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Proceedings

B.1.4 - 316 stainless partially corrugated tube vs polyethylene for service lines: a cost comparison

B. Van Hecke[1]

1 *Nickel Institute, Market Development Manager - Europe, Brussels, Belgium*

Keywords: water loss, leakage, stainless steel, service line, LCC, SPCT, polyethylene

Abstract

The benefits of this cost saving solution were explained previously during conferences in Tokyo (1) in 2017 and in Bucharest (2) in 2019 . Since then, efforts were made to gain a detailed understanding of materials performance, service life and costs of existing service line systems. When considering the attributes of stainless steel, notably its inherent corrosion resistance, long service life and maintenance friendly nature, a life cycle cost approach was chosen to demonstrate the long-term cost benefit of choosing a stainless steel solution. A utility from Australia offered service data from a water distribution network based on polyethylene service lines, which served as the material to compare to the stainless steel. The life cycle cost comparison includes acquisition cost of the components of a complete service line from mains to meter, for both materials. It further addresses maintenance cost based on the likelihood of a service line to exhibit failure and on the cost of repair, which represents a much higher cost than the materials. Necessary replacements of the service line over the course of the investigated service period are factored in too. Finally, the comparison would not be complete without a realistic allowance for water lost due to leakage. The latter is often overlooked in the true costs associated with a leaking network, yet it represents a high economic loss, as regularly updated information by the Tokyo bureau of Water Works demonstrates. The outcome of the life cycle cost calculation is duly discounted to net present value, in order to account for today's value of money and inflation effects. Regardless of the length of the service period considered, the total cost of the stainless steel solution (at higher initial purchase cost) is on par with that of the polyethylene connection after ten to fifteen years.

Details of the partially corrugated Type 316L stainless steel service line product and case studies for the Asian experience will be presented. Key requirements for successful stainless steel service pipe installation with and by local water utilities will be explained.

What is a Stainless Partially Corrugated Tube (SPCT)?

Leaks in distribution systems are costly. Added to the direct cost of the lost water that cannot be sold are the financial and environmental costs of finding, treating and storing more water to compensate for the losses. This problem affects rich and poor cities alike, as shown in the graph below. Many utilities do not know the exact extent of the water loss in their system.

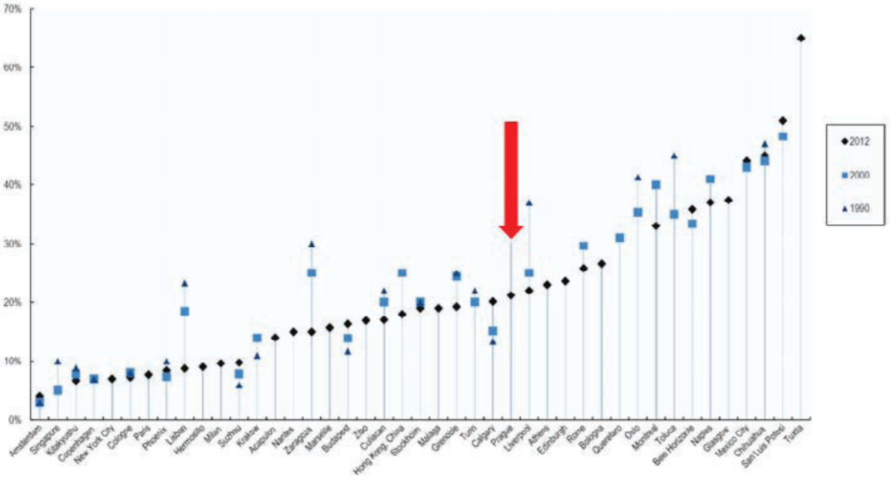


Figure 1: Proportion of water loss in surveyed cities (leakage rate) – red arrow indicates Prague (source: water governance in cities (OECD 2014).

Both Tokyo and Taipei have determined that some 95 % of leakage repairs affect their service pipes of 50 mm (2 inch) diameter or less (3). Historically, service lines in those cities had been constructed of lead, iron or plastics. Once a service line is in the ground, various forces, such as:

- Vibrations from traffic and construction work

- Subsidence and land slides
- Seismic events

can cause the tubes to deform, become disconnected or even break.

The lead lines not only had leakage problems, but they also presented grave health concerns which accelerated their replacement.

In 1980, to combat the scourge of leaks, Tokyo instituted a three part solution to the problem:

- Replace the existing service lines with Type 316 stainless steel and the cast iron mains with ductile iron
- Improve leakage detection
- Improve response time when a leak is detected

In 1998, Type 316 stainless partially corrugated tube was introduced instead of straight tubes. The tube is corrugated at regular intervals so it can be easily bent during installation to accommodate changes in direction without additional joints. It also allows the tube to absorb the stresses from vibrations, subsidence and seismic events. The number of joints was also significantly reduced by using a single length of corrugated tube.

Type 316 stainless steel with typically 17 % chromium, 2 % molybdenum and 10 % nickel content has excellent corrosion resistance in a wide range of soils and is recommended for this type of application. Tokyo expects service life to exceed 100 years. Type 316 stainless steel is essentially inert in potable water, with negligible leaching of alloying elements, and therefore does not adversely affect water quality.

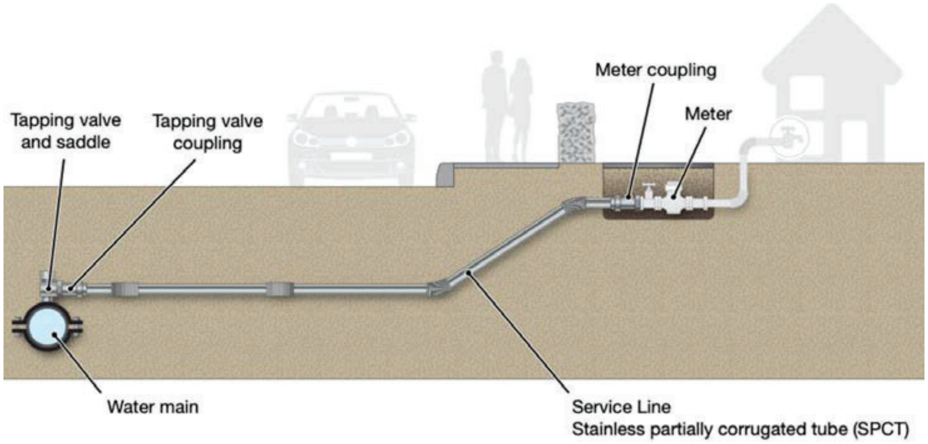


Figure 2: Stainless partially corrugated tube in a mains-to-meter configuration (source: Team Stainless).

Proven cost benefits

Tokyo's replacement program resulted in a water loss reduction from 260 million m³ (15.4 %) in 1980 to 56 million m³ (3.6 %) in 2019. At the same time, repair cases were reduced from 69,000 per year to 7,000 per year. The total savings from both these effects (compared to the initial situation) amount to almost 500 million USD per year. A similar sum was already documented earlier by Tokyo Waterworks Bureau (4).

Tokyo's success at reducing leakage attracted the attention of Taipei and Seoul. Following a drought causing severe water shortages, Taipei began evaluating their program in 2002 and started their 20-year stainless flexible service line installation program in 2005. This resulted in a water loss reduction from 365 million m³ (27 %) in 2005 to 109 million m³ (12.7 %) in 2019, in just 14 years. At the same time, repair cases were reduced from 11,300 per year to 2,600 per year in 2019. When even more severe drought conditions returned in 2014, Taipei had no service disruption. In fact, it was able to maintain a surplus which was distributed to storage reservoirs and other utilities.

In Seoul, following the installation of stainless steel service lines, water leaks reduced from 27 % to 2.5 %. It has also enabled the city to reduce its total water production from 7.3 million m³ to 4.5 million m³ per day, leading to the closure of four of the original ten water treatment plants.

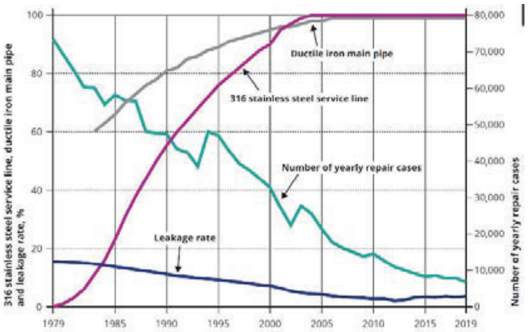


Figure 3: Gains made by using stainless steel in Tokyo (Source: Team Stainless, Tokyo Bureau of Water Works).

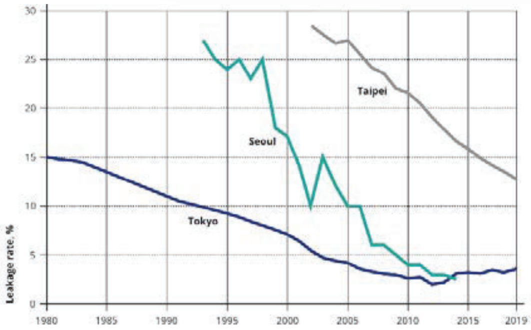


Figure 4: Leakage reduction in Asian cities through use of stainless steel service lines. (Sources: Tokyo Bureau of Water Works; Ministry of Environment, Republic of Korea; Taipei Water Department).

Alternative approach to assess SPCT benefits – LCC methodology

Stainless steel enjoys a strong and enduring reputation for structural durability, corrosion resistance and visual appeal in a wide range of applications and environments. While it may require an initial higher investment when compared with other materials, stainless steel's unique properties deliver long-term performance and economic benefits including minimum downtime, reduced maintenance costs, long service life and reduced environmental impacts. Proper material selection is a decisive factor for the durability and lifespan of infrastructure such as water distribution networks. It is the key to maximum availability and low maintenance costs during its entire life cycle.

According to Japanese sources (5), Tokyo's starting line about using stainless steel for service lines was to prevent water leaks. The ultimate gain was that efforts made to increase earthquake resistance and toughness contributed to management efficiency.

An LCC approach was used to assess the long-term financial benefits of stainless partially corrugated tube for service lines. In order to achieve a comparison as homogeneous as possible, the total cost of one stainless steel tube was compared to the total cost of one polyethylene tube. As stainless steel is expected to last for at least 100 years, this life span was taken as the comparison's timeframe of a worry-free service life. Information about various costs was obtained from Tokyo's feedback during the last couple of years and from an Australian utility that has been running a PE-based system for a couple of decades.

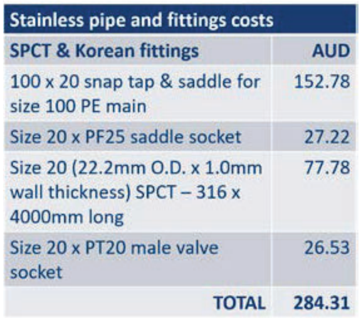
The costs considered were the following:

- Installation cost: Hardware acquisition and installation
- Operating cost:
  - Maintenance (due to leaks, replacement of pipe assumed)
  - Scheduled replacement linked to service life expectation
  - Lost water from leakage

Costs for both the stainless steel tube and the polyethylene tube were discounted to net present value. The concept of "real interest rate" was used for that purpose. The real interest rate corrects the observed market interest rate for the effects of inflation.

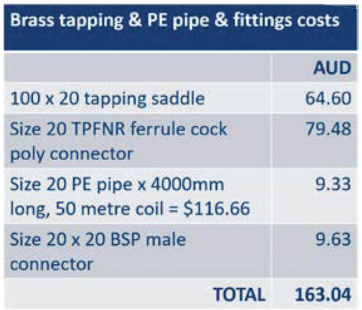
Component and installation cost

Team Stainless Water has been setting up SPCT installation trials for the last couple of years. In order for the utilities involved to have easy access to stainless steel components (and not be constrained by small – trial – order quantities), Team Stainless has put a small stock of hardware in place to feed trials from. Pricing for the stainless steel components that make the connection from mains to meter as purchased during 2020 are shown in Figure 5 in Australian dollars (AUD). As the utility we compared polyethylene-based service line data to is Australian, we sourced relevant Australian PE-systems cost data during the same period. Numbers for 4 metre length of pipe are shown in Figure 6.



Stainless pipe and fittings costs	
SPCT & Korean fittings	**AUD**
100 x 20 snap tap & saddle for size 100 PE main	152.78
Size 20 x PF25 saddle socket	27.22
Size 20 (22.2mm O.D. x 1.0mm wall thickness) SPCT – 316 x 4000mm long	77.78
Size 20 x PT20 male valve socket	26.53
TOTAL	**284.31**

Table 1: 2020 cost of mains-to-meter stainless hardware items.



Brass tapping & PE pipe & fittings costs	
	AUD
100 x 20 tapping saddle	64.60
Size 20 TPFNR ferrule cock poly connector	79.48
Size 20 PE pipe x 4000mm long, 50 metre coil = $116.66	9.33
Size 20 x 20 BSP male connector	9.63
TOTAL	**163.04**

Table 2: 2020 cost of mains-to-meter hardware items to connect a polyethylene tube.

It should be observed that firstly, the cost of the stainless steel items are related to a fairly small size trial order with a Korean mill. It is expected that when stainless steel is used as frequently as polyethylene, the price gap between both materials will become smaller. Secondly, this expectation is backed by experience from the Tokyo Bureau of Water Works stating (5) that the expert committee initially (around 1980) estimated that the stainless steel initial extra cost would be 26 % compared to the conventional lead pipes, but it was judged to be advantageous in terms of total cost. Thirdly, regardless of material of construction, the component cost is just a fraction of the total installation cost, considering how costly breaking up and repairing roads is.

The cost related to breaking up roads, whether it is in a city or in a rural setting, digging the hole and repairing the road again, can vary to a great extent. As we have taken examples from a municipal rather than a rural setting involving paved roads or streets, this cost is rather high. In A 2019 study about costs related to service line replacement or repair (6), various scenarios are presented. The cost for replacement by excavation from this study ranges from 3,000 to 4,000 USD. Discussions with both the Tokyo and the Australian utility inspired us to conservatively fix this cost at 3,950 AUD, regardless of the service line's material of construction. For simplicity reasons, this amount was used for both scheduled replacement of the PE-tube and for leakage related repair work.

Operating cost assumptions

Three cost components were considered: the cost of maintenance which is defined here as the cost of repairing leaks (provided that these are identified), the cost of scheduled replacement (at the end of the projected service life) and finally the cost of water lost because of leakage from the component under scrutiny.

Maintenance cost

Service connections from a drinking water distribution network are likely to require maintenance (including repair or replacement) of various forms. Poorly connected joints, earth movement (because of vibrations) or premature failure of materials can cause leakage, which – if properly identified and located – require frequent revisiting of the service connections. In cities such as Tokyo and Taipei, more than 95 % of leakage was due to service connection failure in one form or another. Experience from those two cities taught that progressive replacement by stainless steel for the service lines drastically reduced such repair jobs. This is no surprise as stainless steel is known to require little maintenance and to exhibit robustness in challenging mechanical and corrosive environments.

The integration of maintenance cost into the LCC approach led us to define maintenance / repair cost as follows:

"Likelihood of a repair of one service pipe" multiplied by "cost of a repair job"

The first factor can be broken down as follows for the stainless steel service tube: based on a sample size reported to us by the Tokyo Bureau of Water Works, we were able to set the share of stainless pipe failures only (since we wish to compare stainless pipe to PE pipe) at a conservative maximum of 5 % of all reported service line repairs (TBWW would not disclose the precise amount). The latter figure is reported (yearly) by TBWW (7) and was at 6,727 in 2019. With Tokyo's 2,200,000 service connections, a service line network failure rate of about 3/1000 is obtained (covering also for legacy lead and PVC pipe to a high extent. Despite the fact that more than 99 % of the service lines are made from stainless steel, only < 5 % of the service line repairs can be attributed to stainless steel. In this sense, the 3/1000 can be multiplied by 5 % resulting in a **"stainless pipe only" failure rate of 0.15/1000 connections, or a 0.015 % likelihood for the one connection which is the subject of the LCC exercise**.

Breaking down the first factor for polyethylene was made possible through detailed analysis of failure and repair experience from the Australian utility. Based on information for the 2019–2020 year they had 122 detected Leaks in Service Lines and 145 Leaks between January 2021 through October 2021. Combining this with 123,991 Total Number of Connected Properties to the water supply, a leakage rate of approximately 0.984 Leaks/1000 Service Line Connections/Year for 2019–2020 to 1.16 Leaks/1000 Service Line Connections for 10 months in 2021 could be established.

Image 1: typical failure of the Australian utility's PE-pipe.

The Australian utility stated that vast majority of the leaks are occurring at the Ferrule, or in other words in that (final) section of the PE-pipe where flexible PE meets the rigid ferrule. The image shows a typical failure. We therefore chose to attribute the amount of failures entirely to the pipe (near the connection of the PE Pipe at Mains Valve) and thus **setting the PE-pipe failure rate at 1/1000 connections or a likelihood of 0.10 %**.

From earlier testimonials at IWA WaterLoss conferences (8), this is a rather good failure rate. For instance, the failure rate of a US water distribution network in good shape is said to be around 2.27/1000.

The second part of the multiplication is the cost of the repair job. For simplicity's sake, we assume the cost of digging a hole to be equal to the cost of a hole for a new installation or 3,950 AUD, since we assume a replacement by excavation in the event that a repair is need in that year. For that reason, we also added the cost of hardware to that amount.

The multiplication product of those factors represents the maintenance cost that is carried into the LCC model.

Scheduled replacement

The LCC model doesn't go beyond 100 years of service, since that is the expected service life expectancy of stainless steel. Besides, water distribution infrastructure decisions do not get taken on a 100 years horizon. As for PE, verification of warranty periods of PE components for the water industry usually do not exceed 25 years. This does not mean that those components are not used for a longer service life. Taking into account the water distribution disinfectants and variations in PE material composition and thermal processing history as well as detrimental effects from poor installation practice make 50 years a fair and realistic assessment of PE-pipe service life.

This is why the Team Stainless LCC approach integrates one scheduled replacement of PE-pipe after 50 years. This takes into account (again) the cost of one set of hardware and an excavation at 3,950 AUD. This cost is not considered for stainless steel as there won't be any need to make the same replacement.

Cost of lost water

Integrating the cost of lost water into the comparison between the life cycle cost of stainless versus polyethylene requires a calculation of the following kind:

"cost of lost water per unit of volume" multiplied by "volume of lost water through a service pipe"

The cost of lost water is often neglected in total cost of ownership considerations. This is partly due to the fact that no two utility cost structures are the same. One way of looking at determining the cost of lost water is when every drop of saved water can be sold at selling price (as an expression of lost opportunity in a scarcity context). On the other hand, to utilities that can rely on endless supply of water, despite having a poorly performing distribution system with leaks, the cost of lost water is nothing more than the chemicals and energy it takes to disinfect it and pump it around. This is the idea of the so called marginal cost of water. If the former scenario were a reality to the Australian utility, we would be looking at the variable – or volumetric - part of this utility's water bill, which corresponds to 4 AUD/m^3. If on the other hand, the latter scenario (marginal cost of water) would apply, the cost of lost water wouldn't be much higher than 0.20–0.25 AUD/m^3. Analysis of the Australian utility's specific "cost of water" structure made it possible to determine a precise amount in between the aforementioned extremes of the spectrum.

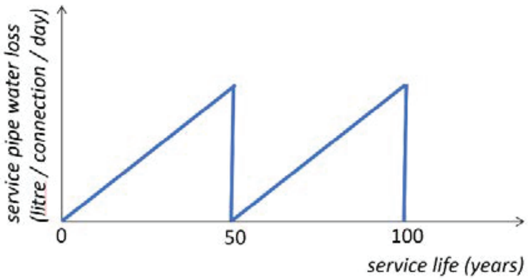
The Australian utility is located in Queensland, where droughts and floods have historically been part of the challenges that the state is facing to manage water infrastructure. This has resulted in investments in dams and desalination infrastructure resulting in reliable bulk water supply by South East Queensland Water to the utility in question, who pay (9) a fixed rate of 3.231 AUD/m^3 to SEQ Water. As this is what the utility has to pay, no matter how well they manage the bulk supplied water downstream themselves, we considered this rate as a representative cost of lost water to the Australian utility. Cost of water in Tokyo (10) has been almost equal to the selling price of around 200 to 210 yen per cubic metre (or 2.5 AUD/m^3). The bulk supply scenario identified for the Australian case is not valid here and marginal cost of water probably is a more plausible assumption, thanks to 40 years of continuous leakage reduction improvement, made possible by stainless steel service connections.

In order to let the LCC comparison focus on leakage reduction gains rather than on cost of water, the cost of lost water to Tokyo was conservatively kept at the same amount as the Australian utility.

Determining the volume of lost water for both examples makes use of the metric "litres lost / connection / day", even if it's derived from high level data with a certain margin of error. This metric fits the reasoning behind this LCC approach well in the sense that the lost water cost of only one pipe is considered.

For the stainless steel case, the document (7) by the Tokyo Metropolitan Government offers the yearly (2019) volume lost through service pipes: 56 million litres. With 2.2 million connections, the Tokyo (>99 % stainless steel service pipe) "lost water metric" is calculated as 70 litre / connection per day. This is the total volume of water lost per service connection. In the section about maintenance / repair cost, it was explained that in Tokyo, a small share (< 1 %) of legacy lead and PVC pipes as well as couplers and the metre account for the lion's share of the service line failures. Stainless steel pipes are responsible for less than 5 % of the failures, setting it at that upper limit – equal to 3.5 litre / connection / day – is a conservative estimate.

The cost of lost water through one polyethylene pipe is calculated as follows. Data from the Australian urban utility's offer an average daily water loss per service connection (in 2019) of 70 litres / connection / day, which purely coincidentally is the same gross amount as for Tokyo's system. In order to make a reasonable estimate of water loss through PE pipe, we set the loss at a conservative 50 % of 70 litre / connection / day (which is in line with the Australian utility stating that "the majority of failures originate from the PE pipe", not from anywhere else). Feeding the performance data of the Australian utility into the UARL formula – as described in eg (11) – produces an allocation of even 75 % (instead of the conservative 50 %) of the Australian utility's losses to service connections (and consequently 25 % only to mains). This alternative scenario will be verified in the paragraph about sensitivity analysis.



In the 100-year running cumulative calculation, we made the mathematical assumption of loss increasing linearly (until the maximum of 70 litre : connection / day) between year one and year 50, when the PE-pipe would be scheduled to be replaced.

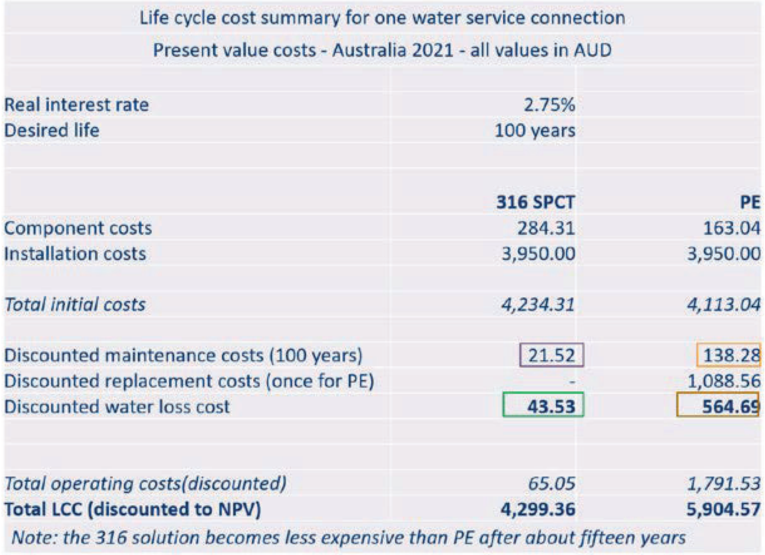
Figure 5: assumed water loss – time dependency.

Result of the LCC exercise

The data and assumptions of the two previous sections were fed into the LCC model. For clarity's sake, the summary below is based on the following data or assumptions:

- Component and installation costs: as per section 5:
  - Cost of a 316 stainless service line: 284.31 AUD
  - Cost of an equivalent PE-line: 163.04 AUD
  - Simplified digging cost: 3,950 AUD for both cases
- Operating cost
  - Maintenance cost:
    - 316: Proportional to a service line failure rate of 0.15/1000 connections
    - PE: Proportional to a service line failure rate of 1.00/1000 connections
  - Replacement cost: based on a (scheduled) replacement by excavation
    - No replacement needed for 316 stainless during the 100 years service life
    - Once, after 50 years for the PE-pipe
  - Water loss cost: proportional to the metric litre / service connection / day (2019 data)
    - 316 stainless: only 5 % of the 70 litre / connection / day from Tokyo
    - Polyethylene: 50 % of the 70 litre / connection / day

These data produce the following summary of the LCC approach:



Life cycle cost summary for one water service connection Present value costs - Australia 2021 - all values in AUD		
Real interest rate	2.75%	
Desired life	100 years	
	316 SPCT	**PE**
Component costs	284.31	163.04
Installation costs	3,950.00	3,950.00
Total initial costs	*4,234.31*	*4,113.04*
Discounted maintenance costs (100 years)	21.52	138.28
Discounted replacement costs (once for PE)	-	1,088.56
Discounted water loss cost	**43.53**	**564.69**
Total operating costs(discounted)	*65.05*	*1,791.53*
Total LCC (discounted to NPV)	**4,299.36**	**5,904.57**
Note: the 316 solution becomes less expensive than PE after about fifteen years		

Table 3: Life cycle costing approach comparing 316 stainless service pipe to polyethylene.

With these assumptions:

- 316 stainless steel service line pipe is clearly cheaper than polyethylene over the entire worry-free service life of 100 years, as the diagram below shows.
- More importantly, 316 SPCT becomes less expensive after only 15 years already.
- In the next section about sensitivity analysis, it will be demonstrated that the point at which stainless steel becomes less expensive can be reached sooner.

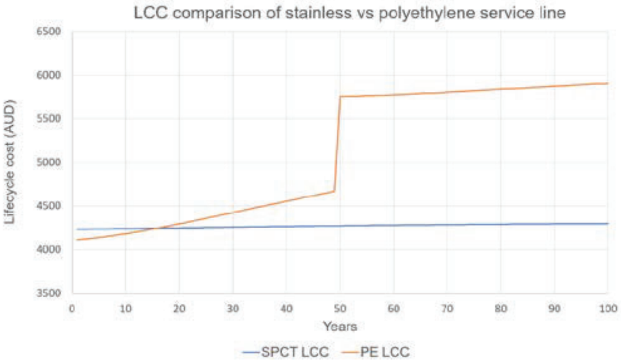


Figure 6: graphical representation of stainless 316 (SPCT) versus polyethylene service line life cycle cost.

Sensitivity analysis

From the previous section's summary, it becomes clear that excavation to install service lines is the most important cost factor. Service line systems that are more prone to leakage will require more frequent excavations. The cost of the hardware is only a fraction of the installation cost. It is therefore important to select reliable materials upfront. 316 stainless partially corrugated service pipe confirms its "fit and forget" moniker in that respect.

If stainless steel were at the same price level of PE (which is not unthinkable, considering that the price of the stainless steel items from this study is one for a small order, not one from an industrially established supply chain), there would be little difference over the entire 100 year period and the stainless steel solution would immediately become cheaper instead of after only 15 years.

The real interest rate is key in this LCC approach. It reflects the value of money over time and is used to evaluate future costs in relation to present costs (such as the installation). The real interest rate is composed of the observed market interest rate, corrected for the effects of inflation and is variable over time. For simplicity's sake (and as the LCC exercise is about the future rather than the past), the real interest rate was kept constant here. Typical rates used by public agencies for long-term investments are between 1 % and 8 %, sometimes even from 0 % to nearly 14 %. The Australian real interest rate that we set at 2.75 % reflects that. The Society of Environmental Toxicology and Chemistry (SETAC) recommends a 0.01 % discount rate for long-term investments (12). In case 0.01 % real interest rate is used and not 2.75 %, the time for the stainless steel service pipe to become less expensive than the polyethylene becomes 14 years instead of 16 years.

The effects of a couple of different assumptions are summarized in the table below. The "base" scenario corresponds to the one described in Table 3, which input is detailed at the start of paragraph seven.

Scenario >	**"base"**	**Loss through PE service lines at 75 %**	**Cost of water at 0.20 AUD/m³**	**Interest rate at 0.01 %**	**PE service life at 25 years**
Stainless LCC	4299 AUD	4299 AUD	4258 AUD	4504 AUD	4299 AUD
Polyethylene LCC	*5905 AUD*	*6187 AUD*	*5375 AUD*	*10658 AUD*	*8663 AUD*
% gain stainless	**27 %**	**31 %**	**21 %**	**58 %**	**50 %**
Years to reach parity	16 years	13 years	50 years	14 years	12 years

Table 4: Effect of different input assumptions on life cycle costing.

Conclusions

Image 2: Installation of SPCT in Tokyo / photo Nicole KINSMAN.

Previous contributions to water Loss conferences (1) (2) detailed the effectiveness of 316 stainless partially corrugated tube against leakage. Case studies were discussed and a rough estimate of annual savings was offered. Apart from the cost savings, other benefits of stainless steel make a difference when designing resilient water distribution infrastructure:

- Hygienic
- Resistant to mechanical damage
- Corrosion-resistant
- Non-reactive with water
- Well suited (metallic) to acoustic leak detection
- No bursting in cold temperatures
- Seismic-resistant
- Fire-resistant

The current paper adds detailed information about costs of stainless steel service lines. It discusses installation cost, maintenance, replacement and water loss cost. The methodology chosen is to compare one stainless steel pipe to one polyethylene pipe and use an LCC comparison over 100 years. The cost to dig holes proves to be the most influential one. Having utilities revisit their infrastructure to address leakage (often caused by poor materials and/or installation) is more costly than the slightly higher upfront cost of choosing a robust material like 316 stainless steel. Asian utilities who have embraced this choice praise the management gains across the service life of the infrastructure, thus proving the "fit and forget" nature of the 316 stainless steel solution for water distribution service lines.

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