“NOT-MODELLING” FOR STORMWATER AROUND THE KAIKOURA ALLUVIAL FANS

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ABSTRACT

The Kaikoura plains are formed by a process of coalescing alluvial fans from several streams which rise in the mountains of the Seaward Kaikoura Range. They are typically very steep, high energy streams. Development on this fan system was, until relatively recently, limited largely to farming - particularly in the steeper areas. However more recent development pressure has resulted in a desire for increased housing and rural-residential (lifestyle) activity in parts of the Kaikoura fans system.
Building regulations require flood hazard of any building site to be taken into account. Typically the areas likely to be flooded in 50-year events are determined (often by modelling), and development is restricted accordingly. However, in some of the Kaikoura area modelling and definition of 50-year flood extents is very difficult, due to the nature of the terrain.
This paper examines one such area where modelling to determine flood extent, depth and velocity is extremely difficult using current technology, and provides justification for non-modelling in this case. Alternative solutions are proposed.

KEYWORDS

Kaikoura, Alluvial Fans, Overland Flow, Flood Hazard.

1. INTRODUCTION

Hydraulic and hydrological models are frequently used to predict behaviour of physical waterway systems, and the general approach is to collect data that describe the physical attributes of the system, collect suitable input data and then calibrate and validate the models under conditions that have previously been experienced. There are many surface flow situations that can be effectively modelled, with such models being most easily adapted to reproduce behaviour of the system in its current (at the time of modelling) state. Morphological models can be used in certain situations, and these are used to predict behaviour under changing physical system conditions.

Models are good so long as the model adequately represents the physical system that has been modelled. This constraint is often addressed by re-survey of the physical system (e.g. cross section survey) and updating the model accordingly at suitable intervals. A potential problem arises, however, when the rate of change in a physical system is too great for re-survey and model updating to take place sufficiently frequently, which leaves behind a series of out-of-date models.

In urban situations this rate of change in the physical system is often controlled, and a certain amount of “re-setting” is able to take place. An example of this is cleaning out collected sediment from a primary system, which re-establishes the physical system to match what may have been previously modelled, at which stage it could be expected that model results can be used with confidence to represent reality once again. If a flood event occurs at a time when the physical system has not been “re-set”, then it would be expected that the actual performance of the system diverges from modelled performance under the same conditions.

In addition to such “re-setting” being able to occur in urban situations, a degree of re-setting may be found in larger river systems to force these to obey certain levels-of-service criteria. For example, stop-bank heights may be adjusted to contain a river to a horizontal alignment under a given level-of-service, even after the bed profile has been changed by sediment deposition or erosion. However, such re-setting is often not a viable option for many other natural systems, and the best management approach may be to work with change that occurs. In such situations modelling is unlikely to be a reliable tool to be used.

This paper examines one such situation where modelling would essentially be a fruitless exercise, since the rates of change in the natural system are too great for a model to be used with any confidence other than at the time at which it was developed. Even then, morphological changes to the physical system can occur that are unable to be predicted by the model, rendering its results unusable. Nevertheless, in such situations decision makers frequently require a similar level of advice and prediction from modellers as that which they are able to obtain in more controlled environments. This advice is often sought to guide and control development, and requires that judgement calls be made that are outside of the envelope of solutions able to be supported by a detailed set of model results.

2. HYDROLOGICAL SETTING

The relatively flat terrain in and around the Kaikoura area is made up of coalescing alluvial fans of rivers draining the Seaward Kaikoura Mountain Range. With the mountain range comprised of several peaks at elevation in excess of 2000m (Manakau 2608m, Uwerau 2213m, Mt Saunders 2146m), and by being reasonably close to the sea, these rivers are amongst some of the steeper ones on the east coast of the South Island. For example, the Kowhai River rises at elevation of about 1800m and falls to sea level (0m) over a distance of some 25km, representing an average gradient of 7 percent.

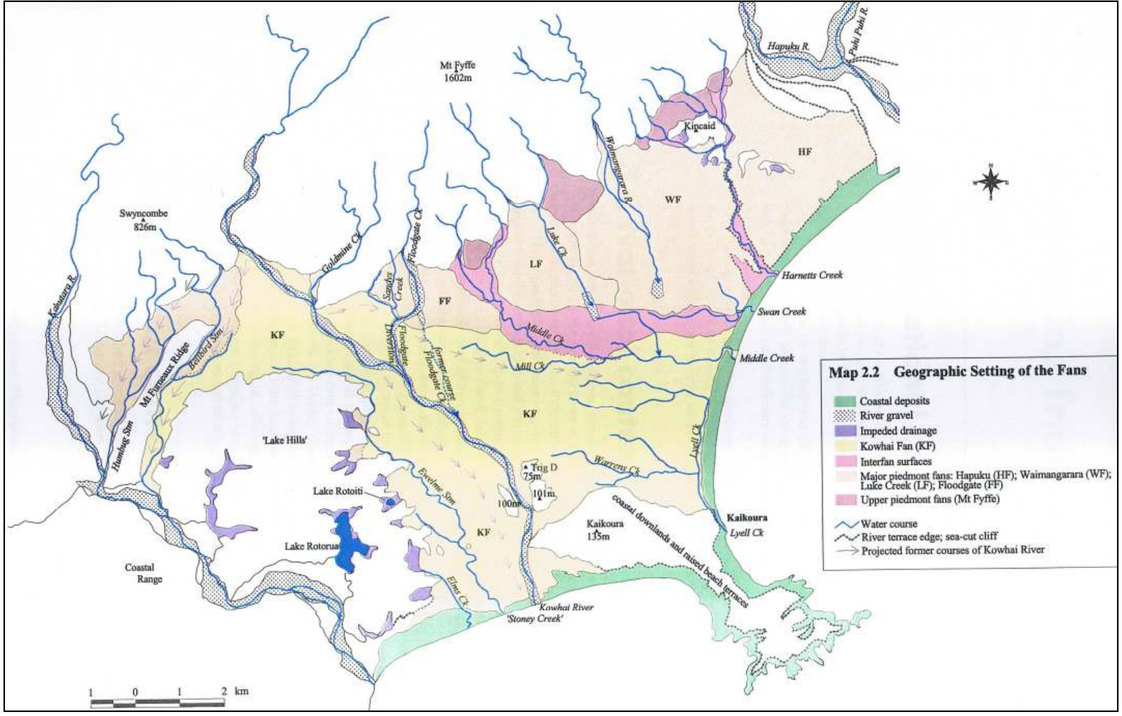
Over time, the Kowhai River has wandered over its floodplain with its mouth switching between north and south sides of the Kaikoura Peninsular, as shown in Figure 1. Lyell Creek, which flows through the “West End” business district in Kaikoura is an old flood channel itself of the Kowhai River, and in the last 140 years the town has been subject to flooding no fewer than 15 times. The unstable nature of the rivers in this area means that they are difficult to control, despite the intentions of engineering works.

The present steep courses followed by most rivers in the Kaikoura Fans system are unstable because insufficient time has passed since their formation to allow these to establish the behaviour commonly associated with single-thread channels. With the passage of time, rivers generally tend towards more stable form meaning that humans can install structures to encourage a waterway to flow in a slightly sinuous single channel, instead of in the less stable braided pattern. Attempts have been made, in the Kaikoura Fans system, to control such waterways and maintain their existing alignment. Such controls typically comprise stopbanks and return banks, examples of which are shown in Figure 2. The echelon banks shown in this figure are intended to return flow from upstream breakouts to the existing course of the river. Breakouts occur often as a result of bedload deposition and damming, and are thus somewhat random and difficult to predict. However certain locations do lend themselves more toward such breakouts, particularly where a previous breakout has eroded a substantial channel. It is in these locations where echelon banks are often located, for obvious reasons.

Figure 2 references the subject waterway of this paper, the Waimangarara River. This river drains the seaward face of Mt Fyffe (1602m) and seems to be distant from some potential equilibrium as a single thread river, as evidenced by the numerous attempts to control its behaviour during flood conditions. The uplift associated with the nearby Hope Fault continues to sustain an environment of instability that keeps potential equilibrium for this river a long way away. The associated fan is steep and continues to grow in size as the river brings down a continuous supply of rock and debris eroded from its upper catchment.

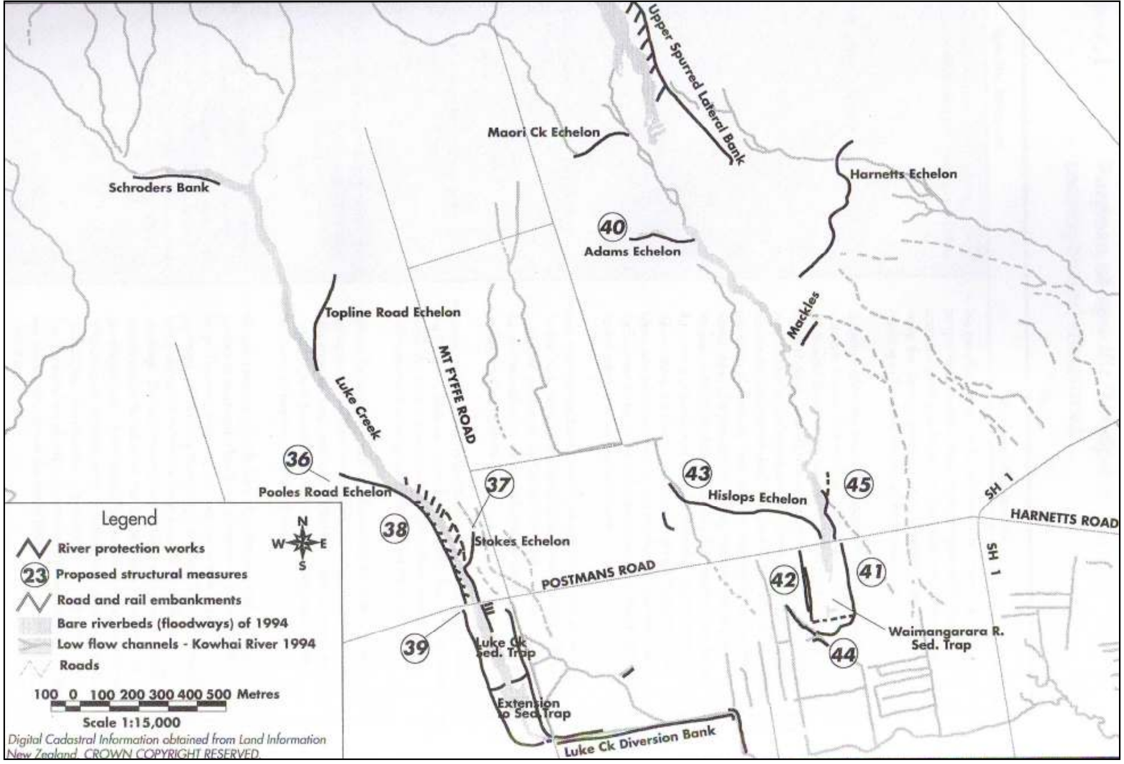
Stream power, being dependent largely on slope and magnitude of flood discharges, has enabled previously constructed flood control measures to be breached, and this is likely to be the case into the future. MfE (2008) suggest that current predictions for rainfall patterns in this area will be towards lower total annual rainfall falling in fewer, more intense events. These more intense events will have greater stream power associated with them and hence could have a greater effect on flood protection measures than under current circumstances.

Figure 1: Geographic Setting of Kaikoura Fans



Source: Canterbury Regional Council, February 1999, *Kaikoura Floodplain, Issues and Options for reducing the impacts of flooding and sediment deposition*.

Figure 2: Flood Protection Works at Luke Creek and Waimangarara River



Source: Canterbury Regional Council, February 1999, *Kaikoura Floodplain, Issues and Options for reducing the impacts of flooding and sediment deposition*.

3. DEVELOPMENT ON THE KAIKOURA FANS

The Building Code (Department of Building and Housing, 2006) requires that (Clause E1.3.2)

> *"Surface water, resulting from an event*
> *having a 2 percent probability of occurring*
> *annually, shall not enter buildings."*

This requirement is usually ensured by initially undertaking an assessment of events of this probability of occurrence. Such assessments often include modelling to assist with finalisation of design water levels in response to events of this magnitude. Following this assessment it is common that planning regulations are drafted to reflect constraints on building in specific areas, and these are designed to ensure that no buildings will be flooded under design event conditions, in accordance with the Building Code.

This presents a difficulty in the Kaikoura Fans system, since it is difficult to predict not only *where* water will go, but also *how* it will go in an event having a 2 percent probability of occurring annually. Both are relevant factors in that they are inter-related, and are required to be understood in order to guide location and minimum level in the development of buildings.

4. CASE STUDY: A HOUSE NEAR THE WAIMANGARARA RIVER

BACKGROUND

The subject site for this paper is a rural residential block adjacent to the Waimangarara River shown in Figure 3. According to flood hazard index maps produced by Environment Canterbury the property is located within a Category 2 flood risk area. Such areas are defined as “Overbank surfaces next most prone [after category 1 areas] to flood discharges”. Category 1 areas are located within actual riverbeds or channels.

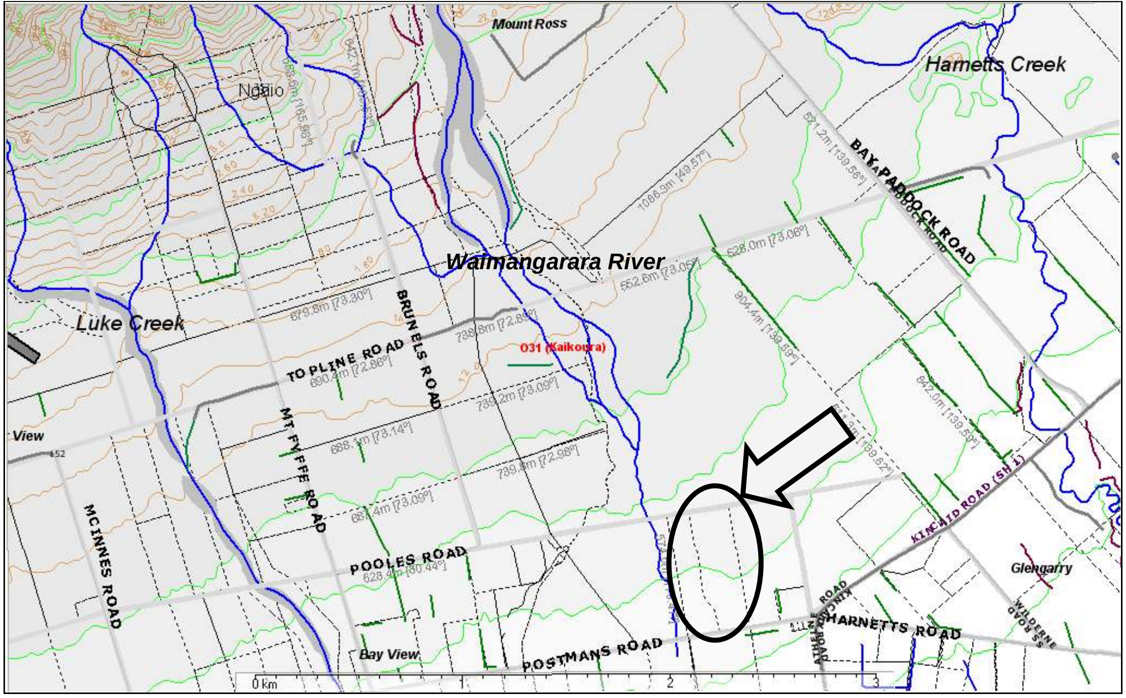
The flood hazard at the subject site would be due to potentially high velocities and either erosion or accretion (potentially large volumes) that could occur as a result of an upstream breakout of the Waimangarara Stream. Flood ponding is not a likely issue here given the steepness of the terrain. Accretion of bedload can have an armouring effect in breakout flows, but can also have a damming effect, forcing flow to alter its path. Once out of the channel flood flow is likely to follow ground contours, but its exact flow path is subject to obstructions such as dense bush and local geographic features, in addition to changes in surface topography resulting from erosion or deposition.

Given the steepness and the erodability of the terrain in the area of the subject site (and upstream), all existing geographic landforms are potentially subject to change with every out-of-bank flood. This means that areas initially considered as outside of major breakout flow risk may end up being in a high risk area following one flood and associated erosion and/or deposition, although the Environment Canterbury hazard maps attempt to account for such risk. It is likely that this is the main reason for Environment Canterbury suggesting avoidance as the best flood mitigation option in this area, since without ongoing maintenance and assessment there is little long-term surety of local flood hazard in this area.

As such it is very difficult to predict the pathway followed by any breakout flows in this and other similar areas. Furthermore, it is also very difficult to predict the location of any potential breakout in steep waterways such as the Waimangarara Stream in this area. That is, it is uncertain not only where a breakout may occur but also what path such a breakout may follow once it has occurred.

The subject site is protected, to some degree, by Mackles Echelon and by Harnetts Echelon (see Figure 2). These are essentially flood return banks designed to return flood water from an upstream breakout back to the main channel of the Waimangarara Stream. Environment Canterbury has suggested a 20-year design level of protection for these. This means that in events of Average Recurrence Interval (ARI) exceeding 20 years these may overtop, which would be likely to result in damage to these banks. Therefore if, for example, a 30-year event occurred that did result in overtopping of one or both of these banks, then unless they were immediately repaired they may not continue to offer 20-year event protection after the 30-year event had passed. This further demonstrates the changeable nature of landforms in this area.

Figure 3: Location of the Subject Site



THE PROBLEM

Some time back an unconsented dwelling was built on this site and the property was subsequently sold. The dwelling was constructed on poles so that it was well clear of potential floodwater coming from the Waimangarara River. The new owner proposed some modifications to the dwelling, including closing in the ground floor, for which building consent was sought (retrospectively). The dwelling is shown in Figure 4.

As stated above, the Building Code requires that floodwater does not enter dwellings in events of ARI up to 50 years. In addition, the Kaikoura District Plan requires minimum floor levels above 500-year level. Thus for the proposed modifications the question arose as to what minimum height local floor level should be constructed. A request was made to model the stream and quote design flood levels for the area.

For the reasons outlined above it is not possible to determine accurate design flood levels in the area of the subject site, and even if it were possible to do so then design levels would be subject to change each time a flood resulted that caused any erosion or deposition that would affect flood hydraulics (even minor floods would cause some changes).

The above discussion essentially means that over the area of concern there can be little guarantee of enduring flood protection, since so much is subject to change with flood breakouts. In order to set a level of protection (eg 20-year ARI) a diligent maintenance regime is required where changes to the system are regularly assessed and any that result in adverse effects on design level of protection are adequately mitigated.

Figure 4: Dwelling at the Subject Site

ANALYSIS

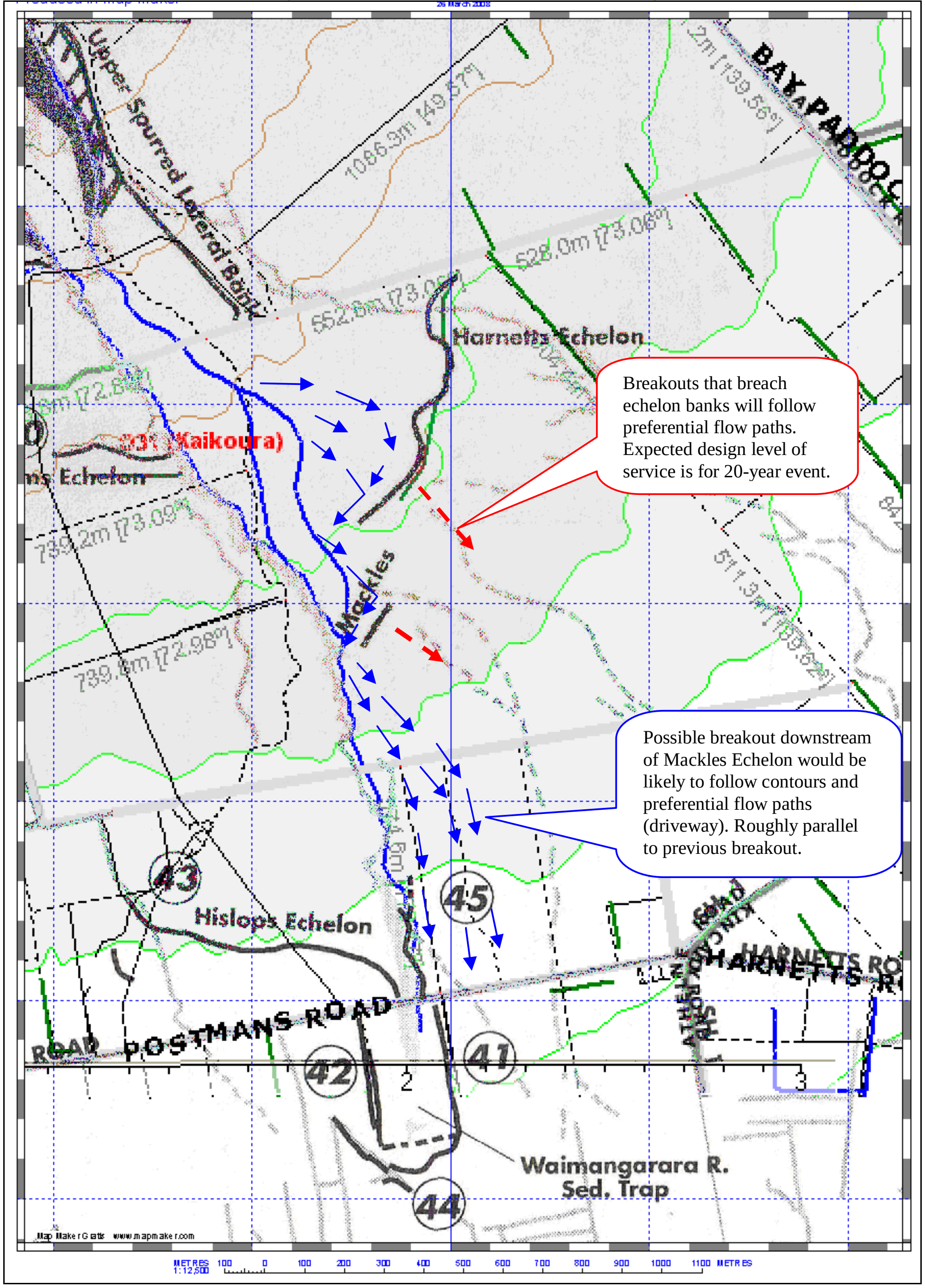
During a flood, a breakout may occur via the following mechanism: Inflow to a channel reach exceeds the availability of the reach to convey this flow. This lack of capacity may be caused by deposition of sediment and/or bedload that has been carried from upstream. Water levels rise as a result and overtop the banks. Overbank flows follow ground contours outside of the banks, and progress along the path of least resistance (taking local obstructions into account). As the discharge via the breach increases the velocity may increase and result in scour of the overland flow path. This can deepen the overland flow path, increasing its capacity. As the flood recedes the ability of the flows to carry sediment is reduced and deposition takes place.

A similar mechanism is understood to have occurred in the area of the subject site in the past, and resulted in the so-called Mackle’s Gut, shown in Figure 2. It is understood that this led to construction of Mackle’s Echelon, which was aimed at prevention of similar occurrences.

The subject site would be most under threat from a breakout to the true left of the Waimangarara Stream that occurred downstream of Mackles Echelon – see Figure 5. The property does receive a degree of protection from both Mackles and Harnetts Echelons from breakouts that occur further upstream, although if such a breakout were to be in response to a very large flood event, the 20-year ARI level of protection offered by these structures may be diminished.

A breakout downstream of Mackles Echelon would be likely to follow ground contours and be affected by vegetation. The previous breakout that resulted in formation of Mackles Gut did precisely this, and it is reasonable to expect that future breakouts in the same area would follow similar paths.

Figure 5: Breakout Threat to Dwelling



Breakouts that breach echelon banks will follow preferential flow paths. Expected design level of service is for 20-year event.

Possible breakout downstream of Mackles Echelon would be likely to follow contours and preferential flow paths (driveway). Roughly parallel to previous breakout.

SOLUTIONS

As alluded to by the title of this paper and by all that has been written above, the solution to the flood level problem in this case is not modelling. This is a clear situation where model construction would be extremely difficult, model calibration and validation would be impossible, and model results would be meaningless.

In this case it is not practical to attempt to find a design flood level in order to set minimum floor level. What is practical is to seek means by which the potentially high flood hazard in the subject area may be reduced. Flood hazard is usually determined as product of depth and velocity. A reduction of either of these would reduce flood hazard.

Breakout flood velocity is largely dependent on ground slope and surface roughness (or surface covering). It is not feasible to change the ground slope over a large area such as that under consideration. The existing surface roughness is almost at a practical maximum, with the overbank areas being covered with very dense bush. However if surface roughness were increased then this would reduce velocity, although the effect of this is likely to be to increase flood depth. Hence not much can be done to reduce potential break-out and overland flow velocity.

Potential flood depth is often reduced by filling. This involves raising ground levels to above predicted flood levels, leaving dwellings located at “flood-free” levels. The existing dwelling is already located on a local high point; therefore flood depth at the dwelling will be lower than elsewhere on property. This would mean a slightly reduced flood hazard at the building footprint than elsewhere on the property. However, breakout flows and the associated erosion potential could result in changes to the local topography in this area. Therefore while being located on a local high point the reduction in flood hazard associated with this may not be significant.

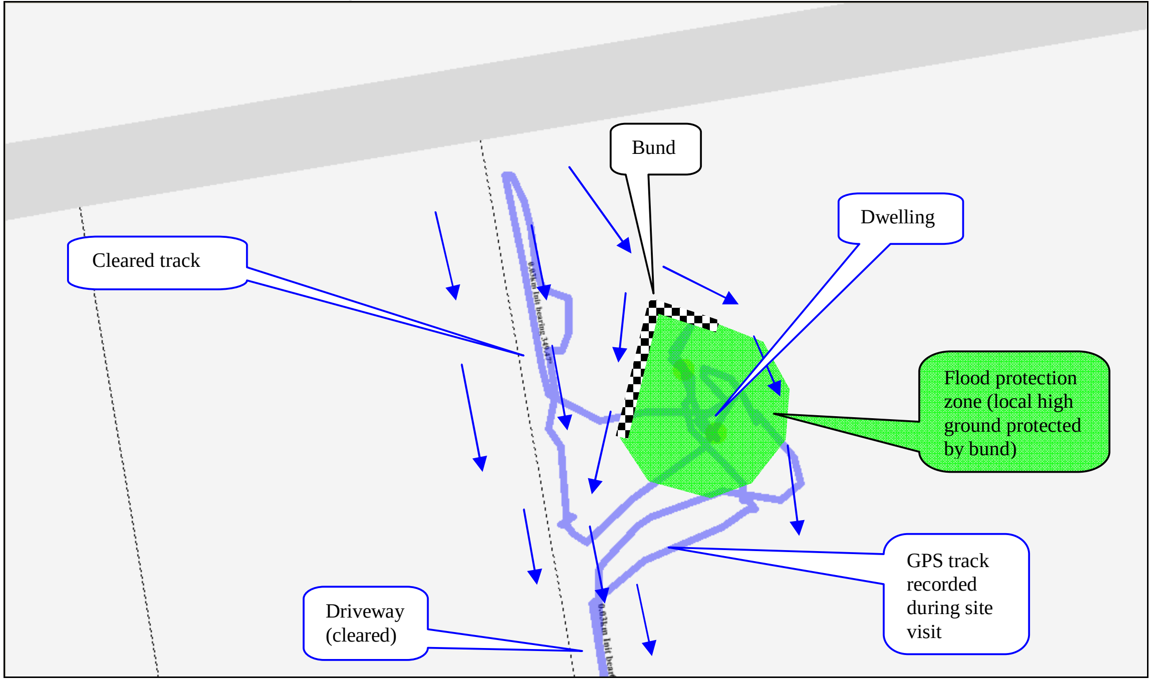
Diversion is possibly the most feasible means of reducing flood hazard at the house site. Discussion with Environment Canterbury revealed that, although they did not support it in this case, elsewhere in the Kaikoura fans system a bund has been considered in order to protect an existing dwelling. This would divert break-outs around the dwelling, thereby removing or significantly reducing the flood hazard.

In the location of the subject dwelling, the local ground slope is greater than what would normally be regarded as suitable for bunding as a means of protection. The major disadvantage of forming a bund in the potentially erosion-prone environment of the subject site is that it may be correctly oriented and sized for current conditions, but it may only take one flood to completely change the current conditions and a re-assessment of any constructed bund would need to be undertaken following any such flood.

The principle behind bund construction would be to align this at a similar orientation to the existing Mackles Echelon. The purpose of the bund would be to direct an upstream breakout away from the existing dwelling. There are at least two options for continuation of the bund, one being to direct the breakout flow back to the Waimangarara Stream. The other option would be to allow breakout flows to follow the driveway down towards Postman’s Road. This option has advantage in that this is a likely preferential overland flow path, being already cleared of vegetation. From Postman’s Road the breakout flow could be directed back towards the ford at Waimangarara Stream, thus keeping flows away from State Highway 1. However, as mentioned above, any flood that causes a breakout from the main channel of the Waimangarara Stream could change local topography to the extent that the bund may not continue to provide the level of protection initially intended. In Figure 6 the form and location of a bund are shown that could divert breakout floodwater away from the dwelling. This would direct runoff down the existing driveway, and scour that could result may lead to the property being temporarily inaccessible following a major breakout flood. However, this would be a likely scenario with or without the bund, since the driveway does appear to be the most likely overland flow path for such a breakout.

Any bund proposed for diversion of overland flow will need to be built from material that will resist erosion during a breakout flood. This could be done by selection of material that exceeds the likely threshold grain size for expected overland flood velocities. This can be calculated (estimated) using standard hydraulic principles.

Figure 6: Bund Protection to Breakout Flows



5. CONCLUSIONS

The recommendation of Environment Canterbury, being avoidance as a flood hazard mitigation option, is endorsed by the author. After this a bund to protect the existing dwelling and associated buildings was seen as potentially the next best option for reduction of flood hazard at the subject site. It was also recommended that the ground floor at the dwelling should be limited to non-habitable use, to reduce the risk to life that could be posed under breakout conditions.

In order to be sure that obligations under the Building Code are met, it is very difficult to be certain that buildings are kept free from surface water under design event conditions in this area. The usual approach of using models to predict peak flood level, and then basing minimum floor level requirements on this level does not work in this specific region. In spite of this the requests for hydraulic information when considering new buildings does not change from region to region.

For the Kaikoura Fans system avoidance is the best approach to flood hazard mitigation. However this is very unpopular, especially given that in many circumstances this is not a viable approach due to historic occupation of certain areas. In these cases more practical flood hazard mitigation measures are required that are able to last into the future, in spite of a rapidly changing and highly unstable hydraulic environment.

6. REFERENCES

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