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Culvert, the choking point of network resilience

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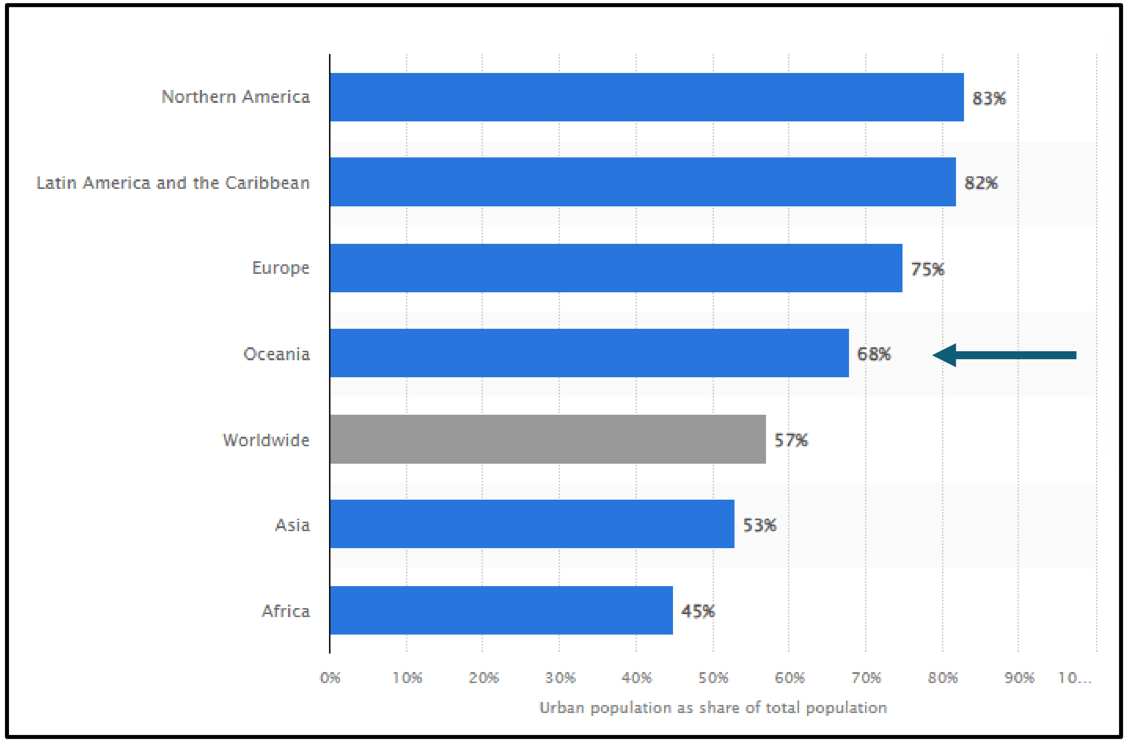
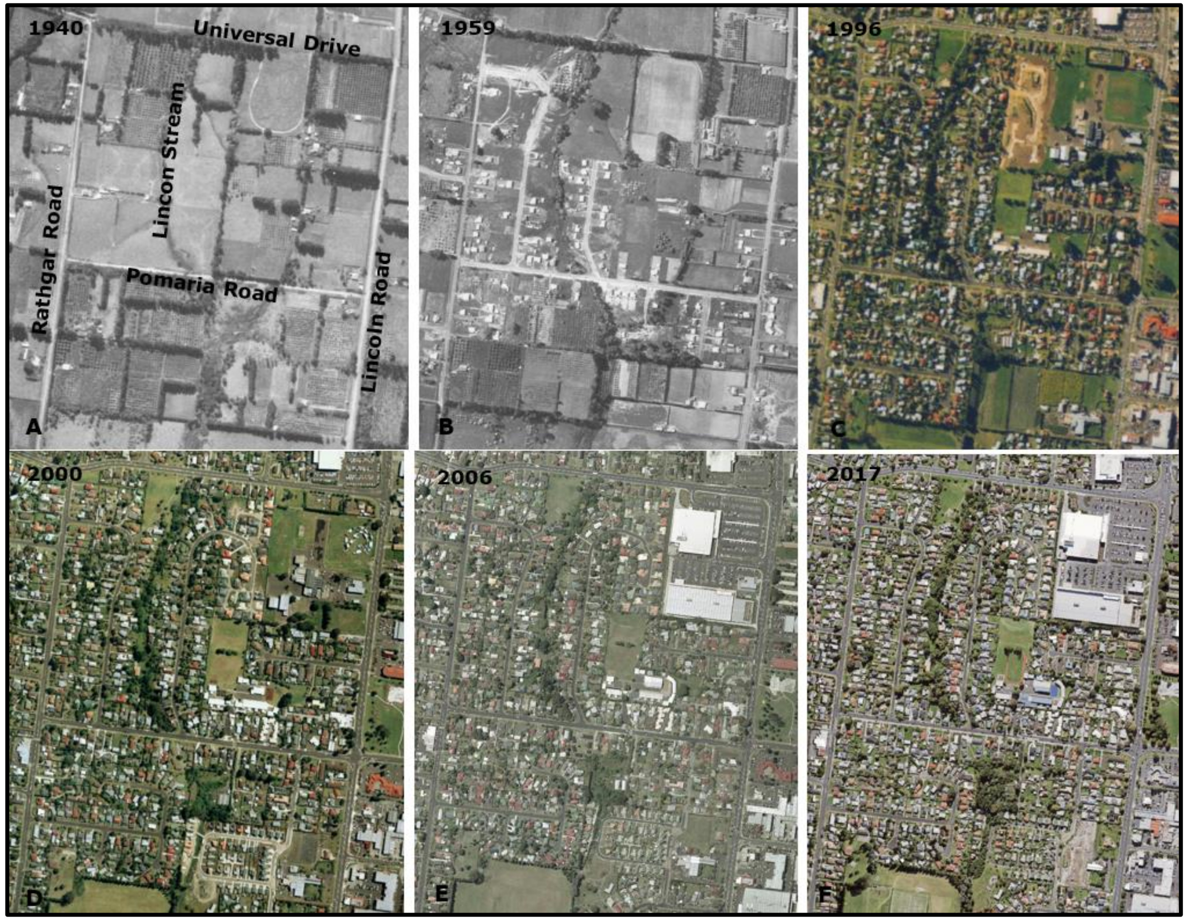
Introduction/Background



https://www.statista.com/statistics/270860/urbanization-by-continent/

- NZ has approximately 5 million inhabitants most of whom reside in urban areas.
- With this urbanisation, the hydrological cycle is increasingly impacted and affecting flow characterises and conveyance in catchments .
- Coupled with changing climate, existing infrastructure is progressively burdened with potentially detrimental consequences including loss of life as experienced during the 2023 Auckland floods.
- In urban settings, culverts are critical conveyance components whose role and the danger they pose (due to design flaws and poor maintenance) may not be fully appreciated.
- Understanding different culvert design principles and approaches within the flood assessment framework is crucial in formulating appropriate mitigation measures and making informed decisions.

Urbanisation

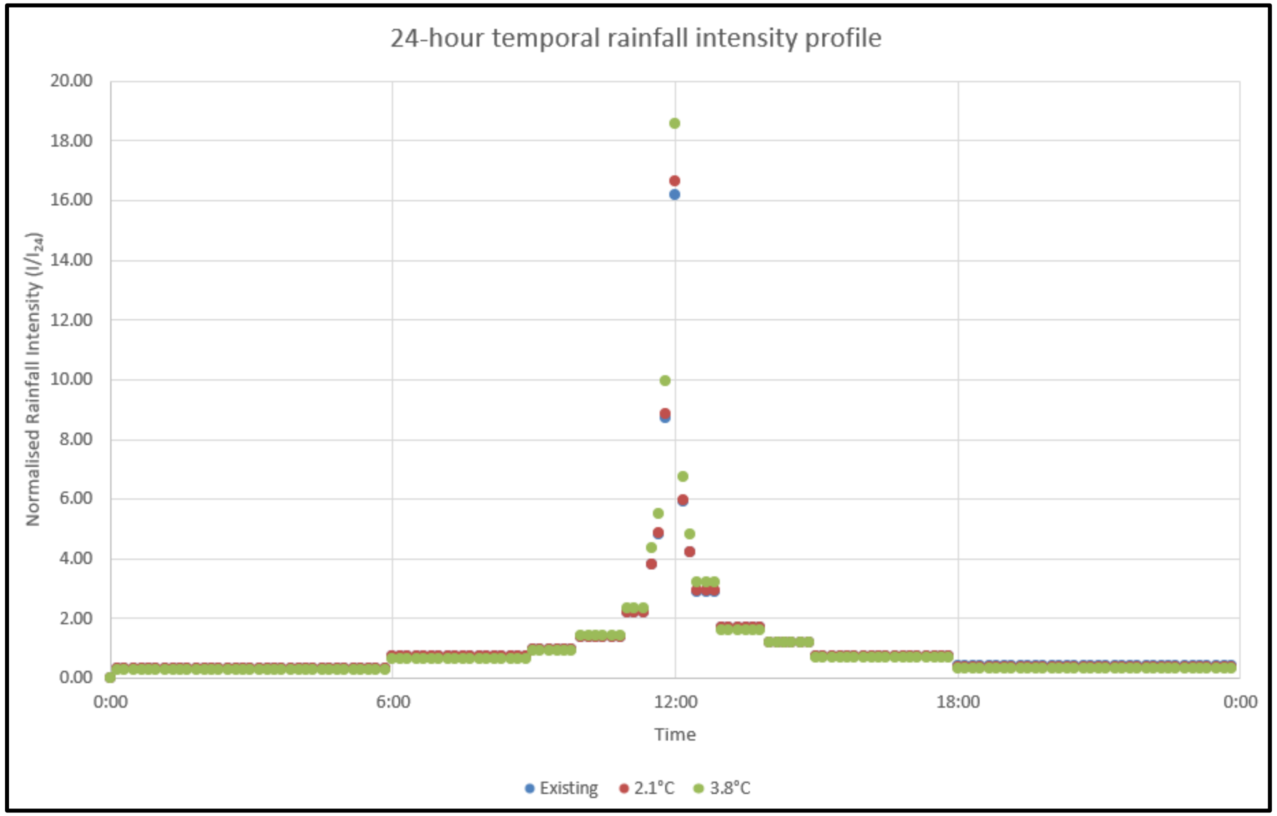


Henderson, West Auckland (Case 1)

From farmland to urban (comprising MHU, THAB, general business zones and open spaces)

Currently at 57% impervious, set to increase to 71% based on AUP zoning

Climate Change Challenges



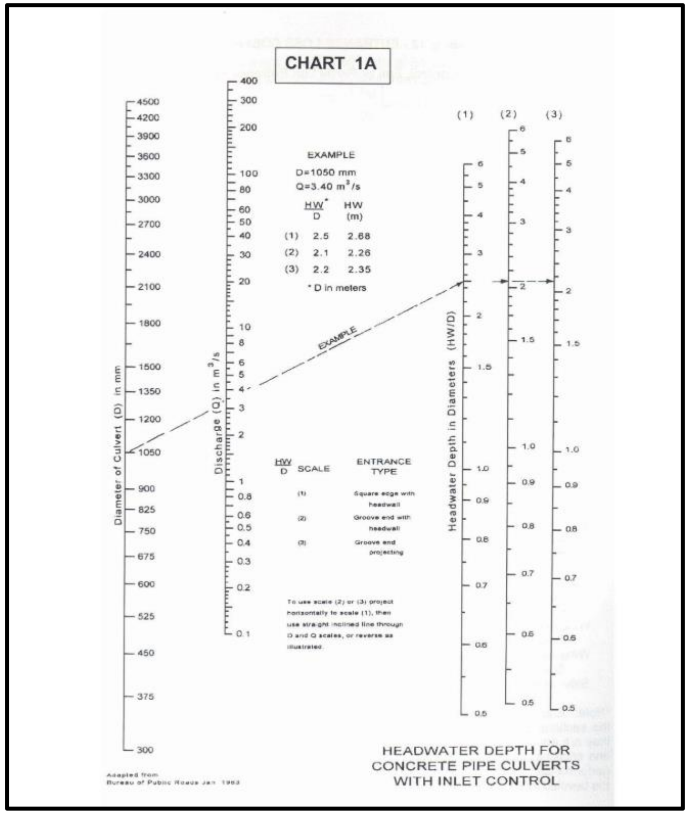
Auckland Region

Stormwater Code of Practice V4 - climate change uplift factor of 2.1°C should be applied for both primary and climate change uplift factor of 3.8°C should be applied for secondary runoff

Christchurch Region

Waterways, Wetlands and Drainage Guide (2020) suggests an RCP 8.5 scenario for the design of permanent infrastructure

Culvert Modelling 1D or 2D?



Box Culvert

Invert Elev Dn (m)	= 52.1000
Pipe Length (m)	= 17.1000
Slope (%)	= 3.8012
Invert Elev Up (m)	= 52.7500
Rise (mm)	= 300.0
Shape	= Box
Span (mm)	= 1200.0
No. Barrels	= 2
n-Value	= 0.012
Culvert Type	= Flared Wingwalls
Culvert Entrance	= 30D to 75D wingwall flares
Coeff. K,M,c,Y,k	= 0.026, 1, 0.0347, 0.81, 0.4

Embankment

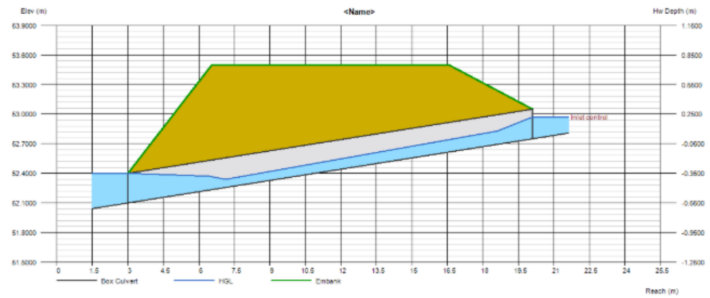
Top Elevation (m)	= 53.5000
Top Width (m)	= 10.0000
Crest Width (m)	= 3.0000

Calculations

Qmin (cms)	= 0.4000
Qmax (cms)	= 0.4000
Tailwater Elev (m)	= Crown

Highlighted

Qtotal (cms)	= 0.4000
Qpipe (cms)	= 0.4000
Qovertop (cms)	= 0.0000
Veloc Dn (m/s)	= 0.5556
Veloc Up (m/s)	= 1.1769
HGL Dn (m)	= 52.4000
HGL Up (m)	= 52.8916
Hw Elev (m)	= 52.9709
Hw/D (m)	= 0.7363
Flow Regime	= Inlet Control



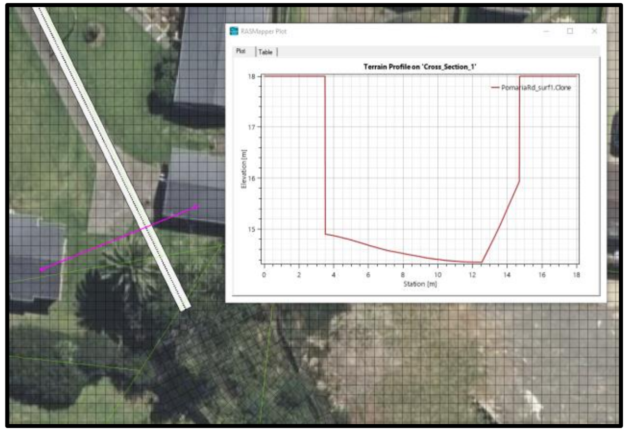
1D Approach

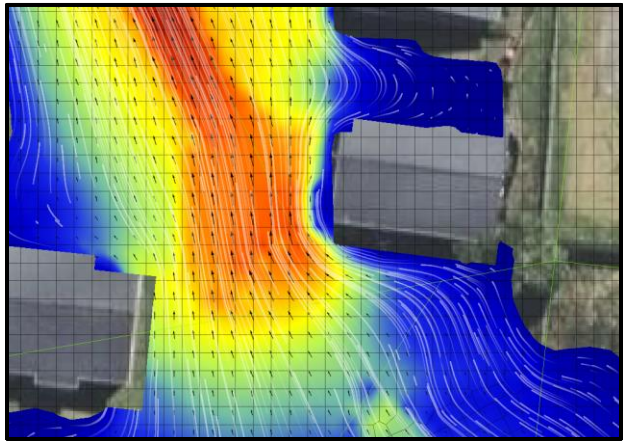
Culvert nomograph Charts
- Culvert size is limited to standard sizes which requires careful interpolation,
  - For high head water depths values read from charts become less reliable
  - Large length/slope ratios exceeding chart values and requiring modifications,
  - The process is more tedious and requires some trial and error.

1D Modelling software better than manual methods:
- Simpler to use
- provides more analysis/results with better diagrammatic representation

But has other limitations:
- Not suitable for complicated projects
- Road's cross sections not easily modelled.
- Requires more input parameters and greater understanding of hydraulics.
- Assumes constant elevations across entire cross section

Culvert Modelling 1D or 2D?





2D Approach

Offers numerous advantages in the design and analysis of culverts in the urban context

modellers can better capture the complexities of flow dynamics including turbulence, eddies, and hydraulic jumps

Risk Quantification and Mitigation

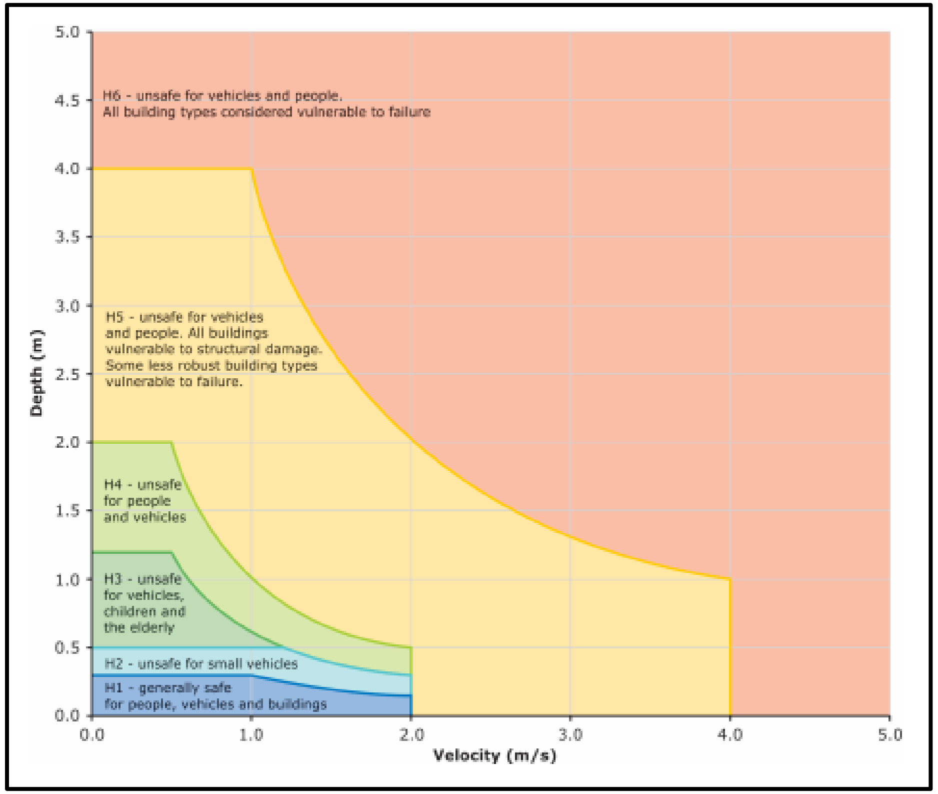
Auckland Council Technical Specification for Stormwater Flood Modelling Version 4 (2011)

Description	Depth-velocity Criteria
Potential Hazard	0.05m < Depth < 0.1m
Minor Hazard	0.1m < Depth < 0.3m and Velocity < 2.0m/s
Significant Hazard	Depth > 0.3m and Depth > 0.1m & Velocity > 2.0m/s

Auckland Transport - Transport Design Manual (TDM) for Road Drainage Version 1.2

Description	Depth-velocity Criteria
Pedestrian safety	No Obvious danger dg x V ≤ $0.6m^2/s$ Obvious danger c ≤ $0.4m^2/s$
Vehicle safety	Maximum height of energy line 300mm above roadway surface for areas subject to transverse flow. The exception is specific floodway design and additional vehicle warning and protection, where dg x Vave ≤ $0.3m^2/s$. On street parking is not to be permitted where overland flow exceeds $0.3m^2/s$.

Australian Rainfall and Runoff Guidelines (ARR)



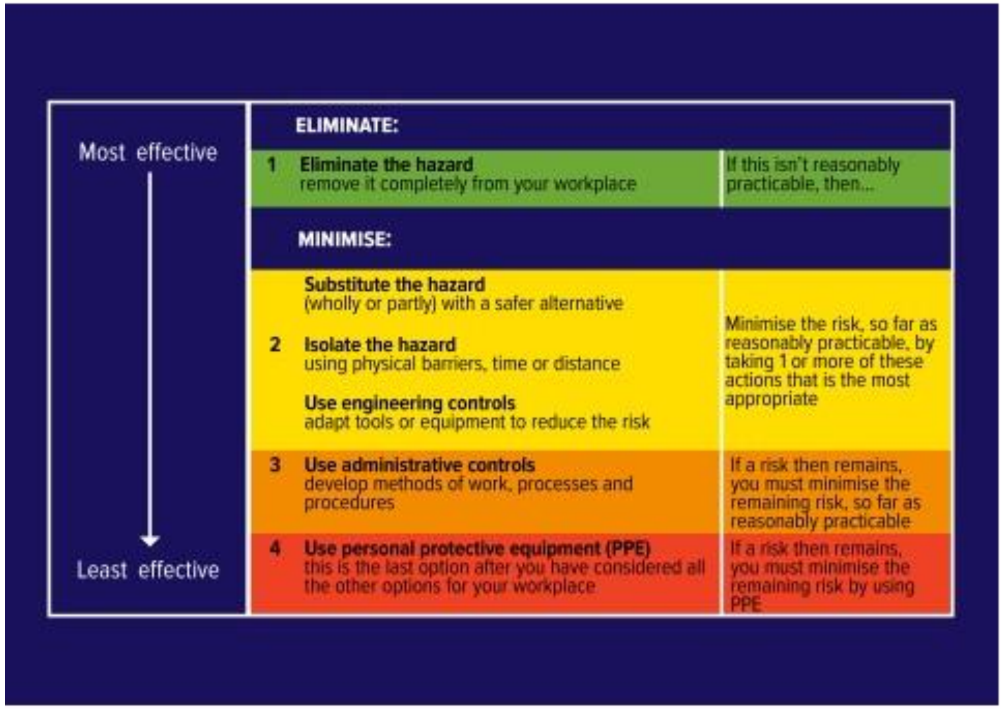
Risk Quantification and Mitigation

Drawing from Site Safe risk control philosophy, the most effective way to address flood hazards is to eliminate the risk.

In an urban catchment this may not always be practicable / achievable thus minimisation key.

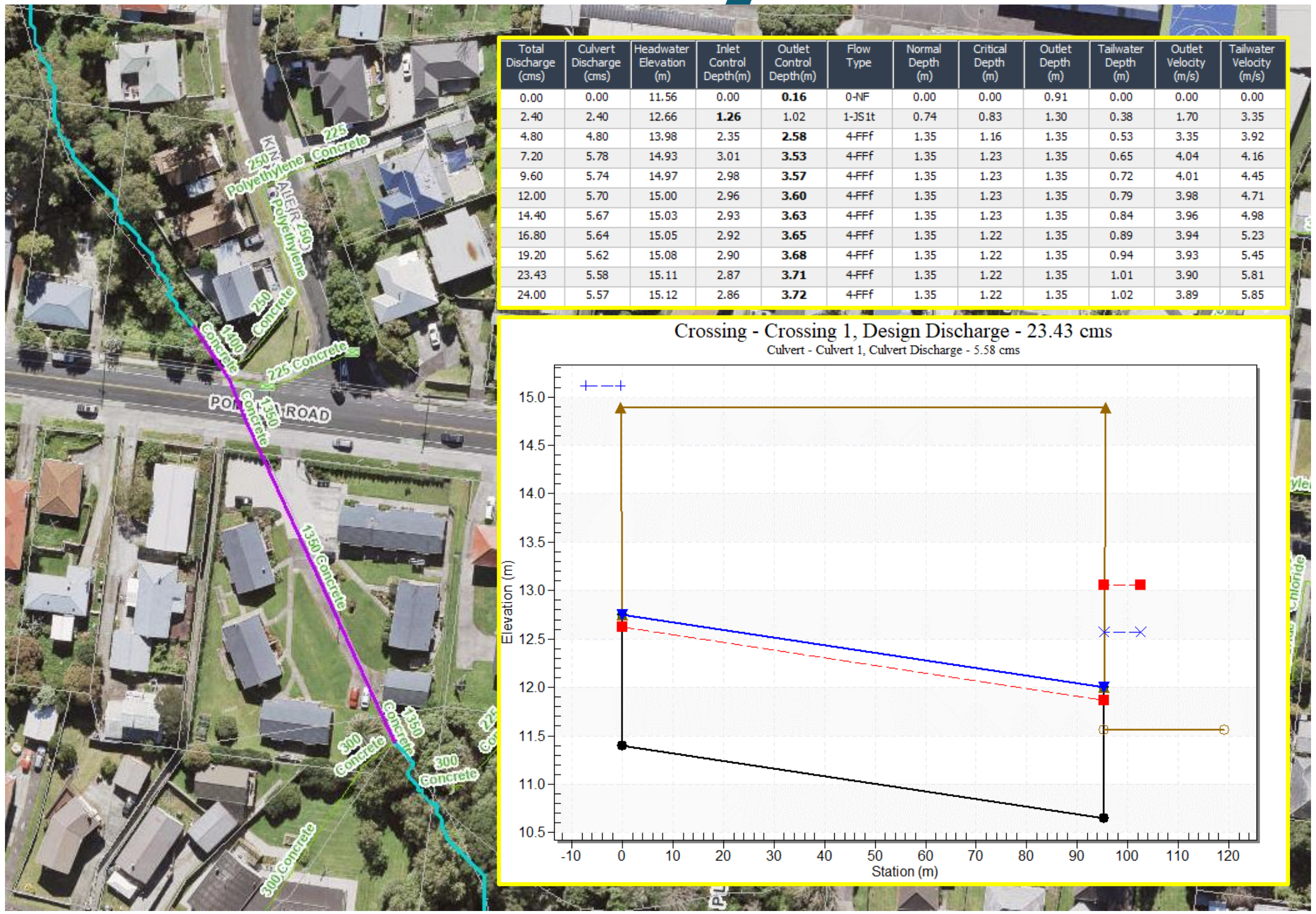
This is informed by the various receptors to the risk, i.e., people, buildings and vehicles.

Culverts fit into this hierarchy as an engineering control that must be appropriately adapted into the overall stormwater management strategy.



https://www.sitesafe.org.nz/guides--resources/practical-safety-advice/risk-control/

Case Study 1



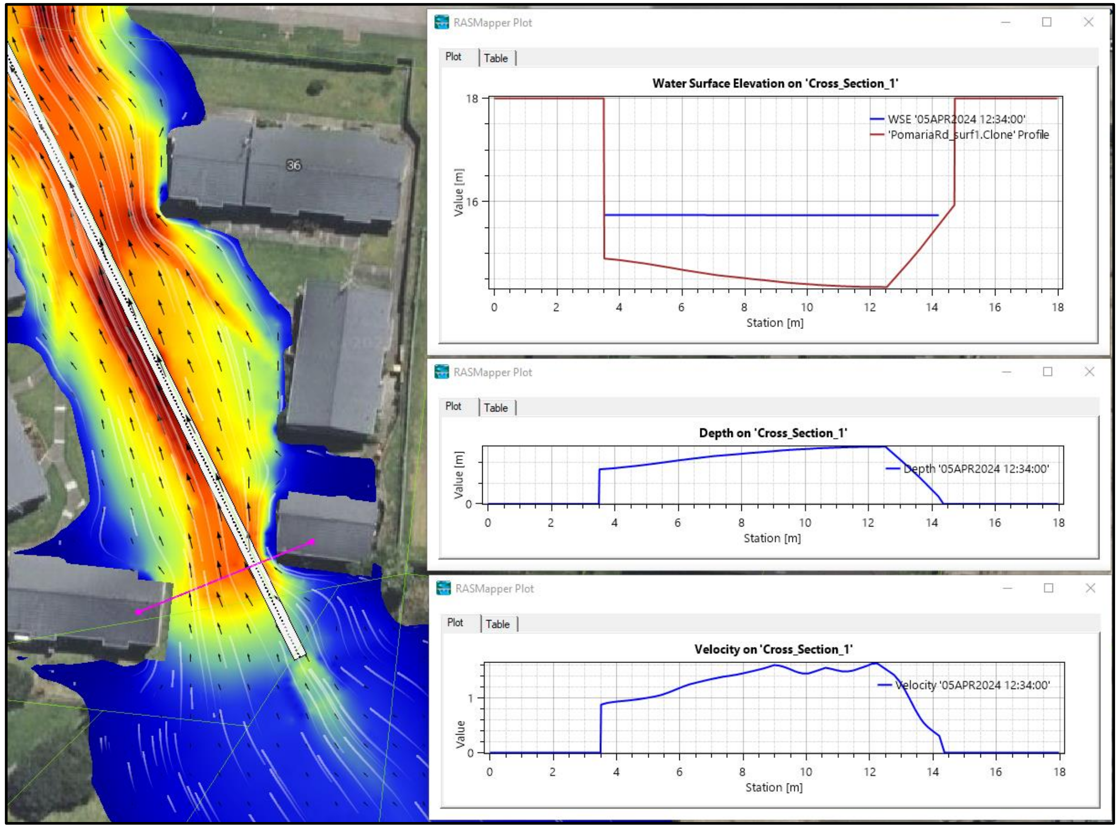
Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth(m)	Outlet Control Depth(m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0.00	0.00	11.56	0.00	**0.16**	0-NF	0.00	0.00	0.91	0.00	0.00	0.00
2.40	2.40	12.66	**1.26**	1.02	1-JS1t	0.74	0.83	1.30	0.38	1.70	3.35
4.80	4.80	13.98	2.35	**2.58**	4-FFf	1.35	1.16	1.35	0.53	3.35	3.92
7.20	5.78	14.93	3.01	**3.53**	4-FFf	1.35	1.23	1.35	0.65	4.04	4.16
9.60	5.74	14.97	2.98	**3.57**	4-FFf	1.35	1.23	1.35	0.72	4.01	4.45
12.00	5.70	15.00	2.96	**3.60**	4-FFf	1.35	1.23	1.35	0.79	3.98	4.71
14.40	5.67	15.03	2.93	**3.63**	4-FFf	1.35	1.23	1.35	0.84	3.96	4.98
16.80	5.64	15.05	2.92	**3.65**	4-FFf	1.35	1.22	1.35	0.89	3.94	5.23
19.20	5.62	15.08	2.90	**3.68**	4-FFf	1.35	1.22	1.35	0.94	3.93	5.45
23.43	5.58	15.11	2.87	**3.71**	4-FFf	1.35	1.22	1.35	1.01	3.90	5.81
24.00	5.57	15.12	2.86	**3.72**	4-FFf	1.35	1.22	1.35	1.02	3.89	5.85

- Residential catchment ~75ha
- 1350mm culvert traversing developed parcel and road
- 1D model outputs culvert flow and amount of overtopping but no indication of the flood extent, velocities and interaction with structures over embankment (which includes housing and road).
- Model shows culvert is insufficiently sized, resulting in flooding
- This shortcoming requires use of other tools to help determine extent/magnitude of problem and how best to address it.

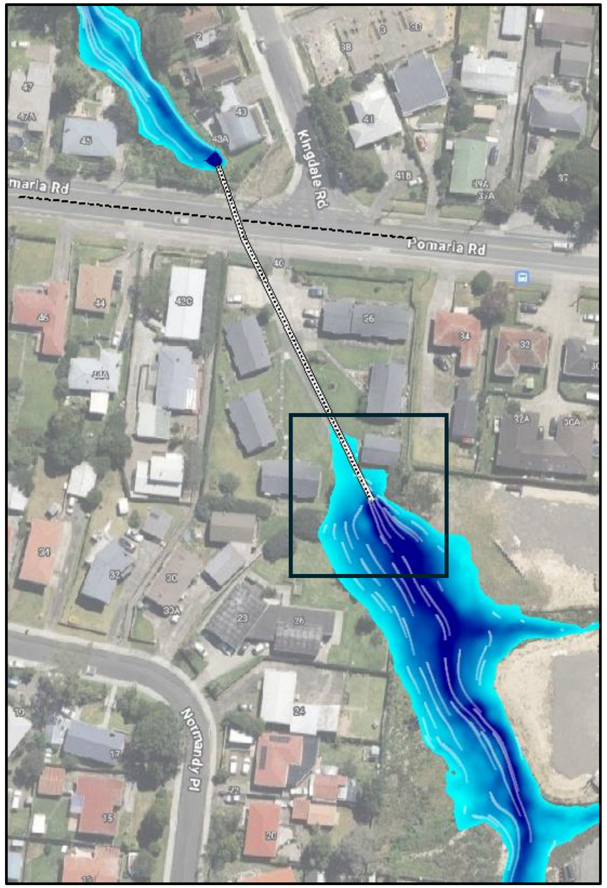
Case Study 1

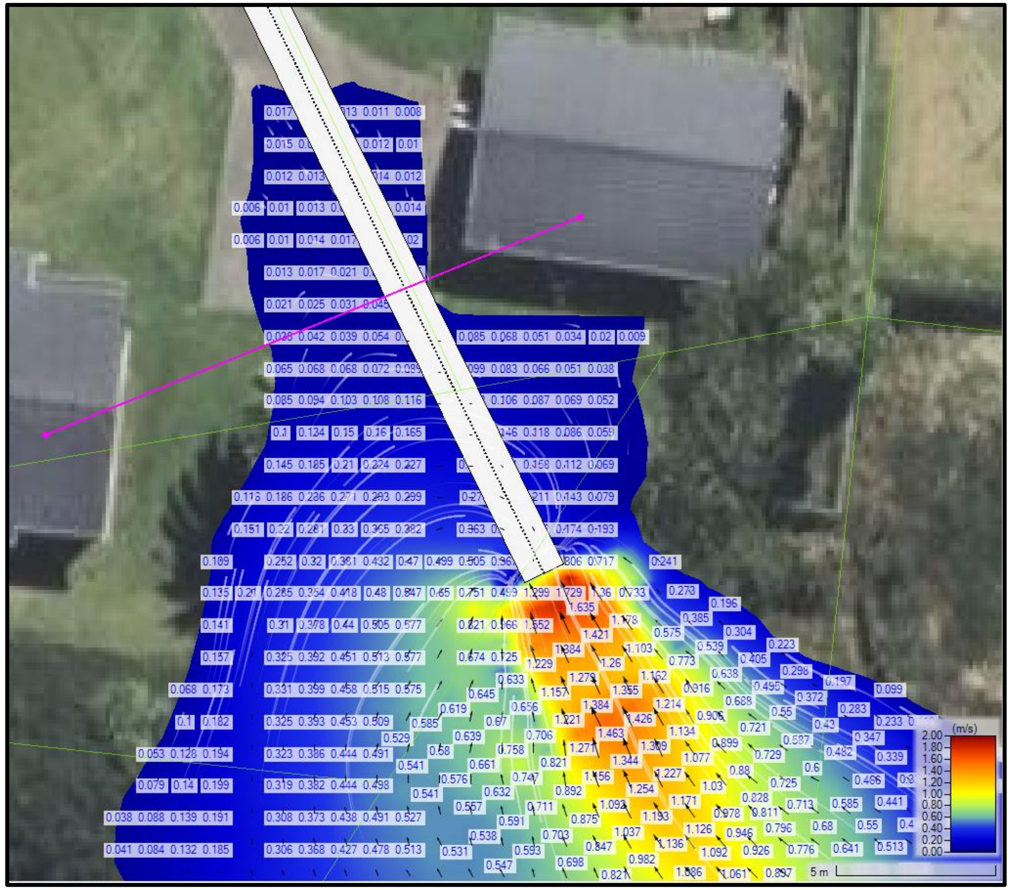
2D model

- Gives a clear indication of the flow extent
- Shows which structures are affected
- Overland flows, velocities and other parameters can be easily extracted to help inform remedial measures that can be taken
- Hazard over the road can be readily quantified and appropriate measures assessed



Case Study 1





In the risk control hierarchy, it is demonstrated using the 2D model that the hazard can be managed through engineering controls where the culvert is upgraded to convey the flow without overtopping.

This integrated 2D approach allows engineers to implement an appropriate measure that significantly reduces potential damage to property and risk to life.

Results from 2D models can be applied in all stages of projects where various combinations of potential problems/issues can be explored and measures to avoid/mitigate incorporated into the design.

Case Study 2

Mainly commercial/industrial catchment over 100ha

3mW x 1.5mH box culvert (Target Rd) and 825mm dia. (Link Dr) Culvert downstream

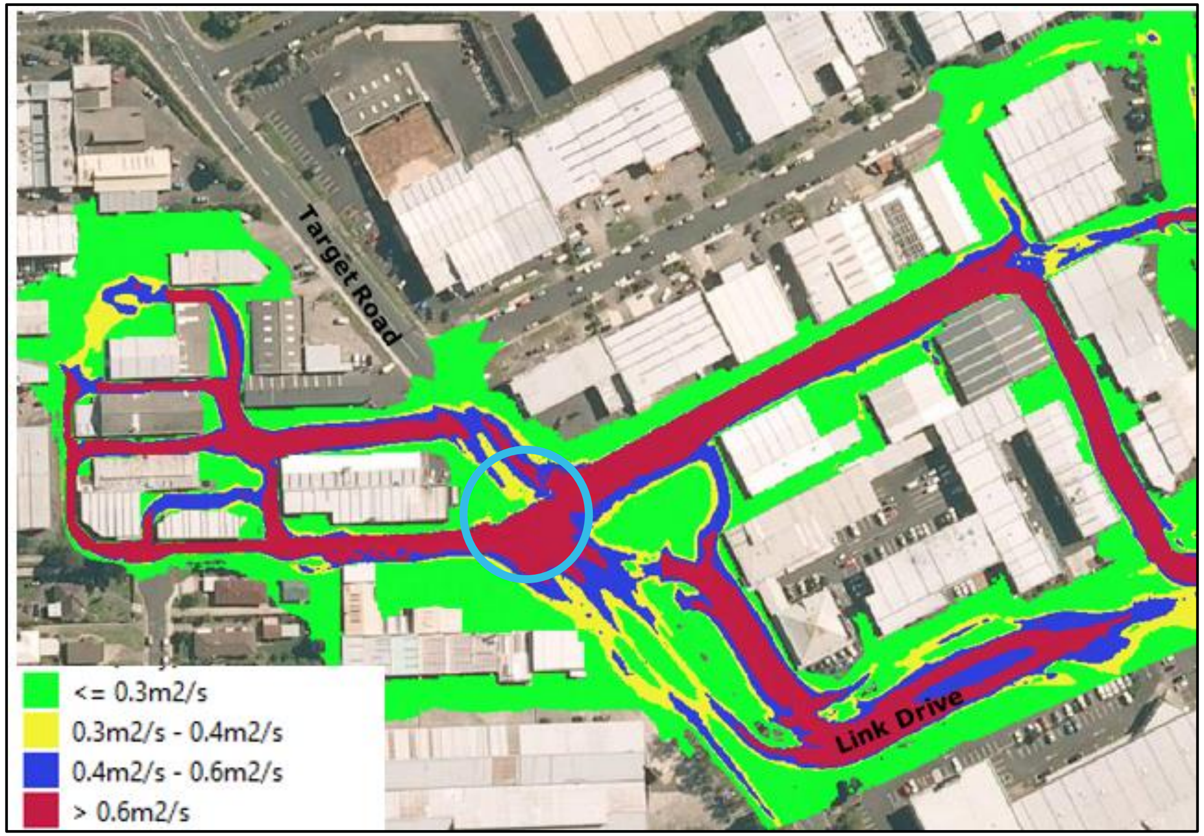
Complex catchment with multiple variables

Case Study 2

2D Modelling adopted for hazard assessment

Results indicate that at Target Rd culvert crossing the risk surpasses safety thresholds for both pedestrians and vehicles (AT TDM)

These results can be utilised in forming site specific emergency escape plans (administrative control in the hierarchy)



Case Study 2

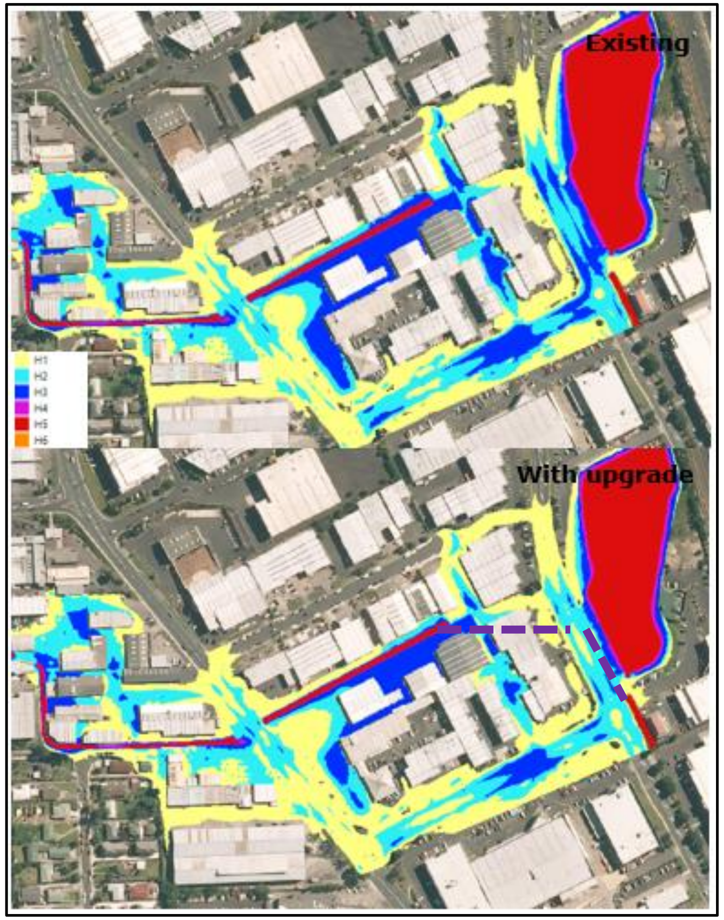
ARR assessment indicates multiple areas (away from the culverts) where the risk to people is significant.

Risk cannot be eliminated in this case and infrastructure upgrades explored.

Replacement of 825mm dia. culvert with a 3mWx1.5mH does not significantly improve safety

Implementing engineered controls in such complex catchments is often challenging and improvement minimal.

Administrative controls are thus important in these types of catchments



Conclusion

- Culverts are critical components in stormwater conveyance systems that require a great deal understanding to reduce their potential for exacerbating flood risks in an ever change urban environment under the cloud of increasingly extreme weather events.
- Advances in computing and data quality has made 2D modelling of culverts an attractive tool over tradition and 1D methods to gain a greater understanding of flooding behaviour in urban areas.
- Enhanced understanding enables engineers and planners to identify vulnerabilities, anticipate potential failures and device appropriate mitigation strategies.

Thank you!
Questions? Patai?

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