Flood Mitigation Works and Planning Levels: A Policy Rethink? The Gold Coast Experience

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Flood mitigation works have long been used as an effective method to reduce flood risk to communities predominately through reducing the likelihood of the hazard by lowering flood levels, e.g. through construction of dams and/or levees/dykes.

Upon completion of flood mitigation works, the question is fairly asked by developers and land owners as to why the mitigation benefits are not passed to communities in the form of lowering flood planning levels and/or changing land use to reflect the lowered flood levels. This would in turn increase land yield and development opportunities and therefore the general prosperity of the community. For the Gold Coast, this question arose as a result of the recent raising of Hinze Dam (Stage 2 to Stage 3) which serves as Gold Coast's primary water supply source and importantly reduces the flood risk for residents and businesses located in the downstream Nerang floodplain.

This paper outlines the Gold Coast experience in addressing this question and demonstrates that reducing flood-planning levels following structural mitigation work would diminish the city's gained flood resilience over time, eroding the initial intent of the mitigation works through exposing future development to the same level of pre-mitigation risk. This risk is exacerbated for the Nerang floodplain due to a "spill" effect in that numerous properties become exposed once flood planning levels are exceeded.

The paper concludes that setting of flood-planning levels following flood mitigation works should undergo a rigorous risk assessment that considers (i) the floodplain response to the entire flood risk spectrum and (ii) the incorporation of future development projections. It also concludes that communication of results is a real challenge and for this study a Resilience Index was developed to better communicate the findings.

Following industry consultation and modelling studies, the policy position of retaining pre-mitigation flood planning levels for the Nerang floodplain was supported by industry and approved by the Gold Coast City Council.

1 INTRODUCTION

The Hinze Dam located in the Gold Coast hinterland has provided Gold Coast residents with clean water supplies and flood mitigation benefits over many years. In December 2003, the Nerang River Flood Mitigation Advisory Committee recommended the raising of the Hinze Dam as the preferred physical flood mitigation option for the Nerang River Catchment. Construction works were completed in December 2011 at a cost of $395M. Raising Hinze Dam to Stage 3 (HD3) provides more flood mitigation storage behind the dam thereby reducing the risk of flooding across the Nerang River floodplain and increasing the City's flood resilience.

Following the completion of the dam two distinct floodplain policy options emerged affecting downstream residents.

The two policy positions before Council were:

- Option 1- retain the current flood planning levels based on the Q100 line prior to raising the dam wall. Option 1 was proposed by the community and expressed through the Nerang Flood Mitigation Community Consultation process.

- Option 2 - lower the flood planning level in accordance to the new Q100 flood line as is generally adopted. Option 2 was proposed by sections of industry through submissions to Council

This paper describes the process that the Gold Coast City Council employed to determine the preferred option. This process included developing an appropriate methodology, analysis of results including a City-wide impact assessment and communication of results to Council and stakeholders. Specifically this paper:

- Quantifies the Nerang floodplain's pre and post mitigation flood resilience through, using flood damage as a surrogate for resilience.
- Demonstrates how the City's resilience changes over time depending on the post mitigation policy option adopted
- Examines the impact of lowering flood planning levels (policy option 2) on (i) the people both within and outside the Nerang floodplain, (ii) the City's economy particularly the development industry and insurance industry and (iii) emergency management.
- Concludes with a discussion on the pros and cons of the two alternative policy positions

2 STUDY AREA

Figure 1 shows the extent of the study area. The Nerang River floodplain is located in the south-east corner of Queensland, Australia. The Nerang River catchment is one of seven major catchments within the boundary of Gold Coast City and encompasses approximately one third of the City's area and a similar proportion of properties across the City. The Nerang River catchment has an area of 454 kilometres and is partially controlled by two dams; Little Nerang Dam on Little Nerang Creek and Hinze Dam on the Nerang River. Hinze Dam has a catchment area of 210 square kilometres and commands 42% of the Nerang River Catchment. The dam was constructed in 1976 at a height of 64.6 mAHD (spillway). The dam was raised to 82.2 mAHD (spillway) in 1989 (Stage 2), and again raised in 2011(Stage 3) to 94.5 mAHD (apillway). In addition to the upstream catchment there are a number of local creeks that flow into the floodplain to the south of the Nerang River, the most significant is Mudgeeraba Creek.

According to Bureau of Meteorology (BoM, 2014) the Nerang River has experienced four major floods, viz. 1947, 1954 1967 and 1974. The most recent flood occurred in June 2005 and is described as a 'moderate' flood in terms of severity.

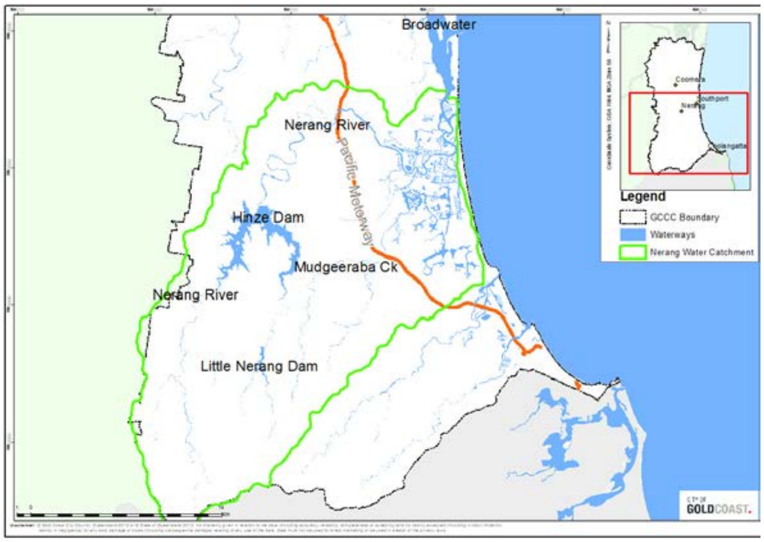

Figure 1 – Study area

3 METHODOLOGY

The methodology was based on estimating the Annual Average Damage (AAD)[1] for a range of scenarios that included the two policy options and future development projections for various time horizons. These projections were based on State government estimates to 2036 and extrapolated linearly for this study to 2060. Table 1 lists the scenarios examined.

Table 1: Modelled Scenarios

Hinze Dam Stage	Horizon	Policy Setting	Comment
Stage 2 (HD2)	2011		As is
Stage 3 (HD3)	2012		As is
Stage 3 (HD3)	2036	FPL* set at HD2	5340 additional dwellings
Stage 3 (HD3)	2036	FPL set at HD3	5340 additional dwellings
Stage 3 (HD3)	2060	FPL set at HD2	10,600 additional dwellings
Stage 3 (HD3)	2060	FPL set at HD3	10,600 additional dwellings

*Flood Planning Level

Once AAD's estimates were calculated, the estimates were converted to a Resilience Index (RI) for the purpose of communicating the results to Council and various stakeholders. This conversion process is discussed in the next section of this paper.

In order to derive Annual Average Damage estimates three types of modelling process were required viz. a hydrologic model to provide inflows for a range of design events (5 year ARI to PMF) to a hydrodynamic model that calculates flood surfaces for each event. These flood surfaces are then in turn input to a flood damage model that integrates the results on a property by property basis to provide annual average damage estimates. This process is applied for each scenario as outlined in Table 1. Details of how the three types of models are applied for this study are discussed next.

[1] AAD is the average damage per year that would occur in a nominated floodplain from flooding over a very long period of time (SCARM Report 73, 2000).

Hydrological Modelling

Hydrological modelling is used to describe and to quantify the interaction between rainfall and the topographic surface that produces runoff as overland flow and stream flow within a catchment. Assessment of hydrologic processes within the study area was undertaken using a calibrated and validated Gold Coast City's numerical hydrology model. Council's model is based on the URBS software platform, using both design event and Monte Carlo simulation approaches (Mirfenderesk et al, 2013).

Hydrodynamic modelling

The hydraulic assessment considers the movement of water through the channels and floodplains and defines flood level, discharge and flow velocity patterns throughout the study area. Calibration and design event modelling of waterways and floodplains was undertaken using Council's hydraulic model for the Nerang River using the MIKEFLOOD modelling software from DHI Water and Environment. MIKE Flood allows coupling of a MIKE 11 (1D) model and a MIKE 21 (2D) model to run in parallel representing channels and floodplains respectively. These two models represent industry standard software packages that are used worldwide. The hydrodynamic simulation output is a flood level surface that is used as input to a flood damage model to quantify floodplain property damage in dollar terms.

Flood Damage Modelling

Gold Coast City Council's GIS based flood damage model Carroll et al (2002) was used to assess tangible damages resulting from a Q100 flood at the Nerang River Catchment. Input to the model includes:

- Council's property database.
- Floor and garage level survey database. This is a growing database; and as of 2013 this database contains more than 9000 surveyed properties.
- Digital Elevation Model of the study area. This is a 5 metre grid based on a comprehensive dataset comprised of Aerial Laser Scan, photogrammetric and depth sounding data collected over the past few years for the whole Gold Coast.
- Flood surfaces of the study area. These data are obtained from the hydrodynamic model of the study area.
- Stage damage relationships for differing dwelling types. These curves are based on findings of an earlier study undertaken by Water Studies Pty Ltd for the Gold Coast City Council (1997, 2001) modified by studies undertaken by Marker (2006), Wehner (2012), Maghsood (2013). and Sargent (2013).

The model calculates damage for each property and then accumulates property damage for each suburb and/or for the whole floodplain. The damage cost for each property is based on the type of dwelling(s) and depth of inundation above floor level(s).

It is important to note that the current estimate of damage is limited to direct damage to residential properties, businesses and industry and roads. Indirect damages, such as loss of value added from affected businesses, disruption to transport when roads are cut, tourism impacts, etc. are not included in this estimate. The intangible damages, such as a negative image for the city, interruptions to daily life, etc. also are also not taken into account. An earlier study (SKM, 2002) has shown that 89% of tangible losses due to flooding is directly attributable to contact with floodwater. Indirect damages are estimated at 7% of the total cost. According to this study, intangible damages account for 6% of the total damage. It is worth nothing that part of the intangible damages such as loss of life, memorabilia, post event stress, etc. cannot be easily identified in monetary term and is excluded from this analysis.

4 CONCEPT OF RESILIENCE AND RESILENCE INDEX

In order to best communicate the results and findings of this study reference is made to term "Resilience" as is now commonly used in the literature.

Resilience has several components (Tourbier, 2012), including spatial (land use planning), structural (levees, dams, dykes etc.), social (community, governance institutions etc.) and risk/financial (insurance, government assistance etc). For the purpose of communicating the results of this study we focus on spatial, structural and financial flood resilience.

In this context, we look to estimates of flood damage or consequence as a surrogate for the City's flood resilience. For example a low flood consequence (in terms of damage cost) is an indication of high flood resilience (or low flood risk) or if a flood mitigation scheme is put in place and there is x% reduction in damages then we can say there is a x% increase in resilience. Changes in flood resilience are assessed through estimating changes in flood consequence as a surrogate. These consequences are expressed as annual average damages that consider the full spectrum of flooding frequencies as discussed in the previous section.

As a further refinement to this concept a Resilience Index (RI) was developed based on the relative changes in City's resilience due to implementation of a flood mitigation scheme. A value of 1 represents the City's resilience immediately post mitigation, whereas a value of zero represents complete loss of resilience relative to the post mitigation condition. Using this index the results of analysis were communicated in terms of loss of resilience, e.g. if we adopt a chosen policy option, then we could say the City's resilience would reduce to 50% by 2050.

It should be noted that with no further mitigation initiatives, some loss of City's resilience occurs over time, the rate of which depends on (i) the flood planning levels set for new developments (ii) the extent to which the floodplain is further filled and (iii) the extent to which properties are exposed to floods that exceed the flood planning level.

It is acknowledged that using annual average damages as a surrogate for resilience requires considerable refinement particularly inclusion of social flood resilience, however when expressed as a relative index it is useful for comparative analysis between various policy settings as outlined in this paper. Accordingly, the following sections use this concept and index to quantify the results of the comparative analysis.

5 MODELLING RESULTS AND KEY ASSUMPTIONS

The modelling results showed that:

- Construction of Hinze Dam Stage 3 has resulted in a 38% improvement in the resilience for residents and businesses of the Nerang River floodplain.
- Policy option 1, i.e. maintaining flood planning level based on Hinze Dam Stage 2 will minimize the rate of resilience loss over the coming years.

- Policy option 2, i.e. lowering the flood planning level to Hinze Dam stage 3 will result in:
    - o Losing 45% of the Hinze Dam stage 3 benefits by 2036
    - o Losing 90% of the Hinze Dam stage 3 benefits by 2060

These estimates are based on:

- State Government Growth Statistics (to 2036) indicating that 5300 new detached dwellings are estimated to be constructed in areas downstream of Hinze Dam.
- Assuming a linear growth in the number of detached dwellings between 2036 and 2060.
- That all new dwellings' flood immunity levels are set at the appropriate policy option.

The estimates do not include:

- Any climate change element, e.g. sea level rise or more frequent rainfall extremes.
- Growth in attached or other type of dwellings within the study area,
- Flood damage to parks, and infrastructure.
- Cumulative filling effect due to future developments on existing properties.

Changes in the City's flood resilience based on these results are discussed in the next section.

6 CHANGES TO THE CITY'S FLOOD RESILIENCE

Figure 2 schematically shows the change in flood resilience in Gold Coast in the past 40 years. As shown in the figure , the resilience of the City was boosted three times in 1976, 1989 and 2012, corresponding to the construction of the Hinze Dam (HD1), raising the Hinze Dam to stage 2 (HD2) and raising the Hinze Dam further to stage 3 (HD3). The direct impact of the dam construction followed by raising the dam to stage 2 and stage 3 heights has been reductions in downstream flood levels. Figure 2 infers that the gained resilience from the construction of the dam and raising it to stage 2 were partly eroded over time as a result of further development in floodplain at the lowered flood planning levels. The degree to which has not been quantified.

Figure 2 shows the changes in resilience following raising the dam to stage 3. Option 1 (shown in dashed line) assumes that Flood Planning Levels will be maintained. Option 2 (solid line) assumes that Flood Planning Levels will be lowered, reflecting the flood mitigation benefits that has been generated by the dam, i.e. a reduction in downstream flood levels for various return periods.

Option 2 (lowering the flood planning level) shows that City's flood resilience reduces dramatically, because development occurs above the designated flood planning level (generally 1:100 year ARI). This means that floods larger than the 1:100 year ARI event continue causing damage and reducing the City's flood resilience.

Option 1 (maintain current flood planning levels) shows that City's flood resilience reduces at a slower rate, because flood planning levels are set based on pre-mitigated 1 in 100 year ARI level (HD2). A pre-mitigated 1:100 year ARI level provides a higher flood immunity. Therefore, the damage associated with larger than 1:100 year flood levels is smaller than what would be experience in Option 2.

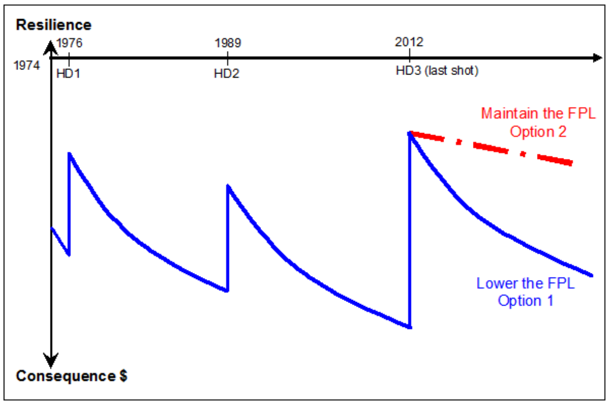

Figure 2 – Schematic change in flood resilience over the past 50 years.

Figure 3 provide a more detailed depiction of post stage 3 change in flood resilience. The figure shows the result of Council's flood damage model, in terms of change in flood consequence, for four different scenarios

- Before construction of HD3 (year 2011)
- After construction of HD3 (year 2012)
- In year 2036 (time horizon set by State Government Growth projection figures)
- In year 2060 (based on continued growth)

As shown in the figure, raising Hinze Dam to stage 3 has increased City's flood resilience significantly. As shown in the picture the resilience index of the Nerang catchment immediately after the construction of the Hinze Stage 3 (at its peak) is assumed to have a value of 1, as per the definition set out above. Based on flood damage modelling results, the resilience index just before raising the dam would be 0.62, indicating 0.38 increase in resilience due to raising the Dam to stage 3. Flood damage analysis shows that 45% of this added resilience will be eroded by 2036 (reducing resilience index to 0.79), if flood planning level is lowered to after mitigation 1 in 100 year flood level. Lowering flood planning level will result in the erosion of 90% of the added resilience by 2060 (reducing the resilience index to 0.66).

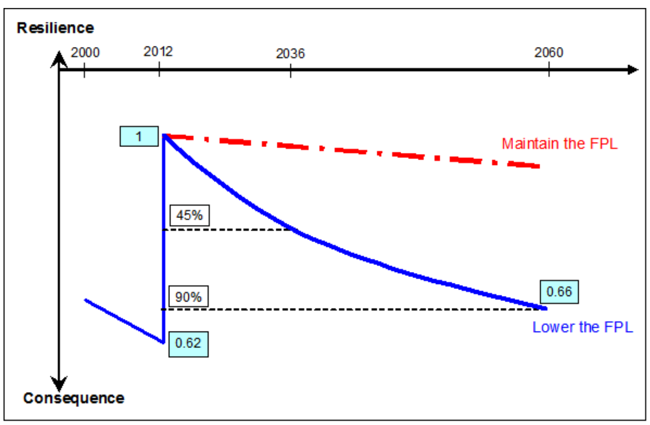

Figure 3 - Change in flood resilience for the two policy options.

One reason for such a reduction in flood resilience is that the Nerang Floodplain is exposed to a “spill” effect. The spill effect is a characteristic of a floodplain whereby once the designated flood planning level has been exceeded numerous properties become exposed to flooding. This causes a rapid increase in flood damage once the FPL is exceeded.

7 IMPACT ANALYSIS

The City’s Economy

The City’s focus on expanding economic diversity and becoming a centre for various national and international cultural and sporting events may result in far greater industrial/commercial flood damage than currently estimated. The potential impact on our major industry, i.e. tourism, may need to be carefully considered particularly should a flood coincide with a major event. For instance, the Gold Coast will host the Commonwealth Games in 2018 with the majority of venues located within the Nerang River floodplain.

The City’s tourism industry in the Gold Coast is responsible for more than 44,000 equivalent full-time job positions with $1 in every $5 spent being derived from visitors (GCCC 2003b). Four of the seven destinations which are the focus of Council’s Tourism Strategy are included within the Nerang River catchment.

An increase in City’s flood resilience can improve City’s profile in terms of being an ideal location for investment and a reduction in City’s flood resilience due to poor policies may have substantial consequences for future business activities in the Gold Coast and detract from an otherwise ideal location for investment. Maintaining the City’s flood resilience does not hamper development. It only encourages development at a safe level; ensuring long-term prosperity of the City’s development industry and economy.

An important issue here is that the impact of a disastrous flood within the Nerang River floodplain not only will impact its residents and businesses but will impact far beyond the catchment boundaries and will cause economic harm at a local, regional, state and possibly national scale.

Insurance

The Insurance industry has repeatedly requested for the implementation of flood mitigation works to increase flood resilience. Lowering flood-planning levels does not reduce flood risk upon which flood insurance is based. On the contrary future flood damage will increase thereby increasing premiums. The only way to minimize the likelihood of insurance premium increases, is to maintain and where possible increase flood resilience of the city. A policy that maintains or increases the City’s flood resilience supports this.

People within the Nerang Floodplain

Raising Hinze Dam provides protection and reduces the flood risk for all floods including floods greater than the 1:100 year flood event. Typically, existing properties that have had a 1:100 year immunity now have their immunity increased to a 1:200 to 1:500 year flood event. Generally the Designated Flood Planning Level (FPL) for development is set at or above a 1:100 year flood level. As already mentioned the

Nerang floodplain suffers from a "spill" effect in that approximately 50% of flood damage occurs above the 1:100 year flood level. This spill effect is characteristic for large extensive floodplains where most properties have been filled to a prescribed level for development. This means that although properties may be above the FPL, the number of properties exposed to flooding above this level is such that considerable damage would eventuate and further any filling of the floodplain above the FPL would exacerbate the situation.

To illustrate, Figure 4 shows a schematised description of the Nerang River floodplain. The dashed lines show 1:100 year and 1:200 year ARI flood levels associated with Hinze Dam Stage 2 (HD2). The solid lines show the 1:100 year and 1:200 year ARI flood levels associated with Hinze Stage 3 (HD3). The solid lines are below the dashed lines; the difference being the flood mitigation benefits resulting from HD3. Because of this mitigation benefit, a parcel of land in location "A" that used to be subject to a 1:100 year flood is now considered for planning purposes not to be subject to a 1:100 year flood. Equally, a house in location "B" that was subject to a 1:200 year flood is now considered not to be subject to 1:200 year flood.

The existing DFL for the Nerang River Catchment is based on HD2 1:100 year flood. If Council reduces the current DFL to reflect HD3 1:100 flood level, the land in location "A" will be above the DFL and no longer be subject to the Council's Flood Code that requires conservation of flood storage capacity. The dotted line in Figure 4 shows the change in 1:200 year flood level, should filling be permitted in the floodplain arising from a relaxed DFL. As a result, properties like the one at location "B" would lose the mitigation benefits from HD3 over time, which is inconsistent with the intent of preserving the benefit of HD3 for community.

As a cumulative result of filling the floodplain, the benefit of raising Hinze Dam to many properties (that are still subject to a larger than 1:100 year flood risk) will be eroded over time. This erosion of mitigation benefits will equally apply to the Council's infrastructure, as they will also lose protection against larger than 1:100 year floods.

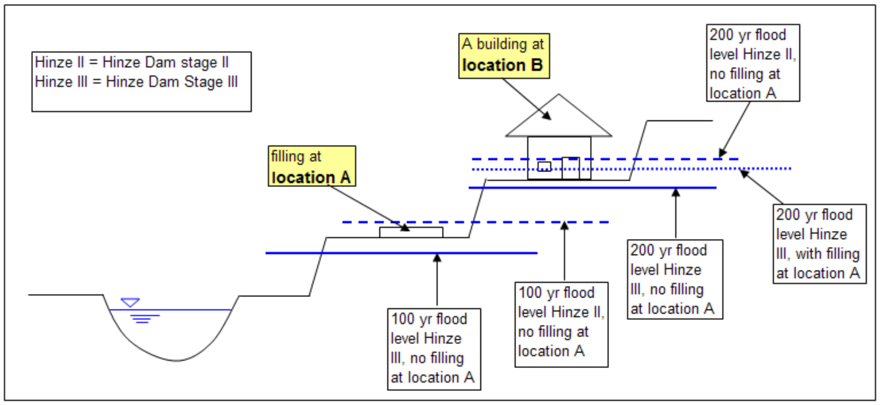

Figure 4 – Flood impact due to new fillings in the Nerang Floodplain

Impact on people outside the Nerang floodplain

The raising of Hinze Dam was a publicly funded project and therefore should benefit the whole City. The Nerang catchment is City's most populated catchment, hosting a large segment of the City's economic activities. The workplace of many people who live in other catchments is within the Nerang River floodplain. The impact of a disastrous flood at the Nerang River is therefore significant and goes well beyond the borders of the catchment. The impact of such a flood will damage the City's image thereby affecting its economy. This would damage the City's flood resilience, resulting in likely increases in flood insurance premiums.

City's flood damage bill

Figure 5 schematically shows consequence-probability curves associated with HD2 and HD3. The horizontal axis shows floods with different return periods (probabilities) and the vertical axis is flood damage (a measure of consequence). The areas under the dashed and solid curves are the Annual Average Damages (AAD's) associated with HD2 and HD3 respectively. The AAD is the average cost of flood damage per year caused by flooding over a long period. As can be seen in Figure 5, the area below the HD3 line (the solid line) is less than the area below the HD2 line (dashed line), indicating that the AAD is less under HD3 condition. The area between the two curves in Figure 5 is equal to the reduction in AAD (mitigation benefit) due to HD3; whose Net Present Value represents the mitigation benefit in monetary terms.

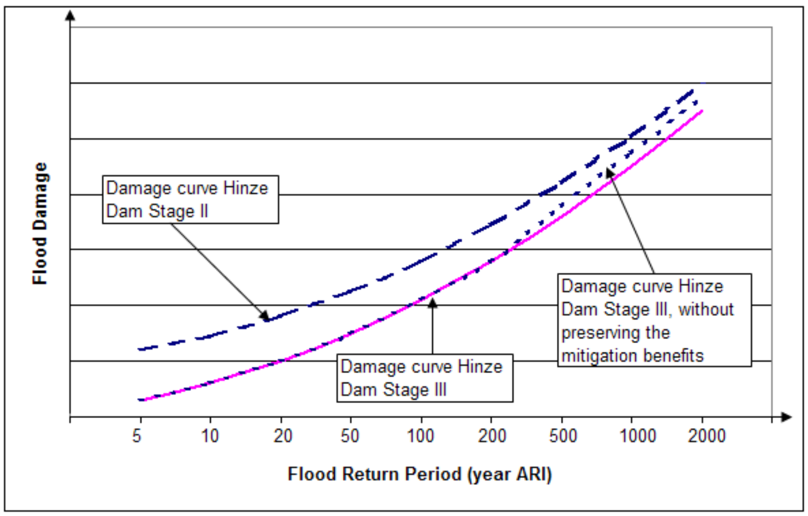

Figure 5 – Impact of raising Hinze Dam on flood damage

The dotted line between the two curves damage curve of HD3 at some time in the future, should the mitigation benefits associated with raising HD3 not be preserved. The area between dotted and dashed line is smaller than the area between solid (HD3) and dashed line (HD2). This illustrates that the AAD will increase over time, if Council allows the mitigation benefits associated with HD3 to be eroded over time.

If the City's Annual Average Damage (AAD) is reduced, Council's and the community's flood insurability will increase. The area between the dashed and solid curves in Figure 5 is an illustration of the measure of reduction in AAD, hence a measure of increase in flood resilience/insurability of the City and the Council.

Further opportunities to increase Flood Resilience

It is important to note that raising Hinze Dam to stage 3 is the last structural flood mitigation opportunity for the City. If the City finds a need to reduce its flood risk in future, there is no viable structural mitigation alternative to generate any substantial reduction in flood risk.

Council's Flood Emergency Management Capabilities

The adverse impact of floods that can overwhelm our protection measures is generally managed through flood emergency management. Maintaining the flood planning level based on Hinze Dam Stage 2 will contribute significantly to the Council's flood emergency management effectiveness by reducing the impact of rare flood events (larger than 1:100 year floods). Lowering flood planning levels will erode over time the flood mitigation benefits and, therefore, will increase the burden on the City's flood emergency management resources.

8 DISCUSSION AND CONCLUSIONS

A good flood policy will generate benefit for the majority of the community and mitigates the likely adverse impacts on the minority to an acceptable level (in an ideal situation the policy will not have any adverse impact on anyone).

Maintaining flood planning levels at Hinze Dam Stage 2 benefits the entire Gold Coast community and no one will be worse off. Council's policy position on protecting the benefits associated with the construction of Hinze Dam Stage 3 has been consistent since December 2003 and as such there was a general expectation that there would be no change in flood planning levels.

Estimates of flood levels are uncertain for a number of reasons. Some of the more important reasons include lack of reliable historical flood data, inaccuracy of rainfall maps, changes to design rainfall estimates, climate variability, etc. As a result, what we currently consider as a 1:100 year flood level may change significantly with the advent of better data and more understanding of climate variability. The issue of uncertainty can be alleviated by considering some safety margin in setting a FPL. Raising Hinze Dam to stage 3 has provided the Nerang River catchment with such a safety margin, enabling Council to be more adaptable to future changes and be able to deal with an accentuation of future flood risk more effectively.

Structural flood mitigation works have long been used as a method to reduce flood risk to communities. These works typically reduce the likelihood of the hazard by reducing flood levels, e.g. through construction of dams and/or levees/dykes. This work shows that structural flood mitigation work, if not complemented by an appropriate policy for managing the generated mitigation benefits, may lose its benefits over time perpetuating the need for further mitigation works in the future.

The study demonstrates that a rigorous analysis of floodplain risk is required to inform policy decisions regarding setting of flood planning levels post mitigation works and that this analysis should consider the floodplain response for the entire flood risk spectrum and include future development projections.

It is also concluded that considerable emphasis must be placed on how best to communicate the project's findings. The concept of Resilience Indexing (RI) provided a simple measure of the effectiveness of a policy and was used to explain complicated engineering findings, enabling the project team to effectively engage with politicians/decision makers and stakeholders. It is acknowledged that the formulation of this index needs to be refined, however for the purpose of this study, which is a comparative analysis between two policy settings, it is considered sufficient.

9 ACKNOWLEDGEMENT

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