HEC-RAS 2D - AN ACCESSIBLE AND CAPABLE MODELLING TOOL

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ABSTRACT

Creating 1D/2D hydraulic models to assess waterway design and flood impacts can be a time consuming and expensive task. Two key factors that can determine the cost of developing a hydraulic model for a project are model build time and software licensing costs. Using the free and intuitive HEC-RAS 2D software, we are now able to reduce modelling costs, making modelling a more attractive option for clients and modelers. This will enhance the accessibility of 2D hydraulic modelling in the consulting industry.

This paper focuses on how the capabilities of the recently released HEC-RAS 2D have been applied successfully to assess flood risk at a highway bridge and evaluate initial design options for flood risk mitigation. Use of HEC-RAS 2D in testing and refining of stormwater culvert design options is presented as a second application. The paper also highlights some of the challenges and limitations of the software.

The Matekerepu Bridge modelling project is an example where HEC-RAS 2D has been used with success. A combination of 1D/2D hydraulic models was required to test existing flood risk and then assess multiple initial design scenarios. The decision was made to invest time and resources into learning and using HEC-RAS 2D instead of other commercially available packages.

Another example of the use of HEC-RAS 2D is the cross-drainage design of the Hamilton Section of the Waikato Expressway. In this project, HEC-RAS 1D/2D coupled models were built to test and verify different design options for several stormwater culverts, and to compare flood levels before and after construction to address consent requirements.

The use of HEC-RAS 2D in the above projects provided us an opportunity to deliver a final product that was robust and cost effective. The case studies should guide others in using the software, and having confidence in the results.

KEYWORDS

HEC-RAS, 2D, hydraulic modelling, flood risk, culvert design

PRESENTER PROFILE

Carey Lintott is an environmental engineer based in Christchurch in Beca's Water Resource and Stormwater team. She graduated with conjoint degrees in Environmental Engineering and Geography from the University of Auckland in 2016, and is interested in water resource management and hydrology. In her work to date at Beca she has been gaining experience in 1D and 2D flood modelling and has helped lead use of the newly available 2D functionalities in HEC-RAS 5.0.

1 INTRODUCTION

Developing a coupled 1D/2D (one-dimensional/two-dimensional) hydraulic model to assess waterway design and flood impacts can be a time consuming and expensive task, with model build time and software licensing costs both key contributing factors to a modelling project's costs. This has at times limited the accessibility and attractiveness of complex hydraulic modelling to the consulting industry.

HEC-RAS (Hydrologic Engineering Centre – River Analysis System) is a freely available, widely used and well established 1D open channel flow analysis tool developed by the Hydrologic Engineering Centre (HEC), an organization within the U.S. Army Corps of Engineers (USACE). It allows users to perform steady and unsteady flow simulations, sediment transport computation and water quality analysis, all within a common geometric data representation and with informative, graphical reporting of results. Until recently use of HEC-RAS was limited to the 1D domain, with limited options for representation of 2D flow such as splitting flow into different channels, using offline storage areas or applying externally calculated lateral inflows.

In February 2016 HEC-RAS version 5.0 was released, introducing 2D unsteady flow modelling capabilities to HEC-RAS for the first time (these capabilities are referred to throughout this paper as 'HEC-RAS 2D'). The latest version available at the time this paper was written is HEC-RAS 5.0.3, and this version has been used in the example projects discussed. 2D flow modelling is achieved in HEC-RAS by adding 2D 'flow area' polygons into the model in the same way as storage areas were added in previous versions of HEC-RAS. Each flow area is then set up with a 2D computational mesh and linked to other 1D or 2D model elements as well as connected directly to external boundary conditions. A simple 2D model can also be set up using a single 2D flow area and no 1D elements if desired. These new 2D capabilities now allow the software to be used for detailed 2D channel and floodplain modelling and to create 1D/2D coupled hydraulic models. A simple internal GIS tool called RAS Mapper has also been added, allowing basic terrain pre-processing and viewing and manipulation of combined 1D and 2D model results.

This paper focuses on how the capabilities of HEC-RAS 2D have been applied successfully in two case studies: testing and refining of stormwater culvert design options for a new section of expressway; and flood risk assessment of a highway bridge and surrounding roads. In each of these projects, the decision was made to invest time and resources into learning and using HEC-RAS 2D instead of using other commercially available packages. In this paper the project background and modelling approach will be presented for each case study. Achievements and advantages of using HEC-RAS 2D in both projects will then be presented together, followed by a discussion on the challenges and limitations that were encountered.

With HEC-RAS now capable of building 1D/2D coupled hydraulic models, the free and intuitive software presents an opportunity to enhance the accessibility of hydraulic modelling in the consulting industry, by reducing modelling costs and making modelling a more attractive option for clients and modelers alike.

2 MATEKEREPU SH2 BRIDGE: USING HEC-RAS 2D IN BRIDGE FLOOD RISK ASSESSMENT

2.1 PROJECT BACKGROUND

A HEC-RAS 1D/2D coupled model was used to inform on flood risk to the Matekerepu State Highway 2 (SH2) Bridge and nearby intersection in the Bay of Plenty region as part of the SH2: Wainui Road to Opotiki project by the Safe Roads Alliance. The effectiveness of several concept design scenarios, including raising road crests to above the 10 year and 20 year ARI (Average Recurrence Interval) flood level, and increasing capacity under the bridge, were also investigated. The wider objective of this project was to investigate the potential to reduce the frequency and duration of flood closure of road access between Opotiki and Whakatane.

Matekerepu Bridge crosses the Nukuhou River, just east of an intersection between SH2 and Wainui Road as shown in Figure 1. The area modelled consists of a large, flat floodplain area around the bridge, confined by gorges upstream and downstream that act as key constrictions to flow, controlling water levels in the floodplain in storm events.

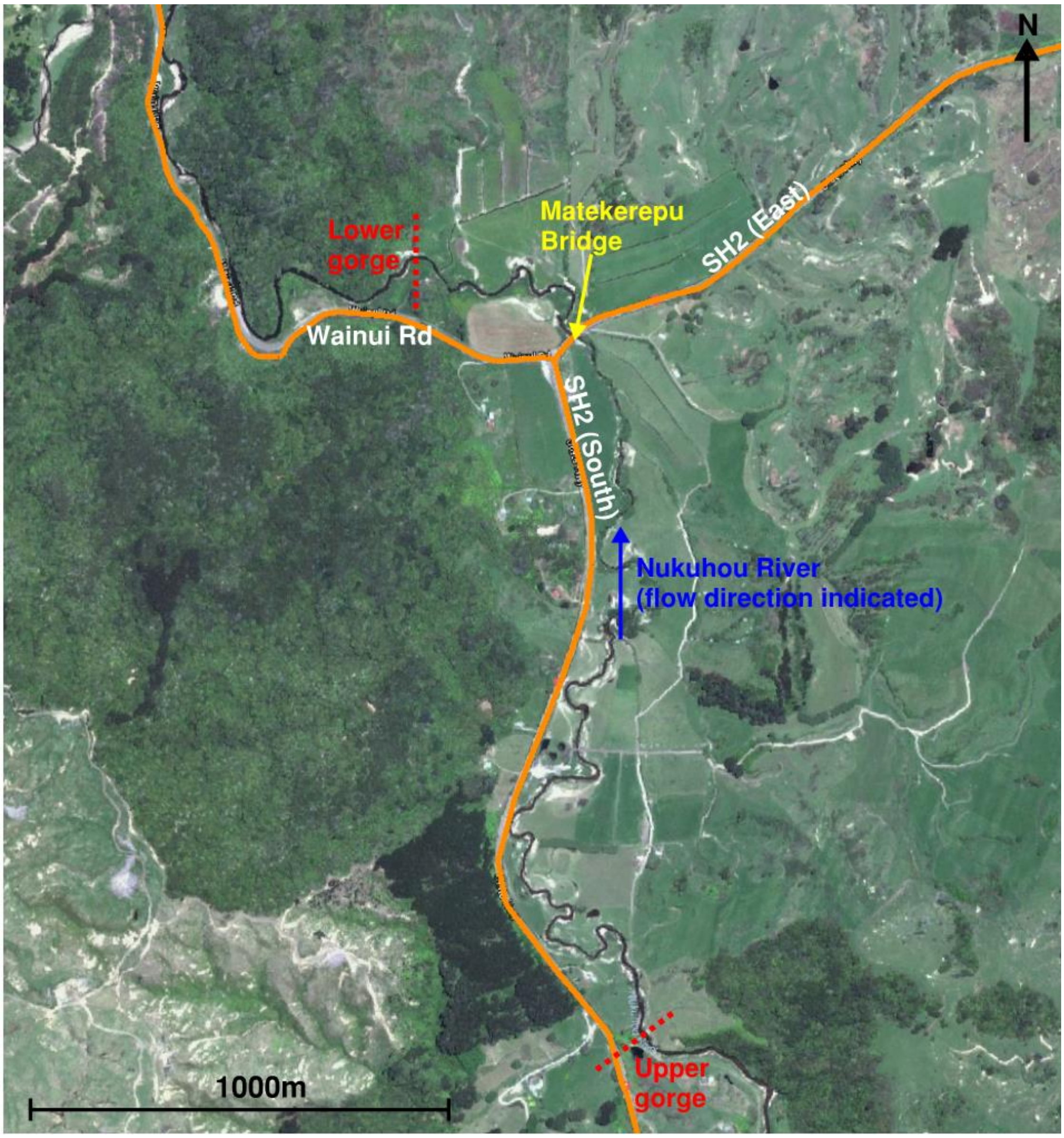

Figure 1: Area of interest for the Matekerepu Bridge project

2.2 OBJECTIVE

The information required from this flood modelling exercise included depth and duration of flooding over the crests of Wainui Road and SH2, as well as flood levels near key properties upstream of the bridge. This data gave insight to the existing flood risk as well as the feasibility and effectiveness of a series of simple mitigation options.

2.3 MODELLING APPROACH

2.3.1 GEOMETRY

A 1D/2D coupled model was set up as shown in Figure 2, covering a 6 km reach of the Nukuhou River extending from the council recorder site to the end of the lower gorge.

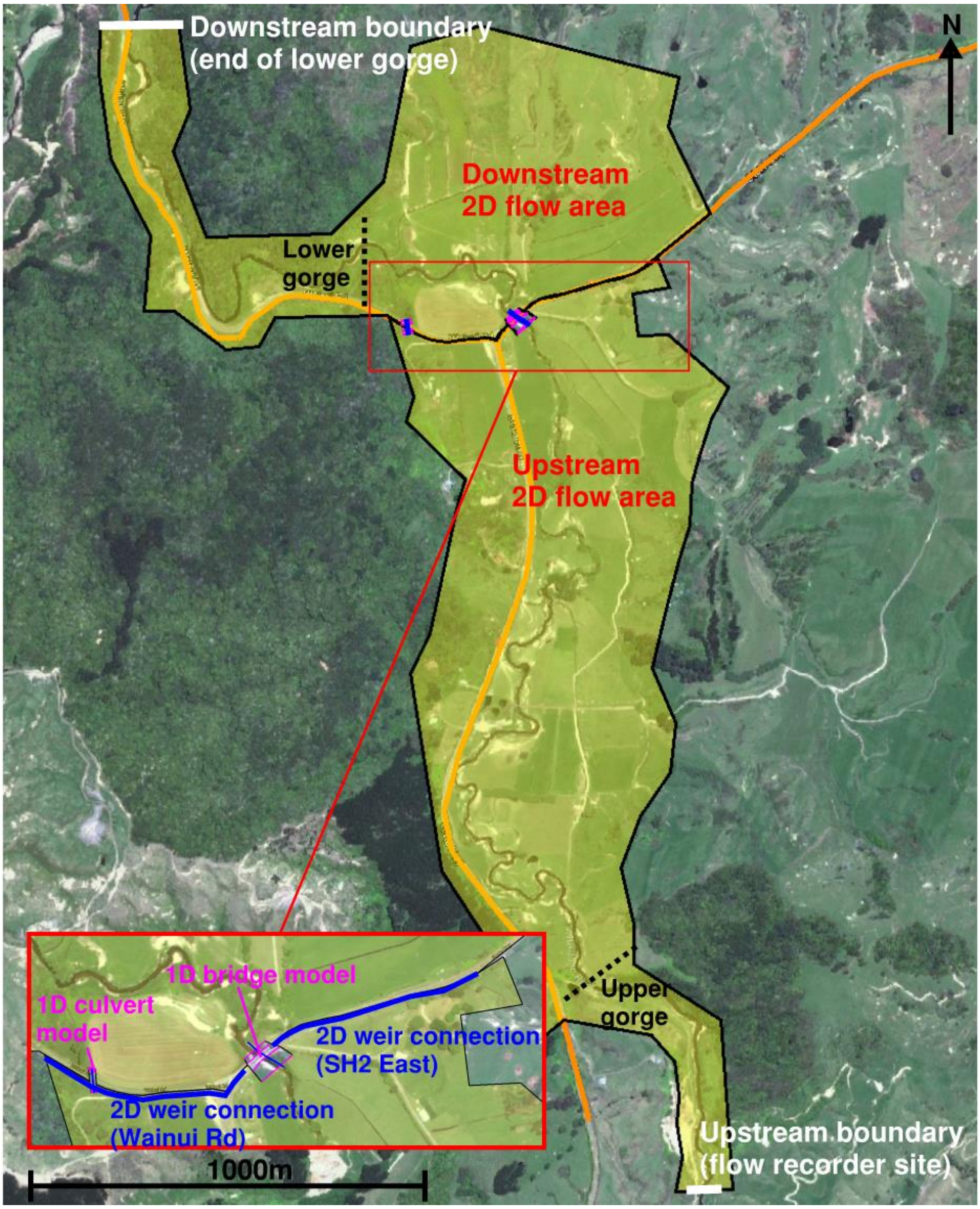

Figure 2: 1D/2D coupled model layout for the Matekerepu Bridge project

The majority of the catchment was modelled as two 2D flow areas; one upstream and one downstream of Matekerepu Bridge. Both areas were set up with a flexible computational mesh, with smaller 2 m and 4 m cells orientated along the river centerline and road crests respectively, and larger 12 m cells drawn orthogonally throughout the rest of the catchment. The upstream flow area contained 17500 cells, while the downstream flow are contained 11100 cells. A close up of this cell structure can be seen in Figure 3. Note that HEC-RAS 2D will process polygon elements with four to eight sides.

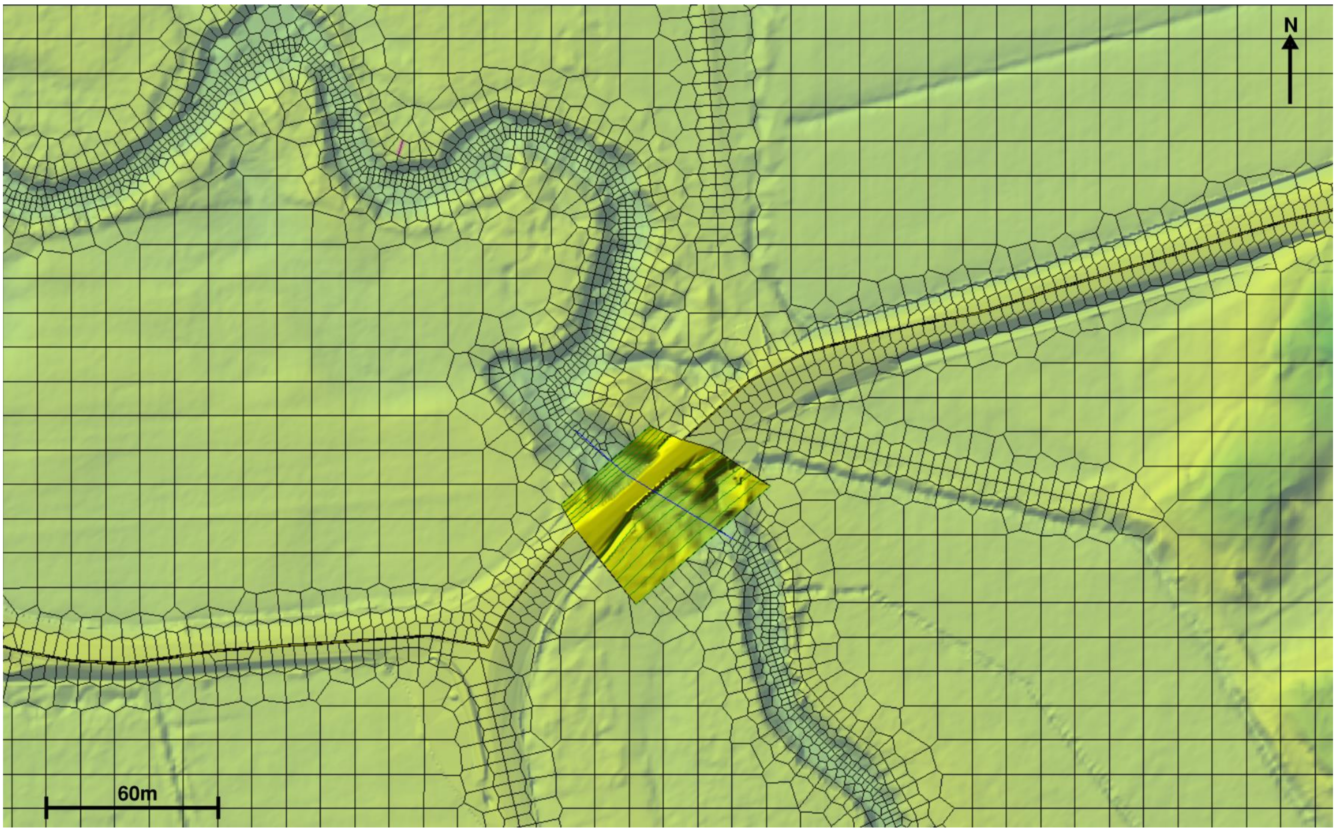

Figure 3: HEC-RAS flexible mesh structure for the Matekerepu Bridge project

Matekerepu Bridge and the surveyed sections of the Nukuhou River immediately upstream and downstream were set up as a small 1D model element. A major culvert to the west of the bridge, under Wainui Road, was represented in the 1D domain in a similar way. These 1D model elements were coupled to the 2D areas at their upstream and downstream ends. Lateral coupling would have been possible but was avoided to minimize stability issues, by keeping the 1D section of river channel as short as possible so that lateral flow would be negligible.

To account for road overflow (which occurs in storm events greater than 10 year ARI) accurately, weir connections were set up between the upstream and downstream 2D flow areas along SH2 East and Wainui Road, with their profile matching that of the road crest. SH2 South was modelled within the 2D domain with mesh aligned to the surveyed road crest.

2.3.2 TERRAIN

A 1 m resolution DEM (Digital Elevation Model) was used to generate elevation data for the 2D mesh. This DEM was interpolated from council LiDAR data, supplemented with survey data to provide accurate road crest levels and river cross-sections in the vicinity of Matekerepu Bridge. New road surface designs were overlaid onto the base case terrain surface using the RAS Mapper tools within HEC-RAS to allow testing of design options.

2.3.3 BOUNDARY CONDITIONS

Design flow hydrographs were generated for different storm events, based on data from a council river gauge at the model's upstream boundary. The recorded flow profile of a major event was also used in modelling to assist with model calibration. These runoff profiles were input as boundary conditions across the width of the Nukuhou River channel at the upstream end of the model. HEC-RAS 2D distributes this flow along the cells at the edge of a 2D flow area, based on a user input energy slope that allows it to compute normal depth from the given flow rate and cross-section data. The downstream boundary condition used was normal depth in the channel.

3 WAIKATO EXPRESSWAY (HAMILTON SECTION): USING HEC-RAS 2D IN STORMWATER DESIGN

3.1 PROJECT BACKGROUND

The Hamilton Section of the Waikato Expressway is a Roads of National Significance (RoNs) project. It begins at the Ngaruawahia section of the Waikato Expressway and connects to the existing Tamahere Interchange extending through to the south-east of Hamilton. The Hamilton section consists of approximately 24.2 km of four lane Expressway as shown in Figure 4. Once complete, the Waikato Expressway will be the primary strategic transport corridor for the Waikato region. The Fletcher, Beca, Higgins and Coffey consortium (named CityEdge Alliance after successful tender) was engaged for the detailed design for this project, which has been staged to match the construction sequence. The scheme design was initially developed and consented by Opus International Consultants.

HEC-RAS 2D was a key tool used in stormwater design for this project. 1D/2D coupled hydraulic models were used to inform cross-culvert design parameters and assess flood afflux to demonstrate compliance with the resource consents. HEC-RAS 2D was used for culverts where the catchments were large and flat with a high potential to cause flood effects outside the project designation. Simpler methods such as Natural Resources Conservation Service (NRCS) hand calculations were used for culvert sizing where the flood effect from culvert was low risk and catchment area was small.

3.2 OBJECTIVE

Hydraulic modelling was used to inform key culvert design parameters such that flood afflux (difference in maximum water level between pre-construction and post-construction development states) in surrounding land outside of the project designation boundary met resource consent requirements.

3.3 MODELLING APPROACH

3.3.1 GEOMETRY

Multiple 1D/2D coupled hydraulic models were set up for this project, with culverts grouped together in the same model where they interacted with the same catchment and floodplain areas. For each group of culverts, a pre-construction model and post-construction model was set up to allow comparison of maximum water levels between these development states, the difference (or 'flood afflux') being key to meeting consent requirements. Two of the HEC-RAS models used in the Waikato Expressway project will be discussed as examples in this paper: the model of the Greenhill Interchange area (Figure 5); and the model of 'Culvert AF' near Ruakura Road (Figure 6).

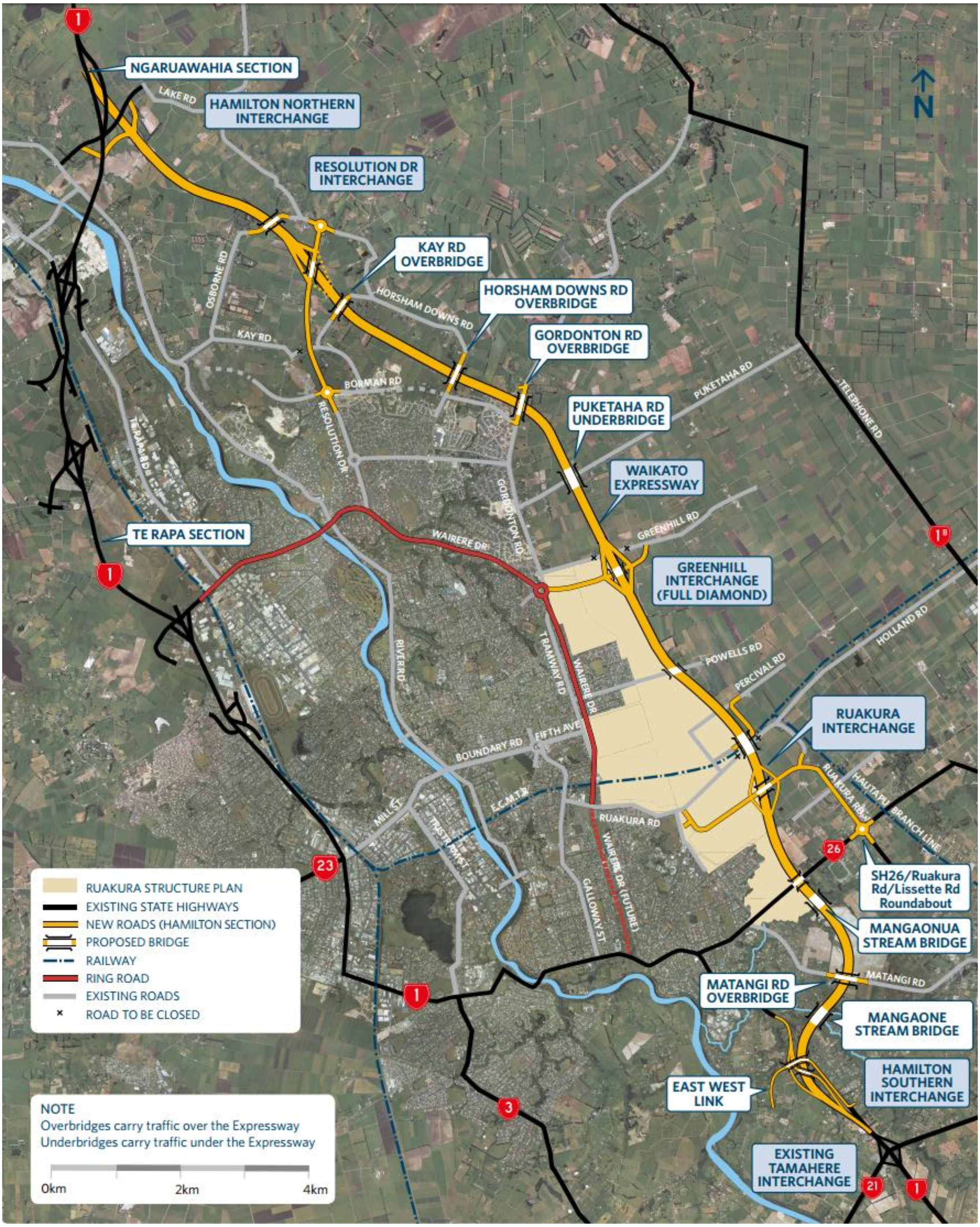

Figure 4: Route and connections of the Hamilton Section of the Waikato Expressway (image source: New Zealand Transport Agency, 2015)

Each model was set up with 2D flow areas of 10 m by 10 m mesh, covering the full contributing catchment to each drain upstream of the Expressway, and extending to an appropriate downstream boundary that would not influence the results produced by the culvert hydraulics. Breaklines were used to provide higher cell resolution and appropriate cell face orientation along the banks and centrelines of major channels, and to orientate cell faces along high points that would control flow direction such as roads. The Expressway itself, and its embankments were excluded from the 2D flow as runoff from this area would be captured, stored and attenuated by separate stormwater systems such as wetlands. The outflowing hydrographs from the attenuation structures were then applied at to the model at the pipe outfall location.

Each culvert, and the area of channel immediately up and downstream was modelled as a 1D element and coupled to the 2D flow area. These elements were coupled in-line to the 2D flow areas upstream and downstream of the highway. In the Culvert AF model, the 1D model element was also coupled laterally to the adjacent 2D flow area as shown in Figure 6, using weir connections with a profile matching the river bank.

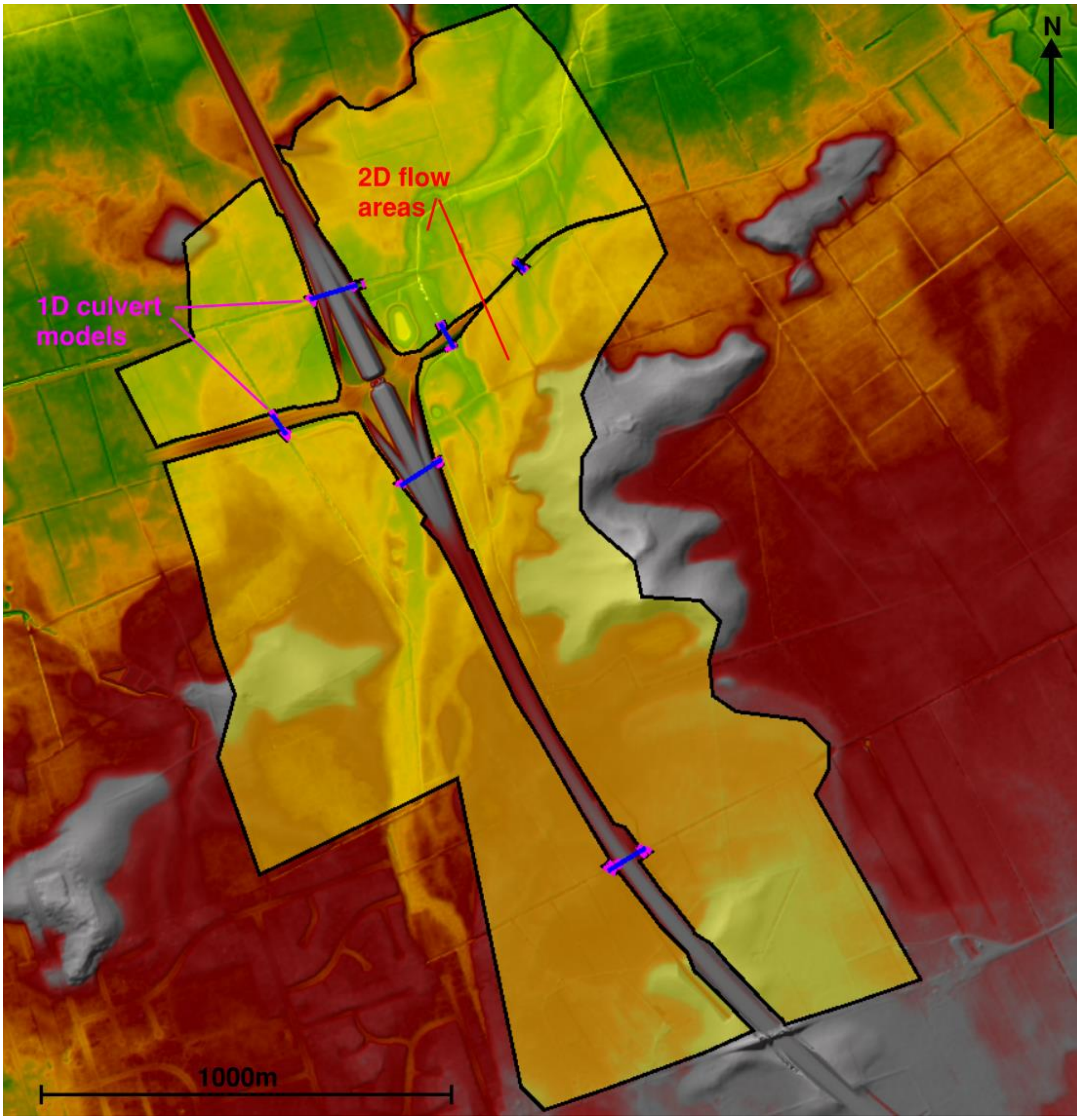

Figure 5: Overall layout of 1D/2D coupled HEC-RAS model of the Greenhill Interchange area, for the Waikato Expressway project.

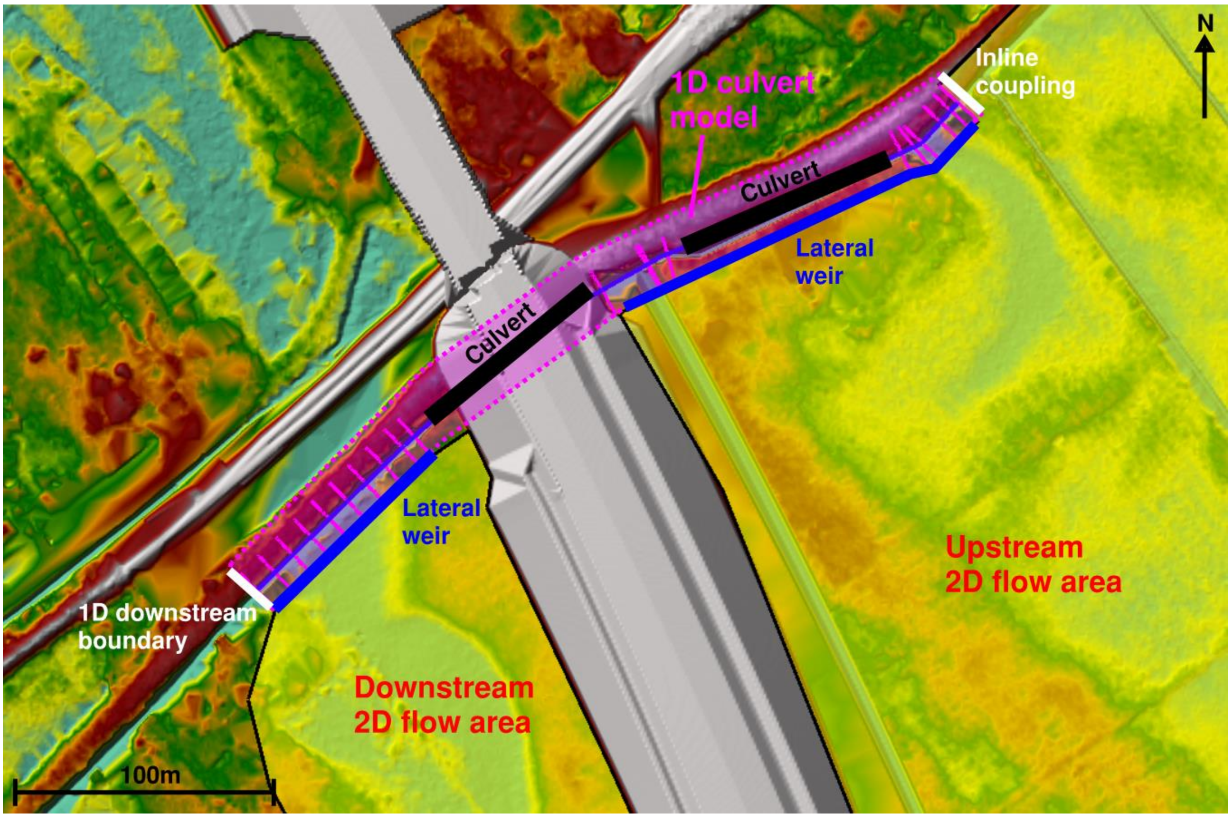

Figure 6: Close-up of HEC-RAS 1D/2D coupled model, with use of lateral and in-line coupling, around "Culvert AF", Ruakura Road in the Waikato Expressway project.

3.3.2 TERRAIN

The base terrain surface used for 2D flow areas in each pre-construction model was generated in the civil modelling software 12d Model V11 as a combined layer of LiDAR and detailed survey where available. For the post-construction model, the design Expressway embankments and any planned diversion drains were exported as surfaces from 12d and stitched onto the base terrain within RAS Mapper. Channel cross-sections and culvert details in the 1D model elements were based on a combination of LiDAR and survey where available. A uniform Manning's n roughness of 0.05 was used as a typical value for a rural floodplain, though land use layers can be used to indicate variation in roughness within an area if needed.

3.3.3 BOUNDARY CONDITIONS

A rain on grid approach was used for all the hydraulic models in this project. This approach would account for catchment storage and hydrologic routing of flows in the very flat catchments involved. HEC-RAS 2D's rain on grid capabilities do not yet allow for calculation of infiltration losses, so net runoff hyetographs needed to be calculated outside of HEC-RAS for use as the input data.

Design rainfall depths for Ruakura were taken from Hamilton City Council Infrastructure Technical Specifications (HCC ITS). This data included increases in depth to allow for climate change of +2.1 °C temperature. Twenty four hour nested storm profiles were then generated from these and adjusted for infiltration losses based on the principles stated in TP108. It should be noted that only one runoff hyetograph can be applied homogenously to each 2D flow area (i.e. the flow area cannot easily be separated into impervious and pervious areas), so to account for this the runoff hyetographs were produced based on a weighted average of the runoff depths for impervious area and for pervious area within each catchment.

Appropriate friction slopes (typically around 0.001 m/m) were used to set normal depth outflow boundary conditions at the perimeter of the 2D flow areas.

4 ACHIEVEMENTS AND ADVANTAGES

4.1 FLEXIBLE USES THAT BUILD ON EXISTING CAPABILITIES OF HEC-RAS

HEC-RAS is widely known and used as a highly capable 1D open channel analysis tool, with capabilities including water quality and sediment modelling, steady and unsteady flow analysis, and detailed analysis of structures such as weirs, bridges and culverts. By adding 2D unsteady flow modelling capabilities, accessible through a single software interface with common geometric representation, hydraulic computations, and viewing of results, HEC-RAS has added to its capabilities significantly.

2D unsteady flow modelling allows the user to effectively deal with complex overland flow paths and wide flat floodplains that, if represented in 1D only, would have unclear boundaries or flow that wasn't perpendicular to the alignment of the cross-sections. In the Waikato Expressway project, the original approach proposed for flood modelling was to use 1D HEC-RAS. The areas modelled in this project consisted of wide, flat floodplains with complex flow paths, making it challenging to build models in 1D alone. It was often difficult to discern floodplain extents and flow direction along farm drains. The watercourse network would also sometimes change between pre-construction and post-construction models due to creation of diversion drains, making it difficult to compare 1D results and determine flood afflux. Use of 2D flow areas to represent floodplains eliminated most of these issues as the full terrain data could be used without creating arbitrary boundaries for each floodplain, and flow could occur in multiple directions. In the Matekerepu Bridge project, the same issue of complex flow paths across wide, flat floodplains was present, and the river system was represented much more appropriately using 2D flow areas.

There is now increased flexibility in how a given modelling project can be approached in 1D, 2D or as a 1D/2D coupled model using the single HEC-RAS software package, such that the choice of software package is not governed by the modelling approach. The same area could be modelled fully in the 1D or 2D domain or as a coupled model, and it is easy to shift from one type to another as all work is done in the same simple graphical interface. This includes existing 1D HEC-RAS projects being upward compatible, as you can now convert floodplains to 2D flow areas where they have been previously modelled within 1D cross-sections or as storage areas (storage volumes with no time component, only a storage-elevation curve). For example, the approach used in the Waikato Expressway project evolved from use of 1D elements only (with floodplains represented in 1D cross-sections but prone to 'glass-walling'), to representing all major channels in 1D with lateral and in-line connections to 2D flow areas (which led to difficulties stabilizing connections), then finally to representing only the channel in immediate vicinity of the culvert in 1D (removing the need for lateral connections, and addressing the associated stability issues).

4.2 QUICK AND INTUITIVE GRAPHICAL INTERFACE

The HEC-RAS software package is intuitive and easy to learn making it more accessible to non-modellers or those with little previous modelling experience, as well as quick to pick up for modellers already experienced in other packages. This has cost benefits in terms of training time requirements. Model set-up in HEC-RAS is based heavily around a to-scale, georeferenced graphical interface, with terrain, aerial imagery and other useful layers able to be overlain. The ‘what you see is what you get’ nature of the program makes it intuitive and easy to learn, and usually similarly straight forward to debug.

Iteration of design options can be done quickly and effectively, for example in the Matekerepu Bridge project, all that was required for each design iteration was for a new road surface to be stitched onto the existing terrain surface in RAS Mapper, and the weir connections raised to represent the new road crest profiles. No other changes to the model configuration or mesh were required. Similarly, with the Waikato Expressway project, being a constantly changing design, a new design surface could easily be loaded into HEC-RAS with minimal other changes required, and culvert sizing could be easily tested within the 1D model parameters.

The interface simplicity means HEC-RAS 2D can potentially be used to create a quick first pass model to scope out work required in another package, or to see where more detailed modelling might be needed in later stages of a project. It could also make HEC-RAS 2D favourable for use by experienced hydraulic engineers who only do flood modelling intermittently, as with a small amount of time spent learning the software and with no financial commitment they could use HEC-RAS to make small changes/design iterations to a project without seeking external assistance.

4.3 AVAILABLE IN PUBLIC DOMAIN

By nature of being a software developed by the U.S. Army Corps of Engineers (USACE), HEC-RAS is freely available for use by individuals and organisations outside of USACE. Being ‘free to use’ software is one of the key benefits of HEC-RAS as a modelling tool. With no licensing fees, there is a direct cost saving on projects modelled in HEC-RAS. There are also time and cost savings from not needing to balance license constraints between modelling projects, as full time use of the software could occur across several modelling projects within a business simultaneously. As an example, in the Waikato Expressway project, HEC-RAS 2D was used full-time by two users over several months, while other modelling projects could run concurrently on other software that did have licensing constraints.

One of the downsides associated with being freely available in the public domain is the lack of official user support, however there is a large, supportive online community of users who are continually collaborating on workarounds to the software’s limitations. There are also external vendors offering assistance and training for HEC software.

4.4 HIGH RESOLUTION SUB-GRID MODEL

The use of high resolution sub-grid modelling in HEC-RAS 2D sets it apart from other modelling packages and allows large systems to be modelled with faster run times and more accurate flow transfer computations. While other 2D packages give each computational cell a flat bottom, and treat each cell face as a straight line with a single elevation, HEC-RAS 2D calculates detailed hydraulic table properties for each cell and cell face based on the underlying terrain (i.e. the terrain is used as a ‘sub-grid’). This means that for example as in the Matekerepu Bridge project, a model could be built with 1 m resolution terrain data but have a computation cell size of 12 m. An elevation-volume table will be generated for each cell so a cell can be partially wet at a given volume. Each cell face can also convey flow using an appropriate wetted perimeter, area, and roughness for a given water surface elevation. Altogether this means that larger computational cells can be used, giving faster run times without much loss of detail or underlying terrain. For example, as shown in Figure 7 a small channel or drain cutting through a much larger computational cell will still be accurately represented in the cell’s storage-elevation relationship, and in terms of channel hydraulic properties.

The ability to use a reasonably coarse 2D computation mesh over a more detailed sub-grid terrain without losing detail in results was beneficial for both the Matekerepu Bridge and Waikato Expressway projects which dealt with large, complex model systems. For Matekerepu Bridge the design storm for this area had a very long duration at nearly 5 days, but models could be run in around 12 hours depending on the number of models running concurrently and the speed of the computer used.

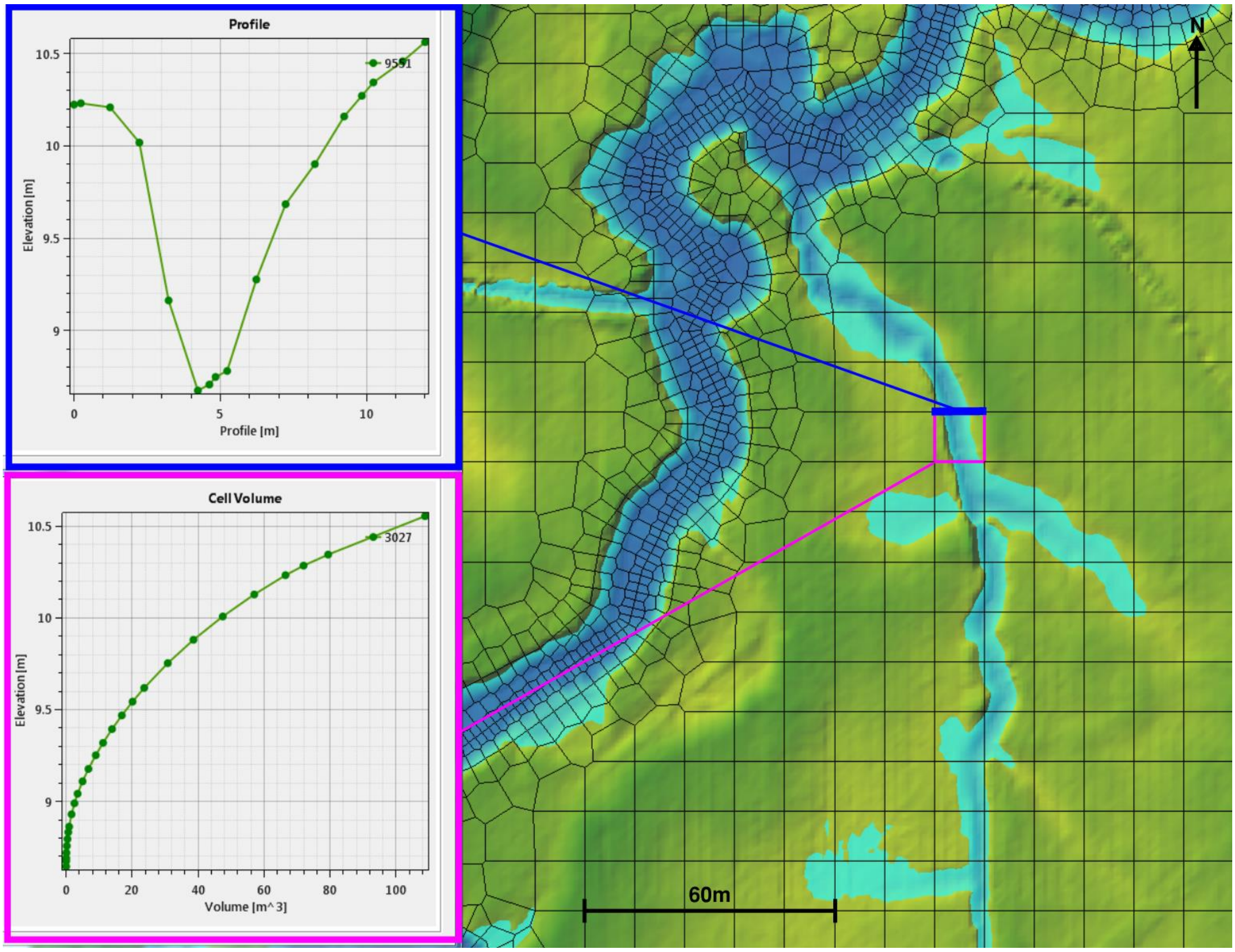

Figure 7: Example of large orthogonal mesh representing sub-grid terrain data in Matekerepu Bridge project. The profile along an individual cell face, and the storage-elevation curve for the associated cell, are also shown.

4.5 COMBINED STRUCTURED AND UNSTRUCTURED MESH

HEC-RAS 2D also helps with modelling large systems with fast run times by allowing the user to generate a computation grid that is a mixture of structured and unstructured mesh types. A mesh can contain a mixture of cell shapes and sizes and the automated tools within the HEC-RAS geometry editor allow a user to quickly customize the mesh to suit the terrain. This means a mesh can be created such that it contains predominantly large orthogonal grid cells, but then uses smaller cells, orientated appropriately along controlling terrain such as road crests, or along important river channels. First a primary cell size is specified, and then key ‘breaklines’ are drawn with specified sizes for the cells orientated along them (cells will graduate back to the primary cell size with distance away from the breakline).

Appropriate use of breaklines is essential given the sub-grid nature of HEC-RAS 2D modelling, as the orientation of cell faces determines hydraulic connectivity between cells. It is important that cell faces be orientated along the crest of any high points in terrain that control water flow so that flow is not conveyed incorrectly (leaked) past the high point as shown in Figure 8. In Figure 8, the left image shows correct use of breaklines along a road crest, and the hydraulic connectivity arrows indicate no flow is 'leaking' past the crest unintentionally. In the right-hand image, where no breaklines were used and large orthogonal cells span across a road surface, some 'leaking' is clearly shown by the hydraulic connectivity arrows.

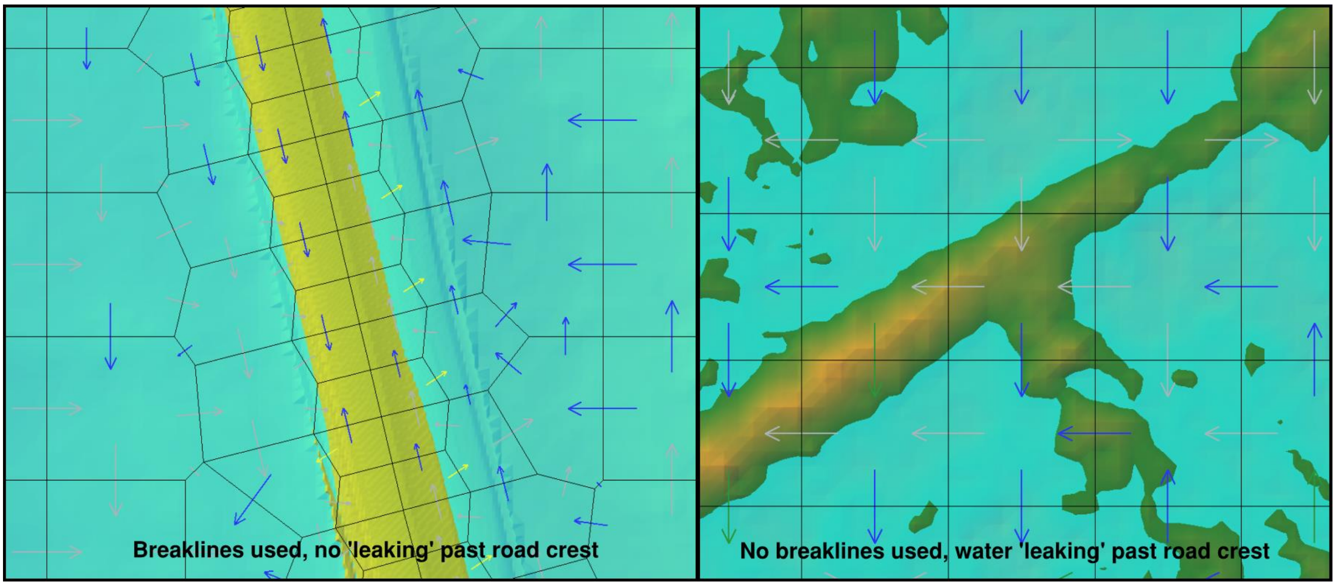

Figure 8: Comparison of HEC-RAS 2D results when breaklines used to orientate cells along defining flow features, and when large orthogonal cells are used and "leakage" of flow occurs. Arrows show hydraulic connectivity between cells.

4.6 INTERNAL GIS VIEWER AND COMPATIBILITY WITH OTHER GIS PACKAGES

The inclusion of RAS Mapper, a basic internal GIS viewer within HEC-RAS has greatly enhanced the pre- and post-processing capabilities for data within the program. This has reduced dependence on external packages, but also means that HEC-RAS results are highly compatible with other GIS packages if required.

RAS Mapper allows some pre-processing of terrain, including interpolating 2D surfaces using 1D cross-section data, and stitching together multiple terrain files of varying resolutions and file formats. The limitations of these tools are discussed in Section 5.1. There are also useful, well-built visualisation tools that help during model build including contours and hillshading, and the ability to load in other GIS layers such as shapefiles or aerial imagery, or web-based layers. If necessary, it is also easy to export a wide range of raster results for processing in an external GIS package. For example, a raster of water levels or depths across the model area can quickly be exported for any time step, or as minimum or maximum values. Shapefiles of inundation boundary are another useful result that can be exported. It is similarly easy to export various time series data for a given point or profile line, or profile data from a given instant in time, for analysis and plotting externally to HEC-RAS.

Integrated 1D and 2D results for a simulation can be viewed and manipulated in several different ways in RAS Mapper. The tool allows dynamic viewing of animated velocity, depth, and water level over time, with particle tracer arrows plotted if required. It is also possible to plot flow, volume accumulation, water level and other variables over custom drawn profile lines (which do not need to be specified prior to a simulation). Mapping of 2D results will be based on the underlying sub-grid terrain, avoiding the coarse gridded nature of flood maps that is an issue in some other packages. Cells can be shown as partially dry and there can be a range of depths across the cell for a single water surface elevation depending on the terrain. As shown in Figure 7 earlier, this means that features such as small streams within a cell will be able to be distinguished clearly in 2D results. Full 1D results can still be accessed for 1D elements wherever more detail is required.

In the Waikato Expressway project, the key output required was flood difference maps. Integrated 1D and 2D maximum flood depth results were previewed and then exported from RAS Mapper and processed further in QGIS to create flood difference maps. An example iteration of one of these maps is shown in Figure 9, which shows that the Culvert AF design is having little impact on flood levels, though further work is needed on other culverts in the model. Note that this figure is for illustration purposes only and does not represent the final design for the culverts pictured. The 1D results for each culvert model were also used, with profiles of each culvert used to compare pre- and post-construction flood depths at the designation boundary.

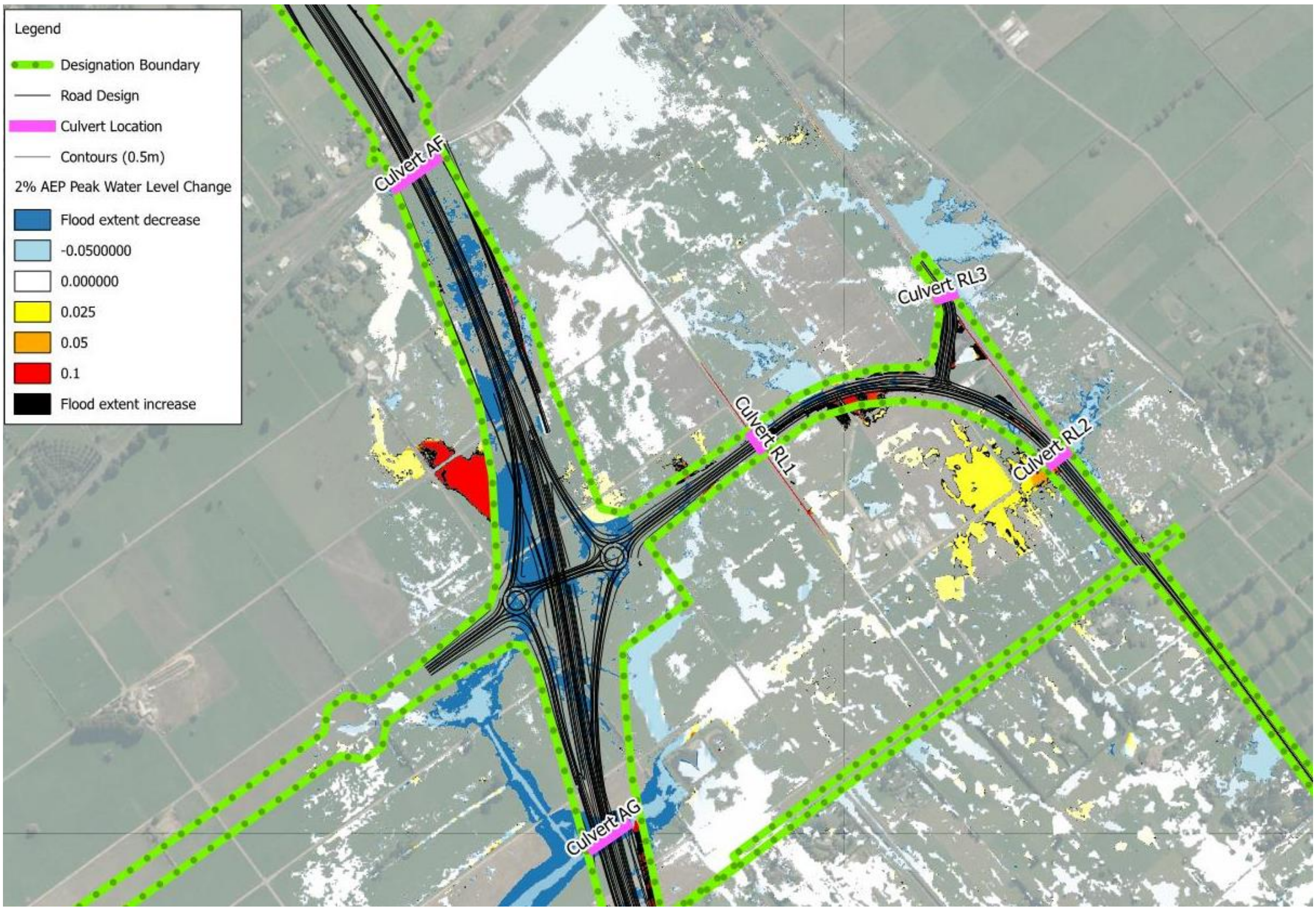

Figure 9: Example output for Waikato Expressway culvert design, showing areas exceeding the 50mm flood afflux requirement. Note this is a draft iteration for illustration purposes only and not the final result.

In the Matekerepu Bridge project a wide range of results were used to assess existing flood risk and effectiveness of different design options. Time series profiles of water level over time were used to determine duration of inundation of each road crest. Dynamic mapping and longitudinal profiles helped illustrate the mechanism of flooding in the area (a gorge downstream of the bridge would constrict flow and allow water levels to build up and inundate the floodplain around Matekerepu Bridge). At the same time by modelling the road crests as 1D weirs and the bridge as a 1D model element, HEC-RAS's wide options for bridge modelling and capabilities for viewing 1D output could still be taken advantage of. 1D and 2D results were also integrated seamlessly in RAS Mapper allowing for easy production of maximum flood depth maps like that shown in Figure 10.

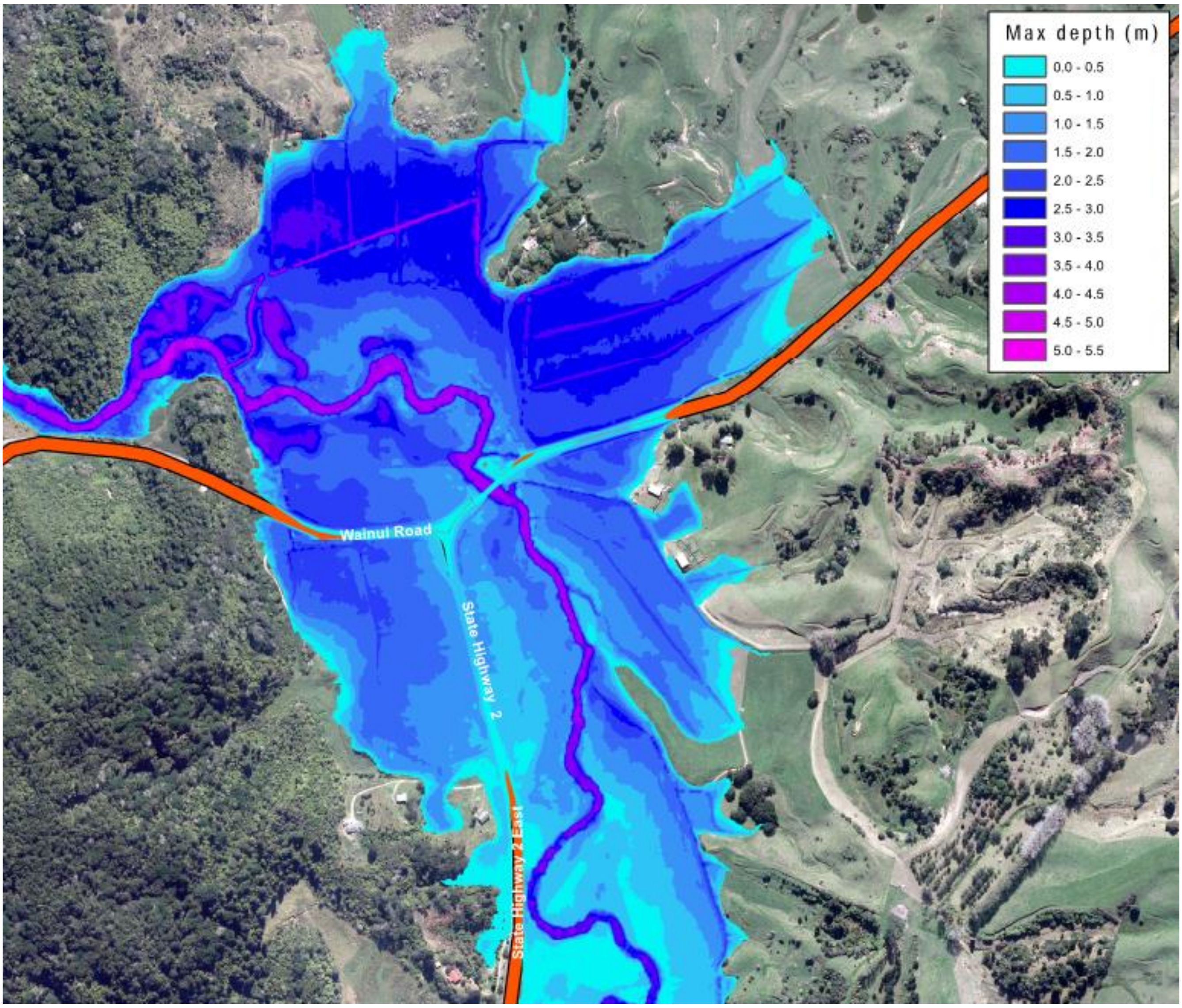

Figure 10: 20 year maximum flood depths at Matekerepu Bridge (data exported from HEC-RAS and then presented using ArcGIS)

5 CHALLENGES AND LIMITATIONS

5.1 DEPENDENCE ON QUALITY OF LIDAR

As with any 2D model, the quality of terrain data (in terms of both resolution and accuracy) is an essential factor in creating a detailed and accurate hydraulic model.

There are some useful tools available to pre-process LiDAR within RAS Mapper, allowing the user to stitch multiple terrain surfaces of varying file types and resolutions together. A terrain surface can also be interpolated from cross-sections in a 1D model to reflect a surveyed stream profile or remove a bridge or culvert, however this feature is of limited use if a 1D model has not already been set up for the area of LiDAR that needs editing, or if individual cell heights need to be edited to remove a sink or spire. With the current

HEC-RAS LiDAR processing tools available, external processing of the LiDAR is often still required. It has also been noted that RAS Mapper sometimes will not interpolate elevations accurately in areas with steep slopes.

In the Waikato Expressway project, there was considerable dependence on LiDAR as the catchment nature was such that maximum flood levels in the 50 and 100 year ARI events would largely be controlled by flow within the watercourse network rather than overland flow. Small inconsistencies in drain invert level could thus act as significant barriers to flow and affect results. This issue could be partially mitigated by smoothing out any mounds in farm drains that were likely to affect conveyance using 12d, informed by surrounding LiDAR levels and by survey or field observation where available. In the Matekerepu Bridge project, the LiDAR quality was less critical as any flows above a 10 year ARI storm event were enough to fully inundate the floodplain in the area considered. As such, any small inconsistencies in farm drain shape and invert level did not affect the final water surface level or conveyance.

5.2 INTERNAL STRUCTURES AND PIPE NETWORKS

The 2D capabilities within HEC-RAS are still in early stages of development, and at this stage the options for including internal structures within a 2D flow area are limited. Similarly, HEC-RAS does not allow for analysis of pipe networks in either 1D or 2D.

While weirs, culverts, and gates can be modelled as internal structures, one of the key limitations is that an internal structure must be based along a single line of cell faces. This means that a culvert with length greater than the mesh size cannot be represented effectively, which was the case for all culverts in the Waikato Expressway project. In the Waikato Expressway project this problem was solved by modelling all culverts as 1D model elements and coupling these elements to the surrounding 2D flow areas. Using internal structures would at times be preferable because 2D flow areas needed to be split up to allow coupling to 1D culvert elements, and there were also frequent stability issues at 1D/2D interfaces. Another workaround that has been suggested (though not tested in the case studies in this paper) involves creating a ‘wormhole culvert’ using a combination of a weir internal structure located at the culvert centreline and a culvert internal structure that spans right from the culvert’s desired entrance face to the exit face.

A second limitation in use of internal structures is that the wider HEC-RAS 1D bridge modelling options cannot yet be used in such a structure. This means bridges cannot yet be accurately modelled as internal structures within a 2D flow area. There are thus three approaches that can be used to model a bridge in a 2D HEC-RAS model: a bridge can be modelled entirely within the 2D domain as a simple narrowing in the channel with no deck or piers (which means the constricting effects of a bridge deck cannot be considered); a bridge can be approximated as a culvert across a single line of cell faces (as often done in MIKE 11); or lastly a 1D model of the bridge can be created and coupled to the 2D surface. For the Matekerepu Bridge project, given the desired accuracy and outputs, a 1D model was used to represent the bridge, and then coupled to the 2D flow areas which had to be split up and downstream of the 1D model similarly to the Waikato Expressway culvert models.

The lack of pipe network modelling capabilities in HEC-RAS limits the use of the software for full modelling of stormwater drainage networks in urban areas or where a pipe network or long closed channel represents a significant portion of drainage in an area. In the Waikato Expressway, some of the cross-culverts were designed as inverted siphons in areas where the Expressway alignment sat below the surrounding terrain. Because 1D models must have open cross sections between each structure, there were limitations to how well an inverted siphon could be modelled using HEC-RAS.

5.3 COUPLING OPTIONS AND INSTABILITIES AT 1D/2D INTERFACE

There are some important limitations to the coupling methods available in HEC-RAS 2D. Given that, as discussed above, use of internal structures is limited at this stage, it was necessary in both the Waikato Expressway project and the Matekerepu Bridge project to create small 1D model elements representing bridges and culverts and then couple these to surrounding 2D flow areas. Both in-line and lateral coupling methods were used and both methods have some key limitations at this stage.

5.3.1 IN-LINE COUPLING

In-line coupling between a 1D model element and a 2D flow area is set up in HEC-RAS by clicking and dragging a channel centerline into a 2D flow area. While easy to set up the user has little control over coupling options beyond ensuring that the terrain profile and roughness values at the 1D/2D interface are aligned. In both modelling projects discussed in this paper, HEC-RAS 2D proved to be quite unstable at in-line 1D/2D interfaces, particularly when setting up initial backwater levels in the early stages of each simulation. There is a high sensitivity to water level differences either side of a 1D/2D boundary. With very limited options available to adjust the coupling between 1D and 2D, at times little could be done to work around such instabilities.

In the Waikato Expressway project, the farm drains where 1D/2D interfaces were located were often of shallow gradient with low flow rates, and the lack of fast, perpendicular downstream flow made in-line 1D/2D interfaces very susceptible to instabilities. A workaround that was used to deal with these instabilities was to use a lateral weir as an in-line 1D/2D connection as shown in Figure 11. Doing this greatly improved stability and gave the user much more flexibility in how the connection was set up such as the weir coefficients used and exact terrain profile at the interface. It was also necessary to add small lateral inflows to each 1D model element as with the flat, low flows the model struggled to keep all cross sections wet throughout the model run (a requirement for a stable model run).

In the Matekerepu Bridge project, the interface between 1D and 2D elements was a wide cross-section on the Nukuhou River, with fast moving perpendicular flow, and instabilities were not much of a problem using the default in-line connection method.

5.3.2 LATERAL COUPLING

Lateral coupling in HEC-RAS 2D is currently a somewhat manual and limited process. This type of coupling is set up by placing a lateral weir structure along the boundary of the 1D model and connecting it to the adjacent 2D flow area. It should be noted that as 1D cross-sections are needed before and after each structure, a lateral weir could not overlap with a culvert or other structure in the same 1D reach, i.e. lateral flow over the culvert deck cannot be modelled. The lateral coupling method works well for uniform, artificial weirs or stop banks along larger river systems but does not work so well as an interface along a natural bank for a small river or drain feature. Instabilities due to differences in water level at the 1D/2D interface were a large issue, and it is also a time-consuming manual process to adjust the lateral weir profile such that it is never lower than the lowest elevation of each adjacent cell face.

Lateral coupling was often used in the Waikato Expressway project, as the approach taken sometimes involved using reasonably long 1D channel models and then coupling these laterally to the surrounding floodplain. In the Matekerepu project, based on learnings from the Waikato Expressway project, 1D model elements were kept as short as possible to reduce the need for lateral coupling.

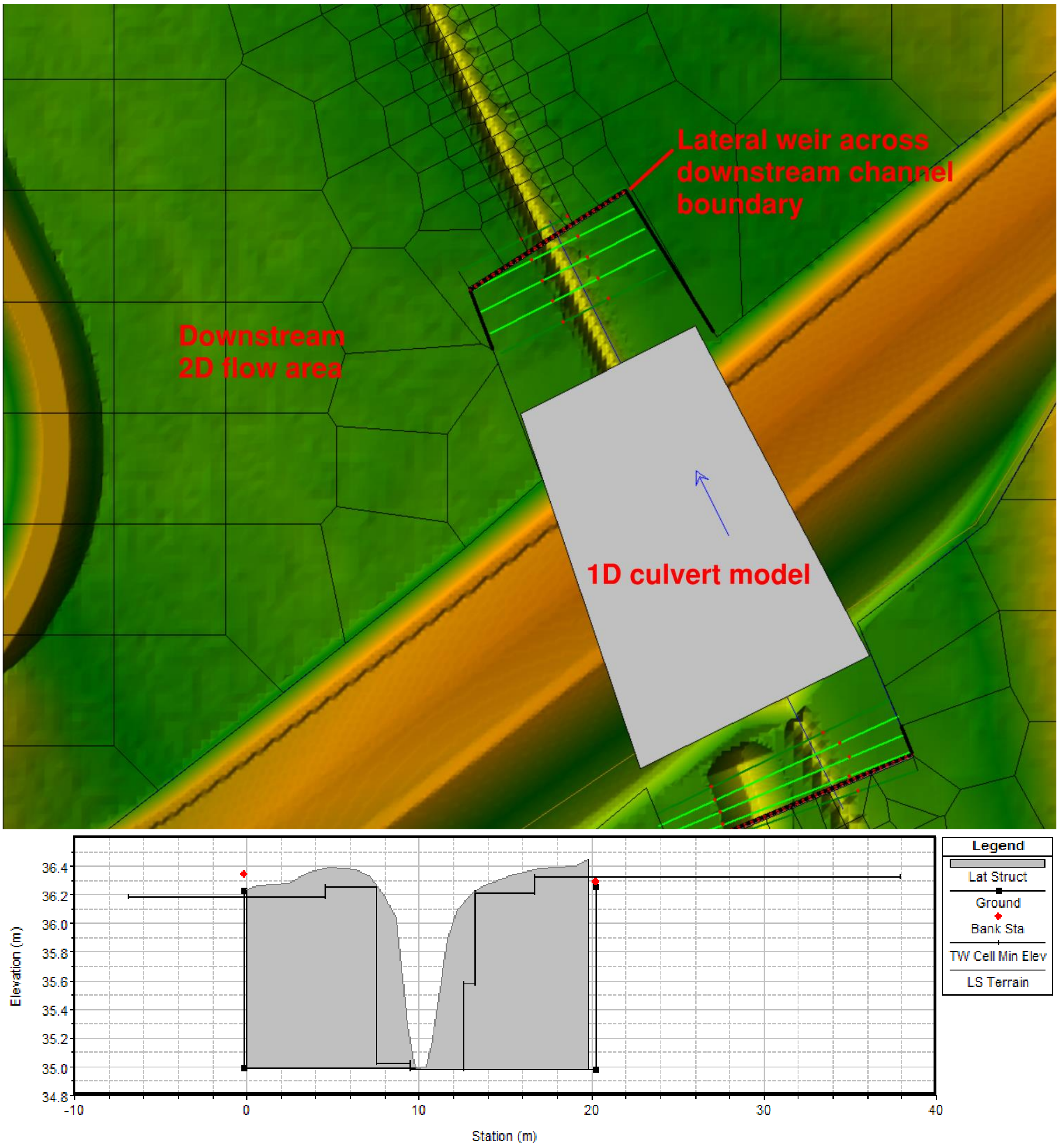

Figure 11: Example of how a lateral weir can be used to represent a downstream model boundary

5.3.3 COUPLING 1D/2D INSIDE A 2D FLOW AREA

Given the limitations around setting up internal structures in HEC-RAS 2D, it was necessary to set up 1D model elements within a larger 2D flow area for both projects discussed in this paper and there are some key challenges in this type of arrangement. Firstly, 1D/2D connections can only be made at the boundary of a 2D flow area, and the user cannot block out a "hole" inside a 2D flow area. This means that a 2D flow area must be split in two to provide a 2D boundary to couple to each end of the 1D model element. This means a risk of losing hydraulic connectivity across the floodplain being modelled, and weir connections must be added to reconnect the split up 2D flow areas. This same issue means that buildings and other obstructions cannot easily be blocked from a 2D flow area, as is often desired in a rain on grid model.

This issue was worked though in both the Waikato Expressway and Matekerepu projects by creating two distinct flow areas upstream and downstream of the 1D model elements as shown in Figure 12. For Waikato Expressway, the road surface was not modelled as its stormwater runoff was being dealt with by separate systems and applied back into the flood model after attenuation was calculated. The alignment was generally high enough that no flow would pass over the Expressway between the two 2D flow areas, therefore no other connections were necessary. For the Matekerepu project, duration and depth of flow over Wainui Road and SH2 were key outputs from the flood modelling so it was essential that flow over these roads was modelled effectively. To do so, lateral weir connections were set up along the road crests either side of Matekerepu Bridge, with a profile to match the road crest profile. This setup allowed the bridge to be modelled in 1D without losing conveyance over the roads, and actually enhanced the ability to report on flow over each road as the 1D HEC-RAS outputs such as flow hydrographs and detailed tabular output could be examined for each road crest weir.

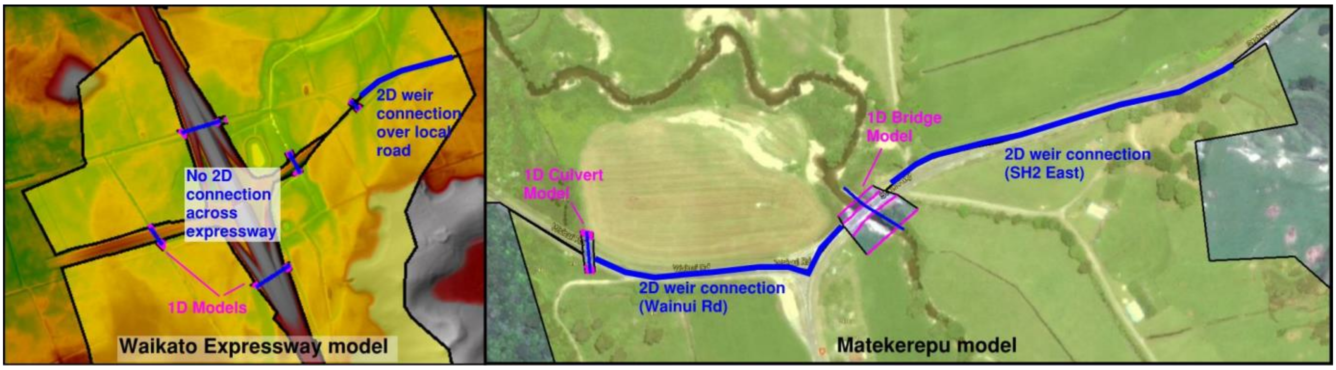

Figure 12: Comparison of coupling between 2D areas in Matekerepu and Waikato Expressway HEC-RAS models

6 CONCLUSIONS

HEC-RAS 2D is an intuitive, low cost yet capable 2D modelling package. Available in the public domain, the program can now be used for a wide range of 1D and 2D modelling applications without the license constraints typical of many other software packages. The use of high resolution sub-grid modelling and flexible mesh generation tools are key technical advantages which set HEC-RAS 2D apart from other 2D modelling packages, allowing large complex systems to be modelled quickly without compromising resolution of results. The internal RAS Mapper GIS tool is also a key advantage, providing flexible viewing and manipulation of seamlessly integrated 1D and 2D results.

There are some key challenges in use of HEC-RAS 2D for certain applications, primarily the dependence on quality of LiDAR (an issue that is common in all flood modelling software), and limitations to internal structures and 1D/2D coupling options. As HEC-RAS is primarily a tool used by USACE for modelling of large river systems, it is unlikely that some of the limitations described in this paper may be improved over time as they are simply outside of the intended purpose for the software, such as effective modelling of complex, flat rural drainage networks, or integration with pipe network models. Other aspects such as the simplistic GIS interface, limited internal structure and coupling options, and the inability to use bridge, sediment transport, or water quality modelling in 2D may improve in later iterations of the program and are simply limited at this stage as the software is still in an early stage of release. Also, as use and recognition of HEC-RAS 2D increases so will testing and benchmarking against other 2D modelling packages.

HEC-RAS 2D was an appropriate modelling tool to use in the Matekerepu Bridge project, and was successfully used to analyse flood risk to the road and assess effectiveness of initial design options. Using HEC-RAS 2D, majority of the area could be modelled in the 2D domain with 1D elements only used where more detailed output and accurate computations were required. This meant model build was simple and intuitive, and much less model build time and fewer approximations were required than if the whole reach was to be modelled in 1D. The Nukuhou River has a large channel with reasonable flow and gradient that meant 1D/2D coupling was straight-forward and stable, and the Matekerepu Bridge could be modelled as a simple 1D model element that took advantage of the 1D bridge modelling capabilities in HEC-RAS.

The Waikato Expressway project, with its complex networks of farm drains and wide flat terrain, was a more challenging and complex application of the tool that revealed some key limitations of HEC-RAS 2D. However most of these could be worked through, and would not necessarily be dealt with better by other 2D modelling packages. HEC-RAS 2D was able to be used successfully to inform culvert design parameters and meet resource consent requirements, and the project provided the opportunity to explore the flexibility and capabilities of HEC-RAS 2D as a 2D modelling tool.

The introduction of 2D unsteady flow modelling capabilities to HEC-RAS, as an already widely used and freely available open channel flow analysis tool, presents an opportunity to enhance accessibility of 1D/2D coupled hydraulic modelling to the consulting industry. The successful use of HEC-RAS 2D in the case studies discussed in this paper indicate that this software can be used to deliver modelling results that are robust and cost effective.

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