BEFORE THE CANTERBURY REGIONAL COUNCIL

UNDER	the Resource Management Act 1991
IN THE MATTER	of application CRC190445 by Christchurch City Council to discharge stormwater to land and water

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JOINT STATEMENT OF WATER QUANTITY WITNESSES
5 FEBRUARY 2019

Introduction

1 As directed by the 4th minute of the Commissioners on 21 November 2018 and the 5th minute of the Commissioners on 29 November 2018, expert conferencing of water quantity expert witnesses has taken place through the exchange of information and a meeting on 28 January 2019 at the offices of Christchurch City Council.

2 The conferencing was attended by:

(a) Graham Harrington (on behalf of Christchurch City Council)

(b) Thomas Parsons (on behalf of Christchurch City Council)

(c) Robert Potts (on behalf of Antonio and Kerrie Rodrigues)

(d) Michael Charles Law (on behalf of Canterbury Regional Council);

3 This Joint Statement records the areas of agreement and disagreement between the experts.

Code of Conduct for Expert Witnesses

4 The witnesses confirm that in producing this Joint Statement they have read and complied with the Environment Court Consolidated Practice Note 2014 – Expert Witness Code of Conduct.

Issues

5 The issues and related matters that the expert witnesses were directed to consider by the Commissioners are:

(a) The choice and application of baseline years

(b) Flow volume targets

(c) Assumptions relating to the Styx River modelling

(d) Levels and attributes for a 1 in 5 year ARI (average recurrence interval) storm event

(e) Effect of Filling near Earlham St

(f) Reporting Frequency and Un-modelled Catchments

Issue (a) – The choice and application of Baseline years

6 Commissioner's Minute #4 Paragraph 7a and Minute #5 Paragraph 11 requested a concise explanation why the various baseline years from 1991 to 2016 were selected.

7 Mr Harrington provided the following explanation.

(a) The development of Stormwater Management Plans for the Styx, Avon, Halswell and Upper Heathcote has occurred over the last 10 years or so. It was anticipated at the start of this process that each of these SMPs would be unique and customised to their respective catchments and separately consented. The relatively recent change of policy to have a Comprehensive Stormwater Discharge Consent covering all the individual SMPs does highlight the different approaches that have been taken for each catchment however there is merit in setting targets for the individual catchments based on their peculiarities of hydrology, stage of development and sensitivity to flooding because such factors are different in each of the main catchments.

(b) The process for identifying an appropriate baseline flooding level ideally involves technical investigations of flood risk throughout the catchment based on historic flooding events and flood modelling of the current and anticipated future developed catchment. This information is shared with stakeholders and the community through the SMP development process and consolidated in the final SMP. The hearing process to date has been helpful in specifying the matters for investigation in SMPs and these will be applied to the new SMPs and the reviews of existing SMPs.

(c) Following is a brief summary of the reasons for the baseline years used up to this point (Table 1).

Table 1 Baseline Year Summary

Receiving Environment	Monitoring Location	Baseline Year	Reason for the Baseline Year
Ōtākaro/ Avon River	Gloucester Street Bridge	2014	Assessment is arbitrarily made at the time of the SMP investigations. It is primarily maintaining the "status-quo" for flooding in the catchment with a

			small allowance for ongoing creep in water levels as a result of intensification of developments and encroachment into waterways over time through various permitted activities in the District Plan.
Pūharakekenui/ Styx River	Harbour Road Bridge	2012	The baseline year relates to the time the hydrologic modelling investigations were being done for the Styx SMP. This modelling anticipated changes in zoning of some rural areas to residential or industrial that have since been codified in the 2016 District Plan. The use of the 2012 baseline year is considered acceptable to Rob Potts. He agrees that although this does not show historical flooding, this consent is not the appropriate platform for using pre earthquake land levels for future mitigation planning.
Ōpāwaho/ Heathcote River	Ferniehurst Street	1991	The South West SMP effectively implements the Heathcote Floodplain Management Strategy (a joint CCC/Ecan study 1998). The Strategy was based on 1991 flood predictions. It was noted in the South West SMP that flood level increases between 1991 and 2002 could be attributed primarily to unmitigated development of Westmorland. This is a good example of the issues investigations which lead to the identification of a particular meaningful target in the catchment.

Huritini/ Halswell River	Minsons Drain confluence*	2016	Although particular targets for the Halswell River were not set in the South West Area SMP, the South West Area discharge consent monitoring plan required a monitoring plan to be developed for discharges from the Halswell subcatchments to facilitate hydrologic understanding of the effect of developments. These have now been installed on Knights Stream (2014) and Creamery Stream (2017) at Sabys Rd culverts in accordance with the South West Area consent. The 2016 baseline date arbitrarily refers to the date of notification of the CSNDC initial application but could be reviewed when this SMP is reviewed and there is sufficient monitoring data to calibrate the flood model of this area. Significant development between 1991 and 2016 has been mitigated by full flood attenuation. This has included retrofit mitigation of pre 1991 areas.

8 The baseline year is used to define the state of urbanisation within the catchment for comparison against the urbanisation state of the assessment year. The modelling used in the assessment is intended to assess water quantity impacts of any increases in development and mitigation measures implemented to address these impacts. As such only variables associated with these activities will be altered within the modelling allowing the modelling to target the effects of the activity undertaken. It would not be possible to do this by using only recorded

data as the impacts of the proposed activities will be ‘mixed in’ with other natural phenomena.

9 For example, if an assessment were to be undertaken in 2024 the actual catchment topography in 2024 would be used when modelling both the baseline and the ‘assessment year’, so if there were another earthquake between the now and 2024 the new post-earthquake topography would be used in both models.

10 The network infrastructure would only differ between the two models for any mitigation measures (such as attenuation basins, new/raised stopbanks, or engineered changes in channel alignment or geometry) that has been constructed and the hydrological model would vary with the increases in imperviousness. This is to limit the assessment to the development effects and means that the absolute flood levels in waterway associated with the baseline will change with time, particularly as sea levels rise.

11 Different baseline years in each catchment does not vary the principle of setting an ‘acceptable’ level of flooding that includes both development and mitigation measures up to the baseline date. If a different date were set then the target water level may vary, possibly up or down, depending on the influences of the subsequent development and mitigations installed.

12 The areas of agreement are as follows:

(a) Targets should be set in the SMP process according to the peculiarities of the catchment concerned and the specific issues to be managed.

(b) Testing flood water level changes resulting from urbanisation and mitigation measures should be done through modelling, as it allows these effects to be isolated out from other effects such as sea level rise and climate variability.

(c) It needs to be very clear what model parameters and inputs are modified, and which remain constant as part of the baseline and updated scenarios, as part of the SMP updates and model reports.

(d) Including design water levels to a datum in Schedule 7 could be problematic if model updates result in changes to baseline flood levels.

(e) Baseline years in schedule 7 are agreed.

13 The areas of disagreement are as follows:

(a) We have not sought agreement on acceptable water level increases in particular the 120mm increase in the Styx River.

Issue (b) - Flow volume targets

14 Mr Harrington provided the following reasons for not specifying a volume limit in response to Paragraph 7(b) of Commissioners Minute #4 and Paragraph 12 of Minute #5.

(a) Water levels are simply an expression of water volume over a given 3-dimensional terrain at a particular time, and at a particular place. Engineers manage water flows and volumes to achieve design water levels at critical points in a waterway system. However, it is the water (or flood) level which is the critical issue for the community. If the 3-dimensional terrain is constant, water levels are the only variable that needs to be measured in order to understand flood effects, with some exceptions as described in Paragraph 15 below.

(b) A water level measurement is preferable over volume simply because it is easily observed by anyone without any technical expertise and is easily recorded. These observations can be in relation to any landmark or with reference to the approximately 100 simple staff water level gauges already in place throughout Christchurch waterways or on the various recording sites which can be viewed and monitored on the internet. A volume is not directly observable and is not meaningful to the public.

(c) A volume which may be of interest for engineering calculations can be indicated by selecting the level of water at an appropriate point in the waterway or ponding area.

(d) Specifying a water level target (or limit) serves the purpose of managing flooding but provides a clearer and more meaningful and widely understood indicator of flood system performance rather than a volume target (or limit).

(e) Should the Panel determine that volume limits are appropriate then the setting of such limits would be a matter requiring significant investigation, modelling and consultation work which would be appropriately addressed as part of SMP development or SMP review. This could be a variation of the proposed condition relating to water level monitoring as per Paragraph 18(a) below.

15 Rob Potts considers that volume is important to understand in specific locations where flooding from the river occurs at a level higher than the surrounding land, i.e. over a stopbank but agrees that it would be extremely difficult to measure/quantify real-time. With regard to the Styx River, ponding occurs out-of-river in the Flood Ponding Area (FPA). If river breakout occurs in the vicinity of the level gauges, then volume can roughly be calculated, however if it occurs further up in the catchment, i.e. between Radcliff Rd and Earlham St, then the volume of breakout is an issue for downstream residents (Rodrigues and others) as this adds to the duration of ponding. Duration of ponding may be mitigated by the reestablishment of natural drainage patterns to Barkers Drain that were evident pre the apparent fill in the vicinity of the Rodrigues. The applicant should consider a condition regarding reestablishment of natural drainage patterns to ensure volume is less of an issue in this area.

16 In summary, volume can be important depending on how and where the flooding/overbank has occurred but is not practical to measure – it would require level, spatial, flow velocity and time measuring. However, volume can be calculated by modelling and if ponding duration cannot be mitigated, then limits may be appropriate.

17 The effect of a volume limit would be to control the quantity of overtopping and subsequent flood extent in areas that are removed from the main river stem by high ground. In other areas, which are directly connected to the main river channel (where level targets are proposed) there would be no additional benefit in setting a volume limit as the flood volume is indirectly controlled by the flood level limits. It would be appropriate to identify locations where volume limits be set during the development or review of the SMPs. At this point in time it is not possible to set volume target locations without considerable further analysis and to do so would necessitate the setting of targets outside of

the context of a wider catchment assessment and the understandings of flood behaviours that such a catchment assessment may offer.

18 The following revision to Condition 6q is suggested by Mr Harrington:

(a) *6 q. Identification of key locations in addition to those identified in Schedule 7 where modelled assessments of water levels* ***and/or volumes*** *shall be made for the critical 2% AEP event and any other relevant return interval. For each additional key location, appropriate water level reductions or tolerances for increases shall be set according to the SMP objectives and shall be reported with the model update results required under Condition 48;*

19 The areas of agreement are as follows:

(a) Water level is the key indicator of flood performance, but consideration of flood volumes and/or flow can be important where the reporting location is upstream of areas subject to flooding; such as the current situation in the Halswell catchment.

(b) Reporting flood volume (or duration of time a given water level is exceeded) is important at locations where flood overtop stopbanks or bunds and / or other areas considered important that are away from the main river channel.

(c) Flood volume is likely to a bigger issue in the Styx and Halswell catchments than in the Avon and Heathcote catchments.

(d) Reporting locations should be in the areas of flooding wherever possible. This could include a reporting location on the Halswell River outside of the CCC boundary; in Selwyn district.

(e) Locations for reporting of flood volume and / or depth should be developed during SMP investigations

(f) A reference to flood volume is to be included in revised wording for Condition 6q.

20 The areas of disagreement or uncertainty are as follows:

(a) None

Issue (c) – Assumptions relating to the Styx River modelling and River Management

21 Mr Parsons has provided the following information in response to Paragraphs 7(c) and 8 of Commissioners Minute #4 and Paragraphs 15 and 16 of Minute #5.

22 A large number of assumptions are necessary to be made when building, calibrating and using hydrological and hydraulic models. One key assumption is that the hydraulic model calibration arrives at suitable modelling parameters to apply in the design scenarios used for evaluating the effects of future development.

23 The existing hydraulic model of the Pūharakekenui / Styx River is calibrated against the August 2008 storm event, considered at the time to be approximately a 1 in 10 year ARI rainfall event. There are two major calibration parameters that were modified within the model during the process:

(a) Hydrological parameters to adjust the model to match the observed / gauged flows at Radcliffe Road

(b) Manning's roughness parameters to adjust the model to match the observed levels

24 The hydrological parameters are impervious area and soakage rates. As these parameters are independent of recent changes in the Styx River channel and maintenance impacts they are not discussed further.

25 The roughness parameters in the model are varied across the river cross sections (based upon differing bank and bed roughness) and along the river. The calibrated roughness parameters are representative of the channel condition at the time of the event, i.e. the level of weed, the undulations in bed shape; and any impacts of un-modelled structures or variations in river cross-section. Given the level of detail in the hydraulic model the bed roughness primarily reflects the weed condition.

26 The parameters arrived at during the calibration for the bed roughness were between 0.032 and 0.044. The bank roughness is not affected by the weed growth as it represents the vegetative cover of the banks.

27 The higher roughness value of 0.044 was applied in the main channel from chainages 9727 - 11004, 11809 – 16178, and 17462 – 21373 with

the rest of the reaches generally having an 'n' value of 0.04. Similarly, the Ka Putahi Creek has a bed roughness of 0.032 between chainages 1266 and 10646 with the remaining reaches set at 0.04.

28 The low flow water level in advance of the August 2008 event as measured at Radcliffe Road and Lower Styx Road was not extreme (Figure 1 and Figure 2) and it is likely that the weed condition at the time was within the normal range (as inferred from the water level records).

29 There is considerable variability in recorded low flow water levels at the Lower Styx (Figure 3) and Radcliffe Road (Figure 4) sites and much less variability at the Harbour Road (Figure 5) site. The flow record at Radcliffe Road (Figure 6) indicates that the variability in water levels at low flow is dominated by the weed condition rather than the flow rate. The water level variance at Radcliffe Road has been observed at up to 1 m, whereas is it approximately 0.5 m at Harbour Road. For the purposes of this response to Minute #4 and #5 the description of river management and channel maintenance is limited to weed harvesting, given the overwhelming significance of weed management.

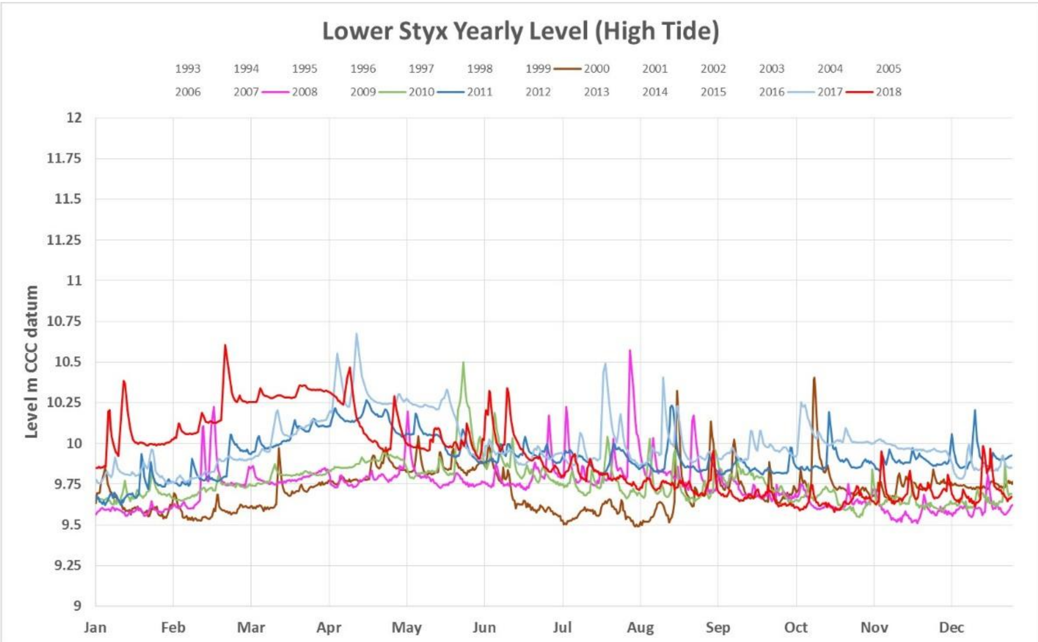

Figure 1 Lower Styx Water Level Record Showing a Limited Number of Years

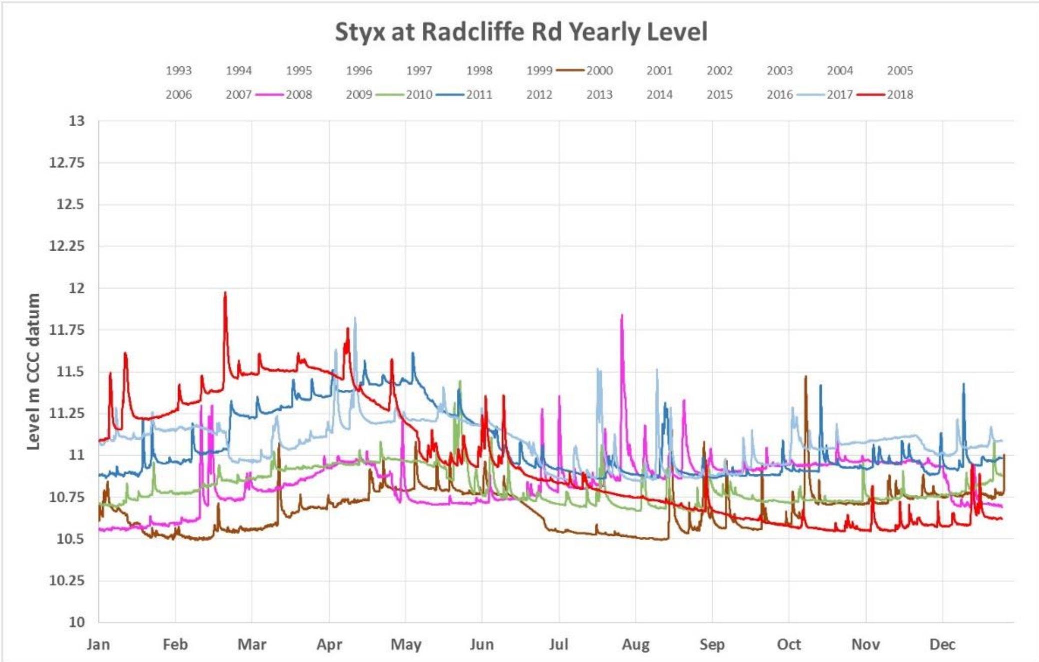

Figure 2 Radcliffe Road Water Level Record Showing a Limited Number of Years

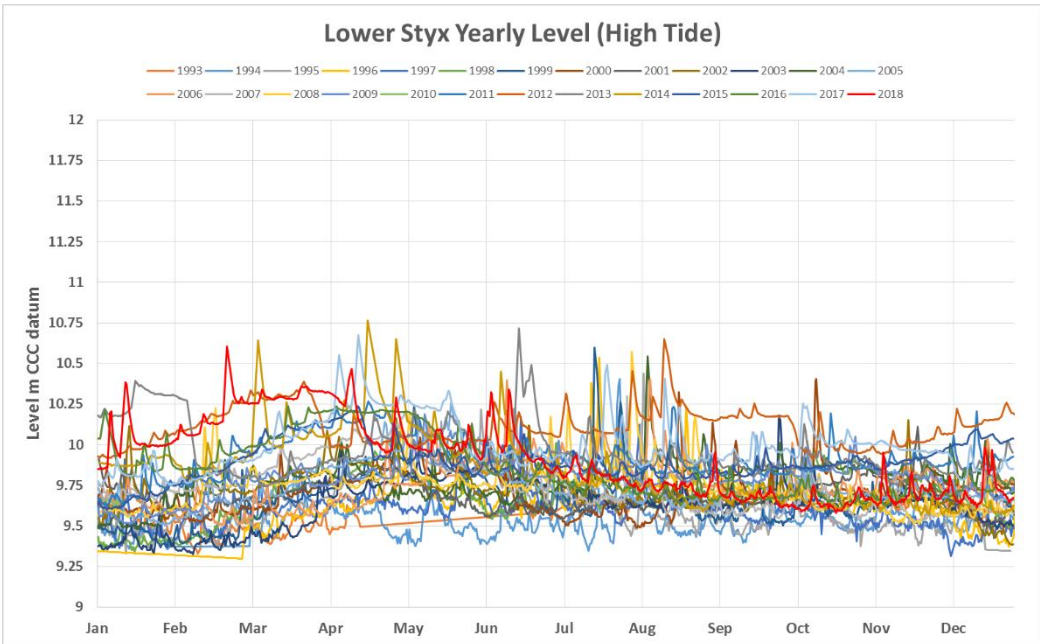

Figure 3 Lower Styx Water Level Record Showing All Years

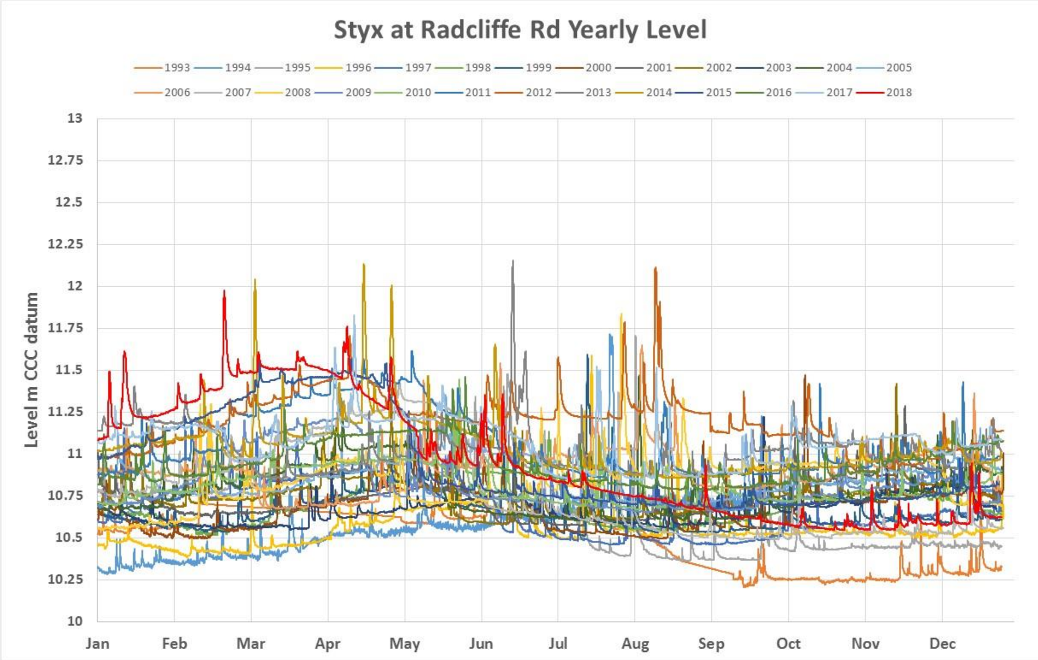

Figure 4 Radcliffe Road Water Level Record Showing All Years

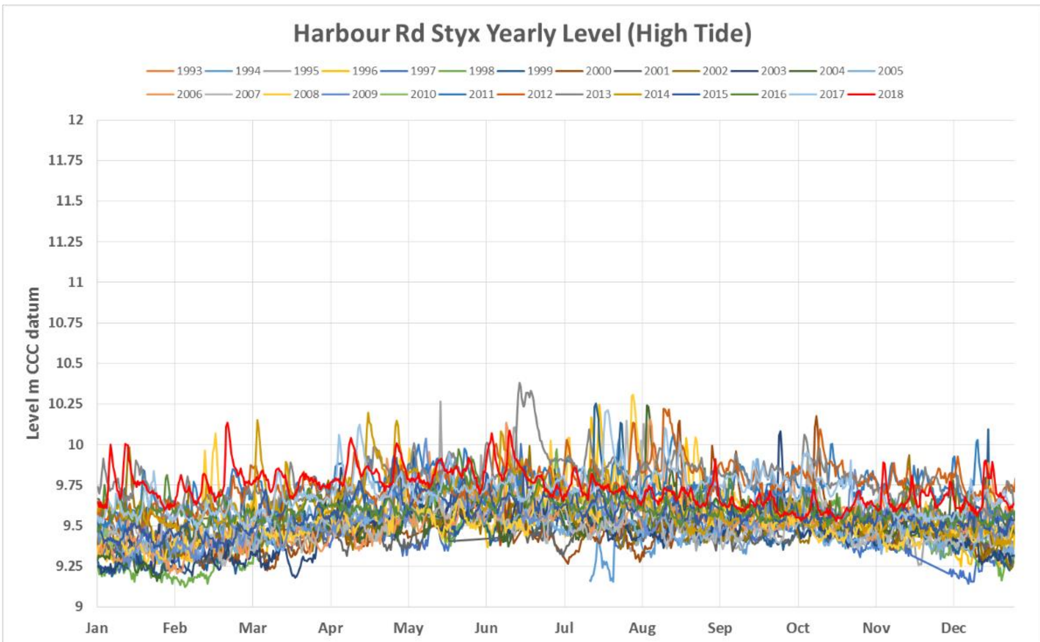

Figure 5 Harbour Road Water Level Record Showing All Years

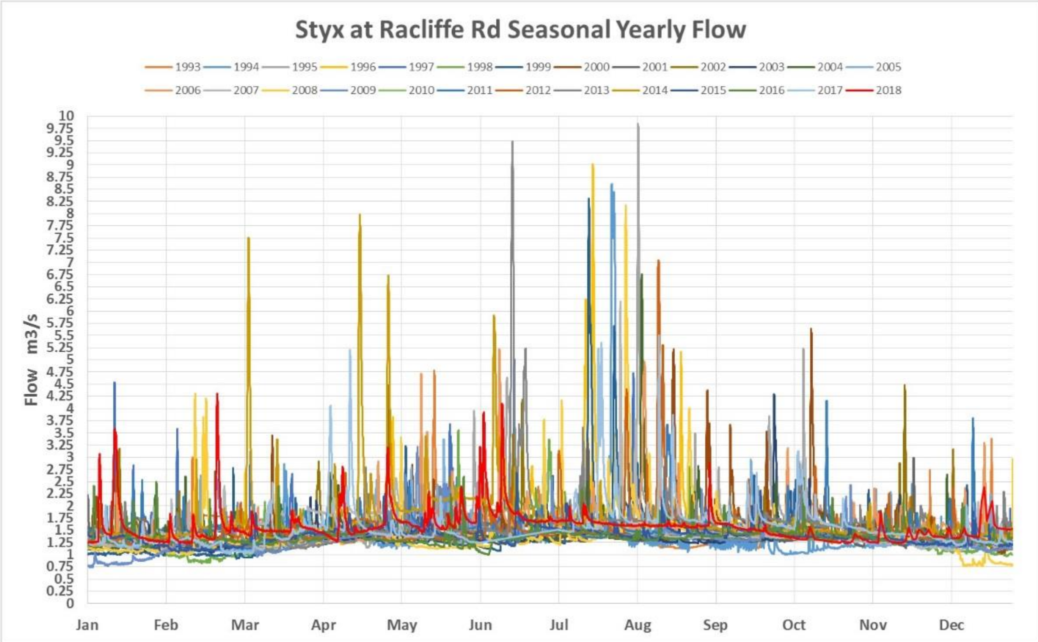

Figure 6 Radcliffe Road Flow Record Showing All Years

30 Given the observed significance of weed growth on water levels in the river a weed harvesting regime was adopted by Council and its predecessor, the Christchurch District Drainage Board. Traditionally the weed was harvested 2 times per year but in the last two seasons this has been increased to 3 times per year. Inspection of the water level record at the Lower Styx site has shown that weed harvesting on average drops low water levels by 300 mm, however, there is significant variability. The effect of weed on the base flow water level is increasing with time and the current weed management practices are unable to stabilise the upward trend in the seasonal effect of weed growth on river water levels. This can mean that smaller storm events such as a 1 in 10 year ARI event has a similar water level as a 1 in 50 year ARI event if it happens to coincide with a period of high weed establishment.

31 The model results show the importance of weed in the system with regard to water levels and, depending on management, could have a greater impact that urbanisation. The model results for a 1 in 10 year ARI design storm event show that water level variations of between 10 and 300 mm might typically be expected depending on distance upstream of Harbour Road and the weed condition in the river. This is reflective of the low flow water level variance at the Lower Styx site.

32 In some areas the river banks are modelled to overtop in the 1 in 10 year ARI design storm event. The modelling indicates that depth of flooding in these areas will be impacted by the weed condition in the river at the

time of the event. The actual weed condition may vary from the values used in the hydraulic model (as derived from the model calibration process) then the resulting flood levels can be expected to vary from those predicted.

33 Additional modelling has been undertaken to assess the sensitivity of the model to a wide range of roughness values. For the purpose of this sensitivity test two roughness scenarios were computed with 0.04 and 0.15 Mannings n applied throughout the model, representing a normal channel and a heavily overgrown channel (noting that the calibrated parameters for the Ka Putahi were below 0.04). The resulting main channel flood differences were generally within the variance that has been observed in the low flow water levels. This is due to the flood plain being activated in the extreme modelled events where the roughness values have remained constant between scenarios.

34 The model results identify that the model is sensitive to weed assumptions with the high roughness in the 1 in 10 year ARI events showing water levels exceeding the calibrated 1 in 50 year ARI event result in the mid reaches of the river (between Earlham Street and Redwood Springs). This is reflected in the observations from the June 2013 flood event where low flow water levels were 150mm higher than the August 2008 event at Lower Styx and Radcliffe Road indicating above average weed levels. The resulting flood was the highest on record at Radcliffe Road and Harbour Road.

35 In the MPD scenarios, which are used to assess the impacts of future development, the calibrated results fit approximately half way between the two extreme roughness results.

36 The consequences of weed-elevated water levels are not major (to the extent that residential floors have been flooded) but they are alarming to residents and do impact the area flooded in smaller more frequent flood events.

37 Fundamental research need to be done into the factors causing the weed growth and the optimisation of the management practices that are employed to manage or accommodate the effect of weed growth in the main river channels.

38 This technical caucusing group recommends that a research programme be established to address this matter that would investigate:

- International weed management practices in similar settings
- The specific prolific weed species in the Styx River and the factors which promote or suppress growth including sediments, stormwater discharges, shading and climatic factors
- Implementation of the best practical options within the Styx SMP
- The best approach to incorporating the variable weed condition within the hydraulic model and resulting design flood scenarios
- Test the model calibration against other storm events, as they arise, to investigate model sensitivity to varying weed conditions

39 In summary, weed growth has a significant impact on water levels during low flow and flood flow conditions and weed harvesting is the single most significant channel maintenance activity that the applicant undertakes. Weed harvesting can have variable effect but is the primary tool for weed control in the downstream reaches of the main rivers. The Pūharakekenui / Styx River hydraulic model is calibrated to a single weed state (as at August 2008) which did not reflect an extreme weed condition. Modelled and actual flooding in a 1 in 10 year ARI storm event could vary by up to approximately 300 mm in areas of concern depending on the weed condition. Further research is required to understand the factors causing weed growth and optimal management techniques.

40 The areas of agreement are as follows:

(a) Improved weed management is essential for the control of the river water levels as per Paragraph 38.

(b) Fundamental research is necessary to find a practical solution.

41 The areas of disagreement are as follows:

(a) No disagreement

Issue (d) - Levels and attributes for a 1 in 5 year ARI storm event

42 Mr Harrington provided the following explanation relating to Paragraphs 7(d) of Commissioners Minute #4 and 14 of Minute #5:

(a) These attributes should be set if it is decided that there are critical issues which arise as a result of urbanisation of the catchment which need to be managed in these relatively frequent events.

(b) In residential areas the channels and pipework is generally designed to manage events up to a 1 in 5 year ARI storm event and so flooding would generally not occur unless there was a blockage or failure of the system – such as leaves collected on pipe inlet grills. Generally the flood management detention facilities are designed for events much larger than a 1 in 5 year ARI storm event.

(c) In many cases the 1 in 5 year ARI storm event would be controlled by the stormwater infrastructure and easily absorbed by any large detention and treatment facilities in the network. Even when these flows are larger in the post development phase they may not be generating any issues of concern and therefore do not require any further consideration.

(d) The primary situation that could result in adverse effects of 1 in 5 year flows would be erosion of waterways below development on the hills. Such matters are investigated in the process of developing an SMP and approaches devised to monitor, mitigate and manage the matters of concern. Up to now these issues are largely mitigated by requiring rain tanks on hill properties and designing outlets from detention facilities which release flows at rates similar to the pre-development rates. Rain tanks are effective at mitigating the erosive effects of peak discharges generated by smaller, more frequent storm events.

(e) Nuisance flooding is normally managed by good design (conservative hydrological and hydraulic analysis, adequate freeboard, provision of robust secondary flowpaths) but where this nuisance is as a result of lawfully established historic development, it is managed operationally on a case by case basis. There is a further opportunity to manage flows where existing developments are retrofitted along with new subdivisions or as part of projects in the Land Drainage Recovery Programme.

(f) Should the Panel determine - in addition to the pre-emptive design approach - that attribute target levels are necessary for the 1 in 5 year ARI storm events, or other events more frequent than 1 in 50 year ARI storm events, then it will be necessary to review the flooding issues that may arise in such events and identify level targets at specific locations aimed at managing such matters. The investigations, modelling and consultation work involved in setting such targets would be time-consuming and would best be done as part of SMP development or SMP review. At present the Applicant does not have sufficient information to generate target levels for a 1 in 5 year ARI storm event and significant investigative effort would be required to do so. To this end the Council has proposed a condition as follows:

6 q. Identification of key locations in addition to those identified in Schedule 7 where modelled assessments of water levels ***and/or*** *volumes shall be made for the critical 2% AEP event* ***and any other relevant return interval****. For each additional key location, appropriate water level reductions or tolerances for increases shall be set according to the SMP objectives and shall be reported with the model update results required under Condition 48;*

(g) This proposed condition includes "*any other relevant return interval"* which includes the 1 in 5 year ARI storm event if that is a matter to be managed in the particular SMP. It could be that a 1 in 10 year ARI storm event is more relevant in the particular SMP as the 10 year ARI storm event relates to the Council's Flood Intervention Policy. In addition to this Council would expect that much greater areas of the city's stormwater network capacity will be exceeded with potentially measurable impacts on the community. Overland flow paths and ponding areas may be activated in a 1 in 10 year ARI storm event, whereas this is much less likely in a 1 in 5 year ARI storm event.

43 Both Mr Law and Mr Potts noted that

(a) Not all parts of the city are served with stormwater networks, or ones capable of containing the 1 in 5 year ARI flows. For example, in Brooklands, there is no primary infrastructure and secondary flow paths have been removed or altered due to fill. There are also large areas of the catchment (most of it) with no detention facilities so the 1 in 5 year ARI flow event is not attenuated.

(b) This contributes to nuisance flooding of roads, gardens, and other areas in events with an ARI of less than 10 years; flooding in Brooklands being experienced in events of less than 8 year ARI.

44 Mr Harrington and Mr Parsons report that CCC already model the 10 year ARI storm event, so less modelling effort would be required to make results available, if a frequent event is to be included. As part of the hydraulic modelling approach the stormwater network is assumed to be clean. This assumption is increasingly significant in smaller events where blockages can have increased influence on flooding outcomes.

45 Mr Law wonders whether the 10 year ARI storm event is too infrequent to be reported as the ‘frequent’ event, and why would targets for the smaller event not be “no increase compared to baseline year”.

46 The areas of agreement are as follows:

(a) SMPs are the appropriate mechanism to set revised or additional targets.

47 The areas of disagreement, uncertainty or clarification are as follows:

(a) No agreement was reached on the choice between the 1 in 5 year ARI and 1 in 10 year ARI storm event for an assessment of flooding in a frequent event to be reported or the allowable (if any) increases in flood level.

(b) Reporting on performance in a more frequent (e.g. 5 or 10 year ARI) storm event, as well as the 50 year ARI storm event

(Mr Law considers this is needed, while Mr Harrington and Mr Parsons acknowledge there <u>may</u> be a need for the additional reporting. However, all parties agree that the need for additional reporting locations should be addressed during the next SMP process in each catchment)

Issue (e) – Effect of Filling near Earlham St

48 The potential effects of filling in Brooklands has been discussed during caucusing and been limited to consideration of apparent filling of 930 and 944 Lower Styx Road. The drainage impacts of this are presented below but the consenting and the legality of such activities are beyond the scope of this technical caucusing. A discussion of the earthquake effects on groundwater in the Brooklands area is also presented to aid in understanding the potential impacts of any filling.

49 The properties located at 3 - 11 Earlham Street are not directly connected to a constructed stormwater network. The properties discharge to land and rely upon soakage to ground and overland flows across the adjoining property (930 Lower Styx Road) into Barkers Drain (shown as a dark blue arrow on Figures 7-9). Barkers Drain collects flows and discharges them directly to Brooklands Lagoon (Figure 7). The drain is particularly flat, low lying, tidally influenced and is poorly defined at its head (being nothing more than shallow shaping of the ground). The drain has limited capacity given the elevation of the catchment relative to the sea.

50 There appears from aerial laser survey data (LiDAR) that the land surface has changed between 2011 and 2015 in and about the head of Barkers Drain (Compare Figure 8 and Figure 9 where lower levels are shown in blue and higher levels are shown in red). This is assumed to be filling.

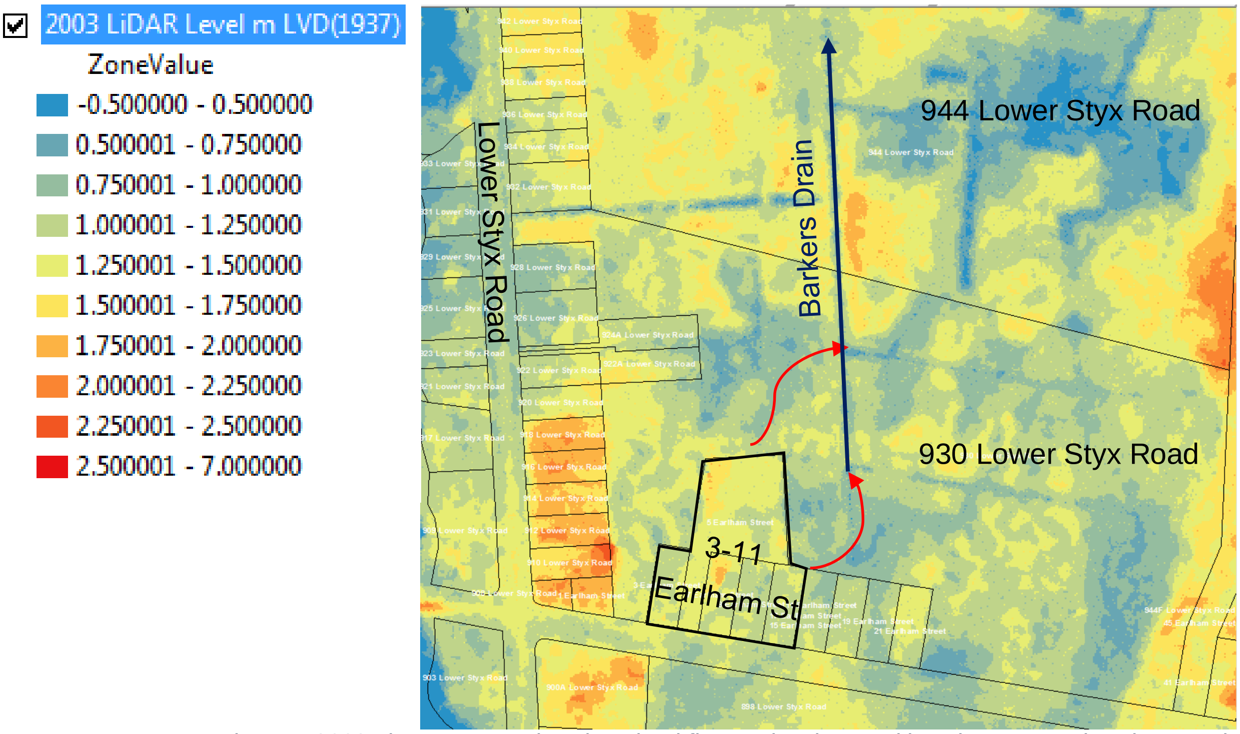

Figure 7 2003 LiDAR survey data (overland flow paths shown with red arrows and Barkers Drain shown in blue)

51 The 2011 LiDAR shows the realignment of Barkers Drain about the dwelling located at 930 Lower Styx Road (Figure 8) and with an area now showing in yellow / orange / red colours representing the new building platform. It also appears that there has been some reshaping of the other field drains within the property, presumably as a result of earthworks rather than natural processes. This has resulted in a lengthening of the eastern flow path connecting with the drain. Given the flat nature of the terrain it is likely that this has reduced the effectiveness of the drain, however, it appears that the resulting ponding is likely to principally occur on 930 Lower Styx Road. The depths of ponding upstream of the drain are similar to that experienced prior to the earthquakes but soakage to ground will be impeded due to the overall lowering of the ground in the area.

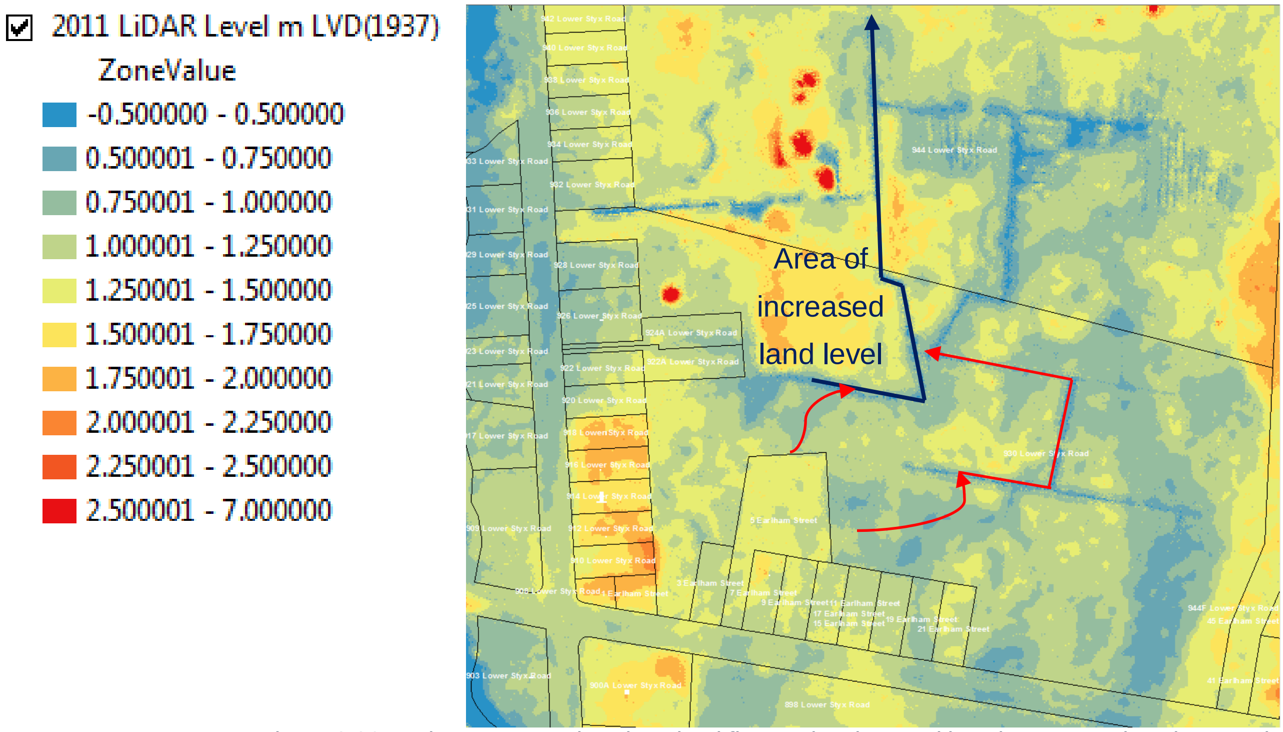

Figure 8 2011 LiDAR survey data (overland flow paths shown with red arrows and Barkers Drain shown in blue)

52 Further land surface change at 930 Lower Styx Road is evident in the 2015 LiDAR data (Figure 9). The survey indicates that the primarily overland flow path away from 3 – 11 Earlham Street has raised, likely to be as a result of filling. This could result in ponding on both 930 Lower Styx Road and on the Earlham Street Properties. This ponded depth may be up to 250 mm (noting the LiDAR accuracy of +/- 100 mm). Generally, the LiDAR indicates that drainage of the properties at 3 – 11 Earlham Street appears impeded by the change in land surface within 930 Lower Styx Road.

53 The discharge of stormwater from the roofs of the new buildings in Earlham St could also have added to the ponding of surface water as this point discharge would not soak away when the groundwater is high.

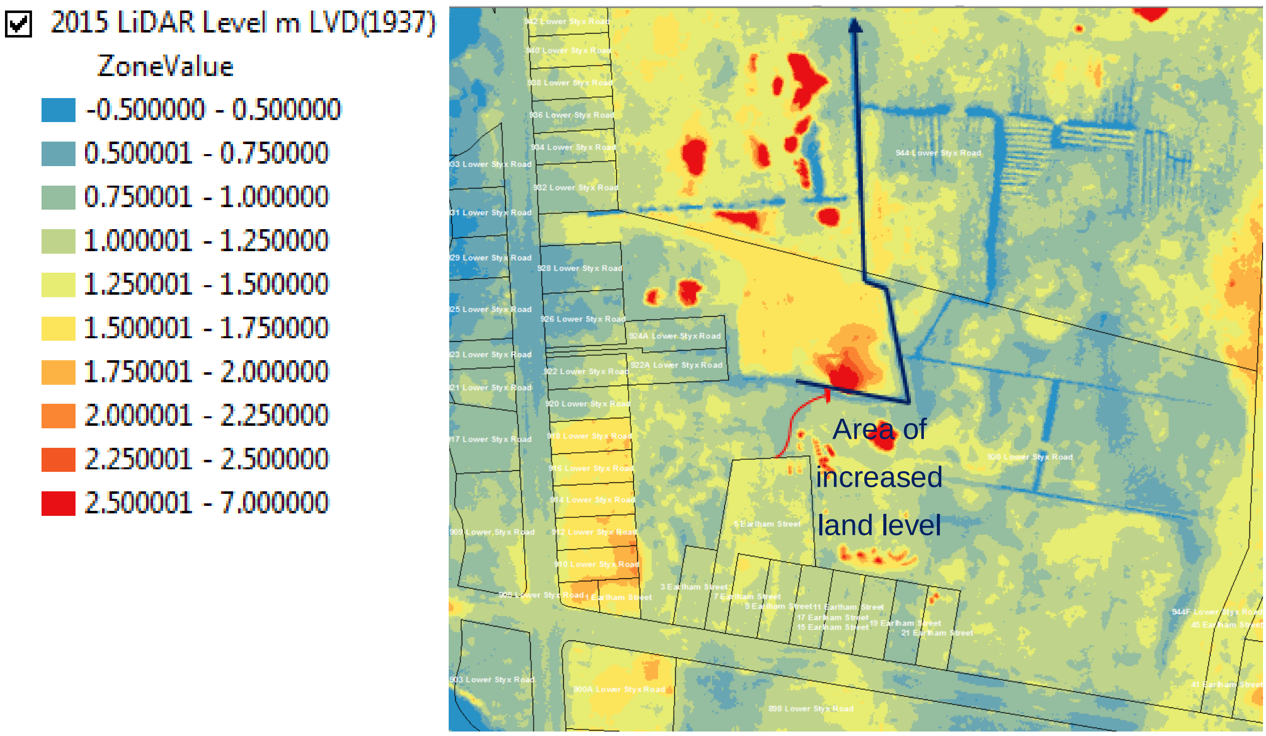

Figure 9 2015 LiDAR survey data (overland flow paths shown with red arrows and Barkers Drain shown in blue)

54 In conclusion, the change in land surface is likely to have contributed some additional ponding and reduced drainage from the Earlham Street properties. Prior to the earthquakes this ponding would have dissipated fairly rapidly through the sandy soils in the area and be drained by Barkers Drain. As such, any historical surface water ponding may have been inconsequential.

55 The post-earthquake elevated groundwater level relative to the lowered land surface means that it is difficult to distinguish between additional ponding due to the filling and the groundwater level being generally higher relative to the land. It appears that lack of drainage and increased (depth and duration of) ponding at the properties is due to a combination of reduced conveyance in surface drainage and reduced separation of ground surface and groundwater levels. The other flooding mechanisms: tidal flooding from Brooklands Lagoon, fluvial flooding from the Styx River will not be materially impacted by the filling given the location of the filling relative to the flood source.

Earthquake effects on groundwater

56 The graph below (Figure 10) shows the groundwater level since 1995 at Dartford St in Brooklands (black line) and the Styx River water level at Harbour Rd (Green). The range of the green band indicates the tidal

nature of the water at this point in the lower Styx River with a low tide level at about 8.4 m.

57 It is evident that there is a strong correlation between the seasonal water levels at Harbour Rd and the groundwater level measured at Dartford St. This correlation was interrupted and groundwater levels dropped when the first earthquake hit in September 2010 and there is also a mild groundwater response to the February 2011 when the second earthquake struck. Groundwater levels have however remained about 400mm lower than normal up until about 2015 and have gradually recovered to their normal level in about 2017 when once again the correlation with the Styx River level at Harbour Rd has been re-established. It is possible that there has been a similar effect in the Earlham St area however, since the ground has also settled by perhaps 200 to 300 mm at the time of the earthquake, the initial perception would be that the groundwater levels are similar to the pre-earthquake levels however now that the groundwater levels have recovered they will perhaps appear much higher than previously and be visible above the ground surface more frequently and for longer periods.

58 An explanation for the immediate post-quake changes in relationship between river and groundwater levels has not been investigated. However, instrument or datum errors have been discounted. However, the river level being the higher of the two records during the time of discontinuity suggests that an aquiclude occurred during that period and that the normal direction of flow is from the river to groundwater; an area of groundwater recharge.

59 Regardless of whether or not this transient earthquake response also occurred at Earlham St the lowering of the ground level at Earlham St means that the groundwater level will be above the depressions in the land more frequently and for longer periods than before the earthquake.

60 Barkers Drain can only remove surface water away from the area. Restoration of groundwater levels to pre-earthquake levels relative to ground surface levels will require a drainage system which is more effective than Barkers Drain (on its own) at lowering the local groundwater level. This could be done by pumping from sub-surface drains and discharging this water into Barkers Drain, if groundwater levels are below drain level. Such a system would not provide flood protection but it could reduce the long term surface water ponding

nuisance by reducing the duration of water ponding around the properties.

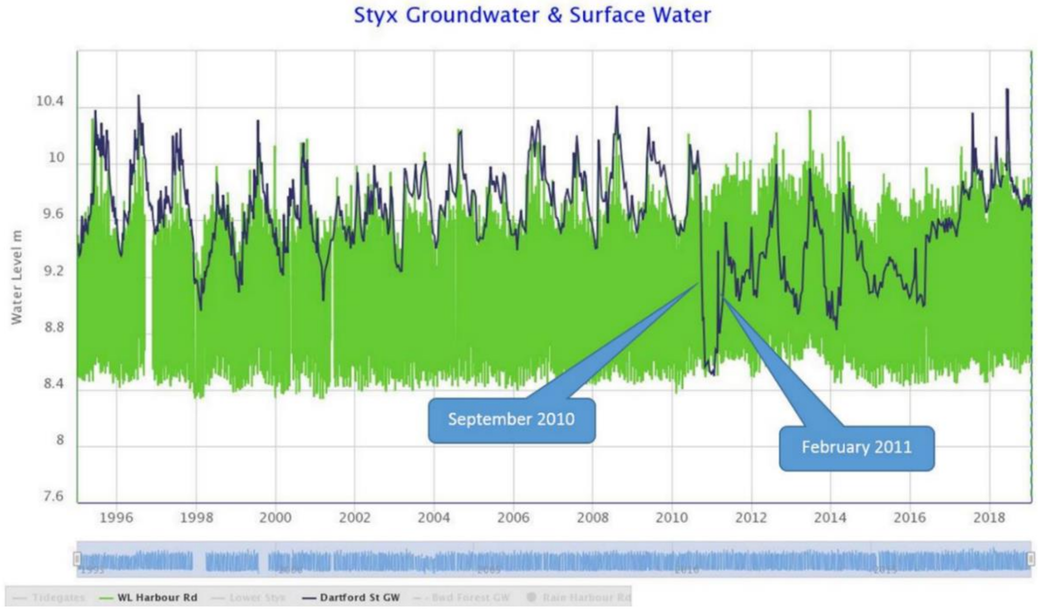

Figure 10 Groundwater data at Dartford Street

61 The areas of agreement are as follows:

(a) Filling of land adjacent to the Earlham St properties is likely to have increased the extent and duration of ponding of water to the Earlham St properties.

(b) The situation could be improved by constructing a channel through the filled area to Barkers Drain.

(c) Recommend that CCC instigates the restoration of the natural flow pattern using a channel as in (b)

(d) Groundwater levels are closely related to Styx River levels in the Lower Styx area and at times of elevated river levels, groundwater could be above the ground surface in lower lying areas

62 An area of uncertainty is:

(a) It is unclear the proportion of the ponding that can be attributed to the filling or the earthquakes

Issue (f) – Reporting Frequency and Un-modelled Catchments

63 This matter relates to earlier disagreements among water quantity witnesses and it is now agreed that:

(a) Five years is an acceptable interval for modelled hydraulic performance reporting and should be aligned to the SMP programme. This rolling programme probably precludes additional reporting after events (previously suggested by Mr Law) as it would put the reporting out of sync.

(b) The proposed approach to stormwater management in currently un-modelled catchments by setting appropriate standards for facilities is acceptable. If the catchments (or significant subcatchments) are modelled during the lifetime of the consent, then water quantity targets may be set in agreement between the consent holder and Canterbury Regional Council

Signed

Graham Harrington

Thomas Parsons

Robert Potts

Michael Charles Law