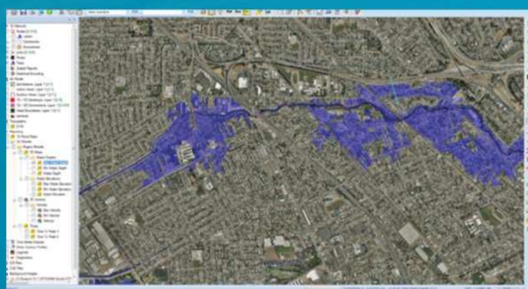
Integrated 1D/2D Modeling

Modules 12-14



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Empowering water experts

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Workshop 12-14 Objectives

- Learn theory of 1D/2D integrated modeling
- Model river and culverts as integrated 1D/2D
- Model urban flooding - nodes connected to 2D
- Simulate sudden levee/dam break flooding
- Prepare flood inundation maps
- Interpret 2D flooding results

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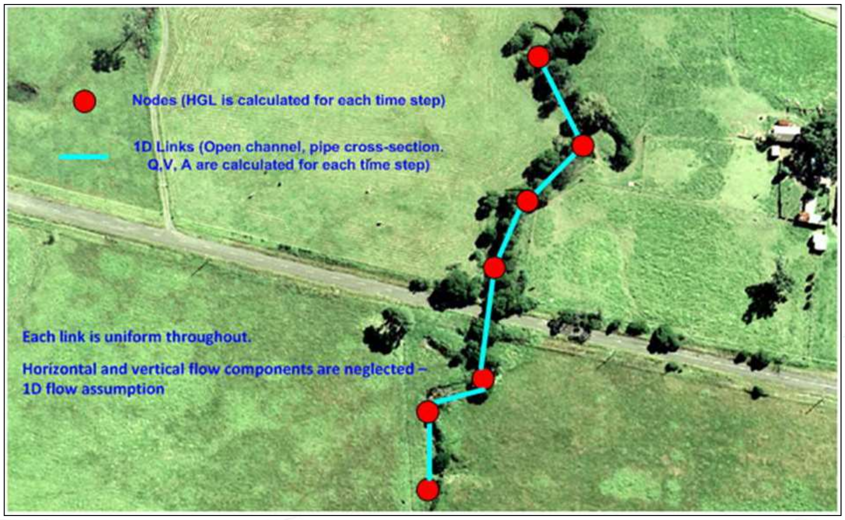
1D Modeling Tools



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1D Flood Modeling Tools

1-Dimensional Models – Advantages:

- Easy and fast to build using cross-sections
- Small amount of input data and a low hardware requirement
- Very large areas can be modeled
- Less complicated theory and easy to troubleshoot
- Plenty of supporting literature and tools available
- Many experienced modelers, it is comparatively easy to find these skills

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1D Flood Modeling Tools

1-Dimensional Models – Disadvantages:

- Cannot model shallow overland flows correctly - pattern is essentially **2D**
- Tends to overestimate the water depth and velocity due to a 1D assumption
- Usually excludes the storage effects in channels such as floodplain storage during high flows events
- Cutting cross-sections can be a tedious trial and error procedure as we can't predict the exact direction and extent of flow before modeling
- Fine scale modeling difficult due to instability
- Requires a lot of engineering judgment and is therefore subject to the skill of the modeler
- Needs a thorough calibration to make the results reliable

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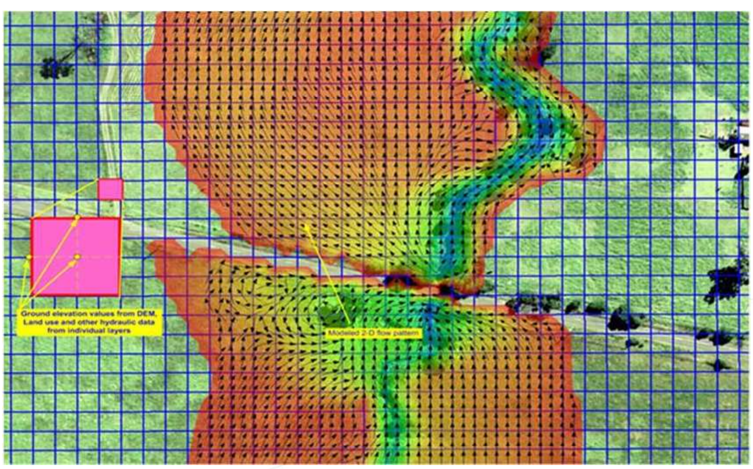
2D Flood Modeling Tools



Grid or Mesh covers the terrain

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2D Flood Modeling Tools

2-Dimensional Models – Advantages

- Flow paths do not need to be pre-determined by the modeler
- Easy to build overland 2-dimensional flood flow models from surface data (Urban flood flow patterns are 2 dimensional)
- Flow paths can change based on water level and the complex topography
- Suitable for fine scale modeling
- Automatically accounts flood flow storage effects (flood fringe, floodway, etc.)
- Losses are automatically accounted for bends, constrictions & expansions
- Suitable for 2D structures such as bridges, culverts and obstructions
- Directly create impressive flood inundation maps
- Less engineering judgment required

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2D Flood Modeling Tools

2-Dimensional Models – Disadvantages

- Precise and dense survey data is desired
- More computational power and time required (GPU helping)
- High storage requirement as the data sets are large for long durations and large cell counts
- Difficult to model very large areas with small cells
- Familiarity means it may be more difficult to troubleshoot than a 1D model
- Fewer experienced 2D models – small user community
- Not all regulators will accept 2D models (changing)

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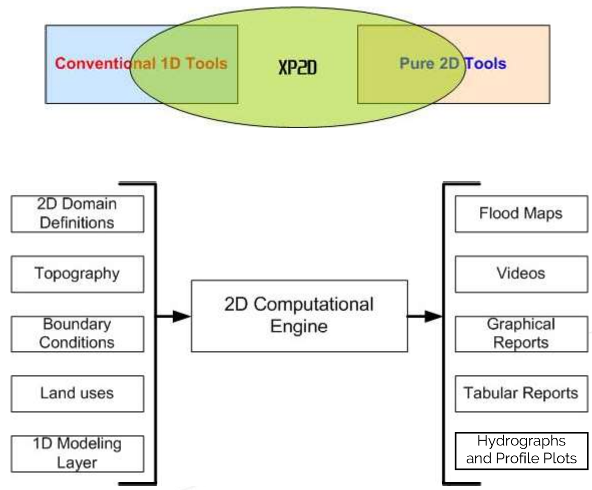
XP2D: Integrated 1D/2D Modeling



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2D Computational Engine

- XP2D is powered by Tuflow
- Shallow Water Equations in 2D Plane
  - Continuity and momentum equations solved in X,Y Plane
  - Hydrostatic pressure distribution assumed
  - Equations are depth averaged
  - Depth of flow is negligible compared to the wavelength

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2D Shallow Water Equations

$$\frac{\partial \zeta}{\partial t}+\frac{\partial (Hu)}{\partial x}+\frac{\partial (Hv)}{\partial y}=0 \qquad \text{(2D Continuity)}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-c_f v+g\frac{\partial \zeta}{\partial x}+gu\left(\frac{n^2}{H^{4/3}}+\frac{f_l}{2g\partial x}\right)\sqrt{u^2+v^2}-\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{1}{\rho}\frac{\partial p}{\partial x}=F_x$$

(X Momentum)

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+c_f u+g\frac{\partial \zeta}{\partial y}+gv\left(\frac{n^2}{H^{4/3}}+\frac{f_l}{2g\partial y}\right)\sqrt{u^2+v^2}-\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{1}{\rho}\frac{\partial p}{\partial y}=F_y$$

(Y Momentum)

where
ζ = *Water surface elevation*
u *and* v = *Depth averaged velocity components in X and Y directions*
H = *Depth of water*
t = *Time*
x *and* y = *Distance in X and Y directions*
c_f = *Coriolis force coefficient*
n = *Manning's n*
f_l = *Form (Energy) Loss coefficient*
μ = *Horizontal diffusion of momentum coefficient*
p = *Atmospheric pressure*
ρ = *Density of water*
F_x *and* F_y = *Sum of components of external forces (eg. wind) in X and Y directions*

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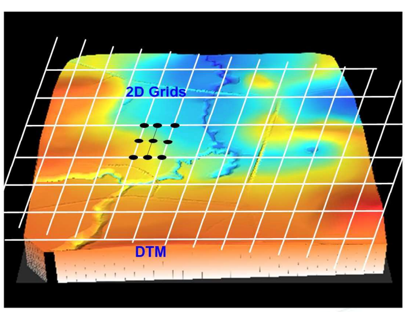
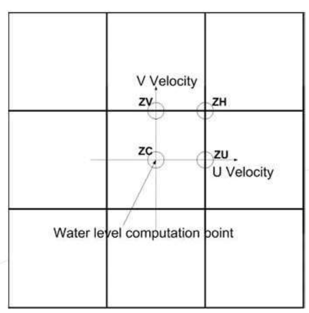
2D Grid Topography

- Topography defined by Z point interrogation of the DTM (TIN)
- 2D model is described as a grid
- C, U, V, and H elevations are interrogated (ZC,ZU,ZV, and ZH)





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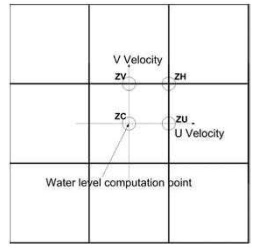
2D Elevation "Z"-Points



ZC Point:

- Defines volume of active water
- Volume = cell area * cell water depth
- Controls when a cell becomes wet and dry

ZU and ZV points:

- Control how water is conveyed from one cell to another
- Are where the momentum equation terms are centered
- Are deactivated if the cell has dried (based on the ZC point) and cannot flow

ZH points:

- Play no role hydraulically
- Are, by default, the only elevations to be written to the SMS .2dm mesh file

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2D Domain Definition

2D Domain can contain:

- Active and Inactive area (buildings, areas of 1D computation)
- Head and Flow Boundaries as polylines
- Landuse Polygons to prescribe roughness and infiltration
- Flow and Rainfall Polygons
- Ridge and Gulley Breaklines
- Fill Area polygons (cut or fill)
- Static and Dynamic Elevation Shapes
- Connections to 1D

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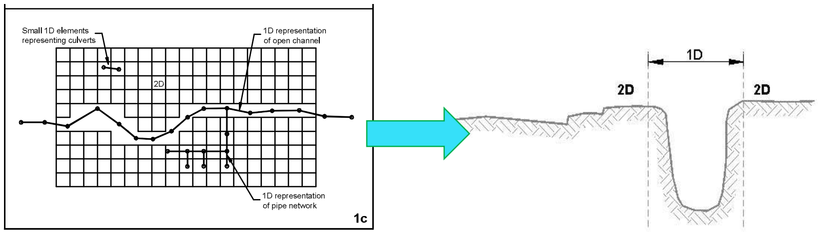
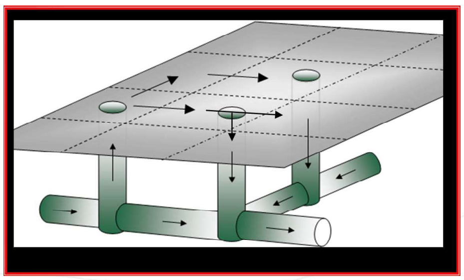
Typical 1D/2D Linkages





- Flooding at storm manholes and inlets
- Flooding due to lack of network capacity
- 1D closed system and 2D overland flow system
- 1D channel flow and 2D floodplain flow

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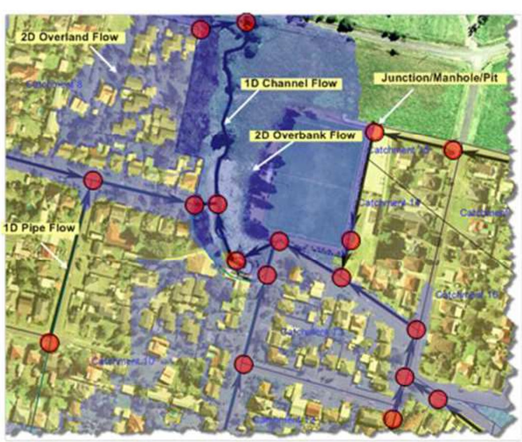
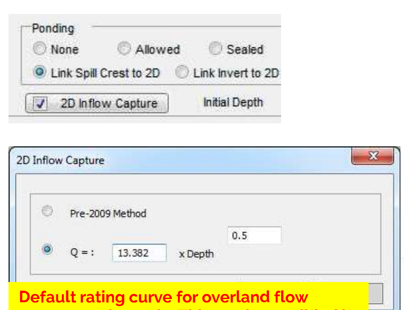
Node: 1D/2D Linkage





Default rating curve for overland flow capture to the node. This can be modified if the user has another one.

The outflow from node to 2D domain is computed by the mass balance at the node.

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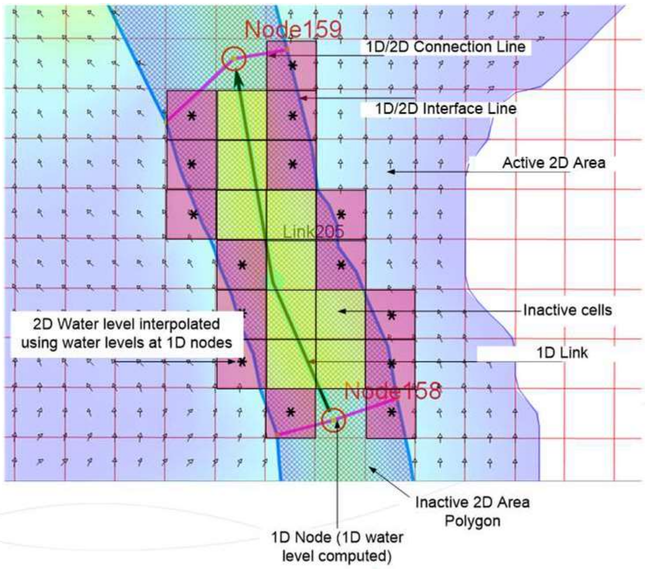
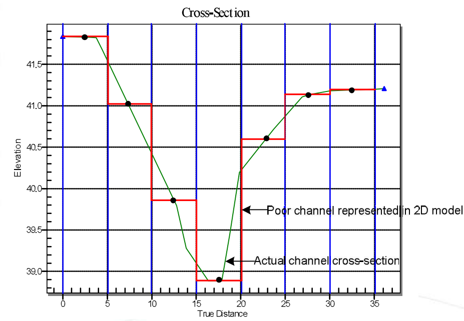
Channel: 1D/2D Linkage





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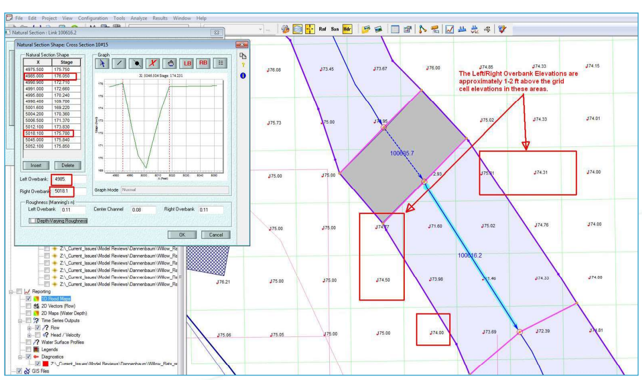
Typical Model Setup Errors

- Locate the 1D/2D Interface along the top of bank
- Width of 1D and width of inactive cells should be equal
- Elevation in 1D does not match well with the grid



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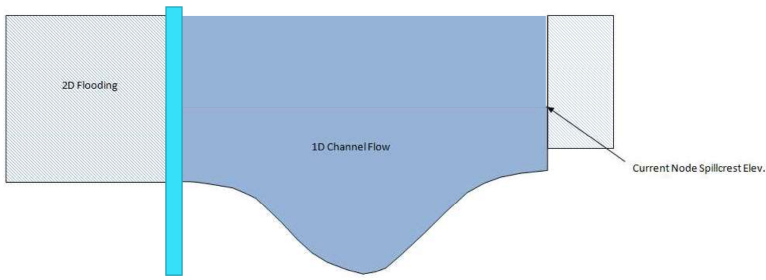
Typical Model Errors

- 1D Nodes are not high enough to allow 1D flow to rise to a flood level (creates pressure flow in the river)
- Need VERT_WALLS=ON and nodes higher than expected flood level
- Raise nodes to at least the expected flood elevation



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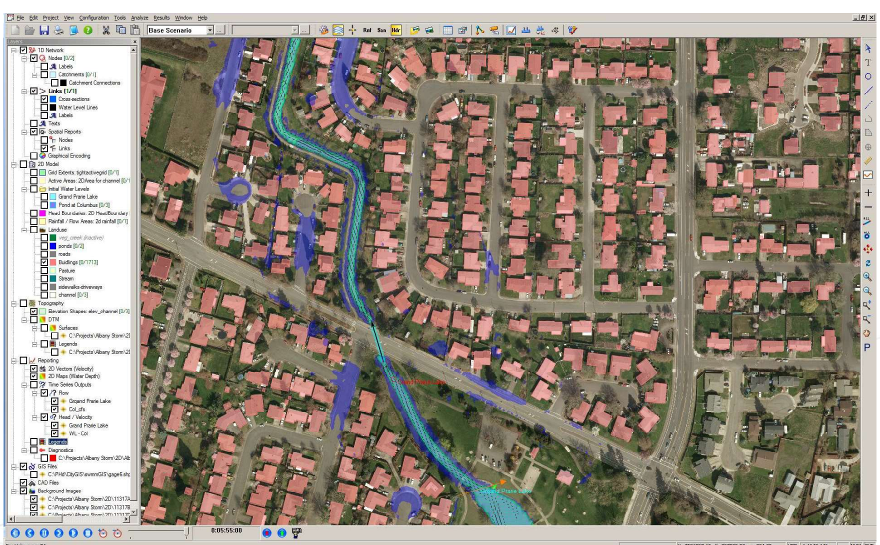
Suitable for Urban Areas



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2D Direct Rainfall on Grid

- Rainfall applied equally to grid cells within a polygon
- Initial & continuing losses, Green Amp and Horton
- Rainfall applied to polygonal areas (1 or multiple polygons)

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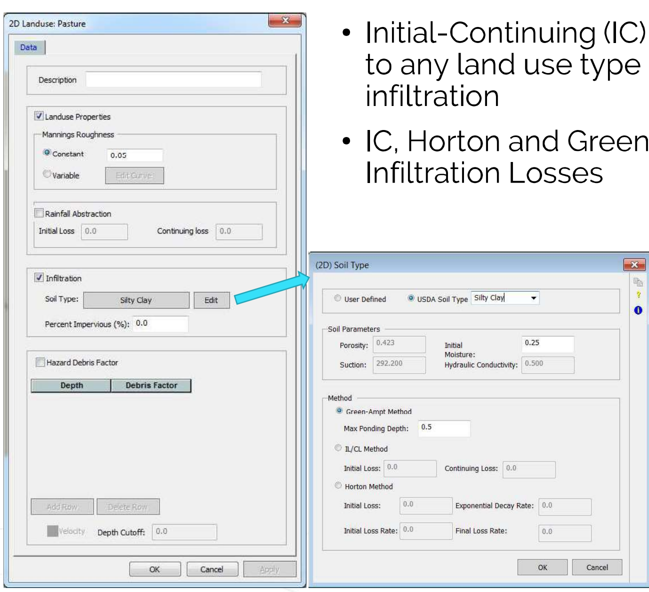
2D Infiltration



- Initial-Continuing (IC) loss model can be applied to any land use type as rainfall abstraction or infiltration
- IC, Horton and Green-Ampt can be applied for Infiltration Losses

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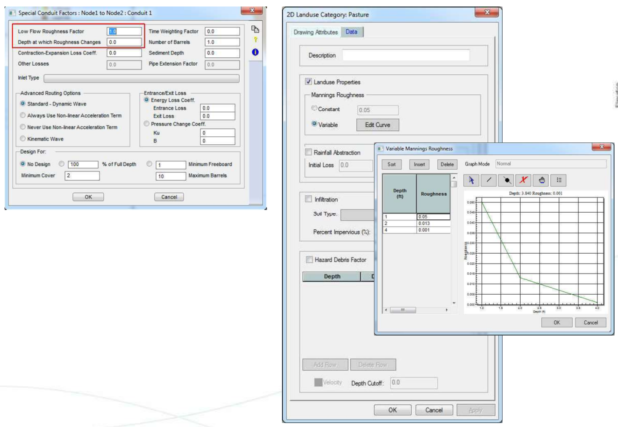
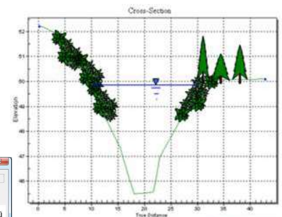
Depth Dependent Roughness

- Roughness is classic calibration parameter
  - 1D vertical changing roughness in Conduit Factors
  - 2D vertical changing roughness based on Landuse polygons





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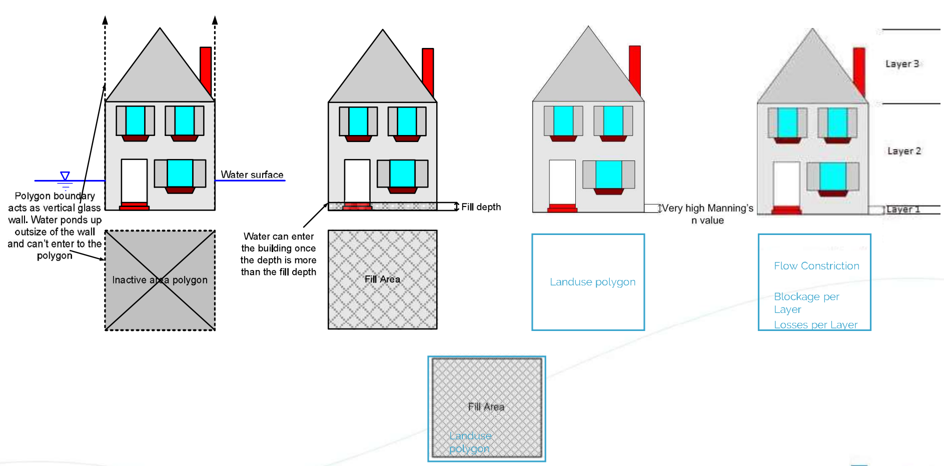
Simulation of Buildings in 2D



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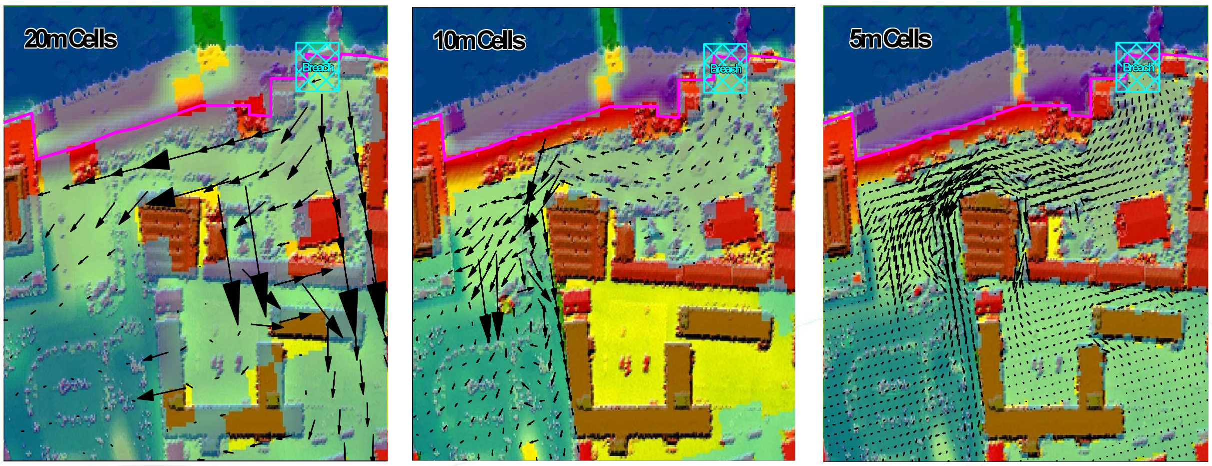
2D Grid Size: Implications



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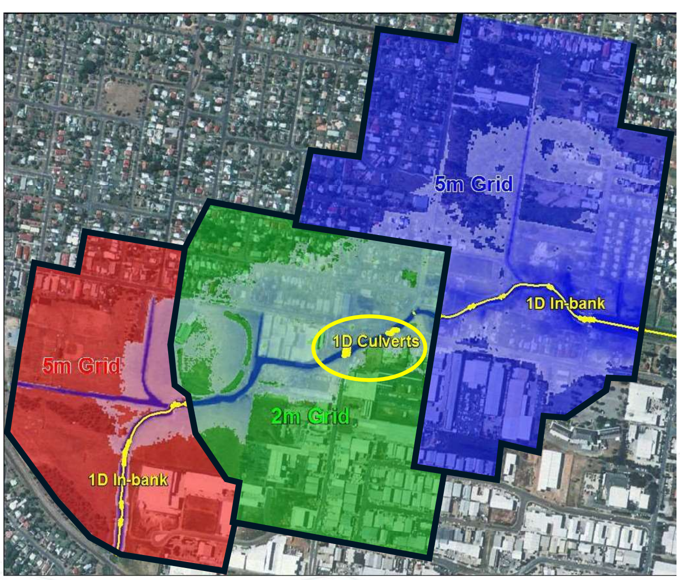
Multiple 2D Domains



- Fine grid over area of interest
- Coarse grid(s) elsewhere
- Use 1D where grid resolution too coarse

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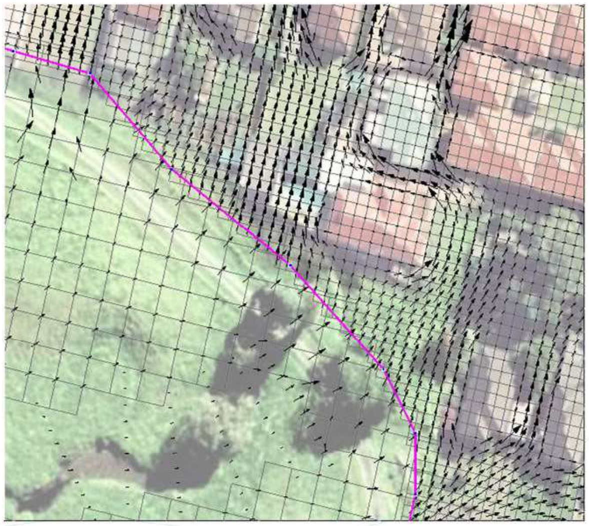
2D/2D Interface – How It Works?



- Multiple Domains of different size
- 2D/2D Interface
- Vertices on 2D/2D become 1D nodes for flow exchange

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Workshop

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