CHAPTER 7

PROJECT OPERATION

Section I. Normal Spillway Operations

7-1. Maintenance of Navigation Pool Levels. The purpose of maintaining a navigation pool on a river navigation project is to assure that the authorized navigable depth is available all the time at every point in the river controlled by the project. In general, the point farthest upstream from the project, which would be the next navigation dam upstream in a system, or the "head of navigation" for a single dam, will be critical in this respect. The minimum pool elevation at which the above purpose is met is usually defined as the "normal pool."

a. Uncontrolled Spillways. These structures consist basically of a fixed-crest weir; a typical example is shown in Figure 7-1. The normal pool is defined as the upstream extension of the weir crest elevation for zero flow condition. The advantage of uncontrolled spillways is their simplicity of both operation and maintenance since the structure contains no moving parts (except for the locks) or equipment that could be subject to malfunctioning. The toe of the weir is subject to high-velocity, turbulent flows and therefore requires relatively frequent inspection to preserve the integrity of the foundation. An operational disadvantage of navigation projects with uncontrolled spillways is the increased possibility of pleasure boat accidents. Since the drop in water surface at the weir is difficult to recognize from upstream, boats unfamiliar with the conditions may ram the weir instead of locking through. As riverflows increase, a pool elevation is reached where project navigation is suspended. In order to mitigate the effect of upstream flooding at uncontrolled spillways, locks are frequently used as floodways. Details of this special operation are described in EM 1110-2-1604.

b. Gated Spillways. The normal pool elevation, consistent with its definition in paragraph 7-1, is maintained by the operation of dam gates. It should be noted that in case of multipurpose projects operated not only for navigation, other pool levels such as "minimum power pool" or "flood-control pool" may exist. These project operations are more complex than dams with navigation as their sole purpose. In the latter case, gates are operated as necessary to control all flows and to maintain a constant upper pool elevation (normal pool). At low dams (see paragraph 7-3b), a normal pool is maintained until the tailwater reaches the normal pool elevation at which time the gates are raised to maximum height and no further control. of the pool level is possible. If the river level rises still farther, an elevation may be reached at which navigation is suspended and the project will be prepared for flooding. A gate operation schedule should be prepared during the design stage. An example of Pittsburgh District's gate operation schedule for the Maxwell Lock and Dam on the Monongahela River is shown in Figure 7-2. The schedule should be consistent with the design and should reflect any operational constraint imposed on the structure by the design. A frequent problem is scour below the spillway apron induced by misoperation of gates, especially at low tailwater levels. The operation schedule should minimize adverse impact on navigation at the upper and lower lock approaches. In general, this concept requires the

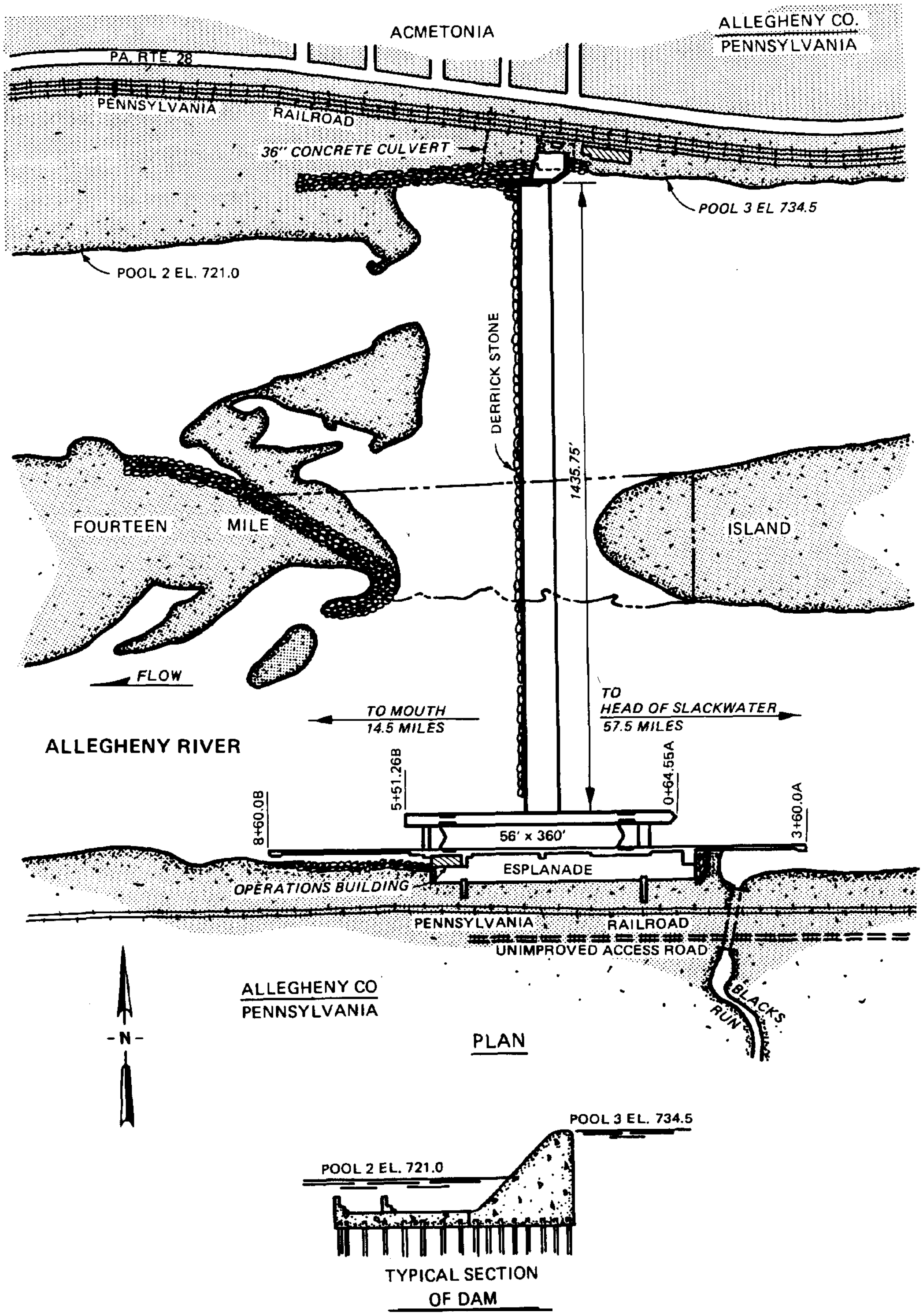
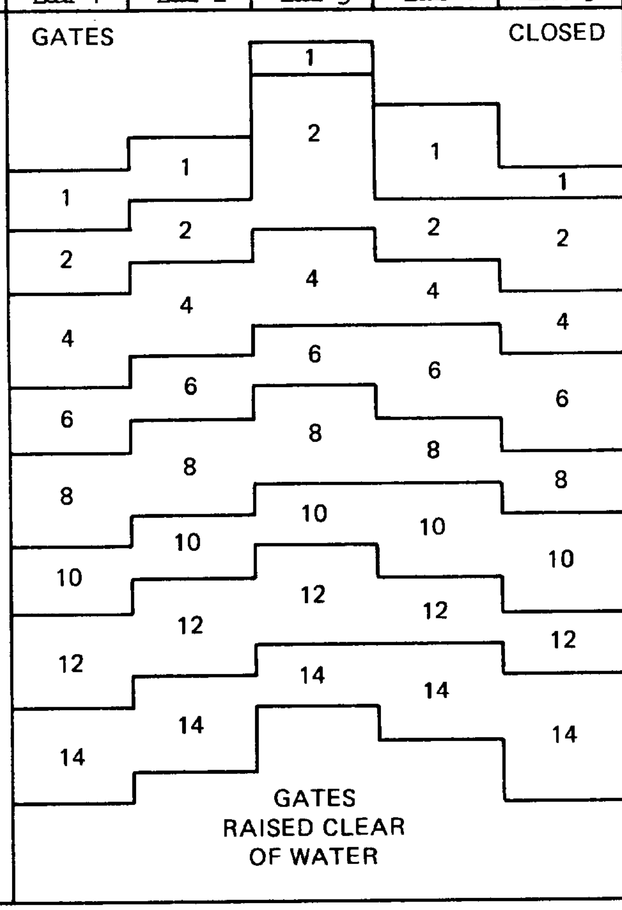


Figure 7-1. Uncontrolled spillway

NORMAL UPPER POOL EL. 763 (GAGE 9.0)
MINIMUM LOWER POOL EL. 743.5 (GAGE 9.0)

Discharge cfs	Lower Pool Elev ft msl	Lower Pool Gage ft	Total Feet Open	Upper Gage in Feet Dam No. 7
0	743.5	9.0		9.0
2,900	743.8	9.3	1	10.3
5,300	744.0	9.5	2	11.0
8,150	744.5	10.0	3	11.6
10,800	744.9	10.4	4	12.0
16,100	745.8	11.3	6	12.9
22,200	747.1	12.6	9	13.6
27,400	748.3	13.8	12	14.2
33,700	749.6	15.1	16	14.9
39,300	750.8	16.3	20	15.4
45,500	752.1	17.6	24	16.0
50,900	753.3	18.8	28	16.4
55,400	754.4	19.8	32	16.8
59,400	755.1	20.6	36	17.1
63,000	755.8	21.3	40	17.4
66,800	756.4	21.9	44	17.8
69,500	757.1	22.6	48	18.1
72,000	757.6	23.1	52	18.3
74,100	758.0	23.5	56	18.6
76,000	758.4	23.9	60	18.8
78,100	759.0	24.5	64	19.0
80,100	759.4	24.9t	68	19.2
83,800	760.2	25.7	78*	19.6
87,400	761.0	26.5	86*	20.1
89,700	761.5	27.0	94*	20.4
92,400	762.0	27.5	110*	20.7

Gate Numbers and Types: Double Leaf 1 | Single Leaf 2 | Single Leaf 3 | Double Leaf 4 | Double Leaf 5



No. 1 gate is next to lock. Gate openings are shown below the gate numbers; these openings are in feet from crest of dam to the bottom of gates. Any operation step may be made in parts for closer control. Two feet is the maximum desirable difference in opening of adjacent gates.

* Effective opening raised clear of water assumed to be 22 feet. Gage readings at Dam 7 (upper) correspond to discharges shown at Maxwell.

t Desirable minimum tailwater for 1 gate fully open.

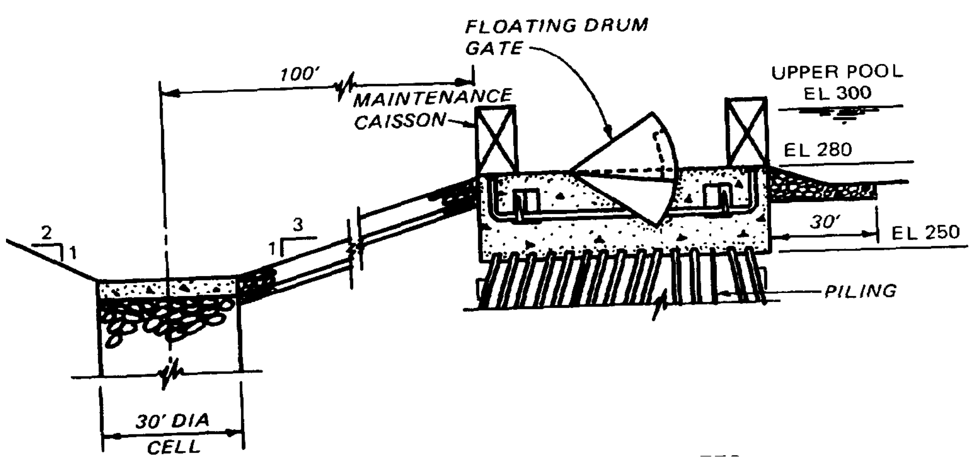
Figure 7-2. Gate operation schedule for Maxwell Lock and Dam uniform distribution of gate openings across the structure to prevent the formation of dangerous eddies downstream. Finally, the attainment of low operation costs and enhancement of water quality at low flows are also important operating objectives. In summary, from the operation standpoint, the gated structure offers greater flexibility to attain project objectives; however, the operation is more complex and requires a higher degree of maintenance to minimize equipment malfunction than projects with uncontrolled spillways. Also, the consequences of navigation accidents on project operation are likely to be more severe (loss of pool due to barges lodged under gates).

c. Movable Dams. At some locations, natural river discharges are sufficient during a portion of the navigation season (which could be continual throughout the calendar year, or extend over part of the calendar year only) to obtain the authorized navigation depth. This is an advantage from the operational standpoint since locking delays are eliminated. However, during periods of low discharges, the dam must be raised to assure sufficient depth for navigation. Movable dams are structures that accomplish this objective. An early version of movable dams were the wicket dams on the Ohio River, the majority of which are now replaced by gated structures. The wicket is a narrow wooden leaf that when raised, is supported in an inclined position by a prop and when lowered, lies flat on the foundation just downstream of the sill. A large number of wickets side by side constitute a movable dam. The wickets are raised and lowered from a maneuver boat. A typical wicket dam is shown in Figure 5-18. The operation of the wicket dams in their original form is rather time-consuming and hazardous, especially during winter periods. Therefore this type of operation can be considered obsolete. An improved version of the wicket dam concept, utilizing remotely controlled hydraulic cylinders, has been built recently on the Seine River in France. A more modern type of movable dam has been proposed for the navigable pass portion of the single dam replacement structure at Olmsted on the lower Ohio River (Figure 7-3). For the preliminary design, a drum gate that is raised or lowered by the upstream hydraulic pressure was considered for the movable portion of the dam. The control is remote to eliminate any hazardous manual operation.

7-2. Low-Flow Periods. The operation of movable dams to ensure navigation depth during low-flow periods has been described in the previous paragraph. No special operation procedures can be implemented at fixed-crest dams during low-flow periods; however, projects with gated spillways can be operated to improve water quality during these periods. A study conducted on the Ohio River found that dissolved oxygen content downstream of navigation dams during critical low-flow periods can be increased by concentrated gate openings. An example of this operation is shown in Figure 7-4. Before implementing such an operation, a careful check must be made to ensure that concentrated gate openings will not result in downstream scour, eddy action, etc. A very special problem can arise in areas where during extremely low-flow periods sufficient water is not available for lockages. Provisions must be made for adequate storage under these conditions.

7-3. Flood Flow Periods.

a. High Dams. Navigation projects with high dams are usually



SECTION THRU DRUM GATES

Figure 7-3. Movable dam

Gate 1	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6	Gate 7	Gate 8	Approx Discharge cfs
				1				3,000
				2				6,100
				3				9,300
				4				12,500
				5				15,600
		1		5				18,400
		2		5				21,400
		3		5				24,400
		5		5				30,600
		5		5		1		33,200
		5		5		3		39,000
		5		5		5		44,700
		5	1	5		5		47,200
		5	3	5		5		52,600
		5	5	5		5		58,000
		5	5	5	1	5		60,300
		5	5	5	3	5		65,200
		5	5	5	5	5		70,200
	1	5	5	5	5	5		72,400
	3	5	5	5	5	5		77,100
	5	5	5	5	5	5		81,600
	5	5	5	5	5	5	1	83,700
	5	5	5	5	5	5	3	88,000
	5	5	5	5	5	5	5	92,400
1	5	5	5	5	5	5	5	94,200
3	5	5	5	5	5	5	5	98,300
5	5	5	5	5	5	5	5	100,400

Note: Gate openings in feet.

Figure 7-4. Gate operating schedule for improved reaeration, Racine Locks and Dam constructed in areas where the topography and lack of dense development in the river valley permit the utilization of greater lift heights, sometimes in excess of 100 feet. An important distinguishing feature of these projects from the low dams is that the tailwater has no effect on the operation of most high dams. Usually the project is authorized to operate to satisfy the demands of navigation, hydropower, and possibly flood control. Flood control is normally achieved by spillway gate operation. However, the gates only control that portion of the flow which is not used for hydropower generation. An example of a multipurpose high navigation dam is the Wheeler project on the Tennessee River operated by TVA (Figure 7-5). During flood periods, spillway gates are operated to pass flood flows until extremely high discharges are reached that the gates no longer control. At this project, the lock walls are above the maximum high-water elevation, theoretically rendering navigation possible at all times. As shown in Figure 7-6, the project is also operated for flood control by drawing the pool down to el 549 in anticipation of spring floods. The minimum pool is established by providing for authorized navigation depth.

b. Low Dams. The operation of low dams during flood periods is controlled by both the tailwater and headwater. Spillway gates are raised for increasing spillway flows by maintaining the upper normal pool until the tailwater reaches that elevation. At this discharge, essentially open-river conditions exist and further increase in the riverflows cannot be controlled by project operation. If hydropower is part of the development, in contrast to high dams, power generation will be possible only during part of the year. Periods of flood flows are excluded due to insufficient head to operate the turbines.

c. Hinged Pool Operation. Under normal spillway operations, the gates are adjusted to maintain the established normal pool level at all times except when flood stages exceed the pool level at the dam. Then the gates are fully opened. Hinged pool operations, which are limited to flood flow periods, involve opening the gates in excess of that required to maintain the pool. Thus

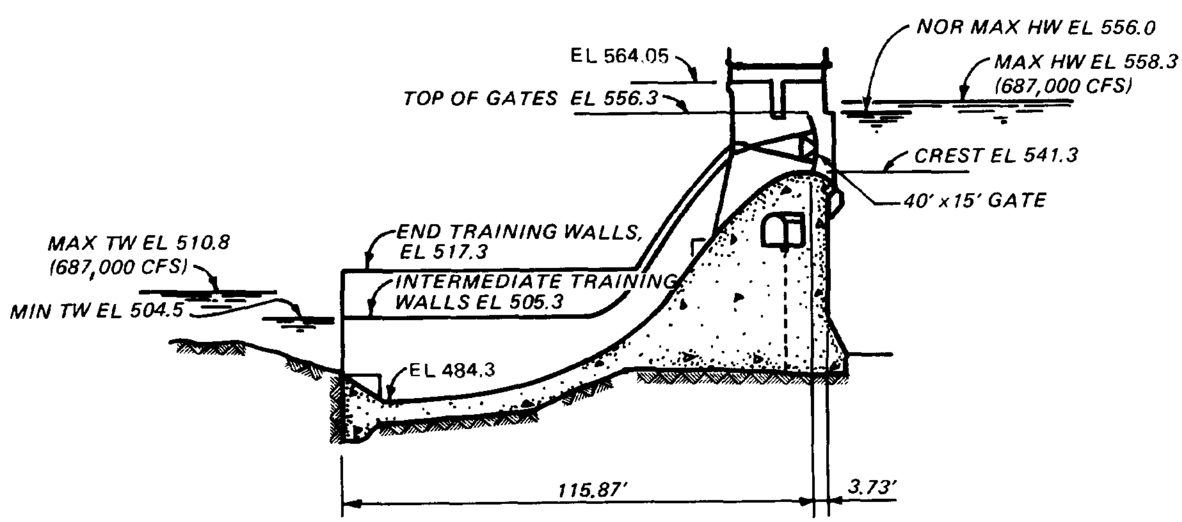
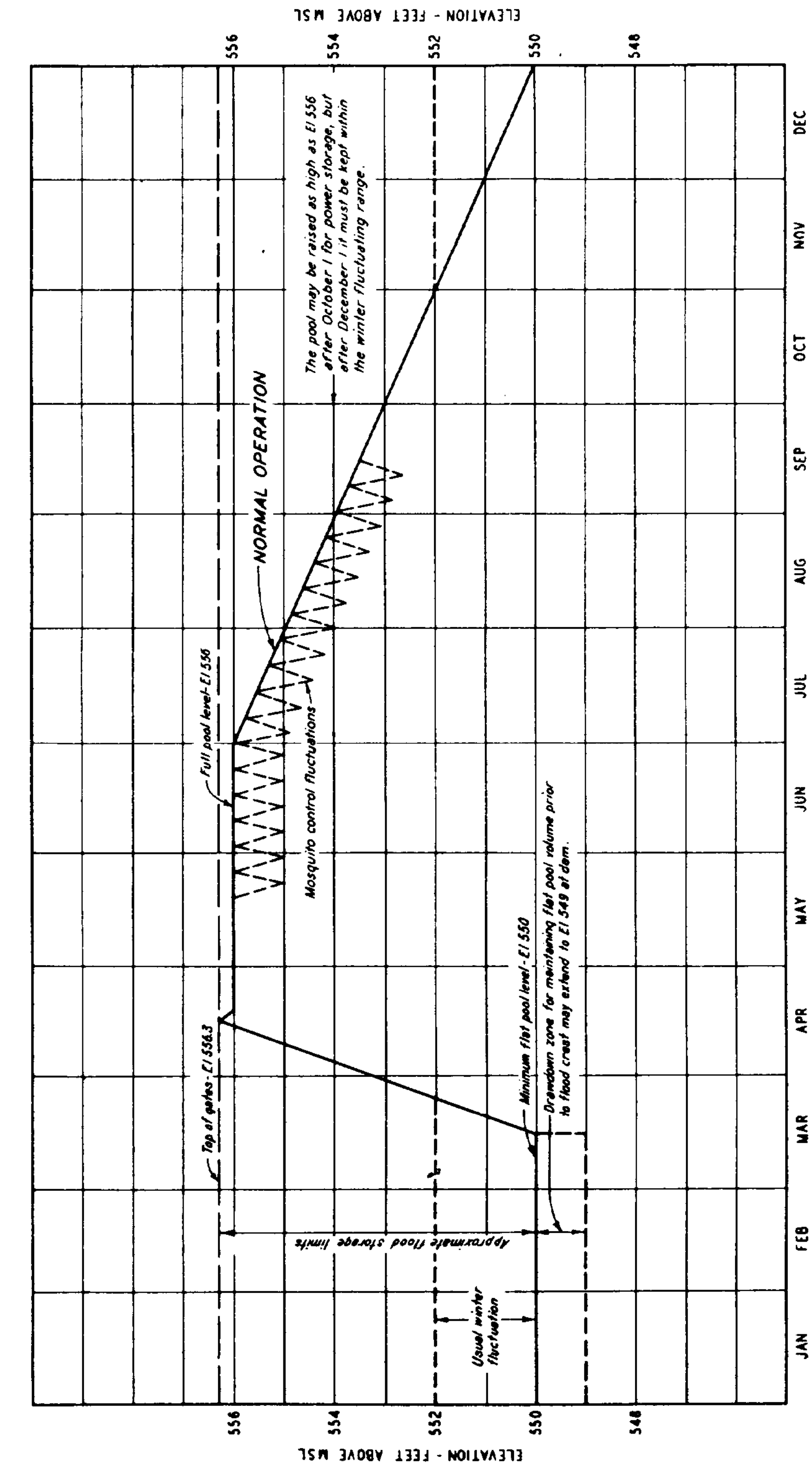


Figure 7-5. Multipurpose navigation project, Wheeler Dam, Tennessee



NOTES:
Elevations apply only at dam.
Maximum level assumed for design of dam-El 558.3

Figure 7-6. Operating curve for pool elevations, Wheeler Dam, Tennessee the lower reach of the navigation pool in the vicinity of the dam would be drawn down to below normal pool elevation. The amount of drawdown or "hinge" at the dam is controlled by the criterion of ensuring adequate navigation depth throughout the entire length of the pool. Three purposes for hinging pools and the consequences of doing so are described.

(1) Stage Control.

(a) Purpose. The purpose is to provide navigation channel depth in the pool reach of the river for flows lower than a specified maximum discharge, at which the authorized navigation depth would exist naturally. Additionally , control stage limits exist at certain point or points within the pool that must not be exceeded for these range of flows. Thus, as discharges increase, approaching that specified maximum discharge, the pool at the dam must be lowered so stages at control point(s) upstream of the dam do not exceed the limiting stage.

(b) Example. In the pool of Dam No. 26 on the Mississippi River, a nine-foot-deep navigation channel must be maintained during flow periods of 210,000 cfs or less. Additionally, stages at Grafton, Ill., approximately 15 miles upstream of Dam No. 26 must not exceed 420.0 feet NGVD. During minimum flows, the pool level at the dam is maintained at 419.0 feet NGVD. As discharges increase, dam gates are opened further and the pool is drawn down so as not to exceed the limiting stage at Grafton, Ill. When approaching a discharge of 210,000 cfs, the pool at the dam must be lowered to 414.0 feet NGVD to accomplish the above purpose. When flows exceed 210,000 cfs, all gates are opened fully and open-river conditions exist. It can be seen that a "hinge" of five feet exists at the dam (419.0 to 414.0 feet NGVD) as discharges increase from minimum flows to those providing uncontrolled navigation depth.

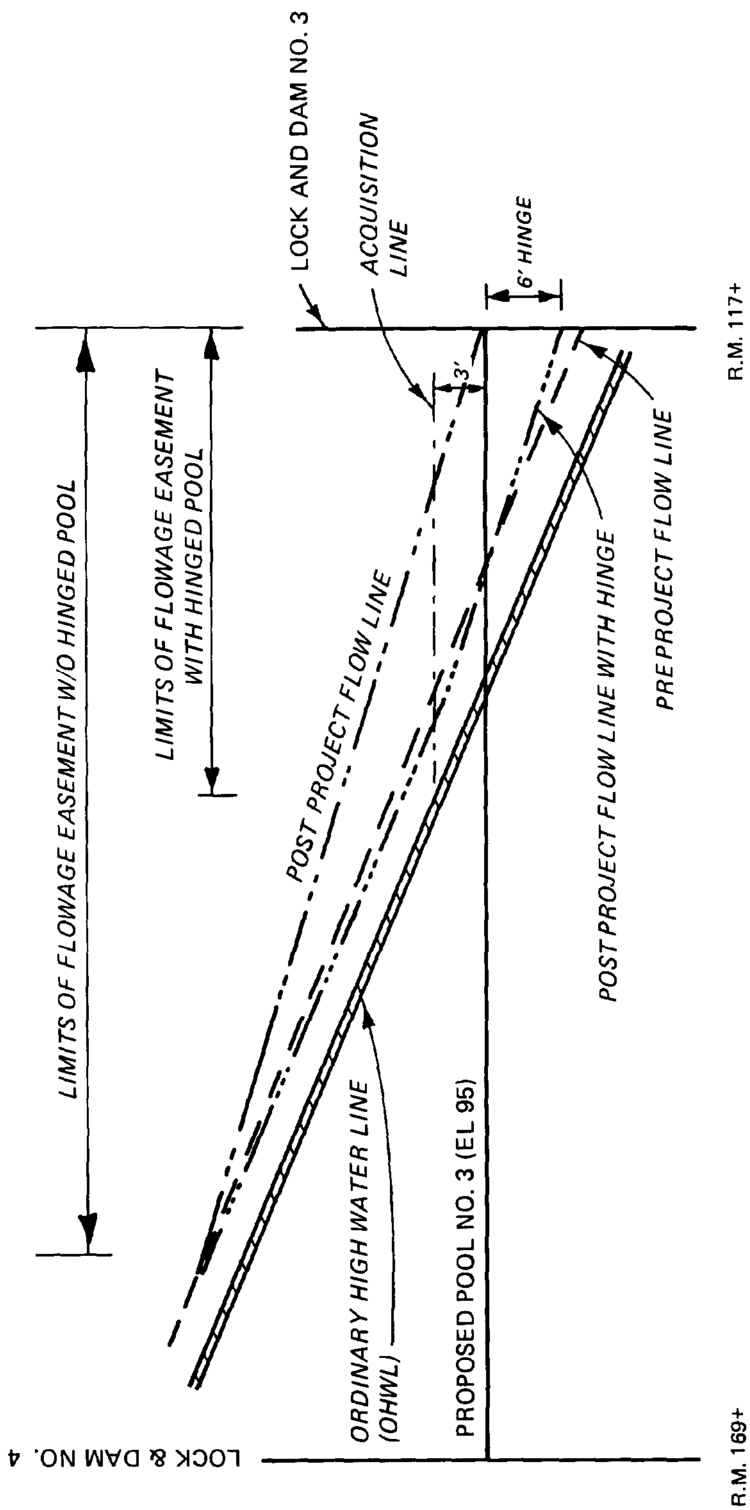
(2) Real Estate Acquisition.

(a) Purpose. For some projects, hinging the pool can reduce the required amount of flowage easement acquisition because of lowered post-project flow-line profiles throughout the pool.

(b) Example. For Pool No. 3 on the Red River Waterway Project, the criteria for real estate acquisition were the ordinary high-water line (OHWL) or the relationship of preproject versus postproject flow lines for any given discharge. Flowage easements were required where postproject flow lines were raised above both the OHWL and preproject flow lines for a given discharge. By hinging the pool, postproject flow lines can be depressed and the length of reach having flow lines above the OHWL can be reduced. Figure 7-7 illustrates the flow-line reductions that can be realized by hinging this pool.

(3) Pool Dredging Quantities.

(a) Purpose. During the recession period of flood flows, sediments tend to deposit in the middle portions of some pools. This occurs where the water-surface slope decreases because of the pool impoundment effects, and flow velocities are reduced. By hinging the pool, these deposits are carried



NOTE: Q = 100,000 CFS FOR THIS ILLUSTRATION

Figure 7-7. Hinged pool operation

farther downstream in the pool where postflooding depths are adequate for navigation without dredging.

(b) Example. Pool hinging to reduce dredging quantities has been tested in several pools on the Arkansas River navigation system. These tests indicated a potential for significant dredging reductions in some pools. Maximizing benefits requires a determination of the optimum time to initiate and to terminate the hinging process for each pool. Additional prototype testing in each pool would be required to optimize potential benefits.

(4) Hinged Pool Consequences. If hinged pool operations are anticipated on a navigation pool, several factors must be considered in the project design.

(a) The upper gate sill to the navigation lock must be set low enough so that navigation depths are provided while operating in the hinged pool mode.

(b) Velocities and crosscurrents in the upper lock approach will be more severe than under normal navigation pool conditions.

(c) Tie-up facilities along the lock guide and guard walls must be usable at the lowered pool levels.

(d) Port, docking, and other facilities located within the affected portion of the pool need to be designed to avoid serious grounding problems from the lowered pool levels. Water withdrawal intake structures along the pool would also need to be designed to operate properly under lowered pool levels.

(e) Sudden pool drawdowns can result in bank instabilities.

(f) The increased complexity of operating the spillway gates for the hinged pool levels can lead to misoperations.

7-4. Ice and Debris Passage.

a. General. A project operation plan needs to include methods of passing ice and debris. These methods can include both structural methods and operational procedures. See EM 1110-2-1612 for additional information.

b. Dam Gates. Regulating gates on a dam structure can be used to pass ice and debris either by underflow or overflow. In the first case, the gates are opened sufficiently wide to create enough flow that accumulated ice and debris are pulled from the upper pool to the lower pool, to be carried from the structure by the current. The magnitude of opening for successful operation depends on local condition and experience; it is usually one-third to fully opened gate depending on tailwater level (see items 15 and 18). Hydraulic model tests give some indication of the required opening for new structures. One of the dangers of this operation is that scour holes downstream are often caused by this type of operation. To prevent occurrence of scour during ice or debris passage, the operation of the gates should not be in conflict with limitations established during the design phase. Floating ice and debris can also be removed by creating an overflow condition, whereby gates are lowered below the normal pool thus permitting the flow to carry the debris over the gate. Naturally, this "skimming" type of operation can only be accomplished on projects equipped with submergible gates. Also, this operation is ineffective against frozen-over ice conditions since it does not create enough drawdown to eliminate support for sheet ice as opposed to the method of opening gates described above. At some projects on the Ohio and Mississippi Rivers, the use of submergible gates has been discontinued due to vibration problems. Both submergible tainter gates and roller gates are used in the North Central Division on the Illinois Waterways and the Mississippi River, respectively. Submergible tainter gates are proposed for several projects on the Illinois River and model studies will be conducted to ensure vibration-free operation.

c. Bulkheads. Some of the newer navigation structures are equipped with emergency gates or sectionalized emergency bulkheads. The primary design function of these structures is to protect against loss of the pool in emergency conditions caused by inoperative dam or lock miter gates. However, they can also be used for routine and nonroutine maintenance and to pass ice and debris. Usually, at least one of the bulkhead sections should be designed for overflow. This unit is placed second from the top in the assembled closure structure, which is then lowered to the closed position with the dam or lock gates closed. When the emergency closure is in place, the dam gates are opened, the top unit of the emergency closure is lifted, and ice and/or debris is "skimmed" through the partially open emergency closure. As with the use of the gates, it is important to prevent scouring downstream of the structure.

d. Other Operations. In areas experiencing ice problems, common practice is to operate dam and lock gates to keep elements from freezing, even when not needed for river traffic or normal pool regulation. Seals on tainter gates are especially vulnerable to freezing. However, oil-heated seal plates have worked successfully at some projects. Ice also builds up between lower chord members of tainter gates and piers due to stilling basin turbulence. Often this is a greater problem than the seals.

Section II. Special Spillway Operations

7-5. Purpose. Special spillway operations can be either intended or unintended. Intended operations may be due to such things as project repair, construction at the project or downstream, or grounded barges; unintended operation may be due to operator error, equipment failure, or tow impact with a dam.

7-6. Loss of Scour Protection. Failure of downstream stone protection below a stilling basin is an example of a condition that may require special operation. If the failure is localized below a limited section of spillway, reducing the opening of the spillway gates in that section or complete closing may be required until repair can be effected. Raising the tailwater elevation by operation of a downstream dam also may be effective in reducing the turbulence in the damaged areas. A combination may be required. Decreasing the flow in one part of a spillway will increase the unit discharge in other sections of a run-of-river project without storage available to adjust the spillway discharge. This can cause increased stress to undamaged sections of the stone protection. The responsible individual will be required to decide on spillway operations that are in the best overall interest of the project, considering project protection, navigation needs, and safety.

7-7. Operator Error. Misoperation of spillway gates has the potential to create various problems with different degrees of seriousness. Outdrafts or adverse currents for navigation, or scour, can be created by the incorrect gate settings. Stone protection can be damaged or destroyed, as discussed in Section 7-6. Misoperation can cause abrupt changes in upper pool and tail-water elevations. It may also cause problems at adjacent locks or hydro-electric plants, such as inability to open lock lower miter gates due to a head differential across the miter gates. The changes in flows may cause problems, or require special operations, at upstream and downstream projects. The responsible individual will need to have the gate settings corrected as soon as possible after the misoperation is discovered. The recovery operation must be executed so that abrupt changes in stage that could cause problems are not created. A survey for damage should be conducted as soon as practicable after the recovery.

7-8. Equipment Malfunction. Many types of equipment malfunctions may require special operations in order to recover normal capability. Some examples are covered below. In any case, the responsible individuals will need to analyze the particularities of each case, and plan and execute necessary operations and repair, in order to return the facility to normal operational status while minimizing the impact on project functions during the recovery period.

a. Jammed Gates. As in all cases, appropriate recovery procedures will depend on conditions and constraints existing at each given site. This may include placement of emergency closure in order to take the gate out of operation and adjustment of the remaining gate settings in order to compensate for the lost gate capacity. In general, it is important to correct the problem expeditiously in order to regain full operational capability and flexibility. It will be necessary for the emergency closure to be operable in flowing water.

b. Hoisting Machinery Breakdown. Appropriate recovery procedures in this case may begin with the attempt to close the crippled gate, if possible. If this can be accomplished, placement of emergency closure may not be necessary. The responsible individual will need to know if the gate load is equally distributed on each side of the gate. If not, the operator runs the risk of causing additional damage when attempting to lower the gate. If the gate cannot be lowered, it may be necessary to install the emergency closure. Additional steps, as in paragraph a. above, may be required.

c. Equipment Vibrations. Flow-induced vibrations have the potential for causing considerable damage to gates and other equipment. Vibrations are discussed in Chapter 5. Vibrations can vary from the nuisance level to a major, structurally damaging problem. Regardless of the perceived seriousness of the problem, vibrations observed by operating personnel should be brought to the attention of higher authority for evaluation. Appropriate immediate action may be to check the seals or sill for loose or jammed materials. Serious vibrations may require closing of spillway gates or other appropriate operational change in order to stop the vibrations until there is opportunity for evaluation and correction. This may require additional gate changes, as in paragraph a. above, or other operational modifications appropriate to the instant circumstances.

7-9. Spillway Maintenance. Limited gate availability operation occurs when one or more gate bays are closed for maintenance or repair work on the gates. The most important consideration in this operation is that the remaining gate capacity should be sufficient to handle anticipated high flows without causing increased upstream stages exceeding that predicted in the design. If feasible, repair and/or maintenance work should be scheduled during low-flow periods. On some projects, locks could be used as floodways should an emergency develop during repair work if they have been designed for this purpose.

7-10. Emergency Operation.

a. General. All navigation projects need to develop a contingency plan for access to spillway gates so closure can be made in case of an accident. However, it will not be possible to include all possible conditions because each navigation accident will be different from others.

b. Navigation Equipment Collision with Spillway Gates and Piers. Potential for very serious damage to a navigation dam exists due to the presence of navigation traffic. Figure 7-8 illustrates an accident at Maxwell Lock and Dam on the Ohio River that occurred in December 1985. In the case of collision, damage can vary from the inconsequential to major damage, including loss of the navigational pool. Serious accidents are more likely to occur during high-water periods than during low water. Designers and operators should be aware of those conditions that are more likely to cause serious damage to the structure in case of collision. For spillway gates, the two positions presenting the least potential for damage at many projects are in the fully raised position, particularly if this is higher than barges or tows passing through gate bays, and in the fully closed position. A particularly vulnerable position is with the gates slightly below or slightly above water level. In a rising river situation, with consequent increasing gate openings, it should be required operating procedure, as well as a design criterion, that the gates should be raised to a position above the highest expected water level or above a potential damaging level due to runaway tows or barges. Designers may find it prudent to include remote operating capability in order to permit quick action on the part of operators during emergencies. In the process of developing an operating plan, the responsible individuals may want to require a staggered gate operation in order to reduce the potential for a current concentration approaching the spillway (e.g., gates 2, 4, and 6 should be raised one increment followed by raising gates 1, 3, and 5).

c. Emergency Closure. Two types of closure devices are common:

(1) Bulkheads. The most common type of emergency closure for spillway gate bays is a bulkhead consisting of one or more sections and

Figure 7-8. Accident at Maxwell Lock and Dam, Ohio River

commonly constructed of welded, high-strength, low-alloy steel. It contains two or more horizontal trusses with lateral and longitudinal cross bracing and vertical tees between the chords of the trusses. A watertight skin plate generally provided on the upstream side, top and bottom seals, side seals, and roller assemblies complete the structure. The roller assemblies bear on bearing plates constructed in pier recesses. The vertical height of the structure may vary from three to twelve feet depending on design constraints of a specific project. Usually, several individual units are required to complete dam closure; some of these may be equipped with an overflow plate attached to the top truss. The purpose of such design is to utilize bulkheads for flushing ice and debris, when necessary. The bulkheads should be designed for placement in flowing water. Local geometry may make designs uncertain, so hydraulic model tests may be required to verify success. Most designs do not permit water flowing over and under the bulkhead units during lowering. Also, the stacking of more units may be required for successful placement on some projects. The units can be stored in a dogged position over the dam. In the latter case, an overhead gantry crane is used to transport the individual units to the gate to be closed. The first unit is dogged over the bay and the next unit is moved from storage, latched on the first one, and then the assembly is lowered and dogged a second time. Additional bulkhead units are latched to the assembly until complete closure is achieved.

(2) stop Logs. Stop logs usually consist of wooden beams that can be placed in the event of gate failure in recesses upstream of spillway gates. Generally, however, operating heads on the dam must be reduced before placement. Since this arrangement would result in partial or total loss of pool, they cannot be considered a true emergency closure. It should be noted

that the bulkheads described in the previous paragraph are sometimes designated as stop logs.

d. <u>Drawdown.</u> Requirements for low-level discharge facilities for drawdown of impoundments are given in EM 1110-2-50. Such facilities may also provide flexibility in future project operation for unanticipated needs, such as major repairs of the structure, environmental controls, or changes in reservoir regulation.