CHAPTER 6

PROJECT CONSTRUCTION

Section I. General

6-1. Flow Diversion Schemes. Lock and dam construction normally requires a dry construction site. As these structures are usually located across or near streams, cofferdams are required for site dewatering and a reasonable degree of flood protection. The construction cofferdam usually creates a restriction in the river cross section. Usually several alternate diversion schemes are investigated before the most feasible and economical solution is found. Several factors need to be considered in developing a diversion scheme.

a. Flooding. When designing a cofferdam scheme, an important design consideration is to limit upstream flooding to acceptable levels. Al though the flooding is only for the duration of construction, increased flooding may cause damage to agricultural, commercial, or other interests. An "acceptable" level depends on the general features and type of developments upstream from the construction site, cost of diversion structures, and cost of flooding the construction site.

b. Erosion. Another consideration is scour in erodible bed streams. Scour must not endanger the stability and/or constructibility of temporary structures (cofferdams) or create conditions that would differ substantially from design assumptions at the permanent structure. Deflector cells are sometimes constructed adjoining the upper arm of the cofferdam to direct flow away and thereby protect the main cofferdam. Scouring increases the cross-sectional area of the restriction and thus decreases the amount of induced upstream flooding. This may be taken into consideration during the cofferdam design. The stability of the riverbank at the restricted section must be analyzed. Temporary protection may have to be provided against induced erosive velocities.

6-2. Maintenance of-Navigation. Diversion schemes should take into account that during construction,navigation may have to be maintained on the river. The restriction caused by the construction cofferdam must not create conditions hazardous to navigation by introducing currents that tows cannot negotiate. Temporary locks may be needed. A value of 4 mph (6 ft/sec) has been used to approximate velocities that tows can generally negotiate, although this depends to a great extent on the power of the towboat. Helper boats may be considered in some situations to assist underpowered tows. In addition to currents, towboats must be able to enter and leave the restricted section safely without damage to the structure. It is preferable to maintain an open navigation section as long as possible to minimize traffic delays. However, at some construction sites this may not prove to be feasible, since the inclusion even of a relatively small portion of the dam in the first stage of the work may result in unacceptable navigation conditions. In this case, the construction sequence must usually begin with the lock so that it will be available for the passage of river traffic as soon as possible. In either case, special measures (reduced speed, helper boats, etc.) may have to be taken to ensure navigation safety. Alternatives of a navigation bypass channel, temporary lock, or portage system may be considered. In some cases navigation improvements can be constructed without interference to existing river traffic, by using a cut across a bendway. In this case, no special provisions for flow diversion are necessary. General hydraulic models with model towboats or navigation simulators are usually recommended for major navigation structures to evaluate various diversion schemes.

6-3. Construction Phases. Since an opening must be provided to divert riverflows and in some cases to maintain existing navigation, projects must be constructed in two, three, or more stages. In general, economy dictates as few construction stages as possible, because of the cost and time delay associated with removal and replacing of earth embankments or sheet piling for cofferdam cells. However, the number of stages must be consistent with velocity limitations to prevent excessive scour and to maintain navigation. Also, savings in initial costs sometimes offset the disadvantage of time delay provided the project can be constructed within the generally adopted schedule. As an example, in an analysis performed by the Little Rock District for the proposed Dardanelle Lock and Dam project on the Arkansas River, it was determined that a four-stage diversion plan was the most economical (Figure 6-1). This plan required the construction of 62-foot-diameter cofferdam cells to a maximum height of 59 feet, requiring 7,400 tons of piling with a total estimated cost of $6 million. Another alternative was a three-stage plan with a stabilizing beam inside the cofferdam that required the construction of 52.5-foot-diameter cells to a maximum height of 66 feet above bedrock. This alternative required 10,200 tons of piling with a cost of $6.8 million. Thus the four-stage plan required less sheet piling because of a smaller increase in upstream stages and it was therefore recommended for construction. It also had the advantage of the reduced headwater flooding. Navigation structures can be constructed in a single phase cofferdam scheme, resulting in significant time and cost savings. Dam 2 Spillway on the Arkansas River is an example. The existing river was not disturbed; the spillway was located on the alignment of a proposed river channel cutoff; the spillway was constructed; and finally the river was diverted to flow through the completed structure. Once diverted, an additional phase was required to construct the closure structure across the old river channel. The time for raising of the pool and the rate of rise must be carefully chosen. From a project operation standpoint, it is preferable to raise the pool as soon as conditions permit; however, environmental, commercial, recreational, and social considerations must be taken into account also. In addition, adequate flow must be maintained during the pool rise to prevent degradation of river water quality. Generally, on rivers with existing open-river navigation, locks must be constructed while maintaining navigation at the same time. To supplement flow capacity lost during later construction phases, the completed lock can be used as a floodway to reduce the effect of induced flooding, but only after careful analysis of hydraulic and structural consequences of such action.

Section II. Cofferdams

6-4. General Schemes. Cofferdams are temporary structures in the river providing an enclosure to permit the construction of the entire or a part of the navigation dam. In the following, a few typical cofferdam layout schemes are presented as illustrations of possible solutions. However, this does not

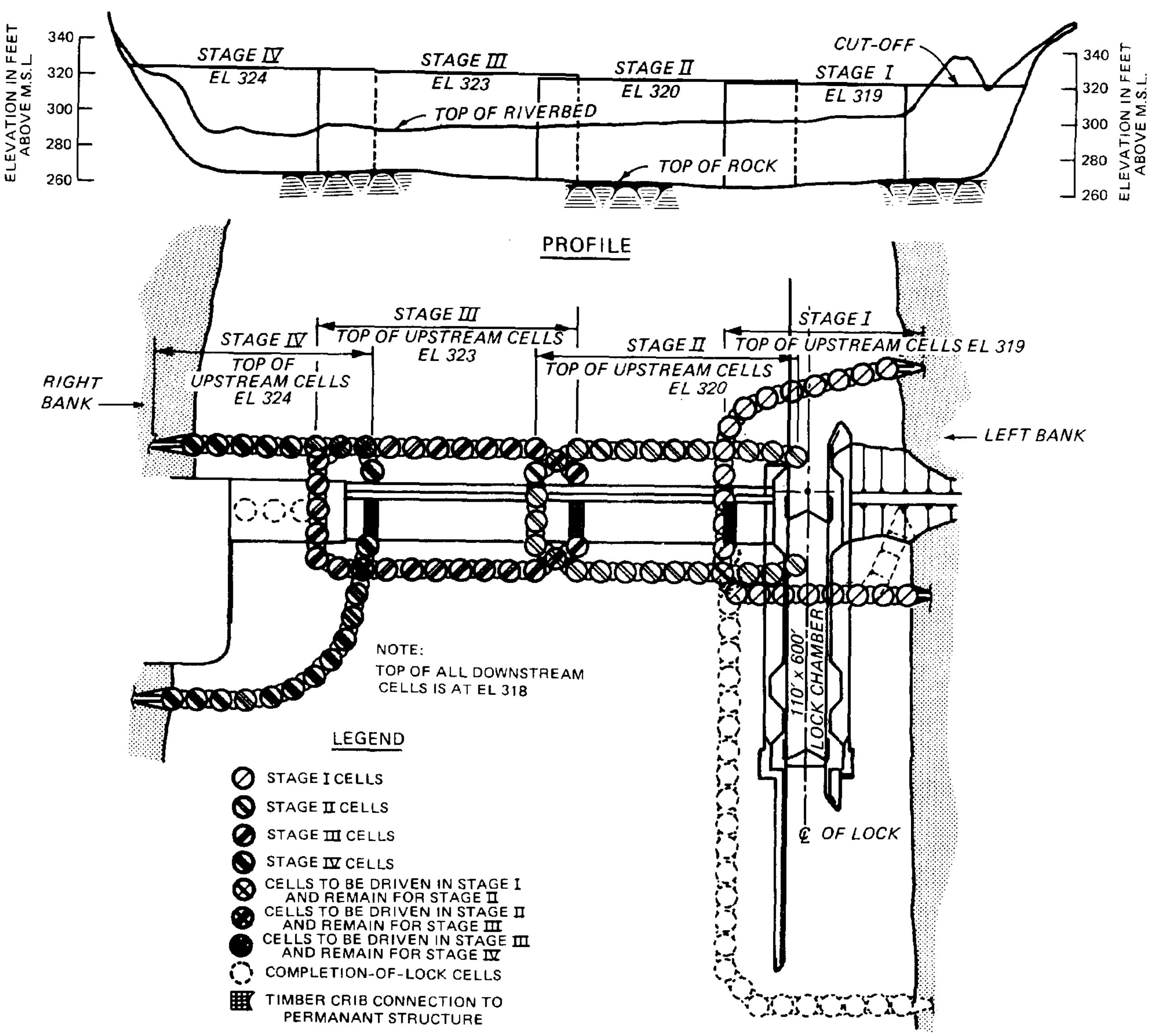

Figure 6-1. Four-stage diversion plan

imply that these are the only possible alternatives; the design should be tailored for specific local conditions. Of interest to the hydraulic engineer is the method of establishing the top elevation of the cofferdam based on the discharge and/or stage frequency-durationships of the river. This subject frequency relationships will be more fully discussed later in this chapter. A typical cofferdam layout for the construction of Greenup Lock and Dam on the Ohio River is shown in Figure 6-2. In this case, two- and three-stage cofferdam layouts were studied, and the three-stage layout was selected to avoid high currents adversely affecting navigation. Another possibility is shown in Figure 6-3 which indicates the construction plan for the replacement of Lock and Dam 26 on the Mississippi River. As shown, 6-l/2 gatebays were constructed during the first stage. River traffic used the opening between the first stage and the Illinois bank during this phase. The second stage involves the construction of the lock, and the remaining one-half gatebay, during which phase the river traffic uses the opening between the second stage cofferdam and the Illinois bank. Riverflows pass through the navigation opening between the second stage cofferdam and the Illinois bank and that portion of the spillway completed during the first stage. In the third stage, the remaining gatebays are constructed and the lock is available for river traffic. Another example of a typical cofferdam scheme is shown in Figure 6-4, which is the recommended layout for the Newburgh Lock and Dam project on the Ohio River. In this case, two alternatives were studied: a three-stage plan involving partial construction of the dam, and a two-stage plan which involves the construction of all 10 gatebays in a single cofferdam. It was found that the recommended two-stage construction was more economical, in terms of initial construction cost and resulted in a shorter construction period for the project. River traffic used the opening between the first stage cofferdam and the left riverbank during the first stage construction, and was directed to the locks upon completion of the first stage. In the second stage, the fixed-weir section of the project was constructed providing nine gatebays for flow passage.

6-5. Cofferdam Heights. Cofferdam layout and establishment of the cofferdam height are primarily oriented toward an economical plan to minimize hazards to construction activity, minimize costs of flooding on adjacent properties, and minimize costs of cofferdam construction. An economic analysis must be done for a range of cofferdam heights to find an optimum elevation. Factors which influence the decision include cofferdam cost for various heights, damage costs due to overtopping of the cofferdam by floods, costs due to delay in construction when the cofferdam is overtopped, risk of flooding during the anticipated construction period, cofferdam maintenance costs, construction and diversion plan that is selected, and anticipated length of time required to complete construction. The determination of the probability of occurrence for the various frequency floods may be based on the following formula:

$$P = \frac{N!p^{i}(1 - p)^{N-i}}{i!(N - i)!}$$

Where P is the probability of obtaining, in N trials, exactly i events having a probability of p of occurring in a single trial. For the special case where $i = 0$, the formula becomes:

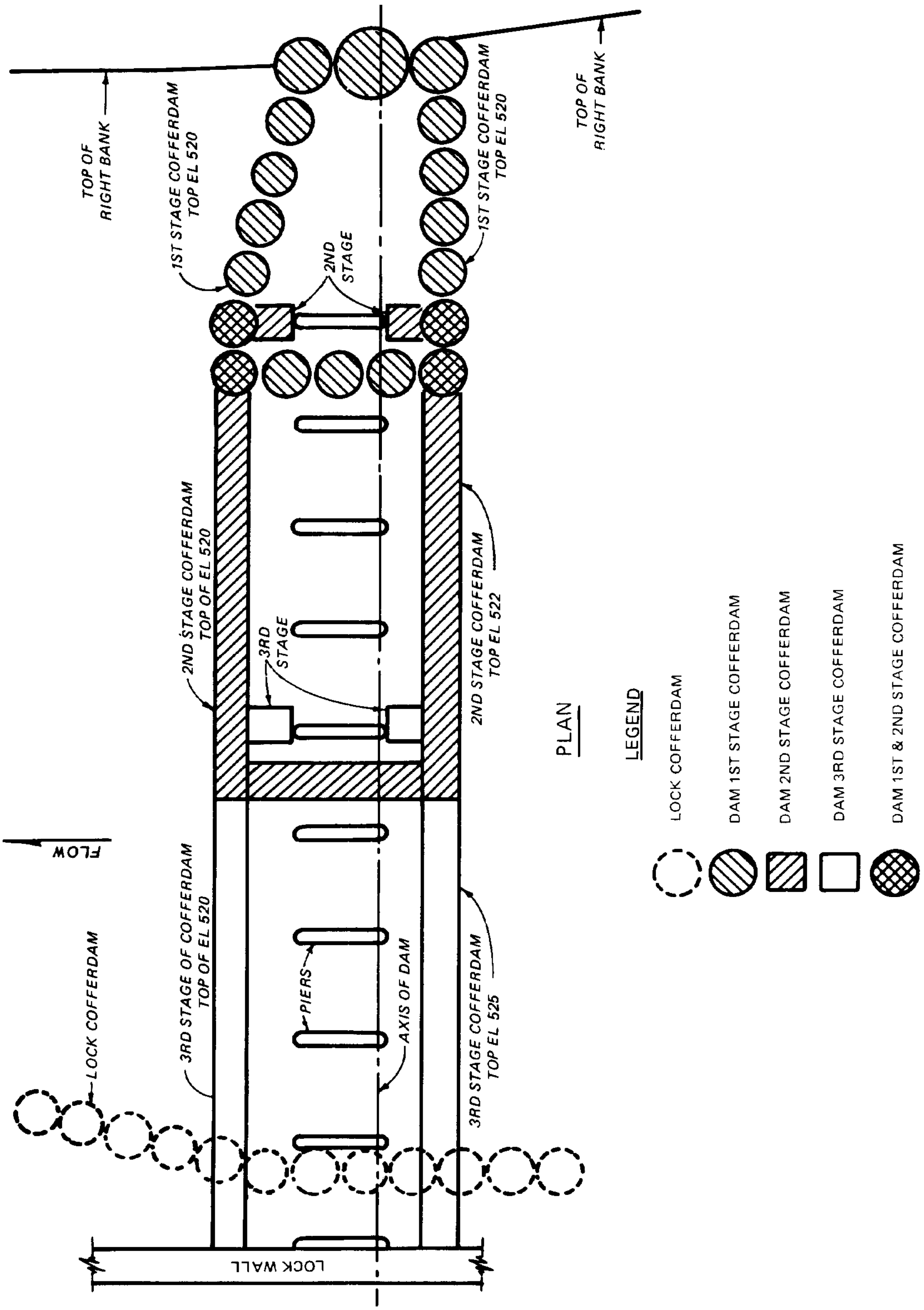

Figure 6-2. Cofferdam scheme, Greenup Lock and Dam, Ohio River

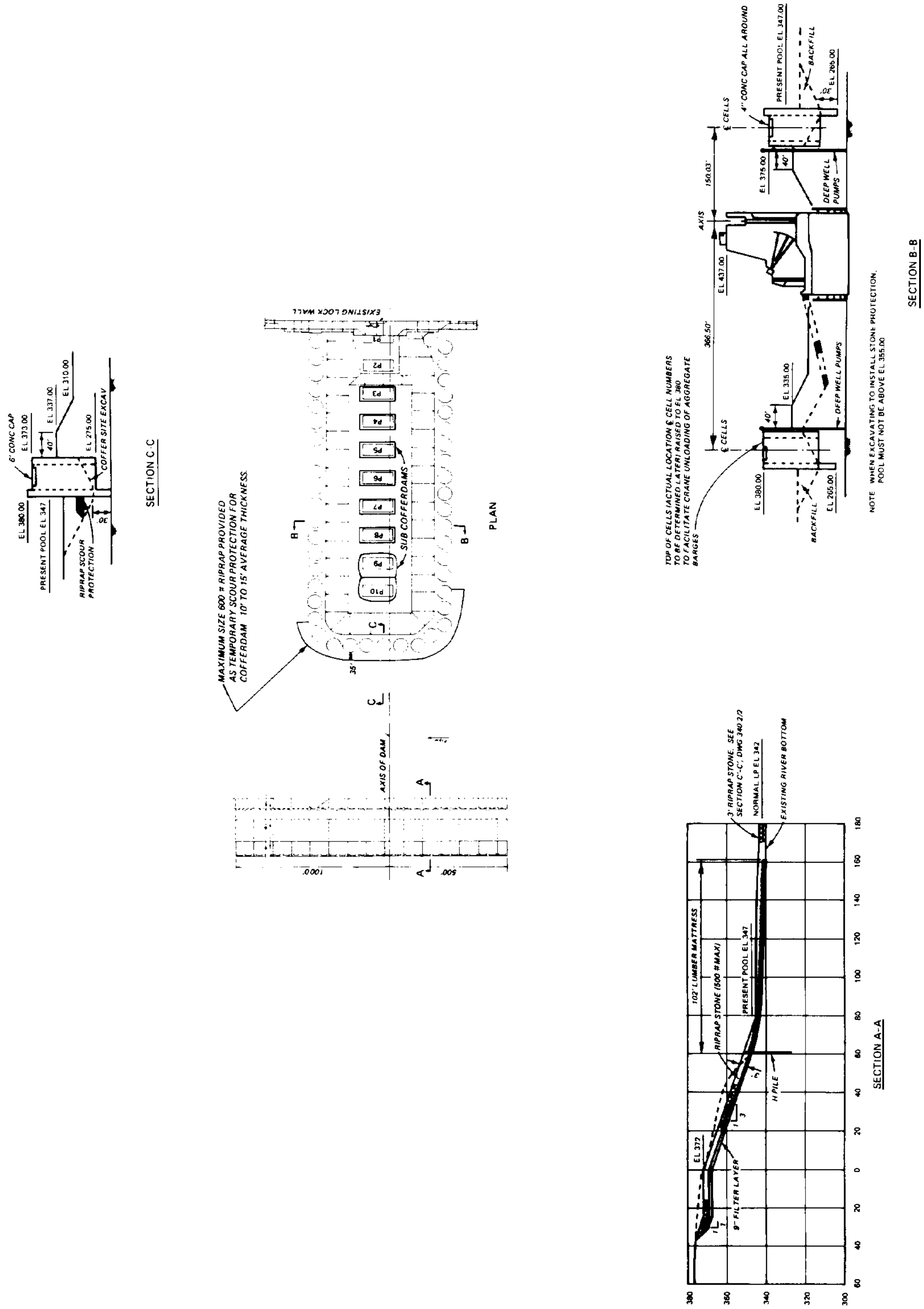

Figure 6-3. Cofferdam scheme, Newburgh Locks and Dam, Ohio River

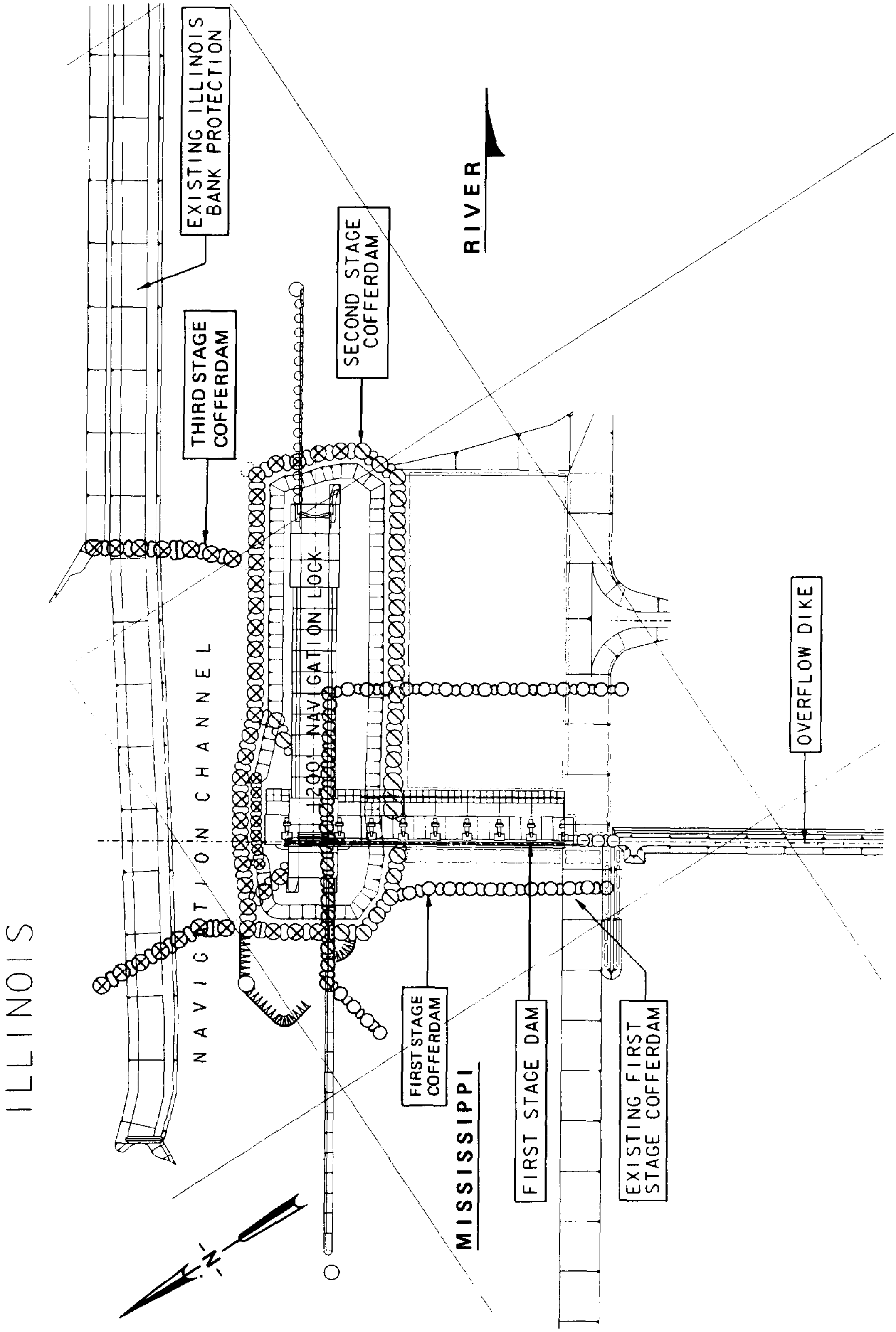

Figure 6-4. Cofferdam scheme, Lock and Dam 26, Mississippi River

$$P = (1 - p)^N$$

the probability of a flood event of magnitude p occurring zero times in N trials. Therefore the probability of event p occurring one or more times in N trials is:

$$P = 1 - (1 - p)^N$$

For example, in a project with a three-year construction period, N = 3 . To analyze the flooding for a lo-year flood, p = 0.1 . Therefore

$$P = 1 - (1 - 0.1)^3 = 0.271$$

or, a 27.1 percent chance that a lo-year flood will occur one or more times in a given three-year period. The total probable flooding cost for each height of cofferdam can be computed by the formula:

$$C_t = P[(D)(C_1) + C_2]$$

where

C_t = probable total flooding cost

P = probability of flooding

D = number of days construction area is flooded before cleanup operation can begin

C_1 = investment losses per day while area is inaccessible

C_2 = fixed cost of cleanup

6-6. Cofferdam Preflooding Facilities. When developing floods are so severe that cofferdam overtopping is predicted, scour damage and subsequent cleanup within the cofferdam can be minimized by preflooding the site. This can be accomplished by providing gated culverts or weir facilities with adequate capacity to raise the interior water level to near the river level prior to the time the river overtops the cofferdam.

6-7. Example Determination of Cofferdam Heights. The following example is similar to a design of the cofferdam height at the Columbus Lock and Dam on the Tennessee-Tombigbee Waterway. The estimated flooding costs, the flood damage costs, the comparative cofferdam construction costs, the method of duration analysis, and the high discharge duration curve are shown in Figures 6-5 to 6-9, respectively. In Figure 6-10, the estimated probable

FIXED COST PER FLOODING

Downtime	------------------- 10 days @ $10,500/day	= $105,000
Pumping and Cleanup	------------------- 10 days @ $ 7,000/day	= $ 70,000
Damage Cost	------------------- Lump sum	= $ 50,000
Investment Cost	------------------- 10 days @ $ 3,000/day	= $ 30,000
Liquidated Damages	------------------- 10 days @ $ 500/day	= $ 5,000
		$260,000

TOTAL COST PER FLOODING

$260,000 + [(D) x ($10,500 + $3,000 + $500)]

$260,000 + (D x $14,000)

where D = Duration of flood in days before pumping and cleanup can start

NOTES: Experience and professional judgment were used in estimating the cost for each of the items used in determining a realistic total cost for flooding of the cofferdam. The equipment downtime cost was based on the assumption that the cofferdam flooding would occur during peak concrete placement at which time the maximum amount of equipment would be on the job site. Pumping and cleanup cost was based on an average time of 10 days to pump out and clean up the protected area. This cost includes extra equipment for the pumping and cleanup crews. Damage cost was estimated considering equipment loss, duplication of work effort caused by berm and slope sloughing, wood form loss, and damage to prepared foundations. Investment cost is the estimated daily interest cost to the Federal Government during construction. Since the construction is on the critical path, downtime during the work phase will extend the total project completion time. This cost was derived by dividing the present estimated value for interest during construction by the construction period to get a one-day cost. The liquidated damages cost is the extra cost incurred by the Corps of Engineers for each day past the schedule completion date.

Figure 6-5. Estimated flooding costs

	FLOOD FREQUENCY, YEARS								
	2	4	5	6	8	10	25	50	100
Probability (3-yr Const)	0.704	0.578	0.488	0.421	0.330	0.271	0.115	0.059	0.030
Q (cfs)	74,000	83,000	90,500	98,000	110,000	118,000	160,000	200,000	240,000
Stage (Elev)	166.4	167.4	168.1	168.6	169.3	169.6	171.5	173.0	174.4
Cofferdam (Elev)	169.4	170.4	171.1	171.6	172.3	172.6	174.5	176.0	177.4
Duration B %	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Duration D %	0.29	0.20	0.14	0.11	0.07	0.05	—	—	—
Duration C (B − D) + 2 %	1.36	1.40	1.43	1.43	1.47	1.48	1.50	1.50	1.50
Duration A B − C %	1.64	1.60	1.57	1.55	1.53	1.52	1.50	1.50	1.50
Duration Days A × Const P	17.96	17.52	17.19	16.97	16.75	16.64	16.43	16.43	16.43
Duration Costs	251,440	245,280	240,660	237,580	234,500	232,960	230,020	230,020	230,020
Duration Cost × Prob	177,013	141,772	117,442	100,021	77,385	63,132	26,452	13,571	6,901
Fixed Costs × Prob	183,040	150,280	126,880	109,460	85,800	70,460	29,900	15,340	7,800
Flooding Costs	360,053	292,052	244,322	209,481	163,185	133,592	56,352	28,911	14,701

NOTE: Natural ground level is 155 where dike will be breached for flooding of the construction area.
Q = 29,400 cfs Duration = 3.00%
Downtime, investment loss, and liquidated damage cost per day = $14,000 (Duration Cost).
Fixed cost of flooding = $260,000.

Figure 6-6. Flood damage costs

TOP OF COFFERDAM ELEVATION, FEET		COMPACTED FILL	STRIPPING	TOTAL COST OF VARIABLES
UPSTREAM	DOWNSTREAM	$	$	$
169.5	168.5	406,100	15,400	421,500
171.5	170.5	510,500	17,200	527,700
173.5	172.5	626,500	19,000	645,500
175.5	174.5	754,400	20,900	775,300
177.5	176.5	893,800	22,700	916,500
179.5	178.5	1,047,200	24,500	1,071,700

Figure 6-7. Comparative cofferdam construction costs

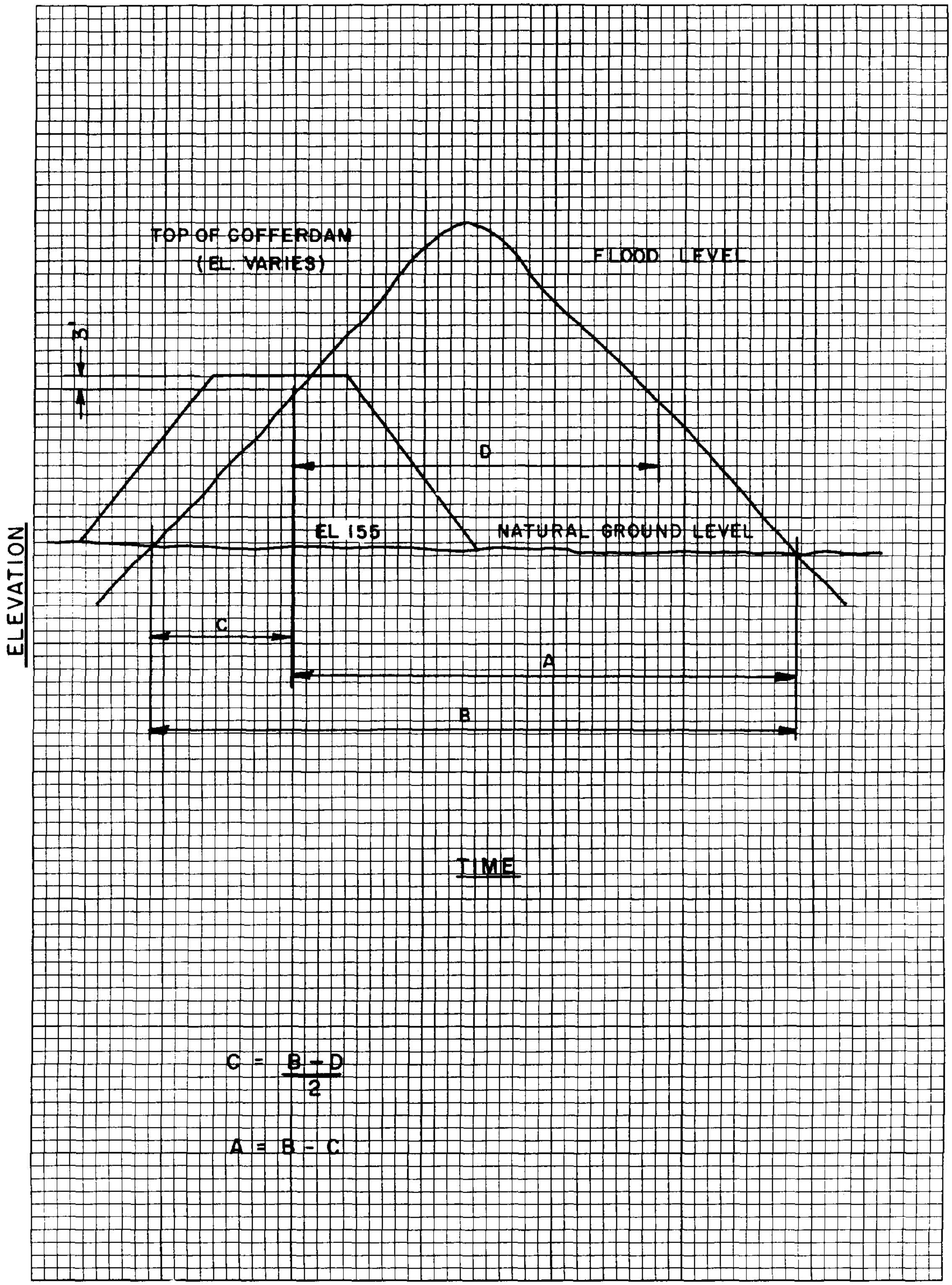

Figure 6-8. Method of duration analysis

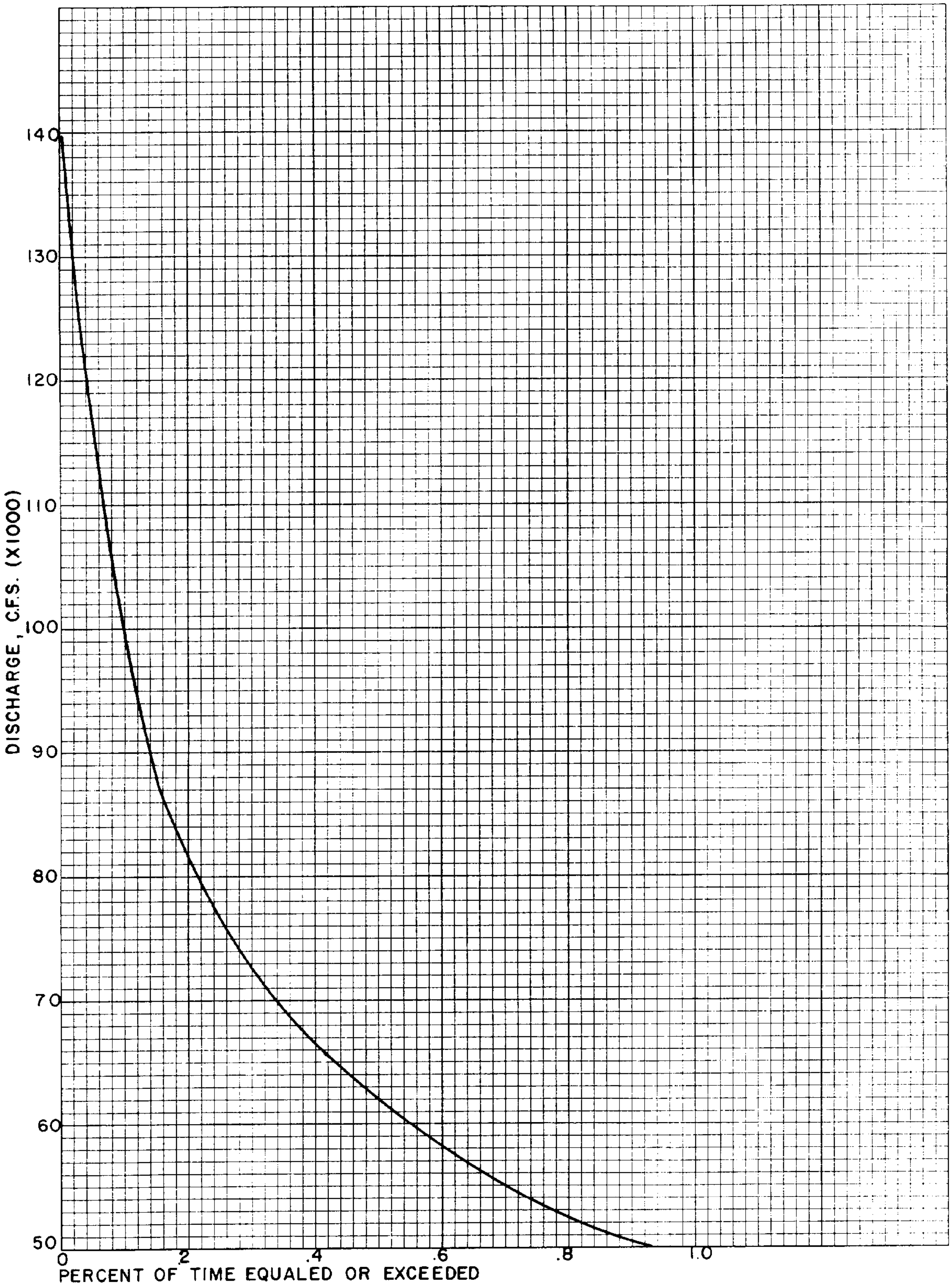

Figure 6-9. High discharge duration curve

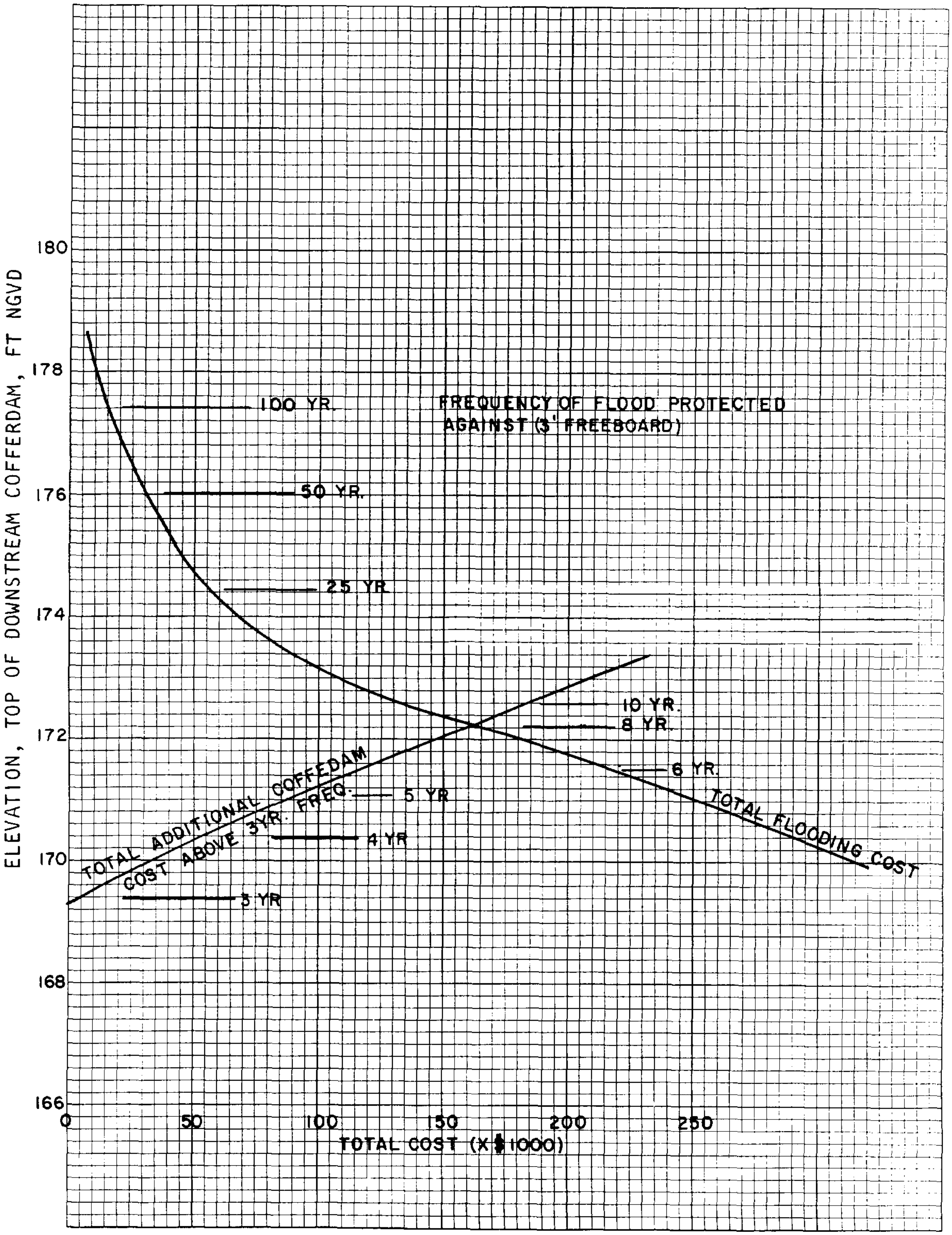

Figure 6-10. Cofferdam and flooding cost curves

flooding cost is compared with the total additional cofferdam cost required to provide protection above the three-year frequency flood level. Visual inspection of the curves indicates that the most economical cofferdam elevation will be near the 10-year flood level. It should be noted that the intersection of the two curves in Figure 6-10 has no significance because the beginning ordinate of the cofferdam cost curve is arbitrary. In Figure 6-11, the probable flooding cost reduction and the additional cofferdam costs were established by determining the slope of the total cost curves at incremental cofferdam heights. The curves show the rate of change in probable flooding cost reduction and the additional cofferdam cost for various cofferdam top elevations. The upper intersection between the two cost curves in Figure 6-11 represents the point of diminishing returns. In this example, the point is at elevation 172.9 which was arbitrarily rounded to 173.0. The design flood frequency was therefore set at 12 years.

6-8. Scour Protection. Each construction scheme must be carefully analyzed to ensure that scour protection is provided where necessary. Successful protection has consisted of timber mattresses or riprap both with and without filter blankets, depending upon the soil types and flow conditions. Physical and numerical models have been useful to assist in development of scour protection designs. The upstream riverward corner of the cofferdam is usually the critical point of scour potential. Wing extensions are sometimes added to the cofferdam to reduce velocity concentrations at this point.

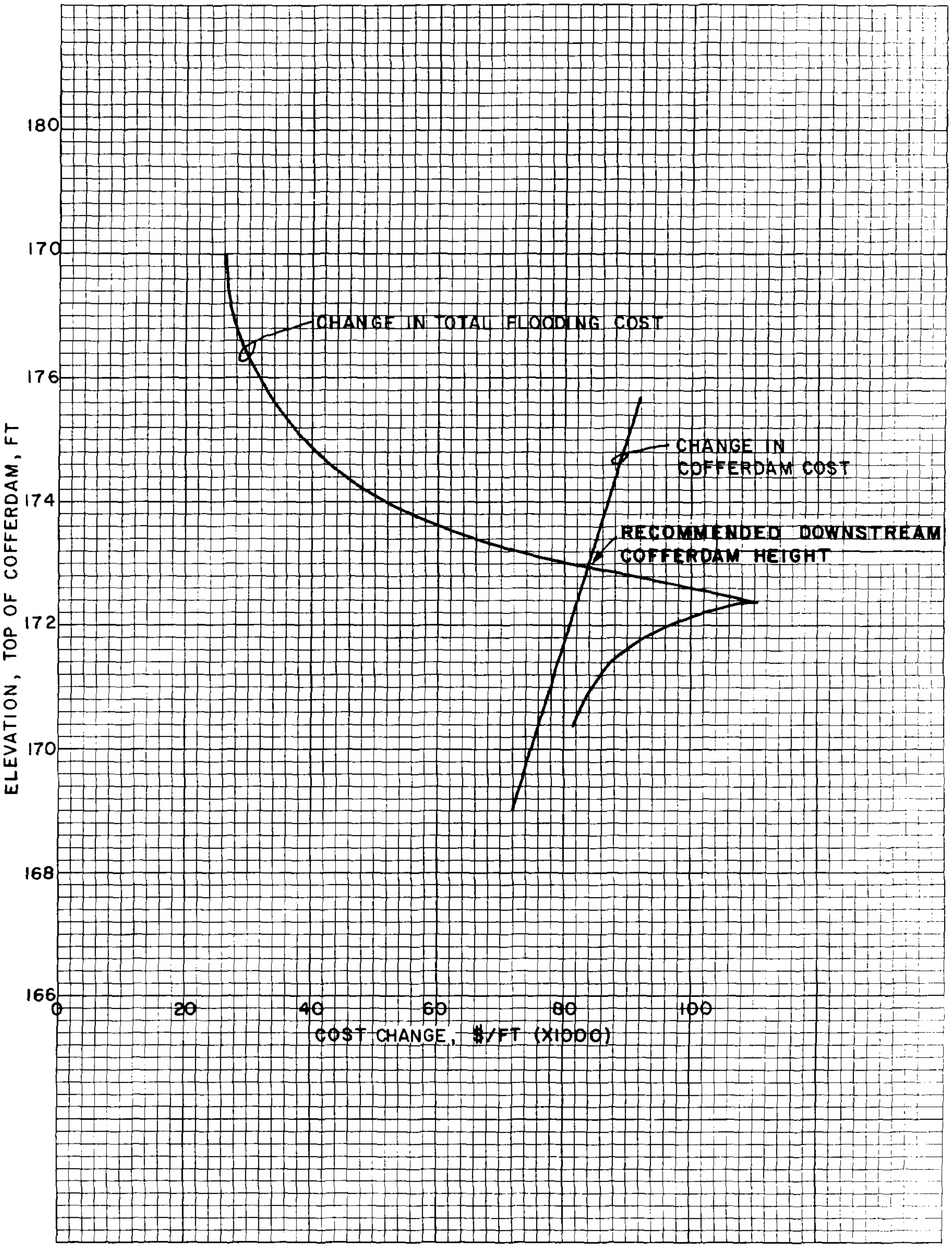

Figure 6-11. Cofferdam and flooding cost change curves