QUANTIFYING ECONOMIC AND HYDRAULIC FLOOD RISK

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ABSTRACT (300 WORDS MAXIMUM)

Traditionally flood management policies have been based on a design standard approach, in other words a degree of protection (i.e. 1 in 20 year event) and have focused on the hydraulic aspects of flooding. So if you built your levees high enough, or your pipes big enough you would be OK.

Increasing community expectations, decreasing financial resources and uncertainty in future weather conditions mean that developing the "best" solution is challenging, as many of the goal posts are moving.

Flood analysis needs to consider the consequence of the flood events with different probability of occurrence and develop the best alleviation measures over a given period of time. Understanding the hydraulics of the flood is critical, and something already done very well by hydraulic models. Equally important is the consequence, as this is what the community react to, and what influences the post flood recovery cost.

This paper will discuss how hydraulic models can be used to develop an Estimated Annual Damage (EAD) value which can be used to compare different flood management strategies, allowing Officers to make economically efficient decisions while maximizing the protection of their communities.

KEYWORDS

Risk, flood risk, Estimated Annual Damages, hydraulic simulation

PRESENTER PROFILE

Ann has worked in hydraulic modelling, strategic planning, water quality, operations and marketing teams, and currently manages the sales, support and training activities for Innovyze across southern Australia. This encompasses all aspects of potable water, wastewater and surface water systems - helping authorities and consultants to use advanced tools that provide efficiencies in the planning and operational activities.

She is an elected member of both the Australian Water Association Victorian Branch and Stormwater Victoria Committee.

1 INTRODUCTION

Recent disasters, both locally and overseas have highlighted how, in times of disaster, people rely on their governments to pay for reinstatement of assets (either at a community level, or to individual asset owners). With the uncertainty of climate change, and the financial pressures put on governments from events such as the Global Financial Crisis, and subsequent economic slowdown, many governments fear they may not have the resources to fund recovery from natural disaster.

Organisations must be able to consider not only the capital reinstatement costs but also the frequency of the event causing the asset failure to decide how to fund future recovery projects. The determination of risk can be a subjective exercise, and the terminology often misused. On various internet forums experts debate whether to use the term hazard, risk or vulnerability; likelihood, probability, impact or threat. The intent behind the semantics is the same. People want to identify, quantify, plan and, if possible, control an event that is uncertain.

It is therefore necessary to understand how risk is considered in hydraulic models, and how these can be extended to provide an economic assessment of different scenarios.

2 TERMINOLOGY OF RISK MANAGEMENT

2.1 CLASSIC RISK EQUATION

The equation in Figure 1 shows us that there are three components for determining risk: A threat (or opportunity) may exploit a vulnerability to cause harm (or benefit) to an asset.

Risk is the likelihood or probability of this combination of threat and vulnerability occurring.

RISK is the PROBABILITY that a THREAT will exploit a VULNERABILITY to cause harm to an ASSET

Or $R = f(T, V, A)$ *Eq. 1*

Figure 1: The Classic Risk Equation

2.2 QUALITATIVE / QUANTITATIVE RISK ANALYSIS

Alternately a qualitative / quantitative[1] risk analysis (Figure 2) states that the risk is defined as the probability that a substance or situation will produce harm under specified conditions. Risk is therefore the combination of two factors: The probability that an adverse event will occur (such as exposure from a chemical incident) and the consequences of the adverse event (such as how ill that chemical could make you).

RISK is the LIKELIHOOD of an event occurring with the defined CONSEQUENCE

$R = L * C$ *Eq.2*

Figure 2: The Quantitative Risk Equation

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[1] Quantitative vs Qualit

The purpose of quanti … phenomena through focused collection of nu… outcome-oriented and relate to a specific study.

The purpose of qualitative analysis is to explain and gain insight and understanding of phenomena through intensive collection of narrative data. The study is generally aiming to generate hypothesis to be tested with conclusions that are tentative (and can change) to be reviewed on an ongoing basis.

For the purposes of this paper I am adopting the quantitative risk equation with the following definitions and terminology.

2.2.1 LIKELIHOOD

The probability, or frequency, of a particular event happening.

Thought needs to be given into what defines an event. Is it just the rainfall, or the combination of the rainfall and catchment conditions? This shall be discussed further below in Section 3.

2.2.2 CONSEQUENCE

The impact, effect or outcome of a particular event occurring.

This is where mathematical model(s) can be used to determine the outcome of any particular rainfall event, or rainfall and catchment condition combination. In hydraulic models outcomes are usually time of inundation, maximum water depth, volume of water etc.

2.2.3 RISK

The combination of the likelihood of an event or action occurring and the effect of that event or action has.

It should be noted that a risk does not occur – risk is a measurement.

Often the output is a risk matrix showing Likelihood and Consequence as it may be impossible to put numeric values to the consequences.

Quantitative analysis is often used where both the probability and the consequences can be measured. For example, consequences may be estimated in terms of tangible flood damage to the community for events of different AEPs. Tangible damages are those damages that are more readily able to be estimated in economic terms and lend themselves to quantitative assessment, including:

- Direct damages to structures and their contents due to water contact; and
- Indirect damages of clean-up of debris and removal of damaged material, loss of wages, sales, production and costs of alternative accommodation, and opportunity costs due to loss of services.

Qualitative analyses are generally undertaken where consequences are difficult to quantify. For example, these can include social and environmental impacts and the costs of fatalities and injuries which are intangible damages that cannot readily be put in economic terms.

		Consequence			
		Small	Moderate	Severe	Catastrophic
Likelihood	Low	Low	Low	Low	Medium
	Moderate	Low	Medium	Medium	High
	High	Low	Medium	High	High
	Very High	Medium	High	High	High

Table 3: Sample Risk Matrix

2.2.4 RESILIENCE/MITIGATION

The concept of resilience (from the Latin verb *resilire*, meaning to rebound or recoil) is attractive to policy makers, practitioners and academics. It suggests an ability of something or someone to recover and return to normality after confronting an abnormal, alarming and often unexpected threat.

3 AUSTRALIAN RAINFALL AND RUNOFF

The forthcoming release of Australian Rainfall and Runoff (AR&R) will adopt different probability terminology from what was used previously.

The new terminology, which has been adopted for the new Intensity-Frequency-Duration curves (IFD), can be summarised as follows:

> *The term Annual Exceedance Probability (AEP) will be used for design events (rainfalls and floods). AEPs are to be expressed as an exceedance probability using percentage probability; for example a design rainfall will be described as having a 1% AEP. For extreme flood probabilities a percentage may not be appropriate – in these cases it is recommended that the probability be expressed as 1 in X AEP where 100/X would be the equivalent percentage probability.*
>
> *For events more frequent than those with a 50% AEP will be expressed in Exceedances per Year (EY). For example, a design event (rainfall or flood) with a 6 month recurrence interval will be expressed as having 2 Exceedances per Year (2EY) when there is no seasonality in flood occurrence.*
>
> *Figure 3: Australian Rainfall and Runoff, Book 1 Chapter 2 Section 2.2.5*

This gives engineers the percentage that they need to include in the quantitative risk equation.

It is important to be aware of the probability relationship between design rainfall and design flood characteristics.

AR&R has gone further than this however to state in Book 1: Chapter 5, Section 2 that:

Flood risk results from the interaction of the community, through human occupation or use of the floodplain, with hazardous flood behaviour. It is the risk of flooding to people, their social or community setting, and the built and natural environment (AEMI 2013).

Flood risk is not simply the probability of an event occurring. An effect is a positive or negative deviation from the expected outcome. Objectives can have different aspects (financial, health and safety, environmental) and apply at different levels (local, state, site).

AEMI (2013) and ANCOLD (2003) express risk in terms of combinations of the likelihood of events (generally measured in terms of Annual Exceedance Probability (AEP)) and the severity of the consequences of the event (see Figure 1.5.1). Risk is higher the more frequently an area is exposed to the same consequence or when the same frequency of event has higher consequences.

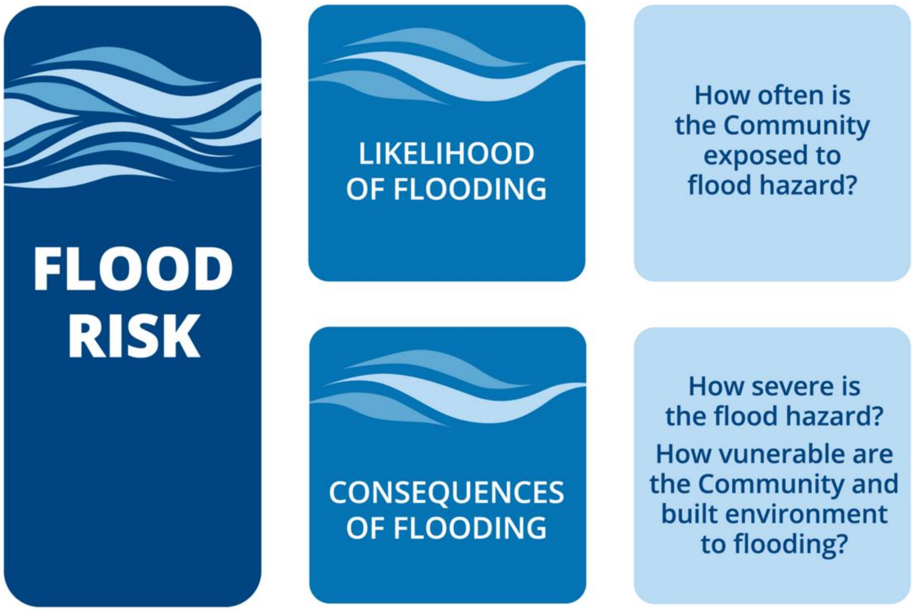


Figure 4: Components of Risk (After McLuckie (2012))

4 AUSTRALIAN ECONOMICS

4.1 THE COST OF NATURAL DISASTER

Australia is highly prone to natural disasters, including catastrophic floods, cyclones, storms and bushfires. Reinsurers such as Munich Re have stated that the cost of natural disasters in Australia is set to nearly quadruple by 2050 but could be dramatically reduced by national investment in preventive measures. As Australia's population density increases, as well as the severity and frequency of storms, floods, cyclones and bushfires, the costs were projected to increase from $6.3 billion a year in 2012 to about $23 billion a year in 2050.

These costs are borne by all individuals, businesses, communities and all levels of government, both directly and indirectly.

4.2 FUNDING OF NATURAL DISASTER RECOVERY

Currently there are four categories of Natural Disaster Relief and Recovery Arrangements (NDRRA) assistance.

- Category A — emergency assistance to individuals.
- Category B — restoration of essential public assets; financial assistance to small businesses, primary producers, voluntary nonprofit bodies and individuals; and 'counter disaster operations' for public health and safety.
- Category C — community recovery packages and recovery grants to small businesses and primary producers.
- Category D — acts of relief or recovery carried out in circumstances deemed to be exceptional by the relevant Commonwealth Minister.

It is likely that future Federal funding for disaster major events will likely reduce, or alternately the Commonwealth Government may switch to annual payments made in advance with no direct additional federal funding when an actual disaster event occurs.

The Commonwealth Government appears to be seeking that the majority of the States increase the level of insurance on assets, improve resilience and mitigate risk.

5 USING HYDRAULIC MODELS

Flood modelling studies tend to use a single peak design storm, or several design storms, applied to a hydrologic/hydraulic model to assess the flooding impact. The worst case scenario is selected and evaluated with a strategy developed to provide the catchment with a solution for a particular design storm. Regardless of the methods used a calibration of the mathematical model(s) need to be undertaken to ensure that the model is accurately representing the physical processes occurring in the flood study.

5.1 PROBABILITY RELATIONSHIP BETWEEN DESIGN RAINFALL AND DESIGN FLOOD CHARACTERISTICS

Each of the processes represented in a model that converts rainfall to runoff and forms a flood hydrograph at the point of interest introduces some joint probability. The catchment condition (wet or dry) may change seasonally. The rainfall also may be different at different times of the year. So a heavy downpour is more likely in summer when the catchment is dry, whilst a slow prolonged event will probably occur in winter when the catchment is wet. El Nino and La Nina cycles are another good example of where there is a probability of certain conditions being observed.

The fundamental problem that the true probability of the derived flood characteristic may be obscure, and its magnitude may be biased with respect to the true flood magnitude with the same probability as the design rainfall, especially at the low probabilities of interest in design. AR&R Book 3 discusses this in more detail.

5.2 "CURRENT" DESIGN EVENT APPROACH

A deterministic simulation approach is where a rainfall event of known likelihood is simulated on a catchment to generate a flood event that is often assumed (sometimes incorrectly) to have the same known likelihood.

The advantages of this approach are that simulations are kept to a minimum with the statistical analysis being performed on the rainfall.

The limitations are that it assumes that other modelled parameters, such as spatial and temporal rainfall patterns, catchment conditions, and the hydraulic routing within the catchment do not change the resultant flood likelihood.

5.3 ENSEMBLES

The Australian Bureau of Meteorology has started to issue forecast "ensembles". These are essentially many equally likely future rainfall scenarios.

5.3.1 ENSEMBLE EXAMPLE: CHANCE OF RAINFALL

The chance of rain is the proportion of available models predicting rain at or above the given threshold, expressed as a percentage.

The advantage of using multiple models to determine rainfall is the ability to estimate the chance (otherwise termed probability, or likelihood) of receiving rain. For instance, if seven of the eight models believe at least 10 mm will fall, then the probability of receiving at least 10 mm will be listed as 7/8, or 88%. Likewise, if only one model thinks there will be 10 mm, then the chance of at least 10 mm will be 1/8, or in other words, 13%. No particular model is favoured. Sometimes there may be a "chance of rainfall" when the total expected is less than 1 mm (and is not marked on the rainfall total maps).

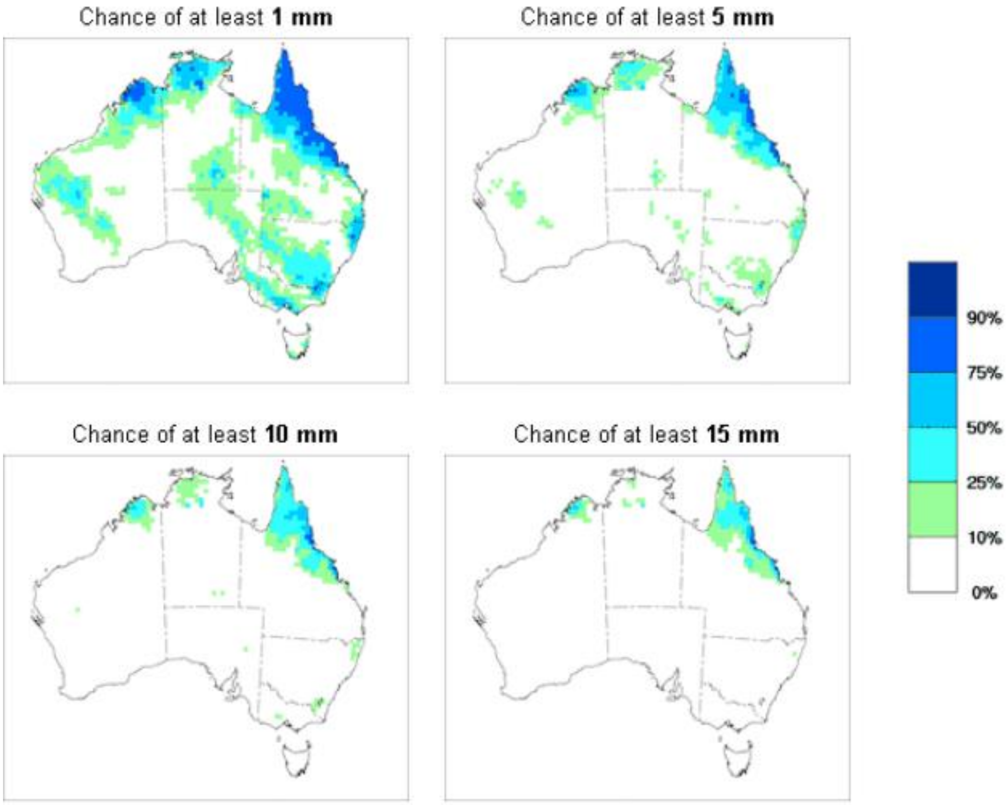


Figure 5: Results of an ensemble of model predictions (BOM)

5.4 MONTE-CARLO

Broadly speaking Monte Carlo simulations use a random sampling of the various inputs to provide the input to a deterministic simulation to then develop a large number of potential solutions from which a probability distribution of can be derived.

Monte Carlo simulations are a "randomised" sensitivity analysis. Care needs to be taken in understanding whether the various inputs are independent. For instance, if the temporal patterns vary seasonally then it makes no sense for them to be sampled independently of the other seasonal factors such as losses.

Historically computing power has been the main limitation in undertaking Monte Carlo simulations, however with GPU technology, distributed computing and multi CPUs computers becoming mainstream this is no longer the case

5.5 CONTINUOUS SIMULATION

Advocates of continuous simulation often state that the benefits of continuous simulations are that the dynamics of the system are considered. For instance, what is the effect of a moderate storm falling immediately after another moderate storm? Is the combination of these two events worse than a large event?

6 HYDRAULIC RISK ANALYSIS

By combining the predicted inundation from many different events, with a database of damages, the outcome is a better understanding of the economic consequence of flooding. The results can be calculated for individual objects in the network (each property) or summarised for a whole catchment, and allows sensitivity analysis of more of the underlying modelling/economic assumptions, which in turn allows for optimisation of the final flood mitigation strategy.

It is necessary to assess the potential damage in the future from a range of severities of flooding, resulting from different depths of flood waters within the property. This will allow the accurate determination of the loss-probability curve.

Risk Analysis runs can be used as a tool to assess the consequence of flooding events at locations in the network, as a monetary value. The locations in the network to be assessed are defined by Damage Receptors in the network. Flood duration and depth results at the receptors are used to calculate a corresponding damage value for each receptor using damage curves referenced by the receptor.

6.1 DAMAGE RECEPTORS

A Damage Receptor is a location that is used to define the location and properties of a structure/building within the flood plain. In the model these are represented as either a point or polygon object located in the 2D mesh. Hydraulic simulation results at the damage receptor include flood duration and maximum flood depth. The results are used in the calculations carried out by a Risk Analysis Run in order to produce an estimate of the impact of flooding at the receptor from an economic point of view, in terms of an estimated annual damage value.

6.2 DAMAGE FUNCTIONS

A Damage Function is used to store a set of damage curves defining the relationship between flood depth and damage values, where damage values are expressed as a monetary value used to calculate the cost incurred by flooding. These are the direct costs, or in other words the cost of restoration of the property to its condition before the flood event, or its loss in market value if restoration is not worthwhile. Indirect costs are defined as those caused by the disruption to the economy, and extra costs of emergency and other actions taken to prevent flood damage and other losses. Many items of flood damage loss are a function of the nature and extent of flooding, including its durations, velocity and contamination of the floodwaters.

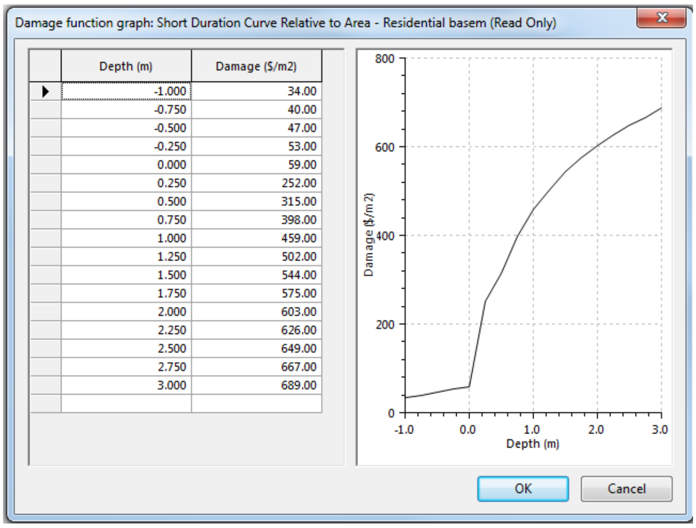


Figure 6: Sample Damage-Depth function

The land use of a flood prone area significantly changes its likely damage characteristics. Houses are affected differently from offices and shops, which in turn suffer different damage from that experienced in industrial or recreational areas. Different curves can be input for these different land use types.

The curves are associated with Damage Receptors at each of the receptor objects.

6.3 OUTPUTS

The risk analysis simulation assesses flood duration and inundation at damage receptors in the network and calculates a corresponding damage value for each receptor using the damage curves referenced by the receptor.

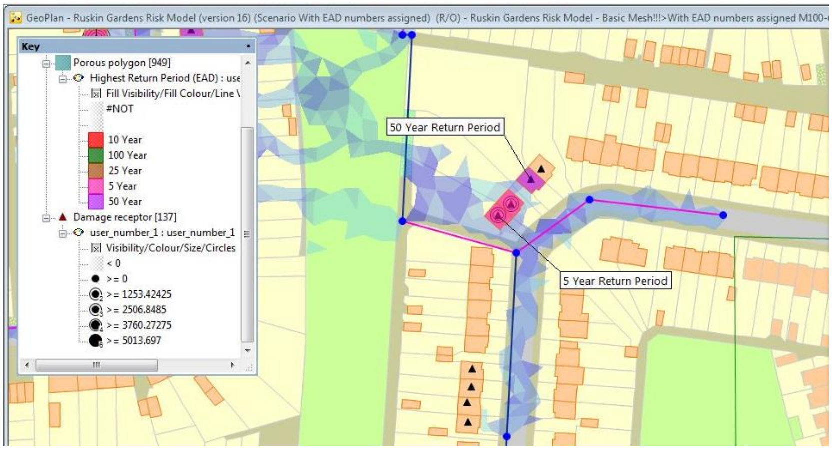
Damage calculations are carried out for each damage receptor as follows:

- Flood duration result for each receptor is used to determine whether to use the long or short duration damage function curve

- Max depth result for each receptor is used to lookup the damage value on referenced damage curves (using linear interpolation)

- Damage values are multiplied by damage receptor weighting values and by damage receptor value/area values if using relative to value/relative to area curves.

The results are then available either in a map view where results can be interrogated spatially or numerically in a variety of tables for further analysis.



Damages ($) for Code: Commercial

Return period	Event probability	60.0 mins	Annual damage
5.0000 yrs	0.450851	22022.045	9928.668
10.0000 yrs	0.086107	36095.469	3108.061
25.0000 yrs	0.055952	58111.492	3251.456
50.0000 yrs	0.019409	104499.789	2028.261
100.0000 yrs	0.009851	144552.234	1424.007
EAD	N/A	N/A	19740.453

Total Damages ($) Over All Receptors

Return period	Event probability	60.0 mins	Annual damage
5.0000 yrs	0.450851	148115.500	66778.070
10.0000 yrs	0.086107	188543.469	16234.849
25.0000 yrs	0.055952	273054.500	15277.950
50.0000 yrs	0.019409	343914.875	6675.124
100.0000 yrs	0.009851	425669.406	4193.337
EAD	N/A	N/A	109159.328

Figure 7: Example of outputs

7 CONCLUSIONS

As with all models the accuracy of the input data is paramount. Where possible hydraulic and hydrologic models should be calibrated against recorded flow (and ideally flood) records to provide confidence that the assumptions in the model are correct for a range of conditions. When considering the variation in damage costs for only a relatively small difference in predicted water level the accuracy of ground levels, and internal floor levels needs to be considered.

The power of computers, in particular the distributed computing of multiple runs means that simulation techniques such as Monte Carlo, and Continuous Simulation can be used to determine the sensitivity of the prediction to various inputs, and to assess a wider range of catchment conditions. This will provide flood managers with more information with which to assess the efficacy of proposed flood risk management schemes to derive an optimal solution resulting in economic benefits for the whole community.

Estimated Annual Damages is a useful metric to use when comparing options for mitigation and also for allocating funds for self-insurers.

REFERENCES

Duncan McLuckie et al, Updating National Guidance On Best Practice Flood Risk Management, Floodplain Conference 2012

Engineers Australia & Australian Government, Australian Rainfall & Runoff Revision Project, http://www.arr.org.au/, 2015

Australian Bureau of Meteorology: http://www.bom.gov.au/watl/about/about-forecast-rainfall.shtml, 2015

Deloitte, Building our nation's resilience to natural disasters, Australian Business Roundtable for Disaster Resilience and Safer Communities, 2012

A McAslan, The concept of Resilience, Torrens Resilience Institute.

Holling, C. S. 'Resilience and stability of ecological systems'. Annual Review of Ecology and Systematics, 1973, 4, 1-23.

Australian Government, Natural Disaster Funding Arrangements, Productivity Commission Issues Paper, May 2014

Penning-Rowsell, E et al, The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques, 2010

Innovyze, InfoWorks ICM Help Files, 2014