1 INTRODUCTION

The leaching of lead from pipes and piping materials is recognized as having adverse health effects for humans, most notably neurological and developmental problems in children. Lead levels in potable water are regulated in the United States by the U.S. Environmental Protection Agency’s Lead and Copper Rule and in Europe by the European Union’s Drinking Water Directive. From 1997 through 1999, the AWWA Research Foundation sponsored a project to test and evaluate existing technologies and promising emerging techniques for rehabilitating or replacing lead piping in the distribution system. The approach included a literature review, utility survey, case studies, and field trials conducted with participating manufacturers at participating utilities in North America and Europe. Results were used to develop guidelines for evaluating and selecting lead pipe rehabilitation and replacement technologies. Utilities that need to abide by the lead pipe replacement requirements of the USEPA Lead and Copper Rule can use these guidelines to plan site-specific programs.

A schematic cross section of a home and service connection in a typical water distribution system is shown in Figure 1. A variety of techniques currently are available for the rehabilitation or replacement of small diameter pipes in the size range typically used for water service lines (<25mm). These techniques can be classified under one of five general technology categories described below (Kirmeyer et al., 2000).

1) **Open trench replacement** – the traditional method for installing or replacing a water service line. The procedure typically requires cut-
ting and breaking of surface pavement and ex-
cavation of soil from the point of connection to
the main along the entire length of the service
pipe.

(2) **Replacement on new route** – the discarded
pipe is left in the ground and new pipe is in-
stalled along a different route using a trenchless
method such as impact moling or guided bor-
ing. The procedure requires excavation of two
access pits, typically located at the point of
connection at the water main and the curb stop.

(3) **Replacement using existing route** – the exist-
ing lead pipe is removed or displaced while si-
multaneously replacing it with new pipe.
Techniques include pipe pulling which removes
the pipe and pipe splitting which leaves the
pipe in the ground but enables the new pipe to
be installed along the original route.

(4) **Slip lining** – the existing lead pipe is lined with
a loose or tight fitting liner made of plastic ma-
terial such as polyethylene or polyethylene
terephthalate. The procedure requires excava-
tion of at least two access pits at the water main
and curb stop similar to other trenchless tech-
nologies.

(5) **Pipe coating** – the existing lead pipe interior is
coated with epoxy, wax, polymer, or other ma-
terial. The procedure requires excavation of
access pits, but the technology can be applied
in certain circumstances by excavating only one
access pit per service line.

2 FACTORS AFFECTING SELECTION OF
TECHNOLOGIES

Factors affecting the use and performance of each of
these lead pipe rehabilitation and replacement tech-
nologies can be classified as non-controllable or
controllable factors. **Non-controllable factors** in-
clude below-grade site conditions, above-grade site
conditions, and the condition of the existing lead
pipe as summarized below.

- **Below-grade site conditions**
  - Site access (proximity to buildings, parked
    vehicles, other immovable objects)
  - Traffic (motor vehicles, pedestrians)
  - Pavement and landscaping (overhead obstruc-
    tions, ambient conditions)

- **Above-grade site conditions**
  - Water main (location, depth, material, age,
    condition)
  - Geotechnical (soil characteristics, depth to
    groundwater, depth to road foundation)
  - Other buried service pipes (sewer, storm drain,
    power, cable, gas telephone, location and
    depth)

- **Pipe Conditions**
  - Breaks and leaks
  - Length of pipe
  - Configuration (e.g., loops, bends, kinks)
  - Pipe diameter and wall thickness
  - Location and buried depth of pipe
  - Common service from the main for more than
    one service

**Controllable factors** include installation issues (e.g.,
operator skills, need for special fittings) and cus-
tomer concerns (e.g., disruption to traffic, suspended
water service).

- **Installation issues**
  - Time for utility staff to acquire skills needed
    for using the technique
  - Time to prepare the site
  - Time to install material or replace the pipe
  - Time for curing (e.g., pipe coating material)
  - Time to reconnect the water service
  - Special fittings needed to reconnect service
  - Operational concerns or special requirements

- **Customer concerns**
  - Time the water supply is disconnected
  - Overall speed of operation
  - Disruption to automobile and pedestrian traf-
    fic
  - Environmental nuisances (e.g., noise, dirt)
  - Adverse effects on water quality
  - Potential interruption of other utility services

These lists of non-controllable and controllable fac-
tors can be used as preliminary checklists for assess-
ing site-specific applications.

The cost of implementing a rehabilitation or re-
placement program can vary widely depending on
site specific conditions and the availability of spe-
cific technologies. For example, the cost to dig an
open trench typically would be lower for a service
line buried 30 inches below a low-traffic road com-
pared to a service line buried 8 feet below a high-
traffic concrete road. Costs are further affected by
Table 1. Estimated Costs per Connection for Lead Pipe Technologies *

<table>
<thead>
<tr>
<th></th>
<th>Open trench replace</th>
<th>Replace existing route</th>
<th>Replace New route</th>
<th>Slip lining</th>
<th>Pipe coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor1</td>
<td>$700 - $1,000</td>
<td>$600 - $800</td>
<td>$600 - $800</td>
<td>$600 - $800</td>
<td>$600 - $700</td>
</tr>
<tr>
<td>Equipment 2</td>
<td>$270 - $550</td>
<td>$300 - $350</td>
<td>$200 - $400</td>
<td>$200 - $600</td>
<td>$300 - $400</td>
</tr>
<tr>
<td>Materials 3</td>
<td>$80 - $120</td>
<td>$100 - $150</td>
<td>$100 - $200</td>
<td>$50 - $90</td>
<td>$100 - $150</td>
</tr>
<tr>
<td>Restoration4</td>
<td>$800 - $1,000</td>
<td>$600 - $700</td>
<td>$600 - $1,200</td>
<td>$600 - $700</td>
<td>$400 - $600</td>
</tr>
<tr>
<td>Total 5</td>
<td>$1,850 - $2,670</td>
<td>$1,600 - $2,000</td>
<td>$1,500 - $2,600</td>
<td>$1,450 - $2,190</td>
<td>$1,400 - $1,850</td>
</tr>
</tbody>
</table>

* Costs are based on estimates per service connection and conversion to 1998 USA dollars (Kirmeyer et al., 2000).

1. Includes utility field crew, supervision and labor hired for specialty services
2. Includes cost to rent or purchase field equipment
3. Includes cost of rehabilitation materials or replacement pipe
4. Includes cost to restore sod, driveway, sidewalk and road
5. Total of labor, equipment, materials, and restoration

local expertise, other simultaneous activities such as main replacement, local labor prices, soil conditions, the length of the service pipe, the type of main connection, and other factors.

For this research, cost estimates were developed that could be used by utilities to compare alternatives and plan site-specific lead pipe rehabilitation and replacement programs. Cost estimates are based on results from field trials and utility responses to the survey developed for the project. Cost estimates for the five technology categories are summarized in Table 1.

3 GUIDELINES

A systematic procedure has been developed as a guide for evaluating and selecting lead pipe rehabilitation and replacement technologies. The procedure is based on findings from the literature review, utilities survey, and field trials for this project. The procedure can be used to screen possible technologies, but the reader should be aware that no technology may be considered 100 percent successful and an alternative technology always should be available on-site. This procedure consists of the following five-step approach.

Step 1 – Eliminate Unsuitable Technologies
Step 2 – Evaluate Technologies
Step 3 – Summarize Evaluation Results
Step 4 – Rank Technologies
Step 5 – Identify Available Techniques

After eliminating unsuitable technologies for a site, the applicability of the remaining lead pipe rehabilitation and replacement technologies are evaluated further based on the following criteria:

- Below-grade site conditions
- Above-grade site conditions
- Lead pipe conditions
- Ease of installation
- Estimated costs
- Customer impacts

The first three criteria pertain to non-controllable factors. The last three criteria pertain to controllable factors. Procedural guidelines, modules for evaluating and selecting technologies, and an example application of the procedure are included in the project report (Kirmeyer et al., 2000).

Figure 2 can be used as a guide for coordinating and implementing a lead pipe rehabilitation and replacement program for site-specific applications (Boyd et al.). Beginning with identification of lead service lines, the flow chart can be used as a checklist for coordinating project team members, collecting samples, implementing fieldwork, and documenting the success of the program.

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REFERENCES


Figure 2. Guidelines for Coordinating and Implementing a Lead Pipe Rehabilitation and Replacement Program