OVERLAND FLOW-FLOOD PREDICTION AND VALIDATION FROM A 100 YEAR EVENT

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ABSTRACT

Auckland Council has identified buildings likely to be affected by overland flow. This has been done region wide using LiDAR and GIS analysis and mapping tools. In the north area the assessment of overland flow issues has also included property inspections to ground-truth the desk studies. Several hundred flood mitigation projects have been scoped from this work and several projects have been completed.

A short duration, high-intensity storm hit northern Auckland on 3 July 2012. The 10, 20 and 30 minute duration intensities reached 100 year ARI. This storm caused the worst flooding for northern Auckland since 2000 and resulted in 70 buildings being flooded. Of these 70 buildings, 80% of the flooding was caused by overland flow and were located outside the 100 year ARI floodplains.

This paper shows the close relationship between predicted flooding from overland flow and actual flooding from the storm affected area and the benefit of mitigation works where they have been already undertaken.

The focus of this paper is:

- The process of ground-truthing potential overland flow flooding issues
- Simple predictive and preventative measures.
- Validating predicted overland flow flooding with the 3 July event
- Overland flow flooding from small contributing catchments
- Assessing the effectiveness of flood mitigation works.

KEYWORDS

Overland flow, flood prediction, validation, mitigation

PRESENTER PROFILE

Barry Carter is the manager of the Northern Stormwater Catchment Planning Team of Auckland Council and is involved with leading the development of catchment plans for the former North Shore and Rodney areas. With a background in Civil Engineering Barry has over 20 years experience within Local Authorities and 15 years experience in the private sector.

1 INTRODUCTION

The mapping of overland flow paths has now been completed on a region wide basis by the Auckland Council Stormwater Planning Group. This has enabled the identification of buildings likely to be affected by overland flow.

In the North Shore area mapping of overland flow paths was carried out several years ago and techniques developed to ground truth and assess the likely impact of severe storms on individual buildings located in close proximity to the overland flow paths.

Subsequent analysis has identified mitigation works for several hundred properties where flood risk has been assessed to be high and several of the projects to mitigate flooding have been completed.

A short duration, high-intensity storm hit northern Auckland on 3 July 2012. The 10, 20 and 30 minute duration intensities reached 100 year Average Recurrence Interval (ARI). This storm caused the worst flooding for northern Auckland since 2000 and resulted in 70 buildings being flooded.

Of the 70 buildings flooded 27 were habitable floors and 43 were non habitable floors. Of the 27 habitable floors flooded 15 properties are located on or close to mapped overland flow paths and using ground truthing techniques described in this paper 9 properties had been predicted to flood, 3 are in catchments yet to be assessed and 3 properties were not assessed. 7 of the flooded habitable floors are on flow paths with a contributing catchment smaller than the 3000m2 threshold used in the method described in this paper and therefore had not been assessed.

Private drainage faults other than inadequate overland flow management have been identified as the cause of the flooding for 5 of the habitable floors.

A further 9 buildings avoided being flooded primarily due to mitigation works having been assessed as part of the overland flow programme and carried out prior to the July storm.

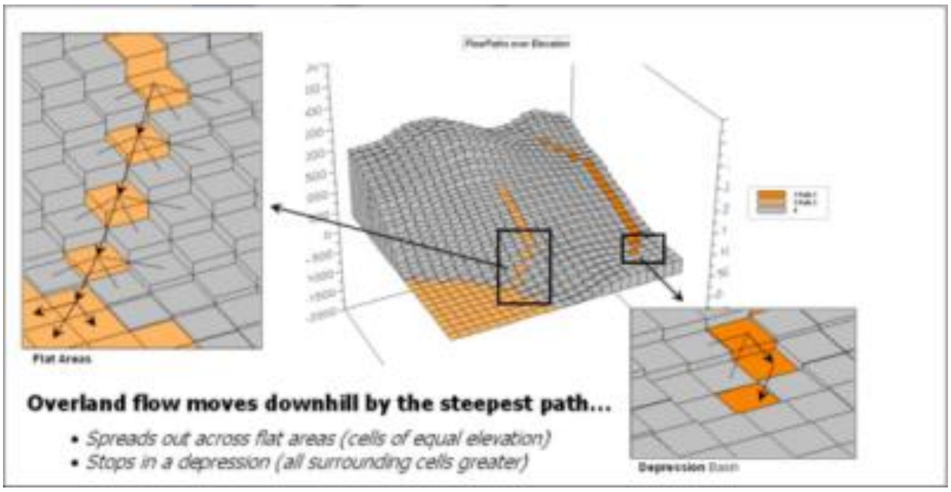
The objective of this paper is to show the value of mapping overland flow paths, carrying out ground truthing and assessment of buildings likely to be flooded by overland flow and undertaking mitigation works. The July 2012 storm provided very strong validation of both the flood prediction techniques and the effectiveness of flood mitigation measures related to overland flow.

2 OVERLAND FLOW FLOOD PREDICTION

2.1 MAPPING OF OVERLAND FLOWPATHS

In the North Shore area mapping of overland flow paths was carried out several years ago. LiDAR ground survey points and GIS techniques were used to create a digital terrain model with a level being assigned to each cell within the model. A rolling ball technique was applied such that where any land area contributing to any lower cell was more than 2000m^2 a line representing the centre of an overland flow path was generated. The technique is represented in Figure 1.

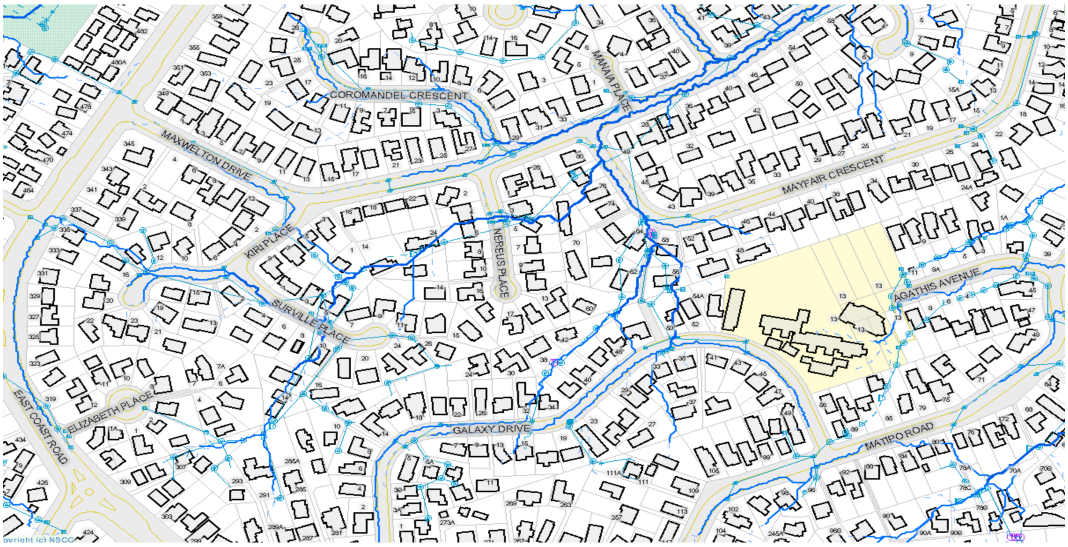
Figure 1: Generating overland flow paths



Reliability of the mapped overland flow paths is dependent on the accuracy and density of the LiDAR survey and on careful post processing of the initial flow paths generated. The inherent limitations of the technique are that the flow paths do not recognize above ground obstructions to flow such as buildings and fences. Alterations to ground surfaces since the LiDAR was flown have not been captured and limit their usefulness in such areas. Nevertheless the mapped flow paths are generally a very strong indicator of the approximate location of significant overland flows likely to impact on a property and associated buildings.

This technique has been enhanced and has recently been applied to the Auckland Region. The depiction of overland flow paths with a catchment area of over 2000m^2 is now available for any area in the Auckland Region. At this stage the accuracy of the flow paths is variable as the LiDAR data across the region comes from a variety of specifications and was flown at different times. As LiDAR is re-flown over the next few years the standards and quality of the data and the resultant overland flow path mapping will improve and become more consistent. Further information on the mapping techniques used in the Auckland Region is contained in the paper by Irvine & Brown (2013).

Figure 2: Mapped overland flow paths



2.2 GROUND TRUTHING OF PROPERTIES IN THE VICINITY OF OVERLAND FLOW PATHS

Techniques have been developed and trialled in the North Shore area of the Auckland Region over several years to ground truth and assess the likely impact of severe storms on individual buildings located in close proximity to mapped overland flow paths with catchments larger than 3000m^2. Note that mapping was carried out for overland flow paths with catchments larger than 2000m^2 but the threshold for assessment was set at 3000m^2.

A desk study is first carried out to identify the buildings in a catchment where mapped overland flow paths intersect building footprints. Particular attention is given to buildings directly below locations where the overland flow paths leave a road reserve or parks reserve. These have been commonly found to be a likely concern in terms of flood risk and are also likely to involve some degree of responsibility for Council. Any suspected anomalies and flow paths with large contributing catchments are also noted for the subsequent site visits.

A letter is then sent to selected property owners advising of the intended site visit to assess potential stormwater issues on their property. In many cases this results in a positive response from owners who have had a history of stormwater concerns and are pleased to provide information and gain an understanding of the problems associated with their property.

The site assessment is carried out by an engineer well experienced in stormwater management and risk assessment. Data is captured electronically using a portable device. A standard set of attributes and information is recorded for each property.

The data captured for an individual property is as follows:

- Property ID / Assessor/ Date/ Photo details
- Flow source from/Contributing address
- Flow exit to/downstream address
- House details/flooding risk/includes pile/ slab-on-ground checklist, site compliance

- Sub-floor details
- Basement construction details/ flooding risk
- Site and boundary obstructions
- Site drainage details/including site paving and gully trap compliance check
- Summary of responsibility /cost of remedial works/ magnitude of flow

Further details of the method are provided in the paper by Tate, Carter and Young (2007)

The site assessment very often reflects that:

- The mapped overland flow path is generally accurate particularly in locating the point at which an overland flow path leaves the road reserve due to a sag point in the road and/or where a low vehicle crossing falls away from the carriageway.
- Where mapped overland flow paths intersect building footprints there is normally a risk of flooding from overland flow unless there has been some careful site management of the overland flow to mitigate such risk.
- There is typically little recognition of the potential risk of overland flow flooding in the way properties have been developed and landscaped.

It should be noted that the automated mapped overland flow paths are generally not adjusted to reflect localized obstructions such as buildings and fences as this would require considerable resources and would result in an inconsistent data set where some areas have been adjusted and other areas not adjusted.

2.3 ASSESSMENT OF OVERLAND FLOW FLOOD RISK

The initial site visit to assess flood risk from overland flow results in an overall assessment into one of the following categories:

- Mapped overland flow path is not accurate and the buildings of concern have a low risk of flooding.
- Mapped overland flow path is accurate and appropriate site development has mitigated the risk of flooding from overland flow.
- Mapped overland flow path is accurate and site development has been carried out in a way that is a concern and provides a risk of flooding of a building from overland flow.

The buildings assessed to be at risk of flooding from overland flow are further categorized as follows:

- The mitigation required is clearly apparent and is the responsibility of the property owner to resolve. (This is conveyed to the property owner for their attention)
- The mitigation required is clearly apparent and will need to involve both the property owner, Council and in many cases Auckland Transport in resolving the issue. (This can be resolved through Council processes and programmes together with input from the property owner and taking Council priorities into account.)
- The flood risk will require further engineering assessment to determine the degree and frequency of risk, flood risk mitigation options and the responsibilities of the owner and of Council.

Where further engineering assessment is carried out as indicated in the last of the categories above, the work usually involves detailed topographical survey, consideration of wider sub-catchment issues, hydrological assessment and consideration of mitigation options to arrive at a preferred solution.

Through the above processes Auckland Council has identified mitigation works for several hundred properties where flood risk has been assessed to be high and several of the projects to mitigate flooding have been completed in recent years.

3 PREVENTING AND MITIGATING OVERLAND FLOW FLOOD RISKS

The experiences within Auckland Council and the former North Shore City Council during the last few years in preventing and mitigating flood risk due to overland flow has revealed many typical issues, options, challenges and successes. These are covered in the following sections.

3.1 TYPICAL FLOOD RISK ISSUES AND PREVENTATIVE MEASURES

Prevention is clearly better than mitigation and the risk of flooding from overland flow is commonly overlooked with new development including alterations. Common risk factors and associated preventative measures are summarized in Table 1.

Table 1: Common risk factors and preventative measures in new development

Flood risk factors in new development	**Preventative measures**
Subdivision layout locates building sites in overland flow paths (particularly below road sag points)	Ensure subdivision design keeps overland flow paths clear of development. (locate flow paths along property boundaries or along road or park reserves)
Proposed building in path of overland flow	Identify and map overland flow paths. Provide overland flow path information to developers and regulators.
Proposed garage foundation below road level.	Ensure that the longitudinal profile from road to garage allows for adequate roll-over of driveway crossing within the road reserve and that the driveway is shaped to deflect the flow path from entering the garage.
Slab on ground construction	Ensure pathways and landscaping features are designed to provide freeboard and unobstructed path for flow around buildings. Ensure step up from garage floor to habitable floor areas.

3.2 TYPICAL FLOOD RISK ISSUES AND MITIGATION WORKS

Mitigation works have been scoped for several hundred properties where flood risk has been assessed to be high and several of the projects to mitigate flooding have been completed. It should be noted that in some cases site constraints and the nature of existing development limits or prevents practical works to mitigate flood risks.

The typical issues and associated mitigation works are summarized in Table 2.

Table 2: Typical risk factors and mitigation works

Typical flood risk issues from Overland Flow	**Typical mitigation works**
Driveway road crossing low with insufficient roll-over and water channelled into garage and house via driveway (particularly on sites below road or with excavated basements)	Reconstruct road crossing with roll-over and shape driveway to deflect overland flow around house
Slab on ground construction with insufficient freeboard above ground and/or landscaping shaped to ensure water is directed to doors	Landscape to ensure freeboard and ensure overland flow paths are directed around building entrances
Reliance on small slot drains in driveways to prevent overland flow entering garages and houses	Reconstruct driveways to ensure overland flows are directed around buildings
Solid fences constructed across overland flow paths causing upstream ponding.	Alter fence and/or reshape ground to provide unobstructed flow path. (Requires liaison with downstream property owners.)
Properties downstream of sag points in roads or at the ends of down slope cul de sacs have overland flows directed to building entrances.	Landscape and reshape ground to ensure overland flows are safely directed around buildings and off property. (Often requires comprehensive approach involving downstream neighbours)

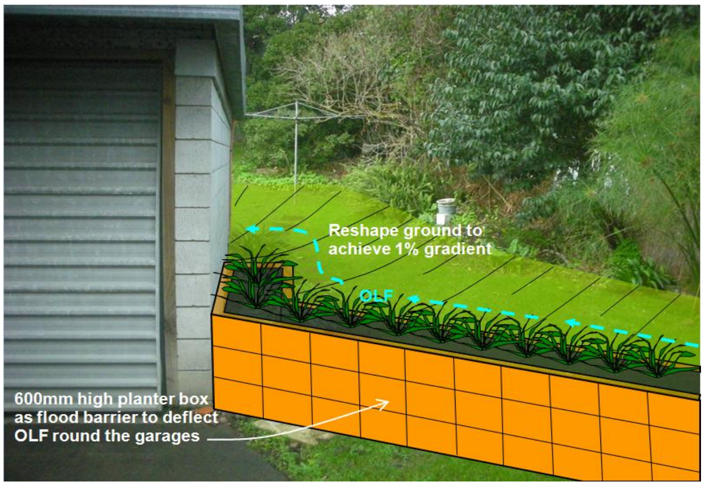
3.3 SPECIFIC EXAMPLES

The following photos demonstrate both typical issues and proposed mitigation works.

Photograph 1: Driveway crossing with inadequate roll over

Photograph 2: Water channelled to garage and entrance-reliance on small catchpit

Photograph 3: Landscape and reshape ground to form overland flow path



Photograph 4: Landscape and contour land to form overland flow path

3.4 EXPERIENCES WITH CONSTRUCTION OF OVERLAND FLOW MITIGATION WORKS

Where flood risk has been assessed to be high this is normally validated by affected property owners having experienced significant overland flows on their property and in some cases flooding of floors.

It is generally much easier to reach agreement to carry out mitigation work on affected properties than neighbouring properties not directly affected by overland flow. Unfortunately in a number of cases the solution to overland flow problems is not feasible to be carried out on the affected property. A number of potential solutions have been put on hold pending agreement of neighbours for the works to be carried out in their property.

It is often difficult for property owners to visualize the scale and impact of proposed work and considerable time is needed to work with the property owners to understand the proposed work and to resolve details.

Property owners often request alternative approaches involving additional detailing or rework to satisfy concerns and to reach agreement to works proceeding.

The impact of having the physical works carried out on private property is often underestimated by property owners and requires careful management by both the project engineer and the contractors.

The quality and timeliness of reinstatement is paramount in achieving positive response from land owners.

The real test of the mitigation works is when a major storm event occurs after completion of a project. There have been several very grateful land owners who have witnessed the safe conveyance of overland flow around their properties following mitigation work.

The actual construction costs for this type of flood mitigation work varies considerably with many projects costing less than $10,000 and the average being in the order of $30,000 per property. The design and project management costs for this type of work are likely to be in the order of 40% of construction costs for an average project. They are time intensive projects with relatively low costs and high benefit in terms of mitigating flood risk.

4 THE STORM OF 3 JULY 2013

On the 3rd July 2012 an intense short duration storm event occurred in the northern Auckland area. Rainfall intensities of up to 135 mm per hour for a duration of 10 minutes, 99mm per hour for a duration of 20 minutes and 84mm per hour for a duration of 30 minutes were recorded at the Oteha rain gauge. These intensities have been assessed to be 100 year Average Recurrence Interval (ARI) intensities for all three durations. Using the rain gauge data available for the area, contours of ARI have been extrapolated and plotted for the storm affected area for 10, 20, 30 and 60 minute durations. A plot of the ARI contours for the 30 minute duration rainfall is shown in Figure 3 below.

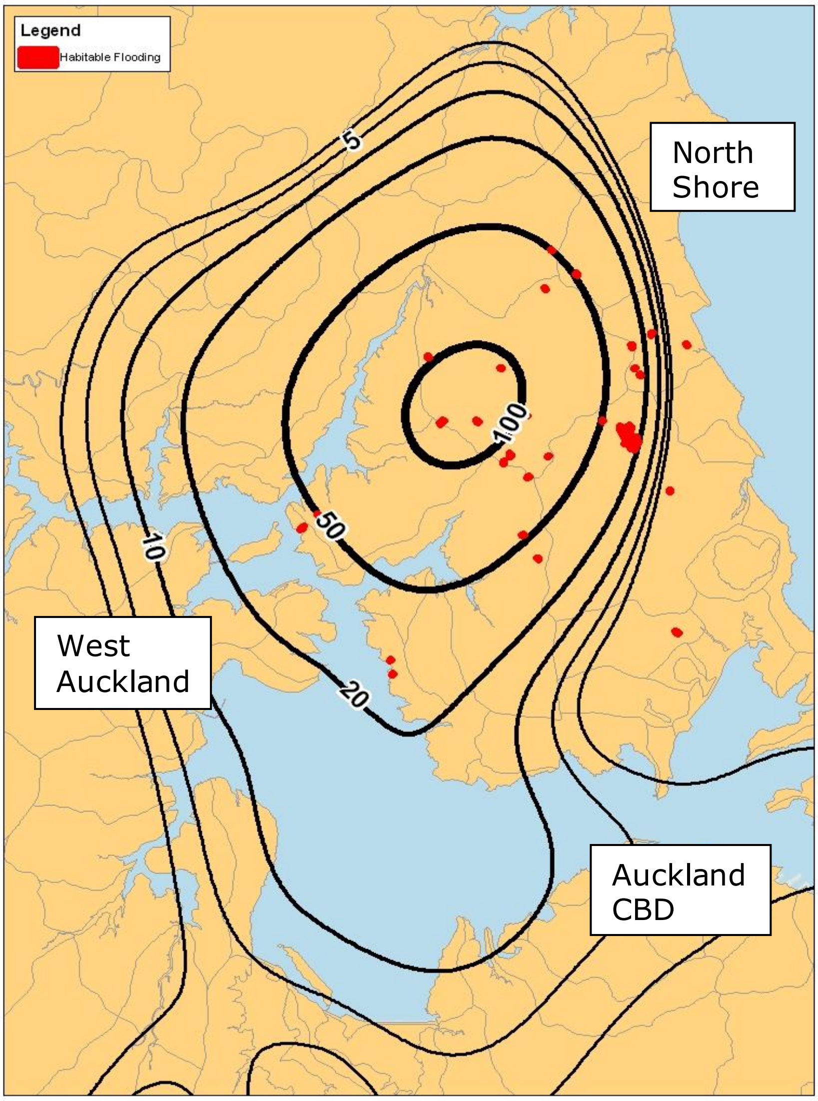
Also plotted are the locations of buildings reported to have suffered habitable floor flooding during the event. The extrapolated contours indicate that 100 year ARI rainfall intensities were exceeded for durations up to 30 minutes at localized areas within the catchments and a significant area experienced ARI' s between 10 years and 100 years for durations up to 30 minutes.

There is a strong correlation between the locations where habitable floor flooding occurred and rainfall intensities of 10 to 100 year ARI's for durations up to 30 minutes.

A total of 27 houses reported habitable floor flooding within the wider North Shore area during this event. An additional 43 non habitable floors were flooded during the event. In the order of 80% of the flooding issues were caused by overland flow entering buildings. This demonstrates the impact of high intensity short duration storms where flow paths activate quickly. In the lower sections of the catchments the streams were full but the flood plains generally did not fill to their modelled extents due to the relatively short duration of the storm.

Tian et al., (2013) provides details of the operational experience and response at the time of the 3rd July storm event.

Figure 3: 30 minute ARI rainfall contours and location of flooded habitable buildings



Significant habitable floor flooding occurred within the 10 to 100 year ARI contours

Photograph 5 and 6: Overland flows from intense short duration storm

5 VALIDATION OF PREDICTED FLOOD RISKS DUE TO OVERLAND FLOW

Mapping and ground truthing of overland flow paths and flood risk assessments using the techniques described in Section 2 above had been carried out for several of the catchments affected by the 3rd July 2012 storm event over the last 5 years.

Figure 4 shows the locations of the 27 buildings that suffered habitable floor flooding from the 3rd July 2012 event.

9 of the properties are on a flow path of more than 3000m^2 and had been predicted to be at risk of habitable floor flooding through the risk assessment work carried out previously.

3 of the properties in the vicinity of flow paths of more than 3000m^2 were not assessed when the catchment was investigated. In these cases one property was flooded via an overland flow path off a private school site, one property was flooded due to the overland flow spilling at a location 15m away from our mapped overland flow path and one property was flooded from flows off a side road from a ridge road. In all cases this event has provided information for considering modification to our methodology for assessment.

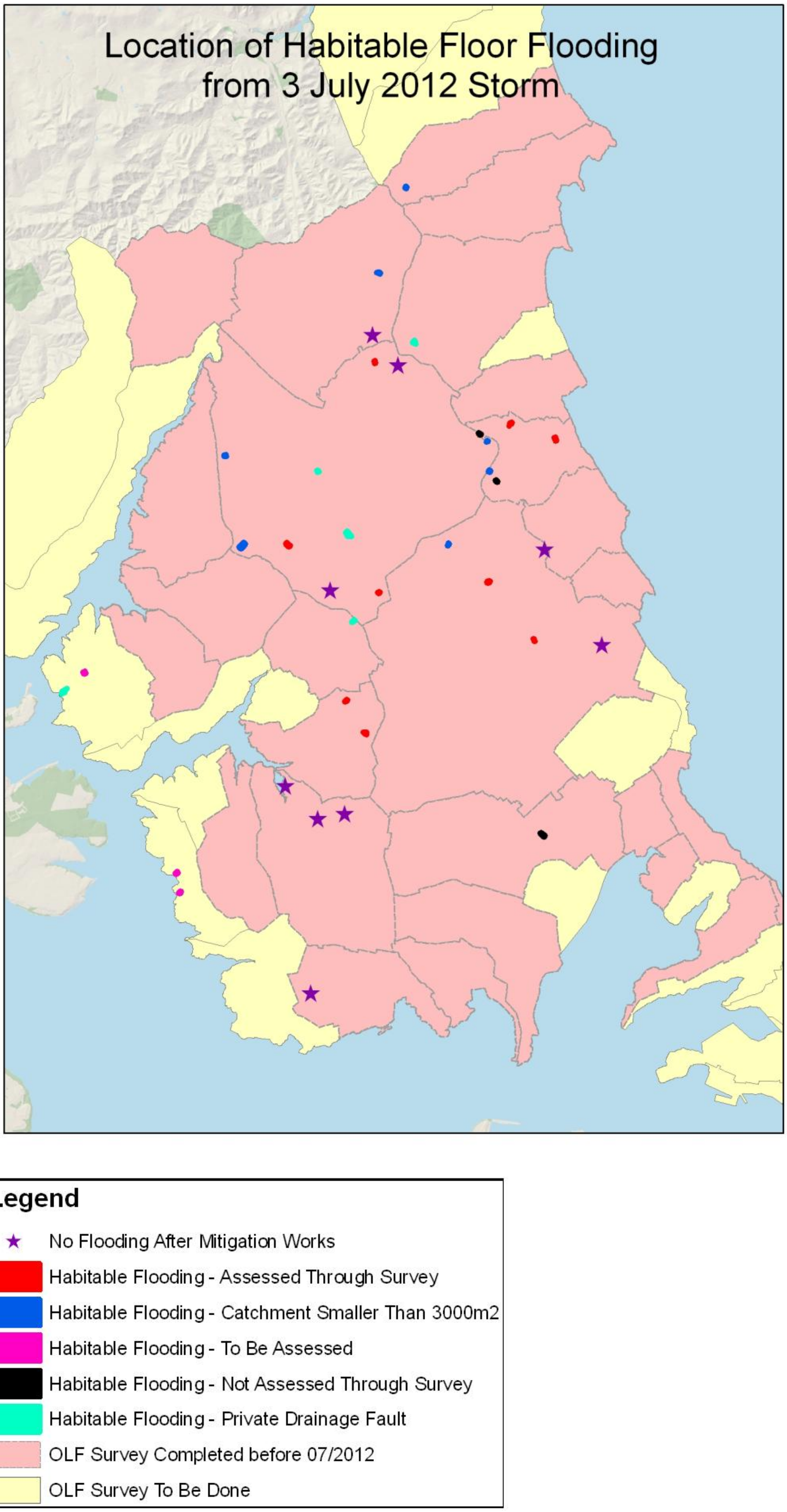
7 properties flooded from overland flows where the contributing catchment was less than 3000m^2.

3 properties flooded from overland flows in catchments where we have not yet undertaken catchment planning work. These properties meet the criteria where we propose to carry out overland flow risk assessments in future.

5 properties flooded due to private drainage faults not related to overland flow.

In addition 9 properties did not flood where flood mitigation work as a result of earlier assessments for overland flow had been completed or was in progress. In all of these cases it is highly likely that habitable floor flooding would have occurred during this storm if the mitigation work had not been carried out.

Figure 4: Correlation between assessed at risk buildings and flooded habitable floors from 3rd July 2012 flood event.



In summary overland flow was the primary cause of flooding for 22 of the 27 properties (approximately 80%) that experienced habitable floor flooding during the 3rd July 2012 event. Approximately 80% of the non-habitable floor flooding was also caused by overland flows.

In most cases the flooded properties are immediately adjoining the downstream side of a road. With intense short duration rainfall on impervious road surfaces significant flows are generated off small catchments and given inadequate on site stormwater management there is a considerable risk of downstream properties being flooded.

As can be seen from Figure 4 about 60% of the properties where habitable floors flooded are located very close to catchment boundaries. These catchment boundaries are typically ridge roads. The high intensity short duration rainfall has generated significant runoff from the ridge roads, flows have spilled off the road reserve at sag points and entered properties resulting in habitable floor flooding.

Inadequate management of overland flow can result in habitable floor flooding irrespective of catchment size, however the techniques developed at Auckland Council and applied for overland flow from catchments in excess of 3000m^2 have predicted 55% of properties with habitable floor flooding due to overland flow in the July event.

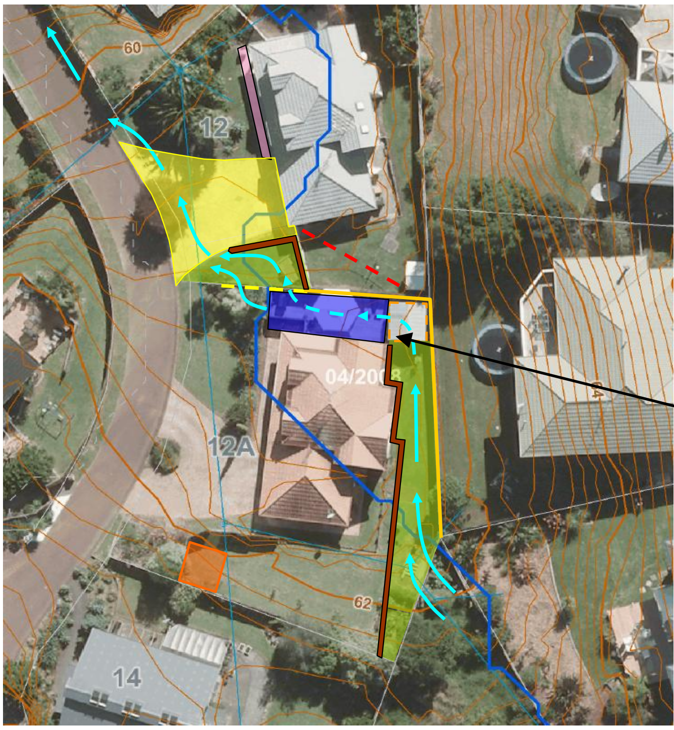
As noted in Tian et al., (2013) compliance with regulations during and after development would in many cases provide adequate protection from flooding related to overland flow.

5.1 EFFECTIVENESS OF FLOOD MITIGATION WORKS

Within the storm affected area mitigation works for 8 properties had been recommended from the overland flow assessment programme and the works had been completed at the time of the 3rd July event. A further mitigation project was in progress at the time of the storm. In all cases overland flows were significant through the properties but were contained by the constructed flow paths and none of the properties suffered habitable floor flooding. The combined value of the physical works for these 9 properties totalled $275,000 being an average of $30,000 per property.

This amount is typical for the works proposed for over 200 properties where mitigation works have been identified and scoped. The following Figure 5 shows the type of mitigation works constructed and photos taken during the storm event.

Figure 5: Example of overland flow mitigation work.



Formed overland flow path in the yellow and blue area

Deck can be seen in photograph 7 below

Photograph 7: Overland flows safely conveyed through property where mitigation works were in progress

6 CONCLUSIONS

Mapping overland flow paths provides a very useful tool for indicating potential flood risks both on sites currently developed and on sites where development is proposed.

Assessing properties affected by overland flows is an effective means of identifying flood risks and mitigation options.

In the 3rd July 2012 storm event on the North Shore 80% of the habitable floors that flooded as a result of overland flow were located on or near mapped overland flow paths with catchments in excess of $3000m^2$ and the remaining 20% were located on catchments smaller than $3000m^2$.

40% of the properties where habitable floor flooding occurred as a result of overland flow were assessed by the processes described in this paper to have a risk of flooding and a further 10% will be assessed during the catchment planning process.

Carrying out relatively minor works on properties to mitigate flood risks from overland flow is often challenging and time consuming but it is cost effective and has been demonstrated to prevent flooding in a major storm event.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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