (Date)	Model Computational Time (hrs) and Simulation hrs/ Computational hrs Ratios	
				R2 – GPU	
				GPU Comp. Time (hrs)	Sim/Comp Ratio
2011 Flood Event (10/12/2013)	483	2013-12-AA-iSP-w64	332.01 (27/11/2013)	21.1	22.9
2011 Flood Event (11/4/2014)	483	2014-04-AF-Dev-iSP-w64	332.50 (4/2/2014)	16.3	29.6

GPU Solver criteria and model runs time

There are approximately 10 million computational grid points in the DMT model. The GPU software uses an adaptive solver with a varying computational time-step from 0.5 to 2 seconds, satisfying three key criteria as outlined in Table 9. The GPU model runs have been run using 3 graphics cards in parallel as detailed in Table 7. It is anticipated that the current model run times detailed in Table 10 could be potentially improved by as much as a factor 2 to 4 times, if the latest GPU cards were to be used in addition with the most recent NVIDIA drivers, in conjunction with a supercomputer that is able to support a 4th graphics card.

Table 9: GPU Solver Criteria

GPU Solver Mode	Calculative GPU Criteria		
	Nc (Courant Condition)	**Nu (Velocity Condition)**	**Nd (Depth Condition)**
Fast GPU Solver	2	1	0.3
Nc Limiting GPU Solver (Maximum Courant Number of 0.8)	1.6	1	0.3

Note: (1) Refer to the TUFLOW 2013-12 Release Notes from TUFLOW.com (2013) for further information on these calculative GPU criteria.

Table 10: GPU Computational Times

3 x Graphics Card in Parallel (Software Release Version)	Model Run Time (hrs)					
	Historical Flood Event (Model Simulation hrs)					**Notional Flood Profiles (*Longer times for larger profiles)**
	2011 (483)	**2013 (336)**	**1974 (192)**	**Jan. 1893 (288)**	**Feb. 1893 (244)**	
(2014-04-AF-Dev-iSP-w64)	16.3	11	6	10	9	6-7.5*
(2014-04-AF-Dev-iSP-w64 + Nc Limiting)	19	13	7	12	11	7.5-9*

Conclusions

The DMT hydraulic model has been developed for the Queensland Government for interim disaster management arrangements pending the completion of the Brisbane River Catchment Flood Study. The context for development of the DMT was the 2013 flood event, which highlighted a need for interim disaster management outcomes, given the BRCFS (developed in response to the 2011 flood event and subsequent QFCoI recommendations) is due to be completed in 2016.

It follows, that the primary objective of the DMT was to expedite and deliver a set of disaster management maps for SRC, ICC and BCC, for a range of notional flood events, in advance of the 2013/2014 wet seasons. That objective was met with the issue of the DMT Interim Calibration Report and associated disaster management maps in October 2013.

Since this time, stakeholder peer review comments on the original DMT hydraulic model and the associated Interim Calibration Report (BCC, 2013) have largely driven a recalibration process, which has resulted in the development of the DMT Mark (Mk) II hydraulic model.

The DMT Mk II hydraulic model utilised a finer grid resolution (20m grid for model computations, in lieu of 30m used in the DMT Mk I model) and produced more detailed gridded outputs (10m x 10m grid resolution for mapping purposes).

The key improvements in the DMT Mk II hydraulic model are with respect to rating curve consistency with other agencies, and matching the ADCP flow gaugings at Centenary Bridge for the 2011 and 2013 flood events. These outcomes have been achieved, as far as practicable, within the scope and limitations of this project, with the final deliverables based on the DMT MK II hydraulic delivered to Queensland Government in November 2014.
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In summary the DMT Mk II hydraulic model produces acceptable calibration outcomes for large historical flood events (2011, 1974 and both 1893 flood events) commensurate with the broad scale disaster management objectives of this project. However the smaller 2013 event is the only historical flood event where further calibration investigations are warranted and this is likely to require a joint hydrologic and hydraulic review. Such a review is out of scope for the DMT project

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    - Department of Infrastructure Local Government and Planning
    - Department of Natural Resources and Mines
    - Department of Science, InformationTechnology and Innovation
    - Department of Energy and Water Supply
- BRCFS Steering Committee and Technical Working Group
- BRCFS Stakeholders including:
    - Queensland State Government
    - Seqwater
    - Bureau of Meteorology
    - SRC, ICC, LVRC, BCC
- BMT WBM P/L for technical support and review
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