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MIPP – Melt in Place Pipe for Water Mains

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ABSTRACT: Cured in Place pipe has been the go-to method for rehabilitation of waste-water pipelines since the 1970's and CIPP is very widely and successfully used for this purpose across the globe. Renovation of water mains, pressurized pipe for the conveyance of potable water, is a rather different challenge, the liner must meet stringent requirements to hold pressure without burst or leakage and must be made from materials which present no risk of introducing chemicals into the water supply network which may be injurious to human health. Installation methodology must return the pipe to service without significant interruption of service, it must address a wide diameter range and meet the additional challenge of timely re-instatement of connections. This paper illustrates the way in which Aqualiner and some other providers have sought to meet these challenges to offer a trenchless solution to the worldwide problems of ageing water pipe.

INTRODUCTION: Utility engineers are tasked with the construction of underground infrastructure to deliver potable water, power and telecommunications to our urban centres, Ideally this work is performed ahead of the surfacing of roads and construction of housing, industry and public services facilities. However in order to maintain, expand or refurbish utility networks it is often necessary to excavate at substantial cost and disruption to the public, their business enterprises and transportation systems. Studies undertaken in the 1970's indication that such work often came at great cost to the community. Engineers searched diligently for alternative solutions and by the mid 1980's several alternatives were identified and established. These included Cured in Place pipe, a variety of close fit and spiral wound pipe lining systems and lining with prefabricated glass reinforced composite pipes and panels.

Cured in Place pipe was invented in 1971 by Eric Wood who impregnated a polyester felt liner with a mix of polyester felt and catalyst, wrapped it in a polymer foil, pulled it into a 1170mm x 600mm egg shaped sewer at Riverside Close in Hackney, London and left it several days to cure at ambient temperature. The first CIPP liner has been examined many times and was sampled for flexural strength and modulus in 1991 and 2001 and was found to compare well with modern forms of CIPP lining. Woods client, the Greater London Councils Metropolitan Water Board were content with the outcome and Wood and his investors created a series of Insituform Companies to develop the technology and license it widely in Europe, Asia and North America. As the original patents fell away in the late 1980s other systems came into being and the terminology Cured in Place Pipe came to represent a wide range of products all based on impregnation, installation and cure of fabric liners to form stiff, strong, durable and close fitting liners in sizes from 100-2700mm. Over 50 years in service CIPP has been a huge success, the company Wood founded, now Aegion, currently operates principally within North America achieving annual CIPP sales exceeding 600 million USD. It has been estimated that some 120,000-140,000km of CIPP have been installed in sewers and currently the installation rate worldwide is 14,000-16,000km each year.

Much of this installed volume is polymer coated polyester felt tube impregnated with polyester resin and cured using hot water or steam to accelerate the rate of reaction. This traditional felt and resin CIPP is much in demand

for small and mid-size diameter liners Properly installed, it provides a robust and serviceable liner using basic technology at a very competitive price. From about 1990 CIPP liners were increasingly made from polyester woven fabrics, glass fibre fabric and specialist products reinforced with highly oriented glass fibre, Kevlar and carbon fibres to provide more substantial reinforcement in the hoop direction of the composite liners so formed. Vinyl ester and epoxy resins were used to increase corrosion resistance and increase stability at higher temperatures.
UV curing methods were introduced in Sweden and the UK in the mid-1980s and have grown in popularity since the Millennium, UV cured is now the predominant form of CIPP adopted in some European countries, its high strength lending itself to use in thinner wall and larger diameter liners. The UV curing method has been developed with highly engineered process controls to provide uniform curing. With these controls fully implemented many system providers can offer substantial independently verified test data to demonstrate consistent process verification which has built confidence in the system and allowed focus by some providers on more demanding niche markets such as gas and water mains lining. It is interesting to note that Wood's first approach to the Metropolitan Water Board was to offer his system as a water main lining process. The Boards engineers encouraged him to prove out his system in their sewers and such was the demand for sewer lining that it was at least 15 years before he restated his objective.

Most close fit lining systems including CIPP for sewer applications are designed as flexible pipes to resist the buckling forces exerted by external ground water pressures and /or soil, traffic acting on deteriorated pipes. From the early days of rehabilitation design the methods used to determine liner thickness employed a modified Timoshenko buckling formula taking account of the flexural strength and modulus of the liner, the 'enhancement' of the liner performance by the existing pipe and a generous safety factor, usually N=2. This approach was generally considered conservative. More modern methods utilize the Glock formula incorporating factors for annular gap and other discontinuities and partial safety factors for a variety of conditions. The traditional approach adopted by ASTM included methods for estimating required lining thickness for pressure applications by determination of the thickness to resist flexural stress and tensile stress induced in the lining by the internal pressure.

WATER MAINS OPPORTUNITIES: Whilst it is difficult to obtain accurate figures for the water and wastewater network renewals some interesting data is published in North America and in Europe. In North America the American Society for Civil Engineers publishes its Infrastructure Report Card every four years. ASCE's 2021 Report Card[1] grades the performance in the drinking water sector as C minus; not at all good. The report indicates a water main network of 3.52 million km which experiences a break every 2 minutes, causing 6 billion gallons of treated water to be lost each day. The situation is slowly improving. In 2015, water utilities in North America were renewing the network at a rate of 0.2% per annum, meaning that water mains should last 200 years whilst in 2019 the renewal rate was reported as being between 1 and 4%, implying that water mains may be expected to last 25-100 years. The report states that in 2020 18000km were slated for renewal and replacement.

The EUREAU Agency 2021 Report - Europe's Water in Figures[2] indicates that the EU water network comprises about 4.4 million km of water main with average leakage running at about 25%. The renewal rate across the region is less than 1%. In UK the renewal rate has dropped to around 0.1% in recent years. UKWIR has indicated that the renewal rate should be about 0.6% indicating a pipe life of 167 years, it says that at least 1.2% renewal is needed for the network to simply stand still and get no worse. In 2018 the Secretary of State for the Environment, Michael Gove[3] criticised the ten privatized UK water and sewerage companies for failing to minimize leaks and pollution, paying out 95% of profits as dividend to shareholders, intent as much upon financial engineering as upon real engineering.

These snapshots of the state of water main rehabilitation in Europe and North America seem to suggest a massive opportunity for innovation in this major market. Much work has been done in this area since the mid 1980's with close fit PE pipe lining, using processes which deform and reform thermoplastic pipe to introduce a tight-fitting line have been employed for semi structural and fully structural lining to good effect. Aegion subsidiary, United Pipeline Systems has reported[4] installation of 32000km of PE pipe, 50-1300mm in diameter, working at pressures up to 50MPa. Whilst other historic products such as Swagelining and Rolldown are seldom seen. These systems require substantial footprint during the installation stage and are perhaps not so well suited to the busy urban environment where much rehabilitation is needed. However there seems to be substantial interest in systems which can be installed from smaller access points, manholes and valve chambers.

Cured in Place pipe liners clearly have characteristics which lend themselves to pressure pipe applications, particularly those which incorporate higher strength components to improve flexural and tensile strength and modulus. Early records obtained from Insituform Permaline indicate that the company lined 155m of 600mm cast iron sewage pumping line for Thames Water at Reading, UK with a 6mm liner in 1975. With experience the company lined numerous pressure mains for industrial and municipal owners and it has been suggested that such projects made up perhaps 5% of installed volume over many years. In Japan Ashimori and Osaka Bosui used their hose lining products for gas and water main projects, both expanded into Europe in the late 1980's and hose lining became popular, first as the Phoenix process and later evolved as Norditube. Close fitting, bonded woven hose lining products have achieved considerable success. Non-bonded products like Insituform's Thermopipe was popular in the UK in the 1990's. A variety of end sealing technologies have been developed to limit product flow into any annular space around such lining products ranging from chemical sealants to mechanical fittings.

Pressure pipe linings for delivery of potable water must sustain internal and external water pressure and other loadings transferred from the existing pipe such as soil and traffic loadings. In addition, in the UK, Regulation 31 of the Water Supply (Water Quality) Regulations 2000 requires that water undertakers shall not apply or introduce any substance or product into public water supplies unless the substance or product has been approved by the Secretary of State for the Environment, Food and Rural Affairs, similar provisions apply in Northern Ireland, Wales and Scotland. The Drinking Water Inspectorate (DWI) operates the approval system on behalf of the Authorities. DWI accepts applications for approval of products used both before and at the treatment works, and in water distribution systems up to the point of delivery to premises. When considering an application for approval, DWI considers only whether the use of a substance or product will adversely affect the quality of the water supplied or cause a risk to the health of consumers. Products approved for use in the treatment and provision of public water supplies under Regulation 31 are listed on the DWI website. DWI is recognised globally as a stringent regulator; few companies and products have gained approval. Aqualiner was approved in 2011 as an in-situ installed (tubular) pipe lining. There are a number of liner products currently under consideration. It is important to distinguish between listings under the Water Regulations Advisory Scheme and approval under Regulation 31. The Water Regulations Advisory Scheme (WRAS) is concerned with products used after the time of supply, when water has passed into the consumers' pipes/buildings. Regulation 31 deals only with products used by water companies in the treatment and distribution of public water supplies.

Materials used for sewer lining, some resins and catalysts may not be suitable for potable water applications. Polyester resins and certain components in vinyl and epoxy compounds used for corrosion protection are thought to be toxic and depending on local regulation may be excluded in the screening process. Some approval systems insist on extended curing cycles to ensure insofar as possible that chemical reactions involved in curing are fully completed, and risky substances cannot be leached into the drinking water. Most approval systems require thorough flushing and in many cases disinfection to minimize risk from free chemicals and organisms that might be introduced during the lining process. It is not uncommon for post lining precautions to involve several days before restoration of normal service.

AQUALINER DEVELOPMENT

The Aqualiner product was initially developed by EPL Composite Solutions Ltd following a consultation with a consortium of three UK Water Companies; Severn Trent Water, Anglian Water and Yorkshire Water who control some 30% of the UK network. EPL and the consortium recognised that polypropylene and polyethylene were widely used as materials in contact with potable water. The consortium helped define the concept in respect of their requirements for water main liners and provided facilities, great enthusiasm and substantial patent expertise. NCC Construction Danmark A/S also worked with the consortium and a fourth UK company Wessex Water, owned by Malaysia's YTL Corporation provided assistance with trial sites and the first live installation in a sewer. The company, Aqualiner Limited, was formed in 2007 and has an exclusive licence on the pipe renewal method for water and sewerage markets based on the initial IP and three patents.

Since formation Aqualiner has raised substantial funds and invested in the development of three generation of equipment for installing liners in water companies infrastructure. Historically the engineering was managed by EPL but since 2015 Aqualiner has undertaken the work directly and has improved the speed, efficiency and controllability of fourth generation equipment to enhance the reliability of the installed product and strengthen the IP portfolio by making patent applications in the name of Aqualiner to support the patents originally licensed by EPL and the Consortium, providing a further twenty years of patent protection.

Aqualiner strongly supported by Wessex Water received the International Society for Trenchless Technology innovation award at the No Dig Conference in Toronto in 2009. The Aqualiner lining system obtained WRc approval for waste-water applications as specified in PT/292/1109-AS. This includes meeting all the requirements of BS EN 13566-4:2002 "Plastic piping systems for the renovation of underground non-pressure drainage and sewerage networks – Part 4". These tests include short term modulus, long term (50 year) modulus and long-term strain in bending, the strain corrosion test. Aqualiner has also met the requirements of Clause 6.10 of WIS 4-35-

01 issue 1 July 2000 for resistance to jetting pressure of 180 bar (2600 Psi). The Aqualiner product is designed for gravity and pressure use in generally in accordance with WRc Sewer Rehabilitation Manual and the procedures of the design appendix of ASTM F1216-09.

The liner can perform as a standalone AWWA Class 4 liner. The American Water Works Association (AWWA) M28 Manual on Rehabilitation of Water Mains has established four classes of design: non-structural (Class I), semi-structural (Class II and III), and fully structural (Class IV). Class I liners only act as corrosion barriers, Class II/III liners are designed to bridge over small holes or gaps in the host pipe, while Class IV liners will carry the full internal pressure without support from the host pipe). Aqualiner product has been approved in the UK under Regulation 31 of the Water Supply (Water Quality) Regulations 2000. Aqualiner has also received NSF 61 Certification.

THE AQUALINER PROCESS

The process involves insertion of a liner tube, comprised of layers of a composite fabric of comingled glass fibres and polypropylene filaments, into the deteriorated pipe. Polypropylene provides a low cost, chemically inert composite matrix with improved strain at failure and potential for electrocoupling. A heating pig is passed through the inserted liner to deliver hot air to heat the material above the melting temperature of polypropylene (200-250°C). The molten mixture of glass fibre and polypropylene is then consolidated against the pipe wall by a pressurised silicone rubber inversion hose, quickly cooling to ambient temperature to form a structurally sound glass reinforced plastic pipe, chemically inert with respect to drinking water and strong enough to sustain soil, groundwater and traffic loads as a stand-alone pipe.

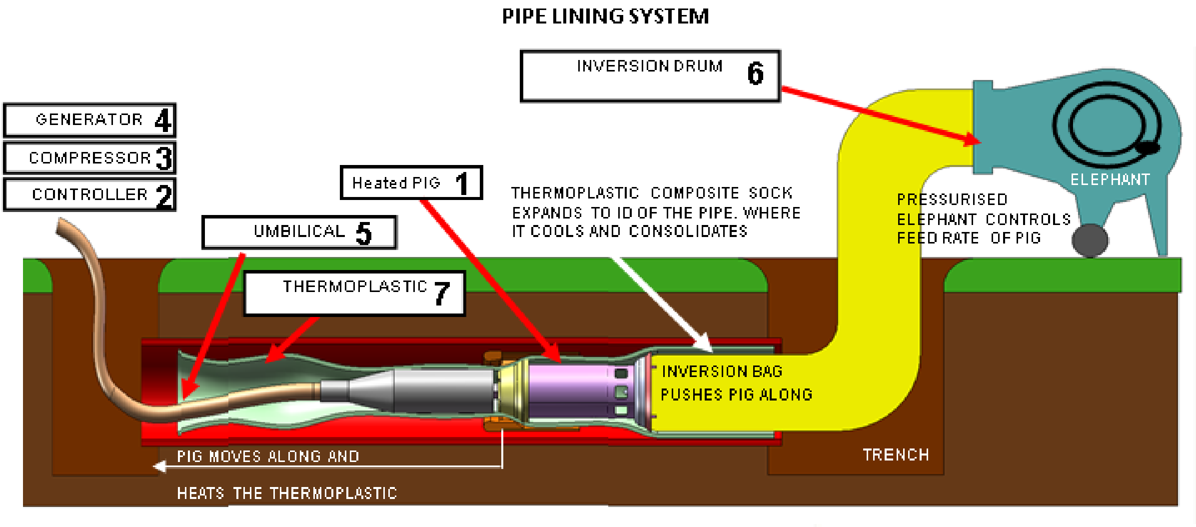

Fig 1 Aqualiner Process – Equipment elements

The latest equipment designed for 200-230mm pipes consists of the following key elements:

• A motorised and process controlled 3MPa inversion drum capable of deploying a 70m silicone rubber inversion bag at a precise rate and under controlled pressure.

• Reinforced silicone rubber inversion bags up to 70m long capable of operating up to 3MPa and process temperatures up to 230° C. The silicone rubber bags being low friction and robust.

• A heated PIG capable of lining pipes with diameters of 200-230mm. The PIGs were designed with 21 Kw heaters coupled with technology to mix and diffuse the hot air efficiently.

• A proprietary process control unit which controls the temperature of the hot air exiting the heated PIG. The process control unit monitors and records all the key process data, namely, temperature and pressure as a function of time.

• A 100m long flexible twin hose umbilical capable of providing the power and compressed air to the heated PIG. The umbilical is light, robust and flexible enough to enable it to navigate around tight bends, inlets and culverts.

ONGOING DEVELOPMENT

The objective is to improve the product and productivity and expand the size range such that waterpipe in diameters 100-300mm can be lined in lengths up to 120m. The development team is confident this will be achieved. Much has been learned about the configuration of glass and polypropylene fibre fabric from which the liner is made and the performance and control of the Heating PIG and the Elephant feeder. It is clear from observance of the UV CIPP process that the key to product consistency in these highly mechanised processes is all in the fine detail of the equipment engineering and the control system. The engineering team has had to go right back to basics to understand the air flow characteristics and heat element performance to create a balanced and symmetrical flow pattern in the heating canister to distribute and transition heat into the liner as it flows through the pig. It is a very precise balance and crucial step in the process with no known parallels in composite processing. The team has developed unique investigative techniques to model the behaviour of the liner material at various stages of the process, all of which should provide valuable insights into the scaling up process.

In 2020 a decision was taken expose the much-modified process to a commercial installation to build confidence in the new developments and feed back field experience to the team. Discussions were held with the consortium members to identify a commercial trial site and a number of potential sites were brought forward and scrutinised. Exposing the development to the water company engineering teams proved a valuable experience. It is essential for development teams to test their understanding of the marketplace and its commercial pressures. Identifying a work site to maximise the product exposure is challenging, the development team is out of its comfort zone, the client engineering team are on new ground and the stakes could scarcely be higher. Severn Trent Water offered several sites. The best fit was found in a commercial length of pipe under the management of Hafren Dyfrdwy (Severn Dee) responsible for STW customers in Wales. The selected pipe was located running along a country road near Wrexham. The 230mm pipe was in poor condition, heavily corroded and at the end of its working life; it had been taken out of service due to water quality issues.

In the event it was an extremely good choice for a variety of reasons, in particular, that the Hafren Dyfrdwy staff had no prior exposure to Aqualiner so that the discussions leading to the lining works started from basics to convince the local team of the products merits to justify the installation. Severn Trent staff shared their thoughts on lining options and their justification for selection of Aqualiner. Alternatives included open cut replacement, pipe bursting and slip lining, all more expensive options with significant carbon footprint. Open cut is recognised as most disruptive, pipe bursting is noisy and has potential to impact adjacent apparatus and slip lining reduces hydraulic capacity. Severn Trent discussed their perceived advantages of Aqualiner

- The system is 40% lower in cost than open-cut and is cost competitive with slip lining techniques.
- Can line any material and does not require the host pipe to be structurally sound.
- Smaller reduction in pipe volume than slip lining. Aqualiner reduced the capacity of the pipe by ~5% compared to ~25% for slip lining.
- The installation process requires a smaller footprint in the carriageway than slip lining techniques. This results in less traffic disruption. The system does this by avoiding the need the join lengths of pipe before they are inserted into the host pipe.
- Aqualiner also has a smaller installation footprint and creates less noise and vibration than pipe bursting. It also avoids issues with repair collars that can occur during pipe bursting.
- Avoidance of the need for heating and extended curing times associated with epoxy lining. The installation process can also be completed within one hour.

The work, undertaken in February 2021, lining a short length, about 30m, was funded through the REWAISE (Resilient Water Innovation for a smart economy) scheme. The pipe was scrapped and swabbed, CCTV surveyed, sampled to provide a baseline for water quality issues and lined in about three hours. The actual lining rate was 0.3m/minute. The post lining CCTV showed the liner was well sized and suitably positioned. The pipe was flushed, and Viking Johnson end couplings were fitted. The pipe was closed up and reinstated. Post lining water quality tests showed a major improvement in water quality and the pipe was returned to service. More such work is anticipated once the development team have achieved their size and installation length targets and Aqualiner Ltd will focus attention on developing and supporting a network of third-party installers to spearhead substantial growth.

REGULATION 31(4)(A) OF THE WATER SUPPLY (WATER QUALITY) REGULATIONS 2016 SI No 614 & THE WATER SUPPLY (WATER QUALITY) REGULATIONS 2010 SI No 994 (W.99)(AMENDMENT REGULATIONS 2016 No 410(W.128))

APPROVAL CONFIRMATION

Product name/designation	Water Pipe Lining
Approval Holder (Name & Address)	Aqualiner Limited Unit 13, Aerodrome Close, Loughborough, Leicestershire, LE11 5RJ.
Instructions for Use	Water Pipe Lining Issue: Version 6 Issue Date: 01/04/2021
DWI Ref Number	DWI 56/4/910

The Secretary of State for Environment, Food and Rural Affairs in respect of relevant water suppliers[1] whose area of supply is wholly or mainly in England, and the Welsh Ministers in respect of relevant water suppliers whose area of supply is wholly or mainly in Wales, in exercise of their powers under Regulation 31(4)(a) of the Water Supply (Water Quality) Regulations 2016 and Regulation 31(4)(a) of the Water Supply (Water Quality) Regulations 2010 (Wales) respectively hereby approve the introduction of the product detailed above, in accordance with the following Conditions of Use & Approval.

CONDITIONS OF USE & APPROVAL

The above named product is approved for application in England and Wales[2] by a water supply company for public water supply purposes subject to the following conditions:

1. Water undertakers and water supply licensees shall be provided with a copy of the Instructions for Use (IFU) detailed above and use of the approved product must be in accordance with the IFU.

2. The Drinking Water Inspectorate (DWI) must be notified, in advance and in writing, by the approval holder detailed above, in respect of any **further** change(s) in –
   a) The Instructions for Use
   b) The formulation of the approved product, including change in source or identity of raw materials
   c) The manufacturing process, including location of manufacture
   d) The designation of the approved product
   e) The name, address or ownership of the organisation holding the approval

Failure to notify such further changes will result in approval being withdrawn.

3. The producer shall ensure that the product is tested for conformity with its formulation, and the source or identity of its raw materials, at such intervals and by such persons, as may be determined by the Authorities. The results of such testing shall be sent to DWI.

4. The use of either the Drinking Water Inspectorate or DEFRA logos, in respect of any approved product (including on the product or in editorial or advertising/trade copy) is not permitted.

5. The following product specific condition(s) apply **– To be applied by authorised contractor**

Signed by authority of the Secretary of State and the National Assembly for Wales

Date of Issue: 20 April 2021
Date of Expiry: 06 November 2026

Marcus Rink
Chief Inspector of Drinking Water
England and Wales

[1] Relevant water suppliers shall include water undertakers, water supply licensees and inset appointees.
[2] Separate approval arrangements apply in Scotland and Northern Ireland

Fig 2 Aqualiner DWI Approval Confirmation

Fig 3 Original pipe, in poor condition as taken out of service

Fig4 Original pipe, scraped and flushed ready for lining

Fig 5 Lined Pipe prior to reinstatement

Fig 6 Reinstated Access Pit

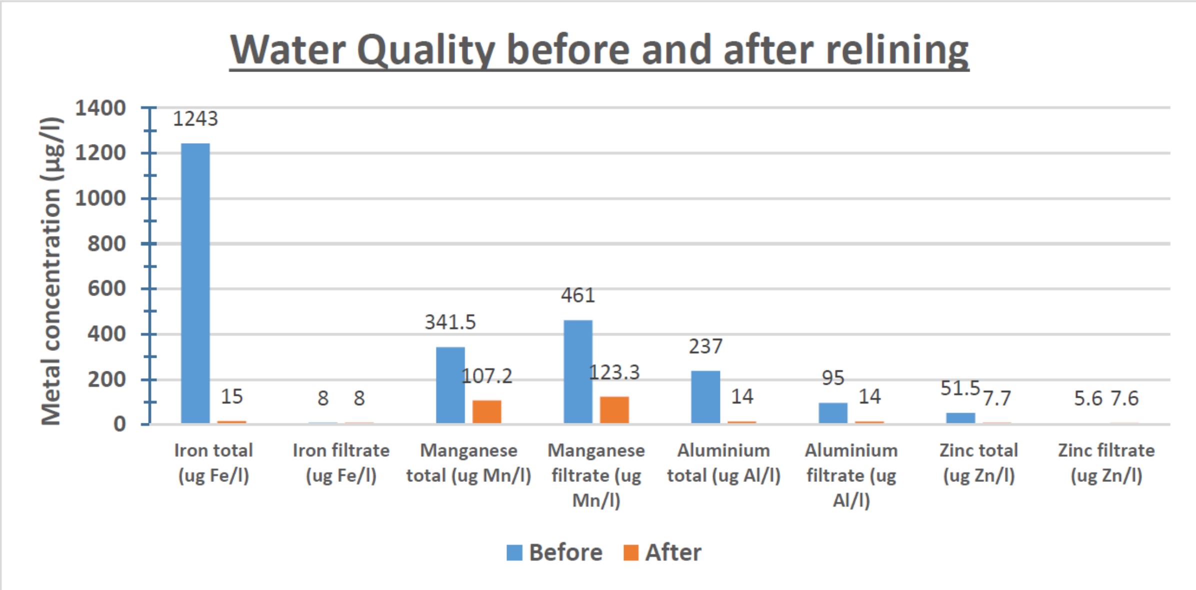

Fig 7 Water Quality results before and after lining

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