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Waimakariri Irrigation Scheme Storage Ponds - Potential Impact Classification

Date September 2012

Waimakariri Irrigation Ltd

Issue 3

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Date September 2012
Waimakariri Irrigation Ltd

Issue 3

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Approved for issue:


Stephen McInerney

20/9/12
Date 20 September 2012

ADDENDUM – January 2013

Peer review of the “Waimakariri Irrigation Scheme Storage Ponds – Potential Impact Classification” report, Issue 3 dated September 2012, identified that the breach of the Tub was not considered specifically in this report, and that the external embankment of the Tub should not necessarily be classified as a High PIC structure for the reasons outlined in this Addendum.

Failure modes for breach of the external embankment of the Tub are identified as follows:

- A. Breach of the external embankment due to piping failure and release of stored water in the Tub (approximately 24,400 m³)
- B. Breach of Pond 1 by internal piping and cascade failure of the Tub due to overtopping and development of a breach through the Tub external embankment. The total stored water released by this failure mode would be the combined volume of Pond 1 (2,000,000 m³) and the Tub (24,400 m³).
- C. Failure of the G5 control gate leading to overtopping of the Tub and overtopping failure of the Tub external embankment, resulting in release of combined volume of the Pond 1 (2,000,000 m³) and the Tub (24,400 m³).

The relatively small volume of water released for failure Mode A, identified above, would not result in significant downstream flooding and would be considered a Low PIC embankment based on NZSOLD (2000) or Building (Dam Safety) Regulations (2008).

Failure Mode B would release similar flood volumes and timing of the flood as identified for breach of the western embankment (refer to Figure B4 of Appendix B). Section 7.2 of this report identifies that a Medium PIC results for breach of the Western embankment, and this PIC would also apply for failure mode B, identified above.

Failure Mode C, would release a significant volume of water, however the release of this water would be throttled to a maximum discharge of less than 20 m³/s due to the outlet pipes G5 controlling flow into the Tub. Release of the stored volumes of the ponds at such a discharge rate of less than 20 m³/s would not result in significant downstream flooding and the PIC for this failure mode would be considered Low or Medium based on NZSOLD (2000) or Building (Dam Safety) Regulations (2008).

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The external embankment of the Tub is therefore reclassified from a High to a Medium PIC, based on the reasons outlined above. Figure A1 presents the PIC for discrete sections of the pond embankments, taking the revised PIC for the Tub external embankment into account. This figure supersedes Figure 2 presented in the main report.



Figure A1 - Summary of PIC assessment for embankments of proposed Waimakariri Irrigation Limited storage ponds, with revised PIC for the Tub embankments.

EXECUTIVE SUMMARY

This report provides an assessment of the Potential Impact Classification (PIC) of the proposed Waimakariri Irrigation Limited irrigation storage ponds. This assessment supersedes a previous PIC assessment carried out in February 2012, as it is based on more detailed information of households surveyed within the dam breach flood inundation zone.

Evaluation of the PIC for a dam is a consequence assessment used to determine the level of design and maintenance required for a proposed dam. The assessment determines a dam's potential impact by correlating the dam's assessed damage level in the event of a breach, with the estimated population at risk downstream. A dam is classified as either a high, medium or low PIC based on the Building (Dam Safety) Regulations (2008) and New Zealand Society of Large Dams (NZSOLD) Dam Safety Guidelines (2000). This classification is then linked to the level of site investigation, design, construction, operation and maintenance of the dam to ensure that an appropriate level of dam safety risk management is applied to the particular dam, to reduce the likelihood of it failing.

Accordingly, the standards and criteria applied to a high potential impact dam are far more onerous than those for a medium or low potential impact dam. It should be noted that the PIC assessment, as described in this report, does not in any way reflect the integrity of the dam or the likelihood of dam failure. Furthermore, a dam breach is a very low likelihood event and the results of dam breach analysis should be considered in this context

The PIC assessment, described in this report, is based on dam breach flood inundation zones calculated with a two dimensional computational hydraulic model and a detailed topographic survey of households within the flood zone. Four dam breach locations were modelled, each located for greatest impact on nearby houses. The four dam breach locations are labelled as "East", "South", "North" and "West" and the resulting flood inundation from embankment failure at these locations are provided as Figures 2, 3, 4 and 5 respectively in Appendix A

Table-I summarises the PIC categories assessed for each of the four breach scenarios using the Building (Dam Safety) Regulations 2008. Due to the location of the breach and volume of water released, the PIC varies for each breach location. PIC assessment using NZSOLD (2000) Guidelines gave different PIC categories, however it is recommended that the PIC evaluated using Building (Dam Safety) Regulations 2008, and listed in Table-I, are adopted as the Building (Dam Safety) Regulations 2008 are likely to come into force on July 1st 2014.

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Table-I – PIC for the proposed Waimakariri Irrigation Limited irrigation storage ponds

PIC Assessment Method	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Building (Dam Safety) Regulations (2008)	HIGH	HIGH	HIGH	MEDIUM

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APPENDIX B – Flood Hazard Maps

APPENDIX C – Waimakariri Irrigation Ponds Dam Breach Analysis

1.0 Introduction

This report provides an assessment of the Potential Impact Classification (PIC) for the proposed Waimakariri Irrigation Limited (WIL) irrigation storage ponds. The classification is required to set criteria for detailed design, building consent, construction, operation and maintenance purposes. The Potential Impact Classification is in accordance with both the Building (Dam Safety) Regulations (2008) and NZSOLD Dam Safety Guidelines (2000).

2.0 Background

Dams, with their large volumes of water and related structures, have a special nature because of their scale, the water forces at work and the use of natural ground for forming the major part of the impounding embankment. The design philosophy for dams considers safety of the dam and structures as a very important component of not only the design, but also of the construction and long-term operation as well. The design, construction and operation practices must address hazards that have the potential to impact on the safety of the dam.

The philosophy is that measures are put in place in design, construction and operation in order to prevent a dam breach from occurring. The assessment of consequences from a hypothetical dam breach allows the determination of the Potential Impact Classification of a dam. Potential Impact Classification is a qualitative categorisation of water retaining structures according to the potential consequences of failure. The PIC links to the design and management of dams because the NZSOLD Dam Safety Guidelines use PIC to define the level of expertise and detail applied to investigation, design, construction, commissioning, surveillance and safety reviews of dams

Dams are classified as either low, medium or high impact based on criteria prescribed in the Building (Dam Safety) Regulations, 2008 and NZSOLD Dam Safety Guidelines (2000). These criteria determine a dam's potential impact by correlating the dam's assessed damage level in the event of a breach, with the estimated population at risk downstream. It should be noted that the PIC assessment, as described in this report, does not in any way reflect the integrity of the dam or the likelihood of dam failure. Dam failure is a very low likelihood event and the results of dam breach analysis should be considered in this context.

3.0 Site Location and Dam Description

The proposed site for the proposed Waimakariri Irrigation Limited (WIL) scheme storage ponds is located between the Waimakariri River and the Eyre River on the Canterbury Plains. The proposed storage scheme consists of two conjoint ponds, as indicated in Figure 1 of Appendix A. The proposed reservoirs will be impounded by lined earthen embankments. The maximum dam height and storage volumes are listed in Table 1. Each pond is a large dam according to the definition of the Building Act (2004), as each pond has a depth of water greater than 3 m and a reservoir volume greater than 20,000 m³.

Table 1 – Proposed embankment heights and storage volumes

Pond Number	Maximum Embankment Height above Natural Ground Level	Maximum Water Depth	Total Storage Volume
1	10 m	9 m	2.00 Mm ³
2	12 m	11 m	6.37 Mm ³
TOTAL			8.37 Mm³

4.0 Assumed Breach Location and Flood Extent

Generally, embankment dams breach from either piping or overtopping failure. Piping failure occurs when water begins to seep through the dam embankment and internal erosion can cause the seepage channel to enlarge over time to form a 'pipe'. Such seepage could occur through a defective area of the reservoir lining or at the interface between a concrete structure and the embankment for example. If the pipe continues to grow, it may lead to the collapse of the embankment and release a significant flood.

Overtopping failure occurs when the reservoir water level exceeds the dam crest level and overflow erodes the dam body. Overtopping could also occur due to a large settlement of the embankment, caused by a severe earthquake.

It is assumed that the breach mechanism for Pond 1 is internal piping of the embankment. Piping failure could occur at any location on the middle embankment of Pond 1 due to earthquake damage or a localised weakness in the embankment in conjunction with leakage through a defect in the reservoir lining. Overtopping failure is considered the breach mechanism for Pond 2, resulting from initial breaching of Pond 1 into Pond 2 and causing Pond 2 to overtop and fail.

Four failure locations located for the greatest impact on nearby houses were analysed and flood inundation maps were developed using a two-dimensional computational hydraulic model. A full description of the hydraulic modelling study is provided in Appendix C. The four failure locations

assessed are labelled as “East”, “South”, “North” and “West” and the resulting flood inundation from embankment failure at these locations are provided as Figures 2, 3, 4 and 5 respectively in Appendix A.

5.0 Assessment of Consequences of Dam Breach

5.1 Population at Risk

During August 2012, a survey of houses within the dam breach flood flow path and surrounding area was undertaken. An assessment of the threshold level at which flood water can start to inundate each house was obtained by surveying the doorstep level. Appendix B shows the location of each of the households surveyed. In total, 270 houses were surveyed. This survey data has been used to determine the population at risk (PAR) for the four dam breach scenarios modelled.

The PAR, as defined by the Building (Dam Safety) Regulations 2008, is defined as “the number of people likely to be affected by inundation greater than 0.5 metres in depth”. The population at risk for hypothetical dam breach of the proposed Waimakariri Irrigation Limited irrigation storage ponds has been calculated for the four modelled breach scenarios using ArcGIS software and is summarised in Table 2.

For PAR assessment, a value of 2.5 persons per household has been adopted based on analysis of 2006 census data for the Waimakariri District (Statistics New Zealand, 2012). The 2006 census states that there are a total of 17,103 dwellings in the Waimakariri District and a total population of 42,834. Therefore there is an average of 2.5 persons per household in the Waimakariri District. This compares with the New Zealand average household size of 2.7 people, also based on 2006 census data. Adopting a value of 2.5 persons per household is deemed conservative for assessment of PAR, as persons per household has decreased in New Zealand generally and particularly in the Waimakariri District.

Table 2– Population at risk (PAR) summary

Parameter		Eastern Breach	Southern Breach	Northern Breach	Western Breach
A	Area of flood zone (km ²)	73	59	66	15
B	Number of households within flood zone	176	75	198	50
C	Households at risk ¹	40	19	35	1
D	Number of people per household	2.5	2.5	2.5	2.5
E	Number of additional people in flood zone (farm workers, people on footpaths or in vehicles, etc) ²	7	6	7	2
F	Population at Risk (PAR) ³	107	54	95	4

1. “At risk” is defined as a property in the dam breach flood zone and inundated by 0.5 m or greater

2. Based on assumption of 1 person per 10 km² within the area of the flood zone

3. PAR = (C x D)+E

To account for agricultural contractors and labourers from outside the district, as well as to take into account people on footpaths and people in cars during the hypothetical dam breach flood, a value of 1 person per 10 km² has been adopted. This value is in addition to those counted in the population per household. It should be noted that farmers live locally in dwellings within the flood zone are already counted in the value for population per household.

It was previously proposed that the two houses nearest to the eastern embankment will be relocated to a safe area out side the vulnerable area shown in the inundation maps. However as this relocation can not be confirmed at present, these properties have been included in the assessment described in the following sections.

5.2 Damage to Households and Infrastructure

The New South Wales Floodplain Development Manual (NSW, 2005) was developed to assist local councils in their management of the use and development of flood prone land and identifies a methodology to assess the flood risk to people and property. The manual provides categories based on the product of flood velocity and depth to identify damage to people and property. The manual has been used in previous dam break flood studies in New Zealand to assess the risk of property on the floodplain and this methodology is considered appropriate in this situation.

The manual (NSW, 2005) recognises the personal danger and physical property damage caused by a flood both in time and place across the floodplain. Flood flows can be swift and deep in some locations, whilst in other places they can be shallow and slow moving. Using laboratory testing with flood conditions that cause damage, hazard rating curves have been determined as shown in Figure 1 and summarised in Table 3.

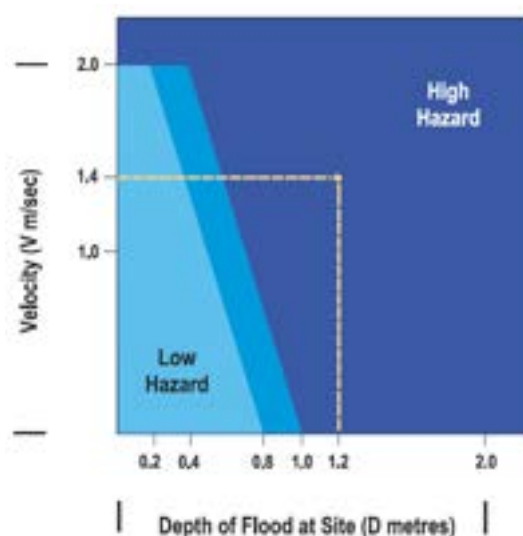


Figure 1 – Hazard rating curves (NSW, 2005)

Table 3 – Summary of hazard levels (after Jakob and Hungr, 2005)

Hazard Level	Colour	Description
High	Dark Blue	Persons are in danger both inside and outside their houses. Buildings can be destroyed.
Medium	Medium Blue	Persons are in danger outside their houses. Buildings may suffer damage and possible destruction depending on construction type.
Low	Light Blue	Danger to persons is low or non-existent. Buildings may suffer little damage, but flooding or sedimentation may affect interiors.

The three hazard zones specified in NSW (2005) have been calculated for the assumed Waimakariri Irrigation Ponds Dam Break analysis as shown in the Figures of Appendix B. Damage to households can be assessed from the NSW (2005) hazard definition maps provided in Appendix B. Houses located in the high flood hazard category are conservatively assumed to be destroyed (rendered inhabitable). Houses located in the medium hazard category are assumed to have some repairable damage, and houses located in the low flood hazard category are assumed to have minor damage. Table 3 summarises the houses surveyed that fall into the low, medium and high hazard zones shown on the Figures of Appendix B. ArcGIS software has been used to calculate the properties which fall in each flood zone.

There is no critical or major infrastructure (e.g. network power supply, wastewater treatment, hospitals, police, large industrial, commercial or community facilities) in the hypothetical dam breach flood zones. However there is likely to be significant damage to farm building, roads, irrigation canals, arable land and farm equipment for the four dam breach scenarios considered.

Table 4 – Damage to households summary

Parameter	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Households outside hazard zone	95	195	72	220
Households in low hazard zone	113	45	138	48
Households in medium hazard zone	22	13	23	1
Households in high hazard zone	40	17	37	1

5.3 Community Recovery Time

If the worst case scenario of breach of the eastern embankment is considered, then approximately 40 houses are in the high hazard flood zone and would be rendered inhabitable in the event of a dam breach flood. Reconstruction or re-location of more than 40 houses is expected to take some months. Roads, farmland and other properties affected by the dam breach flood are likely to also take some months for recovery.

5.4 Damage to Natural Environment

A hypothetical dam breach flood is likely to cause siltation and erosion in the flood zone, affecting the natural environment. Therefore areas of significant but recoverable damage is assumed.

Flood inundation maps provided in Appendix A show that the dam breach flood flows are received by the Waimakariri River. The maximum dam breach peak outflow is approximately 2500 m³/s. This is less than twice the mean annual flood in the Waimakariri River. Peak flow entering the Waimakariri River would be significantly less than the peak breach outflow due to routing effects in the overland flow before flow enters the river. Accordingly, a breach outflow would not cause significant flooding in the Waimakariri River downstream with either normal low flow or flood flow in the river.

5.5 Likely Loss of Life

The relationship between PAR and likely loss of life (LLOL) in a dam breach flood depends on many factors including:

- The proportion of the PAR that is within buildings, and the proportion that is in the open;
- The preparedness of the population in terms of emergency response;
- Whether an early warning system is in place;
- The vulnerability of the population (e.g. age, physical condition, dependants).

The manual "Interim Guide to Quantitative Risk Assessment for UK Reservoirs" (Brown & Gosden, 2004) provides a relationship between the LLOL, PAR and the flood hazard (product of velocity x depth). Applying this relationship to the houses surveyed within the dam breach flood zone, and utilising the hydraulics parameters (i.e. velocity and depth) from the dam breach flood modelling, yields the LLOL listed in Table 5.

Note that the estimation of LLOL is highly dependent on whether warning is given to householders at the time of dam breach. For the current analysis, the worst case where no warning is given has been assumed. Based on the data provided in Table 5, breach of the eastern embankment is the worst case scenario with a LLOL of approximately three people. This LLOL value is largely due to the properties located immediately downstream of the dam breach location.

Table 5 – Likely loss of life

Parameter	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Likely loss of life (LLOL)	2.9	0.6	0.8	0.1

6.0 Determination of Dam Potential Impact Classification

Dams are classified as either high, medium or low PIC, depending on the potential impact of the dam breach outflow. The NZSOLD (2000) and Building (Dam Safety) Regulations methods to determine PIC classification are different. Accordingly both methods have been used, as outlined below.

6.1 Building (Dam Safety) Regulations, 2008

The method for PIC using the Building (Dam Safety) Regulations are summarised in Tables 6 and 7. Based on the categories defined in these tables and the analysis provided in Section 4, the damage levels summarised in Table 8 have been assessed for the four modelled breach scenarios at the Waimakariri Irrigation Limited irrigation storage ponds.

Dam classification using the Building (Dam Safety) Regulations is either Low, Medium or High, depending on the categories listed in Table 7. For each modelled dam breach scenario, a PIC has been assessed in Table 9 based on the PAR listed in Table 2, and damage levels summarised in Table 8.

With reference to Table 9, a HIGH potential impact classification is assumed for eastern, northern and southern embankments of the Waimakariri Irrigation Limited storage ponds based on the Building (Dam Safety) Regulations 2008. The western embankment is assessed as having a MEDIUM potential impact classification.

Table 6 - Determination of Assessed Damage Level
Building (Dam Safety) Regulations, 2008: Schedule 1 Table 1

Damage Level	Specified categories				
	Residential houses ¹	Critical or major infrastructure ²	Natural environment	Community recovery time	
Catastrophic	More than 50 houses destroyed	Extensive and widespread destruction of and damage to several major infrastructure components	More than 1 year	Extensive and widespread damage	Many years
Major	4 to 49 houses destroyed and a number of houses damaged	Extensive destruction of and damage to more than 1 major infrastructure component	Up to 12 months	Heavy damage and costly restoration	Years
Moderate	1 to 3 houses destroyed and some damaged	Significant damage to at least 1 major infrastructure component	Up to 3 months	Significant but recoverable damage	Months
Minimal	Minor damage	Minor damage to major infrastructure components	Up to 1 week	Short-term damage	Days to weeks

Notes:

1. In relation to residential houses, destroyed means rendered inhabitable.

2. Includes:

- (a) lifelines (power supply, water supply, gas supply, transportations systems, wastewater treatment, telecommunications (network mains and nodes rather than local connections)); and
- (b) emergency facilities - (hospitals, police, fire services); and
- (c) large industrial, commercial, or community facilities, the loss of which would have a significant impact on the community; and
- (d) the dam if the service the dam provides is critical to the community and that service cannot be provided by alternative means.

3. Estimated time required to repair the damage sufficiently to return the critical or major infrastructure to normal operation.

Table 7 - Determination of Dam Classification
Building (Dam Safety) Regulations, 2008: Schedule 1 Table 2

Assessed damage level	Population at risk (PAR)			
	0	1 to 10	11 to 100	More than 100
Catastrophic	High potential impact	High	High	High
Major	Medium potential impact	Medium/High (see note 4)	High	High
Moderate	Low potential impact	Low/Medium/High (see notes 3, and 4)	Medium/High (see note 4)	Medium/High (see notes 2 and 4)
Minimal	Low potential impact	Low/Medium/High (see notes 1, 3, and 4)	Low/Medium/High (see notes 1, 3, and 4)	Low/Medium/High (see notes 1, 3, and 4)

Notes

- 1. With a PAR of 5 or more people, it is unlikely that the potential impact will be low.
- 2. With a PAR of more than 100 people, it is unlikely that the potential impact will be medium.
- 3. Use a medium classification if it is highly likely that a life will be lost.
- 4. Use a high classification if it is highly likely that 2 or more lives will be lost.

Table 8 – Assessed damage levels for modelled breach scenarios

Category	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Residential houses	4 to 49 houses destroyed and a number of houses damaged	4 to 49 houses destroyed and a number of houses damaged	4 to 49 houses destroyed and a number of houses damaged	1 to 3 houses destroyed and some damaged
Critical or major infrastructure	Minor damage to major infrastructure components	Minor damage to major infrastructure components	Minor damage to major infrastructure components	Minor damage to major infrastructure components
Recovery time for major infrastructure	Up to 1 week	Up to 1 week	Up to 1 week	Up to 1 week
Natural Environment	Significant but recoverable damage	Significant but recoverable damage	Significant but recoverable damage	Significant but recoverable damage
Community Recovery Time	Months	Months	Months	Months
Damage Level	Major	Major	Major	Moderate

Table 9 – Assessed PIC for modelled breach scenarios (Building Dam Safety Regulations)

Category	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Assessed Damage Level	Major	Major	Major	Moderate
PAR	More than 100	11 to 100	11 to 100	1 to 10
PIC	HIGH	HIGH	HIGH	MEDIUM

6.2 NZ Society of Large Dams (2000) Guidelines

Based on NZSOLD (2000) guidelines for PIC of dams, which are summarised in Table 10, the consequences of dam breach summarised in Table 11 have been assessed based on the reasoning outlined in Section 4. The consequences of breach to life are based on the LLOL estimates described in Section 4.5. For the eastern breach more than one fatality is likely, for the other breach locations loss of life is possible but not expected.

With reference to Table 11, a HIGH potential impact classification is assessed for the eastern, embankment of the Waimakariri Irrigation Limited storage ponds based on the NZSOLD (2000) guidelines. The southern and northern embankments are classified as MEDIUM and the western embankment as LOW.

Table 10 - Potential Impact Categories for Dams in Terms of Failure Consequences
(NZSOLD, 2000)

Potential Impact Category	Potential Incremental Consequences of Failure	
	Life	Socio-economic, Financial, & Environmental
High	Fatalities	Catastrophic damages
Medium	A few fatalities are possible	Major damages
Low	No fatalities expected	Moderate damages
Very Low	No fatalities	Minimal damages beyond owner's Property

Table 11 - Assessed PIC for modelled breach scenarios (NZSOLD Guidelines)

Category	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Consequences of Failure to Life	Fatalities	A few fatalities are possible	A few fatalities are possible	No fatalities expected
Consequences of Socio-economic, Financial & Environmental	Major damages	Major damages	Major damages	Moderate damages
PIC	HIGH	MEDIUM	MEDIUM	LOW

7.0 PIC Adopted for Design, Construction and Operation

7.1 Assessment

Presently in New Zealand there are two methods for assessing the PIC for large dams, as set out in:

1. The NZSOLD Dam Safety Guidelines; and
2. The Building (Dam Safety) Regulations.

The Building (Dam Safety) Regulations are scheduled to come into force in 2014 and the NZSOLD Guidelines (2000) are in the process of being revised to align with the Building Regulations with respect to PIC assessment.

The NZSOLD Guidelines set out the standards for design construction and operation of large dams such as the Waimakariri Irrigation Storage ponds and this in turn would be determined by the PIC assessed in accordance with the Guidelines. The NZSOLD Guidelines set out the design, construction and operation standards for large dams in New Zealand. The Building (Dam Safety) Regulations sets out dam registration, surveillance and dam safety obligations of large dam owners.

In anticipation of revision of the NZSOLD Guidelines and the increase in building of homes in the Waimakariri Irrigation Storage Ponds inundation area, consequent on the recent earthquakes in Christchurch, we consider that the Potential Impact Classifications determined in accordance with the Building (Dam Safety) Regulations should be adopted for determining the standards for design and construction of the Waimakariri Irrigation ponds set out in the NZSOLD Guidelines.

7.2 Adoption of Discrete Sections of Embankment

The PIC is consequence driven and the consequences relate to breach peak outflow, volume and development in the area inundated. This is different for the west embankment from the other, north, east and south embankments particularly with respect to breach peak outflow and volume. This is because only Pond 1, which has less volume than Pond 2, is breached in that scenario. In the other scenarios, Pond 1 breaches into Pond 2 in turn causing Pond 2 to breach, providing breach outflow from the contents of both ponds.

A fundamental principle proposed for Waimakariri Irrigation Storage ponds is that different Potential Impact Classifications can be applied to discrete lengths of the pond embankment, because the downstream consequences of breach vary depending on the section of the embankment breached. It follows that breach of the west embankment would have less

consequence than breach of any of the other embankments. Accordingly, we submit that for the proposed Waimakariri Irrigation Limited storage ponds, discrete sections of the embankment can be assigned a different PIC as is done with large canal embankments. This then results in different standards for design and construction of discrete sections of the pond embankments, as summarised in Figure 2.



Figure 2 – Summary of PIC assessment for embankments of proposed Waimakariri Irrigation Limited storage ponds

8.0 Conclusions

8.1 Summary

This report has provided an assessment for Potential Impact Classification of the proposed Waimakariri Irrigation Scheme irrigation storage ponds. This assessment supersedes a previous assessment carried out in February 2012, as the current study is based on a site assessment and survey of houses within the areas of dam breach flood inundation.

Dam breach flood inundation was calculated with a two dimensional computational hydraulic model. Four dam breach locations were modelled, each located for greatest impact on nearby houses. The four breach locations are labelled as “East”, “South”, “North” and “West” and the resulting flood inundation from these locations are provided as Figures 2, 3, 4 and 5 respectively in Appendix A

Both the Building (Dam Safety) Regulations (2008) and the NZSOLD Dam Safety Guidelines (2000) were used to determine the PIC for the proposed storage ponds. Table 12 summarises the PIC categories assessed for each of the four breach scenarios and method of assessment. Due to the location of the breach outflow and volume of water released, the PIC varies with breach location.

Table 12 - Assessed PIC for modelled breach scenarios

Regulation/Guideline	Eastern Breach	Southern Breach	Northern Breach	Western Breach
Building (Dam Safety) Regulations (2008)	HIGH	HIGH	HIGH	MEDIUM
NZSOLD Dam Safety Guidelines (2000)	HIGH	MEDIUM	MEDIUM	LOW

8.2 Recommendations

We recommend that:

1. Design, construction and operation standards of the proposed Waimakariri Irrigation Limited storage ponds are based on a PIC assessed in accordance with the Building (Dam Safety) Regulations method set in accordance with NZSOLD Guidelines.
2. That the embankments are assessed with a PIC determined by the consequence of a breach, which for the western embankment is a MEDIUM PIC and for all other embankments a HIGH PIC, as summarised in Figure 2.

9.0 References

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APPENDIX A - Figures

Figure 1 – Layout map of proposed Waimakariri Irrigation Limited Storage Ponds

Figure 2 – Flood inundation map for breach of the eastern embankment

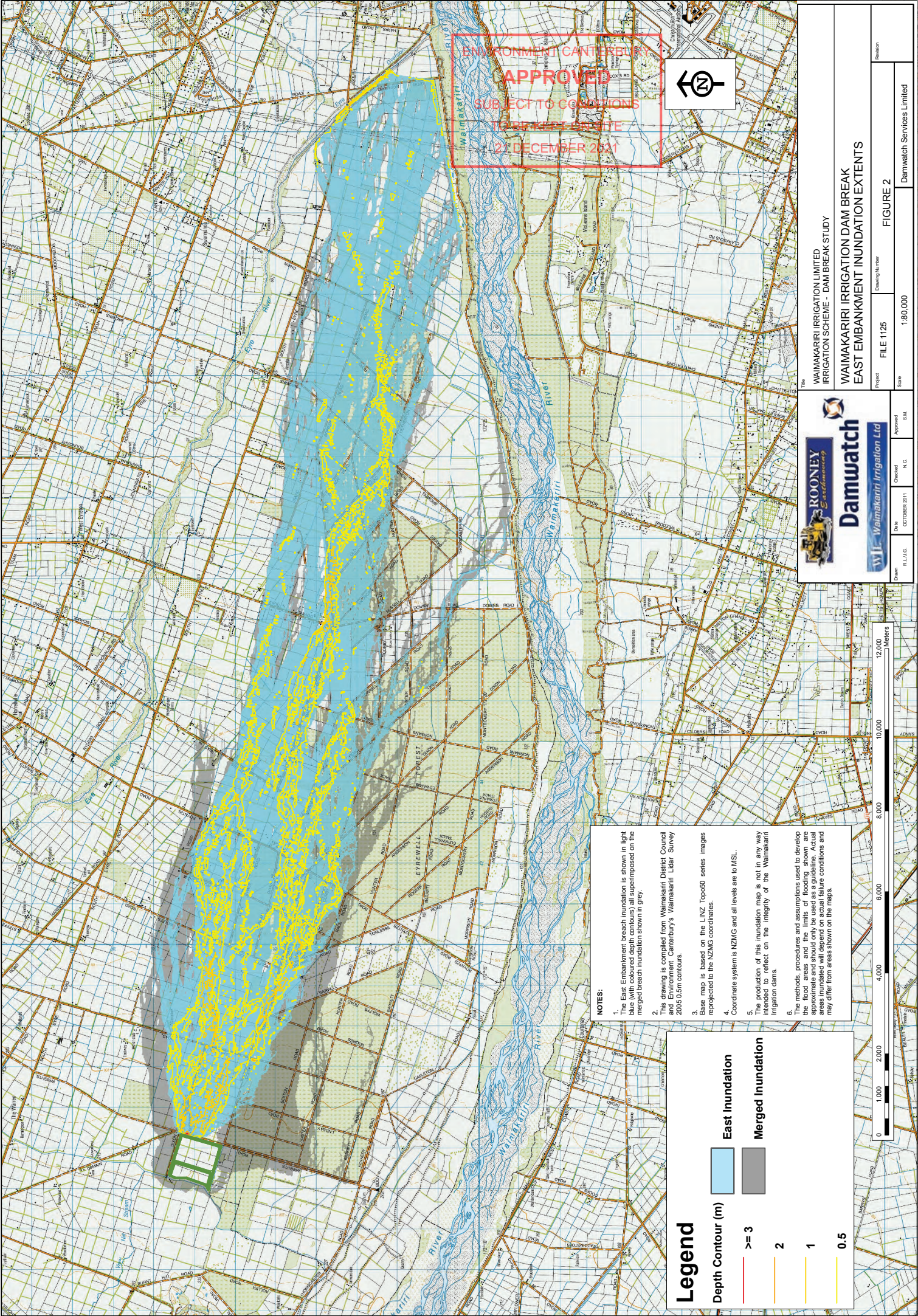
Figure 3 – Flood inundation map for breach of the southern embankment

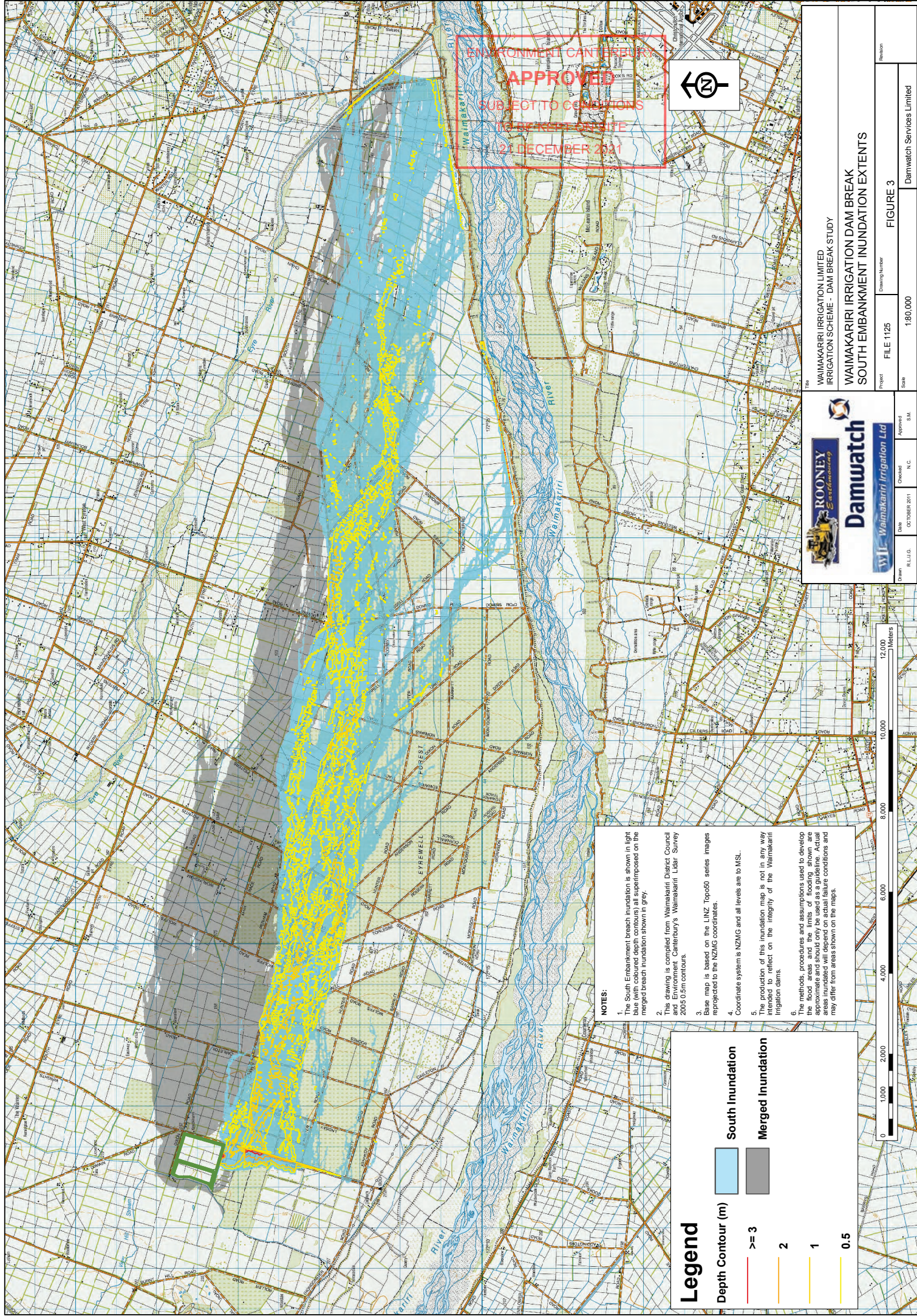
Figure 4 – Flood inundation map for breach of the northern embankment

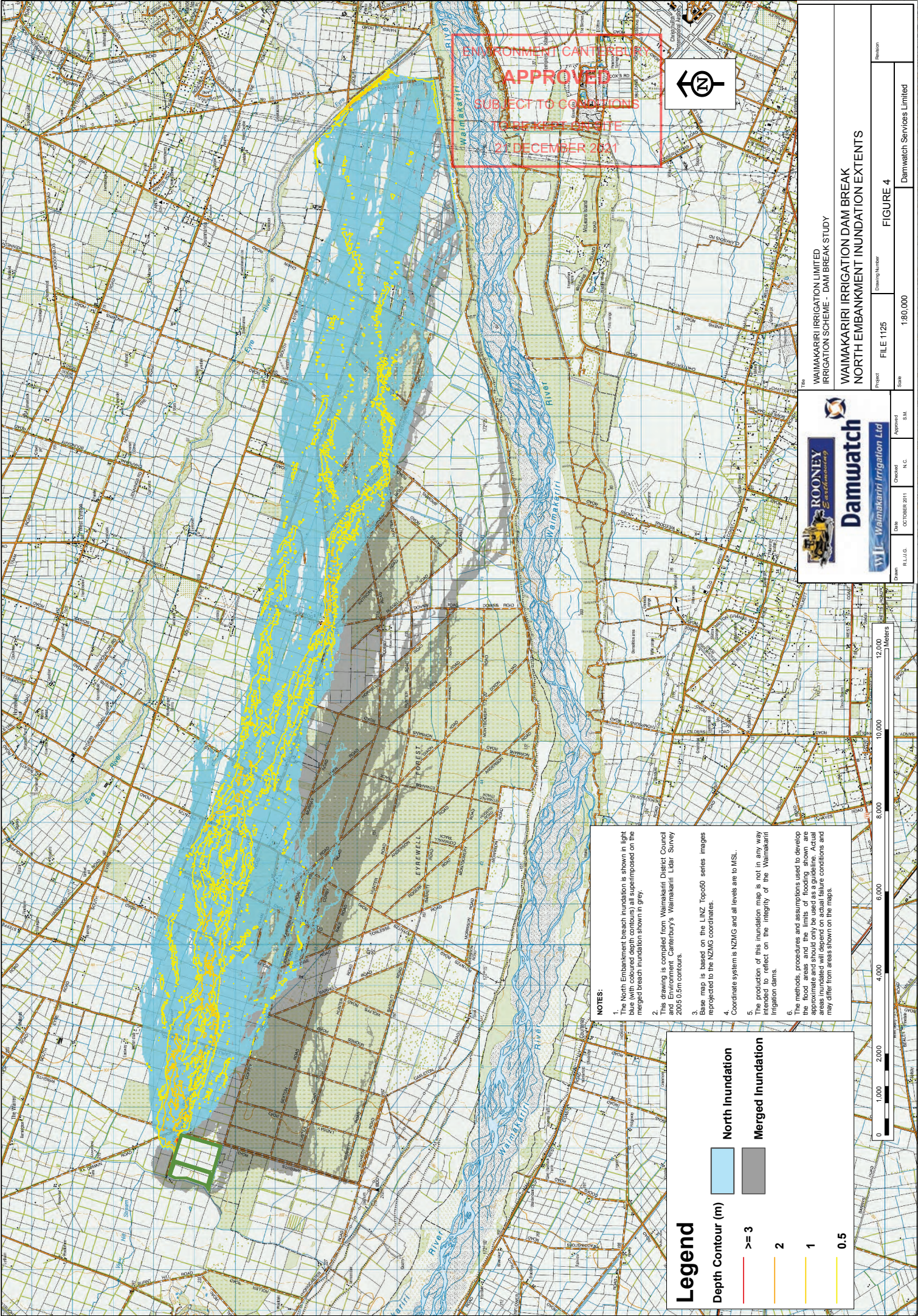
Figure 5 – Flood inundation map for breach of the western embankment

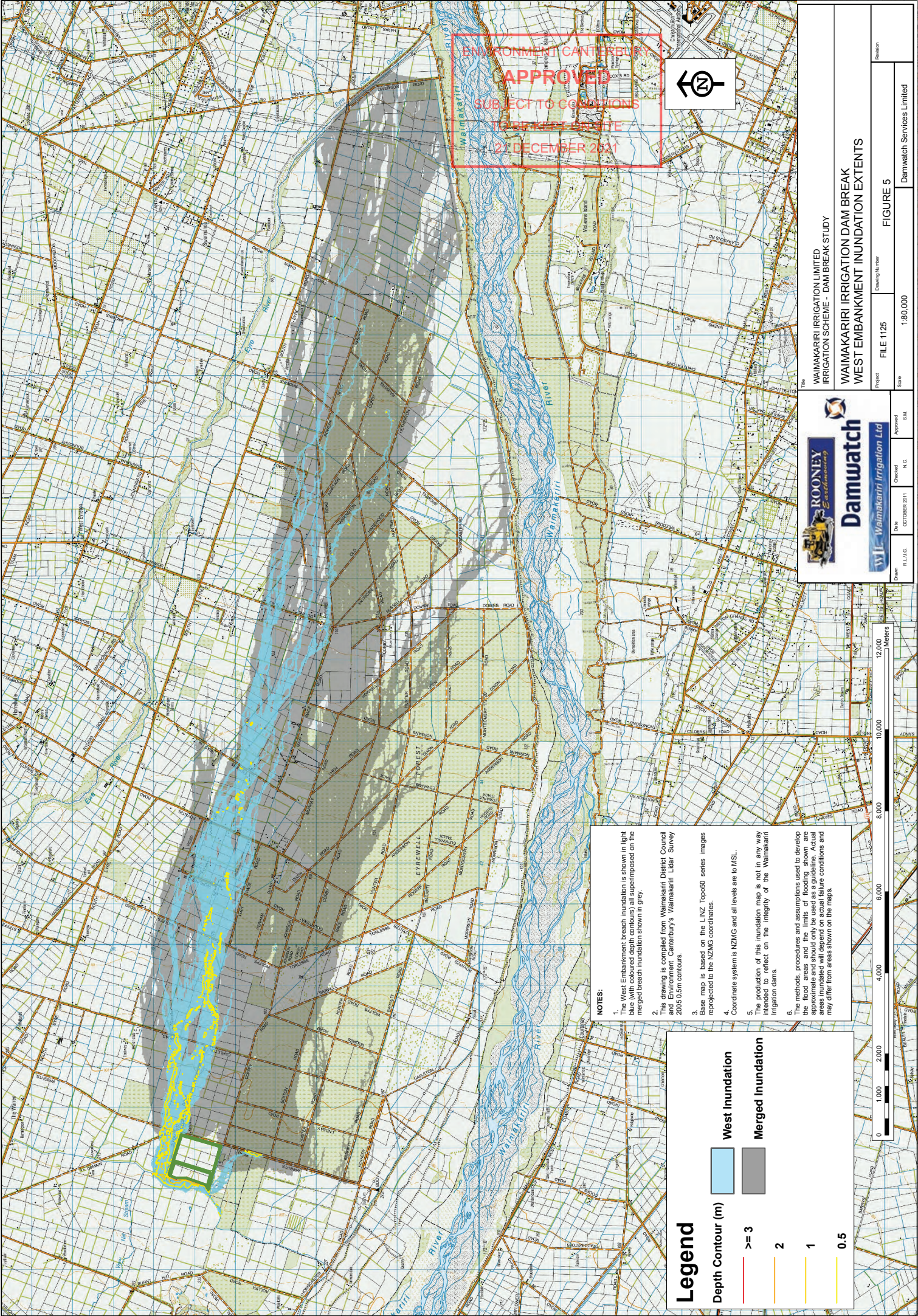


Figure 1









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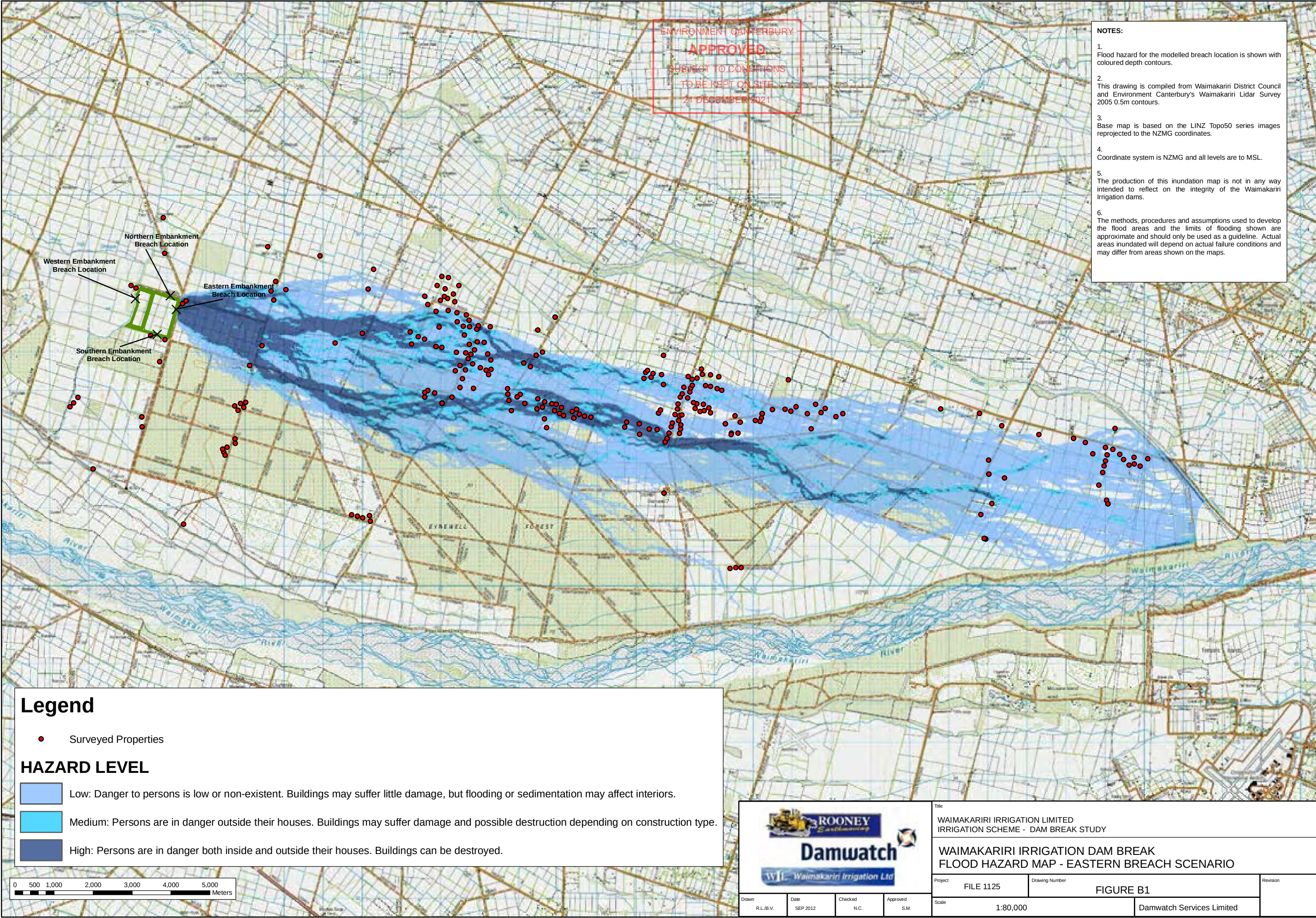
APPENDIX B – Flood Hazard Maps

Figure B1 – Flood hazard map for breach of the eastern embankment

Figure B2 – Flood hazard map for breach of the southern embankment

Figure B3 – Flood hazard map for breach of the northern embankment

Figure B4 – Flood hazard map for breach of the western embankment



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- NOTES:**
1. Flood hazard for the modelled breach location is shown with coloured depth contours.
 2. This drawing is compiled from Waimakariri District Council and Environment Canterbury's Waimakariri Lidar Survey 2005 0.5m contours.
 3. Base map is based on the LINZ Topo50 series images reprojected to the NZMG coordinates.
 4. Coordinate system is NZMG and all levels are to MSL.
 5. The production of this inundation map is not in any way intended to reflect on the integrity of the Waimakariri Irrigation dams.
 6. The methods, procedures and assumptions used to develop the flood areas and the limits of flooding shown are approximate and should only be used as a guideline. Actual areas inundated will depend on actual failure conditions and may differ from areas shown on the maps.

Legend

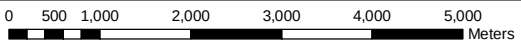
● Surveyed Properties

HAZARD LEVEL

Low: Danger to persons is low or non-existent. Buildings may suffer little damage, but flooding or sedimentation may affect interiors.

Medium: Persons are in danger outside their houses. Buildings may suffer damage and possible destruction depending on construction type.

High: Persons are in danger both inside and outside their houses. Buildings can be destroyed.



 Damwatch WIL Waimakariri Irrigation Ltd 				Title WAIMAKARIRI IRRIGATION LIMITED IRRIGATION SCHEME - DAM BREAK STUDY			
				WAIMAKARIRI IRRIGATION DAM BREAK FLOOD HAZARD MAP - EASTERN BREACH SCENARIO			
Project FILE 1125		Drawing Number FIGURE B1			Revision		
Scale 1:80,000		Damwatch Services Limited					
Drawn R.L./B.V.	Date SEP 2012	Checked N.C.	Approved S.M.				

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Northern Embankment
Breach Location

Western Embankment
Breach Location

Eastern Embankment
Breach Location

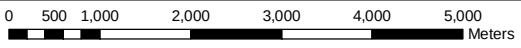
Southern Embankment
Breach Location

Legend

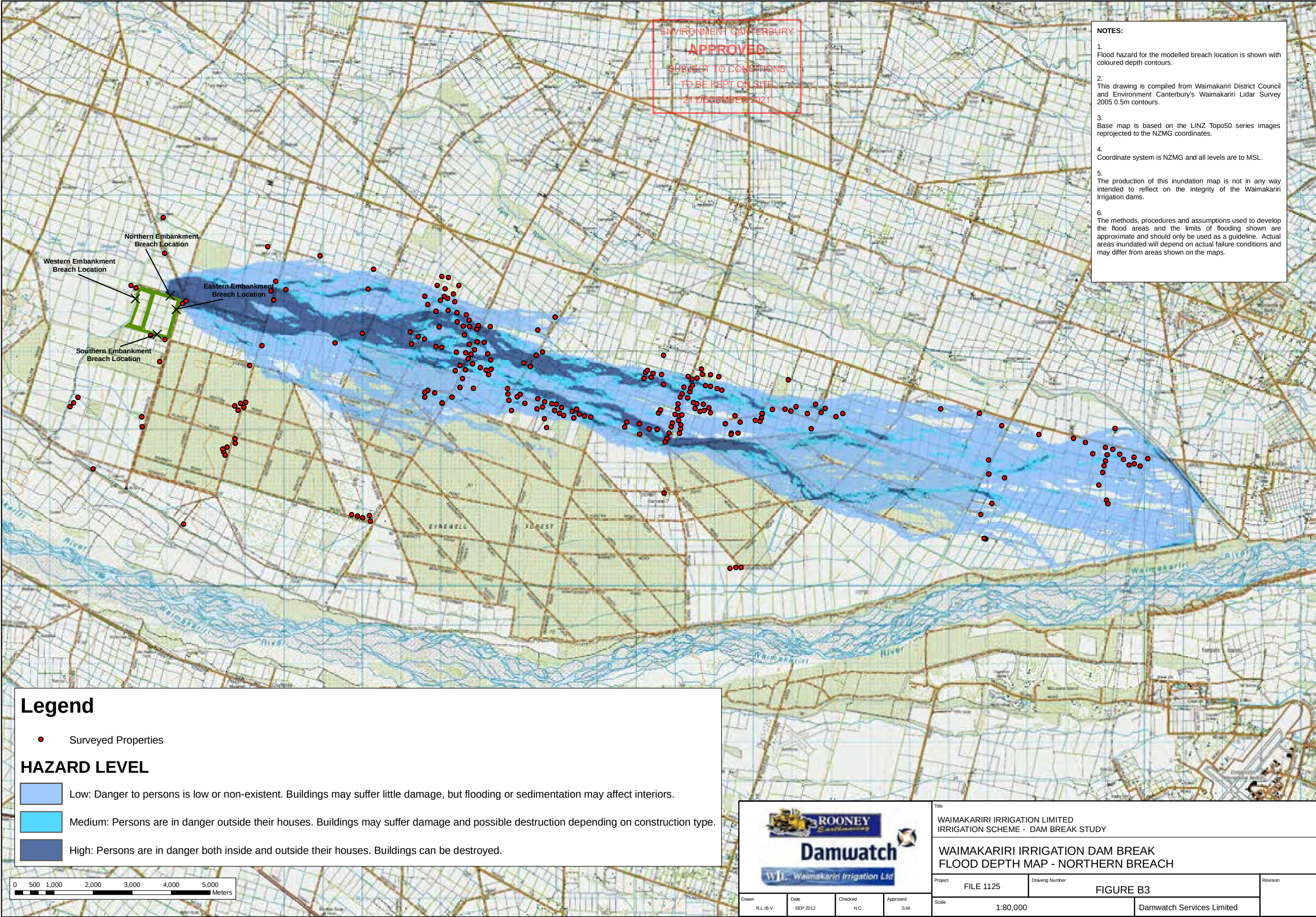
● Surveyed Properties

HAZARD LEVEL

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-  High: Persons are in danger both inside and outside their houses. Buildings can be destroyed.



				Title	
				WAIMAKARIRI IRRIGATION LIMITED IRRIGATION SCHEME - DAM BREAK STUDY	
				WAIMAKARIRI IRRIGATION DAM BREAK FLOOD DEPTH MAP - SOUTHERN BREACH SCENARIO	
Project		Drawing Number		Revision	
FILE 1125		FIGURE B2			
Drawn	Date	Checked	Approved	Scale	
R.L./B.V.	SEP 2012	N.C.	S.M.	1:80,000	Damwatch Services Limited



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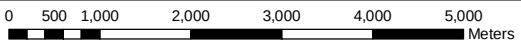
- NOTES:**
1. Flood hazard for the modelled breach location is shown with coloured depth contours.
 2. This drawing is compiled from Waimakariri District Council and Environment Canterbury's Waimakariri Lidar Survey 2005 0.5m contours.
 3. Base map is based on the LINZ Topo50 series images reprojected to the NZMG coordinates.
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 6. The methods, procedures and assumptions used to develop the flood areas and the limits of flooding shown are approximate and should only be used as a guideline. Actual areas inundated will depend on actual failure conditions and may differ from areas shown on the maps.

Legend

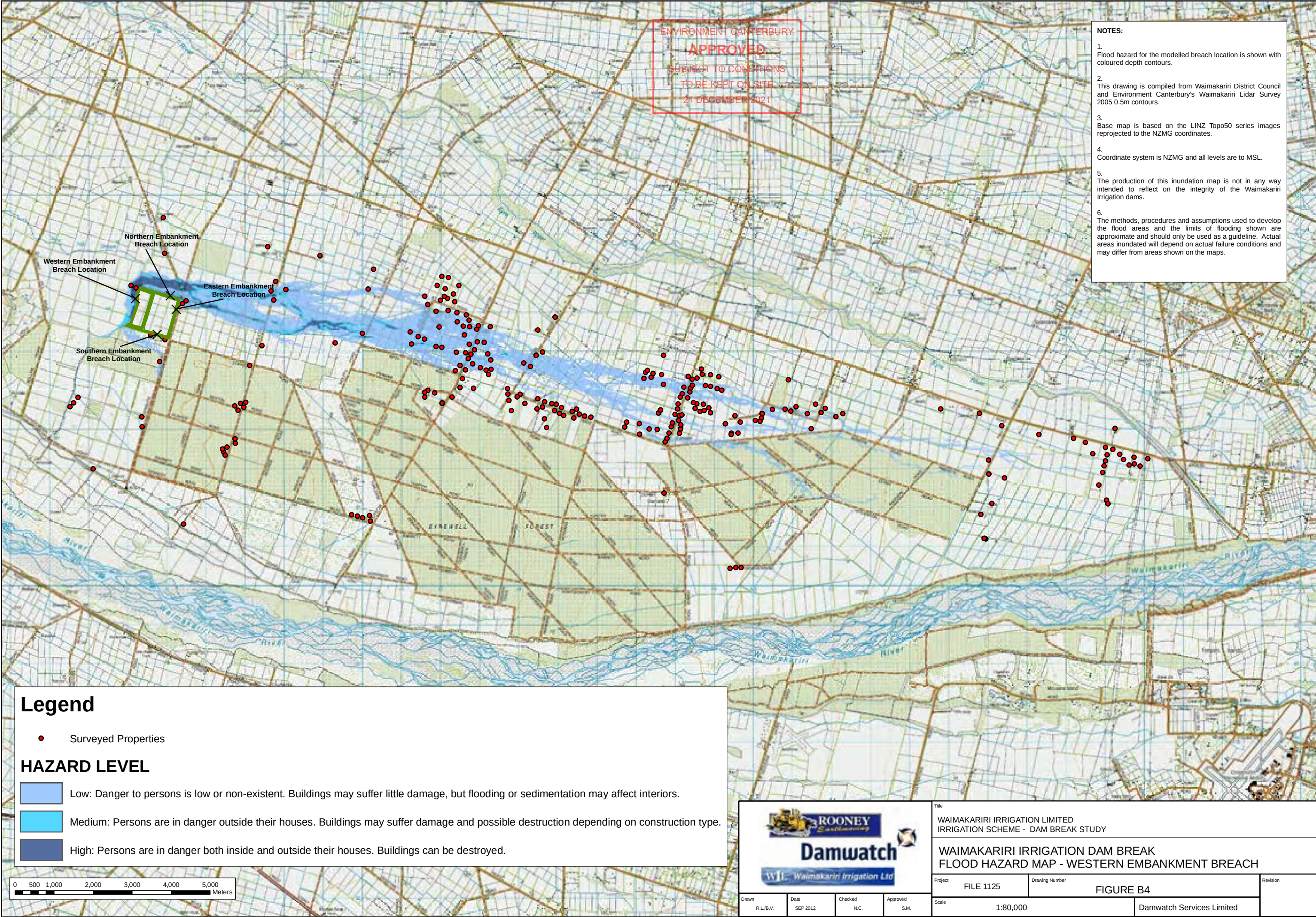
• Surveyed Properties

HAZARD LEVEL

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  				Title		
				WAIMAKARIRI IRRIGATION LIMITED IRRIGATION SCHEME - DAM BREAK STUDY		
				WAIMAKARIRI IRRIGATION DAM BREAK FLOOD DEPTH MAP - NORTHERN BREACH		
Project		Drawing Number		Revision		
FILE 1125		FIGURE B3				
Drawn	Date	Checked	Approved	Scale	Damwatch Services Limited	
R.L./B.V.	SEP 2012	N.C.	S.M.	1:80,000		



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APPENDIX C - Waimakariri Irrigation Ponds Dam Breach Analysis



Our Ref: 44800302

Date: 28 October 2011

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Albany 0752, Auckland
New Zealand

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Web: www.dhigroup.com
Email: info.nz@dhigroup.com

Nigel Connell
PO Box 1549, Wellington 6140
Level 5, Creo House, 57-59 Courtenay Place

Dear Mr Connell

Waimakariri Irrigation Ponds Dambreak Analysis

As discussed this morning by phone, we have now completed a letter-style report on this project to accompany the result files we sent you earlier this week. The report is appended to this letter. It is intended to explain to you what modelling we have done and what the result files contain, but deliberately omits some of the more technical modelling details.

If you have any questions about the work, the result files or the report, please do contact either the undersigned or Colin Roberts (09 912 9663).

We have enjoyed the particular challenges of this project and look forward to working with Damwatch in the future.

Yours sincerely
DHI Water and Environment Ltd

A handwritten signature in blue ink, appearing to read 'G Macky', is written over a light blue horizontal line.

Graham Macky
Principal Engineer

Personal Email: ghm@dhigroup.com

Waimakariri Irrigation Ponds Dam Breach Analysis

Introduction

This report describes a dambreak analysis carried out by DHI for Damwatch for the Waimakariri Irrigation Ponds, which are a proposed two-pond dam between Oxford and the Waimakariri River. The proposed ponds will occupy 100 hectares and hold 8.4 million cubic metres, the upper pond (Pond 1) holding 2 million cubic metres and the lower pond (Pond 2) 6.37 million cubic metres.

The brief from Damwatch was to consider four dambreak scenarios:

1. A breach of the west (uphill) side of Pond 1 (the upper pond), draining Pond 1 only;
2. A breach of the internal dam between Pond 1 and Pond 2, followed by an over-topping failure of Pond 2 on its northern side;
3. A breach of the internal dam between Pond 1 and Pond 2, followed by an over-topping failure of Pond 2 on its eastern (downhill) side; and
4. A breach of the internal dam between Pond 1 and Pond 2, followed by an over-topping failure of Pond 2 on its southern side.

In all scenarios the breach was to occur at the worst possible location with respect to adjacent homes.

Raster files of the results are to be provided for each scenario, giving maximum values of flooded depth, velocity, and flooding hazard. The composite maxima of depth, velocity and hazard are also to be provided in raster format.

Input data provided by Damwatch

Terrain and structures

Damwatch supplied DHI with the following data:

- Ground contours at 0.5m intervals for the area downhill from the proposed dam to the Waimakariri River and the Eyre River /Eyre Diversion.
- Concept plans produced by Rooney Earthmoving Ltd ("Rooneys") for the proposed dam
- Surveyed spot ground levels from Rooneys for the dam "footprint" and for an area uphill from the proposed dam.
- A spreadsheet output of calculated dam breaches, giving the final breach dimensions, the time to reach these dimensions, and estimated peak outflow.
- Concept plans for a proposed canal ("the Mainpower Canal") leading south from the proposed dam.

All these data were used to form the terrain grid used in the 2-dimensional flow model. In addition, an area immediately uphill from the dam, for which no level data were available, was represented by extrapolating the contour information.

During this process, when checking the consistency of the different datasets, it was noticed that the spot height data from Rooneys were significantly lower than the contours (between 40 and 80 cm).

DHI and Damwatch therefore agreed to add 60cm to the spot heights. Furthermore, as Rooney's spot levels are consistent with the levels in their concept drawings for the dam, it was also agreed to raise the levels given in the drawings by 60cm.

Dambreak details

Damwatch provided spreadsheet output of calculated details of the breaches to be modelled in the different scenarios. In all cases, trapezoidal breach cross-sections were to be assumed, with the base at pre-existing ground level. The relevant data from this spreadsheet are reproduced below.

	Final breach width at base (m)	Slope of breach side walls	Nominal depth of breach (m)	Time for final breach to form (hours)	Calculated peak outflow (m ³ /s)
Pond 1 breach on western side	41.8	1:1	9	0.63	1005
Internal dam between Pond 1 and Pond 2	59.0	1:1	6.9	0.59	840
Pond 2 breach on any of three sides	86.8	1:1	11	0.93	2054

Table 1: Dam breach calculation results from Damwatch

Methodology

Software and model setup

2-dimensional overland flow model

The dam bunds, the land likely to be flooded, and the bunds of the proposed Mainpower Canal were all represented in a 2-dimensional flow model in DHI's MIKE 21.

A rectangular grid with a cell size of 10m x 10m was chosen. This grid size allows reasonable computer run times and also provides a level of resolution consistent with that provided by the ground contour lines (which lie about 50m apart).

Figure 1 shows the model area, which is bordered on the south by the Waimakariri River and on the north by the Eyre River.

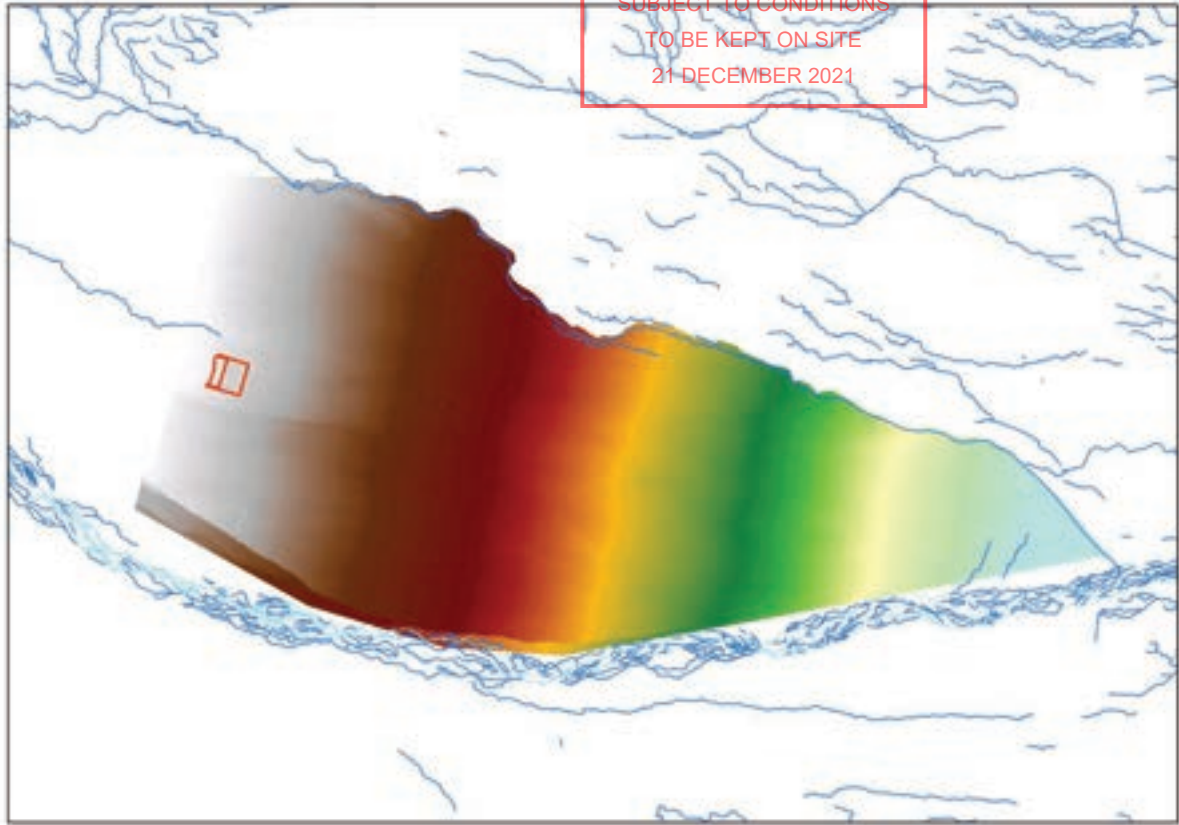


Figure 1: Model area for the 2-dimensional grid, also showing the dam location

Dam breach module

The dam breaches were represented in DHI's 1-dimensional open channel model MIKE 11, which includes a Dam Break module that computes flows through a breach whose growth can be specified by a time series of breach dimensions. The 1-dimensional model was linked to the 2-dimensional flow model using DHI's coupling software MIKE FLOOD.

The four breach scenarios specified by Damwatch (and listed in the Introduction above) were modelled using the final breach dimensions and development time specified in Table 1. The breach width and invert level were in all cases assumed to progress linearly with time, from zero and the berm level respectively. For the three scenarios in which Pond 1 spilled into Pond 2, the subsequent breach of Pond 2 was initiated by its water level reaching a level of 224.25m (5cm from the berm).

Model Results

Digital modelling result files have been forwarded separately to Damwatch, and include:

- For each scenario, raster files of the maximum values over the event of water levels, velocities and flooding hazard for the flooded areas, for each scenario.
- Raster files of the maximum values over all four scenarios of water levels, velocities and flooding hazard.
- (For insight) animations of each dam break scenario, with separate files showing an overall view and the vicinity of the dam.

The results show overwhelming flood depths and velocities within 0.5 km of the breach, but further away flood depths are typically around 1m. Water flows downhill to the confluence of the Waimakariri River and the Eyre Diversion, with most water being contained within a width of about 2 km.

For illustration, images of the flooding extent from breaches to the north and south sides of the dam are appended to this brief report.

Model limitation

Caution is needed in applying the modelled results to detailed examination of small-scale flooding effects. There are three reasons for this caution:

- Buildings were not modelled;
- The resolution of the contour data and the 10m grid size may not pick up minor terrain features; and
- Spatial variations in flow resistance have not been considered.

Validation and Sensitivity Checks

The output datasets have been examined to look for any inconsistencies or errors. The flow conditions and water levels predicted appear reasonable and free of numerical instabilities.

Breach flow volume and rate

As a simple check, the modelled volume of water released by the dambreak breach, and the modelled peak breach flow, are compared in Table 2 with the relevant impounded volume and the peak flow predicted in Table 1 above.

	Modelled		Values for comparison	
	Total volume (m ³)	Maximum Flow Rate (m ³ /s)	Maximum possible volume (m ³)	Maximum Flow Rate from Table 1 (m ³ /s)
East breach	8,238,920	2493	8,370,000 (Pond 1 + Pond 2)	2053
North breach	7,802,580	2173	8,370,000 (Pond 1 + Pond 2)	2053
South breach	7,305,730	2283	8,370,000 (Pond 1 + Pond 2)	2053
West breach	1,380,000	560	2,000,000 (Pond 1)	840

Table 2: Validation checks of modelled dam breach flows

There is satisfactory volume agreement for the east side breach, which is the only one where all of the impounded water is expected to flow through the breach.

In all the other cases, the lesser volume passed reflects the lie of the land, as the assumed breach invert is not low enough to release all the impounded water. The western breach to Pond 1 in particular leaves 450,000 cubic metres trapped in Pond 1. These volumes therefore also appear satisfactory.

The peak breach flow rates can also be regarded as a reasonable match with the prior predictions of Table 1.

Sensitivity Test: Flow Resistance

For an indication of how robust the results were with varying model input assumptions, a sensitivity test was undertaken by rerunning the south breach with a lower value of Manning's n , 0.025 in place of 0.03.

Within 3 km of the dam, this change raised peak velocities by up to 0.5 m/s, and lowered peak depths by up to 0.15 m, and there were similar but lesser changes further downstream. There were only very limited changes to the extent of flooding, and to the calculated flooding hazard (it being based on the product of depth and velocity).

Although this single test does not address flow resistance that varies spatially, it provides some degree of robustness to the predictions, especially given the difficulty in accurately estimating a suitable flow resistance value under such flow conditions.

Possible effect of Infiltration

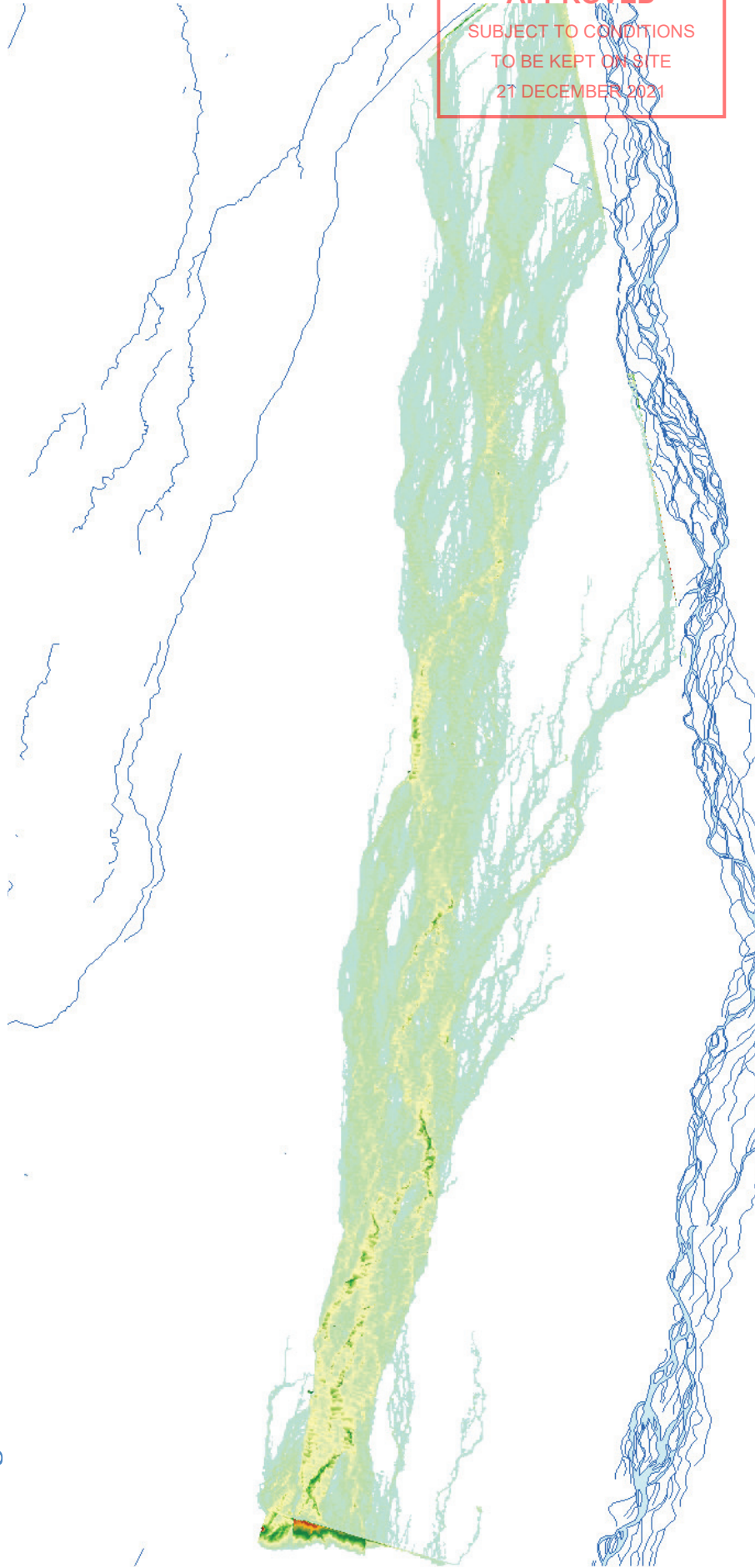
A further model run was carried out to see in broad terms whether infiltration to ground could significantly reduce the severity of flooding. In this run an infiltration rate of 20mm/hour was applied, constant in time and space. The true infiltration rate is not known, but the outwash gravels with thin soils are likely to have quite high infiltration rates.

Significant reductions in the extent and depth of flooding were largely confined to the lower plain more than 15 km from the dam. Here, peak depths were lowered by about 0.17m when this infiltration was accounted for.

Conclusions

This model study has provided computed flooding extent, depths and velocities as they vary in time and space during a dambreak event at the Waimakariri Irrigation Ponds. We consider these results suitable for defining the areas at risk from a dambreak and the level of hazard that those areas face.

Flooding extent for breach on south side



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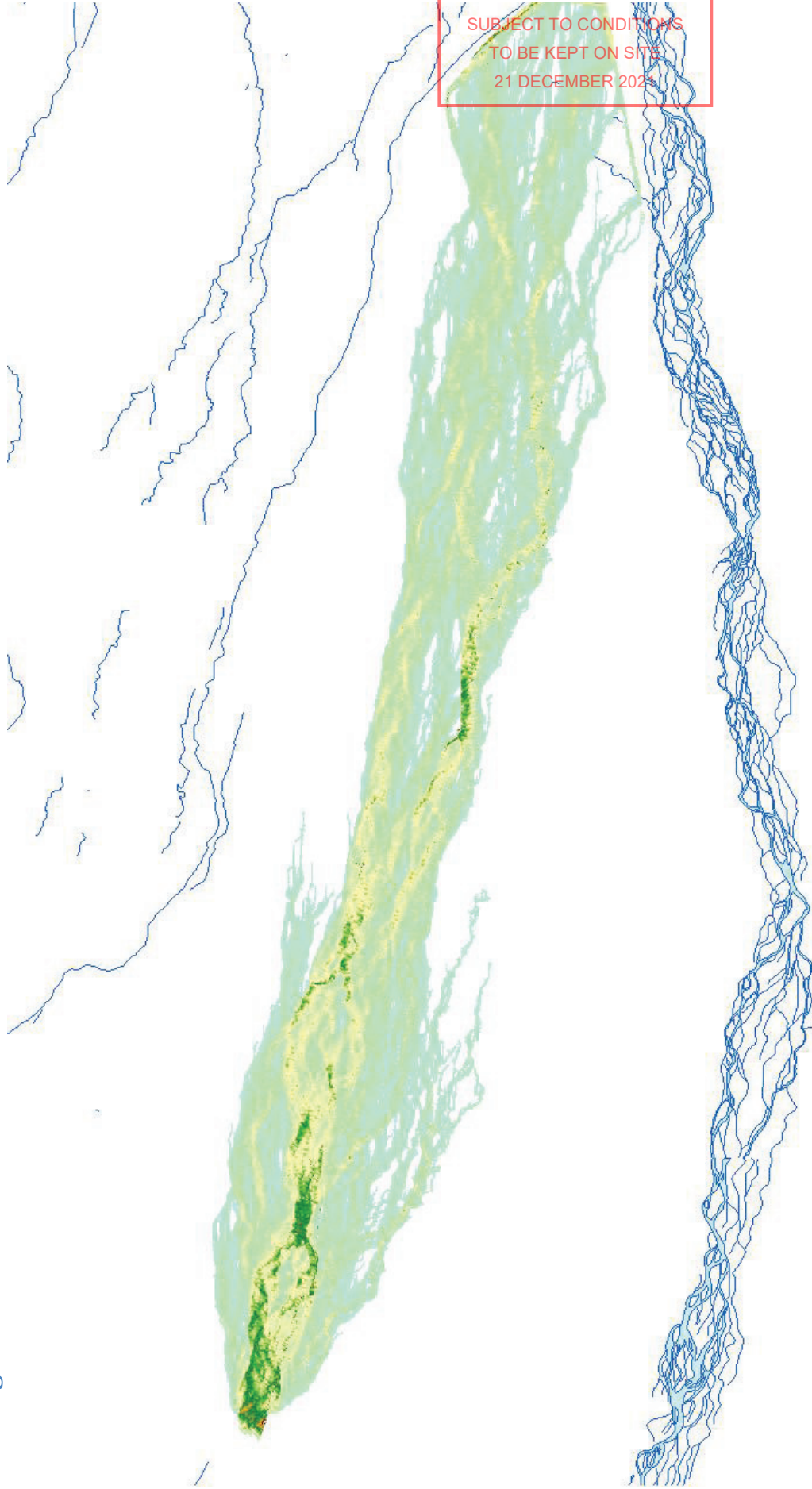
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Flooding extent for breach on north side



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Detail, extent of flooding from north-side breach (also showing local roads)

