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REDUCING HAZARDS TO PEOPLE AND ANIMALS ON RECLAMATION CANALS

Open and Closed Conduit Systems Program

September 1971

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16. ABSTRACT

The Bureau of Reclamation and others engaged in water resource management are concerned with increasing the safety of people and animals exposed to open waterways. An indepth study of the nature and extent of the hazard presented by canals together with an evaluation of preventive measures is given. A survey of human drownings in Bureau canals and a review of protective devices and safety practices currently in effect are presented. A detailed review of the problem of animal drownings is presented. The relative effectiveness and comparative cost of right-of-way fencing, conveying water in buried conduits, and covering canals are presented. These and other proposed solutions, such as installing stepped or corrugated canal linings, are examined and illustrated. The study presents much information related to the problem of public safety and preservation of animal life which will be of assistance to waterway planners, designers, and operators.

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Open and Closed Conduit Systems Program

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September 1971

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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PREFACE

An investigation leading to this report was initiated at the request of the Commissioner of the Bureau of Reclamation. Although the Bureau has an excellent public safety program, people and animals are continuing to drown in canals, which prompted a study of all aspects of the problem.

This report includes conclusions of the investigation. It contains a detailed survey of drownings of people and a brief review of current safety practices and policies. For a complete study of Bureau safety policy and practices relating to Bureau reservoirs and waterways, the reader is referred to USBR General Design Standards, Chapter 3, Safety Design Standards, and the bulletin entitled Canal Safety. A more detailed review of the problem of animal drownings is presented herein because much of this information has never before been published. This report also includes a discussion of both the costs and some of the benefits of placing canals in buried conduits, covering canals, and fencing canals. In addition, other safety considerations, such as using stepped or corrugated canal linings, allowing canals and rights-of-way to be used for recreational purposes, constructing canals with flatter side slopes, and attaching cleats to linings of existing canals, have been investigated and are included in the report.

A detailed economic study of the costs and benefits of reducing or eliminating the hazards of open canals was not made because of the many variables involved in this broad study of the problem. Land costs throughout Bureau projects may vary by 1,000 percent, and can even have a wide range within a project. The value of water varies greatly, and operation and maintenance costs differ from project to project. The size and cost of facilities required will depend extensively upon local conditions. For example, the cost of conveying a given quantity of water by pipe will vary in accordance with the topographical characteristics of each Bureau project. Thus, developing typical costs and benefits would result in meaningless comparisons. However, information is presented herein, related to the problem of public safety, that will be of assistance to waterway planners, designers, and operators.

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Frontispiece – Safety fence and float at inlet to siphon on the San Luis Canal. Photo P-805-236-14106

INTRODUCTION

The loss of a human life is a tragedy which affects the immediate family of the deceased forever. It is also an economic loss to the nation. Unfortunately, this tragedy occurs approximately 30 times every year on Bureau-constructed canals. In the past 5 years there have been 152 public drownings on these waterways. Even more tragic is the fact that 40 percent of the victims were children.

The Bureau has had an aggressive canal safety program for many years. It is Bureau policy to include reasonable safety devices when these waterways are constructed. Yet the drownings persist. Why? There are many reasons. The rapid increase in population, and its mobility, has increased exposure of the public to the hazards of open canals. The construction of urban areas adjacent to canals and the granting of access to these canals for recreational uses in the absence of safety facilities and supervision also contribute to these drownings. Many drownings occur on the canals of older projects that were not considered a hazard when constructed because of their then remote locations. As a result there are both Bureau-operated and privately operated projects which do not include adequate safety features. A contributing factor is the lack of financial assistance by others to the irrigation district for construction of safety features required because of such increased exposure.

In addition to the drowning of people in Bureau-constructed canals, many animals are also lost annually. These consist mainly of big game animals, mostly deer. Although the number of big game animals lost is not tabulated herein, it is estimated that approximately 1,000 to 2,000 deer are drowned annually in Bureau waterways. Although this is a small percentage of the nation's total deer population, these drownings are concentrated in specific canals, resulting in significant depletion of local deer herds. For example, 45 deer were lost in the first 30 days of operation of the Howard Prairie Canal in Oregon. When a condition such as this exists, severe pressure is exerted upon the Bureau to reduce these losses.

REDUCING HAZARDS TO PEOPLE ON RECLAMATION CANALS

There is ample evidence that unguarded and unprotected open canals and laterals present a serious hazard to people, particularly children. Since 1962 the Bureau has maintained a detailed record of drownings on Bureau-constructed facilities, including canals and laterals. Tables 1A through 1D, entitled "Survey of Drownings in Bureau-constructed Canals" contain pertinent information from accident investigation reports relating to the 152 public drownings in Bureau-constructed canals and laterals for the 5-year period from 1964-1968. This survey covers all Bureau-constructed canals and laterals including those operated by irrigation districts, state and local agencies.

1. Survey of Open Waterway Hazards to People

The survey sheds considerable light on the nature and extent of the hazard to people from Bureau-constructed canals and laterals. Fortunately, it also serves as a guide to steps which can be initiated to reduce public drownings in these waterways. The information in the accompanying tables can be summarized as follows:

a. The type of construction, lined or unlined, has had little influence on the number of drownings. Large hard-surface lined canals are more hazardous due to the difficulty in escaping from them. There is greater exposure to young children to the relatively small unlined canals and laterals in the vicinity of their homes. For approximately equal lengths of canal, the 5-year survey shows that 69 drownings occurred in lined canals and laterals compared with 67 in unlined canals and laterals.

b. The survey discloses that canals and laterals of all sizes and depths must be considered as potential hazards. For example, 45 drownings or approximately one-third of the total occurred in waterways with a capacity of 100 cubic feet per second or less. Similarly, 27 drownings or 18 percent occurred in water depths of 30 inches or less, and 77 or over 50 percent of the drownings occured in 5 feet or less of water. The survey indicates that both lined and unlined canals and laterals, regardless of size or flow, constitute very real hazards, particularly to children. Consequently, all canals, regardless of size, flow, or type of construction must be included in considering solutions to the hazards to people.

c. Pertinent to the hazards to people, and to its solution, is the fact that almost all of the drownings occurred in urban and rural populated areas (Class A* and B exposure). Conversely, drownings in canals and laterals located in isolated areas with only occasional exposure to persons, do not present a problem. By far the greatest number of drownings occurred in rural areas (Class B).

*See Table 1C for exposure classification.

Figure 1. Bureau of Reclamation regional boundaries

Table 1A

SURVEY OF DROWNINGS IN BUREAU-CONSTRUCTED* CANALS

(By Region and Year)

Period: Five Years – 1964 through 1968

Bureau-Wide

Region**	Number of drownings
1	22
2	39
3	26
4	5
5	53
6	3
7	4
Total	152

Canal Drownings by Year

1964	31
1965	31
1966	27
1967	24
1968	39
Total	152

*The accompanying survey covers 152 drownings in Reclamation-constructed canals operated by the Bureau, irrigation districts, state and local agencies. Of this total, 85 were in Bureau-operated canals; 67 were in canals operated by District, State, and local agencies

**Refer to Figure 1 showing the geographical boundaries of each of the Bureau of Reclamation's seven regions.

Table 1B

SURVEY OF DROWNINGS IN BUREAU-CONSTRUCTED CANALS

(by canal type, capacity, and water depth)
Years 1964 through 1968

A. Number of drownings related to canal capacity and type

Type	Canal capacity, cubic feet per second 0-100	101-500	501-1,000	1,001-5,000	Over 5,000	5-year total	Annual rate
Lined canals and laterals	14	14	8	30	3	69	13.8
Unlined canals and laterals	18	27	9	11	2	67	13.4
Other (Drains, wasteways, etc.)	13					13	2.6
Total drownings	45	41	17	41	5	*149	29.8

B. Number of drownings related to depth of water and type of canal

Type	Water depth 0-30 in.	31 in.-5 ft.	6-10 ft.	11-15 ft.	Over 15 ft.	5-year total	Annual rate
Lined canals and laterals	12	12	26	6	13	69	13.8
Unlined canals and laterals	6	36	18	5	2	67	13.4
Other (drains, wasteways, etc.)	9	2	2			13	2.6
Total drownings	27	50	46	11	15	*149	29.8

* In three drownings the capacity and water depth are unknown.

Table 1C

SURVEY OF DROWNINGS IN BUREAU-CONSTRUCTED CANALS

(by type of exposure)
Years 1964 through 1968

	Vehicular	Other	5-year total	Annual rate
A. Exposure classification*				
Class A	3	42	45	9.0
Class B	26	77	103	20.6
Class C	3	1	4	0.8
Totals	32	120	152	30.4
B. Site of drowning				
Bank	26	77	103	20.6
Bridge	6	6	12	2.4
Siphon		2	2	0.4
Turnout		1	1	0.2
Check		11	11	2.2
Chute or drop		4	4	0.8
Undetermined		19	19	3.8
Totals	32	120	152	30.4
C. Protective fencing				
Fenced site	9	20	29	5.8
Unfenced site	23	100	123	24.6
Totals	32	120	152	30.4

*Class of Hazard Exposure (Paragraph 3.5, Chapter 3, Safety Design Standards)
Class A—(Urban)—Locations and sites readily accessible to the public from an adjacent or nearby city or school and subject to numerous and frequent visits by the public.
Class B—(Rural)—Locations and sites removed from any population concentrations but subject to infrequent visits by the public from nearby farms or public highways.
Class C—(Remote)—Locations and sites far removed from any dwelling which would be visited by operating personnel and sportsmen.

Table 1D

SURVEY OF DROWNINGS IN BUREAU-CONSTRUCTED CANALS

(by age, sex, type, and activity)
Years 1964 through 1968

A. Age, years	Sex: Male	Sex: Female	5-year total	Annual rate
0-5	36	10	46	9.2
6-10	14		14	2.8
11-15	3	1	4	0.8
16-20	12	4	16	3.2
21-60	54	7	61	12.2
Over 60	9	2	11	2.2
Totals	128	24	152	30.4

B. Type of drowning	Cause: Fell	Cause: Own volition	Cause: Pushed or thrown	Cause: Vehicle	5-year total	Annual rate
Accidental	60	26		27	113	22.6
Apparent suicide		2			2	0.4
Suspected homicide			1		1	0.2
Undetermined				5	36	7.2
Totals	60	28	1	32	152	30.4

C. Activity of deceased	Age group: 0-5	6-10	11-15	16-20	21-60	Over 60	5-year total	Annual rate
Fishing				1	3	1	5	1.0
Swimming			2	3	10	1	16	3.2
Hunting		1					1	0.2
Walking	5	3		1	4	4	17	3.4
Playing	34	6					40	8.0
In vehicle	1	1		4	25	1	32	6.4
Undetermined	6	3	2	7	19	4	41	8.2
Totals	46	14	4	16	61	11	152	30.4
(Under the influence of alcohol)				2	16	4	22	4.4

d. Two-thirds of the drownings, or 103, occurred along the bank of the canal or lateral. Drownings from bridges and check structures claimed 23 lives. The fact that 32 drownings (21 percent) involved vehicles points up the mounting hazard from this source. These incidents involved vehicles entering canals from adjacent public highways, vehicles traveling O&M roads alongside canals where access was permitted for recreational uses, and vehicles traveling O&M roads where access was not permitted and trespassing was involved. In several cases, it was determined that the driver was under the influence of alcohol.

e. Not considering vehicular accidents, only a total of 20, or 4 drownings per year, occurred in reaches of canals or laterals protected by fencing. In most instances trespassing was involved and the fencing varied from simple barbed wire to more elaborate chain link and barbed wire. Significant is the fact that 100 of the 120 drownings, not including vehicular, occurred along unfenced reaches of Bureau canals and laterals.

f. Indicating the danger that open waterways present to children is the tragic fact that 60 were under 11 years of age.

g. The study indicates that almost all the drownings were accidental although 22 or 12½ percent of the drowned persons were known to be under the influence of alcohol at the time. Only 16 drownings involved persons swimming in the canals, compared with 57, mostly young children, who fell in while walking or playing along the waterways.

From the accompanying survey, shown in Table 1D, it is concluded that the greatest single incidence of drownings involves children playing or walking along open canals or laterals. Further, that while lined canals and laterals are potentially the most hazardous, the incidence of drownings is equally great in unlined canals and laterals. The survey indicates that protective fencing is effective in reducing the number of drownings. Conversely, a review of the specific locations where drownings have been prevalent, as listed below, disclosed the absence of fencing or perimeter guarding:

Delta-Mendota Canal	1.8 drownings per year
Yuma Main Canal	1.2 drownings per year
Rio Grande Project	4.8 drownings per year
Middle Rio Grande Project	4.6 drownings per year

Photograph 1. Safety rack installed in inlet transition of siphon. Photo P328-701-9467

In many areas the Bureau's public image has suffered as a result of these tragic drownings of children. Additionally, law suits against the Bureau resulting from drownings in Bureau-operated canals and laterals are becoming more prevalent.

2. Present Practice in Protecting the Public Along Existing Waterways

The Bureau, for some years, has been thoroughly aware of the need to protect the public along existing waterways. In an effort to reduce drownings in canals and laterals an aggressive public safety program, incorporating the following actions, has been initiated:

a. Design. – Current Bureau safety design criteria dictate that all open canals and laterals over 30 inches deep, located in Class A exposures, be protected with either a 4- or 6-foot chain link or wire mesh perimeter fence topped with barbed wire. This protection has also been extended to rural areas depending upon the degree of exposure. All concrete-lined canals with sides more than 30 inches in height are equipped with escape ladders installed at 750-foot intervals. In addition, other escape devices are provided upstream from all hazardous canal structures (such as checks, turnouts, drops, and chutes). These escape devices include suspended cables with droplines, floats or booms across canals, escape nets, safety racks, and trashracks. All inlets to siphons over 30 inches in diameter and all inlets to tunnels are protected with these escape devices and a fence or guardrail. In urban areas, it is the Bureau's policy to construct closed conduits wherever practical.

b. Current practice on existing canals. — During the past 5 years the Bureau has installed siphon protection on Bureau-operated canals and has encouraged water districts to do likewise. Also, safety devices have been installed on other hazardous canal structures on most Bureau-operated canals. Very little perimeter fencing has been installed on existing canals or laterals, regardless of the exposure or the incidence of drownings. However, in cooperation with the districts and state agencies, the Bureau has encouraged local legislation requiring land developers to fence adjoining canals and laterals.

c. Safety maintenance. — Routine inspection and maintenance programs are carried out by all operating offices to ensure that required fencing and protection devices are installed and adequately maintained.

d. Public education. — Since 1961 the Bureau, in cooperation with the American Red Cross, has sponsored and actively participated in an aggressive public water safety program. The program, widely known as "Operation Westwide," currently is composed of 30 community water safety councils promoting water safety on or adjacent to Bureau irrigation projects.

Photograph 2. Safety sign, life buoy and fence at canal headworks. Photo P-328-701-7145

Photograph 3. Checked siphon inlet with safety rack, fencing and guardrail. Photo P-328-700-103NA

3. Potential Improvements for Reducing Waterway Hazards to People

In view of the hazards that open canals present to people, the following steps are proposed to reduce drowning in these waterways:

a. Future fence construction. — Bureau design standards should be revised to provide for construction of protective right-of-way fencing on all reaches of open canals or laterals designated as Class A or Class B exposure. For Class A exposure the fencing should be 5 feet high, constructed of 4 feet of chain link and three strands of barbed wire on metal posts. Adjacent to schools or public playgrounds the fence should be 7 feet high, constructed of 6 feet of chain link and three strands of barbed wire on metal posts. Class B exposures should meet the Class A design criteria except that wire mesh shall be substituted for chain link fencing material on the 5-foot fence. Also, wooden posts may be used in lieu of metal posts.

b. Existing facilities. — Reaches of existing canals and laterals classified as Class A or B, operated by the Bureau, should be either placed in underground conduits or fenced in accordance with the design criteria set forth in a. above. A priority should be established for the fencing of these canals based upon the degree of hazard to the public and upon the incidence of drowning. Irrigation districts operating Bureau-constructed canals and laterals should be encouraged and assisted in an effort to provide similar protection.

c. Safety. – The current safety maintenance and public education programs carried out by the Bureau should be intensified.

d. Increased consideration for use of underground conduits. – In future planning studies for water conveyance structures, more consideration should be given to reducing hazards through the increased use of underground conduits in lieu of fenced, open waterways.

REDUCING HAZARDS TO ANIMALS ON RECLAMATION CANALS

Concrete-lined canals present a very serious hazard to animals. Because of the high water velocities and slick, steep side slopes normally associated with these canals, it is virtually impossible for animals to escape from them unassisted. If they do not die of exhaustion, they drown when swept through siphons. Canals with earth banks do not present as great a hazard because animals can generally escape from them unassisted.

Relatively few domestic animals are drowned in Bureau-constructed canals annually but these can be greatly reduced by the construction and maintenance of cattle guards, gates, and right-of-way fences. The present policy of providing barbed wire or wire mesh fences wherever canals present a hazard to domestic animals is successful and should be continued.

The loss of big game animals in canals is another matter. Limited attempts have been made to reduce the many drownings of these animals. Approximately 95 percent of the big game animals lost are deer, although losses of elk, bear, antelope, and desert bighorn sheep have been recorded. Just how many animals are lost in Reclamation canals is not known because complete records have never been kept. Table 2 is a summary of available data and is presented to give some idea of the number of animals lost.

It can be seen from Table 2 that the problem of big game drownings is primarily a problem of one species, namely deer. These reports cover about 2,200 miles of the 7,000 miles of canals the Bureau has constructed. The data are too incomplete to establish the total number of deer drowned annually on Bureau-constructed canals.

Table 2 reveals that the loss of deer is a problem in only a few canals. The Charles Hanson Feeder Canal in Colorado has annual losses of approximately six deer per mile of canal. The Delta-Mendota Canal in California apparently has annual losses of one deer for every 10 miles of canal. Canals that are in suitable deer habitat usually have annual losses of one or more deer per mile. Thus, the location of a canal will determine the hazard the canal presents to wildlife.

Table 3 shows canal properties of the canals mentioned in Table 2. All canals tabulated are either partially or completely concrete lined, and deer losses were significant only in the lined portions. Also noteworthy is the fact that concrete-lined canals with sideslopes as flat as 2:1 (2 horizontal to 1 vertical) are a hazard. The size of a canal does not appear to be significant, nor does water depth.

1. The Basic Problems of Canals to Big Game

A listing of the basic problems that canals present to big game are:

a. A canal located in an area normally inhabited by deer or other big game can act as an obstacle or barrier that must be crossed. In extreme cases canals may reduce or eliminate access to valuable habitat.

b. Canals may be in resident, summer or winter range or in a transition area. They often intersect normally traveled game trails. They may intersect major migration routes.

c. The danger of canals to deer is threefold: First, deer enter the canal, are unable to find a suitable place to escape, become exhausted, and drown. Second, critical damage to deer's hoofs, pasterns, and knees is often a result of their efforts to escape on concrete- or gunite-lined banks. This damage may later result in death. Third, when concrete-lined canals are dry, deer usually cannot escape unassisted. They die from exhaustion or injury incurred trying to escape.

d. Deer may enter the canal for three different reasons: First, the animal may be attempting to cross to the opposite bank. This is especially compelling if the canal crosses daily or seasonally traveled game trails. A deer might be attracted to something on the opposite bank, such as another deer or feed, and be tempted to cross. Second, deer may be forced to jump into the canal when frightened or chased by people, dogs, or predators. Third, deer might fall or slip into a canal when trying to drink from it. Canals are an attraction to

Table 2

SUMMARY OF BIG GAME LOSSES IN BUREAU-CONSTRUCTED CANALS

Canal—Project	State	Animals lost*	Period involved	Miles of canal involved	Comments	Source of information
Ainsworth Canal—Ainsworth Unit	Nebraska	23	1965	52		(1)
		45	1966			
Charles Hansen Feeder Canal—Colorado—Big Thompson Project	Colorado	25	1957	8.5	Project Manager's letter of February 20, 1969	(5)
		23	1958		Average loss for 12-year record is 49 deer per year	
		58	1959			
		37	1960			
		30	1961			
		33	1962			
		61	1963			
		43	1964			
		41	1965			
		70	1966			
		38	1967			
		32	1968			
Columbia Basin Project	Wash.	36	1953		Losses on 40 miles of concrete-lined canal on Main Canal and West Canal; 25 rough gravel-asphalt escape ramps constructed in March 1955	(2)
		54	1954			
		27	1955			
		13	1956			
Columbia Basin Project	Wash.	171	1952-59		About 10 percent died in dry canals after close of irrigation season	

Table 2—Continued

Canal—Project	State	Animals lost*	Period involved	Miles of canal involved	Comments	Source of information
Delta-Mendota Canal	Calif.	13	1954-55			
		10	1958-59	120		(3)
Friant-Kern Canal	Calif.	12	Per year	153	Fenced against livestock; no escape ramps	(3)
Gateway Canal, Weber Basin Project	Utah	2	July 1957		33 removed from canal. Canal not carrying full flow	(3)
Howard Prairie Canal Talent Division Rogue River Basin Project	Oregon	55	7-21-59 to 8-31-59		55 deer lost in first 40 days of canal operation	(4)
		42	1961	17		
		33	1962			
		26	1963		USBR constructed 18 deer catchers, 5 drinking bays, and 207 deer crossings in 1960. Average loss for 8 years is 24 deer per year	
		21	1964			
		18	1965			
		14	1966			
		25	1967			
		11	1968			
Robles—Casitas Canal Ventura River Project	Calif.	Over 100	1957	8	After 9 ladders and 2 bridges constructed, 9 deer were taken from canal in September 1959	(3)

Table 2—Continued

Canal—Project	State	Animals lost*	Period involved	Miles of canal involved	Comments	Source of information
Robles—Casitas Canal Ventura River Project	Calif.	None	1959—60	—	Since 9 ladders and 2 bridges constructed	(3)
Toketee Project North Umpqua River	Oregon	57 deer 3 elk	1952—59	—	Resident population of deer small; no migration of significance. Decreasing loss over period attributed by Company to bridges	(3)
Wellton—Mohawk Project	Arizona	Many deer Several desert bighorn sheep		Over 50		(3)

*Animals lost are deer unless otherwise indicated

Source of Information

1. Nebraska Game, Forestation, and Parks Commission
2. State of Washington, Department of Game
3. Bureau of Sport Fisheries and Wildlife (see bibliography reference No. 3)
4. Talent Irrigation District
5. Bureau of Reclamation

Table 3

SUMMARY OF CANAL HYDRAULIC AND PHYSICAL PROPERTIES

Canal	Lining	V	S:S	d (ft)	b (ft)	H_L (ft)	Q
Ainsworth Canal							
Reaches 1, 2, 3	Concrete	3.40	2:1	7.22	9.0	8.40	580
Reaches 4, 5, 6, 7	Concrete	6.20	2:1	5.30	7.0	6.50	580
Charles Hansen Feeder Canal	Concrete	4.41	1-1/4:1	8.79	13.0	10.50	930
	Concrete	3.91	1-1/4:1	8.17	7.0	8.67	550
Delta Mendota Canal							
Typical unlined section, 2 miles	Not lined	2.26	2-1/2:1	14.27	50.0	–	4,600
Typical concrete-lined section, 96 miles	Concrete	3.81	1-1/2:1	16.56	48.0	18.08	4,600
Typical earth-lined section, 18 miles	Earth	2.41	2-1/2:1	13.90	62.0	–	3,310
Friant-Kern Canal							
Typical concrete section, 152 miles	Concrete	3.90 to 5.10	1-1/4:1	17.00 to 18.30	36.0	–	5,000 to 3,500
Typical earth-lined section, 25 miles	Earth	3.20	1-1/2:1	15.20	64.0	–	3,500
Gateway Canal	Concrete	4.99	1-1/2:1	6.90	10.0	8.33	700
Howard Prairie Canal	Concrete	3.38	1-1/4:1	2.99	2.2	3.50	60
Howard Prairie Bench Flume	Concrete	3.34	Vertical	2.99	6.0	3.75	60
Robles Casitas Canal	Concrete	5.86	1-1/2:1	5.56	7.0	6.80	500

V = velocity, feet per second
S:S = side slope ratio
d = normal water depth
b = canal bottom width
H_L = height of lining
Q = design capacity, cubic feet per second

Photograph 4. , Male mule deer attempting to escape from the Ainsworth Canal. The deer was unable to escape until it reached the deflector escape structure further down the canal (see Photograph 6). Photograph courtesy Nebraska Game, Fish and Parks Commission.

deer because they offer a source of drinking water. This is especially important in areas where water is scarce. Drinking from a canal can be difficult if the water surface is well below the top of the canal. Deer, in attempting to reach this water, may slide into the canal.

e. The steepness, slickness, and height of the canal bank influence a deer's ability to escape. The depth and water velocity apparently affect the animal's behavior in the canal.

f. Concrete-lined canals present a major problem to big game because the walls are too steep and slippery to allow an animal to get out. Even small concrete-lined canals are a hazard to adult animals as well as fawns.

g. In most cases, canals with earth banks offer few problems to adult deer but may be a hazard to fawns.

The behavior of deer trapped in a canal is not entirely predictable. Normally, they attempt to escape at the point they entered the canal. They continue to try to escape until they become exhausted. Then they swim or float downstream until swept through a siphon and are drowned or until they reach some barrier in the canal where they die. Deer will swim either upstream or downstream searching for an escape point. Normally they will not swim upstream in a canal if the velocity is greater than 4½ feet per second.

The loss of a deer in a Bureau-constructed canal does not result in monetary loss to the Bureau or to its water-users; however, when significant numbers of big game animals are lost in a canal, measures are undertaken to reduce or eliminate these losses. These measures are usually endorsed by conservation organizations, sportsmen's organizations, and the communication media. Directly interested are the state game departments, the Bureau of Sport Fisheries and Wildlife, and state and Federal officials.

In addition, state game departments and the Bureau of Sport Fisheries and Wildlife are requesting that hazards to wildlife be reduced on future canals. For example, on the Fryingpan-Arkansas Project the Bureau will provide 33 miles of deerproof fence and 16 deer crossings at a cost of approximately $350,000 on three concrete-lined canals. This is being done at the request of the Colorado Game and Fish Department. In addition, the State of Nebraska has stated that all future concrete-lined canals should be fenced completely.

On existing canals operated by water districts the problem of deer loss can be complex. Expenditures for animal protective devices can range from very minimal to a large amount. Usually large expenditures for such protective devices may be beyond the financial capabilities of the districts. Cooperative efforts by both the water users and conservationists are needed to find a solution to the problem.

2. Present Practice in Reducing Deer Losses on Existing Canals

Presently there are several measures being taken on different projects to reduce deer losses in existing canals. These include elimination of access by fencing, installation of deer crossings, construction of drinking bays, and installation of escape devices. Escape devices used consist of deflectors, floating log booms, snow fence laid on canal sides, airplane landing mat laid on canal sides, metal cleat steps attached to canal lining, rough gravel-asphalt escape ramps, reinforcing bar grids laid on canal sides, escape steps at siphon inlets, and temporary escape devices for use during the nonirrigation season.

Generally, stock fences have not been effective in reducing deer losses; however, installation of such fencing along canal rights-of-way has been credited with reducing losses on some projects. A conventional stock fence is 4 feet high with four strands of barbed wire. Deerproof fence is 7½ feet high with 6 feet of woven wire and three strands of barbed wire and will almost completely eliminate deer access. Fencing costs are included in this report in the portion entitled "Fencing."

Deer crossings are bridges constructed across canals and their use is limited to animals. They provide a means of animal movement across canals and reduce incidents of animals entering the canal. They should be at least 8 feet wide and have a cover of 4 inches of earth. The effectiveness of these structures has been proven on the Colorado-Big Thompson and Rogue River Projects. Any plan to reduce deer losses in a canal should consider the use of crossings. Crossings should be provided for deer movement if a canal is to be fenced. They present few or no O&M problems if properly constructed. The following tabulation gives estimated costs (May 1969) of deer crossings constructed of timber:

Span of crossing	Width of crossing	Estimated cost per crossing
15 feet	8 feet	$1,650
20 feet	8 feet	2,200
30 feet	8 feet	3,300
40 feet	8 feet	4,400

Installation of drinking bays will reduce incidents of deer entering canals in areas where water is scarce. They are credited with reducing deer losses on the Howard Prairie Canal. Drinking bays can be constructed inexpensively, with the use of natural materials and corrugated metal pipe, and present few O&M problems.

Deflectors are barriers placed in the canal to shunt or force a swimming or floating deer to the sides of the canal where some means of escape is provided. Deflectors can be constructed of metal pipe, wood, or metal pipe and reinforcing bars. They can be floating or stationary.

Photograph 5. Canal deer crossing (or bridge) on the Charles Hanson Feeder Canal. Tracks show deer usage. Photo P-245-713-4111 NA

Photograph 6. Deer escaping Ainsworth Canal at deflector escape structure. Note cleats attached to canal lining assisting the animal's escape. Photograph courtesy Nebraska Game, Forestation and Parks Commission.

On small canals they are usually placed diagonally across the canal and anchored to the canal bank. On larger canals they are usually V shaped in plan (see Figure 2). Wooden or angle iron cleats attached to the canal lining, concrete steps, or flattened canal side slopes have been used to aid the escape of deer from the canal. Floating deflectors constructed of wood have been used on the Southern Okanogan Lands Project in British Columbia where they were credited with reducing deer drownings from 30 to 3 annually. Stationary deflectors constructed of pipe have been used experimentally on the Ainsworth Canal. Their effectiveness has not been fully determined, but it has been concluded that they do aid in reducing deer losses. To be effective, these devices should be placed upstream from all in-line canal structures and at approximately ½-mile intervals along the canal. The structures present several problems and are not popular with irrigation operators. They cause loss of head in the canal, require annual maintenance, and periodic cleaning when the canal is in operation. They present the possibility of causing the canal to overflow when they become plugged. The estimated cost of the deflector for a 20-foot-wide canal is $900, and for a canal 40 feet wide, the estimated cost is $1,200.

The log boom consists of floating logs attached to a chain or cable anchored to the canal bank. Some means of animal exit at the canal sides should be provided. Deer have been observed going over and under them in the canal. They are not used extensively for reduction of deer losses.

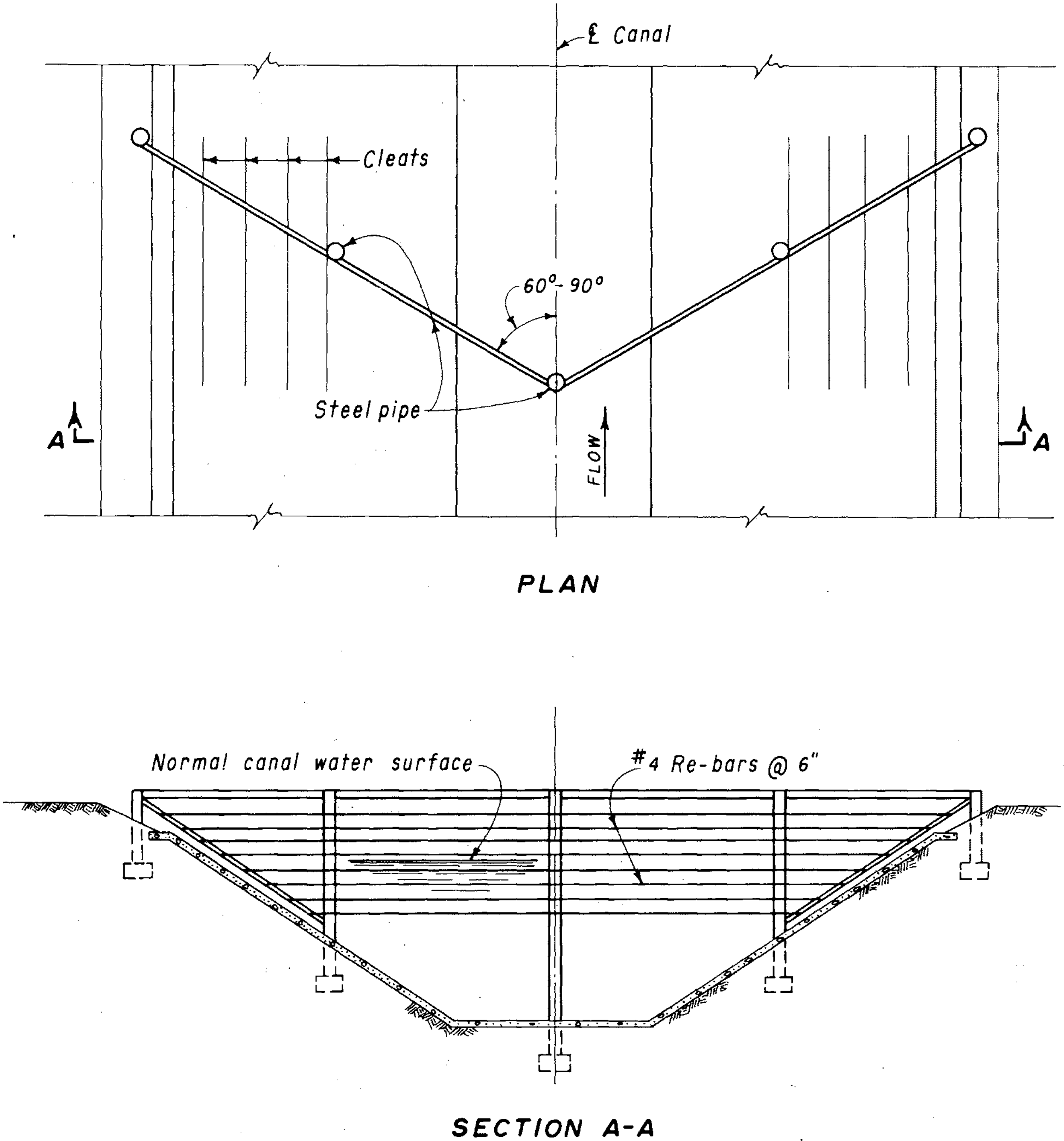


Figure 2. Typical animal deflector on canal.

Snow fence laid on the canal side as a deer escape has been used in some areas but has not proven to be effective. It is thought that its appearance frightens deer.

Surplus airplane landing mat placed on canal sides to aid deer in escape has been used on some canals; however, its effectiveness is not known.

To assist deer in escaping, metal cleat steps are used on the Mohawk Canal, Yuma Project, at all check structures on the canal. These consist of steps of angle iron placed on canal sides and welded to a frame which is anchored to the canal bank. These devices were designed and installed by the Arizona Game Department. The project reports that deer drownings were reduced by 75 percent after the installation of these devices. The metal steps should present no O&M problems. The estimated installed cost of the device is $500.

Rough gravel-asphalt escape ramps consist of a mat of rough gravel and asphalt 1 inch thick, approximately 20 feet wide, applied from the top to the bottom of the canal sides. This escape device is a result of research conducted by the Washington State Game Department. They found that deer are attracted to dark areas in trying to escape. These mats are used on the concrete-lined portions of the Main Canal and on the West Canal of the Columbia Basin Project. Deer have been observed escaping from the canals on these ramps both when canals were empty and with water in them. Project O&M personnel and game department people are satisfied with these devices. They have reduced deer losses on these canals by 75 percent. These devices were also used on the Ainsworth Canal and were found to be ineffective because of the high velocities of this canal. When water velocities exceed 5 feet per second, deer are swept off the mat before they are able to climb out of the canal. This escape device should pose no O&M

Photograph 7. Stepped siphon inlet, Gateway Canal. The concrete steps allow humans and animals to escape from the canal. Conventional reinforcing bar steps for human escape shown in right foreground. Photo 526-400-4213

problems. Their estimated cost is $100 per ramp. At present this device appears to offer the best means of aiding deer in escaping from concrete-lined canals.

Reinforcing bar grid consists of a mat of concrete reinforcing bars welded into a grid placed on the canal sides and anchored to the canal bank. These grids were used on the North Branch Canal, Yakima Project, but were found to be ineffective and their use has been discontinued.

Stepped siphon inlets, consisting of reinforced concrete steps, extend below the canal water surface. They are a monolithic part of the siphon inlet. These steps require an inlet transition of special design, eliminating their use on existing canals. They were developed in the hydraulic laboratory of the U. S. Bureau of Reclamation. Stepped siphon inlets were constructed on the siphons of the Gateway Canal, Weber Basin Project. They are effective when the canal is at or near design capacity. They are completely ineffective when the canal has low flows or is dry. They are credited with reducing deer drownings on the Gateway Canal where deer have been observed using them to escape from the canal.

Baled hay placed in canals after close of the irrigation season is an effective temporary escape device. This has been used successfully on the Tieton Division of the Yakima Project and has eliminated losses of deer and elk during the nonirrigation season.

The degree of effectiveness of all measures and devices reviewed is in some part based on judgment. For some there is little or no data available to make a scientific determination of their effectiveness.

Measures that have been found to be effective in reducing deer losses include deer crossings, drinking bays, and escape devices. None of these alone will prove satisfactory, but an intelligent application of a combination of some of these devices should reduce deer losses significantly. Escape devices that have been found effective are deflectors, metal cleat steps, rough gravel-asphalt escape ramps, and stepped siphon inlets. Escape devices used should be in accordance with canal characteristics and must take into account the conditions peculiar to the locality. These conditions include canal properties, terrain canal traverses, habits of deer, and availability of food and water for deer.

Deer losses can be eliminated by covering canals, conveying water in pipe rather than in open canals, and by fencing open canals with deerproof fence (see bibliography references 1, 3, 5, 6, 7, and 8).

3. Potential Improvements for Reducing Waterway Hazards to Animals

After reviewing the animal drowning problems, experienced by the Bureau on existing canals, it is obvious that future canals should be planned to minimize these hazards. Of first importance in planning is recognizing those areas where wildlife losses are likely to be a significant problem. Then all plans under investigation for water utilization should include adequate measures to protect wildlife. Some measures that should be considered for wildlife protection are conveying water in pipe in lieu of concrete-lined canals, conveying water in earth-lined or buried membrane-lined canals in lieu of concrete-lined canals, fencing concrete-lined canals, provision for animal crossings and drinking bays, and/or escape devices in concrete-lined canals.

SELECTION OF PROTECTIVE FACILITIES TO REDUCE HAZARDS

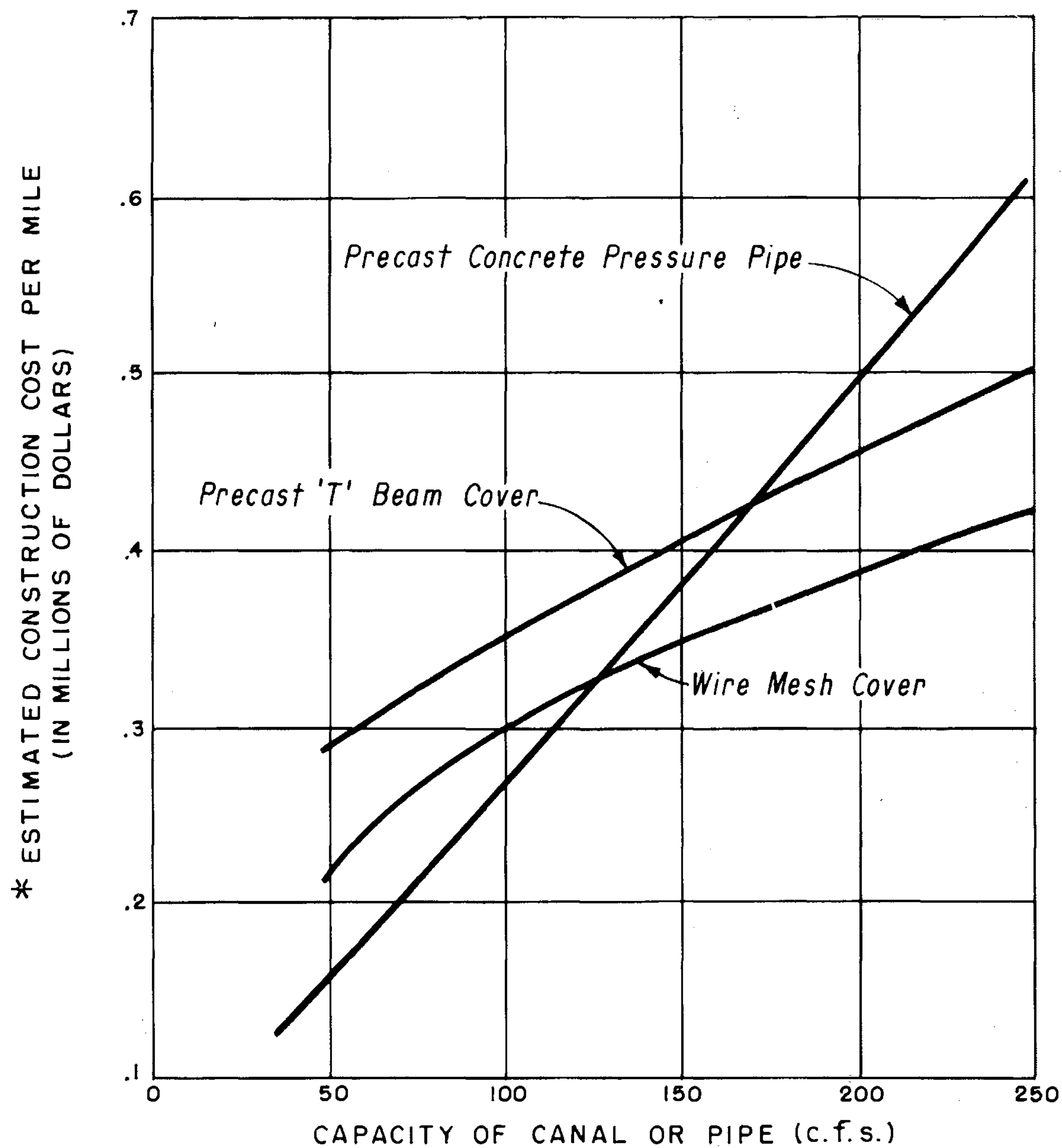
1. Economic Procedures for Selecting Appropriate Waterway Safety Features

Engineering economy is involved in the selection of the most appropriate methods, materials, and types of structures to serve the project purposes Project plans for proposed projects or for rehabilitation and betterment of existing projects should include facilities for minimizing hazards to people and animals. The safety features to be included in each plan should be based on a determination of the potential hazards to people and animals. Basic facilities for public health and safety must be provided for in the plans. Methods for reducing hazards discussed in the preceding sections should be studied concomitantly with all other project purposes For example, the alternatives of fencing waterways or placing them in buried underground conduits for safety purposes will also affect the total costs and benefits associated with the irrigation function.

The separable costs for each purpose must be less than the benefits from that purpose. In general, the selected plan should produce the greatest net benefits but must provide necessary safety features. However, other economic constraints such as the total construction cost per acre of irrigated land, the amount of amortization provided by the water users, and the amount of bâsin fund assistance required must also be given consideration in selection of the appropriate type of facilities to be provided

Procedures for making economic comparison of alternative facilities are available in other documents and are not presented herein. A report entitled "Economic Justification for Canal Lining in Irrigation Distribution Systems," available from the Bureau of Reclamation, is one illustration of these procedures.

Costs and benefits for various safety features are discussed in the following sections. Comparisons of construction costs for pipe and canal covers are presented in Figure 3 and of pipe and fenced



* Costs are as of May, 1969

Figure 3. Comparison of construction costs of covering canals and conveying water in pipe for various capacities.

concrete-lined laterals in Figure 4. Figure 4 indicates that construction costs for a pipe lateral will generally exceed those for a fenced, lined lateral when the lateral capacity is greater than 11 cubic feet per second. However, an economic comparison of these alternatives, considering all related costs and all related benefits, would generally indicate that pipe can be justified for laterals of greater capacity than 11 cubic feet per second.

2. Closed Conduits

Normally open canals are the most economical means of conveying large quantities of water. It can be assumed that the capital cost per lined foot of underground conduits exceeds the cost of open waterways except for those of very small capacity. Comparisons of underground conduits with fenced, open waterways for a proposed project should give consideration to such economic factors as:

a. Comparative Costs

(1) Construction costs, as affected by compactness of area served, alignment of waterways, drainage requirements, right-of-way, severance etc.

(2) Operation and maintenance costs, considering weed rodent, and vector control; drain and waterway cleaning; operating requirements, pumping; energy; etc

b. Comparative Benefits

(1) Net irrigation benefits from water conserved, comparing relative items such as evaporation seepage, operational waste, etc. These benefits may also be evaluated in terms of water use for such purposes as power generation, municipal and industrial supply, quality control, fish and wildlife enhancement, and recreation.

(2) Increased intangible benefits, considering such items as hazards to human lives and animals, esthetics, environment, and ecology.

Table 4 presents an estimate prepared in 1967 of the cost to enclose 982 miles of existing Reclamation canals that constituted a serious safety hazard (see bibliography Reference 11). Although the costs shown in the table may be conservatively high, they indicate the magnitude of costs to convert open canals to closed conduits.

Estimated construction costs for pipe and lined canals are also shown in Figures 3 and 4. These costs are presented for general information only. Construction costs for buried conduit vary greatly with location, pressure in pipe, etc.

For instance, Table 4 shows a construction cost of $457,000 per mile for converting an existing canal of 100 cubic-feet-per-second capacity to a pipe system; while Figure 3 shows a cost of only $270,000 per mile, assuming new work, for a pipe system of the same capacity. This points up the merit of including closed conduits in new work – so that economic water velocities may be used – rather than trying to convert existing canal to pipe systems.

3. Canal Covers

To determine whether existing canals could be covered economically, estimates were made for several types of canal covers. Reconnaissance grade design and estimates were prepared for thin-shelled, reinforced-concrete arches; precast concrete, double T-beams; and chain link fencing supported by pipe arches. See Figures 5 and 6. Obviously canal covers also could be constructed of a variety of other materials. A comparison of the construction costs of covering canals versus the construction costs of conveying water in pipe is shown in Figure 3.

The advantage of covering canals is mainly the elimination of the hazards of open canals. In some instances, the covered canal right-of-way might be used for other purposes such as park or recreation areas. Other benefits might include reduction in canal weed problems and improvement of winter operating conditions. Disadvantages might include increased hazard to animals where wire mesh covers were involved, increased maintenance costs for such items as silt removal, canal prism inspection and repair, etc. It would also be necessary to prevent vehicle access to flat canal covers.

4. Fencing

Construction costs for fencing are generally far less than costs for canal covers or close conduits. Table 5 presents estimated construction costs for fencing. Fencing of concrete-lined laterals with urban safety fence increases costs about $37,000 per mile as shown in Figure 4. The costs shown in Table 5 are based upon the following design criteria:

a. School safety fence. – Fence 7 feet high with 6 feet of chain link and three strands of barbed wire. Steel posts at 10-foot centers with toprail. (Also known as cyclone fence.)

b. Urban safety fence. – Fence 5 feet high with 4 feet of chain link and three strands of barbed wire. Steel posts at 10-foot centers with toprail. (See Figure 7).

c. Proposed rural safety fence. – Fence 5 feet high with 4 feet of wire mesh and three strands of barbed wire supported by posts of metal or wood at 10-foot centers.

d. Barbed wire stock fence. – Fence 4 feet high with four strands of barbed wire and posts at 12-foot centers.

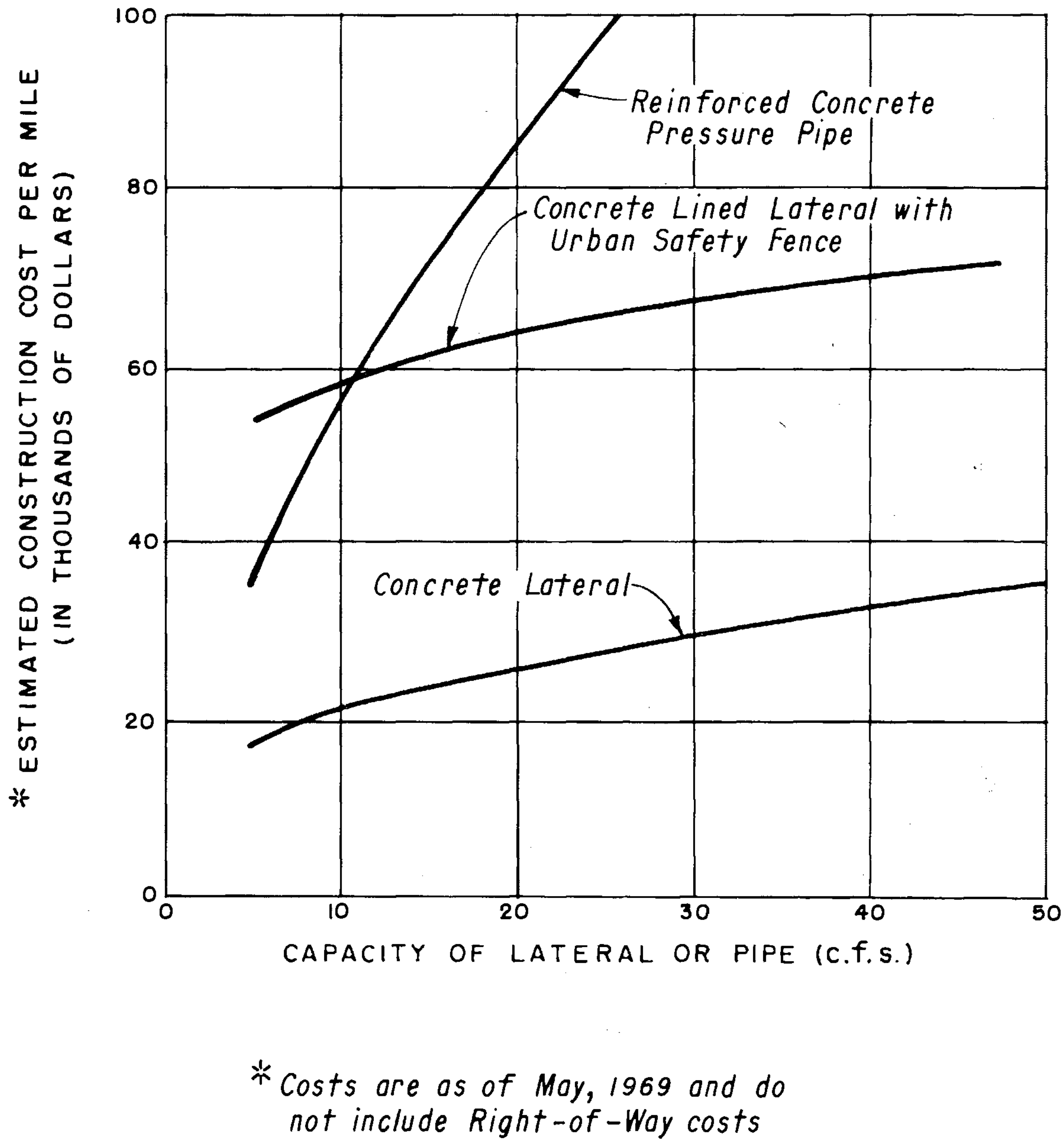


Figure 4. Comparison of construction costs of fenced laterals and conveying water in pipe for various capacities in urban areas.

Table 4

TABULATION OF ESTIMATED COST TO PLACE EXISTING OPEN CANALS IN CLOSED CONDUITS*

(Pipes and boxes)

Capacity, cfs	Estimated miles to be enclosed	Estimated total cost of enclosure	Estimated cost per mile of enclosure**
50 or less	468	$ 79,092,000	$ 169,000
50-100	116	53,012,000	457,000
100-500	271	400,267,000	1,477,000
Subtotal	855	532,371,000	
500-1,000	74	240,352,000	3,248,000
1,000-3,000	23	117,162,000	5,094,000
3,000-10,000	30	230,700,000	7,690,000
Total	982	$1,120,585,000	

*Reconnaissance grade estimate, costs are as of October 1967.

**Costs based on pipes or boxes placed on the same grade as the existing canal. Low velocity of flow, between 2 and 3 feet per second, results in large-diameter structures and relatively high-cost systems.

So that the size of open canals may be visualized, the following tabulation gives approximate dimensions of typical canal sections for capacities that correspond with the capacities shown in Table 4:

Capacity (cfs)	Canal bottom width (ft)	Canal top width (ft)	Canal depth (ft)
50	4	14	3.5
100	9	20	4.0
500	16	40-45	9.0
1,000	20	50-60	10.0
3,000	60	100-120	12.0

Table 5

ESTIMATED CONSTRUCTION COSTS OF FENCING

Fence	Exposure class	Cost per linear foot of fence	Cost per mile of canal*
USBR school safety fence	A	$4.00	$41,200
USBR urban safety fence	A	3.50	36,800
Recommended rural safety fence	A&B	1.05	11,200
USBR barbed wire stock fence	B&C		4,800
USBR woven wire stock fence	B&C		7,200
Recommended deer fence	—	—	20,000
Highway safety fence (6-foot chain link)	A	3.75	40,000
Highway safety fence (4-foot chain link)	A&B	3.25	34,000

*Assuming each side of the canal is fenced.

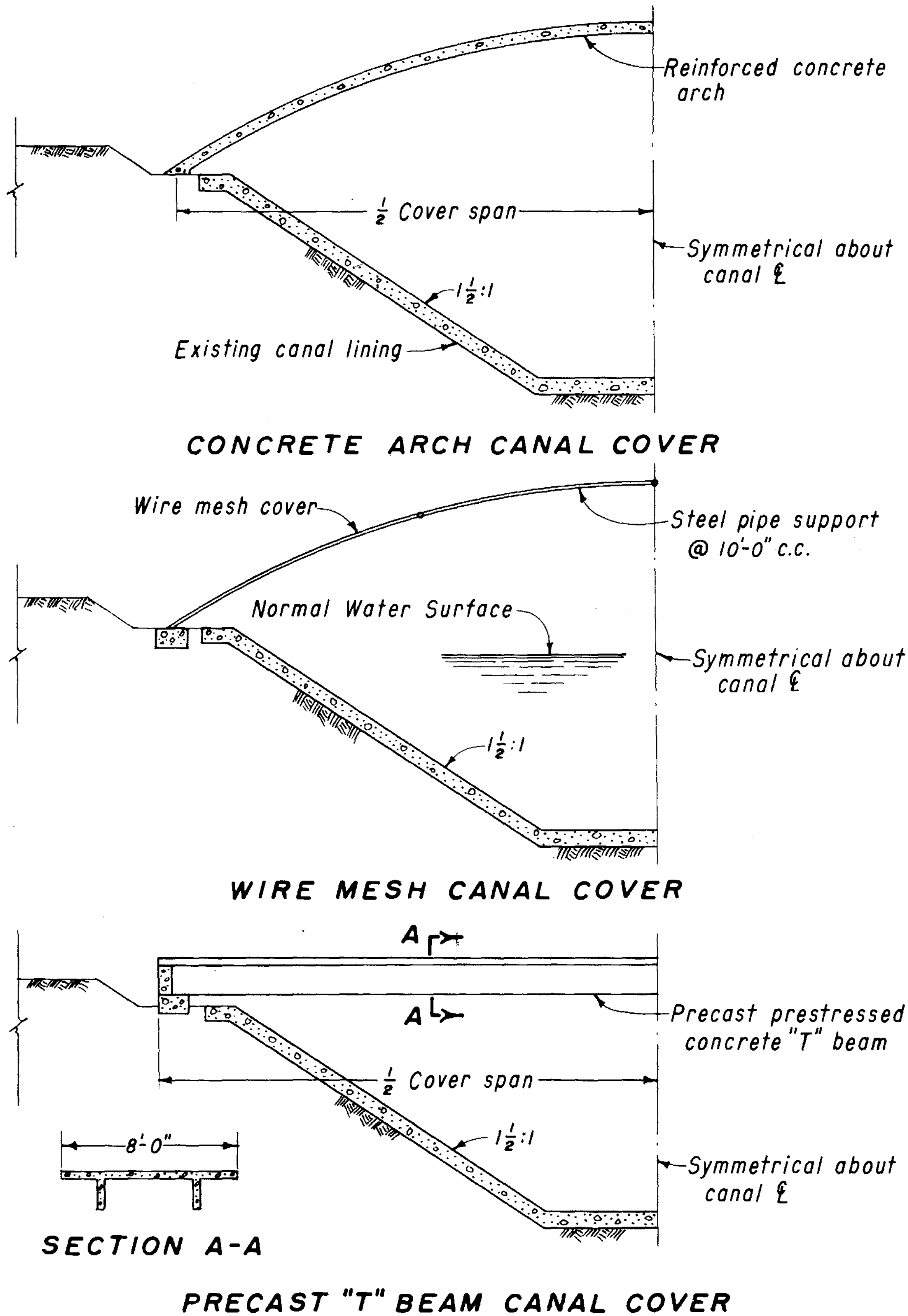
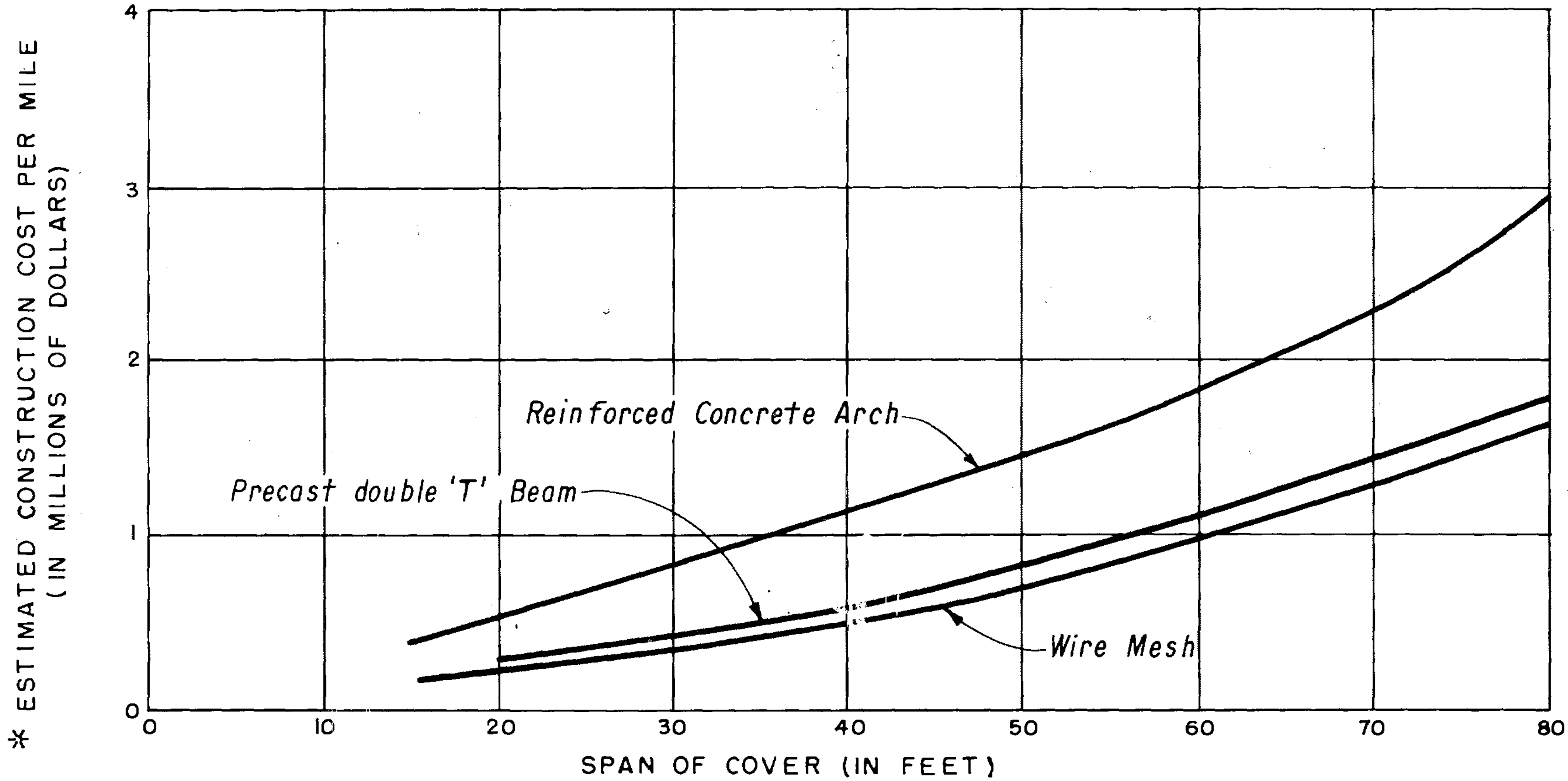


Figure 5. Typical canal covers.



* Costs are as of May, 1969

Figure 6. Estimated construction cost of canal covers.

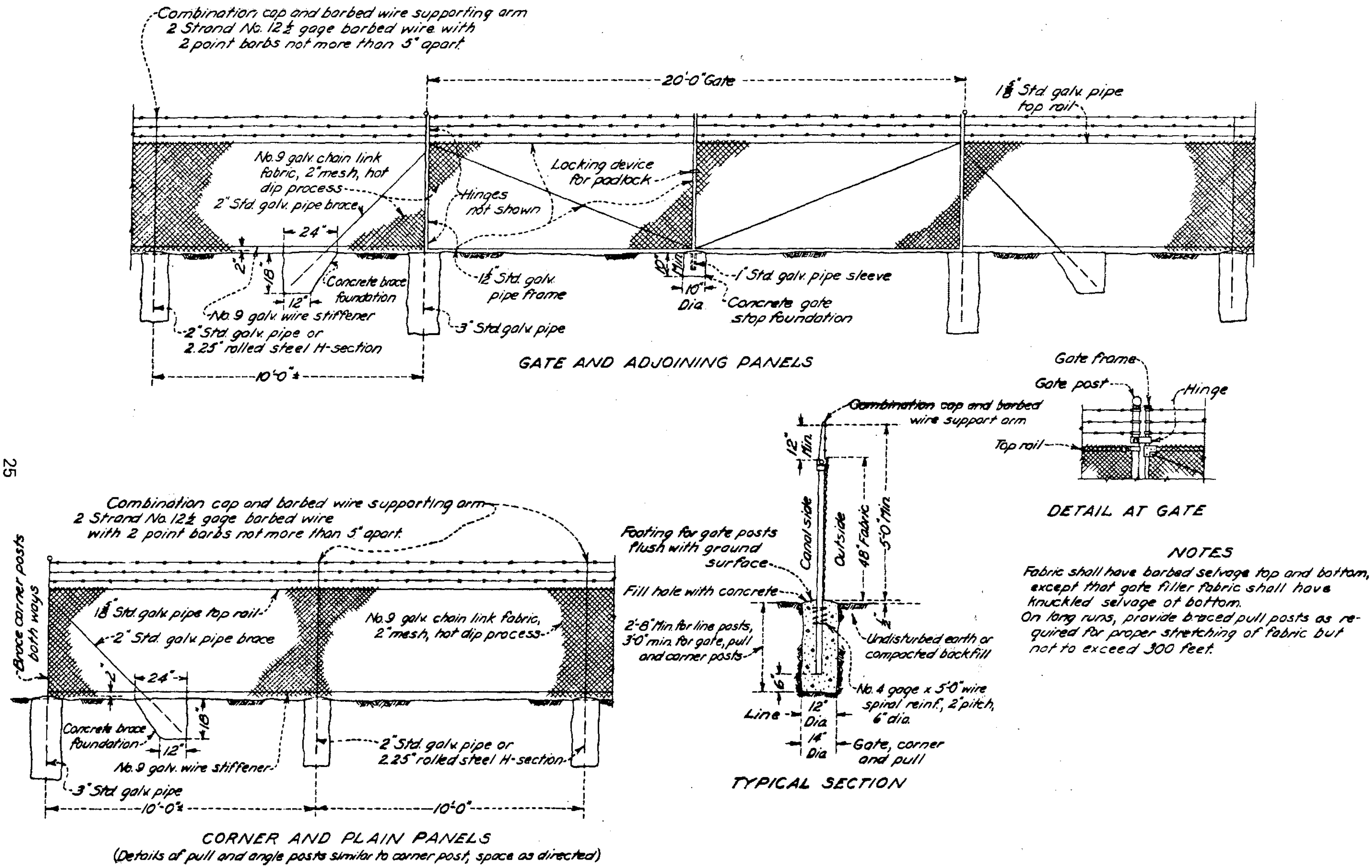


Figure 7. Typical urban safety fence.

e. Woven wire stock fence. – Fence 4 feet high with 2½ feet of woven wire and three strands of barbed wire. Posts are at 12-foot centers.

f. Proposed deer fence. – Fence 7½ feet high and 6 feet of wire mesh and three strands of barbed wire supported by wooden or metal posts at 8-foot centers.

g., Highway safety fence, 6-foot. – Fence 6 feet high, chain link, along all freeways in urban areas.

h. Highway safety fence, 4-foot. – Fence 4 feet high, chain link, in sparsely populated urban areas; or a 4-foot-high barbed wire fence or wire mesh fence where highways are a hazard to domestic animals.

The benefits of fencing are primarily the reduction of hazards to people and animals. In addition to the costs, fencing has another disadvantage – its detraction from the local landscape. To retain its effectiveness, fencing requires particular attention to maintenance. It has been estimated that the average annual maintenance cost for a stock fence is about $50 per mile of fence. Maintenance costs for the various types of fencing will vary considerably with the type of fence and its location.

5. Other Solutions

Among the other possible methods of reducing the hazards which canals present to people and animals are stepped concrete-lined canals, corrugated concrete linings for canals, flattened canal side slopes, attachment of cleats to concrete canal linings, animal repellents, and animal frightening devices. Figure 8 illustrates three of these possible methods. Because of the construction costs for and problems involved in construction of the stepped or corrugated linings as compared to those for fencing conventional concrete-lined canals, no further consideration has been given to these two proposals.

Cleats attached to canal linings would need to be installed the total length of the canal to prevent frightening animals or in connection with the deflectors discussed in earlier sections. Two or more cleats would be required on each side of the canal depending upon the canal depth. The following tabulation gives estimated costs for various types of cleats.

Comparison of construction costs for continuous canal cleats with costs of deerproof fencing indicates fencing to have less first costs. Because of maintenance problems associated with deflectors and the wide variety of designs that have been suggested, no estimates were prepared for deflection structures.

No determination has been made of the maximum angle of concrete linings which people or animals could safely negotiate. Continuously flattened canal side slopes would result in unacceptable hydraulic efficiency and would result in a larger, more expensive canal. When compared with the effectiveness of fencing, this solution is considered infeasible for any but the smallest of canals.

Costs for animal chemical repellent developed by the Bureau of Sport Fisheries and Wildlife in the amount required for effectiveness are such as to make this method infeasible.

The Bureau of Sport Fisheries and Wildlife reports that no deer-frightening devices have proven effective over periods of prolonged use. Therefore, no further consideration has been given to such devices.

While the Bureau must continue to maintain surveillance and provide facilities for the protection of animals and people, as discussed in this report, consideration must also be given to the public interest in use of selected canal areas for recreational purposes. The high values involved in some areas, particularly where other water-based recreation areas are scarce or where canal areas contain unusual opportunities for certain activities, have already resulted in establishment of public use areas on Reclamation canals. It is anticipated that public interest in similar uses in other canal areas, particularly those near towns and cities, will accelerate in the future. Where encountered they should be considered on their individual merits. Care

ESTIMATED INSTALLED COST OF VARIOUS CLEATS

Cleat description	Method of anchoring to canal lining	Estimated installed cost per linear foot of cleat
Unreinforced concrete block (2 by 4 inches by 2 foot 0 inch)	Epoxy	$1.25
Precast reinforced-concrete beam	Expansion anchor	3.00
Redwood timber (2 by 4 inches)	Expansion anchor	2.25
Galvanized steel angle irons	Expansion anchor	3.00
Aluminum angle iron	Expansion anchor	3.00

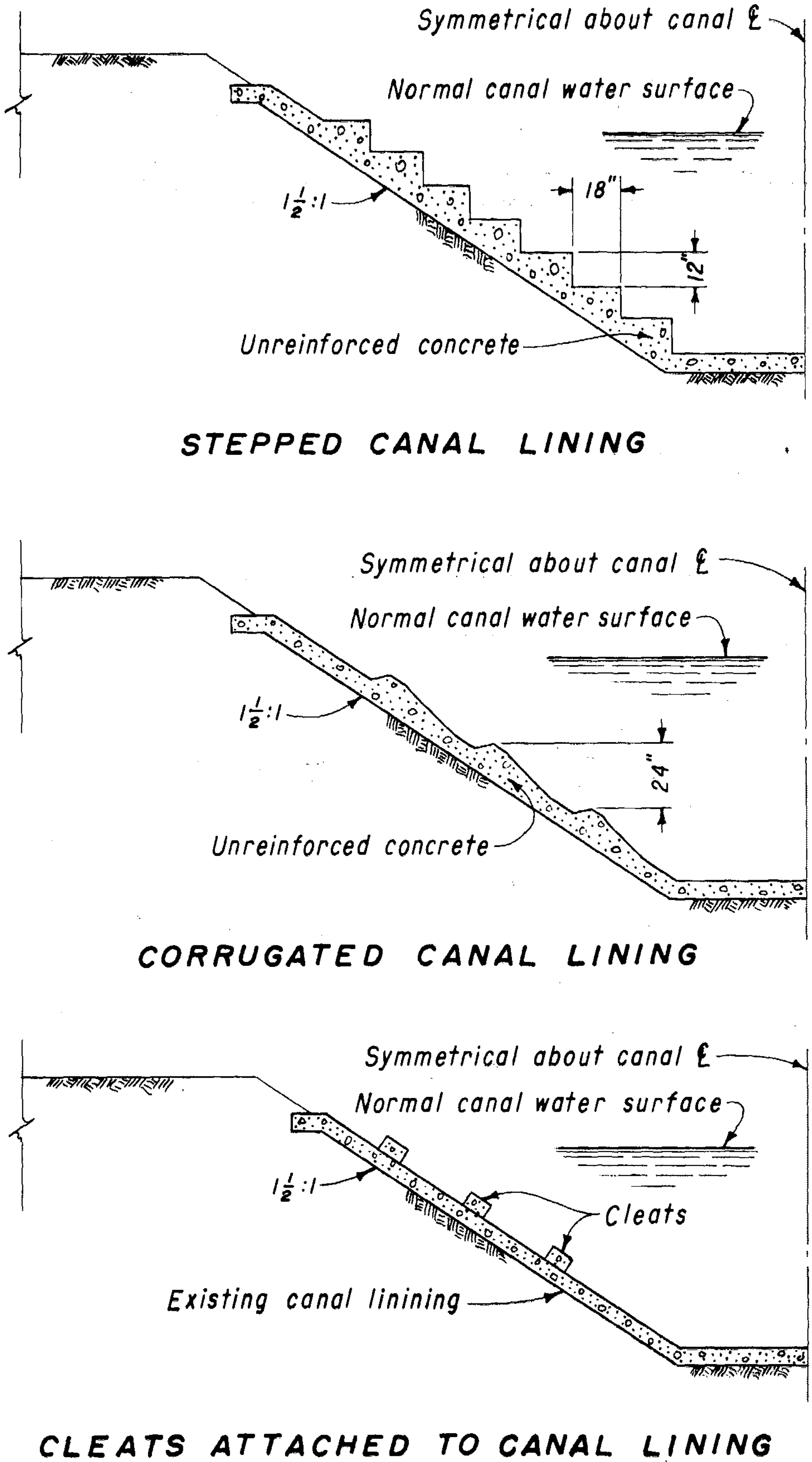


Figure 8. Other proposed canal escape solutions.

must be taken to avoid interference with primary project functions. Any resulting alterations in canal alinement or other characteristics would be limited to relatively small locations and would not call for any general redesigning of canal sections. Prerequisites to recreational development and use of such canal areas are arrangements with a responsible local or state agency or organization to provide recreational, sanitation, and related facilities, and to supervise public recreational use. Through such arrangements the substantial recreational values of Reclamation projects can continue to be extended.

CONCLUSIONS

1. The Bureau of Reclamation is aware of the safety hazards associated with open waterways and incorporates protective features in the design of new facilities and modifies existing irrigation features for the protection of the public. Similar preventive measures have been undertaken for animals but on a smaller scale. Aggressive water safety programs to educate and protect the public have assisted in reducing the number of drownings in some areas.

2. The rapid growth of a highly mobile population, particularly in areas adjacent to Reclamation canals, is increasing the exposure of the public, thereby increasing the number of drownings and the need for implementing additional protective measures.

3. Exposure to both people and animals is virtually eliminated by using pipe in place of open canals; however, the initial cost of pipe is expensive and may be prohibitive. In those cases, fencing of the canals appears to be the most feasible alternative. Right-of-way fencing is comparatively inexpensive and has proven to be an effective deterrent to drownings in Reclamation canals if maintained properly. Financing modifications may require assistance from adjacent land developers, irrigation districts, or other sources.

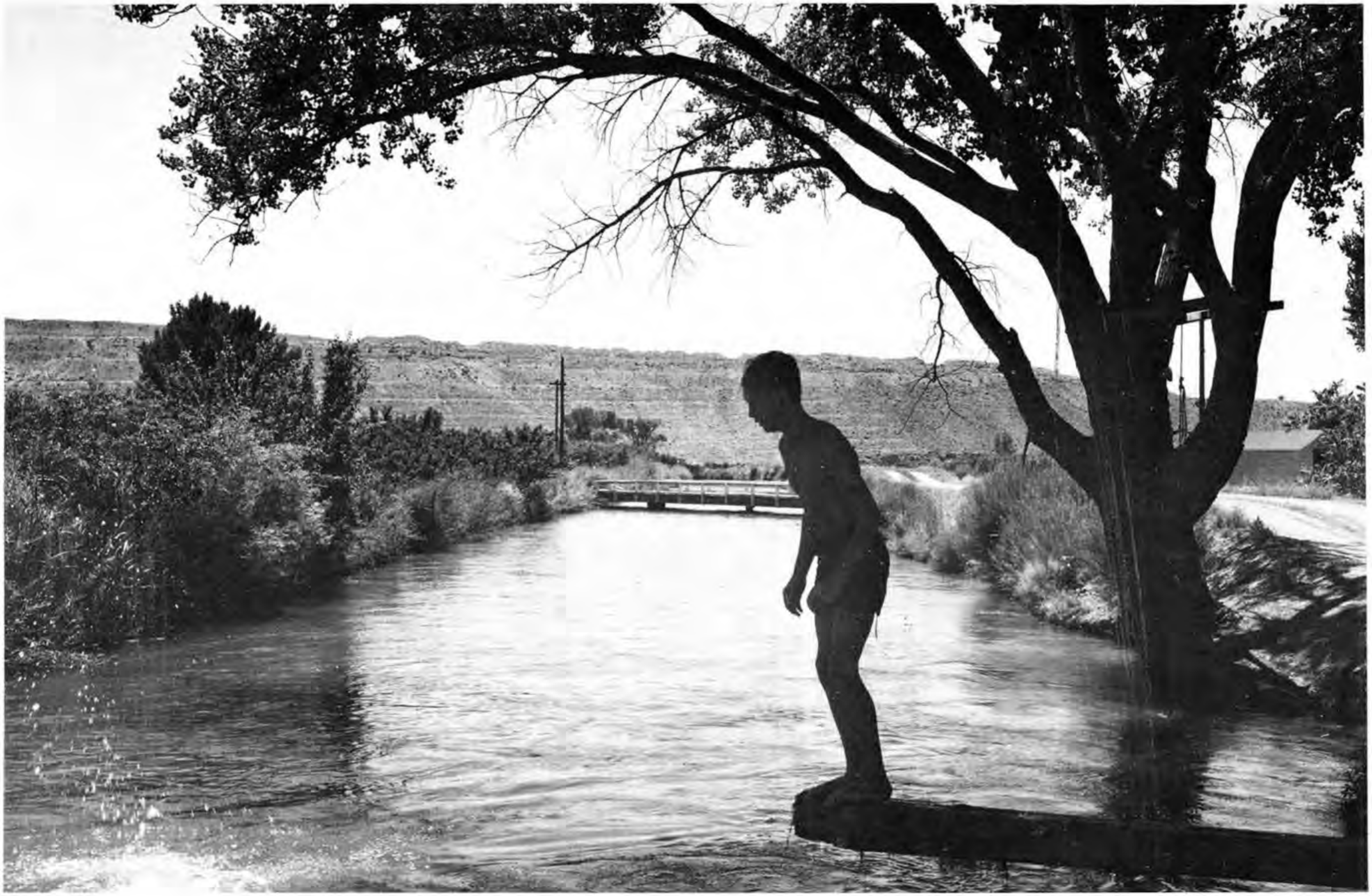
4. Drownings now occur most often along unfenced rural canals and laterals.

5. A high percentage of human drownings in canals and laterals involve children.

6. Protective devices including guardrails on structures, escape ladders, float lines, and siphon guards are effective in reducing human drownings.

7. Large concrete-lined canals present the greatest hazard to animals. Effective animal escape devices include various types of deflectors, cleats, rough gravel-asphalt mats, and stepped siphon inlets. Constructing stepped, corrugated, or flatter canal sides appears impractical and in most cases financially prohibitive.

8. Recreational use of Bureau waterways has always occurred, even in areas where such use has not been officially recognized or permitted, particularly where recreational values for such activities as fishing and swimming were unusually attractive. Such use will undoubtedly continue. Maximizing the attendant recreational values at specific and limited locations through appropriate development and adequate supervision appears more consistent with the public interest than attempting the impossible task of prohibiting all recreational use of Bureau canals and other waterways.



Photograph 8. This photograph gives witness to the popularity of canals for recreational use. Photo P8-400-694

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CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	*0.965873×10^{-6}	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

GPO 837-900

ABSTRACT

The Bureau of Reclamation and others engaged in water resource management are concerned with increasing the safety of people and animals exposed to open waterways. An indepth study of the nature and extent of the hazard presented by canals together with an evaluation of preventive measures is given. A survey of human drownings in Bureau canals and a review of protective devices and safety practices currently in effect are presented. A detailed review of the problem of animal drownings is presented. The relative effectiveness and comparative cost of right-of-way fencing, conveying water in buried conduits, and covering canals are presented. These and other proposed solutions, such as installing stepped or corrugated canal linings, are examined and illustrated. The study presents much information related to the problem of public safety and preservation of animal life which will be of assistance to waterway planners, designers, and operators.

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Bureau of Reclamation, Denver, 31, p, 7 fig, 7 tab, 8 photo, 12 ref, append

DESCRIPTORS–/ *animals/ benefits/ canals/ canal linings/ *safety/ water users/ closed conduits/ accidents/ economics/ *hazards/ *personnel/ thin shell structures/ construction costs/ indirect benefits/ fences/ project planning/ irrigation operation & maintenance/ irrigation systems/ public relations/ prestressed concrete/ reimbursable costs/ *drowning
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