ANUGA THE FREE OCEAN IMPACT MODEL

Rudy Van Drie1, Mike Simon 2, Irene Schymitzek 3

1 Shellharbour City Council, Lamerton House, Shellharbour City Centre NSW 2529

2 HydroTec Aachen Germany

3 BALANCE Research & Development, Burrapine NSW 2447

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. This being the case the model is therefore well adapted to providing a robust modelling solution to all forms of not only Ocean Inundation but also Riverine Flooding and the combination of both these source or raised water levels.

The model has now been used on a variety of scales from a kitchen sink to catchments in excess of 100km2 and coastlines several hundred km long.

The model is robust and very capable as well as providing high definition visual output of the results.

In the context of climate change and the need to model both the impact of climate change on:

- Ocean level rise
- More aggressive wave attack
- Increased rainfall intensities
- Increased interaction of riverine floods and Ocean inundation

The model is seen as a fantastic tool to build capacity within local government and other authorities and state department to build and maintain their own models that remain in their ownership.

This represents a truly monumental step forward in overall capability of addressing the need to investigate the potential impacts of climate change.

Key Words: 2D, Shallow Water Wave, Hydrodynamic, Model, ANUGA, Tsunami, Sea Level Rise

1.0 Introduction

ANUGA is a general fluid flow modelling tool developed to simulate the effects on the built environment from hydrological hazards such as tsunami, storm surges or dam breaks. It is based on a research prototype developed at the Australian National University throughout the nineties. The present incarnation of ANUGA is based on lessons learned from this prototype but was redesigned and developed in 2004 at Geoscience Australia for use with risk analysis of natural hazards.

ANUGA implements a finite-volume method for solving the conserved form of the 2D depth integrated Shallow Water Wave equations. The study area is represented by a mesh of triangular cells in which the conserved quantities of water depth, h, and horizontal momentum (uh, vh), in each volume are tracked. Fluxes across cell boundaries are calculated using the central-upwind scheme of Kurganov, Noelle and Petrova (2001). One advantage of this approach is that the traditional characteristic decompositions and Riemann solvers are replaced by one simple scheme that efficiently addresses super- and sub critical flows, wetting and drying as well as faithful reproduction of planar surfaces. ANUGA uses a second order spatial reconstruction to produce a piece-wise linear representation of the conserved quantities. This surface is allowed to be discontinuous across the edges of the cells, but the slopes are limited to avoid artificially introduced oscillations. As a consequence wave fronts can be arbitrarily steep allowing for stable resolution of bores and hydraulic shocks.

Further details regarding the background and methodology of the model can be found in the user manual available from:

http://datamining.anu.edu.au/~ole/anuga/user_manual/anuga_user_manual.pdf

2.0 NEED FOR MODELING !!!

With the uncertainties of climate change (atmospheric energizing) and sea level rise, comes the obvious need to identify the potential impacts of these influences. The most obvious approach is to find appropriate tools that will be able to predict the impact by realistic modeling. However generally speaking there are very few models that are capable of doing this, let alone doing it well, or being able to account for the potential cumulative impacts of sea level rise and increased rainfall intensity for instance. ANUGA appears to one model that not only is capable but was specifically developed (initially for tsunami) to model these effects. The best outcome of all is that the model is 100% FREE to any one to down load. This is seen as a first step in the right direction by the Australian Federal Government in its aims to build capacity to identify the potential effects of climate change.

3.0 Where did ANUGA come from? :- Modelling Tsunami's

After the Boxing Day Tsunami the Australia Government made a commitment to set up the Australia Tsunami Warning Centre. This is now housed and operational at Geoscience Australia (GA).

Prior to that in 2002 the Federal Government set several mandates one of which was to "Build Capacity" for the identification of HAZARDS and management of RISK.

These are documented in the 2002 Federal Budget Statements and the COAG Review of 2002. Details of which 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

As part of this process GA identified that there where gaps in capacity to model the impact of tsunami striking the coast, even though there were models available to propagate the wave across the Ocean. ANUGA was specifically written to fill that gap in capacity. It now has a proven track record in its ability to model these events and validation of an actual tsunami in 1993 on Okushiri Island as described by Nielsen et al.(2005). An example of a typical tsunami application is shown below.

Fig. 1. Approaching Tsunami clearly visible.

Fig. 2. Resulting Inundation

The model can be applied on a very large scale such as the standard demonstration example of Cairns in QLD., that comes with the model.

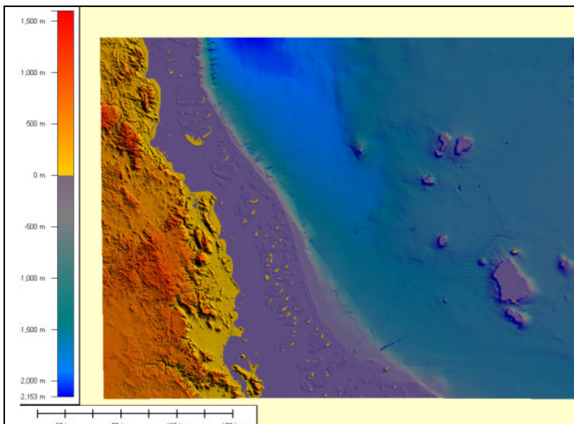


Fig. 3. Model for Cairns (note scale)

Not only can the model seamlessly handle the problem of propagating the effective flood wave from wet to dry terrain (which has in the past been a major problem in some models) it also seamlessly can handle the inclusion of building on the terrain due to its flexible unstructured grid approach.

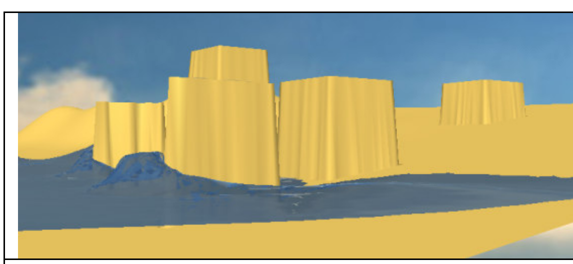


Fig. 4. Anuga handling flow around solid objects in the flow path with the resulting reflective shock wave being formed in front of the building.

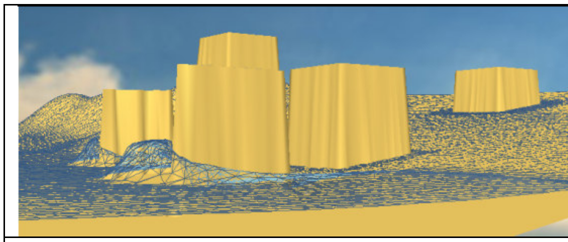


Fig. 5. Showing the flexibility of the unstructured triangular grid approach

4.0 FREE & OPEN SOURCE (Model available to anyone)

Just prior to its public release in December 2006 the author (of this paper) contacted GA with a view to determining if the model was suitable for use in the flood modelling arena. From that initial contact and the fact that the model was then released as FREE and OPEN SOURCE SOFTWARE (FOSS), meaning the code was also accessible, the author has been actively involved in adding capability to the model to enable it to be used for flood modelling and general purpose hydraulic analysis.

This is seen as a great leap forward. Instead of the algorithms being hidden away in some secret black box, where the user is totally reliant on the software developer explaining how the model operates, this approach allows every one to view scrutinise, comment and improve the computational CODE. This will ensure the model continues to develop, improve and increase its capabilities.

The code is now capable of modelling the effects of rainfall directly on the grid, as spatially and temporally varying. Similarly infiltration can be modelled. Currently work is being concluded to add several levels of culvert structures.

It is envisaged that the model will be capable of modelling erosion and sedimentation, beach erosion, potentially water quality aspects and a host of other aspects of 2D-hydraulics as it evolves.

In addition the hydrodynamic model comes with an extensive range of Geo-Spatial tools that make it very easy to manipulate large terrain data sets such as ALS data, and prepare models based on this data.

5.0 POTENTIAL APPLICATION OF EXTENDED CAPABILITIES

From the very initial encounters with ANUGA it was very obvious that this model is considerable more visually rich than most others available. That being the case it provides for a very good platform to inform and educate people about fluid flow. This is both at a gross level of informing the public of flood scenarios but also at a much more refined level in it being used as a teaching tool at Universities for instance.

Once again being FREE and OPEN SOURCE and having some access to the creator of the model the author of this paper was able to quite quickly adapt and run the model for several specific cases and aspects of fluid flow, so much so that it was considered worthy to highlight the capabilities of this model to general industry and community. Thus this paper:

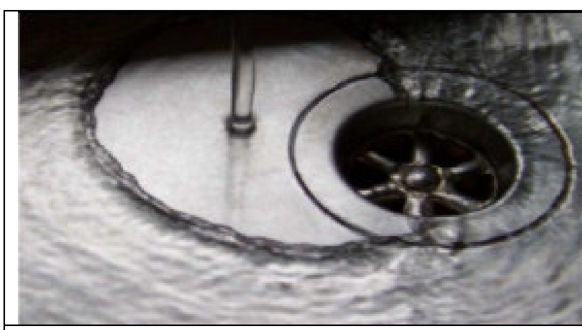


Fig. 6. Classic kitchen sink analysis

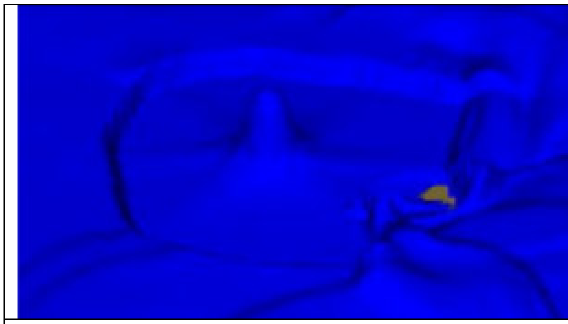


Fig. 6b. ANUGA Style

The real difference between ANUGA and other models is in the way the models CORE code has been implemented. It is written in a language that is pure object based. That is, a high level pure object oriented language called PYTHON. PYTHON is a very flexible and powerful scripting language that is fast becoming one of the most popular and widely used. From online gaming platforms supporting 25,000 multi-players simultaneously to highly specialised complex work flow analysis for the space shuttle program at NASA http://www.python.org/about/success/usa/.

Best of all PYTHON is 100% freely available. Refer to http://www.python.org/ for details. In fact to run ANUGA you need to download and install PYTHON.

The object approach has provided ANUGA with an amazingly flexible platform. Maintaining and Adding code is relatively simple without the risk of affecting the core algorithms through its in built ability to create UNIT TESTS that verify that all components of the model behave as specified.

ANUGA framework implements a form of generic coding that allows the developer to add capability building on the existing code. For instance using a hydrograph, adding rainfall or modelling a culvert all use the same base code, just slight variations on them. This in the object world is called CODE REUSE and POLYMORPHISM. Two very powerful features that set the object approach in its own league.

i. As a Teaching Tool

Those classic university fluid 101 hydraulic flume experiments that provided students with glimpses of the nature of hydraulic jumps and the role of sub-critical and super-critical flow can not only be recreated with ANUGA but due to its flexible capabilities you can track the Froude number for instance and see exactly were Froude = 1.0.

ii. For detailed Hydraulic Analysis

The shock capturing capability of the ANUGA model provides users with a capability that provides for the ability to observe physically realistic flow phenomena. This capability is considerably superior than any other model in this class of model.

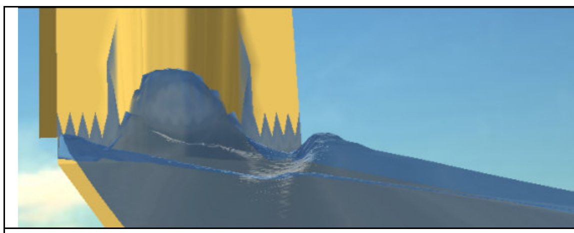


Fig. 7. Detail of the flow leaving a culvert note formation of hydraulic jump

iii. For Flood Modelling

The ability to place any number of hydrographs anywhere on the domain provides one methodology to model the propagation of a flood over terrain. However as mentioned, ANUGA can also model rainfall directly, or a combination of rainfall plus hydrographs. The model has been run and compared to WBNM2007 for the same catchment with very impressive results. The hydrograph shape and overall peak (and total volume) where all similar. As it is envisaged that many larger catchment applications will rely on a hydrologic model to feed the hydraulic detailed model (if that is the preferred methodology adopted by a modeller), it is likely a hydrograph transfer function will soon be available to seamlessly extract hydrographs from a WBNM2007 model of a catchment that can be applied to an ANUGA model.

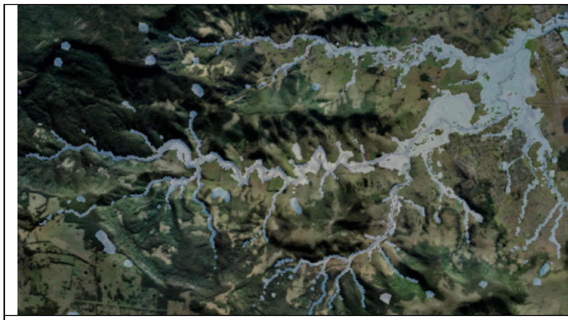


Fig. 8. Entire 110km2 catchment modelled as a 2D hydrodynamic model using rainfall as input directly onto the computational domain.

iv. Erosion & Deposition

It is proposed to add erosion and deposition capability to the ANUGA model. The framework is essentially in place. The only addition code required is that will allow a further conserved quantity to be written to the output file and a suitable algorithm offcourse. Currently there are quite a number of algorithms available. Once again the framework of the code is such that it is likely that there will a considerable range of erosion and deposition routines added, with the added potential to create a hybrid or at least add some intelligence into how and why one algorithm is applied over another at any particular location at any particular time.

v. Beach Erosion

As an extension to classical erosion and deposition a specialised adaptation suitable in the turbulent surf zone may also be added to the ANUGA code without any specific complication. For instance the relatively recent Xbeach code (US Army replacement for the Sbeach Model) includes a morphodynamic module that could simply be added into the ANUGA realm. By comparison it is envisaged that the ANUGA model will be considerably more flexible than the Xbeach model, this is due to Xbeach being reliant on a staggered fixed grid whilst again ANUGA has a totally flexible unstructured grid approach.

vi. Water Quality Aspects

As the ANUGA model contains conserved quantities of depth, and Horizontal Momentum (x &y) it not only suitable to use these to model sediment transport processes but it is also possible to model other secondary processes such as the fate of water pollutants. If it can be estimated by adopting 2-D modelling it is likely that it can be implemented in ANUGA with only minimal effort. Therefore it is likely that a future application of ANUGA will be in the realm of water quality.

6.0 Specific Capabilities:

The frame work of the object approach is such that any approach developed is by virtue of the design of the objects immediately available to all other objects. For instance, in adapting the model to use rainfall it was required to distribute the rainfall over an arbitrary shaped polygon. This now also means that any other quantity can be changed by an arbitrarily shaped polygon.

Similarly any quantity can be set by an number of an combination of:

- Fixed Value
- Function
- File Function (calling a preset list of values from a file)

For example the ANUGA model will allow the user to specify:-

- multiple temporal variable rainfall inputs for multiple polygons over a catchment.
- Any number of depth varying functions to set Manning's roughness to vary with depth
- A function of table of values to set the loss coefficients for the entry into a culvert based on the inlet/outlet conditions.
- A time varying function to change the bed level based on any conserved or derived value. Eg: vary the level of an embankment over time based on the flow rate over the embankment, to simulate embankment erosion and dam failure.

7.0 POTENTIAL IN LOCAL GOVERNMENT & OTHER AUTHORITIES:

It is quite frightening to have learnt recently (FMA committee meeting) (sea level rise seminar) http://www.pittwater.nsw.gov.au/council/council_publications/sea_level_rise_seminar_-_presentations) that after almost 20 years of flood plain management costing the community possibly ~$100million (Who knows??) there are only 10 Councils with NSW (some 173 Councils) that have completed flood plain mapping.

The consulting world has failed to deliver a suitable outcome to date.

To date there has been no other option available than for Council to collate their data, hand it over to consultants who have charged enormous amounts of money to provide at times, a less than adequate result. ANUGA provides the potential to change this situation.

Where in the past Council did not get access to the model or the ability to run the model, ANUGA provides an opportunity for Councils to build maintain and update their own catchment models. This will provide an enormous increase in the "CAPACITY" to undertake and provide flood mapping. Not only for flooding but also Sea Level Rise.

As with many authorities, Local Government has suffered from being dumbed down by loosing experienced staff, and loosing numbers of specialist staff.

It is seen that in order to "BUILD CAPACITY", councils would be well placed, and well advised to invest in professional staff to undertake the role of building and maintaining their own flood models. In the interim it could be that councils employ consultants to set up and build modelling systems on their own (council) computer systems. The potential long-term cost saving and added flexibility to Council's is huge. The flexibility will allow for example Council's to easily update their FLOOD MAPPING based on a new land use layer for instance. In addition the review of DEVELOMENT APPLICATIONS for development proposals that potentially impact overland flow paths Councils will no longer be reliant on consultants providing less than adequate modelling. An example of the assessment of a DA is shown below, where it is clear that the proposed warehouse development impact the overland flow path.

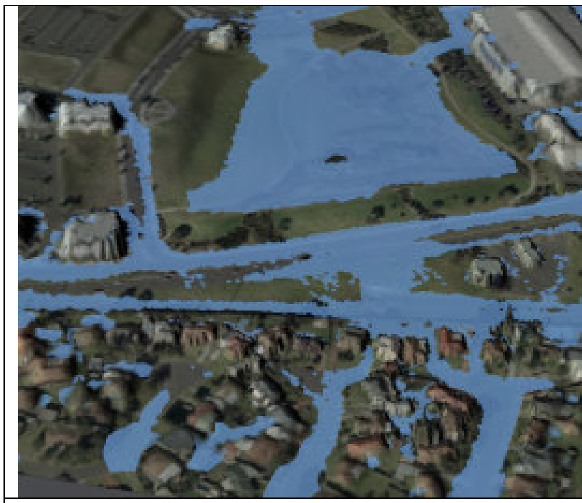


Fig. 9. Pre-Developed Inundation

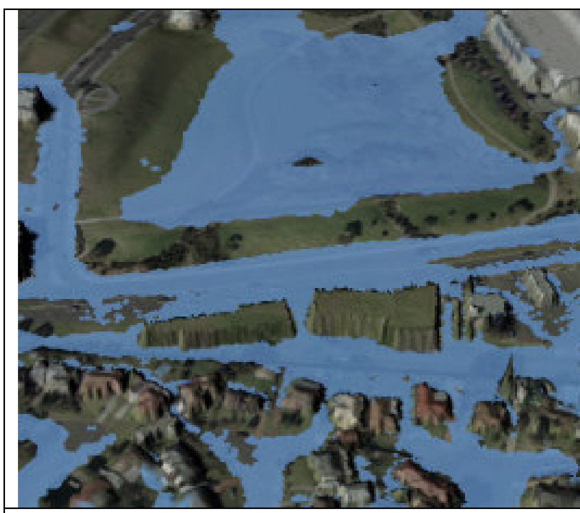


Fig. 10. proposed Post developed inundation (impacting roadway !!)

8.0 CHANGE IN THE LANDSCAPE IN FLOOD MODELLING

With a truly capable 2D hydrodynamic flood model available to anyone who wants it, comes the opportunity for Local government to be actively involved in BUILDING CAPACITY related to NATURAL HAZARD RISK ASSESSMENT.

It seems obvious that the authority that is charged with the responsibility for an area, that also holds all of the data for that area should also have the capability to construct and maintain models based on that data. It is the next logical step.

ANUGA provides Local Councils (and other authorities) with access to the necessary tools to:

- manage data for building flood models
- build flood models at (almost) any scale from entire catchments to portions of catchments and down to a detailed model of a culvert outlet. In fact all of these could be modelled in the same model, or by the same model, by varying the mesh density.
- maintain and
- run complex detailed flood models.
- View the results in 3D fly overs (that are a great tool to aid educate the public)

Prepare output that is suitable for inclusion directly into Councils GIS, as a layer showing the extent of flooding, or a layer that can be used to query depth or velocity or even hazard.

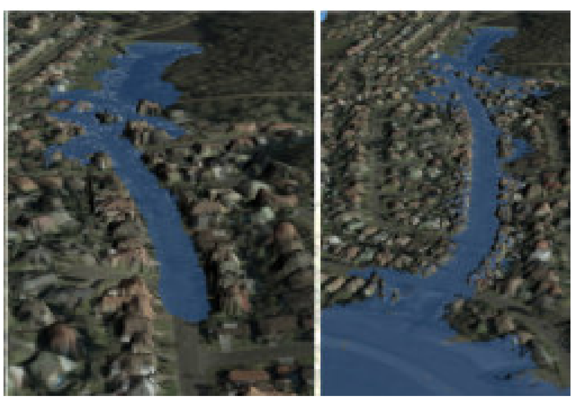
9.0 EXAMPLES OF RANGE OF APPLICATION OF ANUGA:

As a way to introduce some of the capabilities of the ANUGA model, the following images are provided that are simply a snapshot of an ANUGA application.

The following images are the results as viewed with the default ANUGA viewer. It is actually an animated viewer however offcourse these images are simply snapshots of those animations.

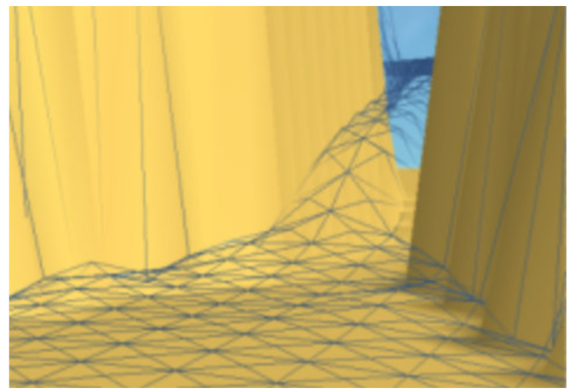
It should be noted that ANUGA can produce output suitable for use in any GIS. So that plots of depth, velocity VxD, etc. can all be created easily.

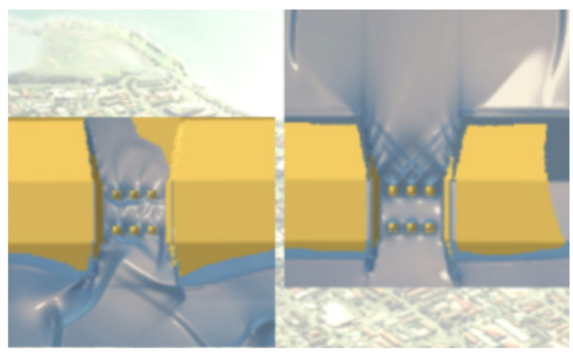
DAM BREAK ANALYSIS:



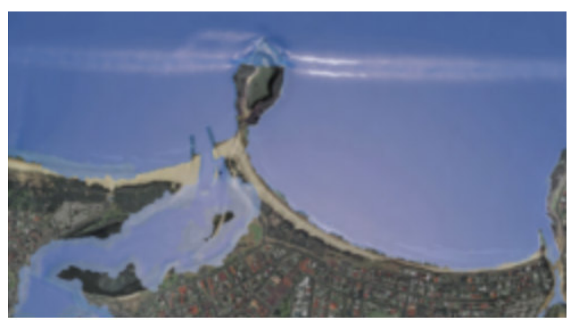
URBAN FLOODING:

DETAILS OF BRIDGE OPENINGS:



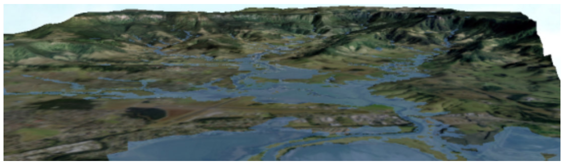


TSUNAMI:



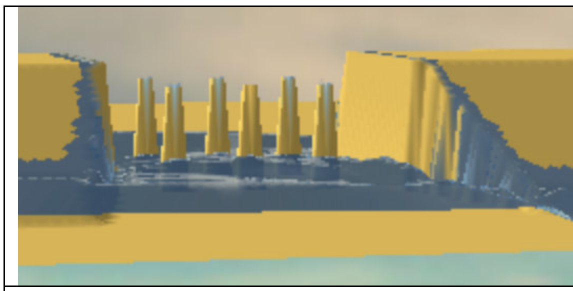
FULL 2-D HYDRODYNAMIC MODEL OF 110km2 CATCHMENT:

Rainfall applied directly to a 110km2 catchment.

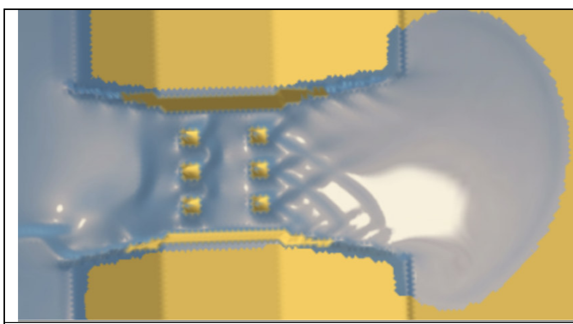


More Details of Bridge Pier interaction:

The ability to vary quantities including bed elevation means it is quite simple to add features such as embankments and bridge piers and even buildings to the original terrain.



Specific detail of bridge pier interaction



Complex Supercritical Criss-Cross Waves from piers interference…

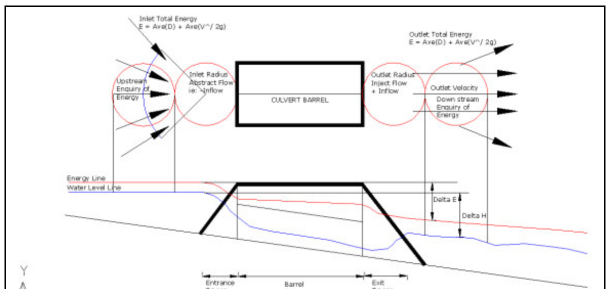
10.0 EXAMPLE: Development of CULVERT ROUTINE:

A current ongoing development within the ANUGA framework is the additional capability to model culverts/bridges. Of course the effects of bridge piers can already be modelled very effectively for an unsubmerged bridge, but not yet the submerged case. Once again due to the frame work of the code current development is targeting having multiple routines available for the culvert modelling capability.

The algorithms will range from a relatively simple weir and orifice configuration, to the US Department of Transportation Algorithms to the HEC-5 5th order polynomial approach, and potentially several others. Again the flexibility is available due to the nature of the object code.

The current approach being trailed has a methodology that automatically makes enquiries in the domain immediately adjacent the inlet and outlet of a culvert. The enquiry will discover the depth, the approach velocity, hence the specific energy and total energy.

From this the flow can be calculated accounting for energy losses due to the length of the culvert and the inlet and outlet loss (and any other specific loss {Bends?}).



The aim is to "subtract" flow from the Higher Energy Location and "Add" Flow to the Lower Energy Location. 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" needs to be different to the Area of Flow "subtraction" or "addition".

Based on the total energy the direction of flow will be determined and thereby the culvert can automatically account for flow reversal (or have a flap gate).

In addition as the culvert velocity can be determined, from this the outlet momentum can also be determined and therefore accounted for. Therefore the model of a culvert will allow the modeller to observe the effects of the outlet jet that is formed.

There is no other model in this class of model that is capable of providing the user with this level of detail. This is seen as a great step forward in allowing designers (modellers) to observe the hydraulic jump being formed at culvert outlets for instance.

Note recently the ANUGA code was augmented to include routines that implement the Generalised Culvert Equations developed by Boyd (1985) that are based on the US Dept. of Transportation Culvert Routines.

11.0 EROSION AND DEPOSITION ROUTINES INCLUDING BEACH EROSION:

The inclusion of specific routines to enable the simulation of erosion and deposition, including aspects of surf zone erosion behaviour is seen as a very important next step in the development of the ANUGA model.

River erosion and Sedimentation are issues that border on being a NATIONAL DISASTER. Ongoing management of the riverine environment requires better tools to enable identification (positive and accurate) of both erosion problems and the simulation of solutions to ensure they operate as intended.

Similarly beach erosion is an area of investigation that currently does not have very robust tools generally available. Models such as the US Army S-Beach are known to be extremely difficult to use in a sensible manner. These purely parametrically driven models are not at all based on physically realistic processes, yet are supposed to be able mimic these processes. Very recently the US Army engaged DELFT HYDRAULICS to provide a new and more robust approach to model beach erosion processes. The result is the new X-Beach model, which is a 2D Staggered Fixed Grid Finite Volume model. There is a morphological block of code that is responsible for the surf zone erosion/deposition simulation.

As ANUGA is fundamentally built on a better approach than X-Beach being on a unstructured grid basis, it is likely that by simply implementing the morphological X-Beach block in the ANUGA code the ANUGA model will be more flexible and robust than the current X-Beach model.

The ANUGA development team have approached the X-Beach developers with a view to collaborating, however to date there has been no response from them.

However regardless of the potential to collaborate, the ANUGA team is committed to delivering this outcome as it is seen as the next important phase of delivery of the mandate in building capacity.

12.0 MODEL AVAILABILITY AND FURTHER INFORMATION:

ANUGA is available as a free download from https://sourceforge.net/projects/anuga/ . As the code is under continuous development users should visit the site at regular intervals to confirm they are operating with the latest code.

ANUGA WORKSHOP BEING HELD BY GEOSCIENCE AUSTRALIA:

On 16 –17 September 2008, Geoscience Australia is hosting a FREE WORKSHOP aimed to inform any one interested in the status of the ANUGA model and plans for its future. Any one interested in any aspect of 2-

D flood model will find this extremely useful and informative workshop.

Further details can be found at:
https://datamining.anu.edu.au/anuga/wiki/SecondAnugaMeeting

More Information on ANUGA:

Information:-
https://datamining.anu.edu.au/anuga

Manual:-
http://datamining.anu.edu.au/~ole/anuga/user_manual/anuga_user_manual.pdf

This paper was written by Rudy Van Drie who can be contacted as follows:

rudy.vandrie@shellharbour.nsw.gov.au

or

rudy@balancernd.com.au

12.0 Conclusion

Based on trials conducted to assess the capabilities of ANUGA as a flood modelling tool, we conclude that ANUGA;

- Is a powerful and highly flexible hydrodynamic model
- Can model Ocean inundation including the effects of Waves and Tsunami
- Is not a model (yet) for modellers with limited programming experience
- Is well able to simulate flooding where structures are not present
- Will grow rapidly in its capabilities and user friendliness over the next year
- Is well worth investigation by anyone with an interest in flood modelling
- Could provide Local Government with a very substantial long term cost benefit in providing flood mapping capability for both flooding and sea level rise.
- Is likely to have a sediment transport capability in the not too distant future.

13.0 ACKNOWLEDGEMENTS

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