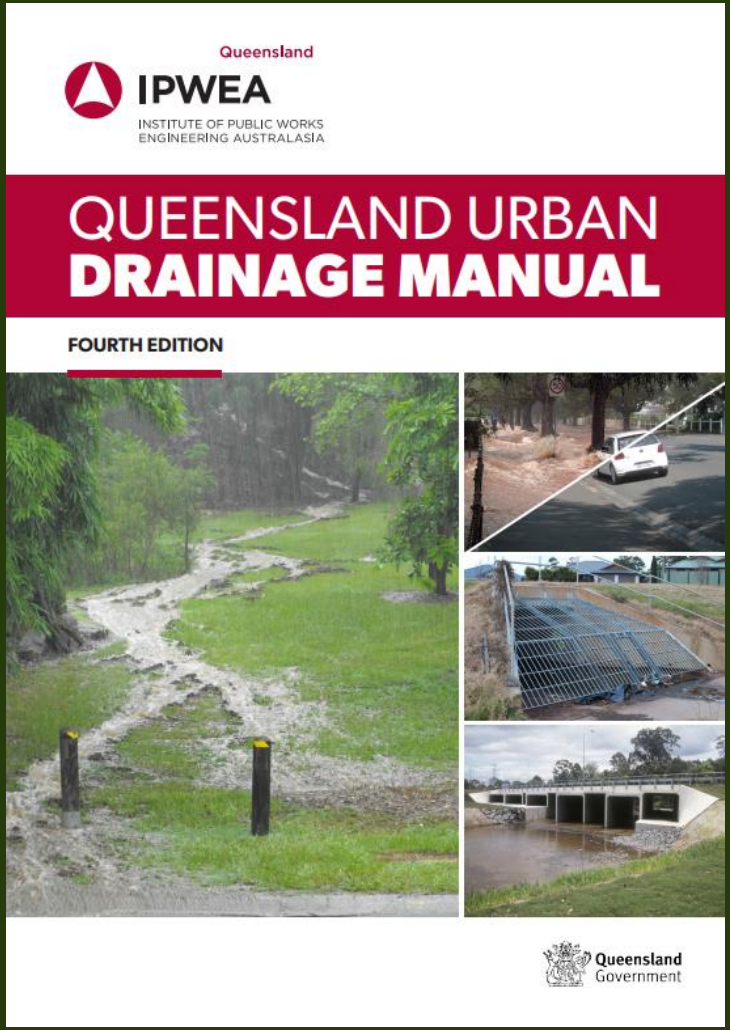
Engineering Fundamentals Stormwater

Pipe Design

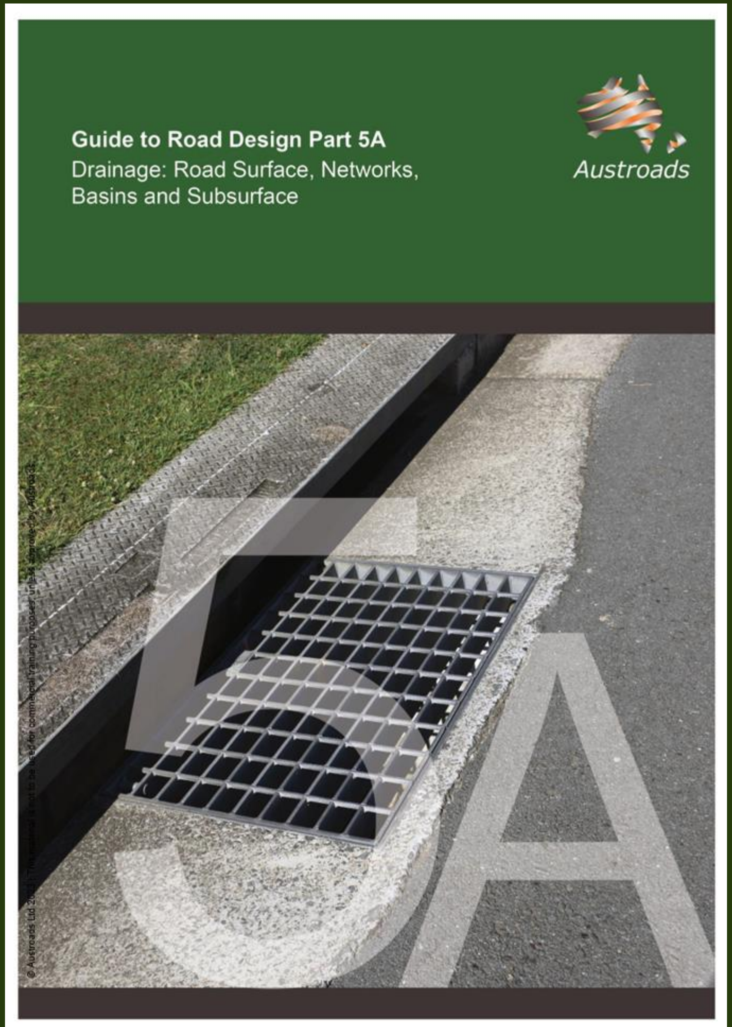
Introduction

Local Standards and Guidelines

- Queensland Urban Drainage Manual (QUDM).
- Austroads Guide to Road Design Part 5A.



Source: Institute of Public Works Engineering Australasia, Queensland 2017



Source: Austroads Ltd., 2023

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Piped Network Elements

- Drainage inlets
- Access chambers
- Underground pipes
- Outlets

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Drainage Inlets

- Capture surface runoff.
- Control flooded limits (width, depth, depth*velocity product).
- Redirect flows underground into pipe network.

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Access Chambers

- Provide access for maintenance.
- Changes of direction, grade, level.
- At pipe junctions.

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Pipes

- Convey captured runoff from inlets.
- Multiple pipes interconnected within a system.
- Can be single reaches too.
- Gravity system that discharges to:
    - Detention basin.
    - Bioretention system.
    - Rainwater haversting tank.
    - Existing pit.
    - Headwall outlet.

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Outlets

- Allows piped network to discharge captured stormwater.
- Headwalls provide a stable, controlled point of discharge.

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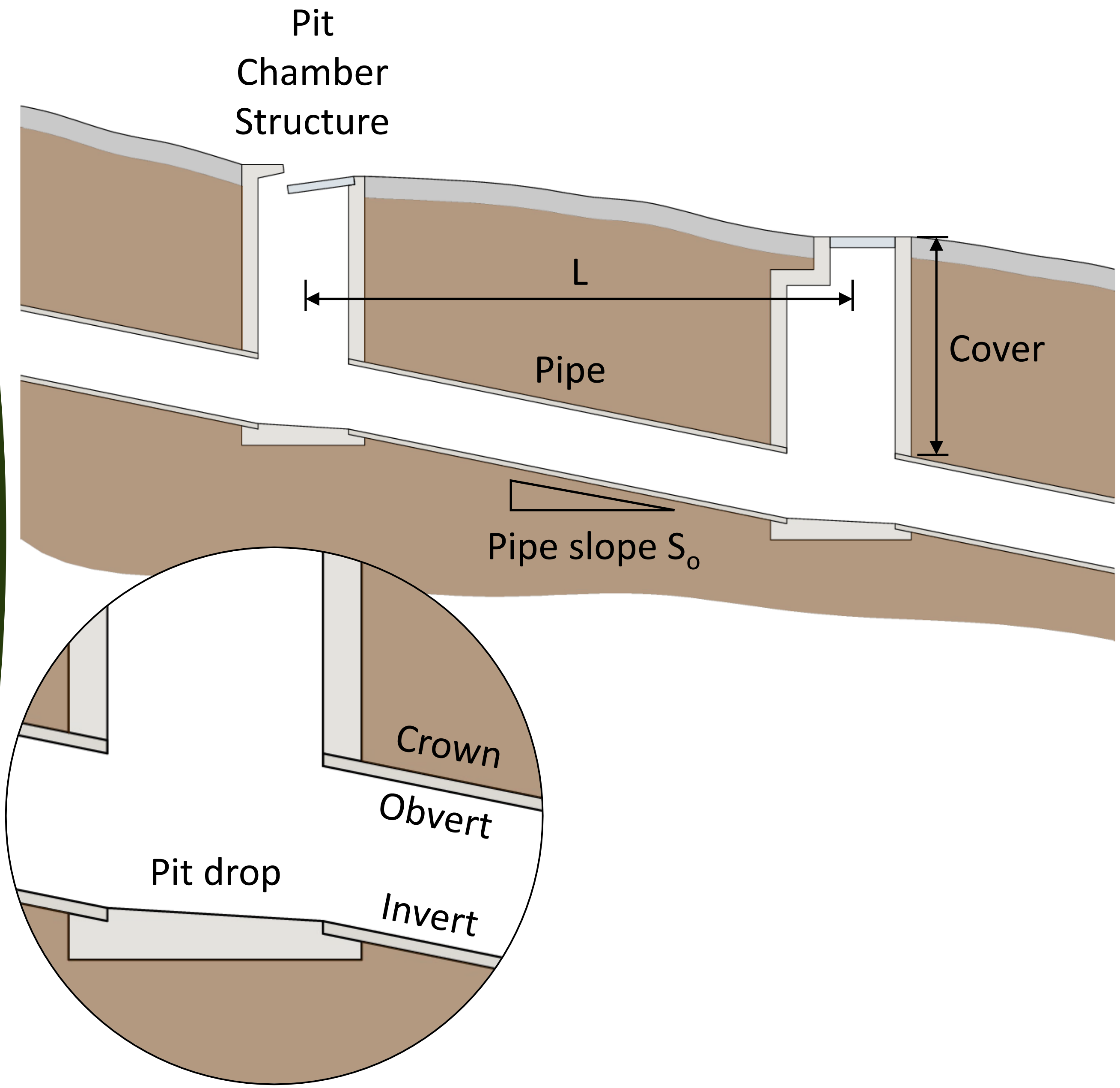
Terminology

- Pipe length measured to centre of pit for design purposes.
- Pipe cover measured vertically from surface level to crown.
- Pipe slope, S_o
  (do not confuse with friction slope, S_f)
- Invert: Lowest point inside pipe.
- Obvert: Highest point inside pipe.
- Crown: Highest point outside of pipe.
- Pit drop: Required to ensure free draining through pit.



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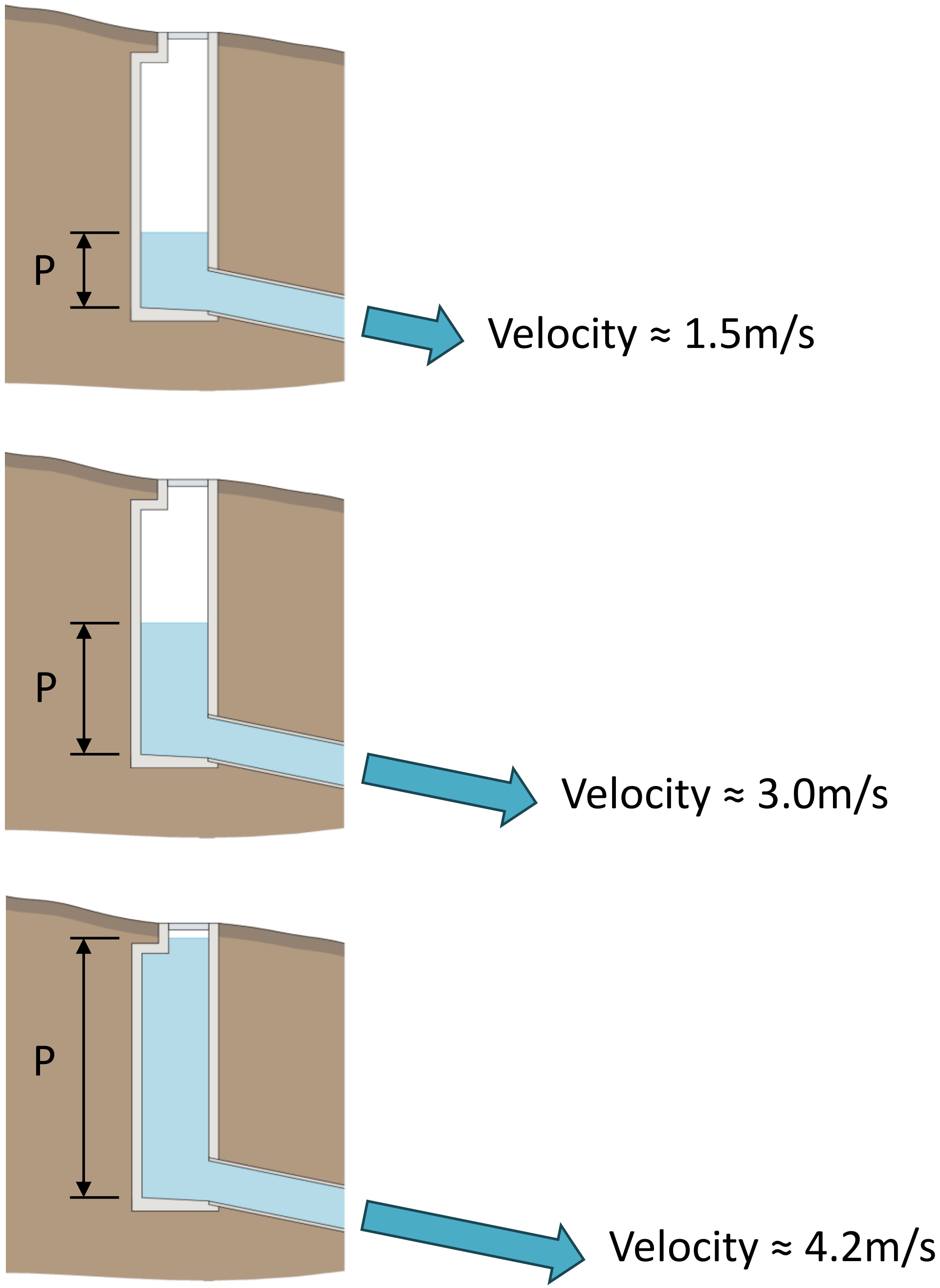
Pressure Head

- The force that water exerts due to the weight of water above it.
- Affects flow rate - How quickly water flows through the pipes.
- The greater the pressure head, the faster the water flows.



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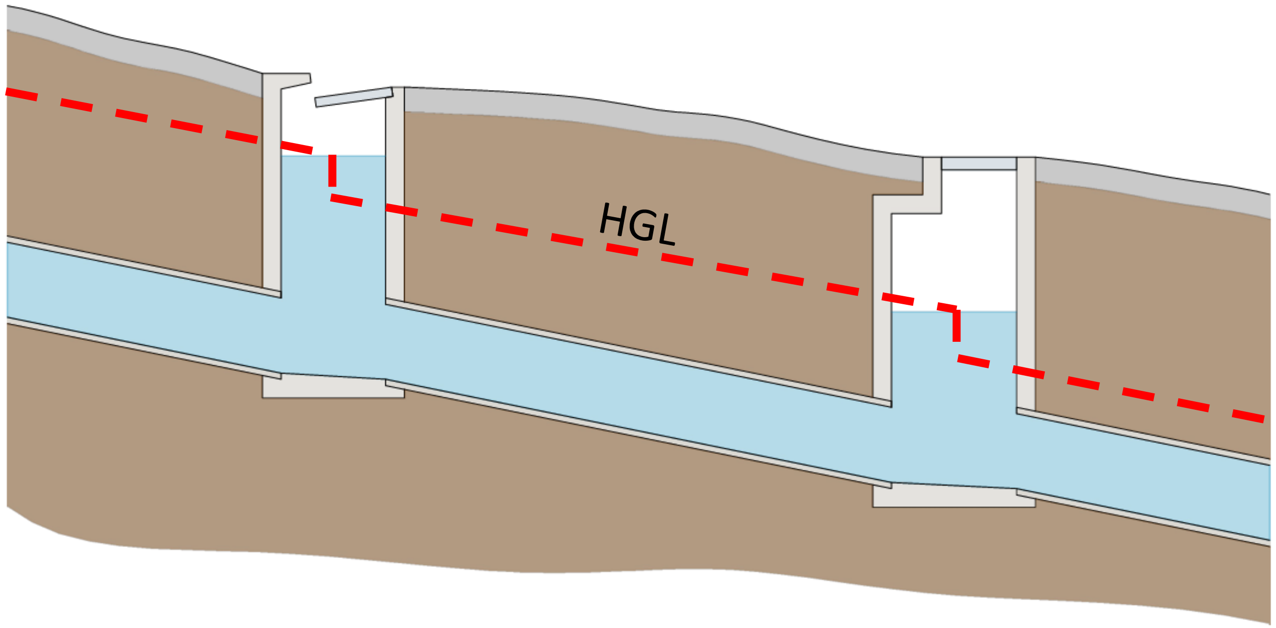
Hydraulic Grade Line (HGL)

- HGL represents pressure head in a pipeline.
- Pressure head at any point along HGL is the vertical distance below that point.
- Think of it as the ‘effective water level’.
- Flow velocity is a function of HGL not pipe grade, S_o.



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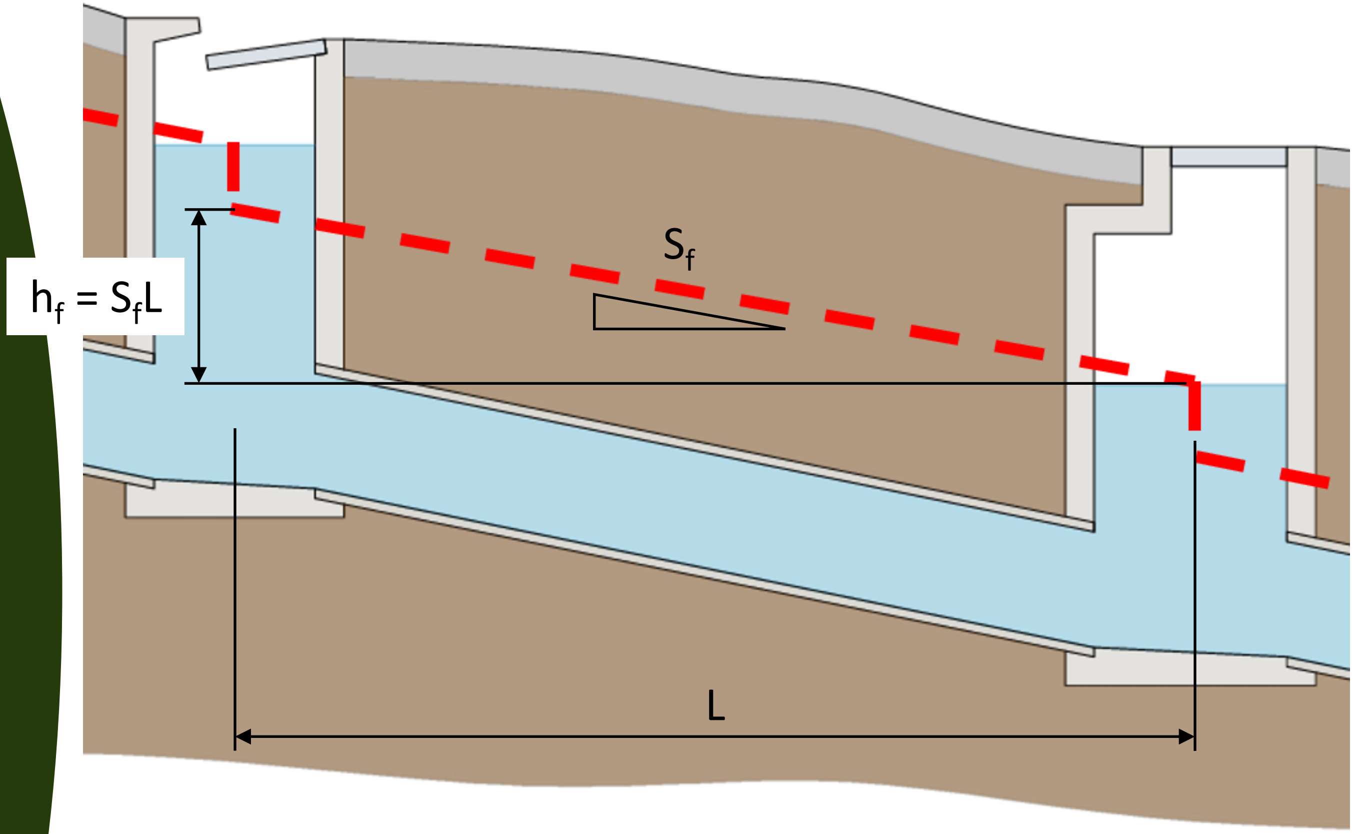
Hydraulic Grade Line (HGL)

Losses due to pipe friction.

$$h_f = S_f L$$

h_f	Head loss in pipe due to friction (m)
S_f	Friction slope (m/m)
L	Length of pipe reach (m)

Friction slope is not the same as the pipe slope!



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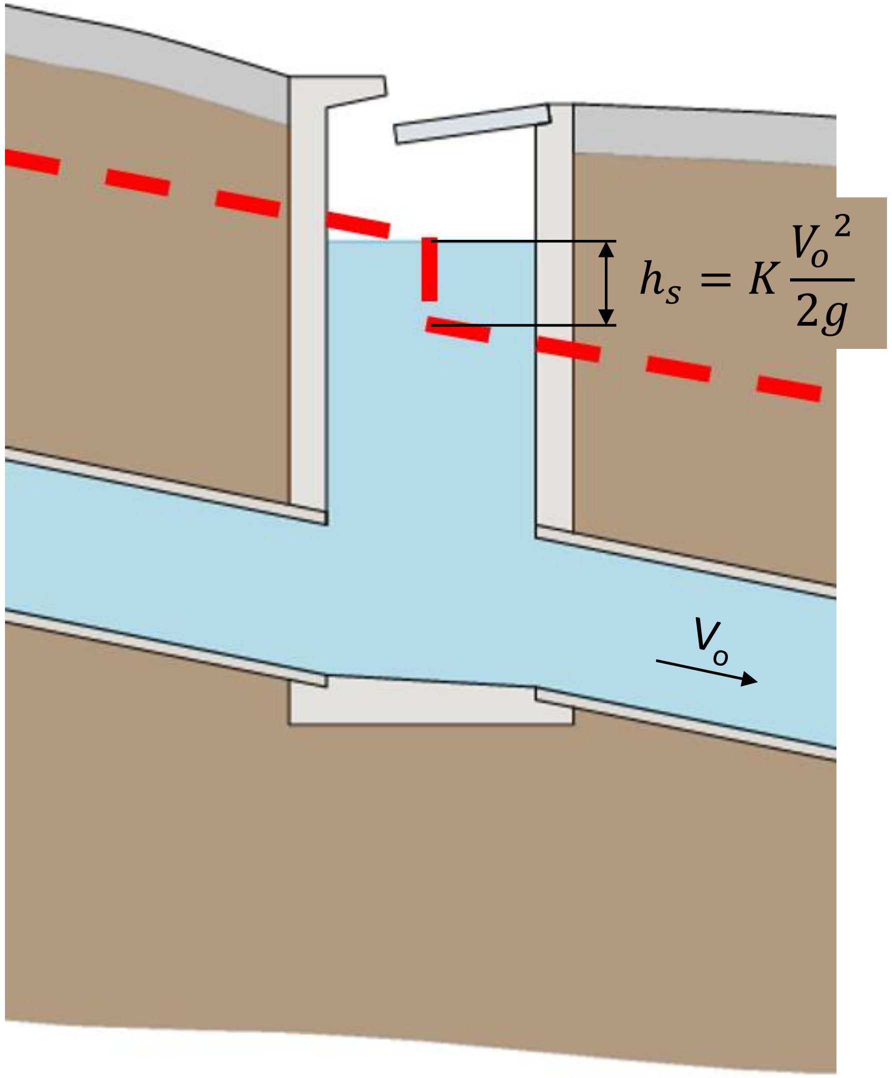
Hydraulic Grade Line (HGL)

Losses due to junctions, structures, bends, obstructions.

$$h_s = K \frac{{V_o}^2}{2g}$$

h_s	Head loss at obstruction, bend, junction (m)
K	Pressure change coefficient
	(Structure loss coefficient)
V_o	Velocity of flow in downstream pipe (m/s)
g	Gravitational acceleration (9.81m/s²)



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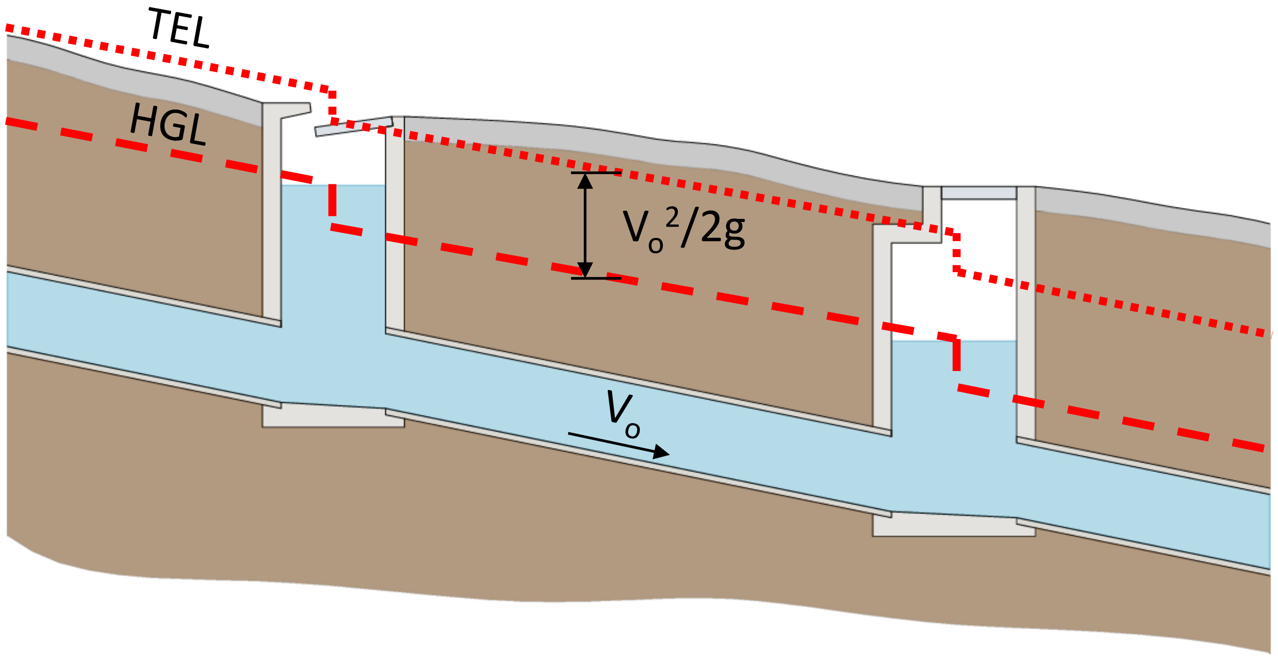
Total Energy Line (TEL)

- Total Energy Line (TEL) is above HGL by a difference equal to the velocity head under steady flow conditions.

$$Velocity\ head = \frac{V_o{}^2}{2g}$$

- Represents total energy available to flow.
- HGL and TEL coincide where velocities are negligible e.g. within a pond.



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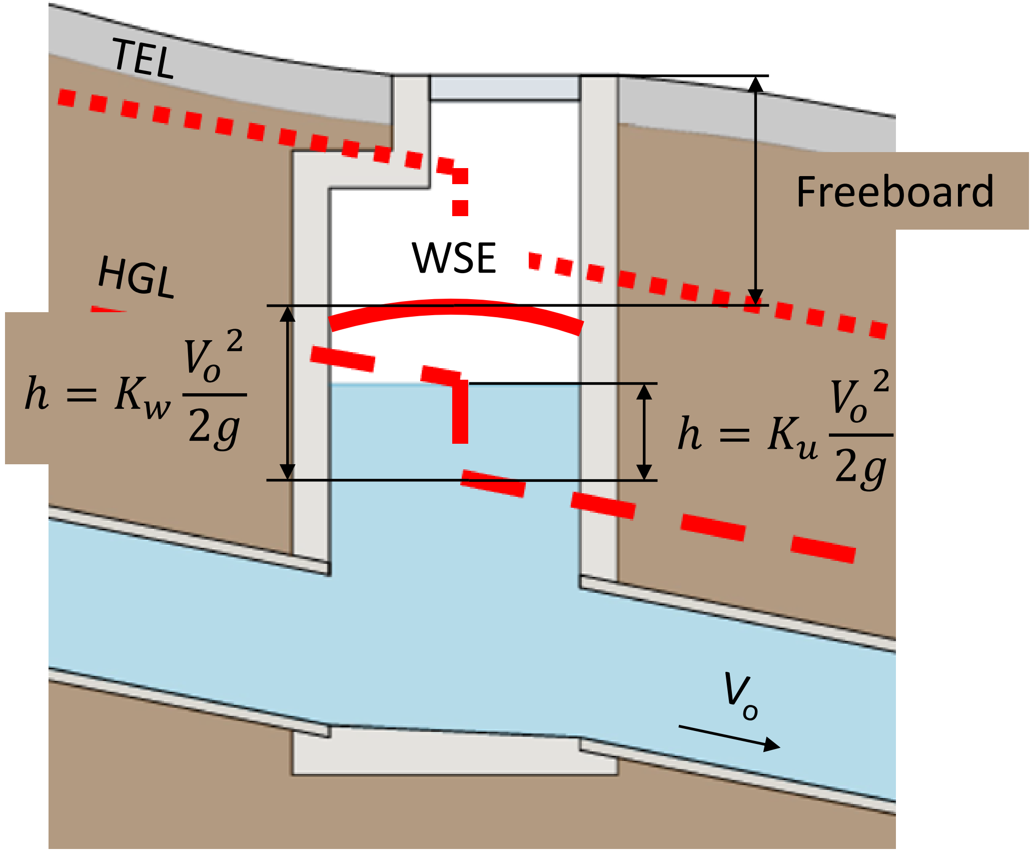
Water Surface Elevation (WSE)

- Water service elevation (WSE) within a pit is typically higher than theoretical HGL.
- Different structure loss coefficients are used:

  K_u Junction pit pressure change coefficient

  K_w WSE change coefficient
- 150 mm freeboard must be allowed above the WSE.



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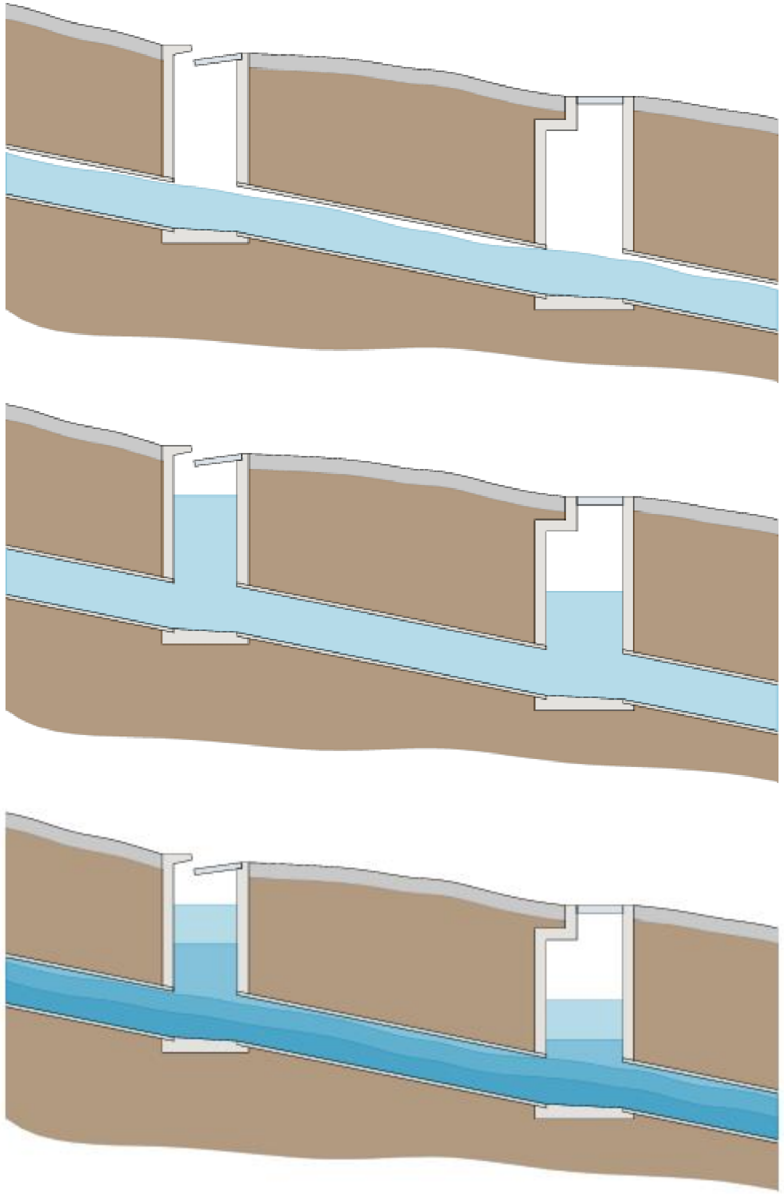
Hydraulic Calculations

Three (3) models for hydraulic systems:

- Simple, steady flow, open channel model
- Steady flow, pressured grade line model
- Complex, unsteady flow model

Steady flow = discharge remains constant through each link



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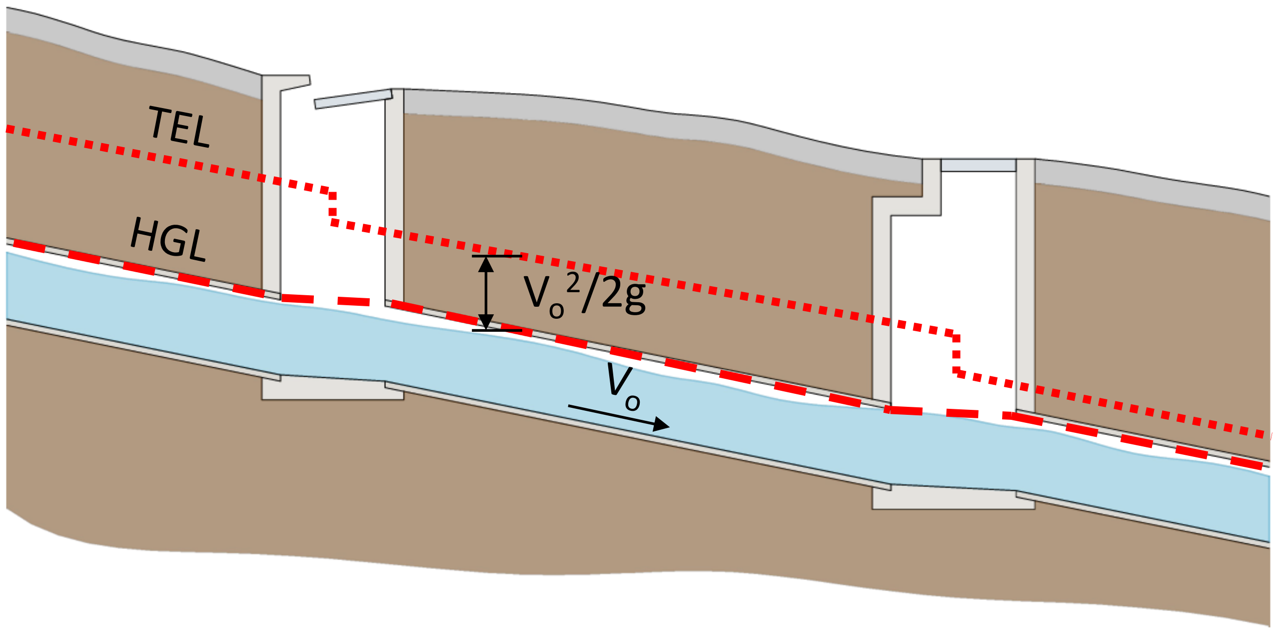
HGL
Open Channel Model

- Assumes steady flow in each section.
- HGL set at pipe obvert.
- Calculated HGL upstream of each pipe matches or is slightly lower than upstream obvert.
- Design flow determined by the Rational Method.
- Series of connected open channels.
- System flows full but not under pressure.



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HGL
Open Channel Model

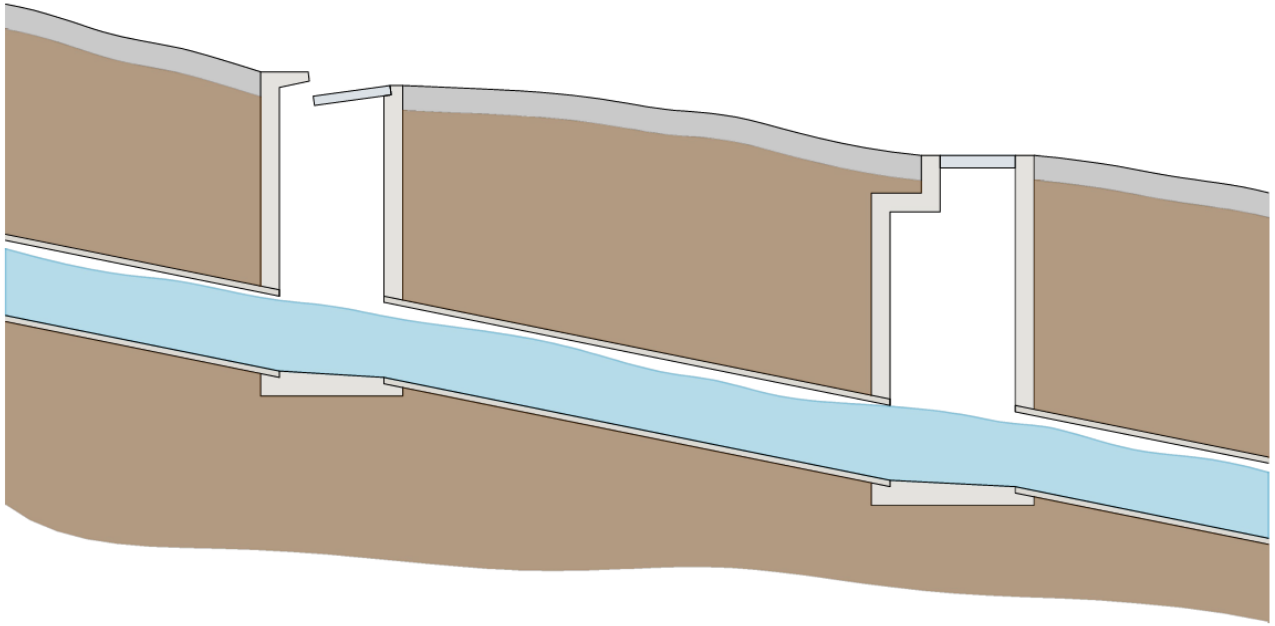
- Manning's Equation used

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

- Volumetric Flow Rate Equation used

$$Q = VA$$

- Pipes treated as open channels with pipe flowing full (simplified)



Tip:
$R = A/P$

And for a circle $A = \pi r^2$, $P = \pi 2r = \pi \varnothing$

Then, $R = \frac{\pi r^2}{\pi 2r} = \frac{r}{2} = \frac{\varnothing}{4}$

So, $V = \frac{1}{n} \frac{\varnothing}{4}^{2/3} S^{1/2}$

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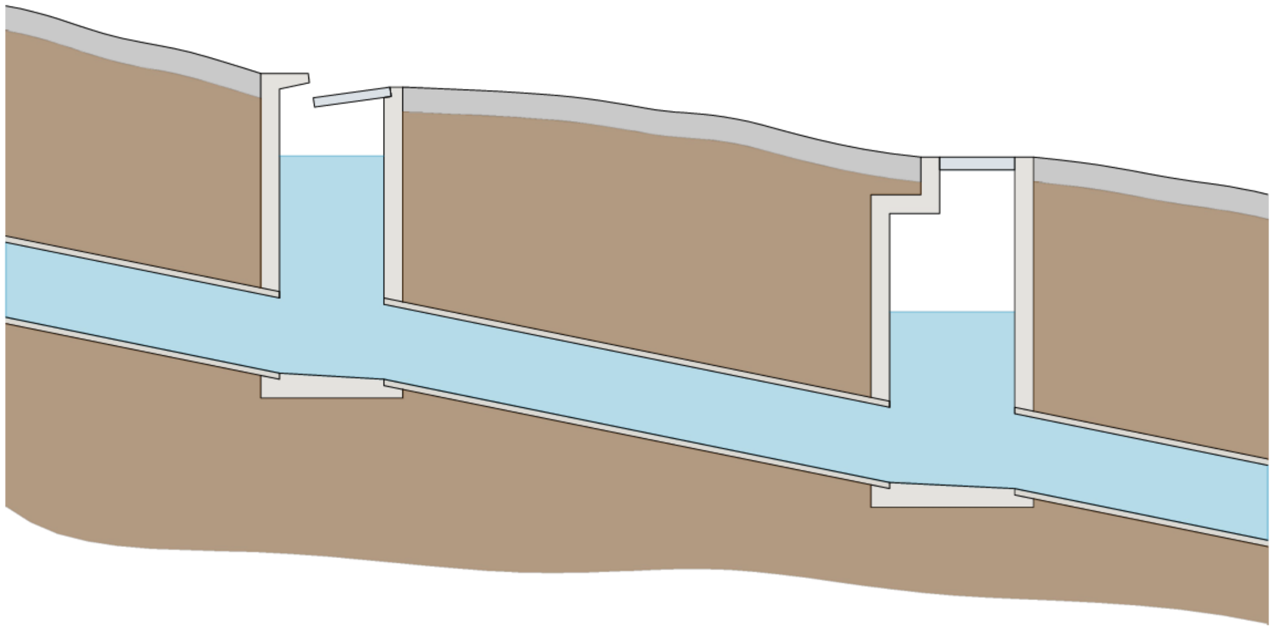
HGL
Pressurised Grade Line Model

- Assumes steady flow in each pipe.
- Hydraulic Grade Line (HGL) is above pipe obverts, indicating pressure flows.
- Allows for pressure changes and energy losses in pits.
- Offers higher velocity of flow through pipes.
- Offers flexibility in choosing pipe slopes.
- Potentially leads to more efficient designs compared to the Open Channel Model.



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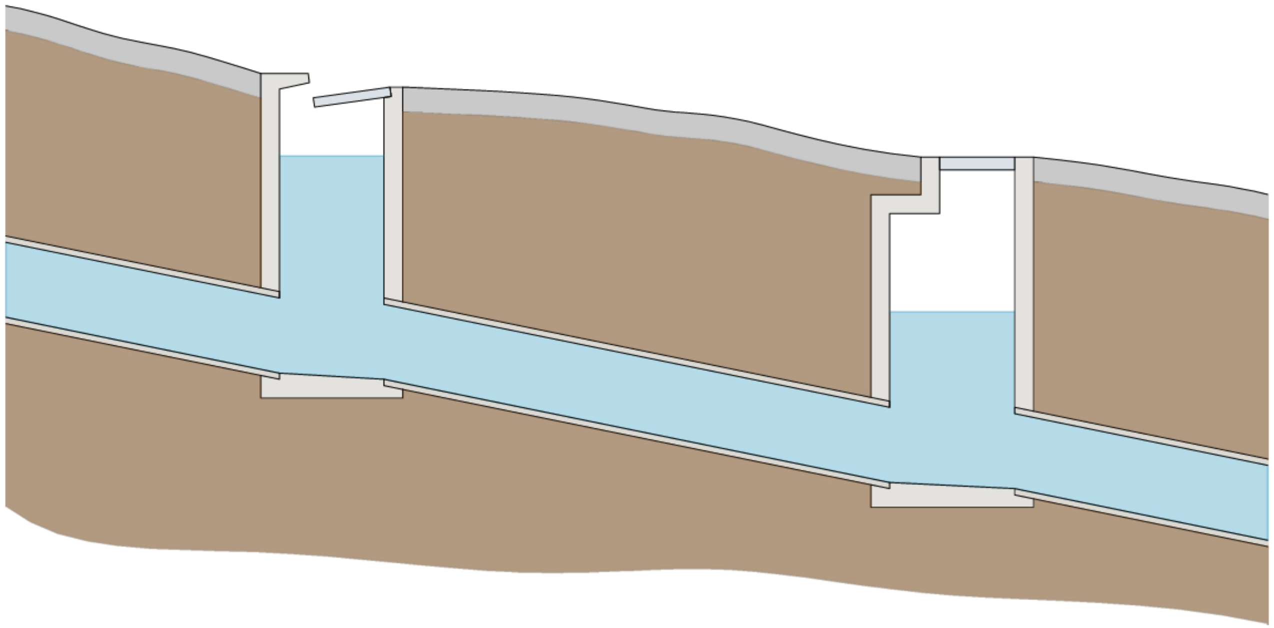
HGL
Pressurised Grade Line Model

- Colebrook-White Equation used

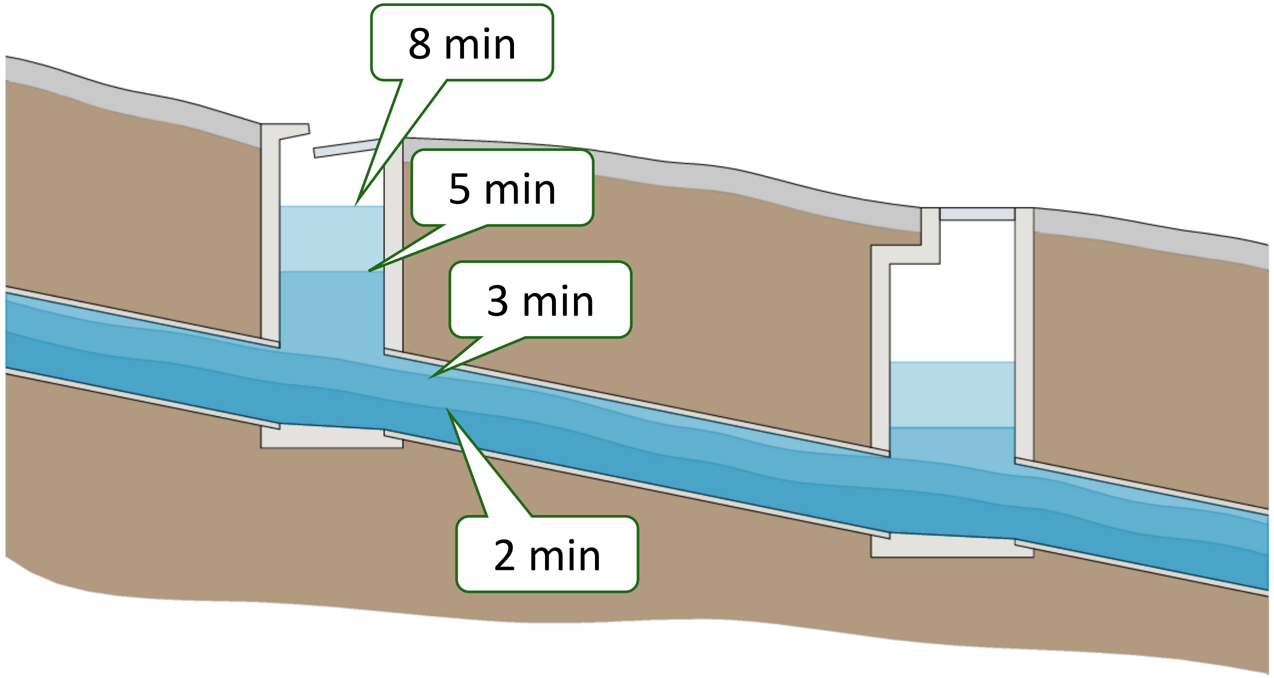
$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k}{3.7D} + \frac{2.51}{R_e\sqrt{f}}\right)$$

- More variables to consider:
  - Friction factor, f
  - Reynold's Number, R_e
  - Understanding of turbulent vs laminar flows
- Iterative equation – Moody Diagram can help!



HGL
Unsteady Flow Model

- Dependent on time, unlike steady flow models.
- Water levels fluctuate during design storm event.
- Requires computer program for analysis.
- Less frequently used for pit and pipe design.



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Hydraulic Calculations

Three (3) models for hydraulic systems:

- Simple, steady flow, open channel model
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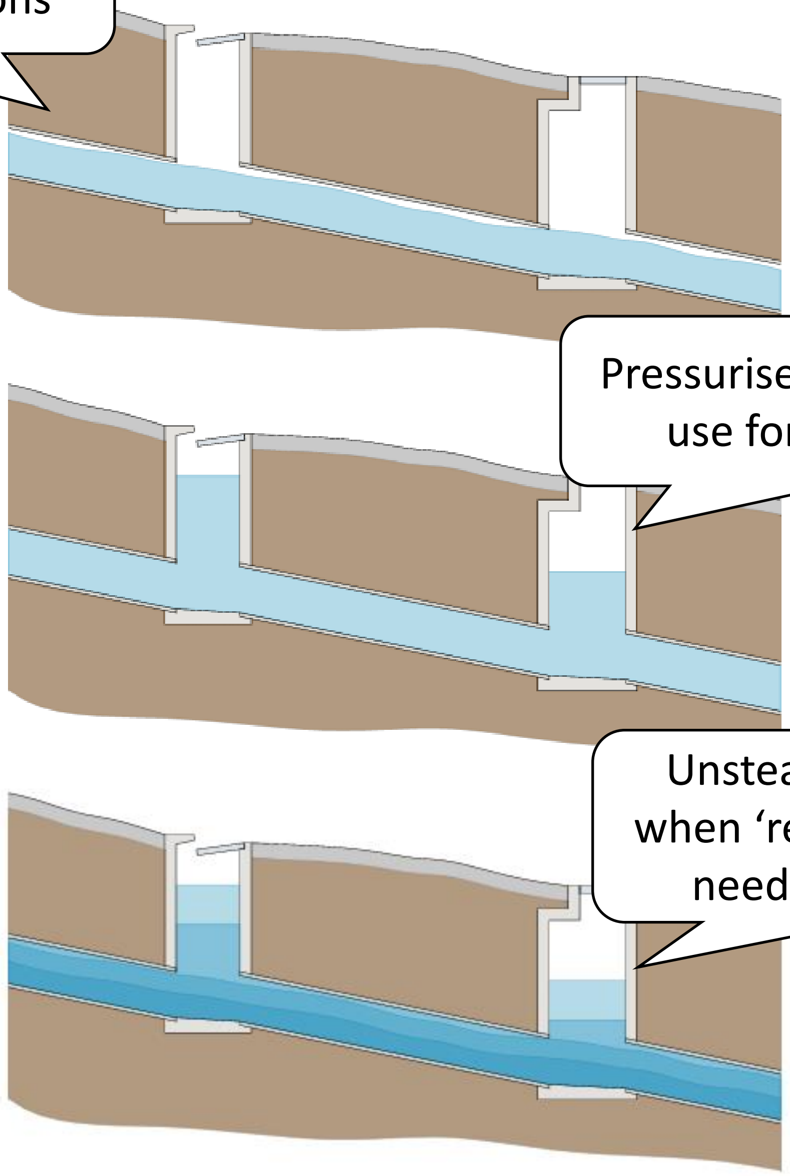

Tailwater Condition (Establishing Starting HGL)

- Essential for backwater analysis.
- Determine downstream HGL, work upstream through piped network.
- Designer's decision can influence design and ultimately performance of built infrastructure.
- Coordination with regulating authority for consensus on starting HGL.

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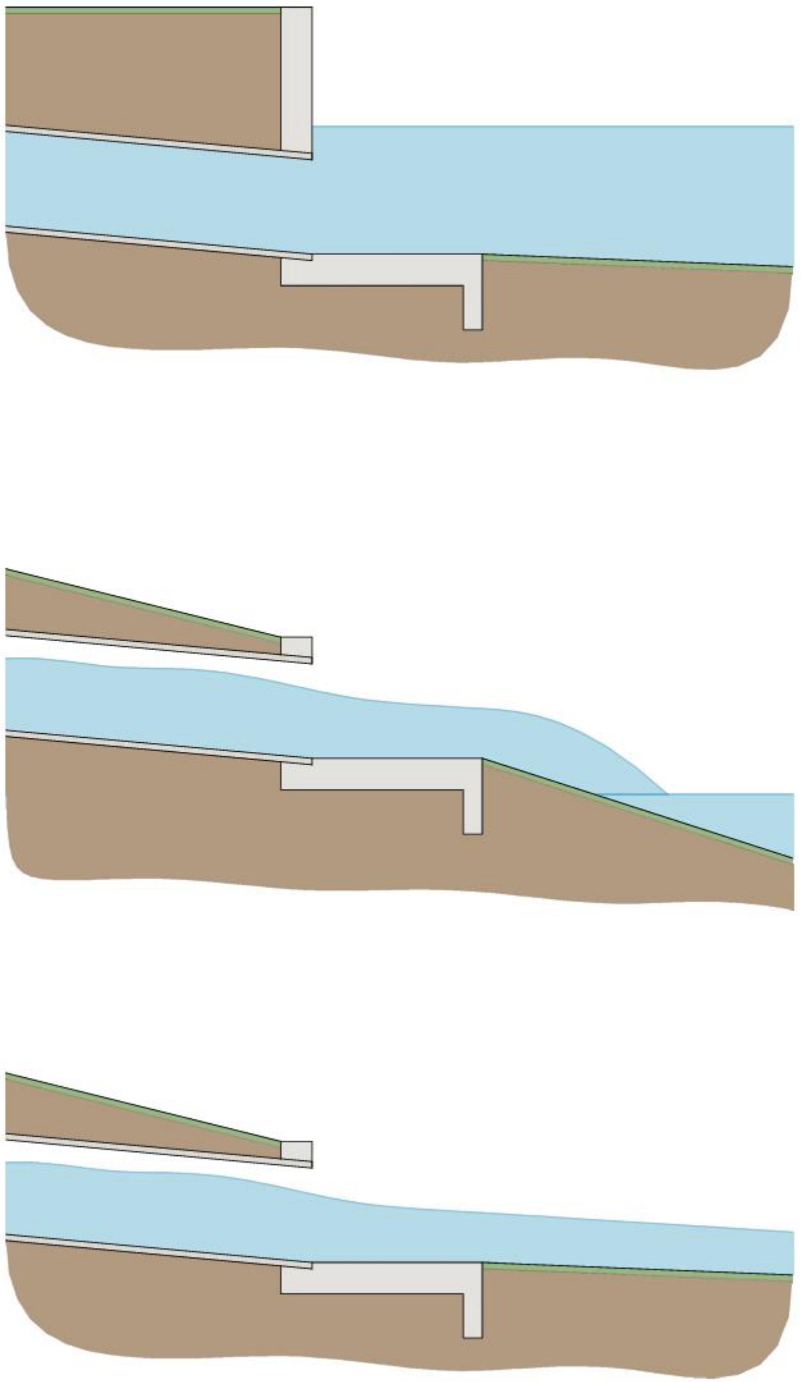
Tailwater Condition (Establishing Starting HGL)

Starting HGL depends on relationship between:

- Calculated tailwater (TWL) in receiving waters
- Critical depth (d_c) of flow in outfall pipe
- Obvert level (OL) of the pipe.



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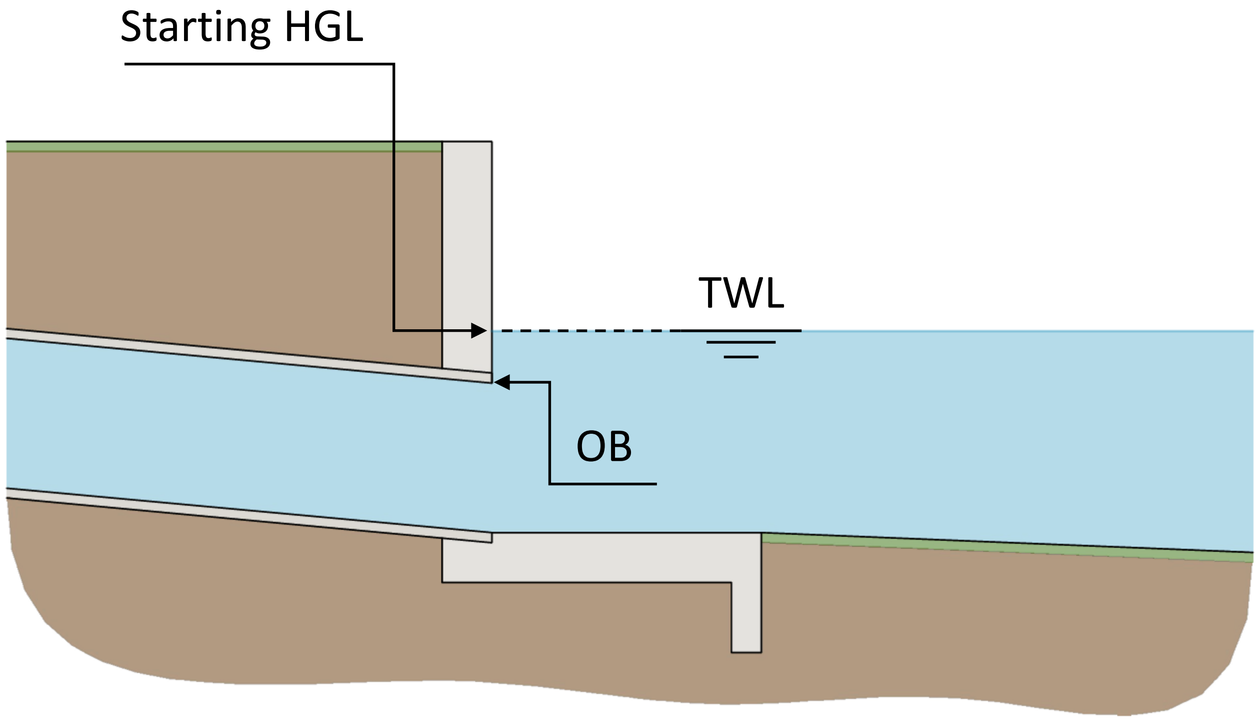
Tailwater Condition (Establishing Starting HGL)

- If tailwater is above pipe obvert level, then starting hydraulic grade line is set to the tailwater level.
- TWL > OL, HGL = TWL



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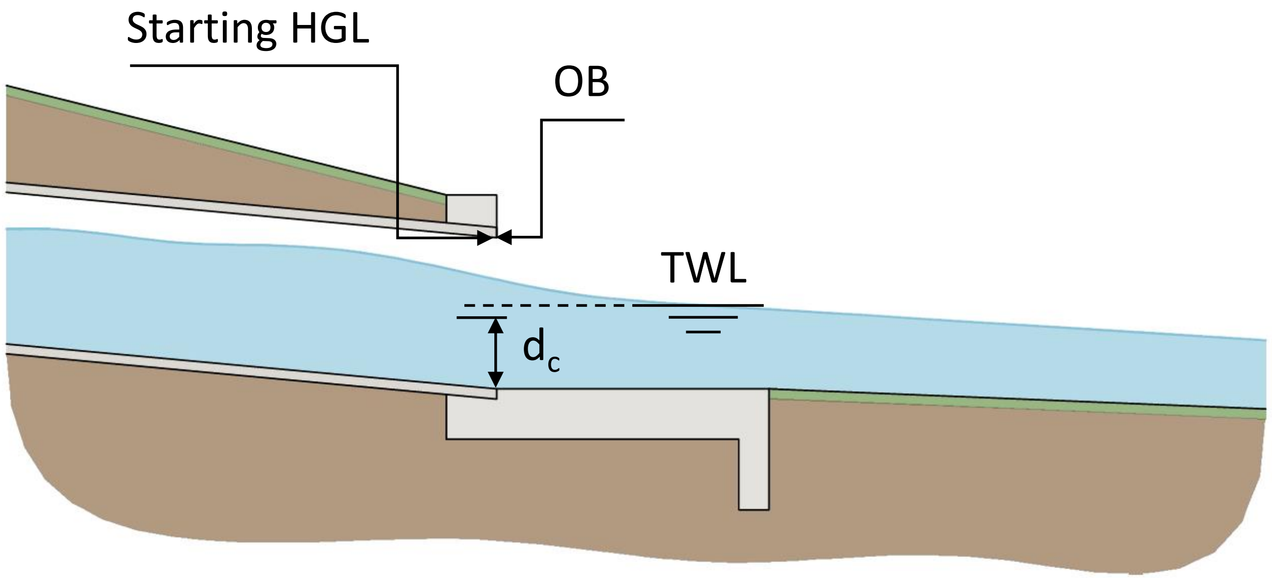
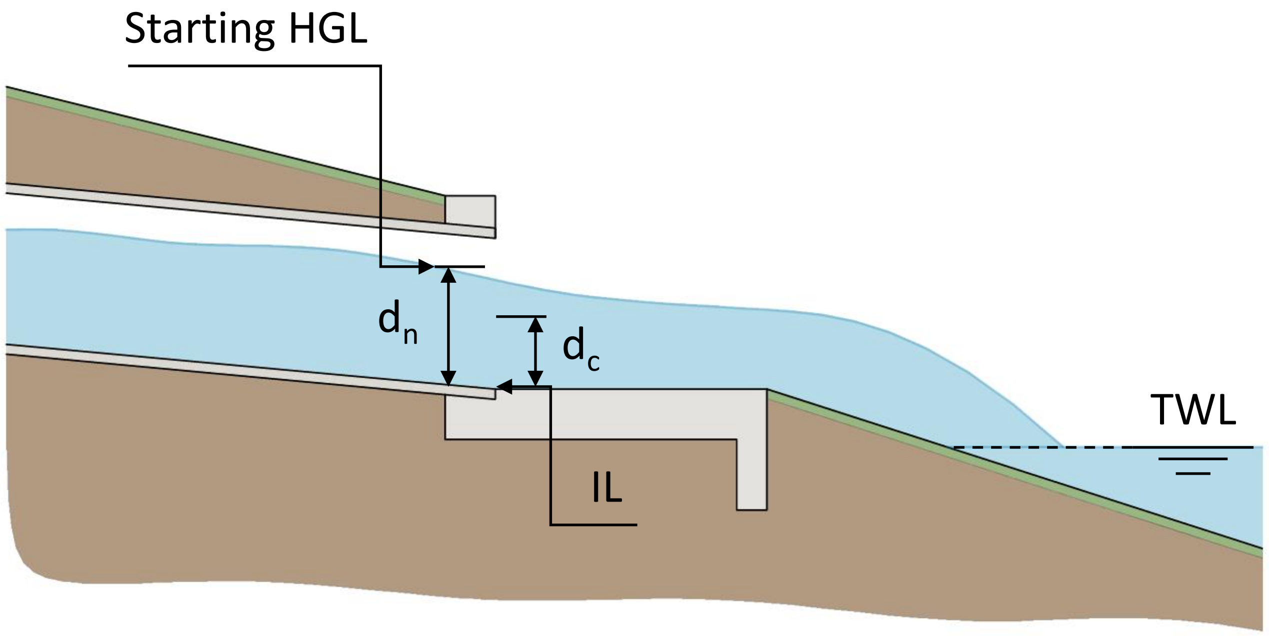
Tailwater Condition (Establishing Starting HGL)

- If tailwater is below pipe obvert level and above critical depth, then starting hydraulic grade line is set to the pipe obvert level.
- TWL < OB and TWL > d_c , HGL = OB



Tailwater Condition (Establishing Starting HGL)

- If tailwater is below pipe invert level or below critical depth, then starting hydraulic grade line is set to the normal flow depth in pipe.
- $TWL < IL$ or $TWL < d_c$, $HGL = d_n$



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Tidal Systems and Flood Gates

- Flood gates prevent water backflow.
- Designers should consider higher hydraulic head loss associated with gates.
- Regular maintenance is crucial for efficient operation, especially in debris-prone areas.
- Designer’s must assess impact of flood gate in closed position during design storm event.

Flood Gate, ecsengineeringservices.com 2024

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Connecting into Existing Pipe Network

- Urbanisation increases discharges, placing existing systems under stress.
- Potentially overwhelming downstream pipes and channels.

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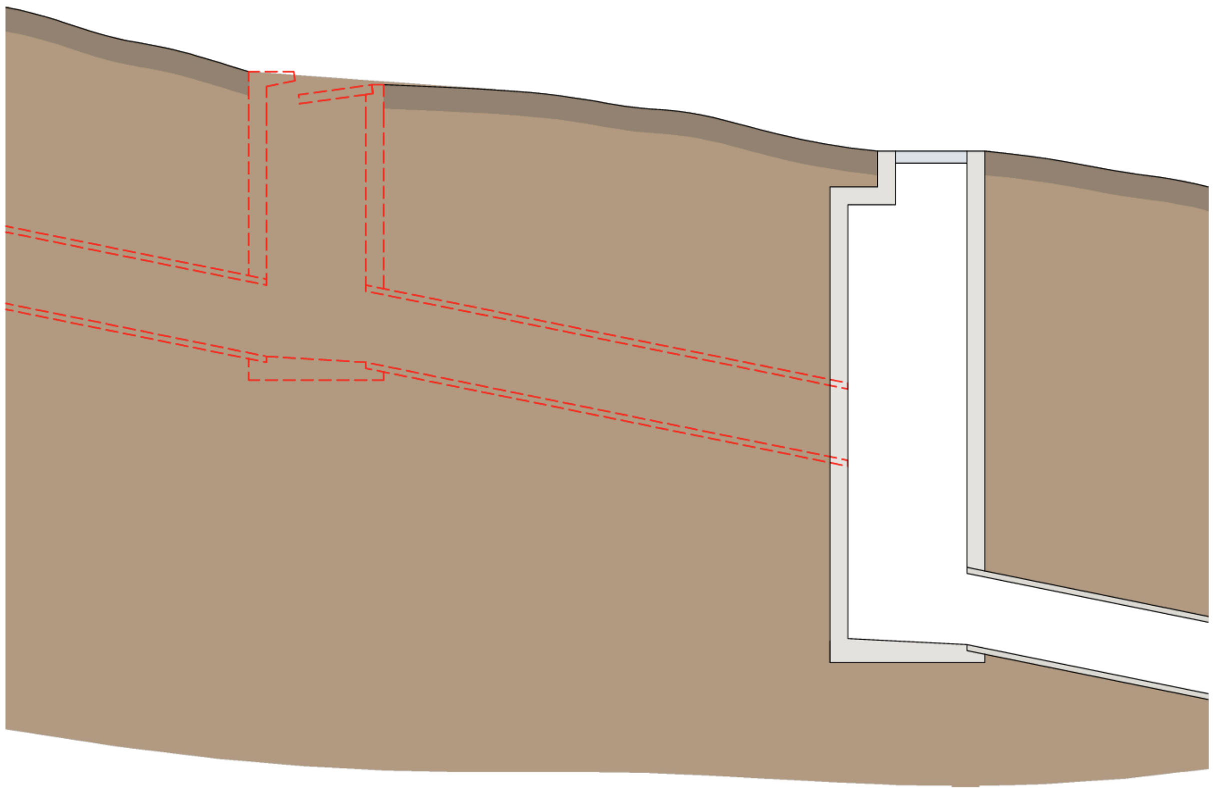
Connecting into Existing Pipe Network

- Structure losses must be assessed when connecting into an existing system.
- Ideally, existing HGL is a direct measurement BUT this is impractical.
- We need to estimate starting HGL (TWL).



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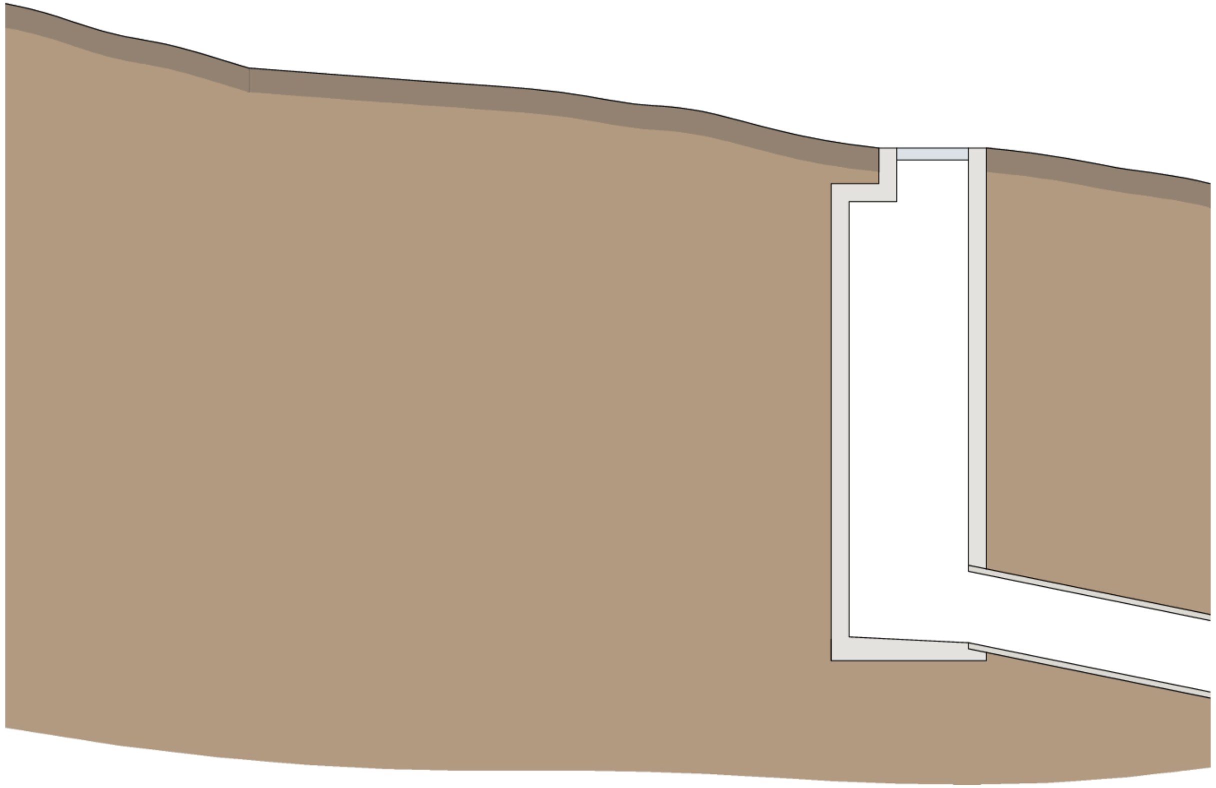
Connecting into Existing Pipe Network

- Before adopting TWL condition, we need to understand how the existing system performs.
- May need to analyse existing network and catchments.
- Liaise with authority as soon as possible.



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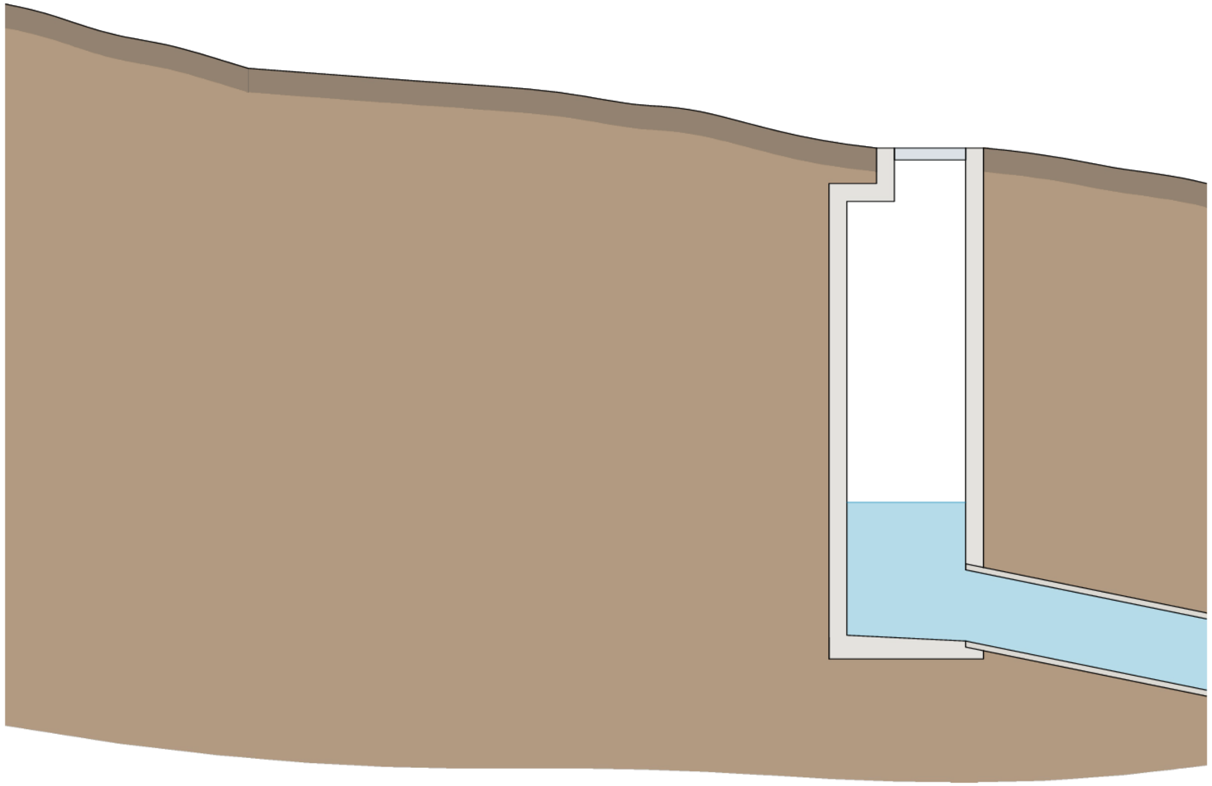
Connecting into Existing Pipe Network

This pit may have a minor event HGL like this?



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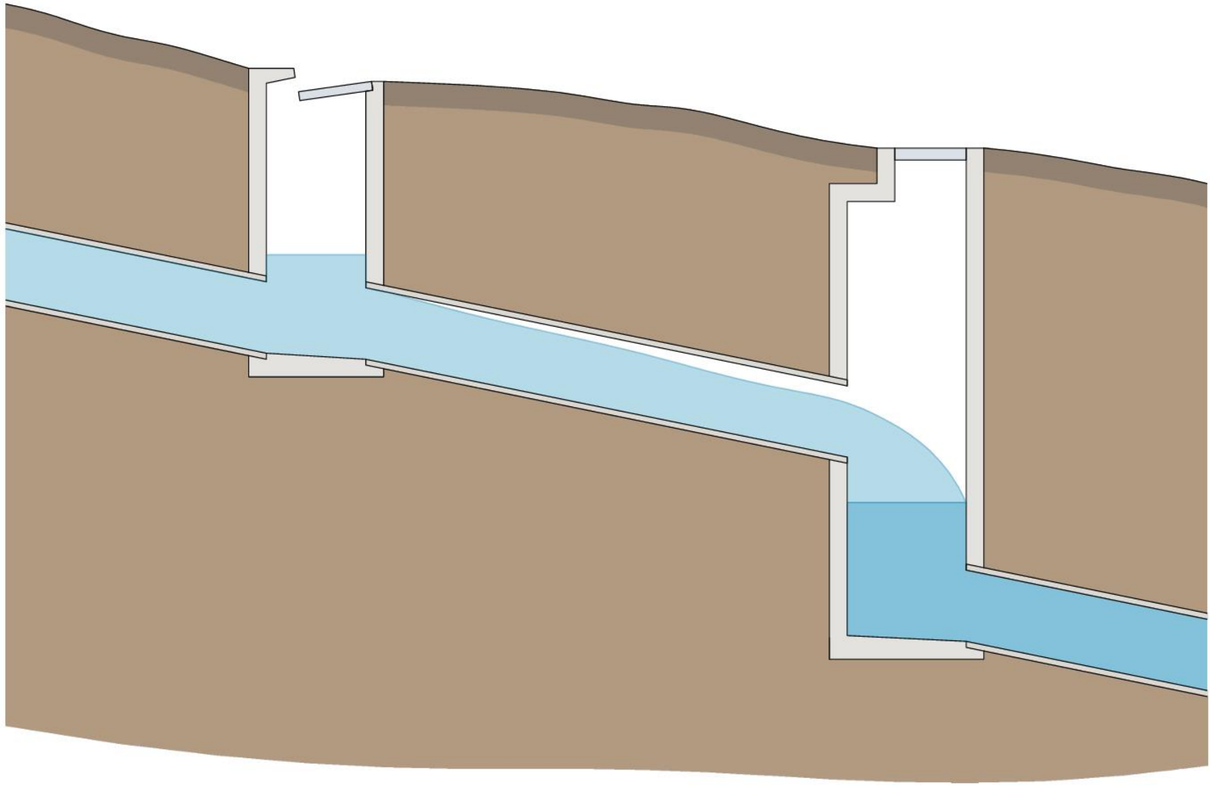
Connecting into Existing Pipe Network

Connection of our new system will probably perform well.



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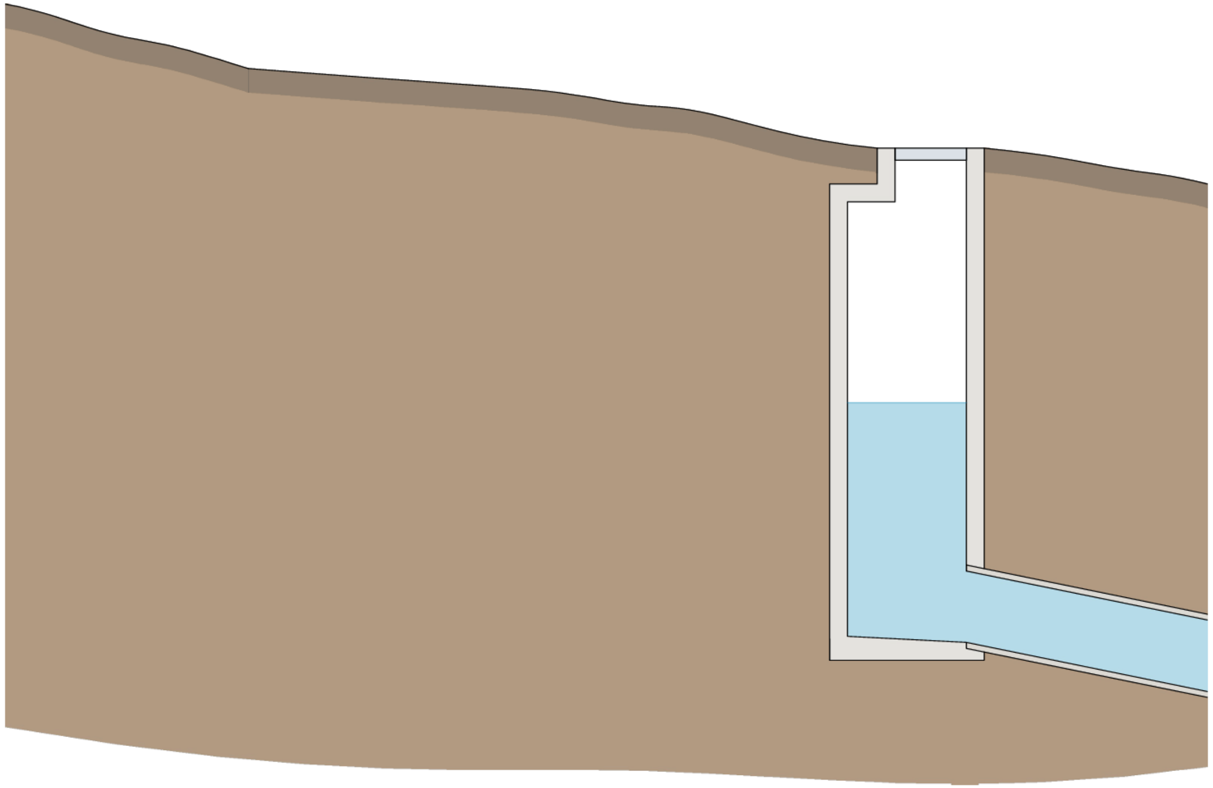
Connecting into Existing Pipe Network

What if our minor HGL was a little higher?



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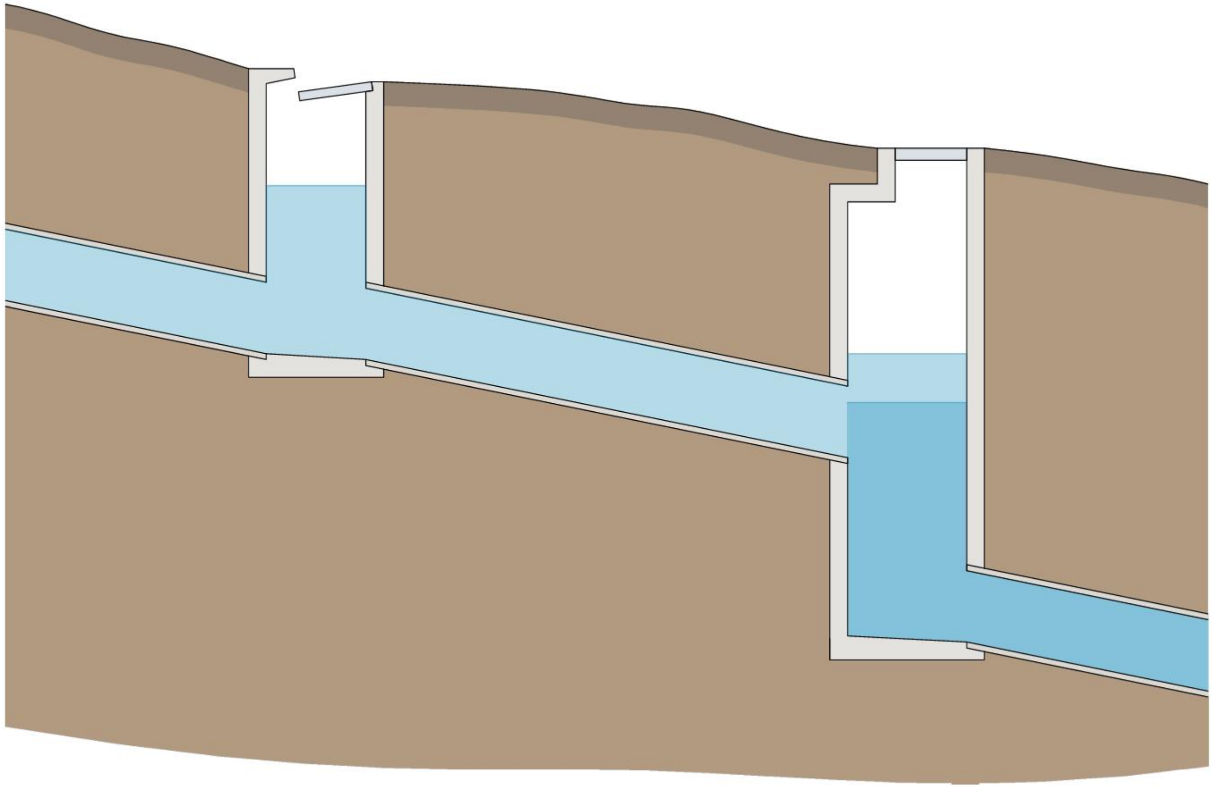
Connecting into Existing Pipe Network

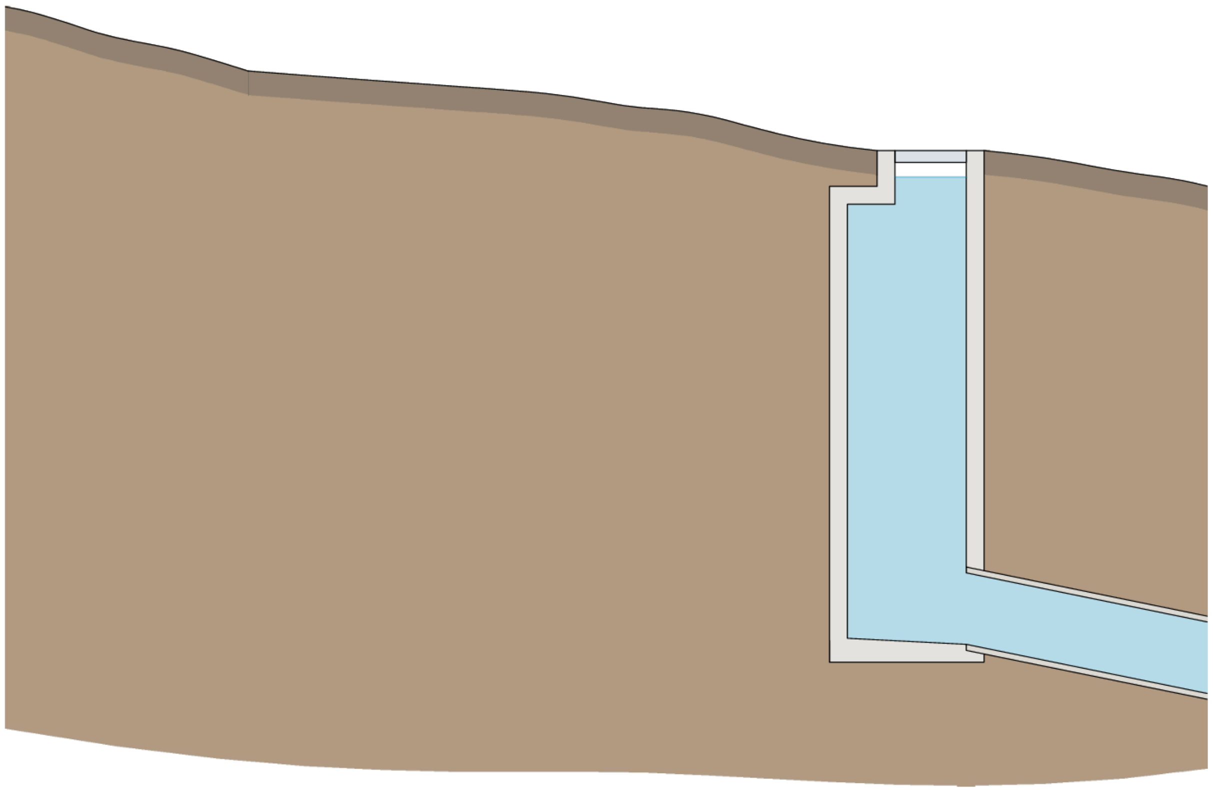
Connection of our new system could still perform as required, though water levels may be higher.



Connecting into Existing Pipe Network

What if our existing system was already close to or at capacity?

This happens more often than you think!



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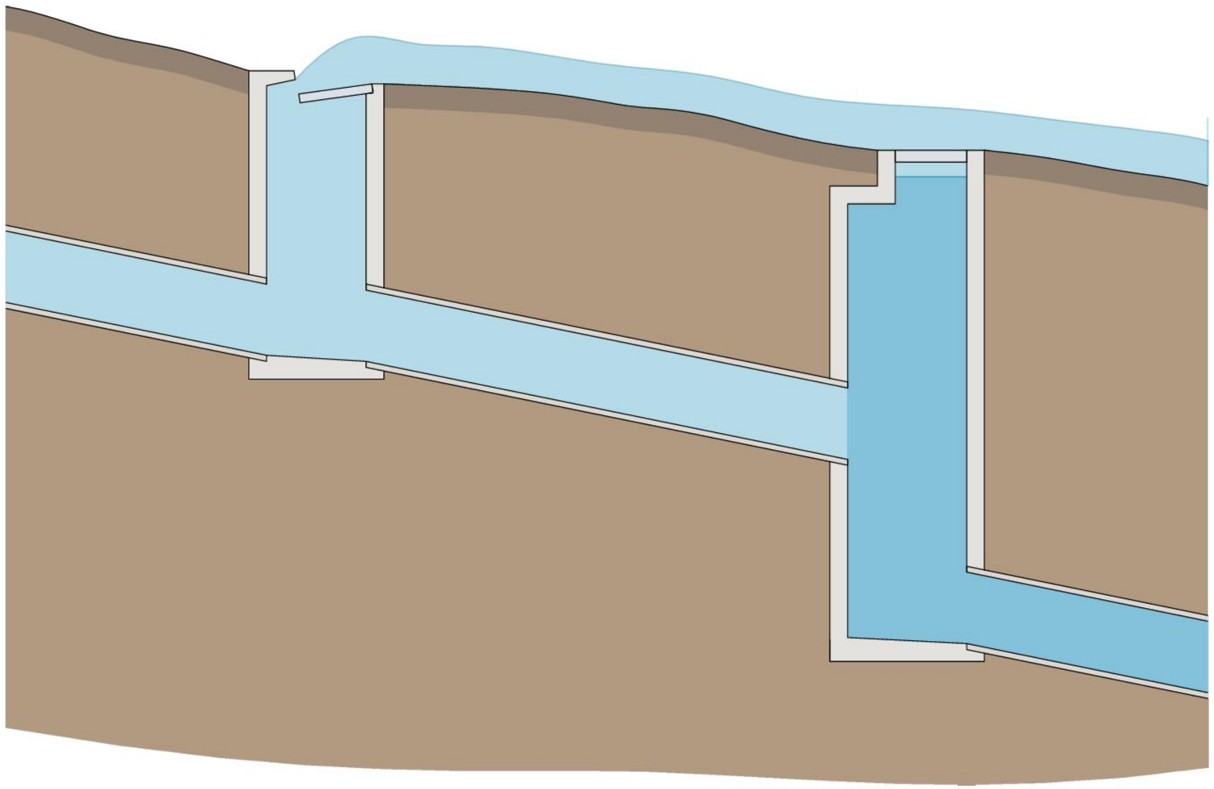
Connecting into Existing Pipe Network

We simply cannot force more water into the existing system.

Surcharge of the system will almost certainly occur!



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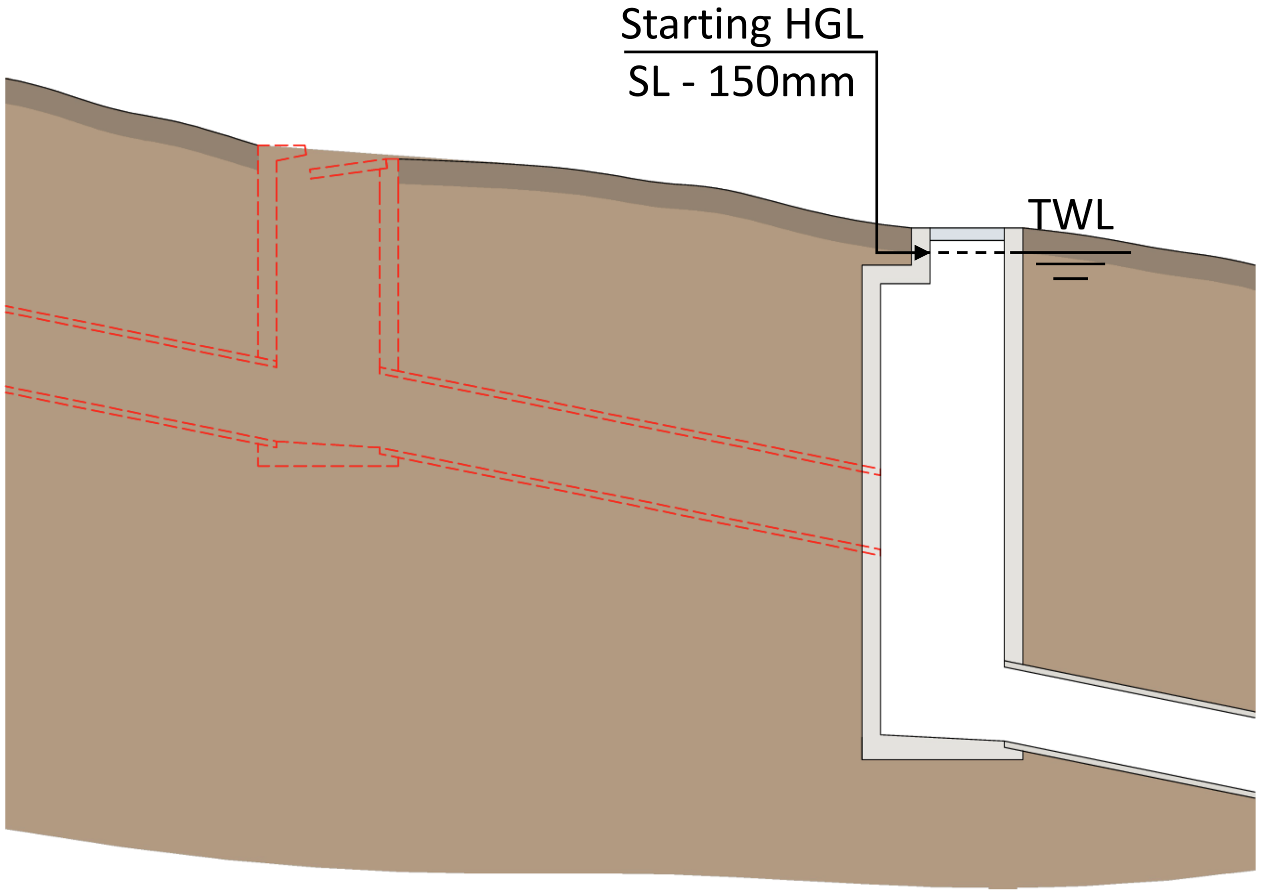
Connecting into Existing Pipe Network

- Adopt starting water level (TWL) 150mm below grate/inlet/lid level (SL).
  - With approval from the authority.
  - Minor design storm only.
- Modifications to an existing drainage system must not compromise the system’s performance!



Hydraulic Calculations

- Hydraulic grade line (HGL) method for underground piped networks.
- Hydrologic analysis:
  Upstream to downstream.
- Hydraulic analysis:
  Downstream to upstream.
  (Start at outfall)

Generally this applies but there are always exceptions!

INLET DESIGN	DRAIN DESIGN										HEAD LOSSES										
INLET TYPE	Qg FLOW INTO INLET (l/s)	TC CRITICAL TIME OF CONCENTRATION (min)	I RAINFALL INTENSITY (mm/hr)	CA TOTAL (C x A) (ha)	Qrat PEAK FLOW (l/s)	Q PIPE FLOW (l/s)	L REACH LENGTH (m)	S PIPE GRADE (%)	PIPE SIZE (mm)	PIPE CLASS	Vf=Q/A FULL PIPE VELOCITY (m/s)	Qcap CAPACITY FLOW (l/s)	Vcap CAPACITY VELOCITY (m/s)	Vt TRAVEL VELOCITY (m/s)	CHART(S) USED	Vf²/2g VELOCITY HEAD (m)	Ku U/S HEAD LOSS COEFFICIENT	hu U/S HEAD LOSS (m)	Kw W.S.E. COEFFICIENT	hw CHANGE IN W.S.E. (m)	Sf PIPE FRICTION SLOPE (%)
BCC-FI2-900x600	9	5	151	0.022	9	9	20	0.5	294	ENVIROPIPE SN8	0.13	65	0.95	0.67	G1	0.001	7	0.006		0.006	0.44
BCC-FI2-900x600	8	5.5	146	0.04	16	16	20	0.5	294	ENVIROPIPE SN8	0.24	65	0.95	0.8	T1	0.003	1.95	0.006		0.006	0.44
BCC-FI2-900x600	8	5.91	142	0.06	23	23	20	0.5	294	ENVIROPIPE SN8	0.35	65	0.95	0.88	T1	0.006	1.56	0.01		0.01	0.22
CC-FI2-900x600	9	6.29	139	0.139	53	53	28.995	0.5	371	ENVIROPIPE SN8	0.49	121	1.11	1.08	T3/T6	0.012	1.99	0.025	2.43	0.03	0.25
CC-LIL-TE-2.4	7	6.74	136	0.155	58	58	21.801	0.3	438	ENVIROPIPE SN8	0.39	145	0.96	0.91	T9/T10	0.008	2.27	0.017	2.73	0.021	0.06
C-KIL-TE-2.4	13	7.14	133	0.187	69	69	21.036	0.3	438	ENVIROPIPE SN8	0.46	145	0.96	0.95	T1/T3	0.011	1.14	0.012	1.21	0.013	0.06
FI1-900x900	2	7.51	130	0.327	118	118	21.118	0.25	514	ENVIROPIPE SN8	0.57	203	0.98	1.02	T3/T6	0.017	2.1	0.035	2.36	0.039	0.09
KIL-TE-2.4	10	7.85	128	0.44	156	156	19.121	0.25	514	ENVIROPIPE SN8	0.75	203	0.98	1.08	T3	0.029	1.73	0.05	2.12	0.062	0.21
IL-TE-2.4	6	8.15	126	0.454	159	159	10.191	0.25	514	ENVIROPIPE SN8	0.77	203	0.98	1.08	T3/T6	0.03	1.93	0.058	2.3	0.069	0.71
MH1050		8.31	125	0.475	165	165	12.774	0.2	591	ENVIROPIPE SN8	0.6	264	0.96	1.01	T3/T6	0.018	1.8	0.033	2.16	0.04	0.07
H1050		8.52	124	0.475	163	163	25.338	0.2	591	ENVIROPIPE SN8	0.6	264	0.96	1.01	T9/T10	0.018	2.33	0.042	2.73	0.049	0.07
H1050		8.93	121	0.535	181	181	6.6	0.2	591	ENVIROPIPE SN8	0.66	264	0.96	1.04	T10	0.022	2.09	0.046	2.66	0.059	0.09
H1500															T6/T9		2.21	0.059	2.52	0.067	
00x600	0	5.02	151	0.059	25	25	10.24	1	223	ENVIROPIPE SN8	0.63	44	1.12	1.15	T3/T6	0.02	2	0.04	2.33	0.047	1.11
00x600	9														T3/T6		1.99	0.025	2.43	0.03	
00x600	0	5	151	0	0	0	16	1	223	ENVIROPIPE SN8	0	44	1.12	2		0	0	0		0	0.45
TE-2.4	13														T1/T3		1.14	0.012	1.21	0.013	
00x600	0	5.02	151	0.135	56	56	14.009	1	223	ENVIROPIPE SN8	1.44	44	1.12	1.44	T1	0.106	0.21	0.023		0.023	1.67
00x900	2														T3/T6		2.1	0.035	2.36	0.039	
00x600	0	5.03	151	0.088	37	37	14.288	1	223	ENVIROPIPE SN8	0.94	44	1.12	1.26	T1	0.045	0.2	0.009		0.009	1
TE-2.4	10														T3		1.73	0.05	2.12	0.062	
600x600	9	5	151	0.02	9	9	22.638	0.5	294	ENVIROPIPE SN8	0.13	65	0.95	0.66	G2	0.001	9.7	0.008		0.008	0.01
H1050															T3/T6		1.8	0.033	2.16	0.04	
-900x600	5	5.03	151	0.056	24	24	30	0.5	294	ENVIROPIPE SN8	0.35	65	0.95	0.88	T10	0.006	2.19	0.013	2.75	0.017	0.05
2-900x600	6	5.6	145	0.14	57	57	36	0.5	294	ENVIROPIPE SN8	0.83	65	0.95	1.08	T6/T9	0.035	2.13	0.076	2.51	0.089	0.34
2-900x600	6	6.16	140	0.224	87	87	24.37	0.5	371	ENVIROPIPE SN8	0.81	121	1.11	1.21	T3/T6	0.033	1.87	0.062	2.25	0.075	0.57
-MH1050		6.49	137	0.267	102	102	10.695	0.25	438	ENVIROPIPE SN8	0.67	133	0.88	0.97	T10	0.023	1.97	0.046	2.33	0.054	0.15
C-MH1050		6.68	136	0.267	101	101	6.563	0.25	438	ENVIROPIPE SN8	0.67	133	0.88	0.97	T3/T6	0.023	1.78	0.041	1.91	0.044	0.14
CC-MH1050		6.79	135	0.279	105	100	8.026	0.2	591	ENVIROPIPE SN8	0.36	264	0.96	0.89	T6/T9	0.007	2.22	0.015	2.48	0.017	0.03
BCC-MH1050		6.94	134	0.299	111	106	38.123	0.2	591	ENVIROPIPE SN8	0.39	264	0.96	0.91	T1/T3	0.008	0.49	0.004	0.55	0.004	0.03
BCC-MH1200		7.64	129	0.381	137	132	16.019	0.2	731	ENVIROPIPE SN8	0.31	465	1.11	0.95	T3	0.005	1.7	0.009	2.02	0.01	0.02
BCC-MH1500		9.04	121	0.917	308	303	12.267	0.2	731	ENVIROPIPE SN8	0.72	465	1.11	1.18	T6/T9	0.027	2.21	0.059	2.52	0.067	0.08
m CONCRETE DETENTION TANK		9.21	120	0.917	306	301	17.526	0.4	371	ENVIROPIPE SN8	2.78	108	1	2.78	T1/T3	0.395	0.61	0.24	0.72	0.284	3.12
BCC-MH1050		9.32	120	0.917	305	300	8.205	0.5	591	ENVIROPIPE SN8	1.09	417	1.52	1.65	T6/T9	0.061	2.59	0.158	3.36	0.205	0.65
BCC-MH1200																					
BCC-LIL-TE-2.4	0	5	151	0.012	5	0	8.66	1	371	ENVIROPIPE SN8	0	170	1.58	2		0	0	0		0	0
BCC-MH1050															T6/T9		2.22	0.015	2.48	0.017	
BCC-FI2-900x600	8	5	151	0.02	8	8	9.861	2	371	ENVIROPIPE SN8	0.08	241	2.23	1.04	G2	0	9.7	0.003		0.003	0
BCC-MH1050															T1/T3		0.49	0.004	0.55	0.004	
BCC-FI2-900x600	35	5	151	0.083	35	35	8.202	2	371	ENVIROPIPE SN8	0.32	241	2.23	2.63	G2	0.005	9.7	0.051		0.051	2.48

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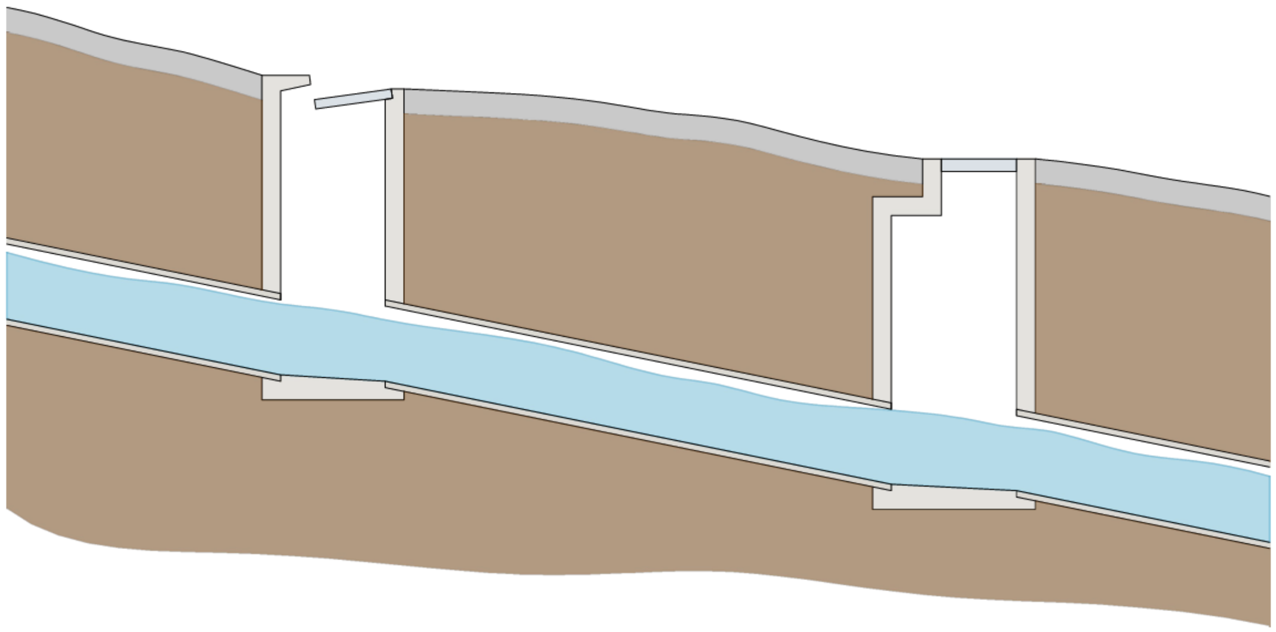
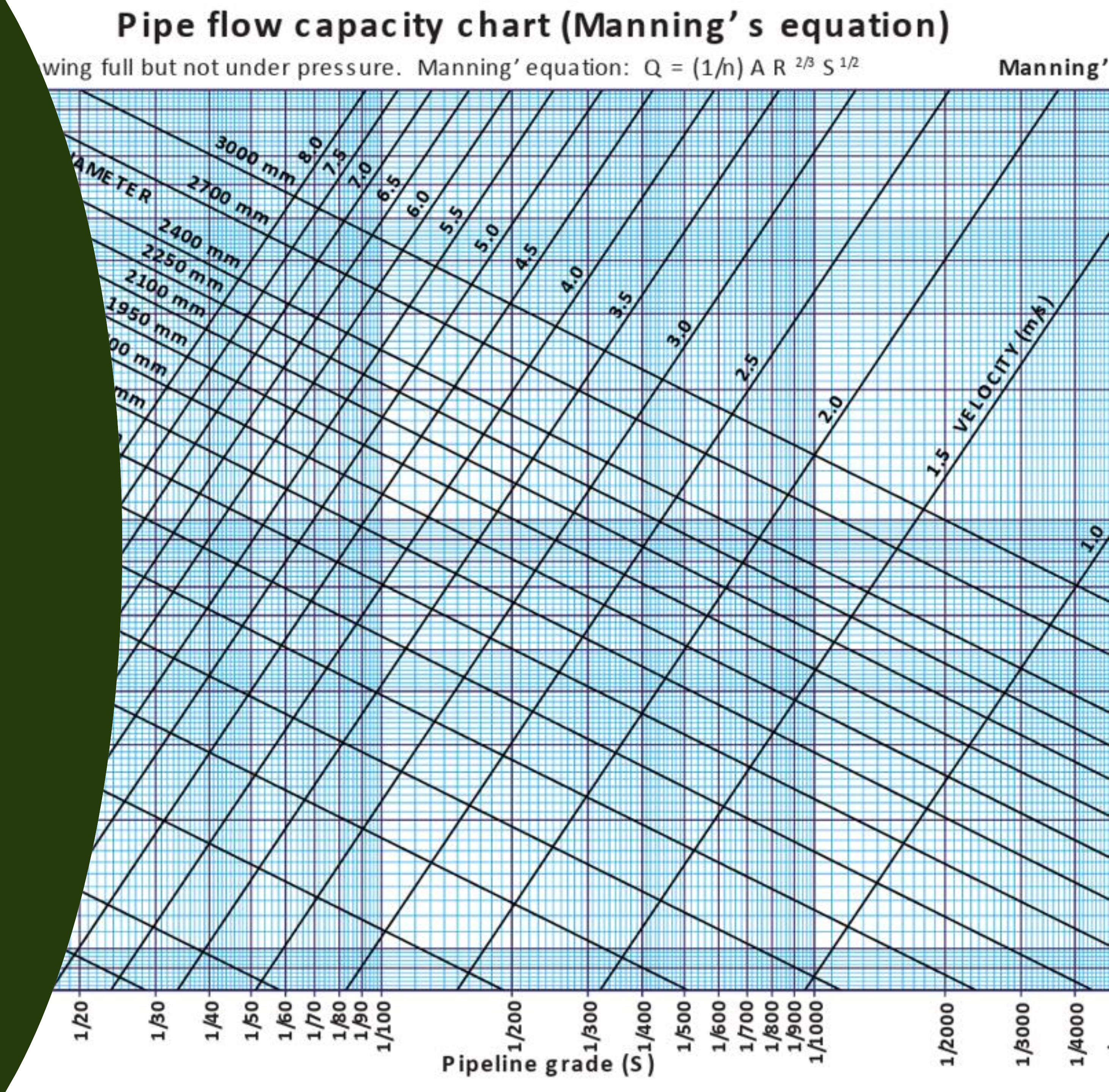
HGL
Open Channel Model

- Series of connected open channels.
- System flows full but not under pressure.
- Use Manning's Equation and Volumetric Flow Equation.



HGL
Open Channel Model

- Nomographs developed based on specific Manning's roughness values.
- Quickly approximate pipe capacity.
- Useful for conceptual designs.
- Not suitable for detailed design.



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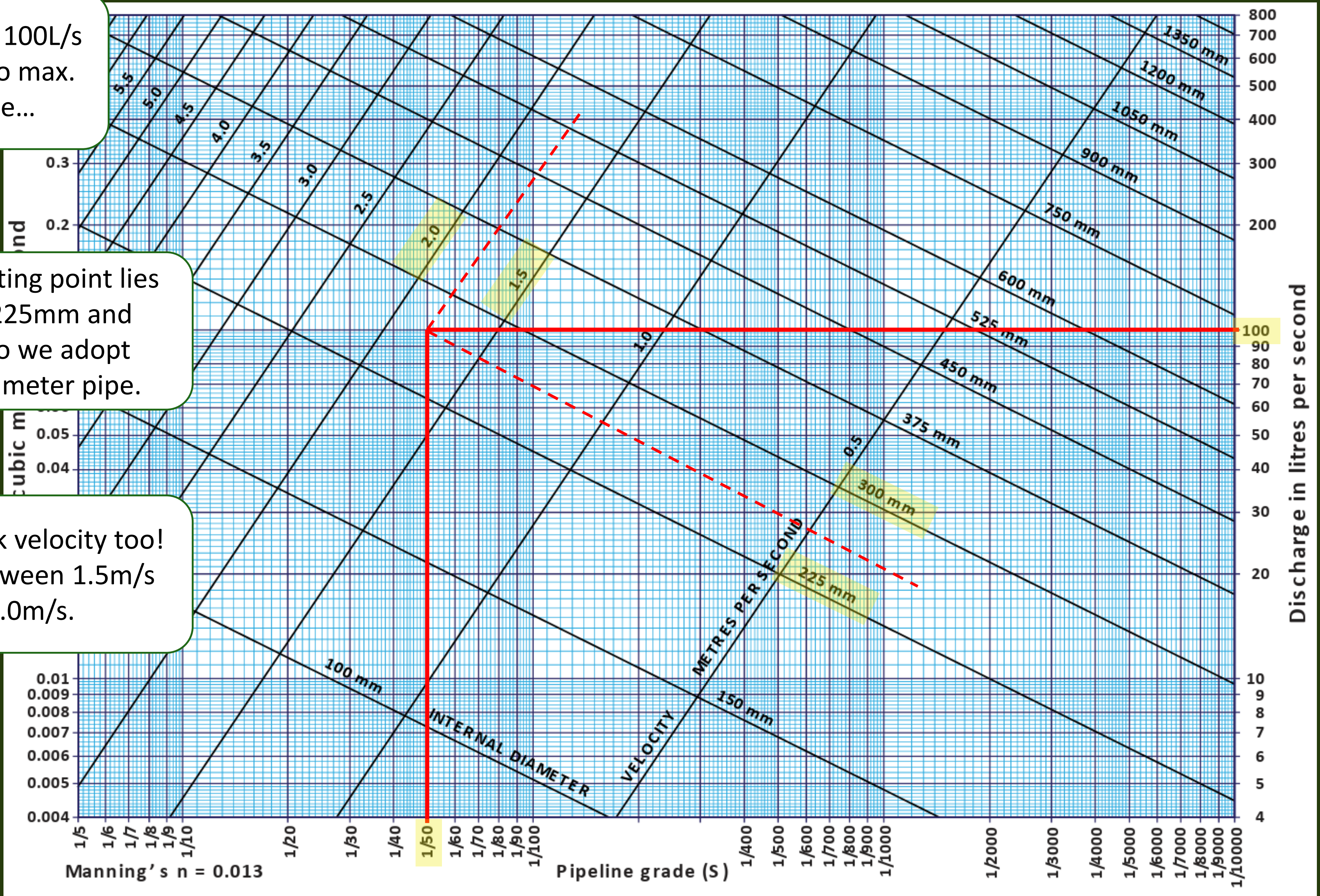
Need to pipe 100L/s but limited to max. 1:50 grade…

Our intersecting point lies between 225mm and 300mm, so we adopt 300mm diameter pipe.

We can check velocity too! Here it's between 1.5m/s and 2.0m/s.



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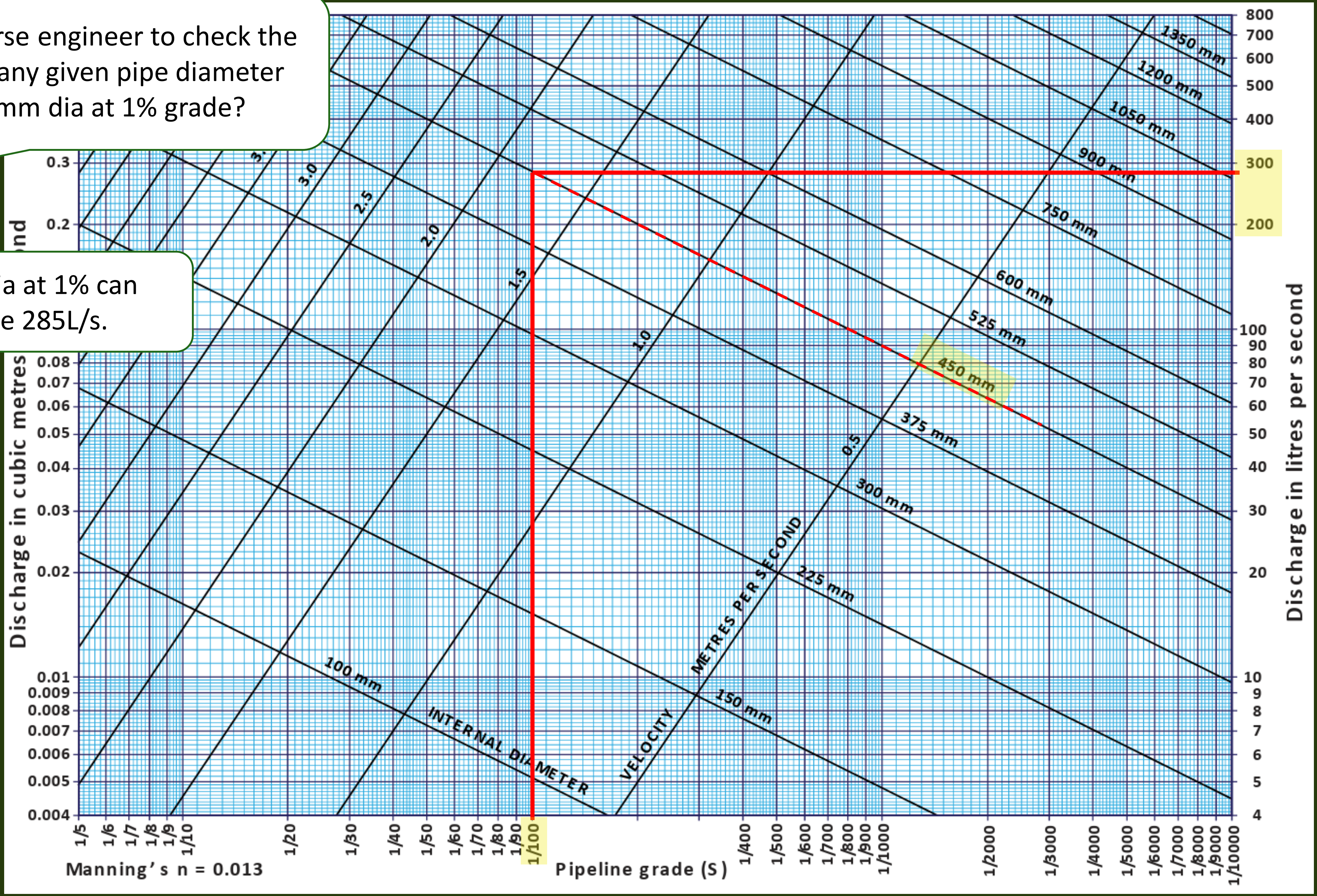
We can reverse engineer to check the capacity of any given pipe diameter e.g. 450mm dia at 1% grade?

So a 450 dia at 1% can discharge 285L/s.



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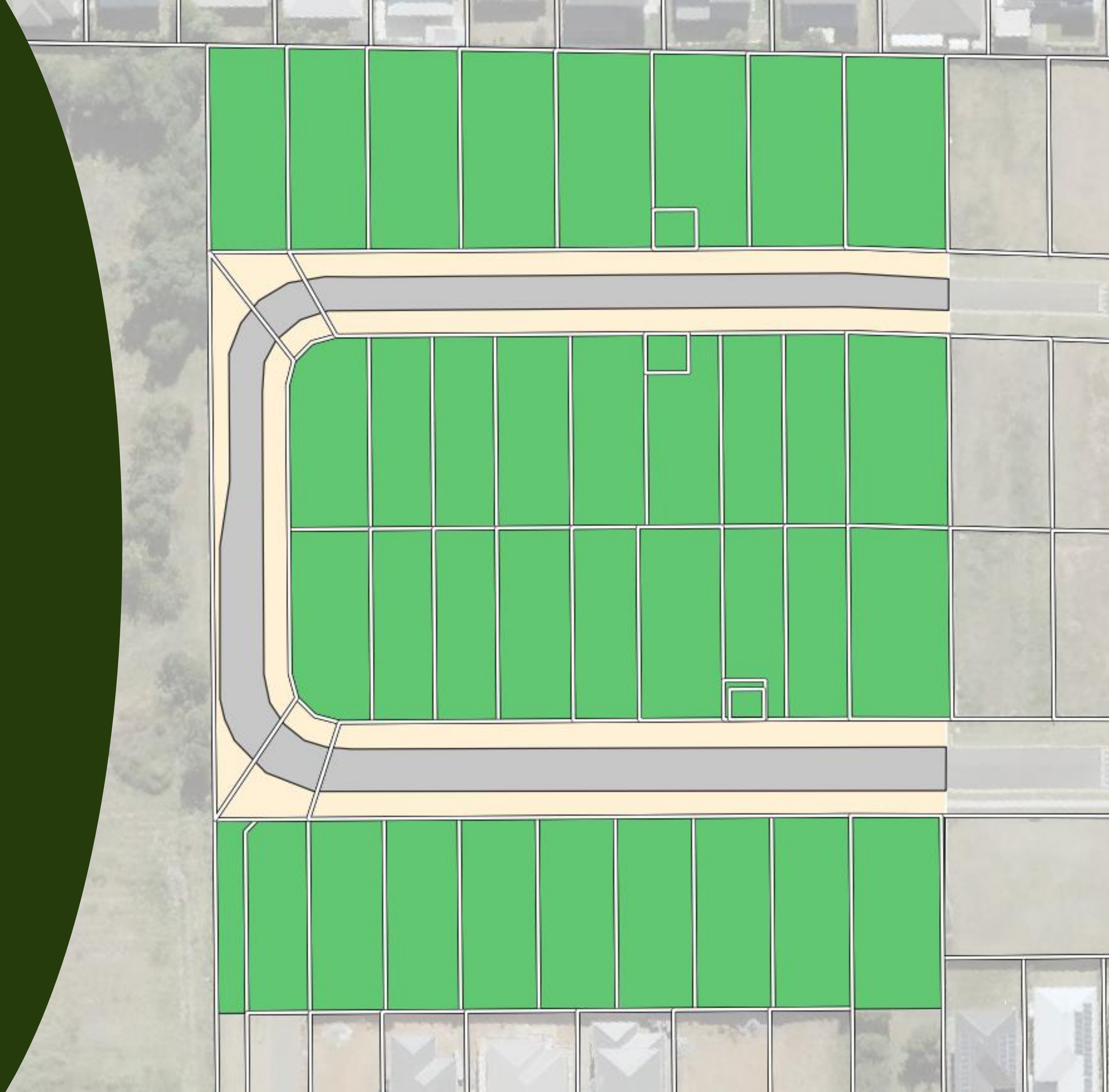
Example Site

Subdivision Plan of Development



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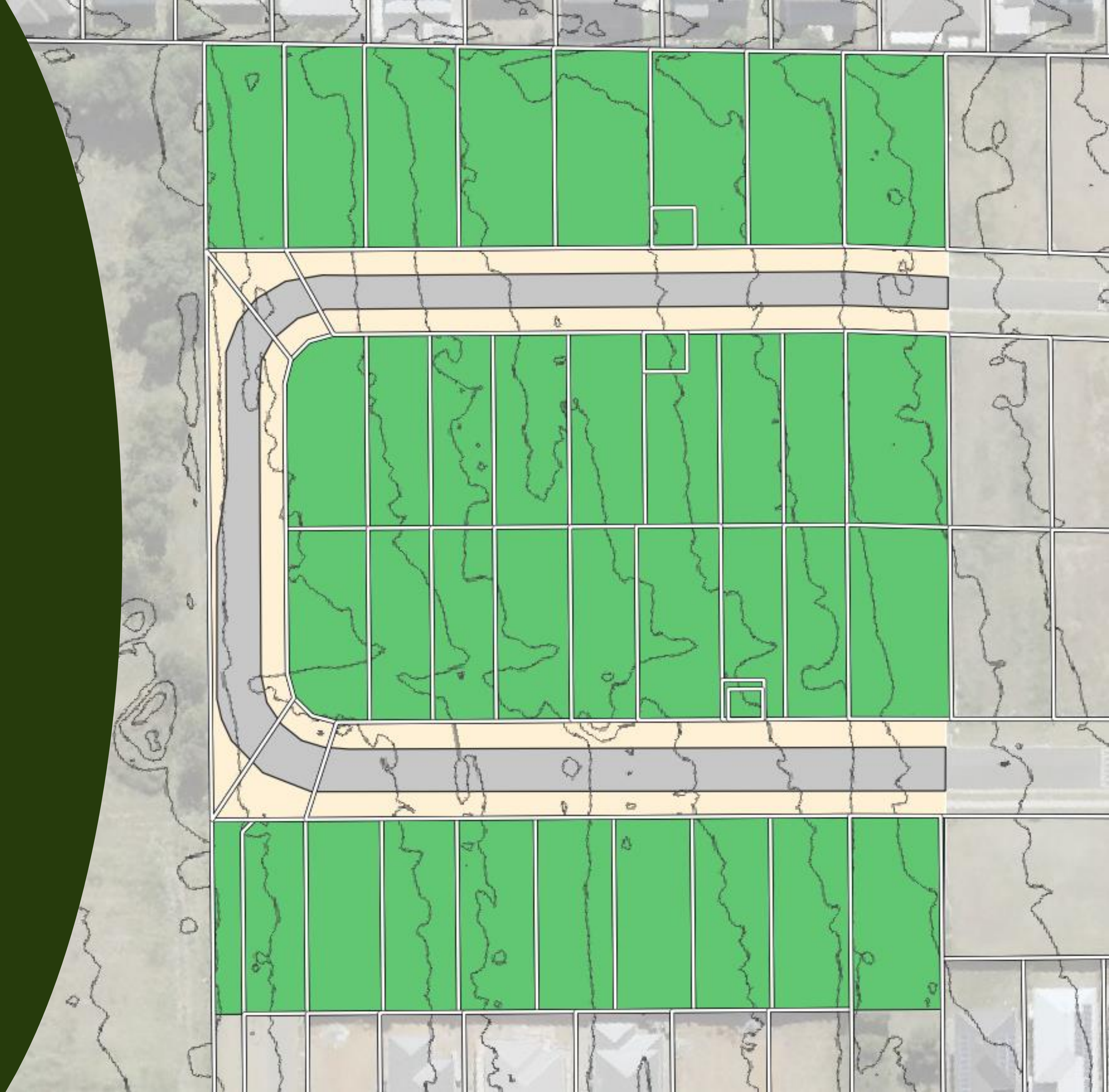
Example Site

First step – obtain existing contours

- LIDAR
- Council mapping
- GIS
- Site inspections
- Survey



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Example Site

Next step – approximate road grading

- Road grading (assume close to existing topography / minimal earthworks)

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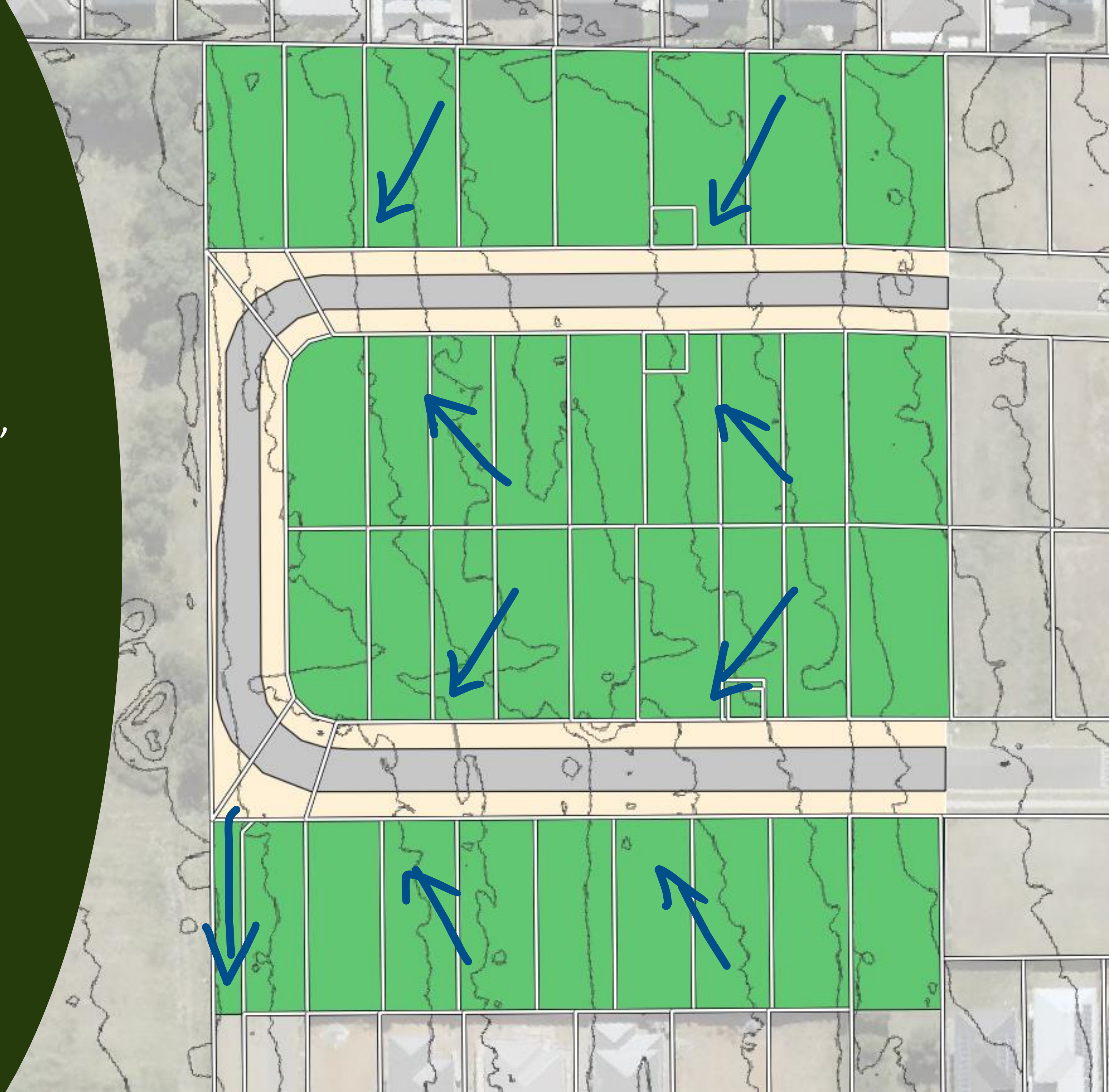
Example Site

Next step – approximate lot grading

- Lot grading (towards / away from road, minimise earthworks)



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Example Site

Next step – site catchment

- Identify catchment boundaries – external catchment, ridges, valleys.
- Identify lawful point of discharge

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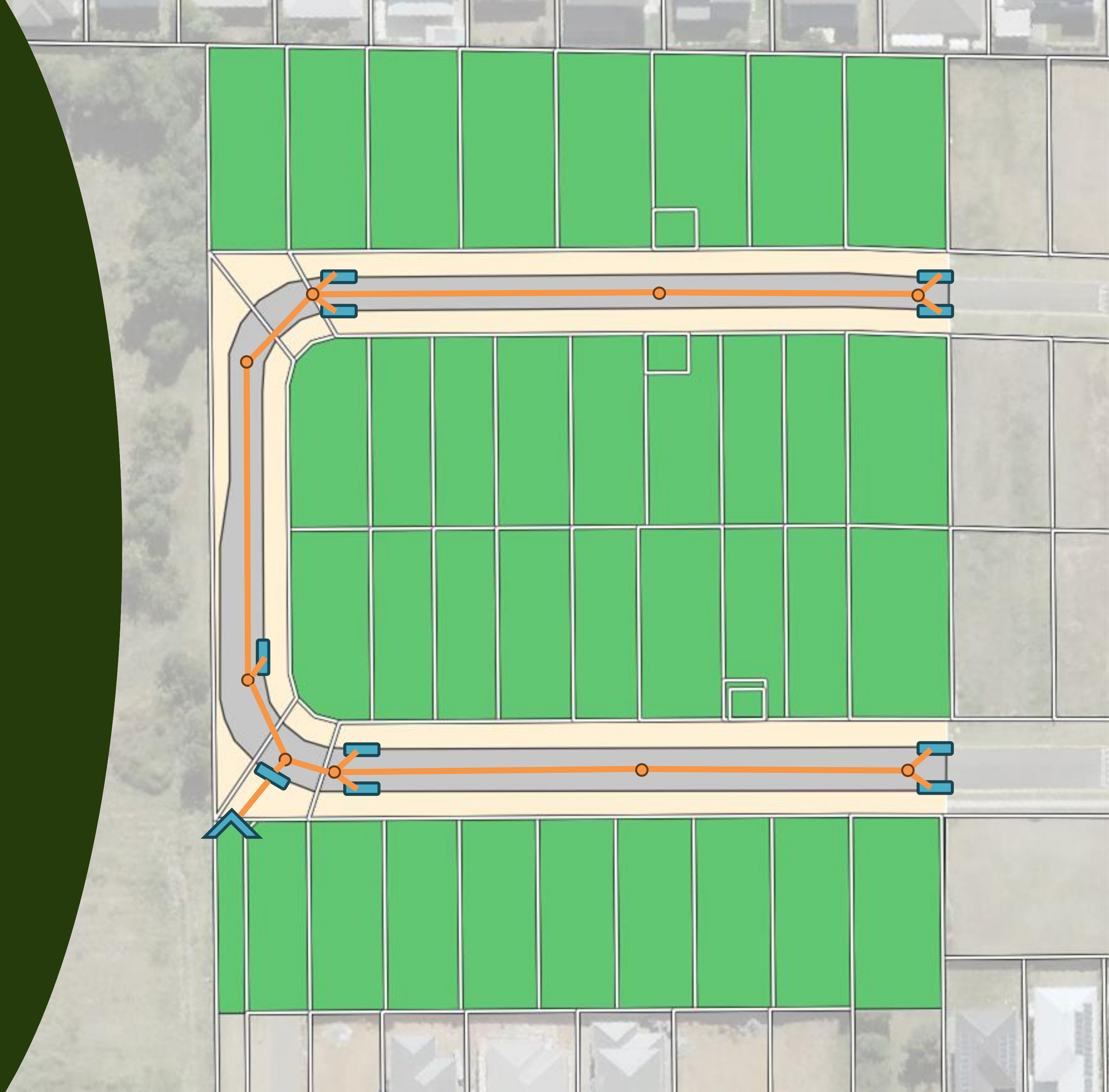
Example Site

Next step – initial inlet locations:

- Sag inlets at low points, sag locations
- On-grade pits at intersection kerb returns
- Headwall outlets at point of discharge



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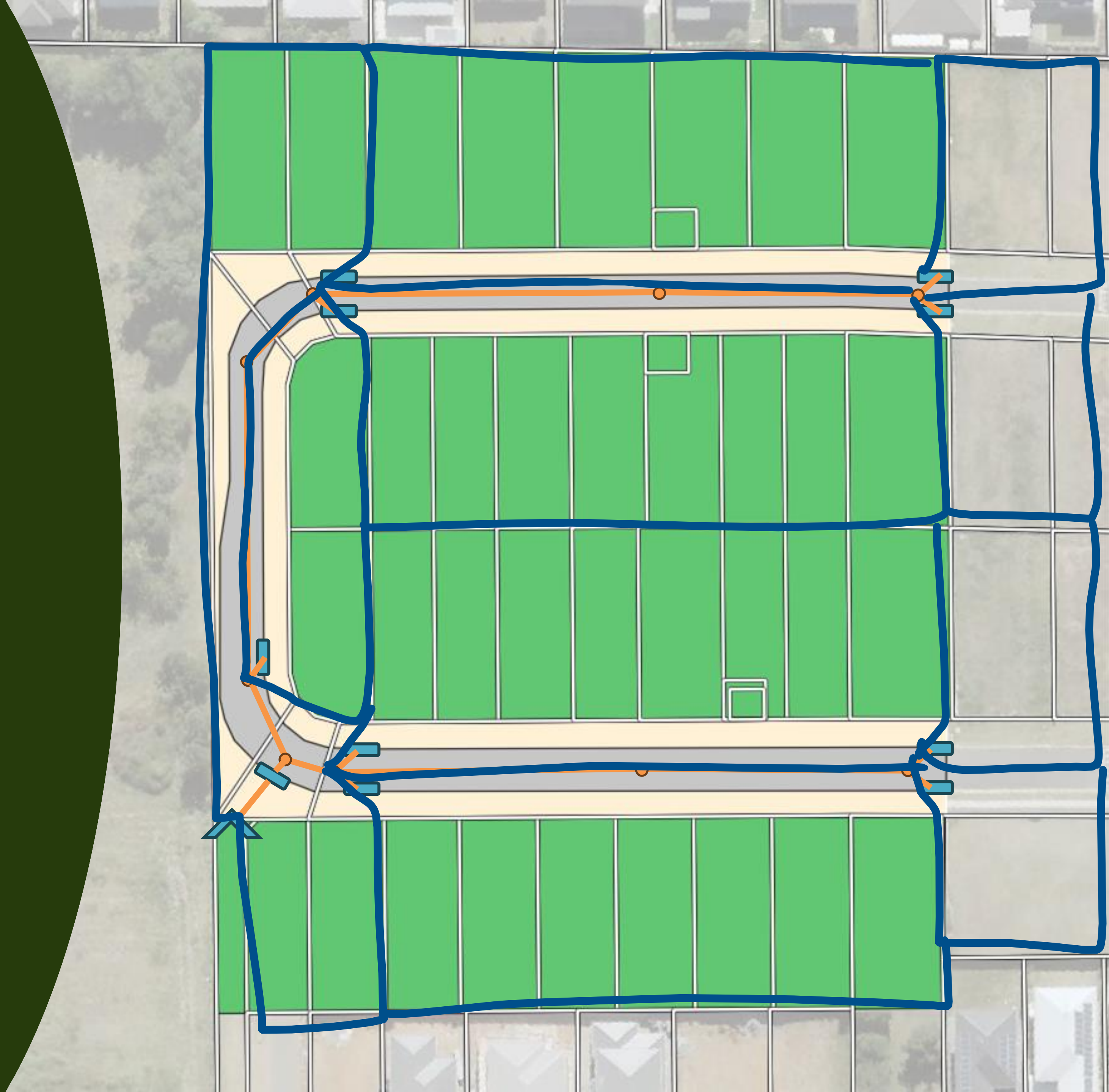
Example Site

Sub catchments for each inlet:

- Rational Method for peak discharge
- Remember Q_c Q_a Q_i Q_b



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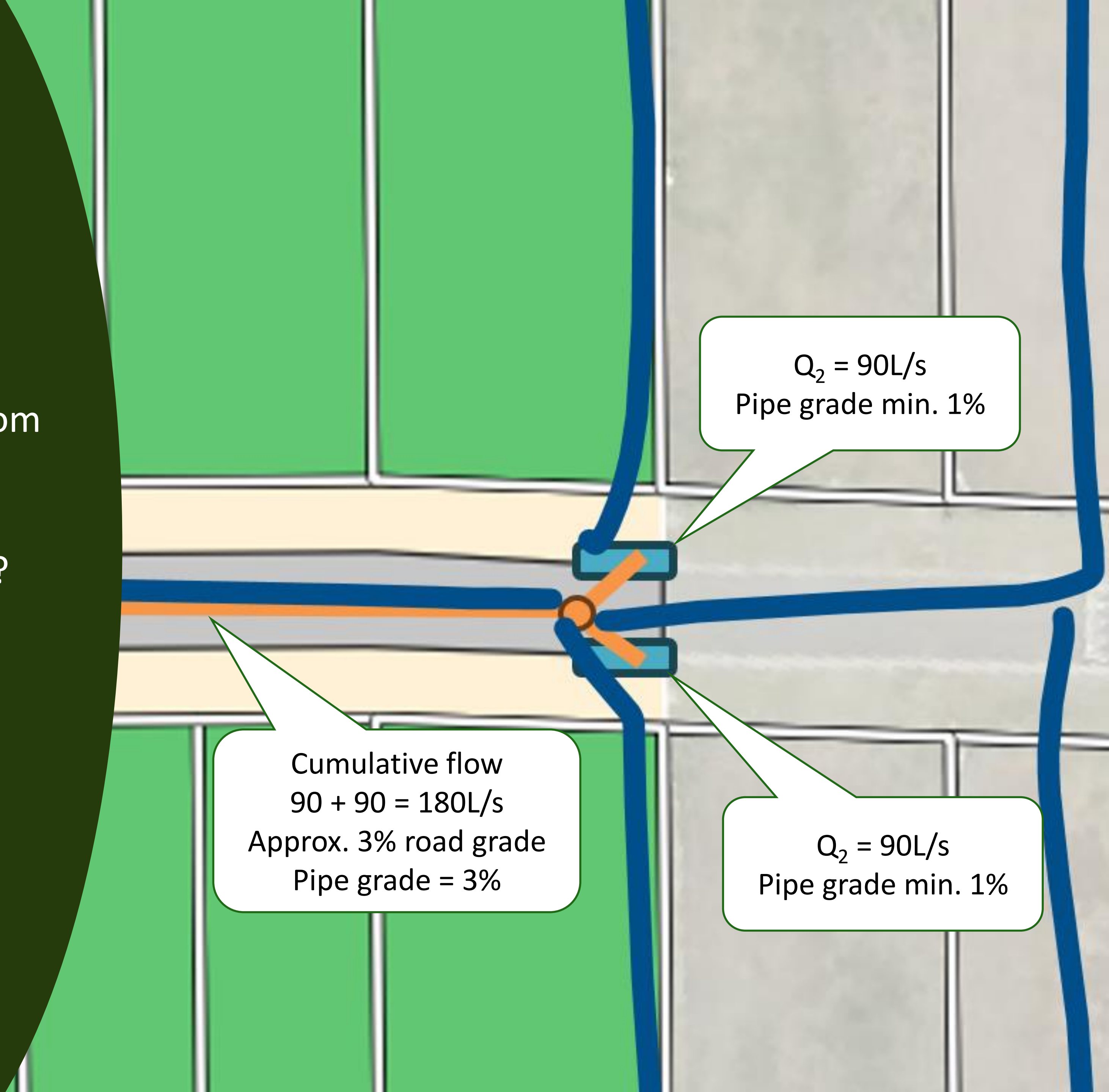
Example Site

Approximate pipe size based on:

- Pipe to convey Q_i (inflow + any flow from upstream pipes)
- Pipe grade based on assumptions – similar to road grade, minimum grade?



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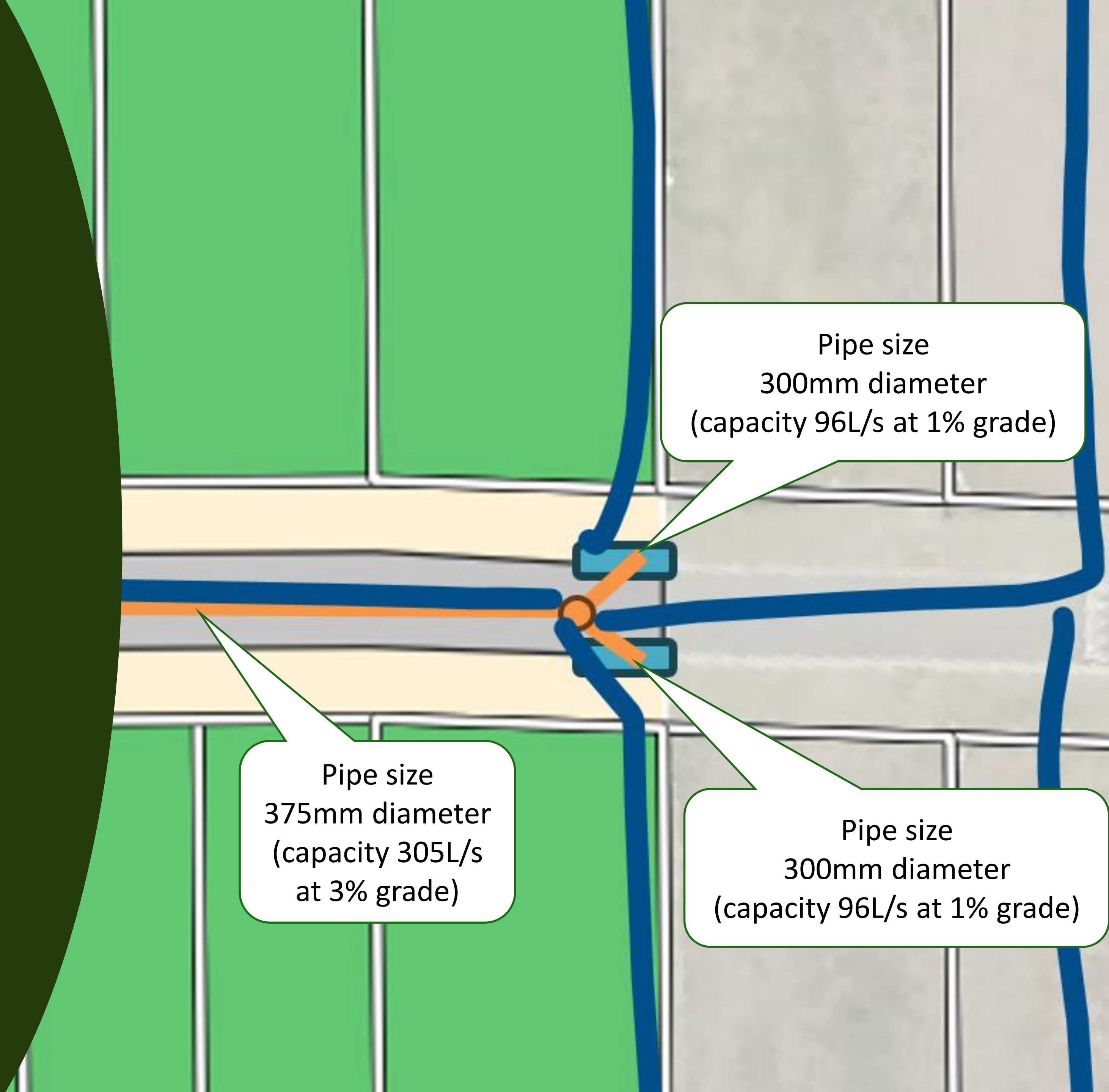
Example Site

Approximate pipe size based on:

- Pipe nomographs

This approach works well for concept designs. Detailed designs will have a more accurate analysis of time of concentration incorporating pipe flow time.



Here are common problems we encounter in the industry:

- Hydraulic Grade Line (HGL) Analysis
- Pipe friction losses
- Pit structure losses (K Values)
- Structural requirements (trench types, construction loads)
- Design parameters (cover, min/max velocities, materials)
- Buoyancy

If these sound familiar but you’re not 100% confident,
get in touch and we can teach you.

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Want to learn more?

We can help with:

- Free consultations
- Online self-paced learning
- Coaching
- Face-to-face workshops
- In-house training delivery

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