Irrigation canals placed in native soil or lined with earth can have seepage water losses varying from 20 percent to more than 50 percent. Well designed, new compacted earth lined canals can have reduced seepage losses similar to concrete lined channels. However, consistent and regular maintenance is required to keep seepage losses low. Older concrete lined canals with deteriorated joints and frost heave or settled sections may also have high seepage losses and require rehabilitating.

The most common and usually the most important purpose for lining irrigation canals is to reduce seepage losses. This may be for any one of several reasons:

1. Save water (reduce seepage)
2. Stabilize channel bed and banks
3. Avoid piping through and under channel banks
4. Decrease hydraulic roughness (reduce flow resistance)
5. Promote movement, rather than deposition, of sediments
6. Avoid waterlogging of adjacent land
7. Control weed growth
8. Decrease maintenance costs and facilitate cleaning
9. Reduce excavation costs (when extant material is unsuitable)
10. Reduce movement of contaminated groundwater plumes

**TYPES OF CANAL LININGS**

The main types of linings are: (a) Paved or hard-surface, (b) Exposed membrane, (c) Buried membrane, (d) Earth or conditioned earth, and (e) Soil sealants and stabilizers.

Paved or hard-surface linings include Portland cement concrete (see Figure 1 for type section), shotcrete, soil-cement, asphaltic concrete, and masonry. Exposed membrane linings (Figure 2) could be asphaltic membranes or, plastic or synthetic rubber films. Examples of buried membrane linings (Figure 3) are hot-applied or prefabricated asphaltic membranes, plastic and synthetic rubber films, and bentonite membranes. Earth or conditioned earth linings (Figure 4) include “thick” or “thin” compacted-earth, loosely placed earth blankets, and soils with
Materials: Usually concrete, could be brick or mortared pitching.

Benefits and Limitations: Seepage, scour, and weed control, low maintenance, wider range of permissible velocities, resistance to damage from livestock and equipment.

Mannings equation roughness coefficient (concrete):
- Cast-on-site $n = 0.014$
- Precast slabs or Bricks $n = 0.018 - 0.022$

Side slopes:
- Formed: Any slope
- Slip Form: 1 horizontal to 1 vertical
- Panel Type: 3 horizontal to 2 vertical

Figure 1. Type Section of Paved or Hard-surfaced Lining, i.e. unreinforced concrete (taken from Lauritzen, 1959, 1960).

Materials: Exposed asphalt lining.

Benefits and Limitations: Controls seepage and weeds to a degree; treatment with chemicals necessary; must be cleaned with care; not suitable where subject to heavy animal traffic.

Mannings equation roughness coefficient: $n = 0.014$

Figure 2. Type Section of an Exposed Membrane Lining (taken from Lauritzen, 1959, 1960).
Materials: Asphalt and plastic membranes.

Benefits and Limitations: Controls seepage but frequently adds to weed problem and the care which must be used in cleaning. Velocities limited to 3 ft/sec.

Mannings equation roughness coefficient: $n = 0.022 - 0.030$

Side Slopes:
- Asphalt membrane: 5 horizontal to 2 vertical
- Plastic film: 3 horizontal to 1 vertical

Figure 3. Type Section for Buried Membrane Linings (taken from Lauritzen, 1959, 1960).

Materials: Natural earth compacted, earth stabilized with chemicals, earth stabilized with small amounts of asphalt or earth stabilized with small amounts of portland cement.

Benefits and Limitations: Controls seepage; weed problem same as in unlined canal; frequently subject to scour unless protected with nonerosive topping such as gravel; cheap to construct under ideal conditions; velocities limited to < 3 ft/sec; protective cover desirable.

Mannings equation roughness coefficient: $n = 0.022 - 0.030$

Figure 4. Type Section for Conditioned Earth Lining Method, with or without gravel cover (taken from Lauritzen, 1959, 1960)
admixtures. Soil sealants and stabilizers could include bentonite, cinders, admixtures, and various chemicals.

The costs (lining only) typically vary from about $2 per sq. yard to nearly $40 per sq. yard, depending on the material (see Table 1). Generally, earth linings are less expensive than concrete or synthetic materials. A summary of the U.S. Bureau of Reclamation experience with geomembranes is given in Table 2. The polyethylene materials (VLDPE and LLDPE) have excellent biaxial flexibility and puncture resistance but only moderate conformance to subgrade. The PVC type material has good to very good conformance to subgrade, only good puncture resistance and is not recommended for exposure to ultra violet.

**Table 1. Types of Canal Lining and Typical and Recent Project Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Recent Costs$/sq-yd</th>
<th>Lining Only</th>
<th>Lining Only</th>
<th>Total Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentonite clay (at 5 lb/ft²) bulk</td>
<td>1.00 - 1.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil &amp; Portland cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin compacted earth (6 - 12 inches)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick compacted earth (24 - 36 inches)</td>
<td>13.53</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Masonry (stone, rock, brick)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonreinforced concrete (3” thick)</td>
<td>5.00</td>
<td>6.30</td>
<td>17.10</td>
<td></td>
</tr>
<tr>
<td>Reinforced concrete (w/ steel)</td>
<td>10.80</td>
<td>21.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gunite, a.k.a. shotcrete, a.k.a. cement mortar (hand or pneumatically applied)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyvinyl chloride (PVC)</td>
<td>5.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC 20 mil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low density polyethylene</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High density polyethylene</td>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt (bituminous)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprayed (“blown”) asphalt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalritic concrete</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthetic rubber</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyl rubber</td>
<td>8.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neoprene rubber</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shotcrete over geosynthetic</td>
<td>37.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete over geosynthetic</td>
<td>26.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced elastomeric bituminous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturated geotextile fiber cloth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fabric reinforced plastic 60 - 80 mil)</td>
<td>11.20-13.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The costs shown should be considered only in the most general relative sense.

a. Recent (late 1980's to mid 1990's) costs from the intermountain area.
b. Includes pad construction, cutting the channel shape and the lining process.
Table 2. Reclamation experience with geomembranes (taken from Table 1 of Morrison and Comer, 1995).

<table>
<thead>
<tr>
<th>Typical Geomembranes</th>
<th>Biaxial Flexibility</th>
<th>Uniaxial Elongation</th>
<th>Conformance to Subgrade</th>
<th>UV Resistance</th>
<th>Thermal Expansion</th>
<th>Shear Friction</th>
<th>Ease of handling¹</th>
<th>Seaming Method</th>
<th>Point Puncture Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>Very Good</td>
<td>Good</td>
<td>Very Good</td>
<td>Not Recommended²</td>
<td>Low to Moderate</td>
<td>Low</td>
<td>Prefabricated Panels easy</td>
<td>Chemical Thermal</td>
<td>Good</td>
</tr>
<tr>
<td>PVC-geotextile</td>
<td>Low</td>
<td>Restrained by Geotextile</td>
<td>Good</td>
<td>Generally Not Recommended</td>
<td>Restrained by Geotextile</td>
<td>High</td>
<td>Rolls</td>
<td>Chemical Thermal</td>
<td>Low</td>
</tr>
<tr>
<td>CSPE-R/CPE-R</td>
<td>Low</td>
<td>Restrained by Scrim</td>
<td>Good</td>
<td>Good</td>
<td>Restrained by Scrim</td>
<td>Moderate</td>
<td>Prefabricated Panels</td>
<td>Chemical Thermal</td>
<td>Low</td>
</tr>
<tr>
<td>EIA</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>-----</td>
<td>Low</td>
<td>Rolls</td>
<td>Chemical Thermal</td>
<td>Good</td>
</tr>
<tr>
<td>EIA-R fabric</td>
<td>Low</td>
<td>Restrained by Fabric</td>
<td>Moderate</td>
<td>Good</td>
<td>Restrained by Fabric</td>
<td>Moderate</td>
<td>Rolls</td>
<td>Chemical Thermal</td>
<td>Low</td>
</tr>
<tr>
<td>HDPE</td>
<td>Low</td>
<td>Design @ yield</td>
<td>Low</td>
<td>Good</td>
<td>High</td>
<td>Very Low</td>
<td>Rolls (stiff)</td>
<td>Thermal</td>
<td>Low</td>
</tr>
<tr>
<td>HDPE-T</td>
<td>Low</td>
<td>Design @ yield</td>
<td>Low</td>
<td>Good</td>
<td>High</td>
<td>High</td>
<td>Rolls (stiff)</td>
<td>Thermal</td>
<td>Low</td>
</tr>
<tr>
<td>VLDPE</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Moderate</td>
<td>Not Good</td>
<td>High but flexible</td>
<td>Low</td>
<td>Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>VLDPE-T</td>
<td>Excellent</td>
<td>Good</td>
<td>Moderate</td>
<td>-----</td>
<td>High but flexible</td>
<td>High</td>
<td>Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>LLDPE</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Moderate</td>
<td>-----</td>
<td>High but flexible</td>
<td>Low</td>
<td>Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>LLDPE-T</td>
<td>Excellent</td>
<td>Good</td>
<td>Moderate</td>
<td>-----</td>
<td>High but flexible</td>
<td>High</td>
<td>Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>PP</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
<td>How</td>
<td>-----</td>
<td>Panels or Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>PP-T</td>
<td>-----</td>
<td>Good</td>
<td>-----</td>
<td>-----</td>
<td>Low</td>
<td>-----</td>
<td>Panels or Rolls</td>
<td>Thermal</td>
<td>Excellent</td>
</tr>
<tr>
<td>Polymer Mod. Bituminous</td>
<td>-----</td>
<td>-----</td>
<td>OK</td>
<td>Surface Crazing</td>
<td>-----</td>
<td>-----</td>
<td>Heavy Rolls</td>
<td>Liquid Asphalt</td>
<td>-----</td>
</tr>
</tbody>
</table>

--- Has not been tested.

¹ Packaging - prefabricated panels generally require less field seaming than rolls.

² Not recommended for long-term exposure unless specially formulated for UV and of sufficient thickness.
JUSTIFICATION FOR LINING CANALS

The magnitude and extent of seepage loss relative to the canal size affects the economics of lining feasibility. For example, if 20% of the water from a 100 cfs canal is lost in a 1/4 mile section out of 20 miles of canal then a decision to line may be more obvious than if the loss were ½ % per mile. Any risk associated with seepage, i.e., embankment failure or high water table and consequent crop yield or property loss may be more significant economically than the value of the water itself.

Factors to consider in evaluating the economics of canal lining include: Value of water saved, location of seepage, drainage benefits (salinity control), protection of canal from failure (value of crop yield loss), increased capacity, life of lining, reduced maintenance (perhaps - less weed control, and reduced side slope and channel shape maintenance), and cost of maintenance.

EXAMPLE ECONOMIC JUSTIFICATION CALCULATIONS

A. Value of recoverable water from eliminating seepage

Assume an unlined canal with 20% seepage loss in a section where the flow is 100 cfs. This amounts to a 20 cfs loss, which over a 100-day period would be equivalent to 4000 acft (4000 = 40 acft/day x 100). At a water cost of $6/acft, the annual lost water is worth $24,000 (24,000 = 6 x 4000).

What is the justifiable bid price of a project to eliminate the seepage loss? Assume money is available at 6% interest.

Ans: The present worth, PW, (assuming that the interest rate accounts for inflation, etc.) is dependent upon the life of the project, i.e.:

For a 21-year life \( PW = $24,000 \frac{[1 - (1.06)^{-21}]}{.06} = $282,337 \)

For a 31-year life \( PW = $24,000 \frac{[1 - (1.06)^{-31}]}{.06} = $334,298 \)

The allowable bid price would the be PW in either case.

B. Avoidance of risk from loss of crop production

Assume 10,000 acres of alfalfa hay, canal break due to seepage caused bank failure with loss of irrigation water for 3 weeks. Yield loss of 1 ton alfalfa per acre as a result. The lost crop yield is valued at $60/ton. This totals $600,000, (600,000 = 60 x 1 x 10,000) per failure.

Assuming this type of failure has occurred about once every 10 years, what is the justifiable bid price of a project to eliminate the risk of this failure? Assume an interest rate of 6%.

Ans: This is a different analysis than example A, as it requires finding the present worth of an intermittent event. Assuming that we look ahead 21 or 31 years, the risk loss present value is:

For 21-year period

\[
PW = \frac{0}{1.06} + \frac{600,000}{(1.06)^2} + \cdots + \frac{0}{(1.06)^{10}} + \frac{600,000}{(1.06)^{11}} + \frac{600,000}{(1.06)^{21}} = $1,048,602
\]
Similarly for a 31-year period

\[
PW = \frac{1,048,602}{1.06^{31}} + \ldots + \frac{600,000}{1.06^{31}} = 1,147,154
\]

The allowable bid price would be the PW in either case.

**FEASIBILITY DETERMINATION**

Formulas may be used which evaluate construction costs, water value, drainage problems, protection from failure, and increased capacity in a reliable manner. However, the life of the lining and its maintenance often must be assumed and are dependent upon site-specific conditions.

Site-specific and variable factors are:
- Climate (freeze/thaw cycles)
- Terrain
- Water velocity
- Available construction materials
- Side slopes
- Effectiveness of drainage
- Cattle
- Adjoining field soil stability
- Period of operation
- Service conditions
- Capacity
- Thickness and type of linings
- Leakage
- Rodents
- Wind

The assumption that lining will solve seepage problems is often unfounded, simply because poor maintenance or incorrect subgrade preparation practices (as with concrete linings) can allow cracking and panel failures, and tears and punctures in flexible membranes.

“Administrative losses” and over-deliveries can add up to a greater volume of water than seepage in some cases. This means that canal lining is not always the most promising approach to saving water in the distribution system.

The final decision to line or not to line an irrigation canal must be made after consideration of *individual* and *specific site factors* and not relying solely on formulas or experience from elsewhere.

**ACKNOWLEDGMENTS**

The following individuals provided various information in support of this fact sheet:
- LaMont Robbins and Cloyd Day (NRCS);
- Mark Beutler, Alice Comer and T. R. Haider (USBR);
- Lee Wimmer (CUWCD);
- Sherm Jones (Jones Concrete Co.);
- Greg Olson (Horrocks Engineers);
- Gerald Westesen (MSU);
- LeRoy Payne and Emmett Dolan (Applied Payne Tech);
- Tom Chivers (Redmond Clay and Salt);
- and Bruce Godfrey and Don Snyder (USU Economics Dept.).

Their assistance is gratefully acknowledged, as is that of Gary Merkley of Utah State University for the use of some of his BIE 606 class notes in preparing the text.
BIBLIOGRAPHY


