INFRAPIPE™

SUSTAINABLE SOLUTIONS FOR GENERATIONS TO FOLLOW

FISHPIPE

DESIGN MANUAL FOR FISH PASSAGE APLICATIONS USING INFRAPIPE RECYCLABLE CULVERT DN (ID)100-3200

The purpose of this document is to assist the ecologist, engineer or asset manager to ensure the best piped solution where Fish Passage requirements must be met by:

- ✓ Proposing a design methodology which combines ecology, hydraulics and civil engineering
- ✓ Explaining the hydraulic and ecological design constraints
- ✓ Proposing solutions in line with "Fish Passage Design & Construction" by the Fish passage Action Team
- ✓ Addressing the relevant areas of the FPG - Fish Passage Guidelines
- ✓ Providing flow velocity and flow rate calculation graphs to select pipe sizes using Mannings number
- ✓ Explaining the lower ecological impact of the installation of lighter materials than concrete
- ✓ Explaining the sustainability benefits of a product that is fully recyclable, has a low environmental impact in manufacture and freight, and is highly abrasion resistant
- ✓ Explaining how these requirements can be met using thermoplastic pipe, in particular:
    - ✓ Providing chord widths for burial levels
    - ✓ Providing Cross Sectional Areas (CSA) for hydraulic capacity
    - ✓ Calculating the effect of differing burial levels on capacity
    - ✓ Discussing overflow options (open or contained)
    - ✓ Explaining the installation options for baffles and other structures
    - ✓ Explaining manufacture and installation options for the pipe
    - ✓ Providing a checklist for design requirements
- ✓ Explaining that the latest version of the FPG now sees multi-barrelling as an equal and valid option
- ✓ Explaining the differing benefits of different designs and materials

FEATURES & BENEFITS OF RECYCLABLE INFRAPIPES

- ✓ Best seismic resistance
- ✓ 100-year life
- ✓ 14 times lighter (7%) than concrete
- ✓ Stronger
- ✓ Quick to install
- ✓ Completely recyclable
- ✓ Best hydraulic performance
- ✓ Easy to freight
- ✓ Best abrasion resistance
- ✓ Chemically inert
- ✓ Biologically immune
- ✓ No maintenance
- ✓ Easy to modify or repair
- ✓ Fish baffles fit permanently and quickly

INFRAPIPE is an New Zealand manufacturer of fully recyclable HDPE culverts using state of the art pipe making equipment. **INFRAPIPE and its products are certified to the highest ISO standards, 9001:2015 and 5065:2005** ensuring the pipe is made with the best resin and will last a century or more. INFRAPIPE also uses design software to produce the most economical pipe for the load case, soil conditions, water table and hydraulic requirements.



CONTENTS

- This design manual is for new installations (or reinstallations) - for the Fish Passage Remediation Training Aid (FPRTA) for existing culverts please visit the ATS Environmental website.
- Use this link for the HY-8 Culvert Hydraulic Analysis Program.
- INFRAPIPE has further data sheets and design manuals available from their website.

INFRAPIPE uses the latest German technology to make completely recyclable pipes

DEFINITIONS/ABBREVIATIONS

Definition	Meaning
BFW	**Bank Full Width** – The width of the stream area at a certain level, which for many installations must be exceeded by the Inner Diameter of the pipes chosen according to a given formula, the formula chosen being dictated by the size of the BFW.
CSA	**Cross-Sectional Area –** the capacity of the pipe expressed as the area of the cross section of the inner pipe in mm2
DN	**Nominal Diameter** for INFRAPIPE this is the ID (Inner Diameter) Note for some competitive products DN is the OD (Outer diameter)
Flow Rate	**The volume of water in m^3** which can/will travel through the pipe, a product of 1 - the water needing to flow through the pipe, 2 - the hydraulic efficiency (plastic pipes are 18% more efficient than concrete) 3 – the gradient and 4 – the cross sectional area (CSA)
Flow Velocity	**The speed in m/s** at which the water will flow through the pipe for a given flow rate
GWL	**Ground Water Level** – the depth of the Ground water in relation to the surface (RL)
HDPE/PP	**The plastics from which INFRAPIPE is made**. They are chemically and biologically inert, non-polluting, fully recyclable - all production waste is reprocessed and reused.
IL	**Invert Level** – the lowest level of the Pipe or river
NES-FW	**National Environmental Standards for Freshwater**
Rest Pool	**An area that is deeper and slower** than the flow would normally sustain, long enough and deep enough that it can accommodate local species
SN	**Ring Stiffness** – the strength of the pipe, typically 4,8 or 16 but INFRAPIPE can engineer products from 2.5 to 40+ as required for the application.

Figure 1 Standard pipe definitions

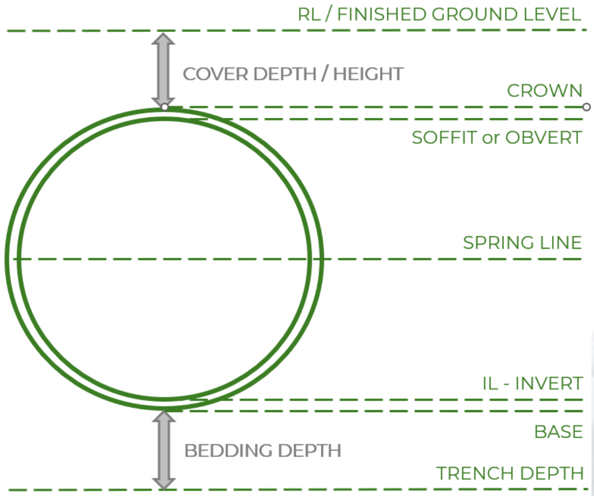
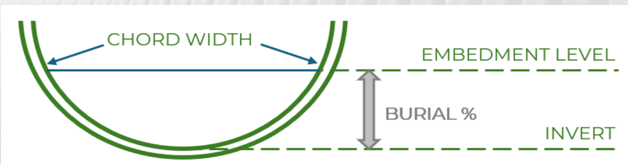


Figure 2 Pipe burial definitions





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SOLUTION SUMMARY

INFRAPIPE manufactures the largest range of pipes suitable for fish passage in New Zealand, and reprocesses all production waste. Flexible thermoplastic pipes, also known as profile pipes, twin wall pipes or helical (spiral-wound) pipes are now the default choice globally for culverts. They are lighter, greener, cheaper, and easier to install than concrete or steel, and have a longer-life with no maintenance requirements. Now with the higher strengths available from INFRAPIPE they are also a highly effective substitute for box culverts, providing a shaped channel and the same load for a lower price and environmental impact.

This document will show that pipes are not just pipes, and the right choice of material, sizes and quantities combined with flexible baffle installation and good inlet & outlet design ensures optimum fish passage.

Table 1 INFRAPIPE Details

Precise weight is dictated by the load, cover depth and soil conditions, weight shown below is typical.

DN	ID	OD	Skt OD	Overall length mm	Effective length mm	Weight
100	98	115	123	6490	6413	5
150	147	171	180	6461	6348	8
225	218	254	268	6429	6283	19
300	295	345	363	6389	6188	32
375	375	437	456	6390	6183	52
450	450	523	545	6340	6123	80
525	525	611	634	6317	6041	109
600	600	702	728	6273	5920	132
700	700	820	840	6000	5800	212
800	800	936	956	6272	5936	224
900	900	1090	1110	6000	5800	329
1000	1000	1166	1186	6283	5892	372
1100	1100	1320	1340	6000	5800	410
1200	1200	1464	1484	6000	5800	464
1350	1350	1614	1634	6000	5800	735
1500	1500	1776	1796	6000	5800	889
1600	1600	1880	1900	6000	5800	1126
1800	1800	2088	2108	6000	5800	1470
2000	2000	2310	2330	6000	5800	1878
2300	2300	2634	2654	6000	5800	2796
2500	2500	2842	2862	6000	5800	3395
3200	3200	3542	3562	3000	2800	2250

STANDARDS

INFRAPIPE holds all the required standards:

1. Certified to AS/NZS 5065:2005 licence no. AMI 74961.
2. Pipes are tested by Infrapipe to AS/NZS5065:2005 in their test lab in accordance with ISO 9969:2016 *Thermoplastic pipes – Determination of Ring Stiffness.*
3. The rubber rings are certified to EN681-1.
4. INFRAPIPE Ltd is certified to ISO 9001:2015 licence no. AMI 78044.

DESIGN PRINCIPLES, OUTCOMES & KEY CONCEPTS

The Fish Passage Action Team (FPAT) identifies the following Principles and Outcomes of Fish passage design:

FISH PASSAGE PRINCIPLES AT MANMADE STRUCTURES & EROSION CONTROL

Assuming it is agreed that there is fish habitat upstream, and sufficient water, fish passage mitigation/remediation interventions should subscribe to the following principles regardless of the species or life stage:

1st Principles (imperative for all species and life-stages)

1. Provide sufficient depths and swimmable velocities or climbable surfaces.
2. Ensure continuity of the steam bed - not perched or undercut.
3. Maintain surface flow - avoid flow going sub-surface.

2nd Principles: (ideal)

1. Create hydrological conditions (depth, velocity & complexity) akin to those occurring naturally upstream - this should provide passage for local fish species.
2. Provide complex flows (various flow directions and velocities down through the water column) – giving a higher chance of meeting a range of fish migration needs.
3. Provide rest pools - areas to rest and/or feed between high velocity zones.
4. Provide a range of options, including wetted margins/splash zones - to cater to fish with a climbing ability.

3rd Principles: (aspirational)

1. Constrain flows and/or increase depth - maximise whatever water is available.
2. Provide shade and cover – structural or vegetation.
3. Retain bed material - without causing blockages.

Practice principles

1. Avoid pouring concrete on site – it is highly toxic and prone to failure over time.
2. Avoid dewatering existing structures for simple remediation – this is stressful for fish, costly, and requires permits.

Practitioners notes

1. The diameter, gradient and length of the structure, along with site specific characteristics, will also determine the nature of interventions.
2. The areas immediately upstream and downstream need to be considered, particularly if within the construction zone where ground has been broken.

OUTCOMES

Ecological Outcomes

1. Fish and other aquatic organisms that arrive at the downstream end of a structure are able to migrate upstream to suitable habitat.
2. Where practical, bed material accumulates and is retained within the structure providing both roughening and, to some degree benthic, habitat for fish and invertebrate communities.
3. Maintain and manage flows to allow for passage for as many days as possible.
4. If possible, provide habitat within structures e.g., provide shade, rest pools, refugia.

Engineering and Hydrological outcomes

1. Match or better the upstream flow characteristics - depth, complexity, velocity etc.
2. Reduce exit velocities - prevent or reverse scouring and the creation of plunge-pools at the outlet.
3. Maintain or improve water depth - maintain surface flow, constrain available flow without inducing fast laminar flows.
4. Meet catchment capacity requirements - pipes of sufficient size to prevent overtopping in flood events.
5. Meet load bearing requirements - culverts selected that will withstand design loads.
6. Increase life of the structure - reducing abrasion/corrosion of the invert.

Overall

1. Meet regulatory requirements - compliant across all regulations and consent conditions.
2. Reasonable cost - within budget.
3. Minimal maintenance - durable and robust.
4. Minimal risk of blockage or failure - design to avoid long-term risk to asset.

KEY CONCEPT – REST POOLS

- Design for Fish Passage can be simplified to the need to provide a series of rest pools which suit local (desirable) fish which are linked by bodies of water with suitable flows which the fish can successfully navigate.
- A resting pool is an area that is deeper and slower than the flow would normally sustain and is long enough and deep enough that it can accommodate the desired local species through the greatest range of flows.

KEY CONCEPT – FLOWS

- ✗ Laminar flow is when water flows smoothly in one direction. This is undesirable for fish passage.
- ✗ Turbulent flow is when water flows in a turbulent (unequal and vertically unstable) manner in (predominantly) one direction.
- ✓ Complex flow is composed of multiple flow directions and velocities down through the water column, creating boundary layers to enable upstream navigation.
- ✓ Flows vary greatly depending on the recent weather. Typical modelling sees rainfall intensities peak at 40 times higher during North Island storms, and a culvert must be capable of accommodating the greatest flow but preserve its fish passage characteristics throughout the remainder of the year.

KEY CONCEPT – DRAINAGE REQUIREMENTS

Any culvert is ultimately a drain – that is it must drain away liquid in order to function. Therefore, a culvert must:

- ✓ Permit the passage of the required amount of water
- ✓ Not cause flooding at the inlet or outlet
- ✓ Avoid the possibility of blockage as much as possible
- ✓ Function in all ranges of flows



DESIGN PROCESS

The following design process suggests the optimum information flow between the relevant specialists:

Table 2 Culvert Design Process

<table>
<tr><th>Ecologist</th><th>Hydraulic Engineering</th><th>Civil Engineering</th></tr>
<tr><td>Provides Bank Full Width determination</td><td></td><td></td></tr>
<tr><td>Provides swim velocities, swim endurance and minimum depths for desirable local fish.</td><td></td><td></td></tr>
<tr><td></td><td>Provides flow rates for a range of flows</td><td></td></tr>
<tr><td></td><td></td><td>Provides possible Invert Level ranges at Inlet and Outlet
Provides range of possible gradients</td></tr>
<tr><td colspan="3">Determine Pipe Burial Level
Determine Flow Velocities
Determine Invert Levels
Select Pipe Quantity and Size</td></tr>
<tr><td colspan="3">Show chord widths, water depths and mean flow velocities for a range of flow rates
If required calculate average velocities for vertical slices</td></tr>
<tr><td></td><td></td><td>Confirm Geotech (soil type and ground water level), load case and cover constraints</td></tr>
<tr><td colspan="3">Determine cover levels and therefore pipe strength (SN rating)</td></tr>
<tr><td>Provide planting requirements and downstream/upstream requirements</td><td></td><td></td></tr>
<tr><td colspan="3">Design Inlet and Outlet areas
Design headwalls, apron and trench</td></tr>
<tr><td colspan="3">Show longitudinal sections (and cross sections) of usable depths from fish perspective</td></tr>
<tr><td>Confirm fish size and hence resting pool size</td><td></td><td></td></tr>
<tr><td colspan="3">Design fish baffle installation requirements</td></tr>
</table>



CHECK LIST FOR DESIGN

This checklist is confined to the design outputs (in addition to the expected civil engineering design) which are affected by fish passage requirements:

1. Inlet
    a. Inlet pool
    b. Headwall/wingwall/inlet design
2. Pipe
    a. Number & Size – Inner Diameter
    b. Length(s) and connections
    c. Design requirements or SN rating
    d. Flexible fish baffles installed – size, spacing and offset
    e. Flood gates installed
3. Outlet
    a. Pool
    b. The Invert Level should be below the downstream stream bed
4. Apron
    a. This should be backwatered into the culvert
    b. Mechanism for constraining low flows (to achieve backwatering)
    c. Shading requirement
5. Resting pools should be sufficient in number in 1-4 above to enable progress of desirable local species
6. Surrounding area
    a. Banks
    b. Channels
    c. Planting
7. Trench
    a. Trench design – dimensions, bedding, embedment material, overlay zone and cover
8. Working area
    a. Excavation
    b. Permitted working area
    c. Preparation for working area
    d. Restitution
    e. Access requirements
9. Temporary diversion
    a. Diversion method
    b. Diversion equipment
    c. Diversion restitution
10. Erosion & Sediment Control Plan
11. Range of flows. Effective Fish passage design can be proven by demonstrating Invert levels and resting pools for the full range of flows anticipated.

Buoyancy is not an issue
Culverts are open-channel and therefore not affected by buoyancy. Whilst the profile of an INFRAPIPE can create buoyancy, the weight of even 300mm of cover is easily sufficient to overcome this.



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FISH PASSAGE DESIGN

HYDRAULIC PERFORMANCE

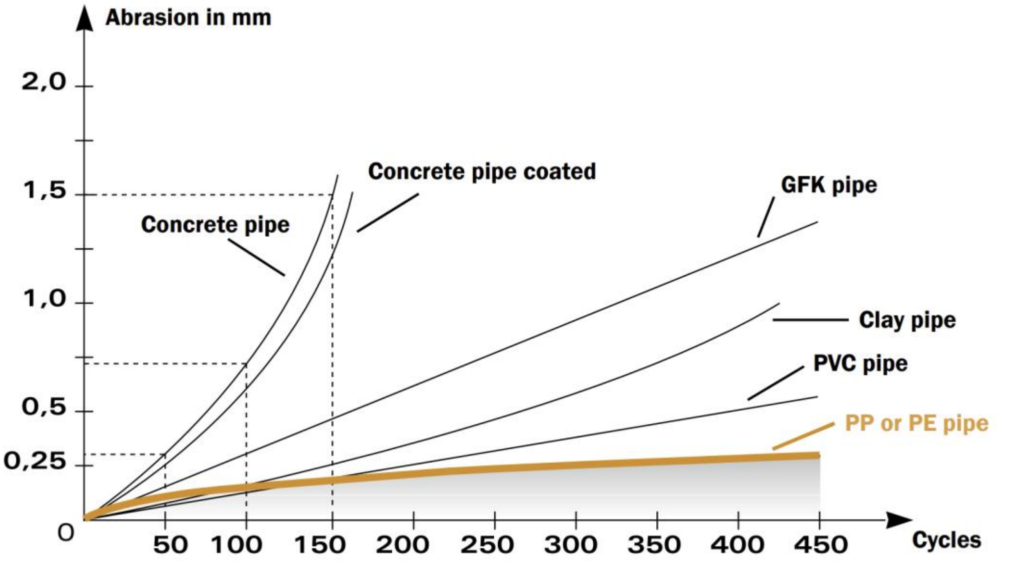
Not all pipes are created equal. Flow through gravity pipes is calculated using the Mannings formula, a part of which is the Mannings coefficient which makes allowance for the differing levels of surface roughness between materials.

For The NZ Building Code, NZTA and KiwiRail, the Mannings number used is 0.011 for plastic pipes and 0.013 for concrete. **This is an average difference of 18% in hydraulic capacity** (and up to 23%), often allowing the use of a smaller pipe to achieve the same flow rate.

Mannings graphs for pipe selection are included at the end of this document.

ABRASION RESISTANCE – PRODUCT LIFE (DARMSTADT TEST)

Abrasion reduces the efficiency of a pipe (and for concrete allows it to deteriorate, being friable). HDPE has the optimum abrasion resistance of any pipe material as proven in numerous tests:



Abrasion curve of various pipe materials according to the Darmstadt procedure.

NB The above diagram is taken from a European paper, GFK is GRP/FRP (GRP is not used as a culvert in NZ).

The Darmstadt procedure, which has been the standard for abrasion testing since the 1960s, simulates the abrasion and resulting wear of liners and pipes that would occur in actual operating conditions by tilting a pipe section containing a mix of sand, gravel and water through 22.5 degrees above and below the horizontal for at least 100,000 cycles. The results for PP or PE pipe show a much greater resistance to abrasion and hence operating life is significantly longer.

The specimen comprises a 1metre length of DN300 pipe that is tilted to and fro in a controlled slow rocking motion at a frequency of 0.18 HZ; this corresponds to 21.6 stress cycles per minute – defined as the movement of the abrasive material in one direction.



This frequency ensures that the abrasion material travels the complete length of the test specimen. The abrasive material is a quartz sand and gravel in a water slurry containing approximately 46% by volume abrasive material in grain sizes 0-30mm. The abrasive material is changed every 100,000 stress cycles (approx. 77 hours).

BANK-FULL WIDTH (BFW)

INFRAPIPE pipes are denominated in their ID, therefore, to simply calculate the pipe (s) required to match the Bank-full Width, use the INFRAPIPE pipe size.

- ✗ **Beware - some competitor products are denominated in their OD to make them sound like a better deal. Always confirm the ID of pipes if they are not INFRAPIPE**

This can cause subsequent embarrassment, always confirm the ID of a pipe (see page 12 for diameters).

TWIN PIPES & MULTI-BARRELLING UPDATES IN THE LATEST NIWA FISH PASSAGE GUIDELINES (FPG)

Previous iterations of the Fish Passage Guidelines stated that there was an ecological requirement to reduce the use of twin or multiple pipes where possible and encouraged the use of box culverts.

- ✓ **This requirement has now been removed – multi-barrelling is no longer discouraged!**

This frees up the designer to choose the optimum combination of pipes to suit the levels of the site, the hydraulic requirements and the Bank-Full Width requirements. Multi pipes offer lower profiles and a lower risk of blocking.

Single or multiple pipes?

At first glance, a single pipe sized to match the BFW appears the logical choice – and often is. However multiple pipe solutions offer a number of advantages in certain situations:

- ✓ The required levels above the watercourse are lower (as each pipe is smaller)
- ✓ The required disruption to the watercourse bed is lower (as each pipe is smaller)
- ✓ Blockage of one pipe still permits water to flow
- ✓ Installation water diversion can be easily achieved
- ✓ If appropriate, differing fish passage solutions can be offered in each pipe
- ✓ A combination of pipes and burial levels can allow optimum fish passage for different flows
- ✓ Overflow pipes can reduce the risk of scouring.

The weight of a box culvert can damage the site

A box culvert 1500mm high and 2500mm wide – a typical small installation – comes in sections that weigh 7.6 tonnes each. This is more than can be lifted by a digger. This page here explains the impact of the lifting distance on the actual weight to be lifted by the crane https://www.prestonhire.co.nz/a-guide-to-reading-a-crane-load-chart/ and this page then calculates this weight at distance https://www.cadmancranes.com/crane-size-calculator/ And the minimum equipment for this small box culvert then becomes this crane, for instance:
https://www.cadmancranes.com/app/uploads/2022/08/TEREX-AC402L.pdf
The requirement for access, and for a stable lifting platform (with ground pads to allow for the stabiliser legs) dramatically increases the disruption of the site and ecological impact.

Box culverts can be very effective, but their installation can do more damage than the rest of the project.

One or more circular pipes is normally less disruptive and can carry an equivalent load.



BURIAL LEVEL & CHORD WIDTH DATA

These tables assist the designer to see the cross sectional area and chord width for pipes when buried to certain levels. For intermediate requirements, contact sales@infrapipe.co.nz

Table 3 INFRAPIPE CROSS-SECTIONAL AREAS (CSA) IN MM FOR DIFFERENT BURIAL LEVELS

	% CSA remaining:	86%	81%	70%	60%	50%
DN	**Burial 0%**	**20%**	**25%**	**33%**	**40%**	**50%**
300	68,315	58,614	47,184	33,029	19,850	9,925
375	110,391	94,715	76,246	53,372	32,077	16,038
450	158,963	136,390	109,794	76,856	46,190	23,095
525	216,366	185,642	149,442	104,609	62,870	31,435
600	282,600	242,471	195,189	136,632	82,116	41,058
700	384,650	330,030	265,674	185,972	111,769	55,885
800	502,400	431,059	347,003	242,902	145,984	72,992
900	635,850	545,559	439,175	307,423	184,761	92,381
1000	785,000	673,530	542,192	379,534	228,100	114,050
1100	949,850	814,971	656,052	459,236	276,001	138,001
1200	1,130,400	969,883	780,756	546,529	328,464	164,232
1350	1,430,663	1,227,508	988,144	691,701	415,712	207,856
1500	1,766,250	1,515,443	1,219,931	853,952	513,225	256,613
1600	2,009,600	1,724,237	1,388,011	971,607	583,936	291,968
1800	2,543,400	2,182,237	1,756,701	1,229,691	739,044	369,522
2000	3,140,000	2,694,120	2,168,767	1,518,137	912,400	456,200
2300	4,152,650	3,562,974	2,868,194	2,007,736	1,206,649	603,325
2500	4,906,250	4,209,563	3,388,698	2,372,088	1,425,625	712,813
3200	8,038,400	6,896,947	5,552,042	3,886,430	2,335,744	1,167,872

Table 4 INFRAPIPE CHORD WIDTHS IN MM FOR DIFFERENT BURIAL LEVELS

	Burial %										
DN	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**33%**	**35%**	**40%**	**45%**	**50%**
300	129	177	211	236	255	270	277	281	289	295	295
375	163	225	268	300	325	344	353	358	367	375	375
450	196	270	321	360	390	412	423	429	441	450	450
525	229	315	375	420	455	481	494	501	514	525	525
600	262	360	428	480	520	550	564	572	588	600	600
700	305	420	500	560	606	642	658	668	686	700	700
800	349	480	571	640	693	733	752	763	784	800	800
900	392	540	643	720	779	825	846	859	882	900	900
1000	436	600	714	800	866	917	940	954	980	1,000	1,000
1100	479	660	786	880	953	1,008	1,034	1,049	1,078	1,100	1,100
1200	523	720	857	960	1,039	1,100	1,129	1,145	1,176	1,200	1,200
1350	588	810	964	1,080	1,169	1,237	1,270	1,288	1,323	1,350	1,350

1500	654	900	1,071	1,200	1,299	1,375	1,411	1,431	1,470	1,500	1,500
1600	697	960	1,143	1,280	1,386	1,466	1,505	1,526	1,568	1,600	1,600
1800	785	1,080	1,285	1,440	1,559	1,650	1,693	1,717	1,764	1,800	1,800
2000	872	1,200	1,428	1,600	1,732	1,833	1,881	1,908	1,960	2,000	2,000
2300	1,003	1,380	1,643	1,840	1,992	2,108	2,163	2,194	2,254	2,300	2,300
2500	1,090	1,500	1,785	2,000	2,165	2,291	2,351	2,385	2,449	2,500	2,500
3200	1,395	1,920	2,285	2,560	2,771	2,933	3,009	3,053	3,135	3,200	3,200

FISH PASSAGE FEATURES

Fish passage is included in design in two ways:

- The design of the site, its civil engineering, gradients, planting and inlet and outlets (sitework)
- The choice of the pipe, the baffle configuration and other requirements connected to the pipe (pipework)

FLEXIBLE BAFFLES

These flexible baffles are becoming the product of choice for the following reasons:

- ✓ They can be configured to suit – flexible in design as well as nature. This means:
    - ✓ They can be spaced at the appropriate intervals for each site to create the resting pools required
    - ✓ They can be used with any amount of offset for each baffle
    - ✓ They can be used horizontally, vertically or part way between the two
- ✓ Their tapered design allows them to function in a wide range of flow rates
- ✓ They bend in stronger flows minimising the resistance to storm flows
- ✓ They are easy to attach to the culvert
- ✓ They do not retain debris
- ✓ They naturally allow some sediment to accumulate
- ✓ Individual baffles can be substituted/modified at any time should conditions change
- ✓ Factory fitted or site fitted (DN900+)

Flexible baffles are semi-rigid notched baffles (100 or 150mm high) which can be installed in all types of culverts and aprons and in any configuration. Whilst they can be retrofitted, factory fitting is cheaper, safer and, for diameters less than 900mm essential. INFRAPIPE works with the supplier of these baffles, ATS Environmental, to provide the best configuration for the ecological requirement.

Table 5 Flexi-Baffle Lengths

FLEXI-BAFFLE LENGTH	
Round culvert diameter	Length
600mm>900mm	450mm
900mm>1200mm	450mm
1200mm>1800mm	600mm
1800mm>2400mm	900mm
2400mm>3000mm	1200mm
>3000mm	1800mm

*150mm high baffles are also available and are suitable for flat bottom culverts and round culverts with a diameter over 1800mm.

Baffles are spaced so as to provide resting pools at an appropriate interval, the table below is a maximum distance between baffles to create effective resting pools. Should the desired fish species require closer spacing, the minimum spacing is 480mm but is typically 600mm or more:

Table 6 Flexible Baffle Spacing for a Given Gradient

Grade %	Degrees	Flexi-baffle spacing
0 > 1	0 > 0.57	2400mm
1 > 2	0.57 > 1.15	1200mm
2 > 4	1.15 > 2.29	1000mm
4 > 6	2.29 > 3.43	800mm
6 > 8	3.43 > 4.57	600mm
8 > 10	4.57 > 5.71	480mm

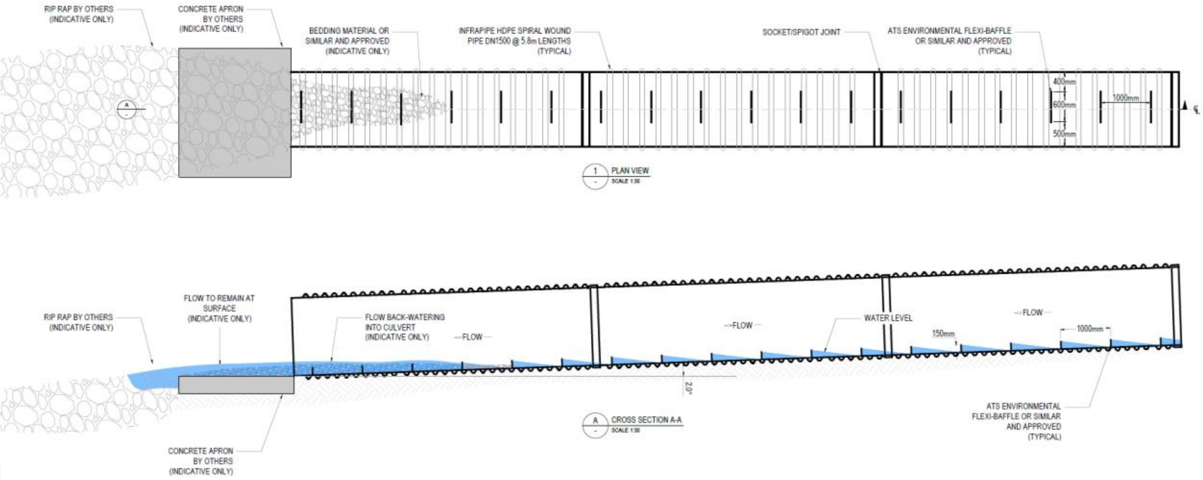
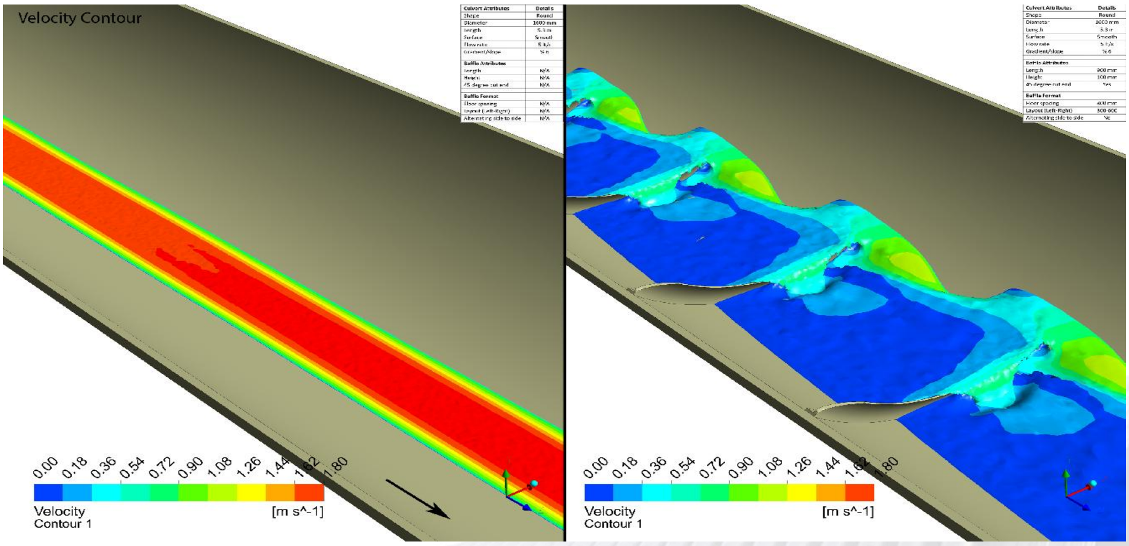


Figure 3 A typical best practice fish passage design showing the installation of rigid baffles and outlet mitigations

Offset flexible baffles on site creating resting pools and in the factory for installation.

For pipe sizes less than 600 (in the factory) or 900 (onsite), safe installation is achieved by baffles being affixed to a pipe liner (of the same diameter as the pipe) or PE strip which is then attached to the pipe at either end.

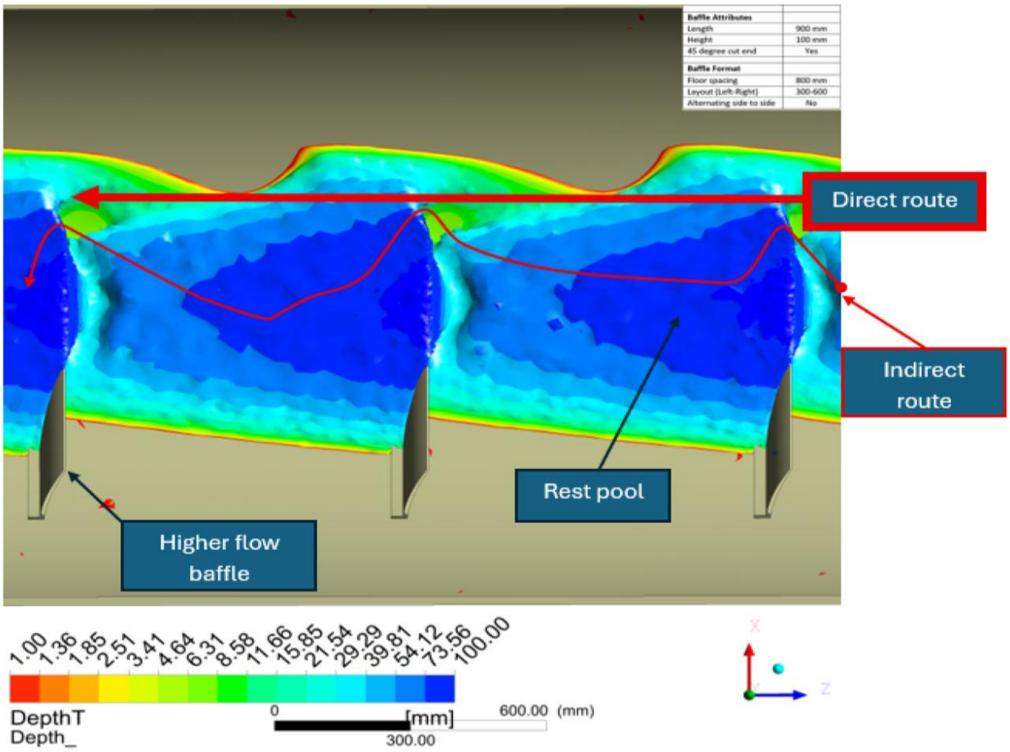


Fast, shallow, laminar type flows (in red) are not good for fish. Complex, deeper flow with rest pools (on the right) are great for fish. As the combination of gradients, target fish, and likely flow rates are unique to every site the flexibility of designing flexible baffle installation for each pipe ensures optimum fish passage for the greatest range of flows.

The CFD modelling shown above and below was recently undertaken by ATS environmental to prove the effectiveness of flexible baffles in achieving resting pools and complex flows to enable upstream navigation. It is reproduced from the Fish Passage Action Team's Advisory Note 11072501 "New Culvert Installation"

Plan view

Offset baffles



FLOOD GATES

Fish-friendly flood-gates (for tidal or inland applications) are available and will be matched to the outfall and the pipe. INFRAPPIPE will co-ordinate this with the supplier, ATS Environmental. Their offset hinge allows upstream movement with low flows and can be configured for any desired range.

For more information on these solutions see ATS Environmental

FLUMING

Fluming – which is half-sections of pipe used to divert or contain water flows – is also available for open channels and for diversion works. These can be used as a permanent channel and are ideal for situations where dewatering or other aspects of the site make a fast installation of the channel essential. These can also be factory fitted with flexible baffles and/or other fittings (to allow the subsequent siting of rocks for example).

LENGTHS AND JOINING

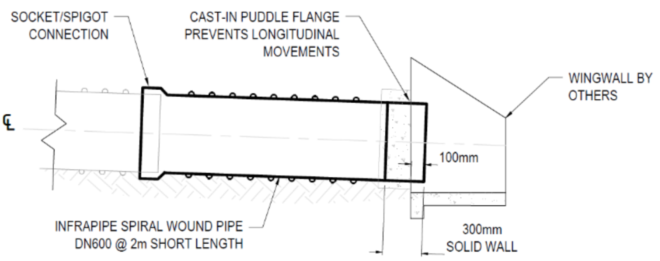
INFRAPIPE is normally joined with a rubber gasket (other options are available) and is available in 6m lengths (effective length 5.8m). However, for quicker install pipes can be supplied in 9m, 11.8m, 15m or 17.6m lengths or made to measure.

ANGLED INFALL/OUTFALL

HDPE can easily be cut and welded so if angled infalls or outfalls are required, the pipe can be supplied accordingly.

DELICATE ECOLOGIES – INTEGRATED HEADWALLS OR WINGWALLS

The use of toxic poured concrete on site can be avoided all together for delicate ecological systems by selecting pipes pre-installed into headwalls, wingwalls or apron structures. INFRAPIPE can provide more details such as the example to the right.



BENDS

There are situations where a bend is required in a culvert. For steel or concrete this has to be achieved with a manhole (which is not ideal for fish passage); INFRAPIPE has several options to provide a bend of any angle and any radius: (see Data Sheet here)

- ✓ Fabricated fittings to make exactly the bend required
- ✓ The pipe can be bent to a radius of 50 * the Inner Diameter (which may need anchor blocks)
- ✓ The pipe can be deflected a couple of degrees using flexibility in the socket and spigot.

Nature does not flow in straight lines, and this allows the best use of the site to provide optimum fish passage!

DEWATERING CHAMBERS

Diversion of existing water flows or dewatering can require a chamber for settlement or catchment purposes. INFRAPIPE supplies pipes for this purpose to which the contractor can then add (if needed) a concrete base, perforations, penetrations for pump hoses and a lid. This chamber can then be cut up on site and returned as scrap to INFRAPIPE free of charge for recycling. See Data Sheet here.

OVERFLOW DRAINS

In situations where the width is constrained a second higher pipe can be used purely as an overflow in a Significant Rain Event. These overflow drains, being normally dry, need not comply with fish passage requirements and reduce the risk of scour or destruction/blocking of fish passage equipment such as baffles.

Maintenance of the drains will need to be considered to ensure the overflow remains clear of material.

INFRAPIPE can advise on the optimum arrangement of sizes, levels and burial for overflow drains.

OVERLAND FLOW PATHS

Increasing the size of a culvert can significantly decrease the requirement for a secondary overland flow path (where this is required) which can offer the asset owner flexibility in design, savings in construction or both. Regional requirements vary but for instance Section 4.3.5.6 of the Auckland Council Stormwater Code of Practice states that:



"Secondary overland flow paths shall be designed with sufficient capacity to accommodate the 1% AEP storm event, assuming the following conditions for the primary network:

- *For pipelines up to and including DN600, assume that the pipeline is 100% blocked*
- *For pipelines between DN600 and DN1,050, assume that the pipeline's capacity has been reduced by 50%*
- *For pipelines in excess of DN1,050, assume that the pipeline's capacity has been reduced by 10%"*

To put this into context, upgrading from a DN600 to DN700 has a typical additional pipe cost of $60/m, and from DN1000 to DN1100 $90/m which can lead to a substantial saving when compared to the potential costs of providing an overland flow path with sufficient capacity.

SUBSTRATE BAFFLES OR FALSE FLOOR

Where fish passage requires a given base level to the culvert and natural sedimentation may take too long, INFRAPIPE has two solutions:

For situations where the substrate must be either added prior to installation or encouraged to accumulate soon after commissioning to ensure fish passage, flexible baffles installed in the factory are the most effective solution. For designers who insist upon rigid substrate baffles, these can be installed in the factory. These are made of recyclable HDPE and can be made to any burial depth. Any spacing is possible and as a minimum they are installed before each socket and spigot (every 6m).

For situations where the correct base level needs to be guaranteed (such as high scour levels when sediment levels need to be maintained) INFRAPIPE can create an engineered solution for the specifics of the location.

STREAM DIVERSION

INFRAPIPE offer special lightweight pipes for temporary works, smooth-skinned if they need to be dragged or inserted with flanges, sheets or other fittings to enable temporary headwalls or other fixtures.

The lighter the pipe, the less disruptive and the quicker the temporary measures need to be.

See Datasheet here.

MICROPLASTICS

To set the record straight, after extensive testing there is no proof (see article) that microplastics originate from thermoplastic pipes (the level of abrasion is simply too low – see below). Line trimmers, clothing, food packaging and other consumer goods are typical sources of microplastics in the environment as they shed particles due to washing or cutting. Of greater concern for aquatic health is the significant rate of abrasion from concrete pipes that contaminates the environment with cementitious particles.

SUSTAINABILITY

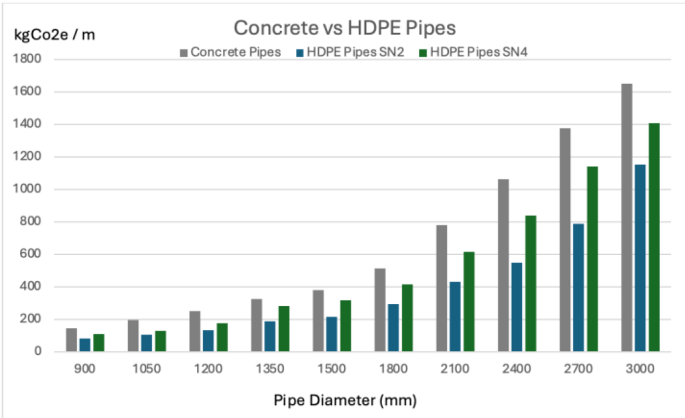
HDPE/PP is the best material for the planet.

- ✓ Polyethylene/polypropylene has been repeatedly proven to have a 100yr+ life.
- ✓ Minimal erosion equates to minimal fugitive particles.
- ✓ Alternatives which are chemically attacked by the environment pollute the soil heavily.
- ✓ Alternatives which are susceptible to biological attack will decay and pollute.
- ✓ INFRAPIPE is completely recyclable. The asset owner has no end-of life disposal liability.
- ✓ All production waste is recycled.
- ✓ Lighter products require less freight, less cranes and less diggers.
- ✓ Lighter products use less global resources in their manufacture

HDPE/PP has one-third (or less) the environmental impact of concrete and a longer life:

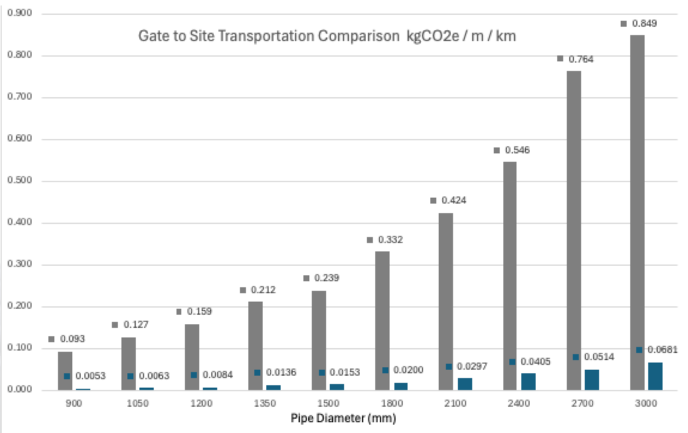
MANUFACTURE

- ✓ **CO2/Pipe**: HDPE pipes have a CO2/kg of approx. 2.2kg/m, where concrete is 0.25kg/m. However concrete pipes are 14 times heavier giving an equivalent CO2 figure of 3.5kg/m which is up to 60% higher than HDPE for cradle to gate depending on the product type.
- ✓ **CO2/Metre**: The improved hydraulic efficiency of thermoplastics allows smaller pipes for the same flow rate (typically 18%), further reducing the CO2 per metre of pipe.
- ✓ **Production waste:** All HDPE/PP production waste is reprocessed.
- ✓ **No waste:** INFRAPIPE is made to measure for large applications so there are no pipe ends or other waste. Manholes are made with connections so there is no waste from creating penetrations on site.



FREIGHT AND INSTALLATION

- ✓ **CO2/Delivery:** Pipes can be nested inside each other and being 14 times lighter, considerably less truck fuel is used.
- ✓ **CO2/Installation**: Smaller installation equipment is required for lighter pipes that are 2.5 or 5 times longer less time.
- ✓ EPDS from foreign manufacturers with identical equipment are available.
- ✓ Cradle to site the difference is even more pronounced due to the weight of concrete products.



(Graphs from "A New Comparative Analysis of the Environmental Performance Between Large Diameter HDPE and Concrete Pipes", Dr Vasileios Samaras [Swansea Univ.] et al., 2025)

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MAINTENANCE AND PRODUCT LIFE

- **Chemical stability:** HDPE/PP needs no maintenance where PVC and GRP/FRP degrade and become brittle. Thermoplastics are chemically inert.
- **Wear resistance:** HDPE/PP has the best abrasion resistance of any material and therefore the longest life.
- **Product life:** HDPE/PP is guaranteed for 100 years but concrete has no certainty of longevity because it interacts with the soil and the fluid being carried. Once concrete abrades, decays or reacts to a point where the reinforcing or cracks greater than 1mm are exposed, the asset manager should condemn and replace the pipe.
- **Biological attack:** HDPE/PP is immune to biological attack where concrete and GRP are vulnerable to it.
- **Soil pollution**: HDPE/PP does not react with the soil. If it is recognized that concrete reacts with some soil types (which it is, some councils even advise installing thicker pipes in anticipation of this) then to install concrete in any such location is an act of pollution in its own right.
- **Seismic longevity:** HDPE/PP has the best seismic resilience, minimizing the environmental impact of a seismic event – pipes do not need to be replaced or repaired and the consequences of any spills remediated.
- **Damage/repair:** HDPE/PP can be repaired quickly and easily with no pollution on site. Concrete and GRP require polluting epoxy solutions.
- **Maintenance:** HDPE/PP needs no maintenance of any form. As it is smoother than concrete, less debris or sediment will accumulate.

RECYCLING OR DISPOSAL

- **Recycling:** HDPE/PP can be exhumed at end of life and sold for recycling. There is minimal recycling of concrete or PVC and none of GRP in NZ.
- **Recycled product:** Recycled HDPE/PP product is used in rural culverts. Recycled concrete loses its strength and leaches into the soil heavily so has few real-world applications.
- **Processing waste:** All HDPE/PP is recycled, concrete pour-off, ends, knockouts etc. are typically buried.
- **Disposal:** There is no disposal cost with HDPE/PP, simply clean it and freight it. Concrete and GRP must be broken down and buried.

ENVIRONMENTAL PRODUCT DECLARATIONS

The EPDs of other users of the same KRAH (profile pipe) equipment as INFRAPIPE have EPDs available to prove the figures above:

Visit EPDHUB and use the code HUB-0168 for the larger, helical wound pipes DN1200+

TEPPFA (the European Pipe Body) produced an EPD for the smaller twinwall pipes DN300-1000

TEPPFA EPD for CIVILPIPE equivalent for the smaller twinwall pipes DN300-1000

There are numerous articles available to confirm the benefits such as this:

Comparative Analysis of Green House Gases of HDPE vs Concrete. Overall, concrete has a greater Carbon Footprint associated with it, compared to equivalent sized HDPE, in both cradle-to-gate and cradle-to-site scenarios. Studies have found that on average, concrete tends to produce 21% more Green House Gas (GHG) emissions in cradle-to-gate scenarios (kgCO2e per unit length) and 95% more GHG emissions in gate-to-site scenarios (kgCO2e per unit length, per km) respectively, compared to the equivalent HDPE. The results show that HDPE is a significantly more carbon efficient product. As a result, HDPE has the potential to actively aid the construction industry in their formidable task of reducing GHG emissions in accordance with the government's targets.

Cowle, Matthew, Vasilios Samaras, and William B. Rauen. "A comparative analysis of the carbon footprint of large diameter concrete and HDPE pipes." *Plastic Pipes XVI, Barcelona* (2012).



PRODUCT LIFE & MATERIAL QUALITIES

MATERIAL LIFE – PRODUCT LIFE

The latest meta study by TEPPFA confirmed that the expected life of HDPE pipes is well in excess of 100 years. This is in addition to the 2006 research conducted on pipes exhumed after 50 years in the ground which confirmed their service life will exceed 100 years, or the study conducted in 2014 which investigated a wide variety of pipes to confirm their service life was 100 years plus.

INFRAPIPE guarantee their pipe for 100 years. Concrete is only guaranteed for 7 days.

MATERIAL CHOICE

Historical culvert material choices were between concrete, steel, SRP or thermoplastics (HDPE).

Steel is not included in the table below because it is so expensive, so heavy, so prone to corrosion and buckling that it is no longer used in new installations. PVC is shown below but becomes cost-prohibitive over 300mm and has no advantages over more economical HDPE, and is UV resistant, heavier and more brittle.
SRP (Steel Reinforced Plastic) is not included in the table below because it is a legacy technology before HDPE pipes in larger sizes became available. Whilst SRP has the flow characteristics of HDPE, it does not have the flexibility or buckling resistance reducing the longevity for no gain.

While concrete is shown below as many contractors will attempt to revert to concrete as they gain more from it, it is less hydraulically efficient by 18% (see below), has appalling abrasion resistance and because it chemically reacts with the soil its life is not guaranteed where HDPE is guaranteed to last 100 years.

Table 7 Comparative material properties

Requirement	HDPE/PP	Concrete	PVC
Material life	Very good	Average	Good
Abrasion resistance	Very good	Very poor	Good
Hydraulic efficiency	Very good	Average	Very good
Weight	Light	Very heavy	Heavy
Tensile Strength	Very good	Good	Average
Compressive Strength	Good	Very good	Good
Ductility	Very good	Nil	Nil
Deformation Recovery	Good	Nil	Nil
Brittleness	No	Some	Yes
Homogeneity	Yes	Yes	Yes
Risk of infiltration	Very good	Very poor	Poor
Ease of modification	Very good	Average	Average
Ease of repair	Very good	Average	Poor
Seismic resilience	Very good	Poor	Average
Water permeability	Very good	Poor	Very good
Biological resistance	Very good	Poor	Very good
Chemical resistance	Very good	Very poor	Good
Recycled in NZ	**Very good**	**Rare**	**Rare**
Sustainable manufacture	Average	Poor	Very poor
Sustainable installation	**Very good**	Average	Average

SEISMIC RESILIENCE

HDPE pipes and tanks have high flexibility allowing them to absorb seismic energy without breaking or cracking unlike more rigid alternatives. The ductile nature of HDPE allows the structure to deform without breaking, allowing pipes to stretch and elongate rather than fracture (elongation can reach 600%) After the Japanese earthquake of 2011, all the HDPE KRAH pipes (the same as INFRAPIPE) in the area were surveyed and none found to be damaged:

Table 8 Results of profile pipe survey after Japanese earthquake of 2011

Place	Date of Investigation	Diameter (mm)	Length (m)	Soil embankment (m)	Ratio of deflection (%)	Appearance
Hiranai town Aomori Pref.	3rd June 2011	1200	68.0	11.0	4.1 %	no damage
Rokkasho village Aomori Pref.	2nd June 2011	1800	140.0	27.5	4.4 %	no damage
Miyako city Iwate Pref.	26th May 2011	2400	5.0	1.0	0.2 %	no damage
Kamaishi city Iwate Pref.	25th May 2011	1800	80.0	9.8	3.9 %	no damage
Kamimasuzawa Iwate Pref.	25th May 2011	1000	75.0	12.0	3.0 %	no damage
Sumida town Iwate Pref.	23rd May 2011	2000	85.0	17.3	1.8 %	no damage
Sumida town Iwate Pref.	23rd May 2011	1100	105.0	10.8	3.0 %	no damage
Rikuzen Takata city Iwate Pref.	24th May 2011	1200	64.6	10.8	3.9 %	no damage
Rikuzen Takata city Iwate Pref.	24th May 2011	1500	65.0	8.0	1.7 %	no damage
Rikuzen Takata city Iwate Pref.	24th May 2011	1000	80.0	15.8	4.2 %	no damage
Rikuzen Takata city Iwate Pref.	28th May 2011	1000	84.8	16.3	3.9 %	no damage
Rikuzen Takata city Iwate Pref.	28th May 2011	1000	74.6	13.5	3.9 %	no damage
Rikuzen Takata city Iwate Pref.	28th May 2011	1000	35.3	6.2	2.5 %	no damage
Rikuzen Takata city Iwate Pref.	30th May 2011	1000	70.0	13.0	4.3 %	no damage
Rikuzen Takata city Iwate Pref.	30th May 2011	1000	66.0	11.4	3.0 %	no damage
Rikuzen Takata city Iwate Pref.	30th May 2011	1000	78.0	13.0	3.9 %	no damage
Rikuzen Takata city Iwate Pref.	31st May 2011	1000	67.8	10.3	1.0 %	no damage
Rikuzen Takata city Iwate Pref.	31st May 2011	1000	58.1	9.3	3.0 %	no damage
Tome city Miyagi Pref.	1st June2011	900	82.0	16.0	3.6 %	no damage
Osaki city Miyagi Pref.	1st June 2011	1200	60.0	10.0	3.3 %	no damage
Fukushima city Fukushima Pref.	27th May 2011	1800	159.0	27.0	0.6 %	no damage

For the layman, plastic pipes bend or stretch with the forces of an earthquake. If left unsupported or floated by liquefaction or soil displacement, their flexibility prevents rupture and disaster. A plastic pipe recovers its shape after damage (see these videos) so if the whole structure is affected by an extreme event, the pipe can be rebuilt by rejoining the sections on site.

INSTALLATION

SPEED OF INSTALLATION

Diversion, dewatering and ecological monitoring all create significant daily costs. INFRAPIPE is the fastest option to install for these reasons:

- ✓ It is lightest
- ✓ It joins quickly
- ✓ It can be supplied in longer lengths
- ✓ It is safer for staff to work in the trench with the pipe
- ✓ Fish baffles etc can be provided factory fitted or for site installation

CONSEQUENCES OF INSTALLATION

Environmental stewardship requires two outcomes:

- ✓ A solution which preserves or enhances fish passage and the ecological value of the site
- ✓ Minimal ecological damage to the site during the process.

A DN600 concrete pipe weighs 318 kg per metre. The equivalent INFRAPIPE weighs 23 kg per metre. The impact on the site is significantly less with INFRAPIPE.

Heavier pipes (14 times heavier) cause greater ecological damage because they require:

- ✗ Much larger, heavier excavators
- ✗ A stronger platform for those excavators – more foundations, more earthworks, more material
- ✗ A larger working space for the larger, heavier excavators and trucks
- ✗ Much longer to install (and thence the risk of diesel or hydraulic oil spill)
- ✗ Bigger, stronger access roads for bigger heavier trucks

In addition to the above ecological consequences, concrete pipes can also have these additional demands:

- ✗ The Health & Safety risks are greater with heavier pipes
- ✗ Concrete pipes often damage each other during installation requiring replacement or repair.
- ✗ Concrete pipes require frequent inspection for decay and repair for cracks of 1mm or over

COVER DEPTHS AND LOADS

The standard cover depths for different loads are shown below, INFRAPIPE can manufacture the exact strength (and length) pipe for each location, minimising the resources consumed.

Table 10 Cover depths and loads for INFRAPIPE

Loading condition	mm	Loading condition	mm
Not subject to vehicles	300	Vehicle load no carriageway	450
Land zoned for agricultural use	600	Vehicle load unsealed carriageway	750
In embankments or construction eqpt loads	750	Vehicle load sealed carriageway	600

- For situations outside the above or depths of 6m+, contact INFRAPIPE for an engineered solution.
- More detail can be found in AS/NZS 2566.1:1998 Buried Flexible Pipelines: Structural design and AS/NZS 2566.2:2002 Buried flexible pipelines – Installation.



MANNINGS GRAPHS FOR CULVERTS

For each Mannings number the tables are split by gradient:

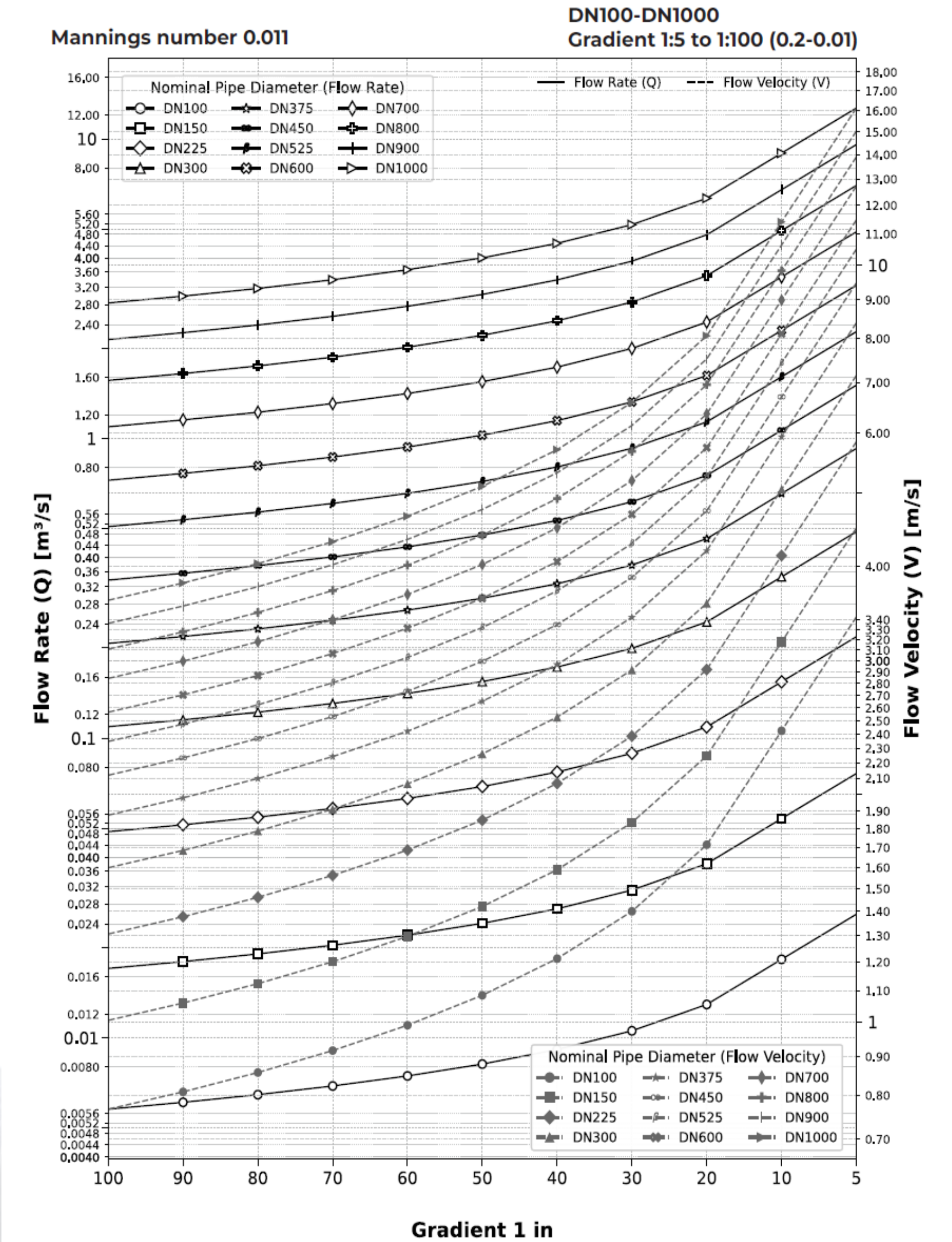
- ✓ One for extreme gradients from 1:5 to 1:100 (0.02 to 0.1), the other for 1:100 to 1:1000 (0.01 to 0.001)

For each gradient group there are then two tables:

- ✓ Firstly DN100:DN1000, then DN1000-DN3200

Starting with a flow rate and gradient, trace up the gradient line to intercept the flow rate and select the **pipe size** (solid line) above it. To obtain the **flow velocity**, then follow the gradient up to the dashed line for that pipe size and read the flow velocity. For more details see INFRAPIPE Mannings Graphs here.

NZ Building code, NZTA & KiwiRail all specify Mannings n of 0.011 for HDPE and 0.013 for concrete.



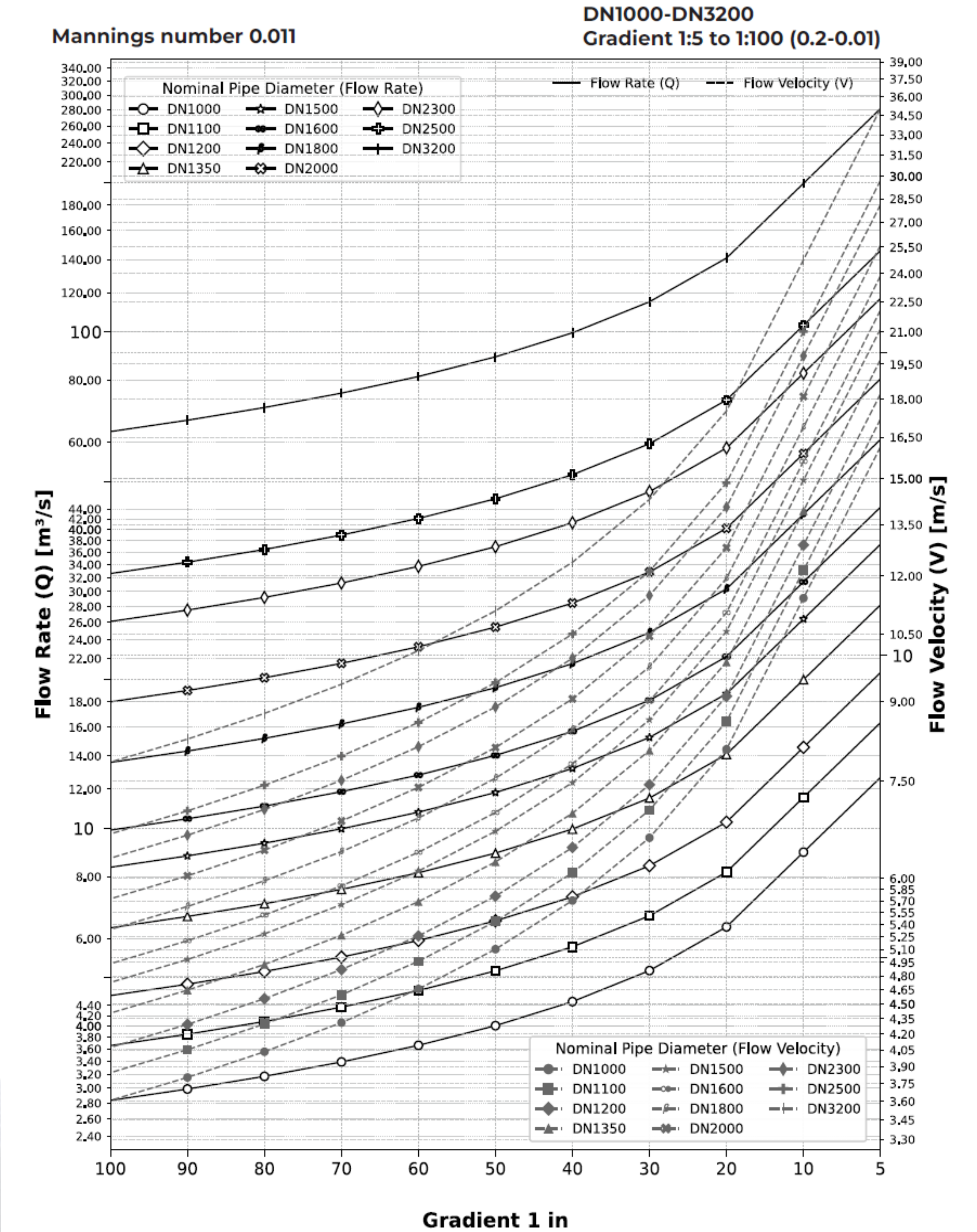


HOW DOES PIPE SIZE AFFECT CONSEQUENCES OF INSTALLATION

Massively! The reduced drag from the effects of the perimeter improves the hydraulic performance substantially – in the examples here, the HDPE DN3200 at 1:100 achieves a flow rate per m² of cross-sectional area of 9.75 (m³/s per m²) as opposed to 8 for the DN2500. Note also the 20%+ increase in performance from the smoother HDPE to the rough concrete!

Flow Rate m^3/s		1:200	1:100
HDPE	**DN3200**	54	78
Mannings 0.011	**DN2500**	28	40
Concrete	**DN3200**	45	64
Mannings 0.013	**DN2500**	23	33

Table 10 Flow rates for a given gradient, ID and material





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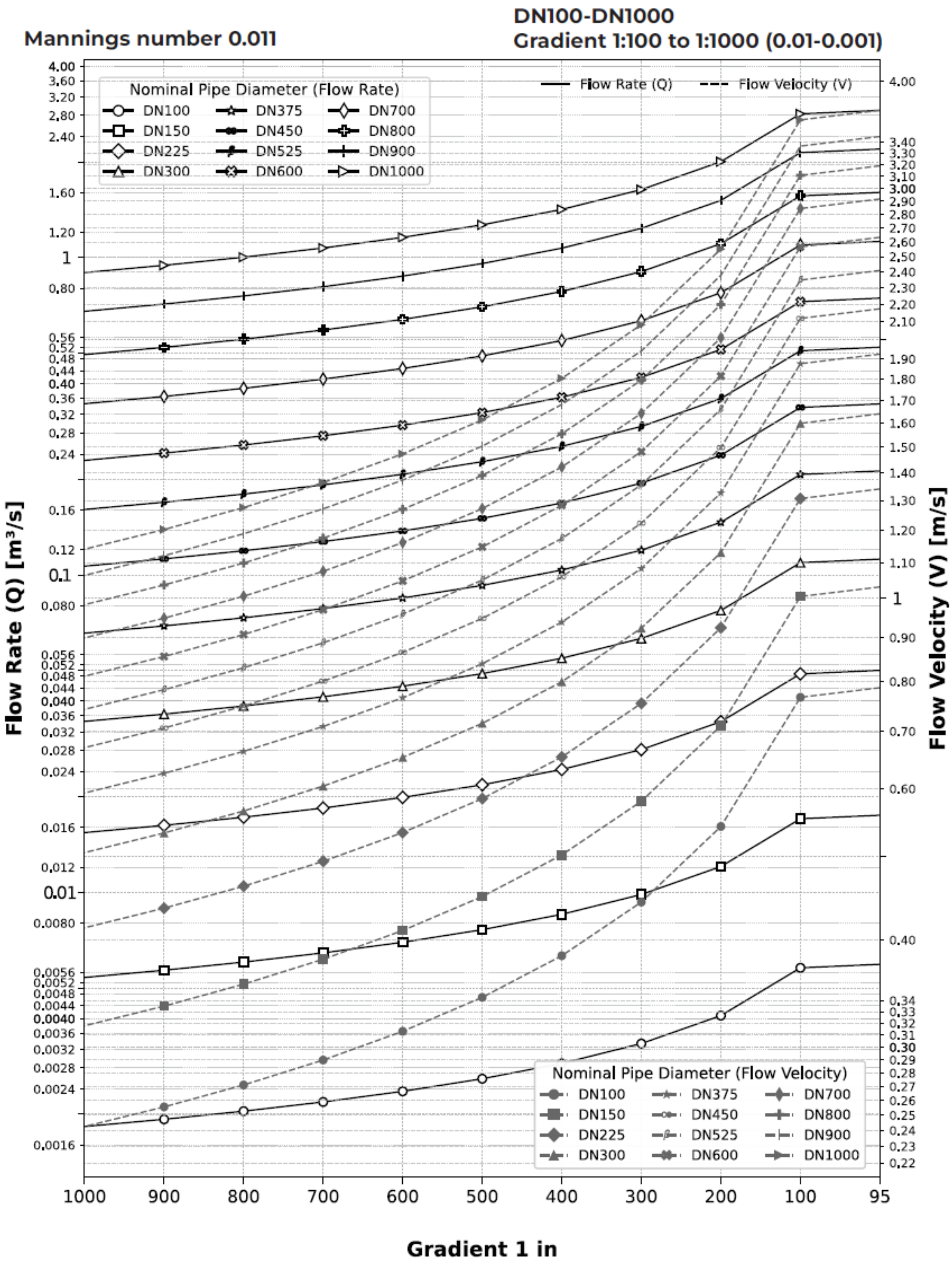

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Mannings number 0.011

DN1000-DN3200

Gradient 1:100 to 1:1000 (0.01-0.001)