[redacted]

From: Richard Dun [mailto:Richard.Dun@canalrivertrust.org.uk]
Sent: 09 December 2015 12:48
To: Steven Healey
Cc: Joy Gill
Subject: Historical Canal Breaches

Dear Steven

I understand that you spoke to my colleague Joy Gill with respect to canal breaches and wanted a little generic information and specifically with respect to the Leeds and Liverpool Canal.

In terms of canals generally we typically have 1-2 breaches a year across the entire country (>2000km of waterway). For your information, I attach a paper I wrote on canal breaches a couple of years ago. This provides a little more background, particularly in the first couple of sections. The paper refers to a database we maintain on historical canal breaches (records their location, waterway name, cause of failure, damages induced etc). I have interrogated the database for the Leeds and Liverpool Canal and note there are 33 breaches recorded since the canals construction. However, this record will inevitably be incomplete as early records are sparse (the earliest breach we have recorded on the Leeds and Liverpool Canal being 1888).

I trust the above is of interest to you, however, should you require further information please do not hesitate to contact me,

Yours sincerely

Richard

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For more information about the water management of our canals please visit our website https://canalrivertrust.org.uk/about-us/our-work/water-management and read our Water resources strategy: putting the water into waterways.

Water Management

Canal breach risk assessment for improved asset management
Dun and Wicks

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Canal breach risk assessment for improved asset management

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Advances in inundation modelling software, computer hardware and national data sets mean that it is now practical to use full solutions of the two-dimensional (2D) shallow water equations (SWE) to undertake national-scale modelling of breach inundation. Such modelling enables much improved asset management activities, which lead to reduced risk to life, lower risk of damage to properties and a much better targeting of investment by asset owners. This paper describes how a 2D SWE inundation modelling system was designed and applied to the UK Canal and River Trust canal system as part of a quantitative high-level risk assessment framework. The framework includes a new approach for estimating breach probability and hydrographs in the canal system for potential embankment and culvert failures. An innovative automated model build-and-run process using Isis 2D software was applied to model inundation in urban areas. Predicted likely loss of life and property damage outputs were used to generate a risk chart to prioritise asset inspection and maintenance.

1. Introduction

Structural breaches have, unfortunately, been a relatively common historical occurrence along Britain's inland waterways. They potentially present a significant area of risk to the UK Canal & River Trust (CRT) business (British Waterways, 2012), (see Figure 1).

Since 2004, CRT (formerly British Waterways) has been compiling a national breach archive (NBA) of information relating to known historical failures (as of January 2013 the NBA contained records of 380 navigation breaches). CRT typically experiences four or five breaches per annum (Table 1) at an average annual cost of approximately £1·1 million (British Waterways, 2012), although there have been no known injuries resulting from these failures.

Culvert and embankment failures account for at least 67% of the total breaches recorded (Figure 2). The low incidence of overtopping failures is in contrast to those associated with historical failures at reservoir dams (Charles *et al.*, 2011). The remaining failures are related to third-party acts (14%), aqueducts (1%), locks, sluices or weir failures (12%), or their cause is unknown (5%).

With increasing pressures on resources it is important that CRT manages this breach risk efficiently. CRT has developed a robust asset inspection system along with a central and accessible database. This, coupled with the development of an archive of historical breach information, improved understanding of breach mechanisms and advances in hydraulic and risk modelling have enabled a national risk assessment methodology for breach risk to be developed. This paper describes this approach, which will assist in focusing mitigation measures at the highest risk sites. Technical developments from this study are discussed in some detail.

2. Effectiveness of the existing CRT asset management system

To prioritise resources to the higher risk sites, CRT has developed a hierarchical risk-based asset inspection process (AIP) that combines information on probability of failure with estimates of potential consequences (British Waterways, 2009). From annual and principal inspections, condition grades (CGs) and consequence of failure (CoF) grades are apportioned to specific asset types (Tables 2 and 3). These grades then influence the prioritisation of works.

The use of CGs has been employed by others as an indicator of the likelihood of failure of assets (Buijs *et al.*, 2007). To assess the effectiveness of the CRT AIP in identifying high-risk sites, recent culvert and embankment failures recorded in the NBA were reviewed. These failures were expressed relative to the total

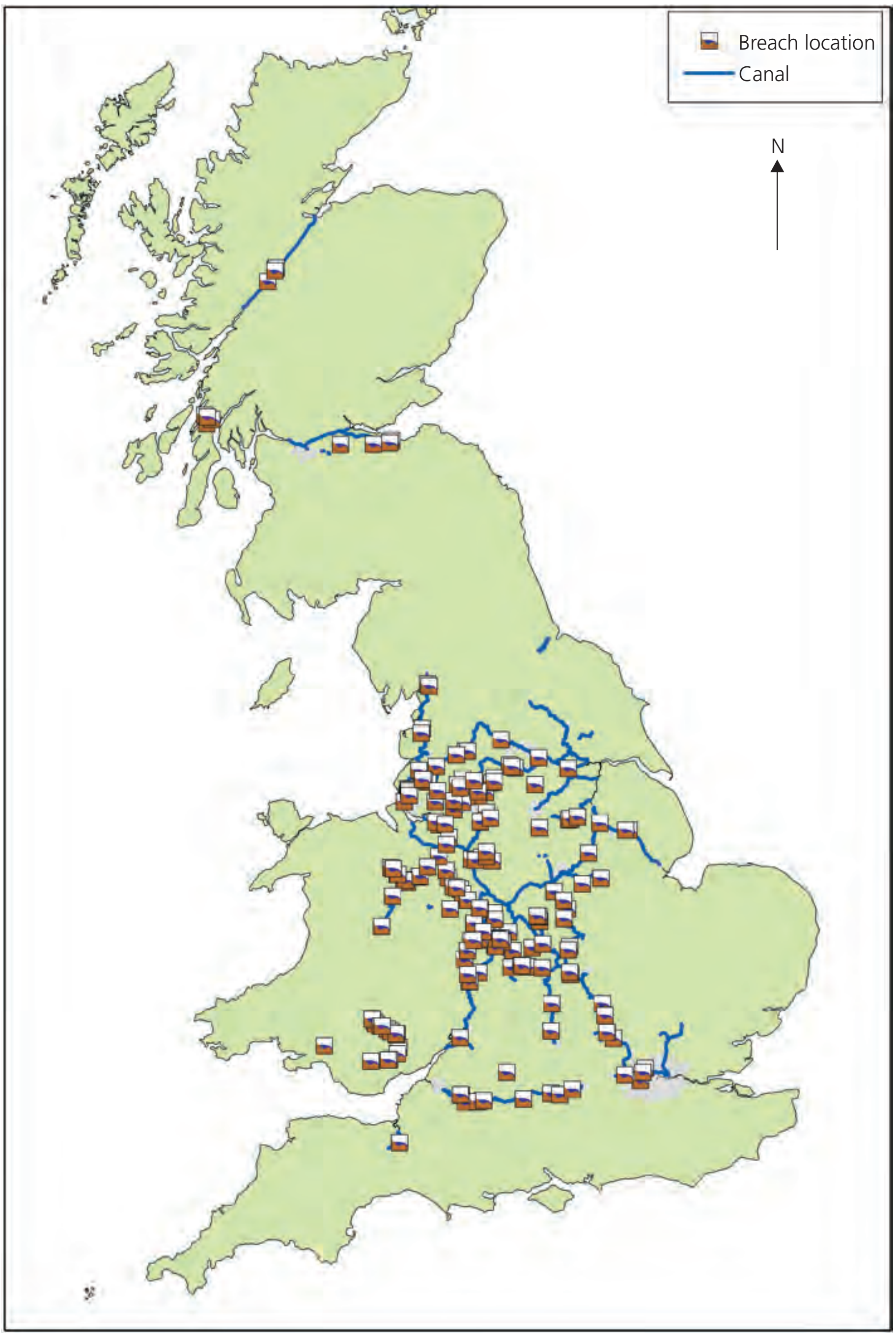


Figure 1. Geographical distribution of known canal and river navigation breaches 1770–2012 (the navigations shown in England and Wales indicate CRT operated waterways). ©Crown copyright 2013, Ordnance Survey 100030994

number of the asset type in that CG, thus presenting a measure of the probability of failure (Figure 3).

Figure 3 illustrates that there is an increased probability of failure with lower CGs for both culverts and embankments. It should be noted that this is based on the 8-year sample period (2004–2011) for which reliable data were available. The above is reassuring and raises confidence in the ability of the AIP to identify structures with a higher probability of failure. There is clearly a significant degree of conservatism (in overestimating the likelihood of failure) adopted by the asset inspectors in allocating CGs D and E (see Table 2) as observed in the absolute percentage

Year	Number of breaches	Total estimated cost: £000[a]
2004	5	1724
2005	2	1559
2006	4	806
2007	8	2387
2008	6	842
2009	8	2160
2010	2	150
2011	1	95
Average	4·5	1116

[a] Third-party damages was 5·5% of total cost

Table 1. Cost of breaches to CRT since 2004

values. Despite this, the above evidence suggests that CG data may be used as an indicator (at least) for the probability of failure for a high-level risk assessment.

It is possible to review the contemporary CoF class for historical breaches according to actual consequences. From the evidence of 26 recent breaches (since 2004) and eight historical breaches, the contemporary CoF assessments are generally consistent with the actual consequences experienced (Figure 4). Conservatism (overestimating the consequences) from the inspectors was apparent at two weir failures, where actual consequences tend to be low due to the downstream watercourse conveyance and storage.

With respect to the AIP, the following points may be concluded (British Waterways, 2009).

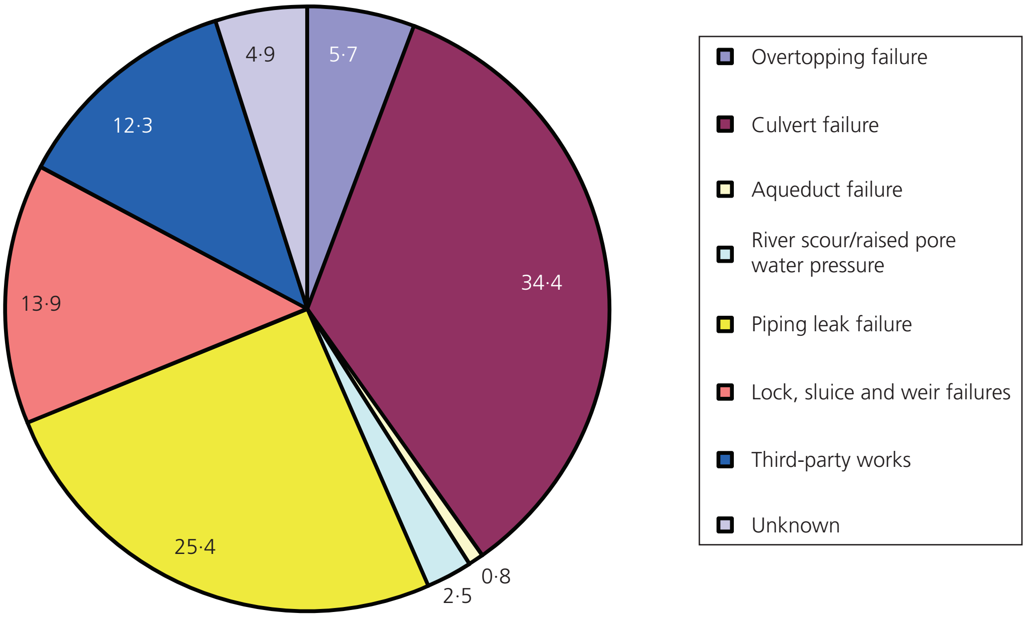


Figure 2. Breach failure mechanisms (1974–2011) derived from total of 122 breaches (British Waterways, 2010)

CG	Rating	Generic description
A	Very good	Sound construction; cosmetic defects that will have no effect on stability
B	Good	Minor defects but structurally sound
C	Fair	Minor defects that may develop into structurally significant defects in the long term
D	Poor	Structurally significant defects leading to potential loss of stability in the medium term
E	Bad	Failed or in an incipient state of failure (about to collapse in the short term)

Table 2. Generic asset condition grades

CoF[a]	Primary: life	Secondary: flooding	Tertiary: claims or prosecution
5	Multiple deaths	Widespread flooding (>0·5 km^2); large urban area/commercial operations affected	>£5 million
4	Multiple serious injuries/single death	Flooding of small community; groups of >4 houses or >1 commercial operation affected; flow across A class roads	£2–5 million
3	Serious injury (<3 in number)	Disruption of a major transport link; widespread flooding of agricultural land (>0·5 km^2); significant crop loss or inability to plant; flow across B class roads	£250 000–2 million
2	Minor injuries	Limited flooding to gardens or agricultural land (<0·5 km^2); minor transport link disrupted; minor roads may become icy	£25 000–250 000
1	Single minor injury	Seepage to gardens/agricultural land; flows <0·5 litres/s causing localised wet areas	£1000–£25 000

[a] CoF is a measure of the failure consequences to third parties and not CRT infrastructure

Table 3. Generic CoF grades

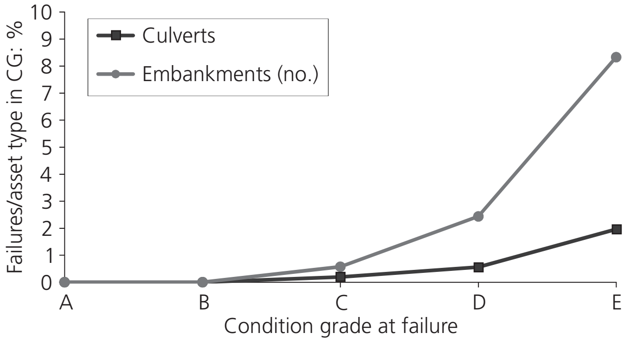


Figure 3. Percentage of assets in each CG reaching failure (2004–2011)

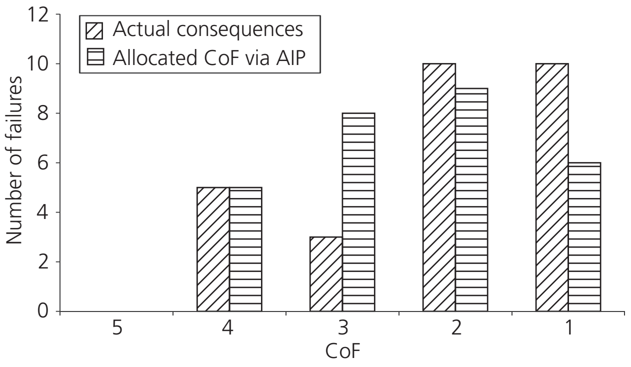


Figure 4. Comparison of CoF grades (as defined in Table 3) and actual consequences of failures realised

- It is effective at identifying risk from prioritising CGs and CoF for general asset management purposes.
- The AIP places a large number of assets in the higher CoF grades. The subjectivity of the inspector in deriving this grade (and the limited technical knowledge of the likely true consequences of a breach) makes the identification of the highest risk sites in relation to loss of life (or monetary damages) unviable via this data set alone. However, the data set does provide a valuable filtering tool for such sites.
- The use of a CG to attribute probability of failure for culverts and embankments helps quantify the likelihood of failure for a high-level quantitative risk analysis. However, it should be acknowledged that the analysis is based on 8 years (2004–2011) of data only, with a consequent relatively low number of breaches. The uncertainty in these probabilities will reduce in the future as the NBA develops.

It can thus be seen that the existing CRT AIP process is suitable for some aspects of asset management planning, but that improvements are required to help optimise the process of asset inspection and maintenance. The identified improvements make use of recent advances in inundation modelling software, computer hardware and national data sets to enable the first national-scale quantified analysis of canal breach consequences using two-dimensional (2D) shallow water equation (SWE) modelling. This new analysis removes much of the subjectivity and bias of the previous inspector-based process, leading to reduced risk to life, lower risk of damage to property and much better targeting of investment.

3. Refining the asset inspection procedure

To improve the quantification of consequence and risk, the following staged approach was developed (British Waterways, 2010).

- Stage 1: filter embankments and culverts for further investigation according to the AIP CG and CoF grades.
- Stage 2: derive quantitative probability of failure from AIP inspection data for each asset filtered in stage 1.
- Stage 3: for the filtered data set from stage 1, derive inundation flood extents from hydraulic modelling.
- Stage 4: derive likely loss of life and flood damages via

model results and methods described by Defra (2008) and Penning-Rowsell *et al.* (2005) respectively.

- Stage 5: combine stages 2 and 4 to derive annual average fatalities per kilometre and average annual damage per kilometre (AAD/km) for each of the priority sites from stage 1.
- Stage 6: carry out quality checks and present results to stakeholders at various scales.

3.1 Stage 1: filtering AIP data

The CG and CoF grades were utilised to filter culverts and embankments, utilising data from the detailed asset-specific inspection process to best advantage. The filtered assets then went forward to the next stage. Clearly, a key decision in the analysis was the 'cut-off' on the CG and CoF matrix. A more inclusive cut-off will carry less likelihood of missing a truly high-risk site while including a greater number of assets in the next stage. A less inclusive cut-off will result in the converse. The cut-off adopted was CG = C, D and E and CoF = 4 and 5 for both culverts and embankments based on the following.

- No actual failures in CGs A and B have been recorded.
- Relaxing the CoF from >3 to >2 doubles the number of embankments and triples the number of culverts going forward to stage 2. Given the low likelihood of a CoF 3 resulting in high consequences (due to inspector conservatism) such an inclusion was not considered proportionate to the additional work required in later stages.

3.2 Stage 2: allocation of probability of failure

The probability of failure for any particular asset was derived from the correlation between the CG and the number of historical failures (Figure 3 and Table 4). A further refinement of this estimate of failure probability for a particular asset may be derived by appraising the condition of the structure for discrete lengths. For example, an embankment may be given overall CG of D, but closer inspection may reveal that 90% of its length is CG C and only the remaining proportion is CG D. Thus, the embankment could be split into lengths and the risk assessment applied to these. CRT is currently refining the AIP data to reflect this. This refinement may be applied very rapidly when higher resolution CG data become available.

As discussed earlier, the provenance of the above probabilities should be acknowledged, being derived from data covering only 8 years (2004–2011). This choice of sample period was constrained by the incompleteness of earlier data sets, which would unjustifiably distort the results. It was also important that the process reflected recent asset inspection systems and not earlier and obsolete practices. Such a short data set does, however, introduce a consequential uncertainty in the quoted values. It is therefore essential that the NBA continues to be maintained. In time, these probabilities may be refined and their associated uncertainties will reduce.

3.3 Stages 3 and 4: mapping inundation extent and calculating impacts

Figure 5 shows a flow chart of the data preparation, modelling and risk calculation activities undertaken. Mapping the inundation of a breach may be considered via a two-step approach: derive the outflow hydrograph at a potential breach site and then derive the inundation zone downstream of the potential breach site.

Following recent breach failures (British Waterways, 2008; Dun, 2006), breach outflow hydrographs were derived from detailed site-specific 1D hydrodynamic models. These models utilised improved understanding of the hydraulic mechanisms active during failures (Dun, 2006). These techniques were shown to closely correlate with water levels monitored during each of the failures. Undertaking such detailed analysis as part of the high-level approach was not proportionate. To address this, a spreadsheet-based 'hydrograph generator' was developed via regression methods; this was subsequent to the application of detailed 1D hydrodynamic models to a wide range of system characteristics. These characteristics included, for example, pound length, pound width, pound depth, relative breach position along a pound and embankment material (cohesive, non-cohesive and mixed). A detailed description of the hydrograph generator is available from British Waterways (2010). (This and other British Waterways documents cited in this paper are available for viewing by request from Water Management Team, Canal & River Trust, Heritage Centre, Canal Lane, Hatton, Warwicks, CV35 7JL, UK.)

Once the flood hydrograph is produced, this can be fed into a flood inundation model. Following a review of available tools

	Annual probability of failure		
	CG = C	CG = D	CG = E
Principal embankment: breaches/km per year	0·001534	0·003675	0·013036
Non-principal embankment: breaches/km per year	Assumed distribution as per principal embankments		
Culvert: breaches/year	0·00032	0·00093	0·00327

Table 4. Baseline annual probabilities of failure

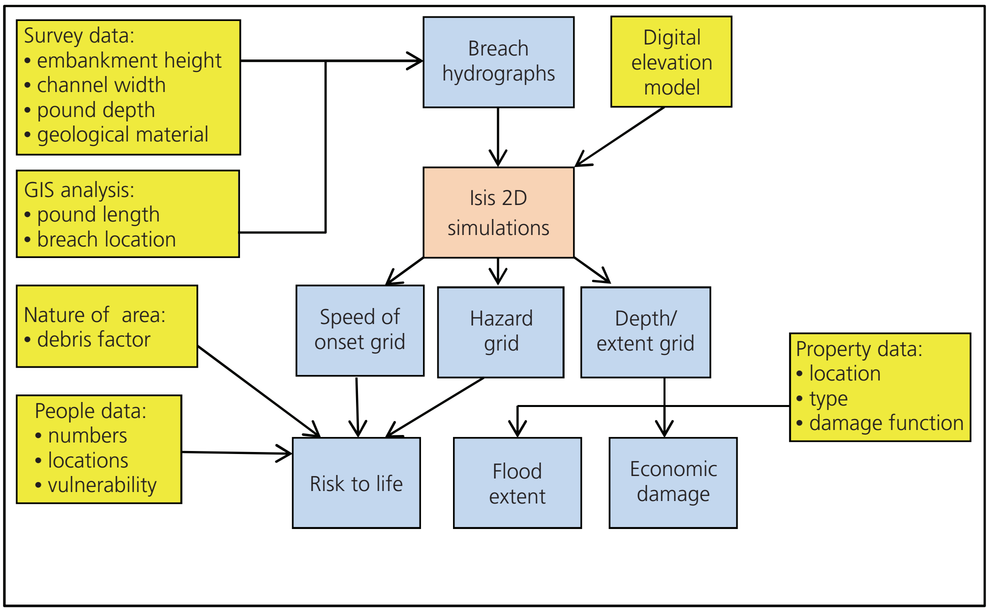


Figure 5. Flow chart illustrating the modelling and risk calculation process

(ranging from simplified rules, 1D, 2D and nested 1D–2D sewer models) (British Waterways, 2010), it was concluded that Isis 2D (www.halcrow.com/isis) would provide a technically robust and reasonably rapid method of deriving inundation extent. The model also contains both an implicit and explicit solution scheme, which may be employed according to the nature of the local terrain (e.g. steepness).

The requirement to efficiently undertake a large number (about 2000) of fully hydrodynamic 2D model simulations necessitated the implementation of an approach that automated many of the pre-processing, model running and post-processing tasks. This was supported by collating the geospatial data into a bespoke database. Roughness values were assigned to the 5 m model grid cells directly from Ordnance Survey MasterMap land use polygons (Manning *n* values used include 0·014 for road surfaces, 0·1 for 'natural environment' and 1·0 for buildings).

Various scripts were written to determine the location of each breach automatically. Hydrographs were calculated in batches, using system characteristics determined from CRT ArcGIS data and a macro that automatically ran and stored the calculation from the hydrograph generator tool.

The Isis 2D models were set up and run automatically, again based on a prescribed process that selected the correct terrain data tiles, the inflow was added and re-ran until it found a timestep and solution scheme that was stable. This allowed more time for the modellers to focus on detailed schematisation and checking of results.

This approach did not include the effects of urban drainage in reducing surface flooding, and uncertainty in predicted flood depths will increase with distance from the breach location. Therefore, a pragmatic decision was taken to focus on the flood impacts within 2 km of the breach location as this zone was observed (from historical failures) to contain the vast bulk of impacts.

The study made use of topographic data available through the CRT national contract with Infoterra. However, for some areas in Scotland, it was necessary to seek agreement from the Scottish Environmental Protection Agency to access and use their IfSAR topographic data. Table 5 presents a summary of the digital terrain data used to build the breach models.

Model results were post-processed automatically, including the calculation of damages and risk to life. ArcGIS projects were created automatically for each embankment and culvert, with only the labels requiring manual placement on the maps. Again,

Priority	Description
1	Lidar – 1 m resolution
2	Lidar – 2 m resolution
3	Photogrammetry – 5 m resolution
4	NextMap IfSAR – 5 m resolution

Table 5. Terrain data, listed in order of preference for use in the study

this allowed more time for detailed checks to be carried out on the final results, ensuring a consistently high standard of outputs.

For the damage calculations, CRT holds a licence with Ordnance Survey for mapping and MasterMap data. For this study, CRT obtained permission to use the Environment Agency's national receptor data set (NRD), which includes a property layer covering England and Wales. However, such a data set did not exist for Scotland and a new equivalent data set covering the study area in Scotland was produced. There are some notable assumptions and limitations associated with the NRD property points layer.

- Property types consist of residential properties and non-residential properties. Non-residential properties are further grouped into five sub-categories of retail, warehouse, office, factory and non-bulk (i.e. miscellaneous properties not in the other four classes). Infrastructure such as roads, railway, electricity transformers, water supply works and sewerage works are not included in any of the categories and hence were excluded from property damage calculations.
- Property valuations were for 2003 and were based on national averages.
- Since a single property point (as opposed to the building footprint) was used to determine whether or not a property was flooded, large buildings can be missed in terms of damage calculations. In most cases, visual checks carried out on the results identified these buildings and damages were adjusted to include these buildings.
- Hospitals do not have a representative depth–damage curve. The depth–damage curve for universities was used as a surrogate.

Likely property flood damages were calculated using the standard depth–damage approach described in the 'multi-coloured manual' (Penning-Rowsell *et al.*, 2005).

Likely loss of life was calculated using the method recommended by Defra (2008). A set of automated scripts was developed to undertake the following calculation steps.

- Determine the flood hazard, which is defined as a function of flood depth, flow velocity and debris factor – the flood hazard is an automated output from Isis 2D.
- Determine the area vulnerability, which is a function of flood warning (assumed to be not available for canal breaches), speed of onset and the nature of the area.
- Determine the number of people expected to be in the inundated areas (derived using occupancy data from Defra (2006) and the NRD property layer) and their vulnerability (from Defra (2008)).
- Calculate the likely loss of life as a function of flood hazard, area vulnerability, expected numbers of people within the inundated area and their vulnerability (using the Defra (2008) method)

3.4 Stage 5: annual average likely loss of life (AALLoL) and average annual damage (AAD)

The AALLoL is the average number of lives that will be lost in any year at any particular structure. For any structure, this is expressed by

$$1. \quad \text{AALLoL} = P_\text{f} \times N_\text{f}$$

where P_f is the annual probability of failure and N_f is the likely number of fatalities from failure. For this high-level approach, the annual probability of failure was derived from AIP CG data and known historical failures; this was expressed in failures/year per kilometre (for embankments) and failures/year (for culverts). A similar approach was adopted for economic property damages whereby the likely loss of life would be replaced by the estimated damages. This then yielded an AAD/km for each embankment segment.

3.5 Stage 6: quality checks and presentation of results

The following rigorous three-step quality assurance process was adhered to throughout the analysis.

- Step 1 – modeller checks. Each model was thoroughly and systematically checked by a modeller. For example, modellers checked that the model passed the peak flow, looked for potential missing flow blockages and flow routes, and carried out mass balance checks. Each review was recorded in a model log file in accordance with pre-prepared guidance.
- Step 2 – project manager/project director checks. On completion of each batch of models, the project manager reviewed the hydrograph, floodplain flow path and carried out a sensibility check on the damages and likely loss of life. The project director also reviewed each map prior to approval.
- Step 3 – CRT checks. The CRT modelling team checked the hydrographs generated and undertook visual checks on inundation extent for reasonableness on all models. CRT also carried out detailed checks on a random sample of models, including checking that all necessary files were in place and sufficient to enable models to be re-run, the models could be loaded and re-run by CRT, the mass balance errors were within an acceptable tolerance (typically $<5\%$) and that the maps, damages and likely loss of life values all looked sensible.

At each step, any of the selected models or results not meeting the agreed quality criteria were re-run or re-processed. The small number of re-runs resulting from the third step of checking carried out by CRT demonstrates the effectiveness of the systematic and detailed checks carried out before handing over the models and associated results.

The results were to be utilised at national, regional and local levels throughout CRT, from strategic overview of risk down to the management of specific assets. It was thus important that the presentation of results met the different needs of these various stakeholders.

At a national level, a risk chart was prepared (Figure 6), which plotted each segmental length (containing embankment and/or culvert) for AALLoL and AAD. This plot enables comparison of the portfolio of sites nationally in a consistent and transparent way. Similar plots to these may be prepared at a regional level (CRT is managed as 11 regional waterway units) or for a specific canal or waterway.

The results are also available in tabular form to facilitate filtering and searching for particular embankments. In addition to the numerical data, supplementary notes are provided for some sites, typically noting flooding of major infrastructure (roads, railways etc.) or limitations with the property damage calculations. These notes guide those using the results to consider in further detail how these local issues may affect use of the results.

Inundation maps were prepared, bringing together potential flooded areas with summary numerical data including CG and potential impacts. Figure 7 presents an example of a breach inundation map for an embankment that overlaps with a culvert. These pdf maps are available for inspection within the CRT ArcGIS suite.

The data were also made available as layers in ArcGIS. Presentation of the data in this way had a number of advantages

- easier access throughout the CRT business
- spatial analysis of highest risk or consequence sites at national and regional levels
- mapping of addition outputs, such as loss of life, AALLoL, monetary damage, AAD and net risk (integrating AALLoL and AAD)
- facilitation of routine data updates, including background mapping and annual updates to CG and, therefore, AALLoL and AAD.

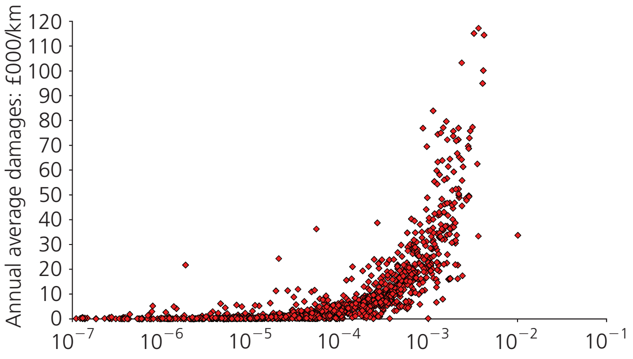


Figure 6. National risk chart for modelled sites

Figures 8–10 illustrate national, regional and structure-specific overviews of the results presentation within the CRT ArcGIS framework.

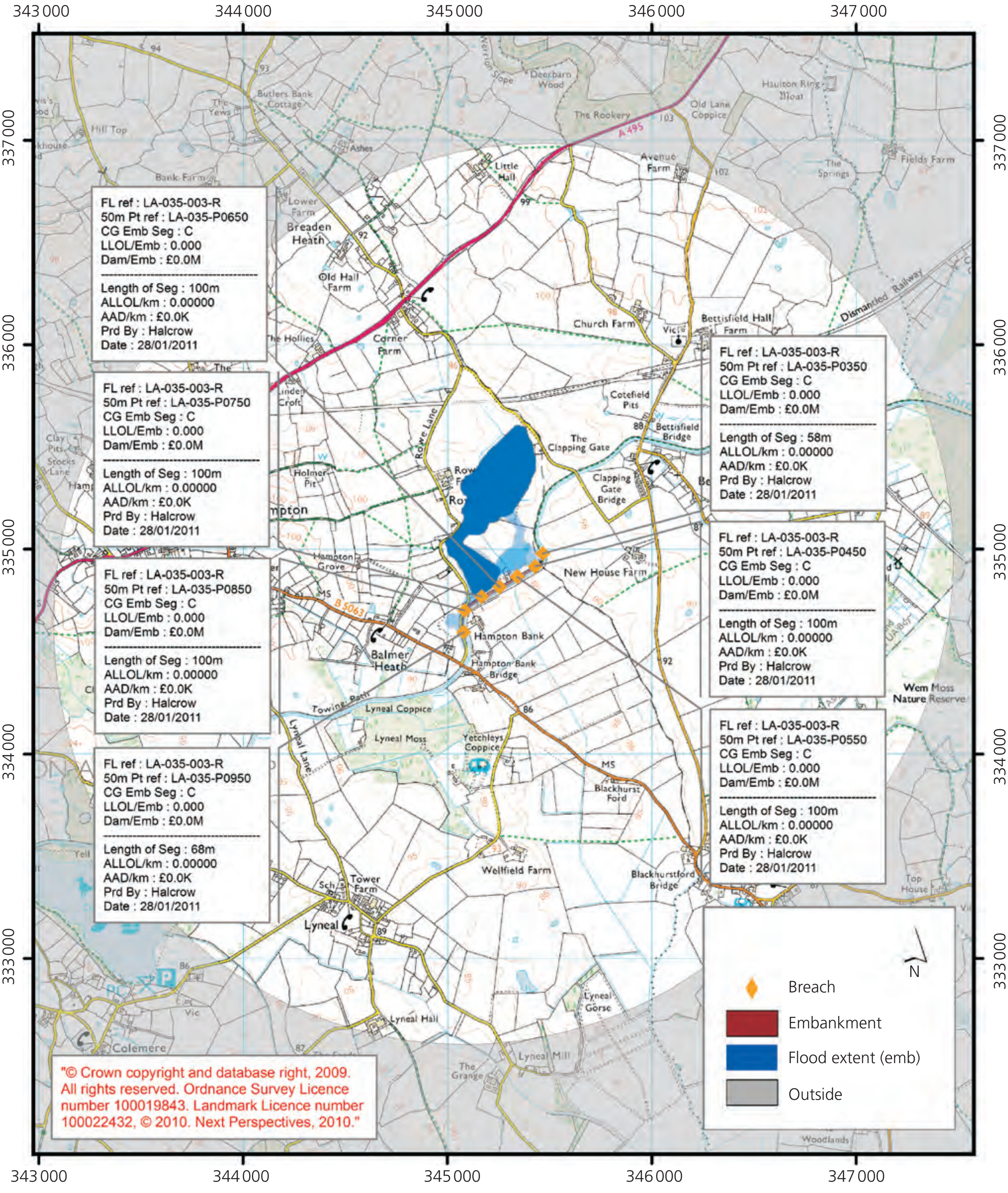
4. Limitations and local issues

Two important limitations of the quantitative high-level approach for canal breach risk assessment are noted.

- The approach utilised a relatively short breach data set to derive probabilities of failure. Provided CRT continues to populate the NBA, the probability of failure can be updated for each site, and the risk chart updated, without the need to re-run the models or event damages.
- The approach does not take account of any large-scale morphological change that could result from a breach (as has been observed for a number of breaches on the Monmouthshire & Brecon Canal (British Waterways, 2008)).

When considering higher risk sites in detail, it is recommended that the following list of potential local issues is considered and further investigated where they could influence the asset management decision at specific locations.

- The embankment material (cohesive or non-cohesive) is typically assumed to share the characteristics of the underlying geology. However, where local geotechnical data are available (e.g. from historic investigation), this information has been used to update the analysis. The embankment material is an important parameter in the hydrograph generator tool and if further local information on material type becomes available, then this should be used to support any local analysis.
- Potential losses to urban drainage systems have not been accounted for since it was not practical to gather data for urban drainage systems for a high-level national assessment. However, where breach flows to drainage are believed to be locally important, and could reduce the event damages significantly, then the models should be reviewed and re-run if necessary.
- In some areas, where photogrammetry data have been used, it may be possible to source more detailed Lidar data to improve representation of the topography.
- Several breaches flow towards and into watercourses of varying sizes. The assessment of the capacity of each watercourse to carry the breach flow was subjective, and based on the best judgement of the modellers/reviewers. Regardless of the capacity of each watercourse, there is always the chance that a breach will occur at a time when the watercourse is already running at bank full and would thus not carry any of the breach flow. In cases where the capacity of the watercourse has the potential to significantly affect the results, further local data should be sourced (perhaps by undertaking a site visit) to improve confidence in the results.
- The project estimated AAD values based only on direct property damage and these were only calculated for



FL ref : LA-035-003-R
50m Pt ref : LA-035-P0650
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 100m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0750
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 100m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0850
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 100m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0950
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 68m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0350
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 58m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0450
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 100m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

FL ref : LA-035-003-R
50m Pt ref : LA-035-P0550
CG Emb Seg : C
LLOL/Emb : 0.000
Dam/Emb : £0.0M

Length of Seg : 100m
ALLOL/km : 0.00000
AAD/km : £0.0K
Prd By : Halcrow
Date : 28/01/2011

♦	Breach
🟥	Embankment
🟦	Flood extent (emb)
⬜	Outside

Figure 7. Example of breach inundation map for a principal embankment

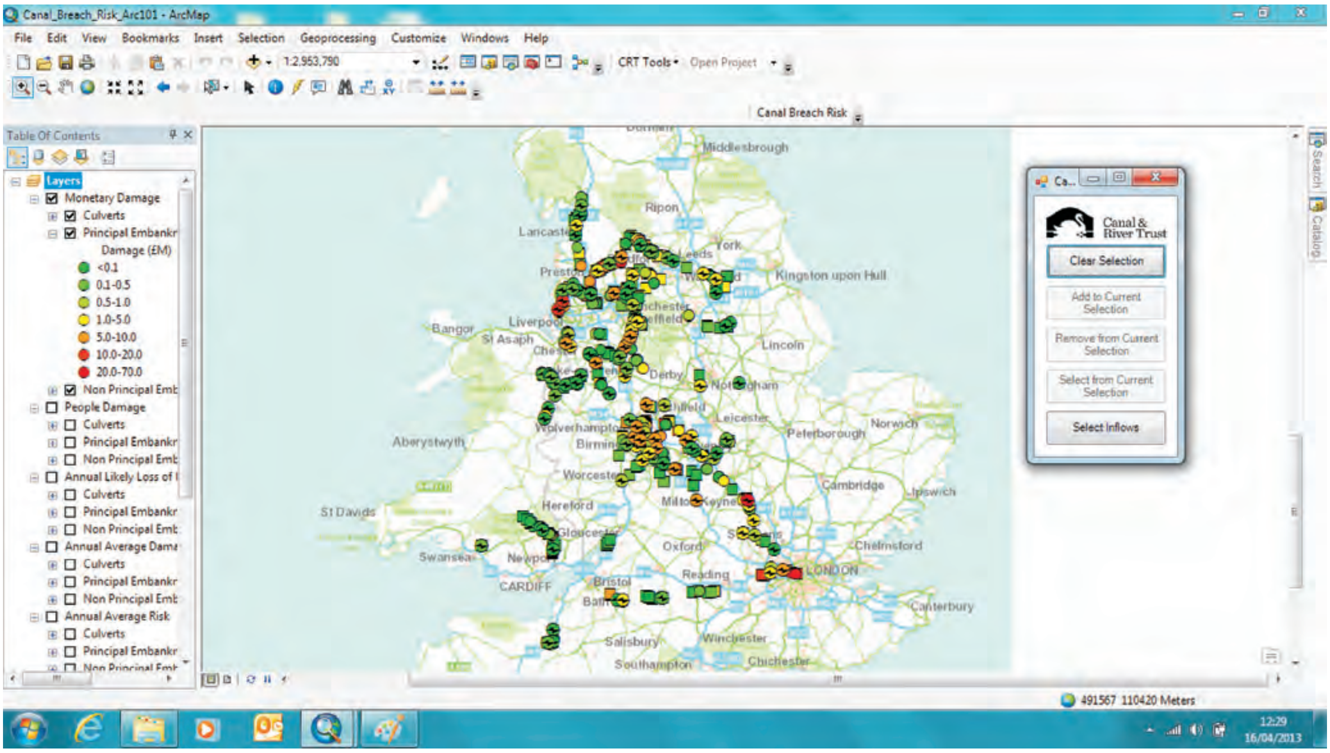


Figure 8. Example of GIS national overview of results from breach risk analysis

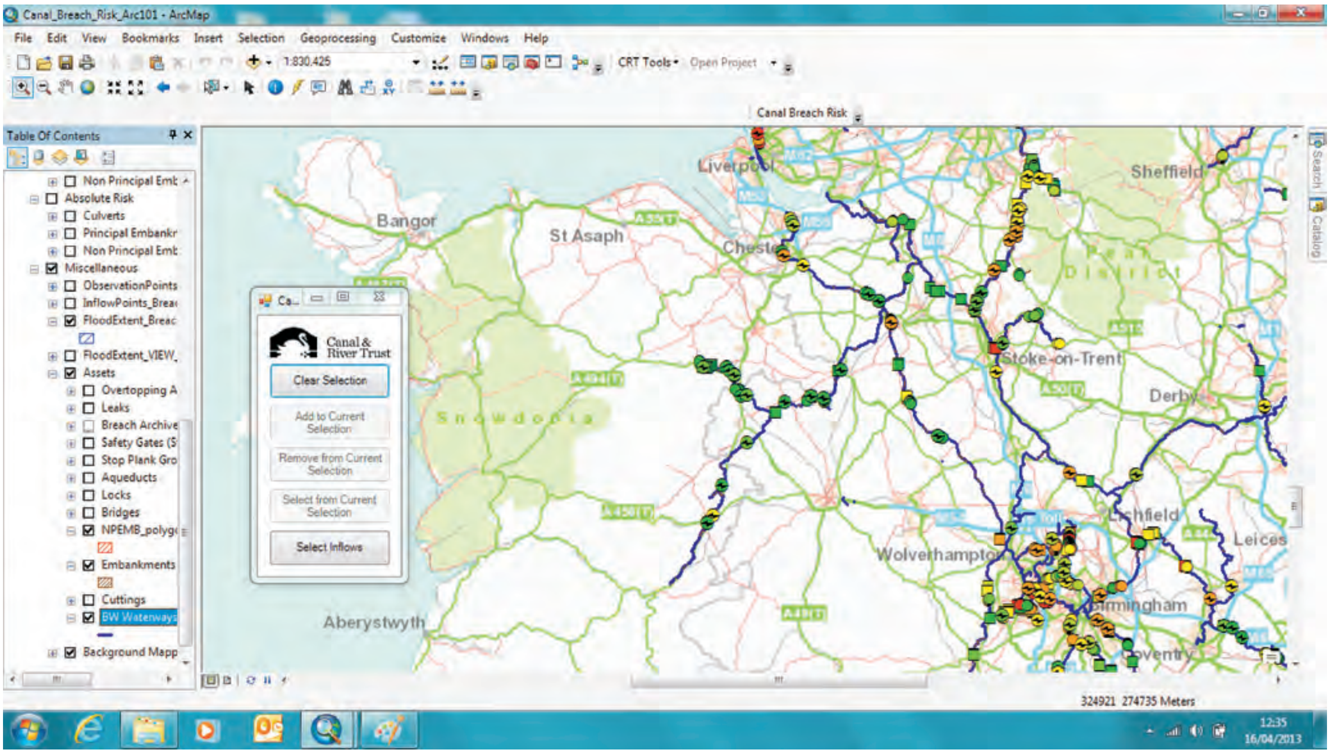
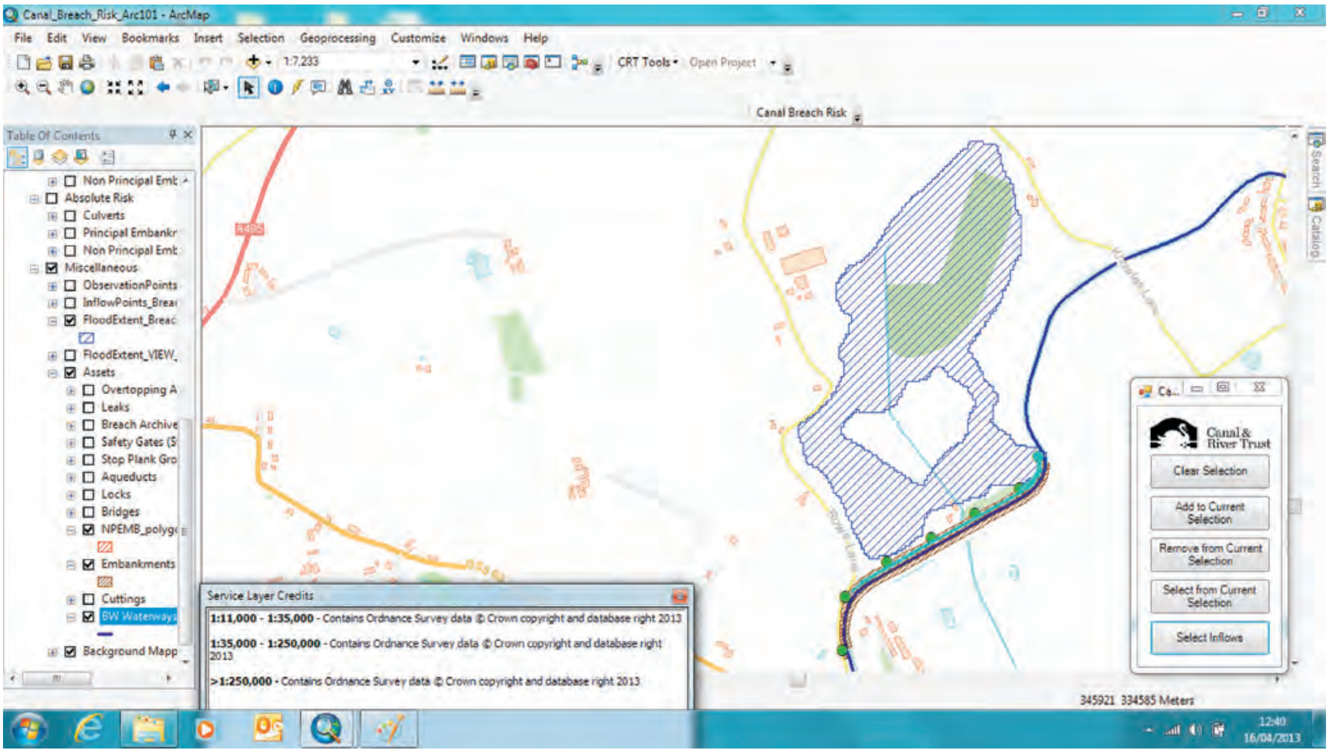


Figure 9. Example of GIS regional results from breach risk analysis



Service Layer Credits

1:11,000 - 1:35,000 - Contains Ordnance Survey data © Crown copyright and database right 2013

1:35,000 - 1:250,000 - Contains Ordnance Survey data © Crown copyright and database right 2013

>1:250,000 - Contains Ordnance Survey data © Crown copyright and database right 2013

Figure 10. Example of GIS local overview of results from breach risk analysis

properties that are present in the national property data sets. Indirect damages and impacts associated with key infrastructure have not been estimated. In certain locations, these additional damages could be significant.

- The approach taken to estimating direct property damage is appropriate for the high-level analysis. However, there are many detailed issues in damage estimation that may significantly affect results locally. These include potential property type, threshold and footprint area errors in the national data sets, and issues with damage calculation methods for basement flats, ground-floor flats and upper-storey flats (all are assumed to flood once depths exceed 0 m). In some urban areas where there is a predominance of high-rise flats, this could lead to damages being significantly overestimated. As such, users should take the nature of housing into account when analysing the damage data.

5. Conclusions

The method discussed in this paper has improved the understanding of risk to people and property from canal breaches. The primary improvements are

- the quantification of probability of failure at a particular site as derived from AIP data
- improved understanding of the consequences of breach failures using appropriately derived breach outflow hydrographs, 2D inundation modelling and up-to-date methods for quantifying likely loss of life and likely property damages.

These developments enable CRT to manage risk by concentrating efforts and resources on reducing the likelihood of failure at the higher risk sites. Outputs provide CRT with a much more informed picture of location and scale of high-risk infrastructure assets and allow better optimisation of expenditure of maintenance and repair work. Sites identified as higher risk from the national approach will go forward to a more detailed local risk assessment and options appraisal.

In terms of the process of deriving the risk data, a number of innovations were introduced to the calculation process to enable delivery of the required outputs to the required time, quality and budget constraints. The following examples may also be applicable to similar studies.

- Automated 2D model build processes to, for example, define active areas, identify required input data and define roughness values directly from OS MasterMap data.
- Automated run processing, including use of automated batch processing of Isis 2D simulations across a cluster of workstations, introduction of a ‘run to maxima have been obtained’ function to Isis 2D so that users do not have to pre-define simulation end times, and automated timestep and

solution technique adaptation whereby models are automatically re-run using either a smaller timestep or alternate solution technique if they fail at a higher timestep.

- Automated calculation of risk to life and property damage.
- Automated generation of flood extent and key data mapping (e.g. Figure 7).

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WHAT DO YOU THINK?