MAPPING OF FLOODWAYS AND FLOODPLAIN DEVELOPMENT ZONES USING 2D MODELS

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ABSTRACT

Strategic floodplain management benefits from classifying inundated areas into differing degrees of hazard, risk, and suitability for future development. While quantifying hazard and risk is reasonably straightforward, identifying zones for future development is a difficult and contentious process. However, to successfully plan our urban growth on flood liable land, and to minimise flood risks and adverse flood impacts on existing development, identifying these flood development zones in advance is fundamental. Fully 2D hydrodynamic models offer the opportunity to provide more accurate flood impact assessments, and intuitive identification and mapping of these zones, but cannot necessarily apply the conventional approaches used for 1D models.

This paper presents a simple technique using the velocity depth product (VxD) to classify floodways and floodplain development zones using 2D models, and how to easily evaluate the impacts of future works and land-use changes within the floodplain for strategic planning. Examples are discussed and illustrated.

KEYWORDS

Flood Modelling, Flood Management, Floodplain Development, Hydraulic Categories, Flood Hazard, Flood Risk, Floodway

PRESENTER PROFILE

Bill Syme has over 25 years experience in flood modelling and flood risk management. He has carried out and managed numerous flood modelling and flood risk management investigations, and is the author and manager of the TUFLOW flood modelling software. Bill is an Associate of BMT WBM based in Brisbane.

1 INTRODUCTION

Towns and cities were established near rivers because of their close proximity to navigable waterways and for water supply. These communities may have been initially located on flood free ground, but as they expanded, the urban sprawl crept out onto the floodplain, with only the occasional flood interrupting progress. Flood management was either lacking, or tended be reactive rather than proactive. Levees protecting urban areas are good examples of reactive flood mitigation measures.

The proactive or strategic approach is to identify in advance flood liable land that is suitable for urban development with minimal (ie. acceptable) flood impacts on surrounding areas. Greenfield sites in particular offer the opportunity to be proactive and put in place controls prior to development.

The alternative of total flood prevention by banning all development on flood liable land is generally not palatable to communities, developers and politicians, especially in high growth urban areas. In some communities, flood-free land may not exist!

The challenge for engineers and planners is to:

- identify future urban development zones on our floodplains in advance;
- provide criteria that minimise flood impacts from future development; and
- exercise planning controls that offer appropriate flood immunity.

A key part of this process is the classification of flood liable land into floodways and other categories to help identify where future urban development should or should not proceed.

The traditional approaches using 1D models for zoning flood liable land by, for example, delineating floodways, are not so readily applied to the more popular and accurate 2D models in use today. Alternative approaches for 2D models therefore need to be considered and developed.

2 ZONING FLOOD LIABLE LAND

The NSW Floodplain Development Manual, Appendix L (Ref 1) recommends classifying flood liable land into zones using hydraulic categories as follows:

- Floodway
- Flood Storage
- Flood Fringe

The general principle is that Floodways are “no-go” areas for urban development as flood waters travel in great volumes and speed. Floodways are highly dangerous and very destructive during a flood, and are not an option for urban development.

Flood Storage areas are usually located off to the side of Floodway Zones. They represent deep, and still or slow moving water, and are the backwaters of the floodplain where considerable volumes of water can be “stored” during a flood. Extensive Flood Storage areas can have significant natural flood attenuation effects, behaving somewhat akin to the effects of a dam. Flood Storage zones are not ideal for urban development, and should generally be avoided.

Flood Fringe Zones lie around the edge of flood liable land. They are characterised by shallow depths and still to slow moving water. These areas are the safest and best suited for urban development.

In the USA, Regulatory Floodways are used to zone or reserve flood liable land. A Regulatory Floodway is defined as (Ref 2):

> “A Regulatory Floodway means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations.”

In England, flood liable land for fluvial and tidal flooding is zoned according to flood extent with Zone 2 representing the 1,000 year event extent, Zone 3 the 100 year fluvial event or 200 year tidal event, and anything outside of Zone 2 and 3 (ie. very extreme flooding) being Zone 1 (Ref 3). Fluvial Zone 3 is further subdivided into 3a and 3b, with Zone 3b being the termed the "Functional Floodplain" that is usually derived using the 20 year event extent as a starting point, and Zone 3a the remainder. There is some correlation with the NSW approach in the sense that the term "Functional Floodplain" (Zone 3b) would be equivalent in concept to combining the Floodway and Flood Storage Zones, and Zone 3a equivalent in concept to Flood Fringe, although the NSW approach would not use the 20 year flood extent to derive these zones. Development is prioritised in order of Zones 1-3 using a "Sequential Approach" where Zone 1 is preferred over Zone 2 which is preferred over Zone 3.

3 STRATEGIC PLANNING – WHERE CAN WE DEVELOP?

History has demonstrated that without a plan for the whole floodplain, development occurs ad-hoc, and the cumulative effect of these developments is often not considered. An individual development may have minor or negligible flood effect, but many individual developments may have adverse flood effects resulting in existing properties being inundated more frequently, and sometimes relatively new developments having reduced flood immunity.

To aid strategic planning of future urban development on flood liable land there needs to be a consistent approach:

- on how Floodplain Development Zones are defined, and
- on what are acceptable flood impacts.

Regarding the latter, impact acceptability criteria need to be established that set:

- Limits on flood level increases, typically in the range of zero to 0.2m depending on land-use. For example, an increase of 0.1m in the Q100 flood level on rural land might be deemed acceptable, while in existing urban areas the limit might be no increase in flood levels.
- Other limits such as changes to flood duration, velocity, stream power and bank erosion potential.

The flood immunity of development also needs to be defined. Usually a common standard (eg. Q100) is adopted, however, increasingly planners and engineers are using a risk based approach by taking into account a greater range of flood immunities and other criteria such as warning time and building type. For example, residential buildings may require better flood immunity than industrial buildings, or properties in flash flood areas may have a higher freeboard or greater flood immunity than those where there is ample warning time.

For 1D models, the approach to identify Flood Development Zones has generally been to change the waterway cross-sections. The left and/or right banks of a cross-section are initially encroached based on criteria such as 10% of the conveyance. The model is re-run and the increases in flood level are tabulated and mapped. Where the increases are too high, the cross-sections are enlarged (ie. the encroachment is reduced), and where the impacts can be increased the cross-sections maybe further encroached. The process is iterative and time-consuming.

For 2D models, there are no cross-sections to adjust, but the process is similar. Areas are filled, and the model is re-run. The extent of fill continues to be adjusted based on the change in flood levels and other criteria in a similar iterative manner described for 1D modelling above. This is also time-consuming, especially given the much longer run-times of 2D models.

For strategic planning, it would be advantageous to be able to quickly identify the extent of potential fill based on some measure or output from a model. The NSW Hydraulic Properties Categories discussed previously provide an excellent approach for initially identifying areas potentially suitable for urban expansion. As discussed, Flood Fringe areas are shallow with still to slow moving water. These areas are ideal for urban development as they play a minor role in the behaviour of a flood. A proportion of Flood Storage areas may also be suitable depending on the impact acceptability criteria being used and the extent of the encroachment. Floodways are not an option for any form of urban development.

4 MAPPING FLOODPLAIN DEVELOPMENT ZONES

Delineating Floodway, Flood Storage and Flood Fringe Hydraulic Categories using 1D models is historically based on criteria such as:

- Percentage of Conveyance or Flow. For example, Flood Fringe occurs where the conveyance or flow is less than say 10% of the total conveyance, Flood Storage 30%, and the remainder is Floodway.
- Other non-numeric criteria such as all areas between a river's left and right bank must be designated as Floodway (Ref 4).
- Maximum Increase in Flood Level. The floodplain at the sides of the cross-sections are increasingly filled until the rise in flood levels does not exceed an acceptable increase. The unfilled section is designated as Floodway.
- Combinations of the above.

These criteria are designed for modifying 1D model cross-sections that represent transects of the river or creek and its floodplains. For 2D models, cross-sections are not used (a DTM, Digital Terrain Model, is used), and the identification of Floodways, Flood Storage and Flood Fringe areas is not so easily carried out using the above criteria.

The method proposed for 2D models is to initially use the Velocity Depth Product (VxD). VxD is also known as Unit Flow (ie. flow per unit width with units of m^2/s), and is a very effective measure for defining both flood hazard categories, and the contribution towards conveyance of flood waters. VxD is also independent of flow width, and so can be used irrespective of 2D model element or cell dimensions.

Flood Fringe areas are characterised by low VxD values, ie. shallow and/or slow moving water. To define the Flood Fringe and ascertain the impacts on flood behaviour of developing the Flood Fringe, an iterative process of filling areas up to a specified VxD value, quantifying the impacts, adjusting the specified VxD value up or down and repeating the process is carried out until the acceptability criteria are met.

The 2011 version of the TUFLOW software enhances this iterative process by being able to specify multiple scenarios of filling to different VxD values. The floodplain is automatically filled by the software according to the VxD criteria either over the entire model or within control regions. Control regions can have different VxD values to cater for spatial variations.

Through this iterative approach, Floodways and potential Flood Development Zones are established and mapped. These maps and findings from the analysis then form the basis for controlling future urban development over the floodplain.

5 EXAMPLE 1 – SIMPLE CASE SCENARIO

Two areas on the left and right bank have been identified as sites for future urban development as shown by the site boundaries in Figure 1. The flood impact acceptability criteria set for minimising impacts are:

1. There is less than a 5cm increase in peak flood levels at existing buildings.
2. Flood level increases must be less than 10cm on neighbouring properties and less than 15cm within the in-bank areas of the waterway.
3. Flood level increases greater than 10cm are permissible within site boundaries as these can be accommodated through higher fill levels.

Other criteria such as limits in the change in velocity or erosion potential could also be specified, but for the purposes of this exercise are not considered.

Figure 2 shows the VxD map for the section of the 2D model developed to assess these sites. The shading is described in the figure's caption. The approach to establishing areas that can be filled with minimal impacts on flooding is to focus on areas of low VxD (ie. the green and yellow shaded areas).

Prior to carrying out an iterative analysis to optimise the areas of fill, it is often of benefit to stakeholders to evaluate the worst case scenario, ie. in this case the entirety of both the Left Bank and Right Bank Sites are filled. As illustrated in Figure 3 and discussed in the caption, this causes unacceptable impacts, so clearly is not an option!

A series of runs using TUFLOW's scenario manager and automatic filling of areas within a specified VxD amount were carried out with minimal effort by the modeller. The initial findings were that filling to a VxD less than 0.1 and 0.2 had acceptable impacts on flooding. A VxD limit of 0.3 and 0.4 caused some unacceptable impacts with the results for VxD < 0.4 illustrated in Figure 4. Unacceptable impacts occurred for a VxD limit of 0.5 as presented and discussed in Figure 5.

Based on the iterative exercise described above, the boundary of the Left Bank Site was adjusted to solve the problem of the increases in flood level along its southern boundary and assigned a VxD limit of 0.4 for locating fill. For the Right Bank Site a VxD limit of 0.5 was assigned. Figure 6 illustrates the impacts caused by this scenario are within the acceptability criteria. Figure 7 shows the new VxD mapping that shows the waterway between the sites is essentially now entirely Floodway as indicated by the orange and red shades.

By using VxD as the guide for identifying areas suitable or not suitable for filling, and an iterative approach to establishing impacts on flooding, the extent of fill is optimised in terms of extent and minimising flood impacts.

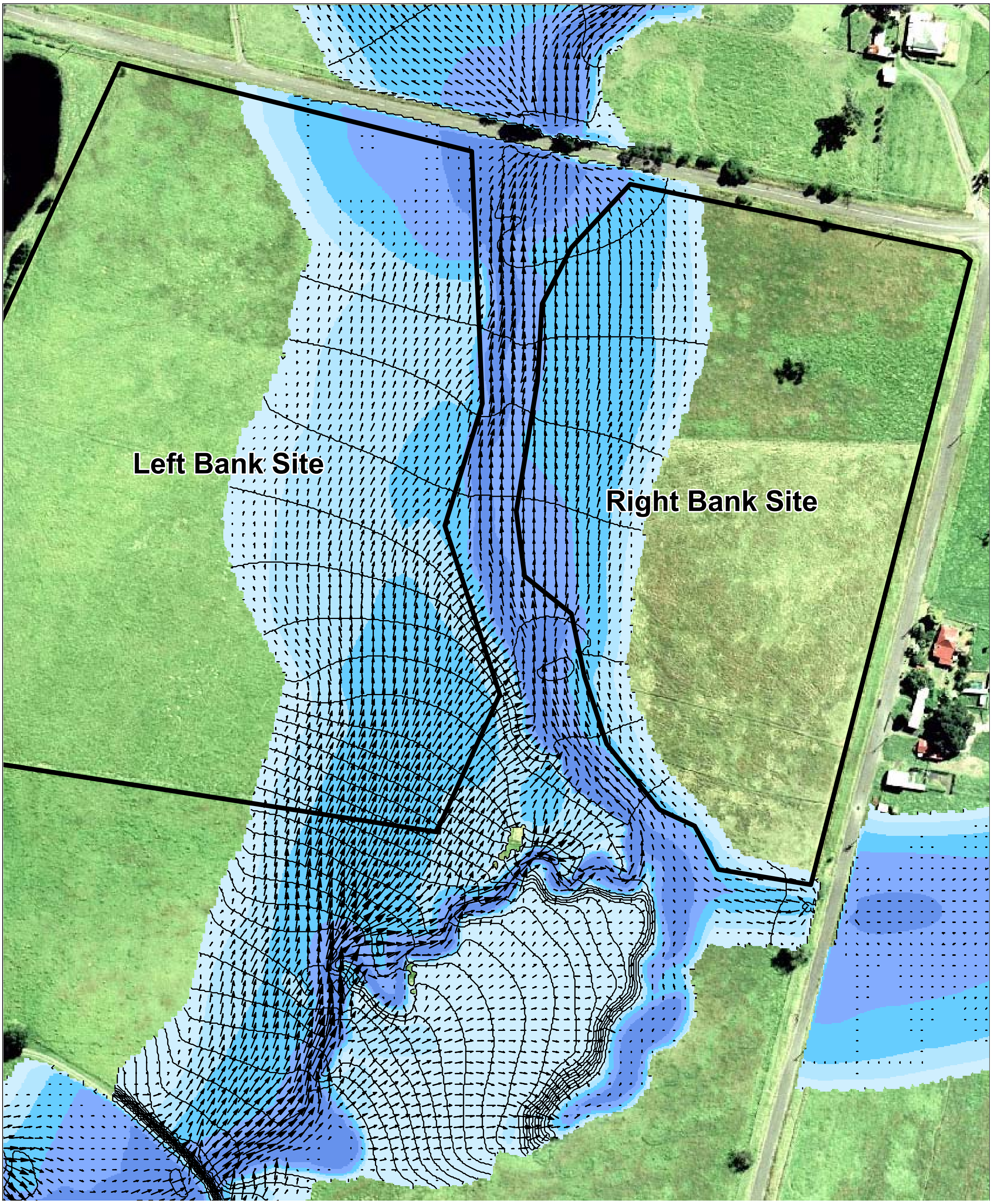

Figure 1: The flood depths using darker shades of blue for deeper areas, velocity of the water using scaled arrows, and black lines for water level contours at 0.2m increments.

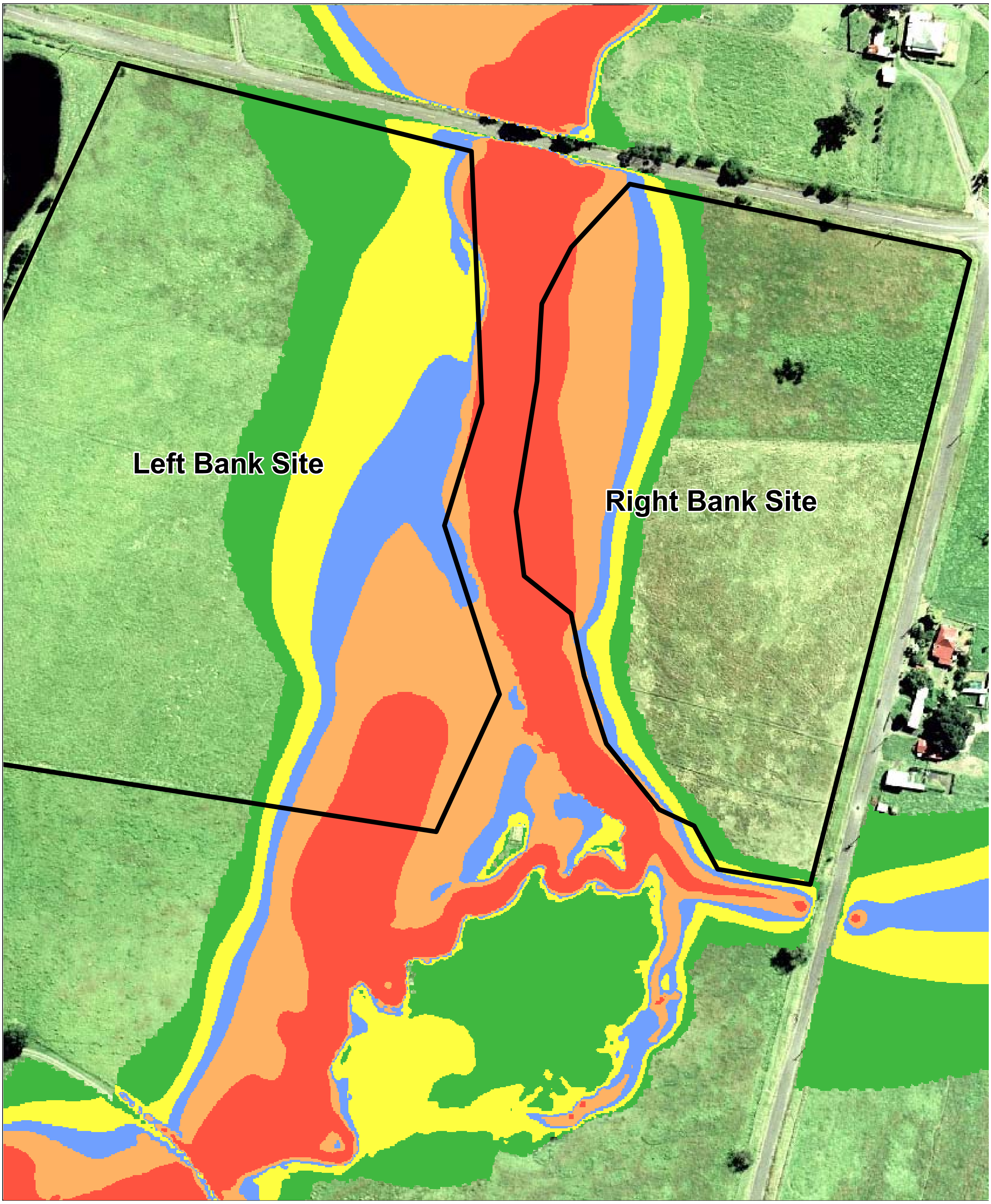

Figure 2: Map of the VxD product. Green areas are VxD less than $0.1m^2/s$, yellow from 0.1 to 0.3, blue from 0.3 to 0.5, orange 0.5 to 1.0 and red greater than 1.0. Floodways will lie within the higher values (eg. red areas) and the Flood Fringe will be in the lower values (eg. green/yellow areas).

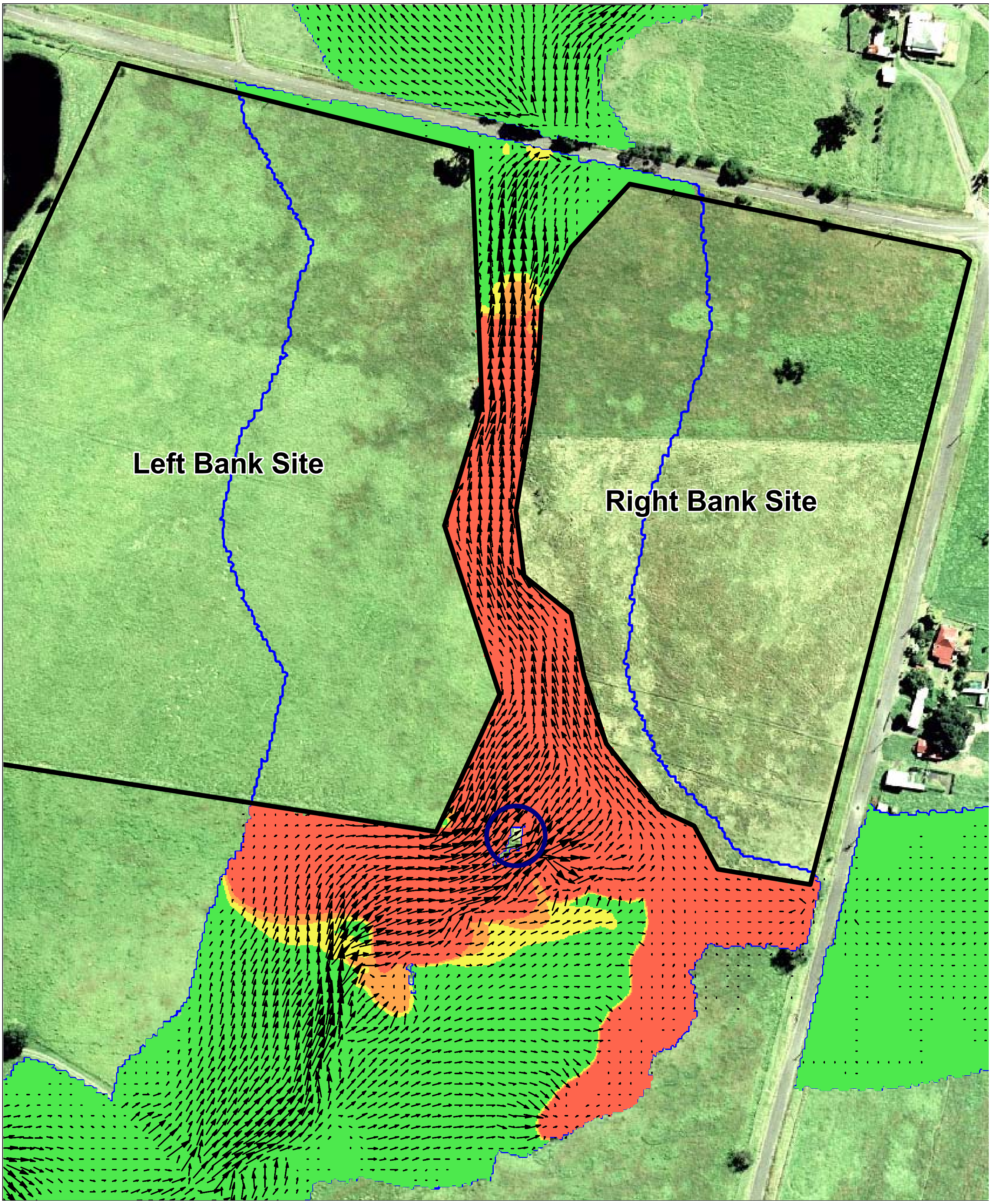

Figure 3: The impacts on flooding if all of both sites are filled. Green shades are areas that experience less than a 5cm increase in flood levels, yellow shades, 5 to 10cm, orange shades 10 to 15 and red shades greater than 15cm. As can be seen the outcome is unacceptable as there is a greater than 5cm increase in flood level at the building circled in dark blue, and substantial increases beyond the sites' boundaries. There would also be substantial changes in flood velocities as evidenced by the change in the arrows.

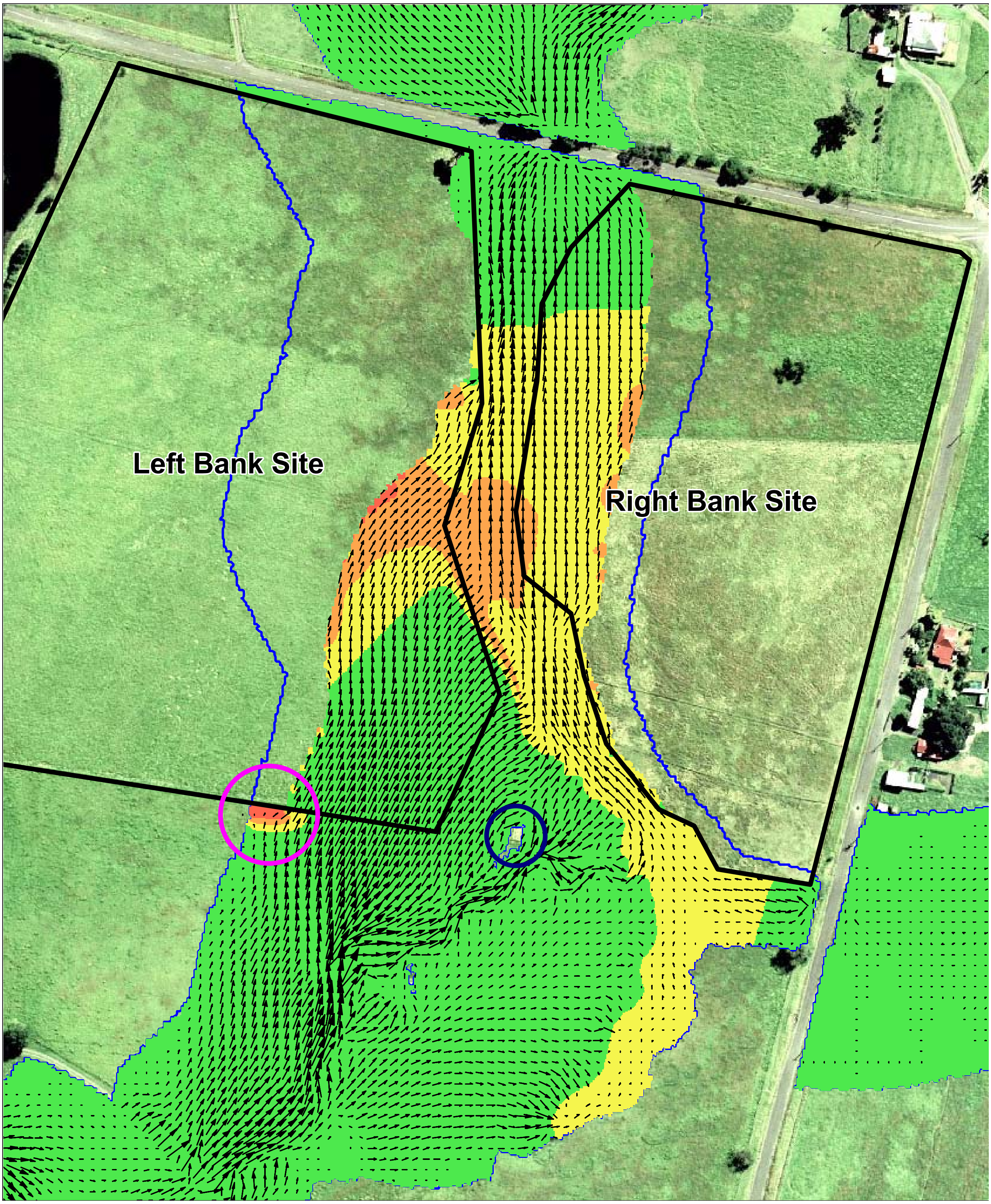

Figure 4: The changes to peak flood levels if only areas that have an existing VxD value of less than 0.4 are filled. The increase at the building is acceptable (less than 5cm) the increases within the in-bank waterway are acceptable being less than 15cm. There is an unacceptable increase in levels at the southern boundary of the Left Bank Site as circled in magenta. The original flood extent is shown by the pale blue shades and blue line.

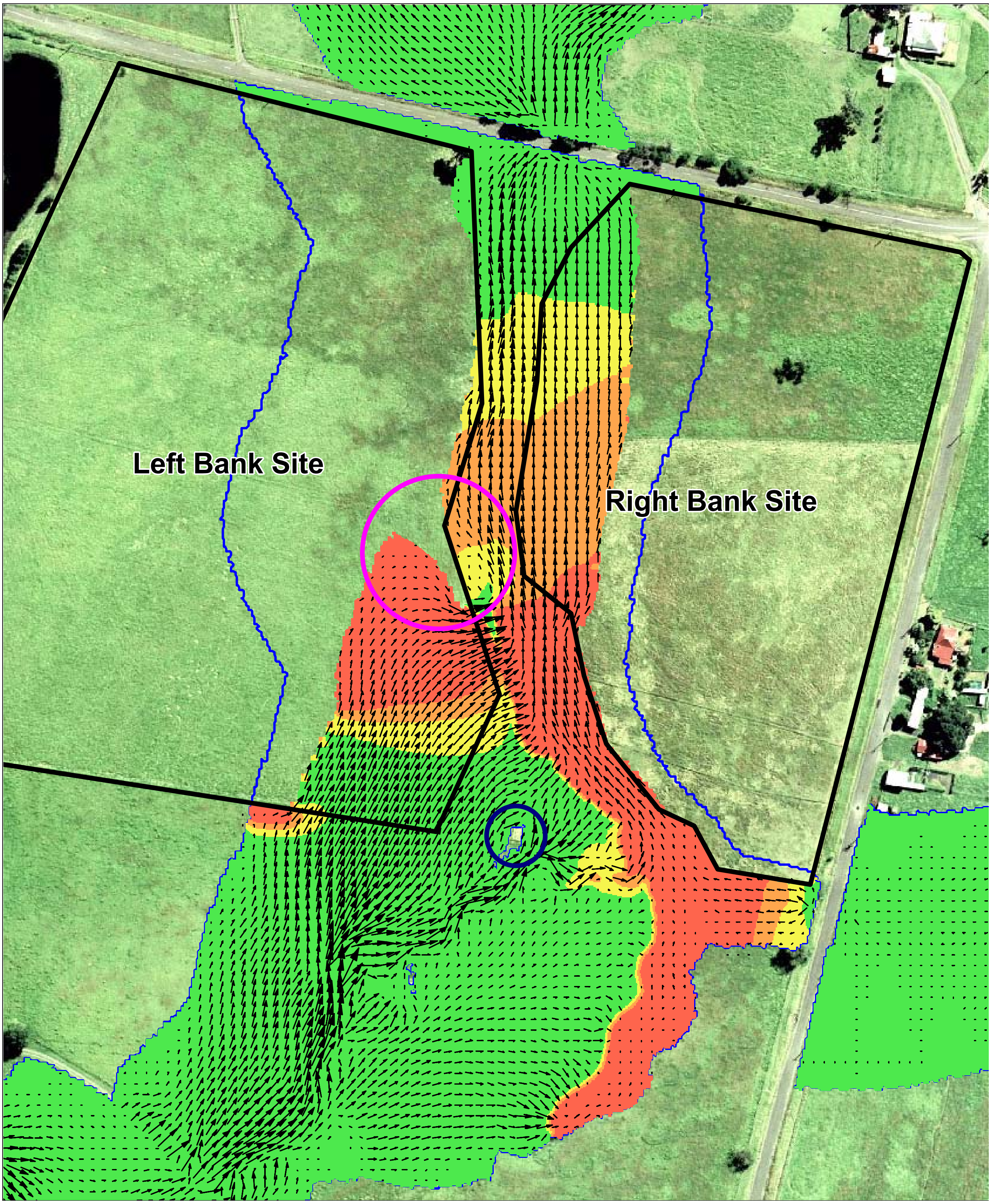

Figure 5: The flood effect of filling areas with a VxD less than 0.5. This causes unacceptably high increases in the levels within the waterway banks, primarily caused by the finger of land within the magenta circle that is blocking overland flows. The unacceptably high increase on the southern boundary of the Left Bank Site remains. The increase at the building has remained below 5cm.

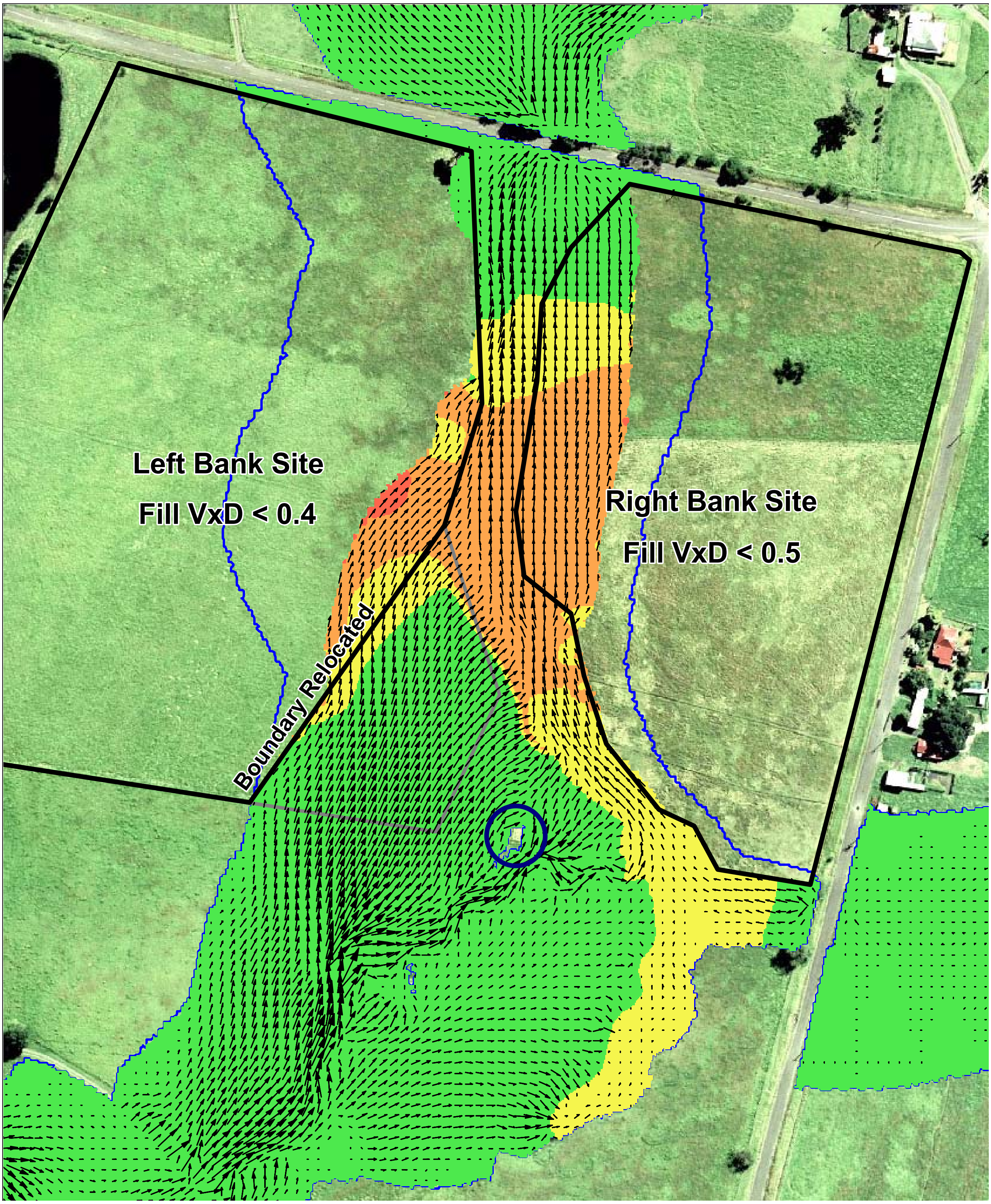

Figure 6: A possible final solution. The region for the Left Bank Site has been relocated to remove the increase along the southern boundary, and a limit of VxD of 0.4 has been set for locating fill. For the Right Bank Site a VxD limit of 0.5 has been set. The only increase exceeding 15cm (red shade) is confined on-site midway along the Left Bank Site. Increases within the waterway are all less than 15cm and the increase at the building is less than 5cm.

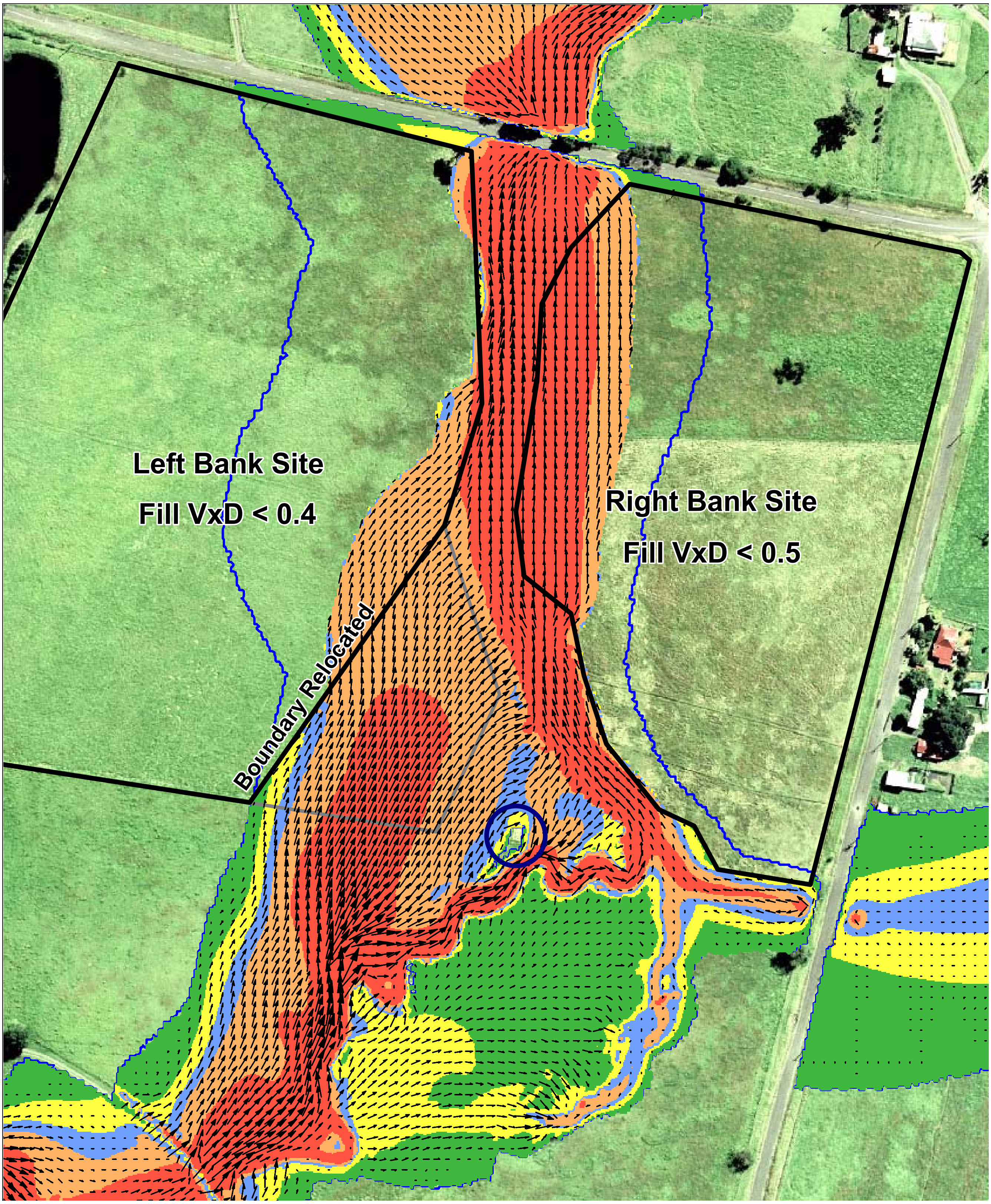

Figure 7: The VxD mapping for the final solution adopted. As can be seen, between the developments there is little green or yellow shading representing low VxD areas. The entire floodplain between the filled areas should now be classified as Floodway due to the high VxD values (orange and red shades).

6 EXAMPLE 2 – TWEED RIVER, NSW, AUSTRALIA

The Tweed River is the most northern river in NSW, Australia. It's entrance to the Pacific Ocean and its catchment border the Gold Coast of Queensland to the north, and are less than an hour and a half from Brisbane. The region behind the beautiful beaches south of the Tweed entrance is under major urban growth pressures as the population from the Gold Coast corridor pushes southwards. Some of the prime land identified by developers lies on the Tweed River floodplain. Tweed Shire Council and BMT WBM are in the process of carrying out a Flood Risk Management Study and Plan that will address the issue of strategic planning and development controls for flood liable land.

A calibrated TUFLOW 2D/1D model of the Tweed River was used to map the VxD values. Figure 8 shows the VxD mapping for the 500 year (Q500) flood event. The same colour scheme as used previously in this paper is used, ie. green for VxD less than $0.1m^2/s$, yellow for 0.1 to 0.3, blue for 0.3 to 0.5, orange 0.5 to 1.0 and red for greater than 1.0. The red shade clearly shows the main river and overland flowpaths that would be labelled as Floodways, while the green and yellow shades are areas that might be categorised as Flood Fringe. Figure 8 also shows two regions bounded by black/magenta lines under pressure for urban growth that lie either side of a new motorway. The region to the north lies between the motorway and the river, and is already partially urbanised. The southern larger region lies south and west of the motorway and extends to southern and eastern extremities of the floodplain.

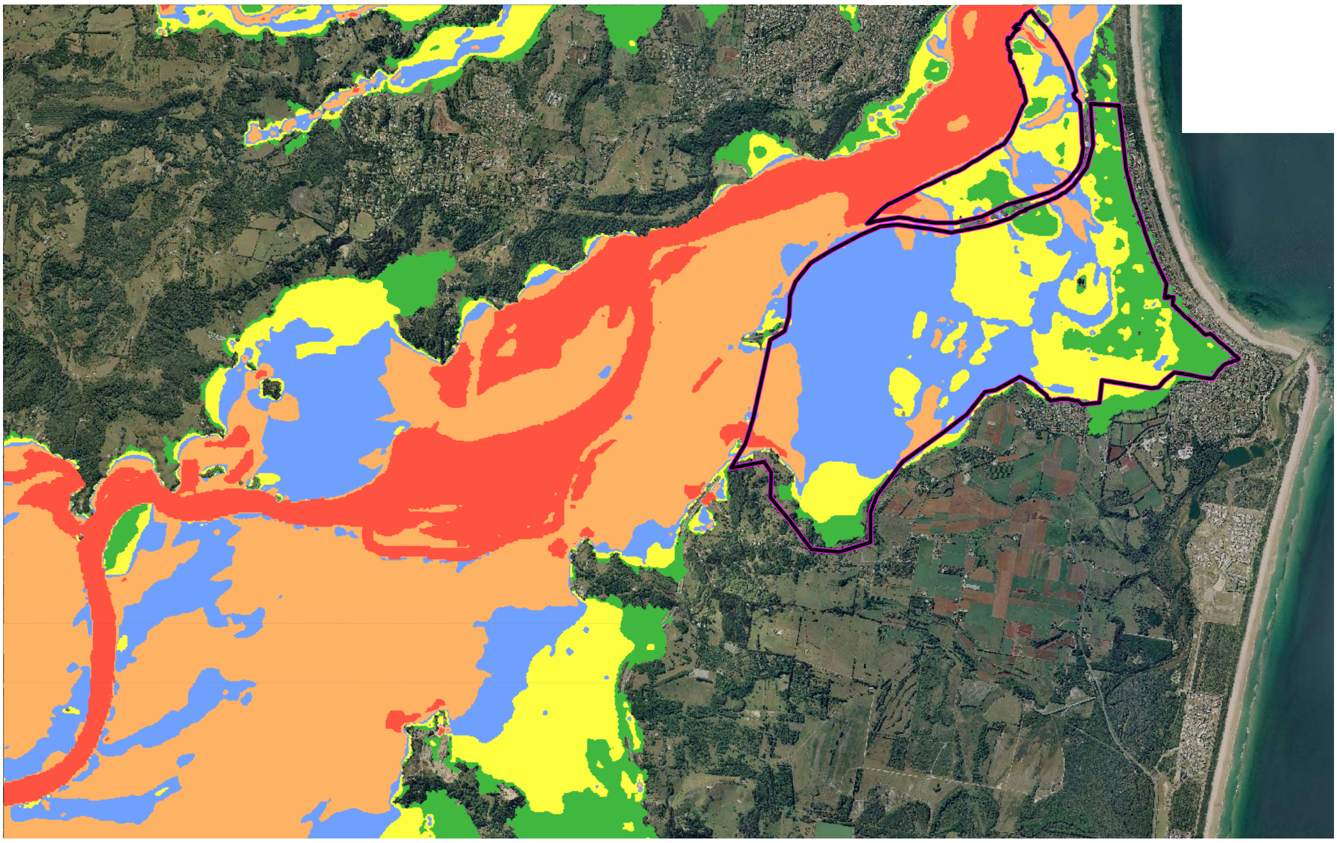

Figure 8: The VxD mapping based on the Q500 event for the Tweed River. Green shades are for VxD less than $0.1m^2/s$, yellow for 0.1 to 0.3, blue for 0.3 to 0.5, orange 0.5 to 1.0 and red for greater than 1.0. Floodways would typically be red and possibly orange shades, with Flood Fringe typically green and possibly yellow shades.

Figure 9 shows the impact on the peak 100 year flood levels should the entirety of these two regions be filled. The green shade indicates change in peak flood level of less than 5cm, yellow is a 5 to 10cm increase, orange 10 to 15cm increase and red more than a 15cm increase. As can be seen, the impact of filling these two regions is substantial.

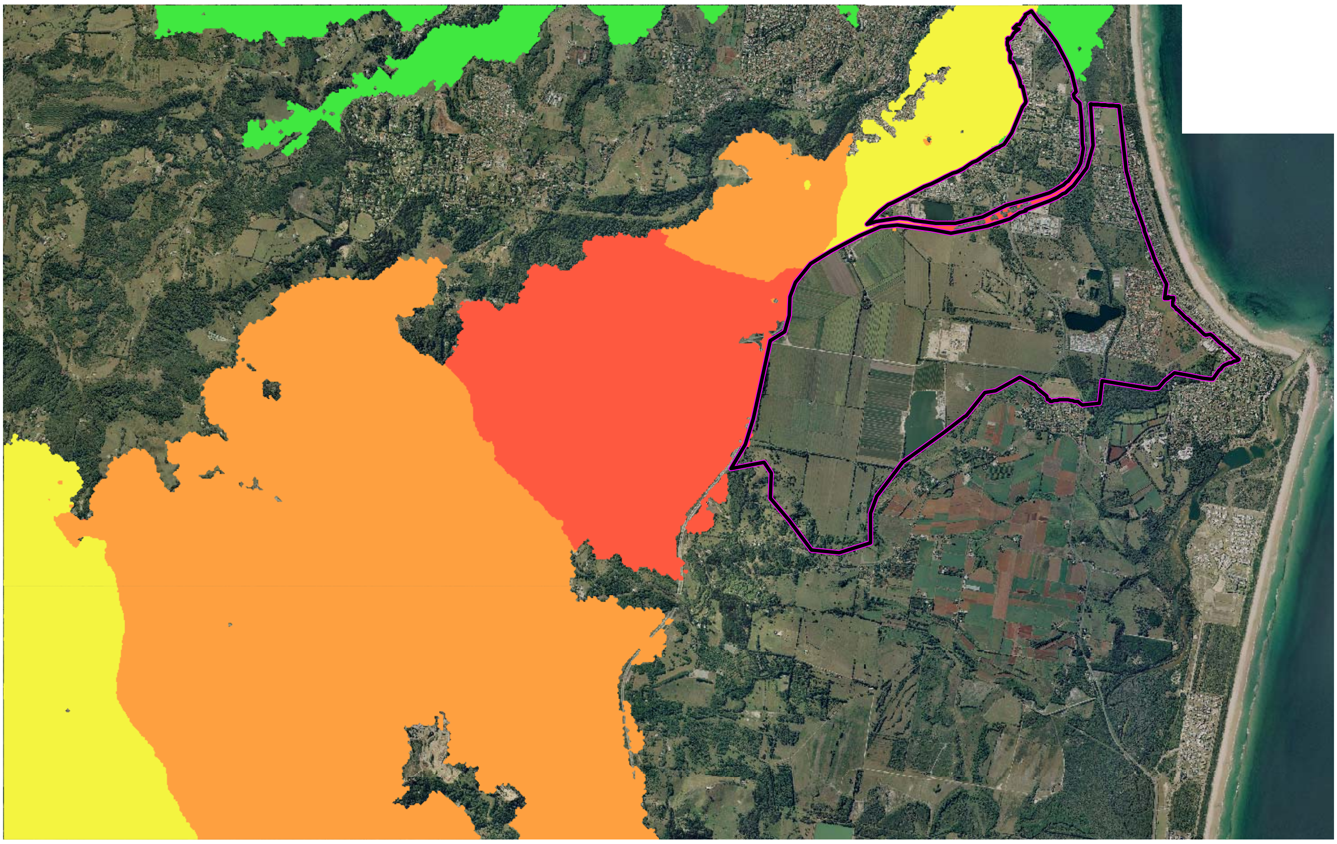

Figure 9: The impacts on Q100 flood levels if the two regions shown in pale magenta are filled. The green shade is less than a 5cm increase, yellow 5 to 10cm increase, orange 10 to 15cm, and red is greater than 15cm.

Using TUFLOW's automatic filling based on VxD criteria, Figure 10 shows the impact on the peak 100 year flood levels if only the areas within the two regions with a VxD from the Q500 event of less than 0.3 m^2/s are filled. The increase in flood levels is substantially less with no increases greater than 10cm. The analyses for filling VxD less than 0.2 and 0.1 show even lower impacts. The Q500 VxD mapping was used rather than the Q100 so as to include any rare flowpaths that develop during this larger event that don't occur for lesser floods.

Through these initial analyses, the consequences of filling the Flood Fringe areas, and possibly Flood Storage areas are easily established. Guidelines are being developed as to whether properties lying within these regions should be considered for future urban growth, and if so criteria such as a maximum VxD for fill areas can be specified so as to minimise the flood impacts from long-term cumulative development of the floodplain. It will also provide the development industry with greater degree of certainty into the future over land that can and can't be developed.

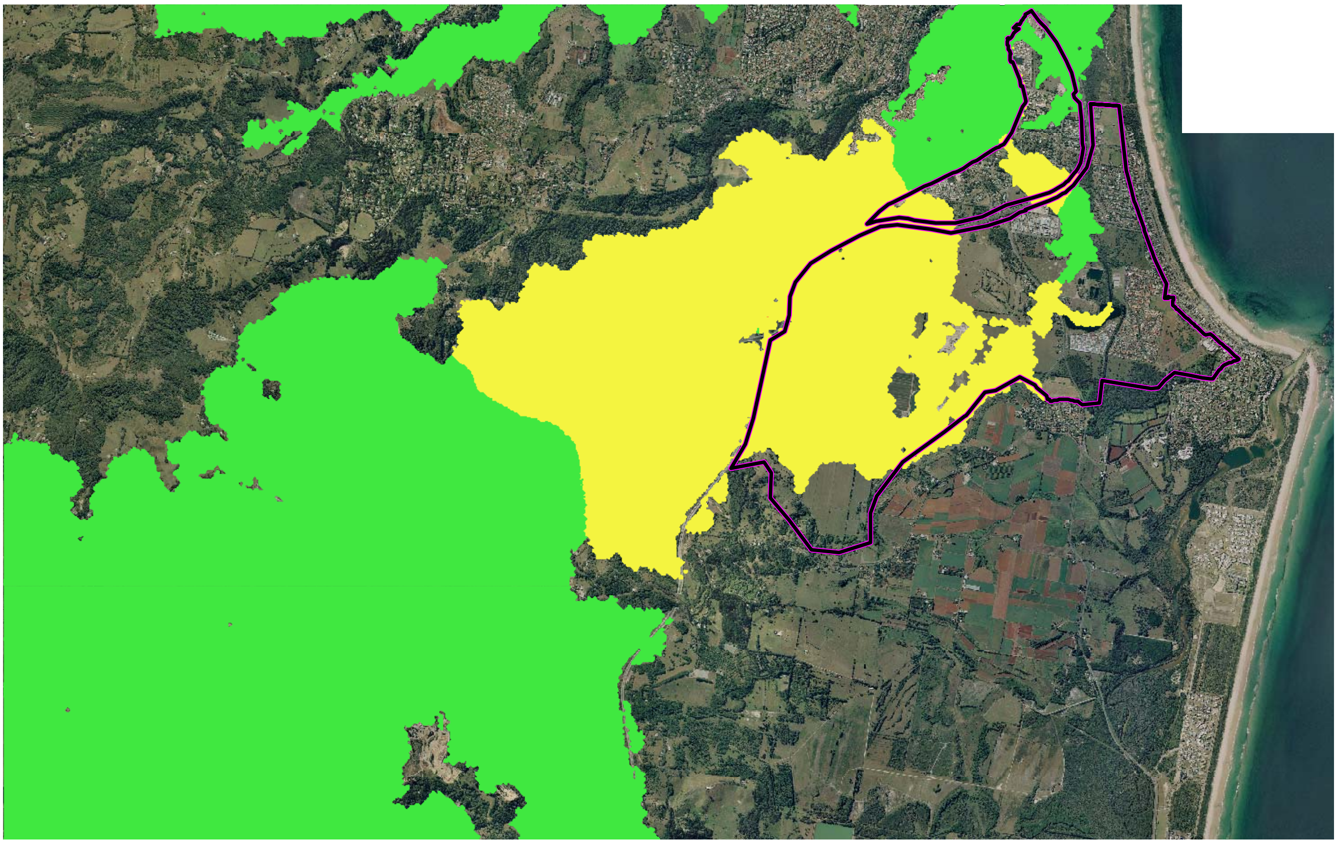

Figure 10: Increase in Q100 flood levels if only those areas with a VxD of less than $0.3m^2/s$ within the two regions in a Q500 event are filled.

7 OTHER CONSIDERATIONS

Once potential Floodplain Development Zones are identified, there are usually a number of other considerations that may warrant further adjustments or analysis. Examples are:

1. VxD values and flood behaviour can be highly dependent on seasonal changes to the Manning's n or roughness parameter. For example, VxD can vary significantly over cropped lands depending on the type and maturity of the crops, or whether the land is fallow. If the land-use changes, this may also cause a significant change in roughness. Sensitivity testing may be required to firm up on how best to manage these changes.

2. VxD values may change due to the construction of infrastructure such as road and rail embankments, therefore these should be included as part of any strategic planning.

3. Predicted increases in flood levels due to long-term filling of Floodplain Development Zones should be taken into account when setting today's minimum fill and floor levels.

4. Flexibility should prevail when development applications are submitted so that developers have the opportunity to fine-tune the areas they can fill, or propose alternatives by cutting and filling, provided the impact acceptability criteria are met and the overall long-term strategy for the Floodplain Development Zone is preserved.

8 CONCLUSIONS

There are significant benefits in the longer-term of flood proofing our future urban areas. In practice, this requires planners and engineers working together to identify these areas, and putting in place impact acceptability criteria and planning controls on future development.

By using the Velocity Depth product (VxD), 2D models can be used to identify areas suitable for future urban development that have minimal impact on flood behaviour and peak flood levels. The value of VxD varies depending on the impact acceptability criteria (eg. maximum increase in peak flood level), but values in the range of 0.1 to 0.5 m^2/s are typical. Floodways can also be readily mapped and zoned using VxD values of greater than 0.5 to 1.0 m^2/s.

The VxD approach in conjunction with 2D models offers greater accuracy and more intuitive mapping of flood impacts and potential floodplain development areas than the traditional approaches using 1D models.

ACKNOWLEDGEMENTS

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