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2D Hydraulic Modelling over a Wide Range of Applications with ANUGA

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Abstract: In December 2006 The Australian National University and Geoscience Australia released to the public a Free 2D Unstructured Grid, Finite Volume, Hydrodynamic Model. The model was a resultant of a Mandate put to GA by the Australian Federal Government to build capacity to identify and manage Hazard and Risk. This was interpreted and actioned by providing a software tool to aid in assessing the impact of tsunami. The model was based on work done by Zoppou and Roberts (1999). However the code provides a solution to the shallow water wave equation with specific focus on capturing shocks. This therefore also provides an opportunity to utilise the model for a broader range of situations than those it was originally written for.
To date the model has been extended to model floods resulting from rainfall and is now being extended to model structures such as culverts and bridges. In fact one outcome of this is this paper which investigates how well the model can be used to model momentum aspects of culvert and bridge flow and the potential to model energy dissipation.

Keywords: 2D Hydrodynamic, ANUGA, GeoScience Australia, Modelling, Analysis

1. INTRODUCTION

The solution to the full equation of fluid motion through the Navier-Stokes equations is a time consuming and computationally costly undertaking. For this reason various levels of simplification have over the decades provided fast results, although to some extent these simplified models do at times not capture the detail required to adequately identify some types of flow behaviour. These models are however used to model and design infrastructure un-questioned.
The Navier-Stokes equations solve all manner of fluid flow simulation including compressible fluid flow (aerodynamics). Simplification by limiting the range of problems to incompressible fluid with uniform velocity distribution in the vertical direction, hydrostatic pressure distribution and relatively small bottom slope, leads to the St. Venant or Shallow Water Wave Equations. Further simplification leads to the Diffuse Wave equation and simpler again to the Energy Equations, which are solved by models such as HEC-RAS (US Army).

However application of models such as HEC-RAS at times is inappropriate as identified by VanDrie, Herngren (2006), as it is not capable of addressing 2-Dimensional flow or momentum specific problems properly. The design of structures where momentum is a consideration requires a model that will conserve momentum in addition to energy.

The relatively recent development (Dec. 2006) of the ANUGA model by Geoscience Australia coupled with the philosophy of making the model Free and Open Source, has led to the model being adapted quite quickly to a range of situations for which it was not specifically written. The ANUGA model was specifically written to address a perceived lack of adequate models that are able to handle the complexities of a large wave (tsunami) striking a built up (urbanised) coastline. It forms part of the core computational requirement of the “Joint Australian Tsunami Warning Centre”, operated by Geoscience Australia and the Bureau of Meteorology. However it has also now been adapted to model Riverine Flooding and also urban overland flow flooding. Currently there are additional capabilities being added such as modelling culverts and bridges. The aim being to provide a relatively accurate reflection of momentum jets from the outlets of these structures. This is seen as providing a very robust approach to addressing energy dissipation assessment for these outlets.

Further serious consideration is being given to the code being further developed to include scour and deposition routines. This will provide it with still more amazing capability in modelling geomorphological processes and dam break including potential piping failure. Again with regard to culvert / bridge outlets this additional capability will aid in assessing scour potential and requirement for scour / erosion protection.

This paper aims to portray the evolution of ANUGA to date and show the range of applications that it has been used for. From Tsunami's to modelling energy dissipators and identifying complex flow behaviour around bridge piers, and the effects of Dam break on urban environment.

2. ANUGA AND ITS APPLICATIONS

To date ANUGA has been applied to model:

1. Coastal Inundation from Tsunami and storm surge
2. Complex Flood Modelling
3. Urban Flood Models
4. Dam Break
5. Bridge Hydraulics
6. Energy Dissipator behaviour

2.1 Birth of the ANUGA model :- Geoscience Australia Mandate

In 2002 the then Australian Federal Government set several mandates, one of which was to "Build Capacity", for the identification of hazards and management of risk. Details are documented in the 2002 Federal Budget and the 2002 COAG review. Details are also reflected at the following internet links:
http://www.ga.gov.au/about/corporate/workprogram/2006_07/gemd_wp.jsp
http://www.ga.gov.au/urban/projects/nrap/dmap_background.jsp

One of Geoscience Australia's stated key priorities is to "deliver natural hazard risk assessment methods, databases and decision support tools in support of the Disaster Mitigation Australia Package." Another is to "deliver an operational capability to support critical infrastructure protection in Australia".

At the end of 2004 the Indian Ocean Boxing Day tsunami provided a very clear focus for identifying hazard. As a result the Joint Australian Tsunami Warning Centre (JATWC) http://www.bom.gov.au/tsunami/ was set up.

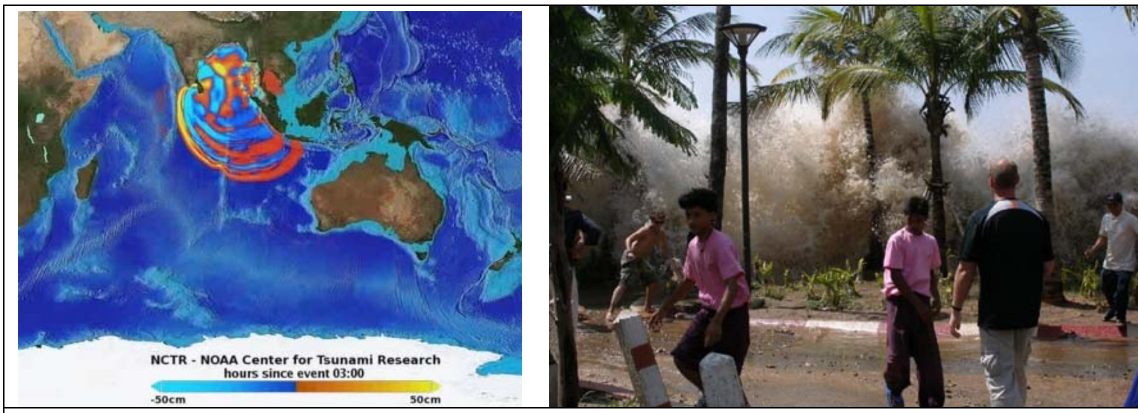

Figure 1 – The 2004 Boxing Day Tsunami, Trigger For The ANUGA Model

During this process it was apparent that although there were abundant good deep water Ocean models that could predict the propagation of a tsunami across the Ocean, there was a lack of modelling capability that identified what would happen when such a wave would strike the coastline (particularly a built up {urban} coastline). Hence the ANUGA model was formulated from previous work completed by Zoppou and Roberts (1999) on a robust algorithm for handling supercritical flow entering upon dry land.

2.2 WHAT IS ANUGA?

The ANUGA manual describes it as:-

- *"The core of ANUGA v1.0 is the fluid dynamics module, called shallow_water, which is based on a finite-volume method for solving the Shallow Water Wave Equation. The study area is represented by a mesh of triangular cells. By solving the governing equation within each cell, water depth and horizontal momentum are tracked over time. A major capability of ANUGA v1.0 is that it can model the process of wetting and drying as water enters and leaves an area.*

This means that it is suitable for simulating water flow onto a beach or dry land and around structures such as buildings. ANUGA v1.0 is also capable of modelling hydraulic jumps due to the ability of the finite-volume method to accommodate discontinuities in the solution."

Further details of the model and its algorithm and how it is applied can be found in the user manual and source code which can be downloaded from the internet at no cost at: http://sourceforge.net/projects/anuga. The other notable point about the model as described in the manual is that it is written in Object Oriented Programming (OOP) language called Python. This provides it with several exceptional qualities.

2.3 WHAT CAN ANUGA BE USED FOR?

As mentioned the ANUGA model was specifically written to model the impact of waves (tsunami) striking the dry coastline and if required accurately interacting with obstacles such as buildings and the like. However the general solution being based on the SWW equation solved with a finite volume approach provides the potential to utilise the model for far more wide ranging flow scenarios. Here in is given a brief overview of some of the application it is being trialled for. The range of application is from a thimble to a 110km2 catchment.

2.3.1 Water Drop in Thimble

The robust approach of the algorithm is quite apparent when a single drop of water is released into a square thimble. The violet splash and wave action in the thimble is an impressive visualisation of the models capability. However this of course is of limited use in the real world.

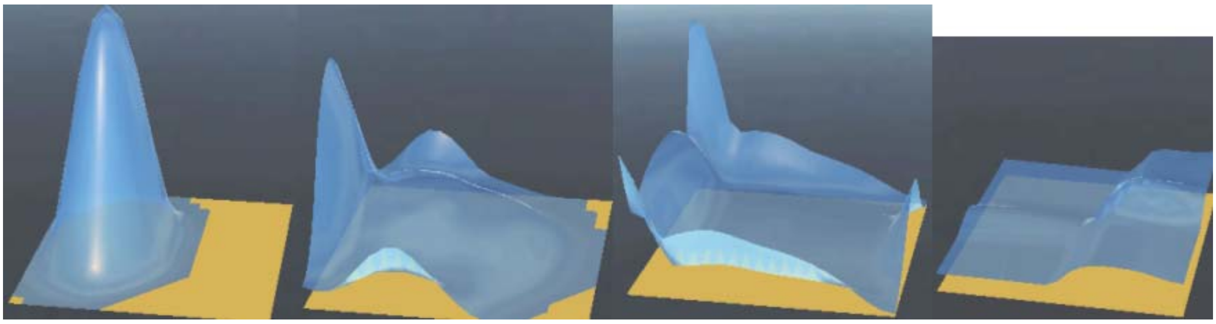

Figure 2 – A Water Drop Falling Into A Square Thimble

2.3.2 Kitchen Sink Hydraulic Jump

Increasing the scale of the simulation from a water drop to a tap flowing into a sink, the model again authentically replicates observed behaviour. The initial hydraulic jump due to the supercritical thin lens of water interacting with the reflective wave that results from water building up on the sink bowl are all clearly visible.

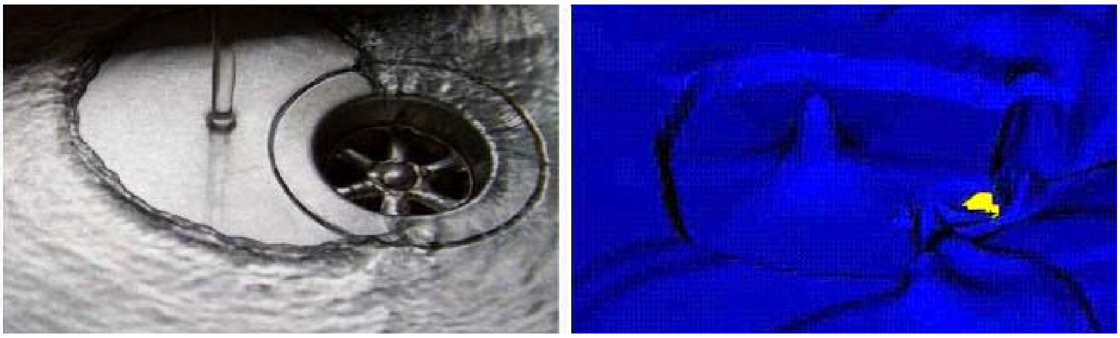

Figure 3 – Example Of Kitchen Sink Simulation

2.3.3 CULVERTS

The "object" (OOP) framework of the code of this model allows the adaptation of additional capability to be augmented relatively easily. For instance as will be described in more detail below the addition of the capability to model culverts has been able to be added without having to change any aspect of the existing code. A culvert simply removes flow from one location an places it at another location whilst maintaining the correct momentum and energy losses. In this manner the momentum jet from the outlet of the culvert can be modelled.

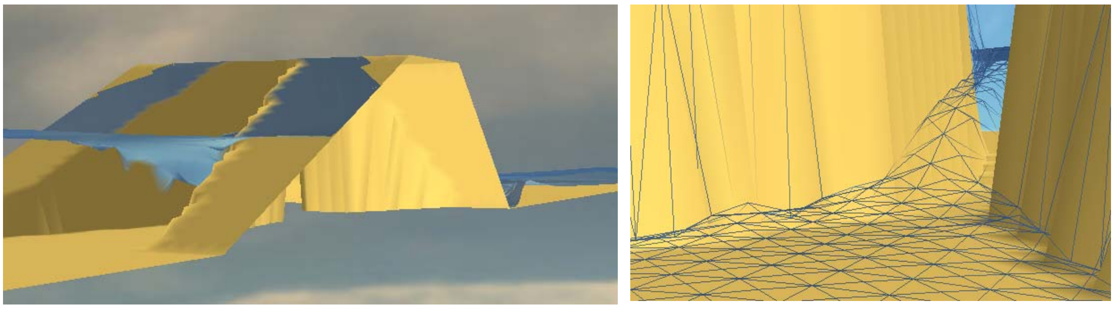

Figure 4 – Culvert Model Inlet And Part Full Outlet

2.3.4 BRIDGES and BRIDGE PIERS

Currently there are limits as to how the model can simulate a bridge opening. When the flow remains below the bridge deck the existing model can already model the bridge through the inclusion of the piers in the model. However once the flow is in contact with the bridge deck, or the deck is submerged, either it can be modelled in a similar manner to a culvert, or what is envisaged is that a ceiling object will be added to the code that will allow a change in flow behaviour to be added when this occurs.

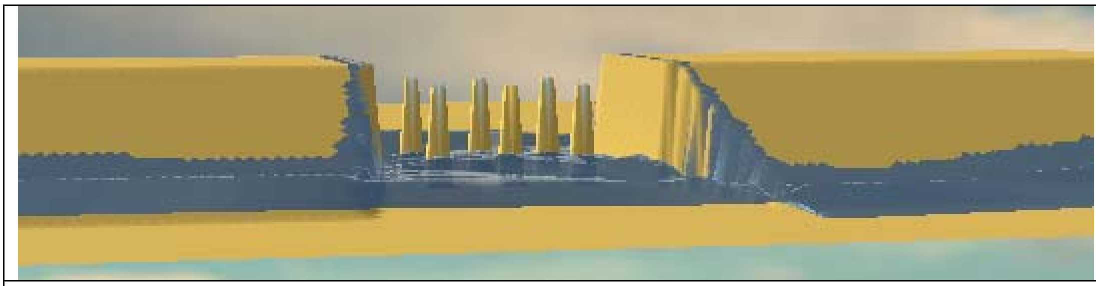

Figure 5 – Bridge Piers Model

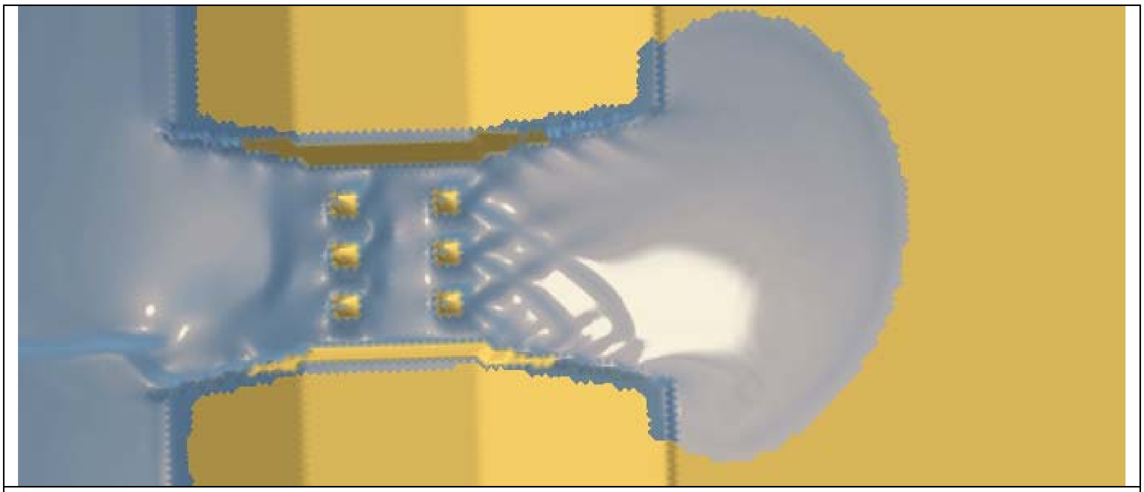

Figure 6 – Bridge Piers Top View Note Complex Supercritical Criss-Cross Waves

2.3.5 Urban Catchments with Buildings

In a similar fashion as the bridge piers, the specific inclusion of obstacles on a flood plain such as buildings does not present any particular problem, as these can simply be added to the domain elevation with current build in polygon functions. This provides an enormous amount a flexibility and capability.

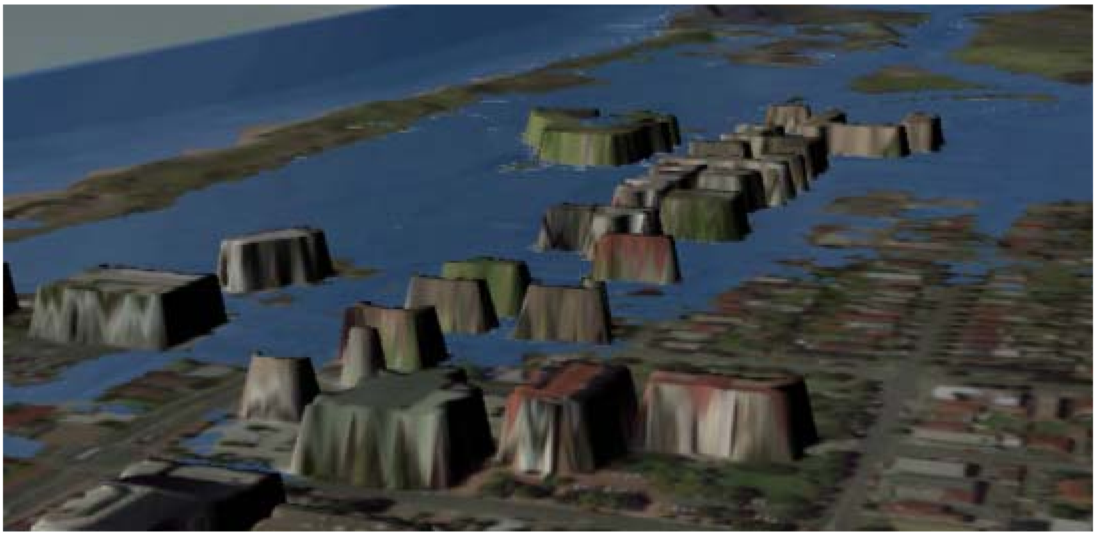

Figure 7 – Urban Flood With Buildings Included

2.3.6 ASSESSING IMPACT OF PROPOSED DEVELOPMENT

The ability to include building effectively onto of existing terrain provides authorities such as local government with an immensely useful tool for assessing the impacts of proposed developments on the behaviour of overland flow paths. This example shows that by constructing the two buildings as show the flood level in the up stream roadway will rise be around 350mm. (Note that existing inbuilt facilities exist to easily produce GIS output of flow depth and velocity that can be simply imported into a GIS and overlain on cadastre or air photos etc.).

Figure 8 – Development Assessment Pre & Post Developed Site

2.3.7 DAM BREAK Flood Wave

The ANUGA model has been used to assess the impact of a 30ML dam break for a structure that adjoins an urban development. The models capability show the complex interaction of reflective waves that effectively bounce of buildings increasing the depth before a fast moving dam break flood wave front races down the roadway.

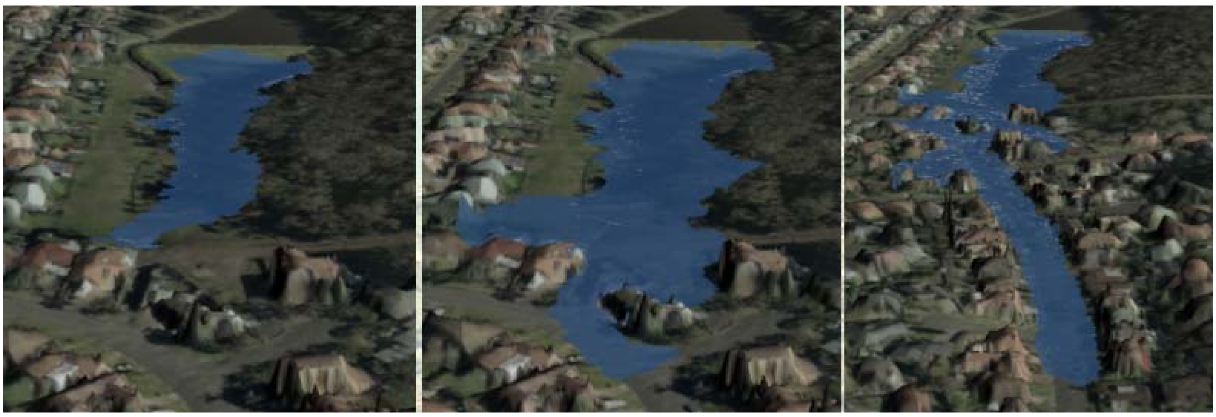

Figure 9 – Dam Break Flood Wave In Urban Environment

2.3.8 UPSIZE to a 110km2 CATCHMENT

In order to assess its usefulness, the ANUGA model has been used in an attempt to model an entire 110km2 catchment by applying rainfall directly to the 2D computation domain. The preliminary results are very impressive. The ability to have a fine triangular grid cells over the watercourse and large cells over other areas away from the watercourse provides an efficient means to model the entire catchment. It is noted that similar exercises attempted by Clark etal (2008) on a 12km2 catchment with fixed grid models such as TUFLOW and SOBEK concluded that although these two models are quite similar in their operation the results varied significantly, with an unexpected:- “degree of sensitivity to changes to grid cell and time step parameters that was not anticipated”. It was concluded that more testing was required in order to provide advice on the use of these models as:- “ these models are too variable for their generic application and it is not possible to give guidance on their general use”.

It appears that ANUGA may not be afflicted with this type of constraint due to the capabilities of the unstructured grid approach.

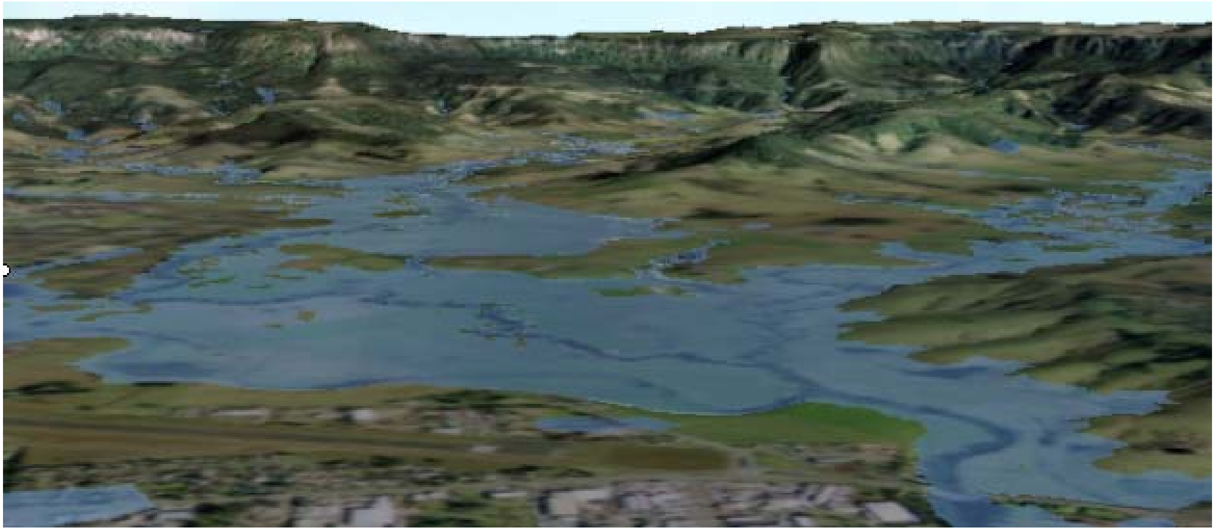

Figure 10 – Entire 110km2 2D Hydrodynamic Catchment Model

2.3.9 MODELLING LARGER CATCHMENTS

At present it is unknown what the limitation (regarding size of catchment) ANUGA has to model riverine catchments. However it is envisaged that ANUGA could be run in conjunction with other hydrologic model that will provide the hydrology of the catchment that seamlessly marries with a 2D hydrodynamic model of portions of the catchment. Investigations are underway to determine whether it is possible to link the WBNM model directly to the ANUGA model. This will result in the ability to model virtually any size catchment.

2.3.10 BACK TO TSUNAMI and the OCEAN

Again the ability to model waves and tsunami lead one to surmise that the model may also be suitable for use to model Ocean /Riverine interaction. The potential inclusion of sediment and erosion routines will make the ANUGA model a very worthwhile platform to consider for this type of analysis.

Figure 11 – Tsunami Striking the Coastline

2.3.11 MULTIPLE WAVE Train (Ocean Erosion?)

The application of multiple wave trains in association with a future sediment and erosion algorithm has the potential to provide a platform that may allow some sensible ocean erosion routines to be included in the model. Once again the framework is such that a generic erosion algorithm can have a variety of behaviours depending on calculated parameters derived by the model itself. This provides the potential to allow very specific application of various algorithms, even the creation / inclusion of hybrid algorithms.

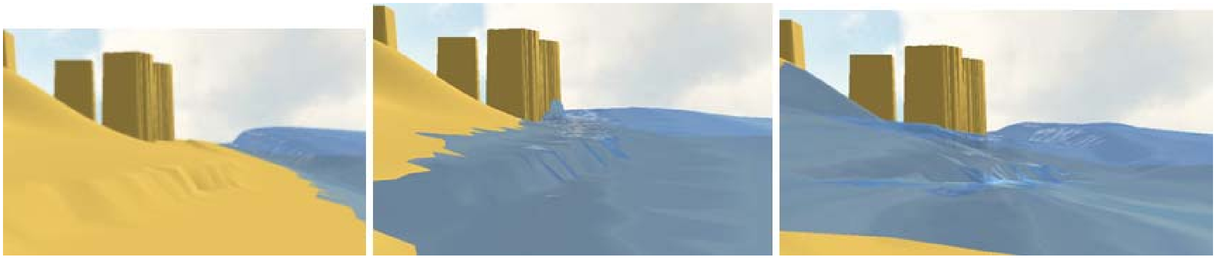

Figure 12 – Multiple Waves, Runup, Setup, (Need Erosion)

3. DETAIL OF IMPLEMENTING CULVERTS

As mentioned the core code of the ANUGA model has not had to be changed in any way to include the ability to model culverts. The object structure is such that the inclusion of an instance of a different type of object will seamlessly include itself to the rest of the code. In a similar way the application of rainfall directly to the 2D cells and to polygons that only cover a specified region of the model can also be implemented. Therefore spatially varying rainfall is also achievable (and currently included). With regard to the mechanics of the culvert algorithms, it is envisaged that there will eventually be several options as to how the culvert is assessed/analysed. Currently there are options available to model the structure as a mix of weir and orifice flow based on inlet /outlet water depth / culvert height and total energy differential. In addition energy losses can be accounted for specifically taking into account full barrel or part full barrel velocities. In addition the momentum of the outlet jet is correctly conserved. The velocity of flow leaving the culvert will correctly result in supercritical flow if it occurs and provide the resulting hydraulic jump if it is indeed present.

Although specialised routines have had to be added to create polygons for both the inflow abstraction/ outlet injection and enquiry fields for those locations, this was able to be completed using existing in built routines already available within ANUGA. The model was at times found to be so sensitive to the flow behaviour at the culvert inlet and outlet that it was necessary to create separate enquiry areas to determine the total energy. The enquiry areas are created automatically based purely on the location of the inlet and outlet co-ordinates. The concept of how this operates is shown in the following figure.

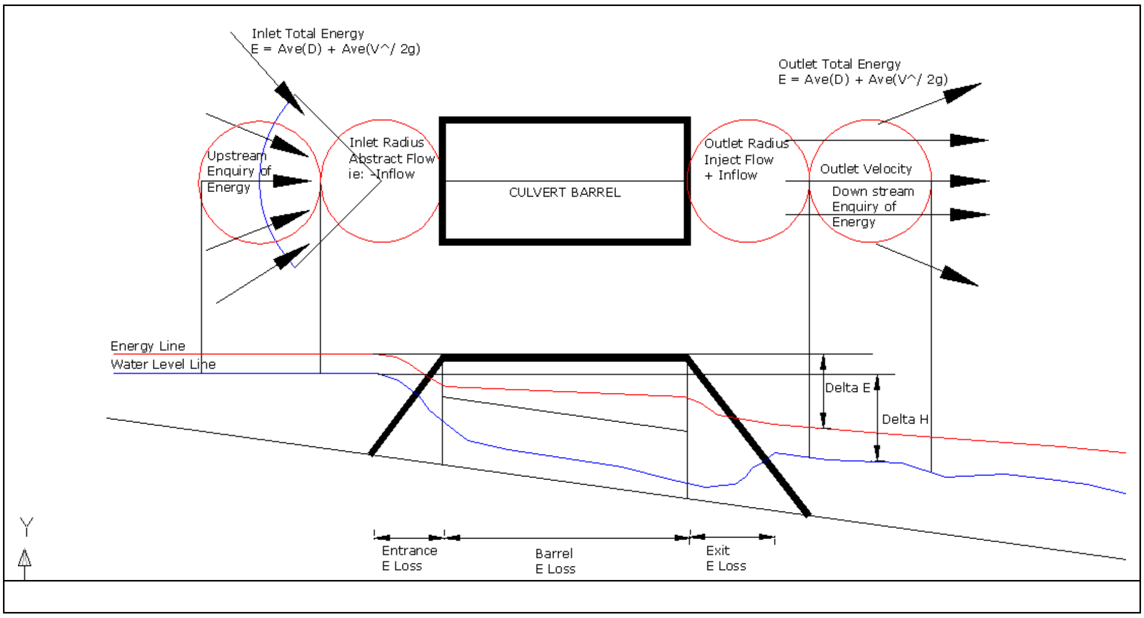

Figure 14 – Detail Of Implementing Culvert Routine in ANUGA

The culvert routine has the ability to "subtract" flow from the Higher Energy Location and "Add" Flow to the Lower Energy Location taken into account the net energy difference, the energy loss, whilst maintaining the momentum of the culvert outlet jet. The enquiry of the level of energy needs to not be overly influenced by the fact that flow is being subtracted or added to the domain. Therefore the area of "Enquiry" can be different to the Area of Flow "subtraction" or "addition". This was achievable within the existing framework of the model.

4. VALIDATION OF THE FLOOD MODEL CAPABILITY

As mentioned although the ANUGA model has been validated as being capable of simulating a tsunami striking the coast, it has not been validated (specifically) to simulate riverine flooding. However it is proposed to utilise a 350m long concrete flume with a flow rate of up to 14m3/s and the ability to add complex obstacles to validate the models capability in simulating riverine flows. This work will be undertaken at the Penrith White Water Stadium in the near future.

Figure 15 – Preliminary Validation Underway

5. CONCLUSIONS

It is concluded that although the ANUGA model was specifically written for the specific requirements of modelling coastal inundation due to the impact of a tsunami, the framework and application of the SWW equations is such that the model is equally suited to a very wide range of general flow applications. As the model is FOSS (Free and Open Source Software), anyone is free to down load and use it. This makes it readily accessible to consultants, local government engineers and even academics and students. This therefore provides local government and other authorities with the ability to create and maintain there own flood models for instance. With issues regarding climate change, sea level rise, Ocean hazard and the need for ongoing modelling and remodelling as boundary conditions change, the ANUGA model is likely to become a formidable ally to many authorities as they struggle to keep up with the need for current models in the future.

6. RECOMMENDATIONS

It is recommended that authorities, particularly local government consider utilising this tool in their arsenal of tools for addressing the ongoing needs for all manner of fluid flow assessment and more specifically flood flow assessment relating to identify hazard.

7. ACKNOWLEDGEMENTS

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