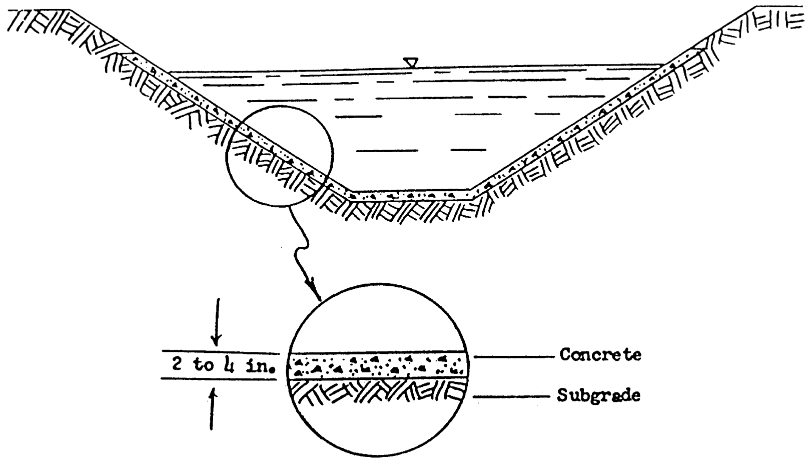
Materials: Usually concrete, could be brick or mortared pitching.

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 = .014**
	Precast slabs or Bricks	**n = .018 - .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 = .014

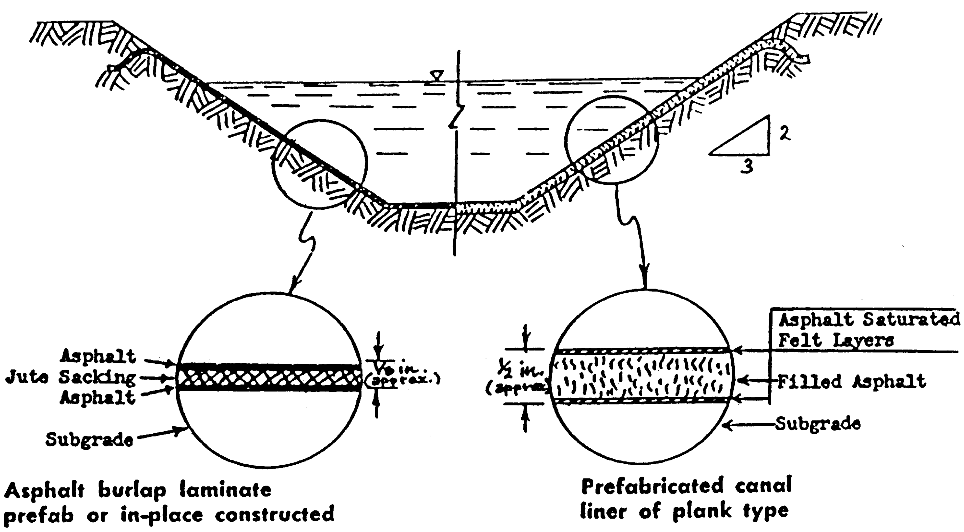
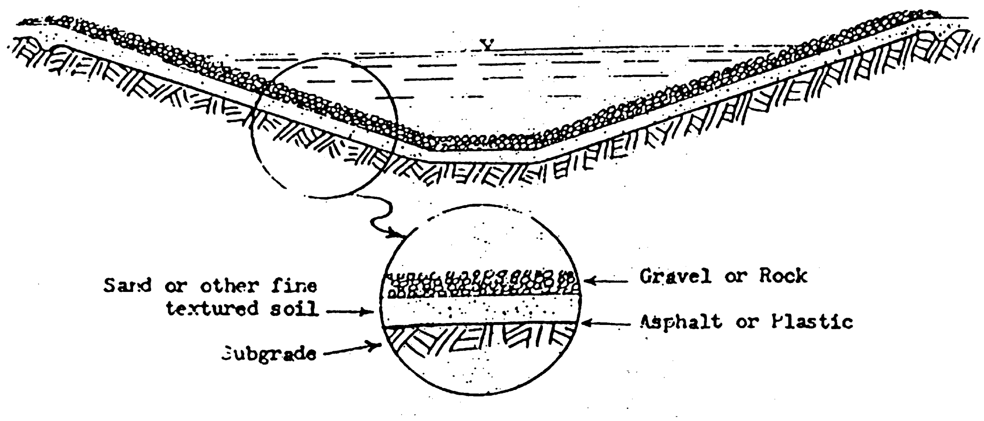


Figure 2. Type Section of an Exposed Membrane Lining (taken from Lauritzen, 1959, 1960).

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 = .022 - .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 nonerrosive topping such as gravel; cheap to construct under ideal conditions; velocities limited to < 3 ft/sec; protective cover desirable.

Mannings equation roughness coefficient: n = .022 - .030

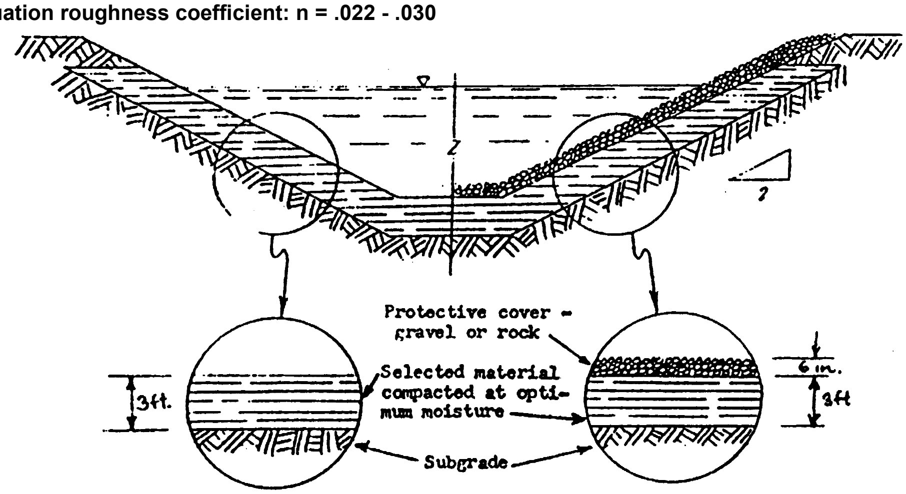


Figure 4. Type Section for Conditioned Earth Lining Method, with or without gravel cover (taken from Lauritzen, 1959, 1960)

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

		Recent Costs[a]	
	Lining Only $/sq-yd	Lining Only $/sq-yd	Total Project[b] $/sq-yd
Soil			
Lime			
Bentonite clay (at 5 lb/ft^2) bulk		1.00 - 1.60	
Soil & Portland cement			
Thin compacted earth (6 - 12 inches)			
Thick compacted earth (24 - 36 inches)		13.53	25
Masonry (stone, rock, brick)			
Concrete			
Nonreinforced concrete (3" thick)	5.00	6.30	17.10
Reinforced concrete (w/ steel)		10.80	21.60
Gunite, a.k.a. shotcrete, a.k.a. cement mortar (hand or pneumatically applied)			
Plastic			
Polyvinyl chloride (PVC)	5.00		
PVC 20 mil		4.80	14.90
Low density polyethylene	4.00		
High density polyethylene	10.00		
Asphalt (bituminous)			
Sprayed ("blown") asphalt			
Asphaltic concrete	4.00		
Synthetic rubber			
Butyl rubber	8.00		
Neoprene rubber			
Shotcrete over geosynthetic	37.00		
Concrete over geosynthetic	26.00		
Reinforced elastomeric bituminous		12.60	16-19
Saturated geotextile fiber cloth (Fabric reinforced plastic 60 - 80 mil)		11.20-13.50	

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).

Typical Geomembranes	Biaxial Flexibility	Uniaxial Elongation	Conformance to Subgrade	UV Resistance	Thermal Expansion	Shear Friction	Ease of handling[1]	Seaming Method	Point Puncture Resistance
PVC	Very Good	Good	Very Good	Not Recommended[2]	Low to Moderate	Low	Prefabricated Panels easy	Chemical Thermal	Good
PVC-geotextile	Low	Restrained by Geotextile	Good	Generally Not Recommended	Restrained by Geotextile	High	Rolls	Chemical Thermal	Low
CSPE-R/CPE-R	Low	Restrained by Scrim	Good	Good	Restrained by Scrim	Moderate	Prefabricated Panels	Chemical Thermal	Low
EIA	Good	Good	Good	Good	-----	Low	Rolls	Chemical Thermal	Good
EIA-R fabric	Low	Restrained by Fabric	Moderate	Good	Restrained by Fabric	Moderate	Rolls	Chemical Thermal	Low
HDPE	Low	Design @ yield	Low	Good	High	Very Low	Rolls (stiff)	Thermal	Low
HDPE-T	Low	Design @ yield	Low	Good	High	High	Rolls (stiff)	Thermal	Low
VLDPE	Excellent	Excellent	Moderate	Not Good	High but flexible	Low	Rolls	Thermal	Excellent
VLDPE-T	Excellent	Good	Moderate	-----	High but flexible	High	Rolls	Thermal	Excellent
LLDPE	Excellent	Excellent	Moderate	Good	High but flexible	Low	Rolls	Thermal	Excellent
LLDPE-T	Excellent	Good	Moderate	-----	High but flexible	High	Rolls	Thermal	Excellent
PP	Excellent	Excellent	Good	Good	How	-----	Panels or Rolls	Thermal	Excellent
PP-T	-----	Good	-----	-----	Low	-----	Panels or Rolls	Thermal	Excellent
Polymer Mod. Bituminous	-----	-----	OK	Surface Crazing	-----	-----	Heavy Rolls	Liquid Asphalt Thermal	------

----- 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 $PW = \$24{,}000 \{[1 - (1.06)^{-21}]/.06\} = \underline{\$282{,}337}$

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

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

$$PW = \frac{0}{1.06} + \frac{600{,}000}{(1.06)^{1}} + \ldots \frac{0}{(1.06)^{10}} + \frac{600{,}000}{(1.06)^{11}} + \frac{600{,}000}{(1.06)^{21}} = \underline{\$1{,}048{,}602}$$

Similarly for a 31-year period

$$PW = \$1{,}048{,}602 + ... + 600{,}000/1.06^{31} = \underline{\$1{,}147{,}154}$$

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.

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