CHAPTER 4

OPERATIONAL CHARACTERISTICS OF WATER CONTROL FACILITIES

4-1. General Considerations

a. Background Information. The water manager must have full knowledge of the operational characteristics of water control facilities insofar as they relate to the problems of control and management in the achievement of water management goals. This requirement covers a broad spectrum of knowledge regarding the types of design, hydraulic characteristics and methods of operation of these facilities.

b. Types of Facilities. The water control facilities most commonly used at projects for the control of water flow are (1) spillways and (2) outlet works consisting of sluices, conduits or tunnels. These facilities are usually gated, but under some circumstances they are ungated. Furthermore, there are several other types of water control facilities which are constructed for specialized functions and have an important relationship to the regulation of streamflow, water level, and the conditions of water quality at the project or at downstream locations. These include hydroelectric power units, navigation locks, fish passage facilities, sluiceways for passing trash or ice, interior drainage facilities, hurricane and tidal barriers, bypass structures, and selective withdrawal facilities for outlets or power turbines. The specific design limitations and methods of operation must be accounted for in the project regulation criteria, as well as in scheduling of water releases. This chapter will summarize the types and design of water passage facilities at projects and identify requirements, methods, capabilities and limitations in utilizing each of the types of water passage facilities to meet the water management goals.

c. Design Criteria. Guidance in the design of hydraulic features at Corps projects is contained in Engineering Manuals prepared by HQUSACE. Specific reference is made to those manuals dealing with the design of hydraulic features, as listed in Chapter 1. In the design phase of project development, specific design of hydraulic structures is documented in the feature design memoranda. These design documents include information pertaining to the functional design criteria, design capacities, operating restrictions, control equipment, and methods of operation. These criteria are arrived at in coordination between the design branch and the water management, hydrology or other appropriate branch dealing with water regulation activities during the design phase. After a project becomes operational, experience gained under actual operating conditions may provide additional information regarding capacities and operating limits of these facilities.

d. Terminology. The following definition of terms have been adopted for describing flow passage facilities at dams and conform with general design practice in the Corps:

- Spillways. Gated or ungated structures used to release floodwater which normally cannot be passed by other water passage facilities at the dam; primarily to prevent overtopping of the dam.

- Outlet Works. Project outlet works or conduits required for passing flows to meet project functions or controlling reservoir levels.

4-2. Spillways

a. General. There are particular operating problems that are dealt with in the design of spillways and appurtenant facilities which are of significance to the water control manager. These include:

- Cavitation

- Erosion

- Vibration of gates

- Gate operation with regard to manual, remote, or automatic operating mechanisms, incremental openings, operation under partial gate openings, and selective spillway gate operation to achieve desired flow patterns for hydraulic considerations or for improving fish passage.

- Gate operation with regard to the functional use of storage, particularly with regard to control of floods and the use of surcharge storage.

- Problems related to passing or handling debris.

- Problems related to ice formation in the reservoir, ice flows, and the effect of ice or subfreezing temperatures on gate operation.

- Problems related to the passage of upstream and downstream migrant fish.

EM 1110-2-1603 describes the technical aspects of design for the hydraulic features of spillways, spillway chutes, energy dissipators, and spillway gates. The various types of spillways normally encountered at dams and reservoirs are described in the following subparagraphs.

(1) Concrete Overflow Spillways. Concrete gravity dams usually have overflow spillways. This type of spillway may be constructed for either high or low dams, and the cross-sectional shape is characterized by an ogee section which conducts the water flow from the headwater to the tailwater at the dam. The energy of the falling water is dissipated in a stilling basin or by some other means in which the erosive power of the high velocity water flow is safely expended.

(2) Chute Spillways. The chute spillway is commonly used for earth dams and is located in the abutment or a saddle some distance from the dam. A chute spillway consists of a spillway crest, a chute normally constructed as a concrete-lined channel that conducts the water from the headwater to the energy dissipator, and an energy dissipation facility that provides for the safe passage of high velocity flows in the tailwater area some distance below the dam. In some cases the chute may be in an unlined channel, and the energy dissipation may be designed to occur in erodible material.

(3) Other Spillway Inlets. Upstream inlets are sometimes necessary for dams in narrow canyons or may prove economical at other sites where the design discharge requirements are relatively small. The spillway inlet structure may be either a side channel or a morning glory spillway. The upstream inlet usually discharges into a tunnel driven through the abutment. Side channel spillways for relatively low dams have been used in conjunction with a chute through an open cut in the abutment.

b. Energy Dissipators. Energy dissipation is probably the most important technical hydraulic problem with regard to the design of spillways and outlet works. Energy dissipators are designed to minimize damage resulting from high velocity flows that are experienced either in the stilling basin or in the areas immediately downstream from the dam. The energy that must be dissipated is extremely high for spillways constructed at major dams, particularly for those with high head. For example, for dams whose hydraulic head is approximately 100 feet, between 5,000 and 20,000 horsepower per foot of spillway width must be dissipated, depending upon the depth of water flowing over the spillway crest. In general, there are four possible causes of damage to energy dissipators:

- Cavitation, resulting from high velocities and negative pressures downstream from baffle blocks, lateral steps, or other projections in the stilling basin.

- Abrasion, caused by the presence of gravel, boulders, or other hard materials in the stilling basin or roller bucket, which will erode the surfaces and also may enhance the damage by cavitation.

- Pulsating pressures, which may cause failure or deformation of sidewalls or splinter walls constructed in or adjacent to stilling basins.

- Erosion and scour of the area immediately downstream from the energy dissipator which results in undermining.

(1) Types. Three basic types of energy dissipators have been used. The most commonly used have been stilling basins employing the hydraulic jump to dissipate energy. The roller bucket has been used at some projects where substantial tailwater is available, and the energy is dissipated immediately downstream from the bucket in the area of turbulent flows created by the rolling action. The flip bucket (or ski jump spillway) throws the jet of water some considerable distance downstream from the dam, so any riverbed erosion does not occur close to the downstream toe of the dam or terminal spillway structure. Flip buckets are generally used where the downstream channel is located in sound rock, where water depths for the impinging flow are relatively great, or where erosion in the stream bed would not endanger the dam or appurtenant structures.

(2) Operation. In the operation of prototype facilities for energy dissipation, performance of the facilities may be of utmost importance to the water control manager. If significant damage occurs in the stilling basin, the basin may be inoperative or only partially operative for a period of repair. The scheduling of repairs must maintain the safety of the structure, particularly with regard to extreme flows that must be provided for during the repair period. Also, the scheduling must consider the normal flow requirements that may be impacted by the repair, and such considerations may require adjustments to the normal operating schedules. The use of any other facilities that may cause damage to the energy dissipators should be minimized. In addition, consideration should be given to minimizing adverse effects that may result from flow conditions in the stilling basin on fish migration, nitrogen supersaturation, navigation, and public safety.

c. Spillway Gates. Spillway crest gates are used to control the spillway discharge in accordance with specified conditions of operation to achieve predetermined water regulation goals, primarily for flood control, but they may also be used for controlling water flows in connection with other water use requirements. The fact that gated spillways provide the ability to make sizeable releases, perhaps well in excess of the reservoir inflow, requires special care in scheduling gate releases and assuring that the outflows are controlled to predetermined standards of operation. There are three main types of spillway gates commonly used and these are described as follows:

(1) Tainter (Radial) Gates. Many major projects utilize tainter gates with a design head of 30 to 60 feet and a width of 30 to 50 feet. Tainter gates are not designed for overtopping, and they are usually designed for 2 feet of freeboard with maximum operating pool when the gates are closed. The gate seal on the spillway crest is usually located downstream from the crest axis. This assures that the water jet issuing from under the gate has a downward direction, resulting in positive pressures immediately downstream from the gate. Tainter gate side arms which carry the load to the trunnions, eliminate the need for gate slots. Spillway gates have been known to vibrate for various reasons, such as bottom hip and/or spill design. Spillway gates can not always be tested upon completion because of lack of water so operators should be aware of the potential for vibration.

(2) Vertical Lift Gates. Vertical lift gates are most commonly used on low head dams. The split-leaf option for vertical lift gates allows the top portion to be hoisted independently of the low portion. The hydrostatic load of a vertical lift gate is carried to the structure through bearing plates in the gate slots rather than through a trunnion as is the case with the tainter gate. The type of side bearing characterizes the gate as a wheel gate, tractor gate, or Stoney gate.

(3) Drum Gates. Drum gates, although seldom used at Corps of Engineers projects, have been commonly used at U.S. Bureau of Reclamation dams (e.g., Grand Coulee Dam). A drum gate is designed to float on water in a chamber located in the spillway crest. The water which is being spilled flows over the top of the drum onto the ogee section of the spillway. The drum is raised by hydrostatic pressure and its range of operation is from its lower limit where the top of the drum is at the spillway crest elevation (fully open) to its upper limit where the top of the drum corresponds to full pool level (fully closed).

d. Spillway Capacity and Discharge Ratings. Spillways are sized in accordance with criteria and methods for computing extreme floods contained in EM 1110-2-1405 and other instructions and publications issued by HQUSACE, pertaining to spillway design flood criteria for various types of dams. The details concerning the methods for determining the ratings for spillways are presented in EM 1110-2-1603.

e. Operation of Spillway Gates. Spillway gate operation is based on prescribed discharges set forth in reservoir regulation schedules. In some cases (run-of-river power-navigation projects, for example), the spillway gates are operated to maintain a particular water level. Some gate control mechanisms have a safety override feature which prevents opening the gates more than a prescribed increment without an intentional restarting of the gate operating mechanism. Spillway gate control equipment is usually located near the gate, but at some projects, the gates may be operated remotely from the project control room, which may be at site or at another location. At a few projects, spillway gates may be operated by automatic control, based on reservoir levels or hydroelectric power load.

4-3. Outlet Works

a. Functional Requirements. The following paragraphs, extracted in part from EM 1110-2-1602, briefly summarize functional requirements and related design considerations for outlet works used for regulating streamflows at dams and reservoirs. This summary provides a general background of the principle elements and engineering considerations in the design and use of outlet works in the management of water control systems.

(1) Flood Control. Flood control outlets are designed for relatively large capacities where close regulation of flow is less important than are other requirements. Although control of the outflow by gates is usually provided, the conduits may be ungated, in which case the reservoir is low or empty except in time of flood. Special provisions must be made for design of gates, water passages, and energy dissipator at projects where large discharges must be released under high heads.

(2) Conservation. Reservoirs that store water for subsequent release to downstream navigation, irrigation, and water supply, usually discharge at lower capacity than flood control reservoirs, but the need for close regulation of the flow is more important. Where water quality is of concern, multiple intakes and control mechanisms are often installed to assure reliability, to enable the water to be drawn from any selected reservoir level to obtain water of a desired temperature, and/or to draw from a stratum relatively free from silt or algae or other undesirable contents. Ease of

maintenance and repair without interruption of service is of primary importance.

(3) Power. Outlet facilities required for operation of hydroelectric power are discussed in Engineering Manual 1110-2-1701. Power tunnels or penstocks may be used for flood control and other water passage requirements.

(4) Diversion. Flood control outlets may be used for total or partial diversion of the stream from its natural channel during construction of the dam.

(5) Drawdown. Requirements for low-level discharge facilities for drawdown of impoundments are discussed in ER 1110-2-50.

b. Sluices for Concrete Dams. Sluices constructed in concrete dams may be rectangular, circular, or oblong. Those designed primarily for flood control releases may be sized to provide a relatively large number of individual sluices, each being in the general range of 4 to 6 feet wide and 6 to 10 feet high. The flow through each sluice is controlled by individual gates or valves, thereby providing a finer degree of control than from a smaller number of sluices of larger cross-sectional area. Sluice intakes are provided with trashracks where debris protection is required.

c. Gate Passageways. The gate section is that portion of the sluice in which the gates operate. It is specially designed to eliminate or reduce the effects of cavitation as much as possible. Particularly when high head gates are operated under partial opening, they may be subject to severe cavitation and vibration and have a high air demand. Air vents are provided and are specifically designed to reduce cavitation for control valves that do not discharge into the atmosphere. Normally, two gates in tandem are provided for each sluice to assure flow regulation if one becomes inoperative. Emergency gates shall be provided for each service gate passage so that if a service gate is inoperative in any position, closure of the gate passage can be made. Bulkheads which allow inspection and maintenance of the upstream gate frame and seal are also provided for each gate passage. Gate passages of circular cross section are designed when necessary to accommodate circular gates or valves, such as knife or ring-follower gates or butterfly, fixed cone, or needle valves. Rectangular gate passages are used for slide, tainter, and tractor or wheel-type gates.

d. Control Works. Control works for sluices are classified as gates and control valves. Vertical lift gates may be either slide, fixed wheel or tractor gates, which are operated by hydraulic cylinders, cables, or rigid stem connection to the hoist mechanism.

Hydraulically operated gates are preferred for high heads and for long periods of operation. Tainter gates are also used as service gates operating at high heads. Control valves, including knife gate, needle-type, fixed-cone, and various commercial valves, have been used for flow control for discharging water freely into the air or into an enlarged, well-vented conduit. Commonly used valves include butterfly, needle-type (hollow jet), fixed-cone, and commercially available valves for small conduits.

e. Operation of the Control Works. The operation of control valves or service gates may be based on manual, automatic, or remote control. In a few cases the outlet works are under automatic control, and the outlet works are controlled by water level sensors. Vertical lift gates are usually manually operated by use of lifting mechanisms, which may be "dogged" at fixed increments of elevation to approximate a particular gate setting. Tainter or slide gates that are driven by hydraulic or electrical hoists may be controlled either at the site of the gate machinery or, in some cases, remotely from the project control room. The gate control mechanisms may have an override feature that limits the opening increment to a pre-established small value. The operation of the gate then requires successive iterations to exceed the pre-set incremental opening. Special problems may arise with the operation of the outlet works, such as ice, trash, excessive vibration, erosion or cavitation. Such problems must be resolved to assure the reliable operation to meet the water management goals and also to maintain the integrity of the project facilities.

f. Discharges. Discharge is normally determined from theoretically derived discharge ratings, however, metering devices for monitoring flow through conduits may be provided under unusual circumstances, especially when accuracy of flow determination is important for regulation of outflows.

g. Outlet Facilities for Embankment Dams. Outlet facilities for embankment dams are provided through use of conduits and tunnels. The intake structure may be gated tower, multilevel, uncontrolled two-way riser, and/or a combination of these. The control structure may be either in the intake tower or in a central control shaft. A combined intake and gate structure is most commonly used, but underground control structures may be more economical and offer certain other advantages. Gate passage and control gate designs for sluices also apply to conduits through embankment dams. Special problems involved in the operation of outlet works through embankment dams include:

- Head loss, boundary pressures, and vortices in the approach of the intake structure
- Protection from debris by use of trashracks
- Hydraulic loads for vertical lift gates
- Gate "catapulting", resulting from water pressure building up on the downstream side of the intake gate during the process of watering up the space between the service and emergency gates
- Vibration and resonance of cable supported gates
- Transitions and exit conditions of the conduit or outlet tunnel

h. Low-Flow Facilities. The operation of large gates at small openings (less than 0.5 ft) is not recommended because of the increased potential for cavitation downstream from the gate slot. Projects which require low-flow releases are designed with low-flow bypass culverts, center pier culverts, multilevel wet well facilities, or a low-flow gate incorporated into the service gate. Where a single tunnel is used and other water release facility is not available, a bypass is desirable to keep water in the river during periods of repair.

i. Selective Withdrawal Systems. Selective withdrawal systems may be provided to draw water from specified elevations in the reservoir. These structures fall into three general types: (1) inclined intake on a sloping embankment; (2) freestanding intake tower, usually incorporated into the flood control outlet facilities of embankment dams; and (3) face-of-dam intake, constructed as an integral part of the vertical upstream face of a concrete dam. Types (2) and (3) predominate at Corps of Engineers projects. Selective withdrawal structures include: (1) inlets and collection wells, (2) control gate passages, and (3) exit passages. Inlet ports are designed to be operated fully open or closed, and the total flow is regulated by a downstream control gate or power unit. The inlet ports are operated manually with gate hoists or other operating equipment. Some existing, successful, single-well systems allow for blending of water withdrawals from more than one level. An inlet port that is not totally submerged can be operated as an inlet weir, and the combined operation of the weir and downstream control can be balanced to provide the desired flow characteristics. Collection wells are provided for directing the flow of water from the intake system to the outflow passages. In dual wet well systems blending of flows for water quality purposes should be done by blending flows from separate wet wells. Each wet well should have individual flow control, and inlets at only one elevation should be open in each wet well. Submerged weirs upstream of outlet works can be used to prevent withdrawal of bottom waters from reservoirs by flood control conduits and penstocks. Conversely it may be desirable to withdraw bottom waters as rapidly as possible after a flood; for example, when turbidity is a consideration. In general, all water quality control devices for selective withdrawal are individually designed to meet the particular project requirements, and the regulation of these facilities must be based on the experience gained during the operational phase.

j. Energy Dissipation. Energy dissipation for all types of outlet works constructed at dams is an important feature of the hydraulic design of the water control systems. A hydraulic-jump type stilling basin is most frequently used for energy dissipation from conduits or sluices. The stilling basin may also incorporate the energy dissipation requirements for spillway discharges. Stilling basins are generally but not always designed for optimum energy dissipation of controlled flows equal to the capacity of the outlet works. The design of the stilling basin requires a detailed hydraulic analysis, which usually includes hydraulic model studies. In summary, the energy dissipation effected by the use of stilling basins or other methods is an important consideration in the overall management of water releases from projects, and the effectiveness of the system may have particular significance to the water manager.

k. Summary. The water control manager should have general knowledge of the hydraulic design of the outlet works in order to evaluate special operating problems that may arise. Specific knowledge of the detailed design for projects is also required in order to fully understand design limitations, unusual operating problems, discharge characteristics and other factors that may influence the use of these facilities on a day-to-day basis. This summary of outlet work design is only a general description of outlet facilities and design requirements. The reader is referred to EM 1110-2-1602 for a more complete description of the methods of design for outlet works and to the individual feature design memoranda for a description of the design of outlet works for specific projects.

4-4. Flood Control Operation

a. Project Outflows. Chapter 3 presents the basic methods for developing reservoir regulation schedules for flood regulation. The project outflows to meet the flood control schedules are usually obtained through use of either the spillways or outlet works, but the total project outflow requirement may be met by combined use of these facilities and the outflows from hydroelectric power units for those projects with hydropower facilities. The regulating outlets are sized to provide the pre-flood or post-flood evacuation of reservoir storage, as well as the pre-flood requirements for maintaining the storage space in the reservoir prior to the time that water is stored in the interest of downstream flood regulation. Also, during the flood regulation period project outflows must be frequently specified in order to achieve the downstream flood control objectives. In general, the outlet works are designed to be used for controlling releases during the pre-flood period and the actual period of flood regulation. The spillway may be utilized when the reservoir approaches full pool level or in connection with the need for induced surcharge storage in the reservoir. Thus, the outlet works and the spillway provide the principal means for regulating the reservoir levels to achieve the downstream flood control objectives.

b. Controlling and Monitoring Outlet and Spillway Gate Regulation. The water control manager issues flood regulation schedules and operating instructions to the projects. These instructions may include direction as to total discharge, gate settings, rates of change and selection of where outflow is to be released. The project operational data reports (described in Chapter 5) inform the water control manager of the actual operation of the facilities in the form of discharge amounts, gate settings, and reservoir levels for monitoring the reservoir regulation. For some projects, automatic sensors at gate openings provide continuous reservoir regulation data to the control center. The water control manager must be informed of any problems which may involve the operation of the outlet works and the spillway. Any adjustments to reservoir regulation that may result from restrictions in the use of the outlet or spillway facilities should be coordinated between the project operator and the water control manager.

c. Combined Use of Outlet Works and Spillways. One technical hydraulic problem related to the flood control regulation of reservoirs is the combined use of outlet works and spillways to pass the required outflows during flood periods. Many projects base the spillway design discharge capacity (usually the probable maximum flood) on the combined use of the full capacity of the spillway and outlet works. In some cases, this capacity includes a portion of the capacity of hydropower units that can be expected to be operable at the time of the flood. Combined use of outlets and spillways depends on evaluations of the hydraulic and structural designs at the particular project. These evaluations include:

- The flow characteristics of the spillway and outlet works with regard to symmetry of flow in the spillway or outlet channel;

- The allowable head on the outlet works;

- Cavitation in the outlet works or spillway;

- Back pressure on the outlet tunnel resulting from high tailwater;

- Tailwater conditions which affect the performance of the stilling basin;

- Gate operation with partial gate openings for both outlet and spillway gates;

- The effect of the discharges on the flow patterns in the stilling basin;

- Erosion or damage in lined or unlined channels which conduct the water to the river below the dam;

- The interrelationships among flow conditions affecting other facilities such as fish passage, navigation channels, revetments, etc.

Some projects are designed for rare use of spillways. This would be the case if the outlet channel to the spillway is unlined, and the use of the spillway would result in erosion in the spillway and the downstream river channel. In such cases, every effort should be made to utilize the full capacity of the outlet works in order to minimize the probability and/or the magnitude and duration of flows passing over the spillway. The preceding discussion highlights problems related to the combined use of the outlet works and spillways. Each project has its own particular design characteristics, and the project should be operated in a manner to minimize damage to the project structures based on knowledge of design, experience gained from project operation and anticipated flood regulation requirements. This information should be incorporated into the project water control manuals, and periodically updated to reflect the experience gained from actual operation.

d. Free-Flow Operation of Gated Spillways which Control Large Natural Lakes. Some projects are constructed with dams and gate controlled spillways to regulate the water surface elevations and outflows of large natural lakes. Such projects may also have at-site hydroelectric power installations, navigation locks, or other water control facilities. Usually, the operating range of the reservoir levels is limited to relatively modest amounts; that is, the difference in elevation between minimum and normal full pool levels is normally only 15 to 25 feet. The primary purpose of these projects is to supply water for downstream use on a seasonal basis for hydropower production, irrigation, or water supply, utilizing the storage that would be approximately equal to the uncontrolled natural storage in the lake. The mode of operation for seasonal storage regulation for these projects is to fill the storage space during the high-flow season to the normal full pool level, hold the water in storage until needed for at-site or downstream flow regulation, and then use the stored water to augment streamflows during the low-water period. Projects of this type utilize spillways which are designed to provide approximately the equivalent capacity of the natural lake outlet. The spillway discharge may be augmented by outflows through power units.

4-5. Induced Surcharge Storage

a. General Principles. Reservoirs controlled by dams with gated spillways present special operating problems during flood regulation. Particularly for large floods, the use of spillway gates (sometimes in combination with the outlet works) must be carefully scheduled to minimize downstream flood flows to the extent possible by optimum use of the storage capacity. Also, when circumstances require that the spillway must be utilized, the transition from normal low outflows to significantly higher outflows resulting from the use of the spillway must be performed gradually so as not to constitute a major hazard to downstream interests. The operation of spillway gates during floods must be regulated to compensate for potential changes to project inflow hydrographs which can result from:

- lost valley storage
- changed river channel hydraulic properties
- synchronization of tributary inflows
- rain falling directly on the reservoir surface areas

b. Surcharge Storage for Free-Flow Ungated Spillways. The degree of control afforded by the free-flow operation of a spillway is determined by reservoir storage routing of unsteady (nonuniform) inflows, expressed as a time series. The computation of storage routing may be performed by a number of methods and uses basic storage and flow relationships applied to the storage and flow characteristics of a particular reservoir. Reservoir simulation models can be easily applied either for study purposes to develop operating criteria or for operational use to project the effect of reservoirs on current river system regulation and to compare natural and regulated flow conditions for the system in real time. The effect of reservoir spillways operated on a free-flow basis is to induce water into surcharge storage, causing the reservoir to rise and fall in accordance with the inflow, outflow, and storage relationships. The regulation of flows is automatically achieved by the storage and flow characteristics for the particular spillway and reservoir. Due to the fact that there is no chance for error in regulation based on this criterion, free-flow operation is considered to be fail-safe and highly desirable in this regard.

c. Development of Induced Surcharge Envelope Curves. The maximum elevation of induced surcharge storage depends upon the design characteristics of the dam and spillway, design flood elevations, and limitations imposed by flowage rights in the reservoir. In general, the maximum elevation of induced surcharge storage is limited to approximately 4 to 8 feet. Figure 4-1 illustrates the various levels and conditions which are involved in spillway gate operation for induced surcharge storage. A curve representing the maximum reservoir levels that would be permitted at various rates of spillway discharge when operating under the induced surcharge plan is referred to as the Induced Surcharge Envelope Curve. The envelope curve is developed as described in the following subparagraphs:

(1) A set of spillway-rating curves is computed showing the discharges that would occur with all spillway gates raised collectively by successive increments of 1 foot until fully opened (see Figure 4-2).

(2) Elevations of the top of spillway gates corresponding to various gate openings is superimposed on the rating curves (see Curve G, Figure 4-2). Induced surcharge storage could not exceed the elevations indicated by this curve without overflowing spillway gates in their partially opened position. It should be limited to a lower elevation in order to provide some freeboard, particularly after gate openings of a few feet are attained. It is desirable to provide gates with a freeboard of 1 or 2 feet above top of flood control pool when in the closed position.

(3) An elevation at which all spillway gates should be fully opened is selected after consideration of several practical factors. The benefits that may be realized from partial control of spillway releases by induced surcharge decrease very rapidly as the gate openings increase. Provisions for a higher induced surcharge level

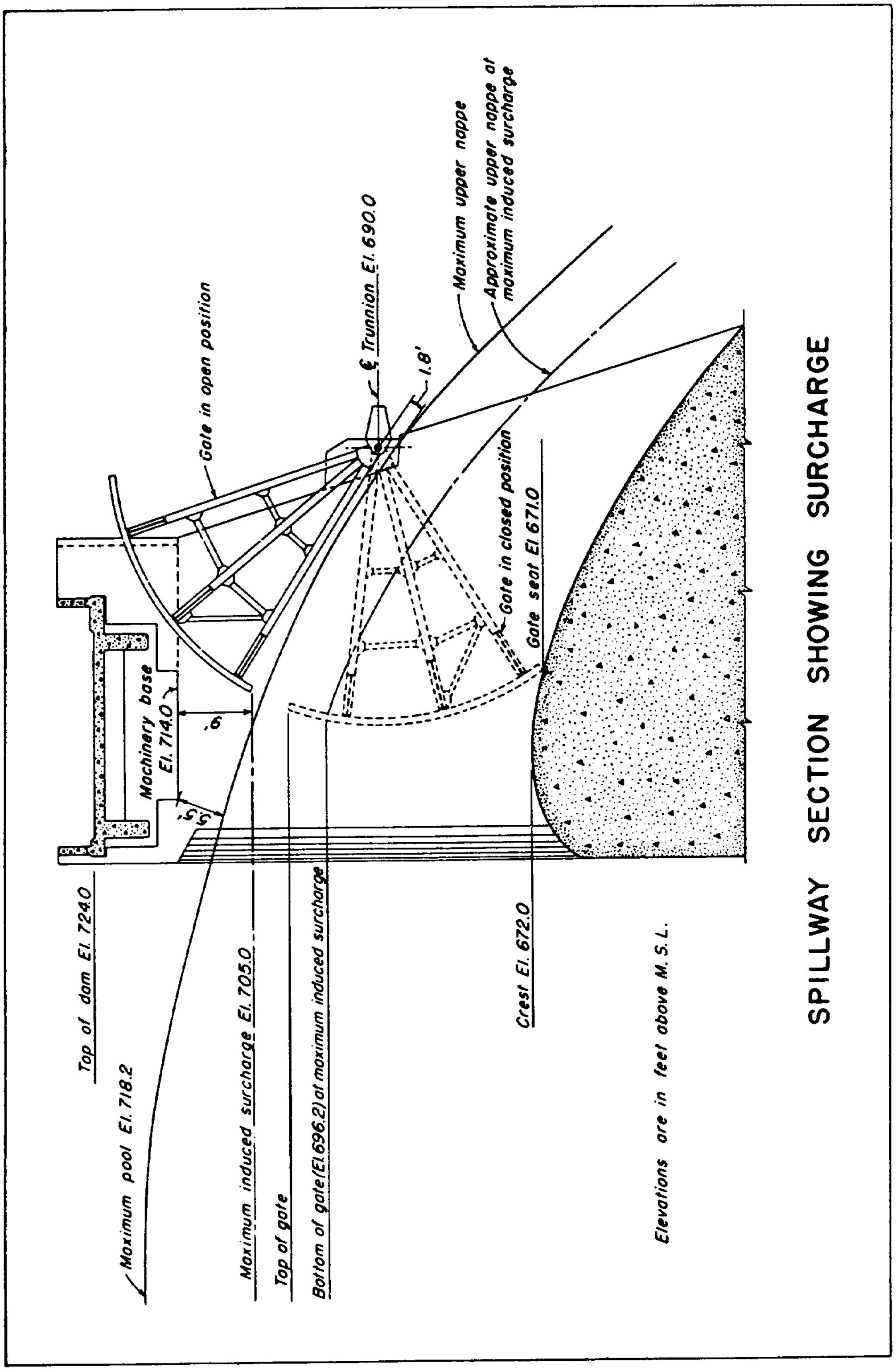
SPILLWAY SECTION SHOWING SURCHARGE
Maximum upper nappe
Approximate upper nappe at maximum induced surcharge
℄ Trunnion El. 690.0
1.8'
Gate in open position
Gate in closed position
Gate seat El. 671.0
Machinery base El. 714.0
9'
5.5'
Top of dam El. 724.0
Maximum pool El. 718.2
Maximum induced surcharge El. 705.0
Top of gate
Bottom of gate (El. 696.2) at maximum induced surcharge
Crest El. 672.0
Elevations are in feet above M. S. L.

Figure 4-1

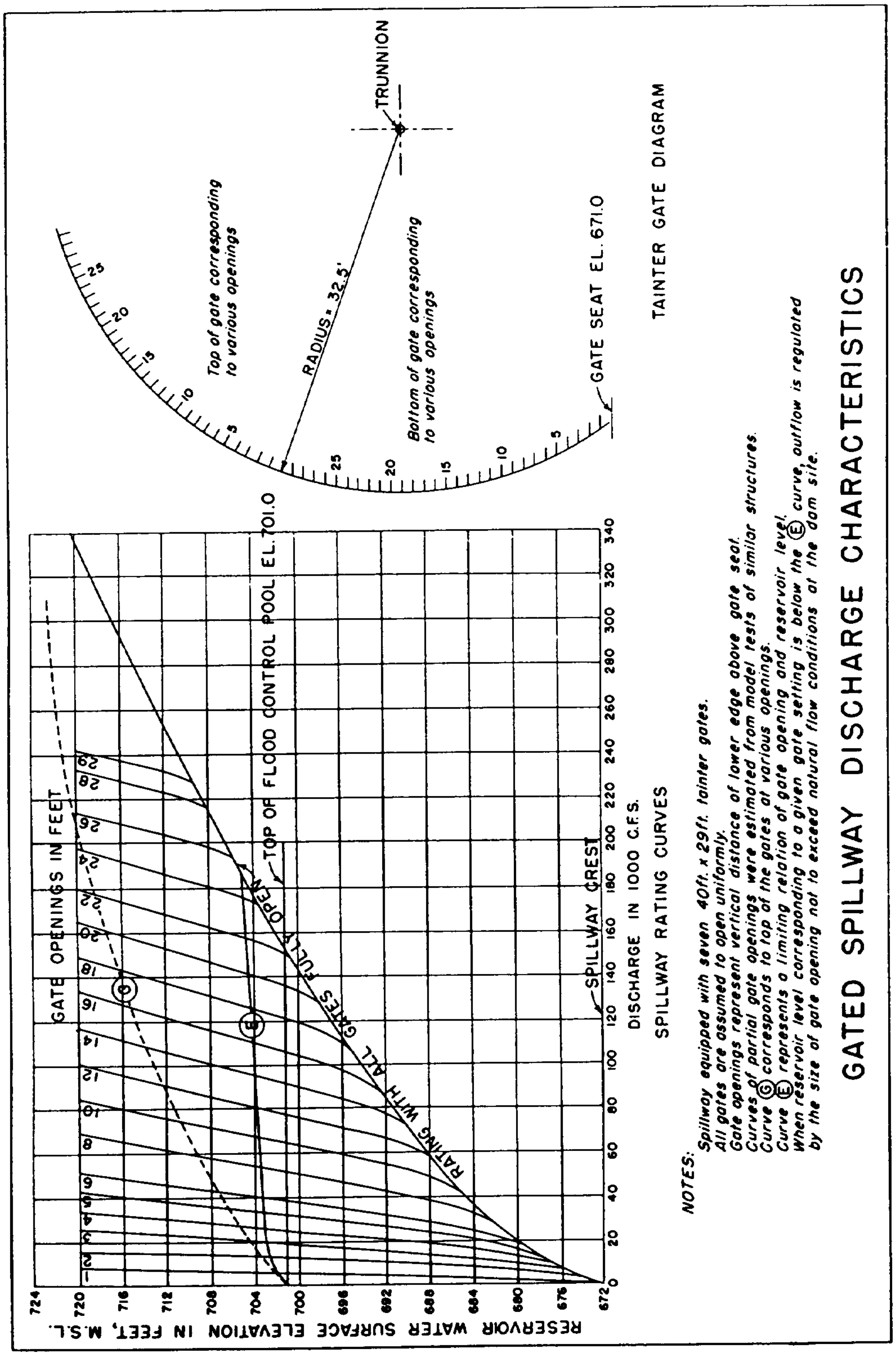
GATED SPILLWAY DISCHARGE CHARACTERISTICS
TAINTER GATE DIAGRAM
TRUNNION
RADIUS = 32.5'
GATE SEAT EL. 671.0
Top of gate corresponding to various openings
Bottom of gate corresponding to various openings
SPILLWAY RATING CURVES
DISCHARGE IN 1000 C.F.S.
RESERVOIR WATER SURFACE ELEVATION IN FEET, M.S.L.
GATE OPENINGS IN FEET
TOP OF FLOOD CONTROL POOL EL. 701.0
RATING WITH ALL GATES FULLY OPEN
SPILLWAY CREST
NOTES:
Spillway equipped with seven 40ft. x 29ft. tainter gates.
All gates are assumed to open uniformly.
Gate openings represent vertical distance of lower edge above gate seat.
Curves of partial gate openings were estimated from model tests of similar structures.
Curve G corresponds to top of the gates at various openings.
Curve E represents a limiting relation of gate opening and reservoir level.
When reservoir level corresponding to a given gate setting is below the E curve, outflow is regulated by the size of gate opening not to exceed natural flow conditions at the dam site.

Figure 4-2

may require substantial changes in design at an increase in cost out of proportion to the advantage gained. Also, possible damage to property within the surcharge storage pool often discourages the use of induced surcharge storage more than a few feet above the top of flood control pool elevation. The selection of the elevation at which all spillway gates must be completely opened during an emergency operation should be based on consideration of the circumstances prevailing at each project.

(4) The Induced Surcharge Envelope Curve is drawn from a point corresponding to the non-damaging flood control release at the top of flood control pool elevation to the free discharge capacity of the spillway corresponding to the elevation at which all gates must be fully opened, as illustrated by Curve E, Figure 4-2. A straight-line connection would assure the minimum rate of increase in spillway discharge under critical flood conditions and may be the proper selection in some cases. However, curvature as illustrated by Curve E, Figure 4-2, permits a lower release rate in the lower surcharge ranges which would be the most frequently utilized. The minimum permissible slope of the line at the higher elevations is governed by the rate of increase in spillway discharge that may be considered acceptable during infrequent and extraordinary floods.

d. Development of Spillway Gate Regulation Schedules. Induced Surcharge Envelope Curve projects with gated spillways should have a Spillway Gate Regulation Schedule. This is a family of curves that relate inflow, outflow, and project storage. A procedure has been developed that computes the minimum volume of remaining inflow expected at a given time during a flood, based on typical recession volumes. The procedure is used to compute a family of curves (termed the spillway gate regulation schedule) that relate the inflow, and residual reservoir storage volume (including induced surcharge storage) to determine the outflow required to avoid the consequences of making regulated downstream flows greater than under a pre-project condition while at the same time providing for an orderly increase in outflows during extreme floods such that project overtopping is prevented. The first step in the procedure is to analyze recession characteristics of inflow hydrographs to obtain a recession constant that will be used in predicting a minimum inflow volume that can be expected when only reservoir elevation and the rate of rise of reservoir elevation are known. For conservative results the assumed recession curve should be somewhat steeper than the average observed recession and normally can be patterned after the spillway-design flood recession. The recession constant can be obtained by plotting the recession curve as a straight line on semilog paper, with the flow on a logarithmic scale and time on an arithmetic scale. The recession constant, T, is defined as the time required for the discharge to decrease from any value, say Q_A, to a value Q_B, where Q_B

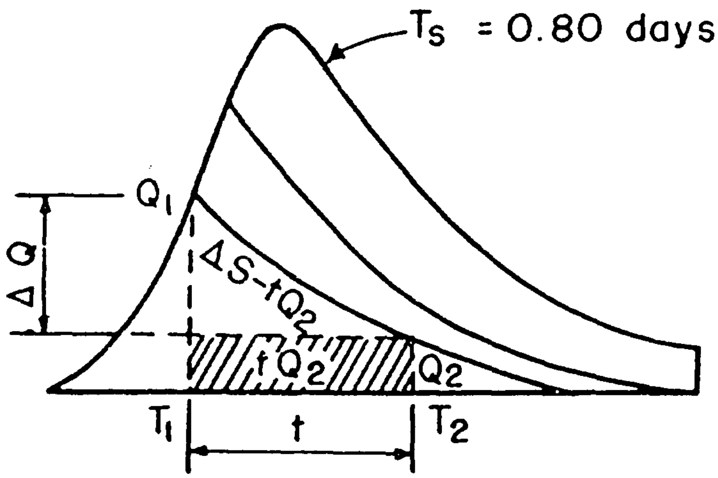

Figure 4-3. Schematic Hydrograph

equals $Q_A/2.7$. A relationship to compute the volume of water that must be stored for a hydrograph receded from an initial flow to a constant output flow can be derived from continuity considerations. Consider Figure 4-3, which schematically illustrates terms to be used in solving for the volumes to be stored, S_A. In the Figure 4-3, Q_1 represents the inflow and Q_2 represents the constant outflow. The recession constant, T_S, may be defined as:

$$T_S = S/Q = \frac{(S_A/2) + Q_2 t}{Q_1 - Q_2} = \frac{S_A + 2Q_2 t}{2(Q_1 - Q_2)} \qquad (4\text{-}1)$$

then,

$$t = T_2 - T_1 = -T_S \log_e (Q_2/Q_1) = T_S \log_e (Q_1/Q_2) \qquad (4\text{-}2)$$

substituting (4-2) into (4-1) and rearranging

$$S_A = 2T_S [Q_1 - Q_2 - Q_2 \log_e (Q_1/Q_2)] \qquad (4\text{-}3)$$

$$S_A = 2T_S [Q_1 - Q_2 (1 + \log_e (Q_1/Q_2))] \qquad (4\text{-}4)$$

For each of various inflow rates and for each of various outflow rates, compute the volume of water that must be stored, S_A, using equation 4-4. Then determine pool levels by subtracting S_A from the storage value for the given outflow as defined by the induced surcharge envelope curve. The computations are illustrated in IHD Volume 7, Flood Control by Reservoirs, HEC 1/. The pool levels thus determined represent the maximum pool levels that should be permitted for the corresponding inflow and release rates. Obtain a family of regulation curves by plotting the pool levels corresponding to various outflows using inflow as a parameter. The family of curves is shown as Regulation Schedule A on Figure 4-4. A family of curves such as those shown in Figure 4-4 are appropriate for use in a central office, but relationships to be used as an emergency operation schedule for damtenders are more directly usable if the rate of rise of reservoir level is substituted for the inflow. This is readily accomplished by obtaining the difference between the volume of inflow and outflow for a selected time interval and expressing the volume as a rate of rise for any particular reservoir elevation. A typical family of curves is shown as Regulation Schedule B on Figure 4-5. The time interval to be used as a basis for determining rate of rise should be based on a consideration of the reservoir and drainage basin characteristics, with 1 to 3 hours being typical. Adjustment in gate openings at 1- or 2-hour intervals is adequate for most projects.

e. Testing Spillway Regulation Schedule. Spillway gate regulation and induced surcharge envelope curves should be tested by utilizing them in the regulation of historic or hypothetical floods. Several computer programs are available to do this conveniently. The tests should involve a variety of storm patterns and magnitude, that are considered reasonable for the project under consideration.

f. Methods of Operation. There are several options available during rising and falling reservoir stages which should be described in project water control manuals.

(1) Rising Reservoir Levels. When predictions indicate that anticipated runoff from a storm will appreciably exceed the storage capacity remaining in the reservoir, the opening of spillway gates may be initiated before opening is required by the spillway gate regulating schedule. Opening of spillway gates should be scheduled to limit the rate of increase in outflow to acceptable values. When outflows are required by the spillway gate regulation schedule, induced surcharge is utilized to exercise partial control over outflow rates. The elevation attained and the volume of induced surcharge storage used will vary with the volume and rate of reservoir inflow during individual floods and the exact schedule of gate operation.

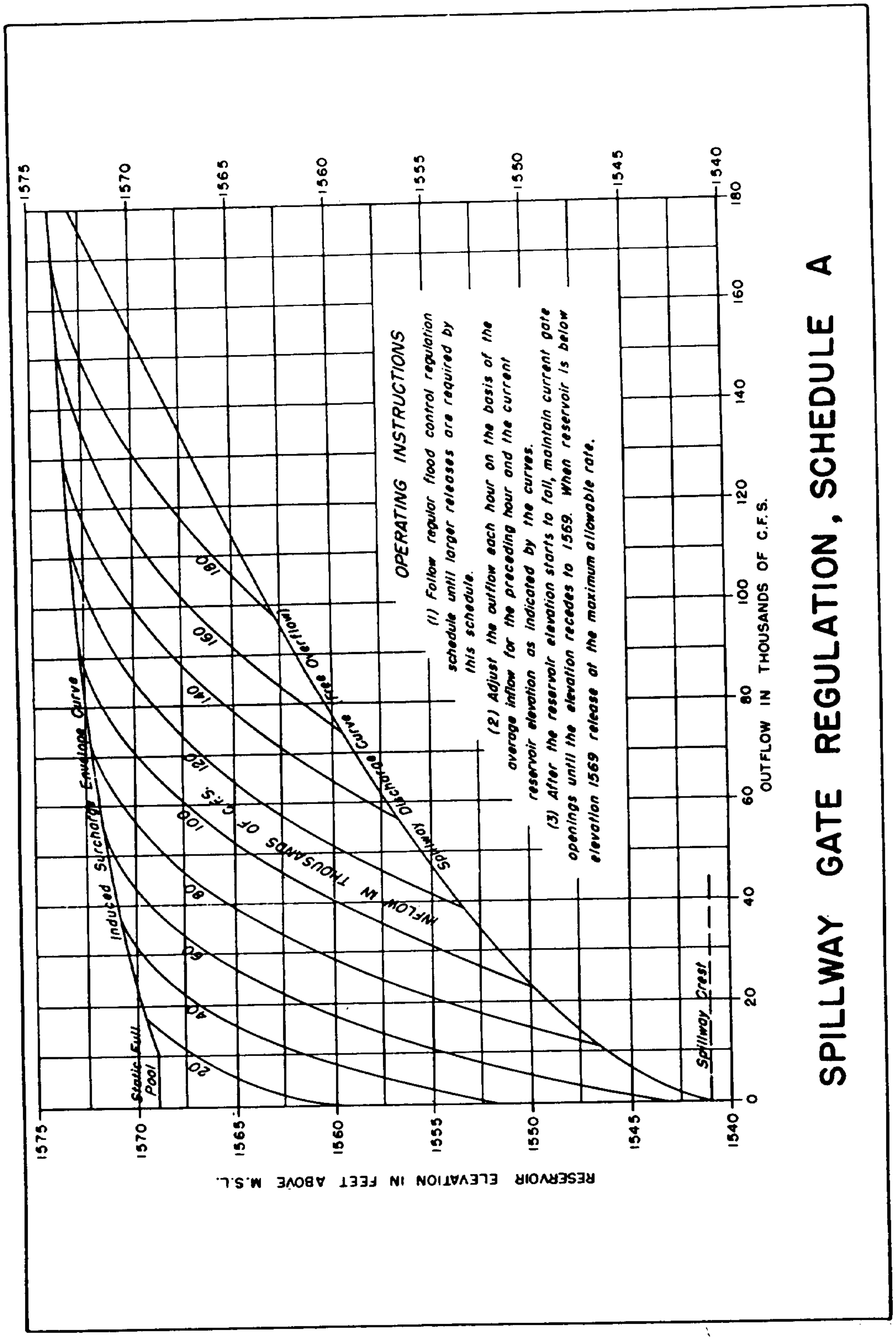
SPILLWAY GATE REGULATION, SCHEDULE A
OPERATING INSTRUCTIONS
(1) Follow regular flood control regulation schedule until larger releases are required by this schedule.
(2) Adjust the outflow each hour on the basis of the average inflow for the preceding hour and the current reservoir elevation as indicated by the curves.
(3) After the reservoir elevation starts to fall, maintain current gate openings until the elevation recedes to 1569. When reservoir is below elevation 1569 release at the maximum allowable rate.
OUTFLOW IN THOUSANDS OF C.F.S.
RESERVOIR ELEVATION IN FEET ABOVE M.S.L.
INFLOW IN THOUSANDS OF C.F.S.
Induced Surcharge Envelope Curve
Spillway Discharge Curve
Free Overflow
Static Full Pool
Spillway Crest
0
20
40
60
80
100
120
140
160
180
1540
1545
1550
1555
1560
1565
1570
1575

Figure 4-4

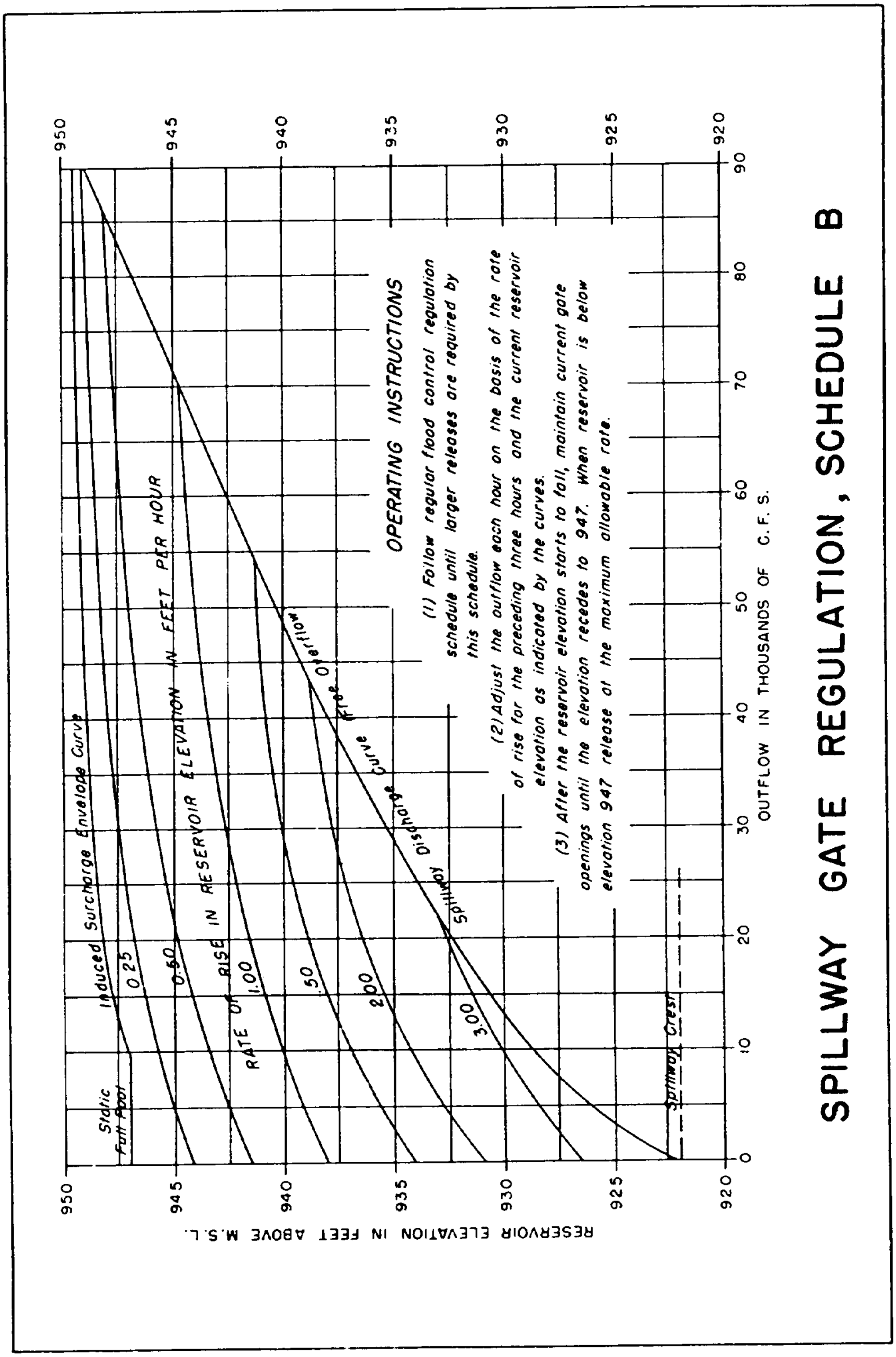
SPILLWAY GATE REGULATION, SCHEDULE B
OPERATING INSTRUCTIONS
(1) Follow regular flood control regulation schedule until larger releases are required by this schedule.
(2) Adjust the outflow each hour on the basis of the rate of rise for the preceding three hours and the current reservoir elevation as indicated by the curves.
(3) After the reservoir elevation starts to fall, maintain current gate openings until the elevation recedes to 947. When reservoir is below elevation 947 release of the maximum allowable rate.
RATE OF RISE IN RESERVOIR ELEVATION IN FEET PER HOUR
0.25
0.50
1.00
1.50
2.00
3.00
Induced Surcharge Envelope Curve
Spillway Discharge Curve
Free Overflow
Static Full Pool
Spillway Crest
OUTFLOW IN THOUSANDS OF C.F.S.
0
10
20
30
40
50
60
70
80
90
RESERVOIR ELEVATION IN FEET ABOVE M.S.L.
950
945
940
935
930
925
920

Figure 4-5

(2) Falling Reservoir Levels. For falling pool levels after surcharge storage has been induced, releases can be based on the most appropriate of several possibilities. In any event, the surcharge storage should be evacuated rapidly, consistent with downstream runoff and reservoir conditions. Upon completion of drawdown to the top of flood control pool level, the regulation schedule for releasing stored waters should be followed. The following are some of the more common procedures for drawdown of induced surcharge storage for falling reservoir levels and decreasing inflow:

- Draw down gradually to top of flood control pool level within a specified number of hours

- Maintain maximum spillway gate opening

- Release some fixed percentage (over 100 percent) of the mean inflow for the preceding 3 hours

- Make the release in excess of the inflow by some specified increment of discharge

- Make the release conform with a hydrograph similar to the natural inflow hydrograph

If all spillway gates are opened fully during the storage operation, discharge is uncontrolled until the outflow decreases to the value at which the uncontrolled condition began. Regulated operation would then begin in accordance with one of the preceding release schedules for falling reservoir levels.

g. Effect on Spillway Gate Design. The most efficient induced storage operation would normally require that the spillway gates be designed for operation at partial openings and with individual operating mechanisms. Unless the gates are designed for overtopping, it would be desirable for the height of gates to be 1 or 2 feet greater than required for the induced surcharge operation since it will not be feasible to raise all the gates simultaneously to obtain the desired discharge.

4-6. Outlet Works for Water Supply

a. General Considerations. The design requirements for outlet works in connection with their use for water supply functions are different from those for flood control. Generally, the water releases for irrigation, navigation, municipal, industrial, or other water uses are fairly uniform over a period of days or weeks as compared with the rapidly changing requirements for flood control, and they may be of relatively low magnitude. The use of outlet works for water supply functions may involve special operating problems which should be taken into account by the water control manager.

b. Special Requirements and Problems. Outlet works that are designed primarily for flood control may have some restrictions when used for low-flow regulation because of cavitation. Also, operation of flood control gates may not allow the required degree of control for gate settings that precisely achieve the low-flow requirements. Some types of gate operating mechanisms have a tendency to "creep" over a period of time, and the gate setting must be re-adjusted periodically to maintain the desired uniform outflow from the project. The water control manager must also be aware of hydraulic problems of long-term operation of outlet works, such as the adverse effects of spray that may result from the use of a ski-jump energy dissipator, turbulence or undesirable flow patterns in the downstream tailwater area, problems related to ice formation and cold weather operation, and the general continuity of operation of outlet work facilities where they are generally unattended except as required to make adjustments in outflows.

4-7. Diversion and Bypass Structures

a. Project Purposes and Types. Diversion structures and systems vary widely in size, complexity of operation, and degree of control. In many cases excess flood water is carried away from a main stream by a control structure and auxiliary channel to reduce flood flow and stages at potential damage centers on the main stem. Water supply diversions for M&I and irrigation purposes are the most common and include closed conduit bypass facilities, as well as open channel flow diversions. Other.reasons for diverting flow may be for recreational purposes, fish and wildlife enhancement, suppressing saltwater intrusion in estuaries, or lowering the ground water table. The least common in number are manmade navigation channels, e.g., the Tennessee-Tombigbee Waterway. Also, diversions to existing channels for other purposes may help provide navigation depths incidentally. Water is diverted back into some reservoirs at night following a hydropower generation cycle (pumpback) and reused for the same purpose in the next generation cycle. Power is also generated by passing flow through turbines in route to an auxiliary channel where the diversion is for other purposes. There are diversion systems whose objectives are seasonal in nature related to high flow only, low flow only, and to both high and low flow conditions. Still others operate continuously, and some control the flow both into and out of given area.

b. Regulation Procedures and Schedules. Diversion projects that have uncontrolled structures do not require water control decisions; however, it is often necessary to anticipate when these structures will begin and cease operating in order to notify the general public, evacuate auxiliary channels, and take other action as appropriate. The most complete hydrometeorological data available, including forecasts of stage and discharge, should be used when applying regulation procedures. Detailed analyses are often made for controlled structures because of the importance attributed to water management, whether it be for flood control, water supply or other project purpose. Withdrawal from a stream or impoundment for any reason can be a highly sensitive issue that leads to court claims, and signed agreements with appropriate interests are advisable that address both normal and rare climatic events. Long-range regulation schedules are made in an effort to define the duration of an event and to define stage and discharge hydrographs upstream of, at and downstream of the control structures. Various factors are taken into account: time of inundation, stream and channel capacities (stage or flow reduction targets), navigation depths, relationship to dredging, levee grades, river stage and lake levels, water quality in lakes, streams and estuaries, and seasonal considerations. In general, physical operating characteristics of the control structure, such as energy dissipation and velocities, are critical.

4-8. Hurricane or Tidal Barriers. Hurricane barriers are operated to protect coastal communities from tidal flooding associated with severe storms. The design and operation of projects take into account the effects of interior runoff, pumping station requirements and availability of ponding. It is also necessary to know how long it takes to open and close navigation gates and whether navigation gate opening operations can be initiated when there is significant head differential on a gate. The manager should also be aware of the discharge capabilities of emergency sluices, in case the navigation gate becomes stuck in the closed position or has to be closed for maintenance purposes for an appreciable length of time. It is important to have firsthand knowledge of the protected area and what damages would result at various water levels.

4-9. Interior Flood Control Facilities

a. General. Interior floodwater is normally passed through the line-of-protection by gravity outlets when the interior water levels are higher than water levels of the exterior (gravity conditions). The floodwater is stored and/or diverted and pumped over or through the line-of-protection when exterior stages are higher than that of the interior (blocked gravity conditions). Gravity outlets, pumping stations, interior detention storage basins, diversions and pressure conduits are primary measures used to reduce flood losses in interior areas. Other measures, such as reservoirs, channels, flood proofing, relocation, regulatory policies, and flood warning/emergency preparedness actions, may also be integral elements of the interior flood loss reduction system. Reference is made to EM 1110-2-1413, which provides general guidance for the analysis of interior flood control facilities.

b. Operational Criteria. Generally the Corps plans, designs and documents detailed operating criteria for newly completed interior flood control facilities for use by the local interest responsible for operation and maintenance. These criteria should include instructions for obtaining and reporting appropriate hydrologic data, including current and forecasted values of exterior river stages, interior area rainfall and ponding levels. The criteria should describe proper use of the data to effectively operate the facilities. Provisions for obtaining supplementary data should be included, when necessary. General flood emergency preparedness plans and all arrangements required to assure timely closure of gravity drains, to implement emergency closures, and to operate pumping plants should be carefully described. Periodic schedules for inspecting, testing and maintaining the facilities should be defined.

c. Legal Requirements. The capability of an interior flood loss reduction system to function over the project life must be assured. This requires legally binding commitments from the local sponsors of the project to properly operate and maintain the system. Real estate requirements and specifications for operating and maintaining detention storage areas, pumping facilities, and conveyance networks, are integral to all agreements for implementation of an interior system of flood measures.

4-10. Hydroelectric Power Facilities

a. General. The functional utilization of hydropower facilities encompasses a broad spectrum of technical knowledge. At Corps hydropower projects, the power units, control facilities, power transformers, switchyards, and operational techniques all embrace complex equipment which are under the operational control of the Corps. However, there is the much broader consideration of electrical power system operation and integration, which requires a basic understanding of not only the physical hydropower facilities, but also regional electrical power system operation. This knowledge is needed to make judgments that affect the operation of the total regional electric power resource and the interrelationship of power operation with the management of multipurpose river developments.

b. Engineering Manual On Hydropower (EM 1110-2-1701). This manual provides guidance on the technical aspects of hydroelectric power studies from pre-authorization through the General Design Memorandum (GDM) stage. Specific areas covered include need for power, determination of streamflows and other project characteristics, estimation of energy potential, sizing of power plants, cost estimating, and power benefit analysis. Other engineering manuals have been prepared that cover details of design for selected hydropower facilities such as powerhouse design and selection of turbines and generators. While EM 1110-2-1701 primarily deals with hydropower, it also provides much background information that pertains to operation of power systems and the general features of hydroelectric development.

c. Major Hydroelectric Facilities. Hydropower projects are classified by type of operation as run-of-river, pondage, storage, pumped storage, and reregulating projects. All hydropower plants include the following major hydraulic components: dam and reservoir, intake, conduit or penstock, surge tank (when necessary), power unit, draft tube, and tailrace. The types and designs of each of the components are determined by the specific design requirements for individual projects, and they vary widely depending upon the type of operation and physical characteristics of the project. The heart of a hydropower plant is the powerhouse, which shelters the turbines, generators, control and auxiliary equipment, electrical buswork and disconnects, and sometimes erection bays and service areas. Transformers are usually placed on or adjacent to the powerhouse, and switchyards are nearby.

d. Plant and Unit Control Systems. Control equipment is necessary to facilitate the automatic or manual operation of the power units and other necessary power plant equipment. Control systems vary widely in scope and complexity, as a function of the size and staffing of the plant, the level of operator skill and responsibility, the need to automatically regulate power generation to outside demands, and the desirability and location of the central electrical control and dispatch center. Unattended small scale hydro plants often demand apparently disproportionate control equipment expenditures because of the need for automatic fail-safe operation and outside plant trouble reporting. Larger multi-unit attended plants often have a central control room and automatic control requiring large computer based Supervisory Control and Data Acquisition (SCD) control systems.

e. Plant and Unit Operation. In general, individual power units, multiunit power plants, and large interconnected power systems are operated by a variety of manual and automated control systems. In recent years, there has been a significant increase in the use of automated systems for operating hydropower plants remotely from a centralized control center. At Corps of Engineers projects, the hydropower facilities and control systems are generally operated under the supervision of the Operations Division, which has direct responsibility for the operation and maintenance of the individual projects. The operation of these facilities for day-to-day regulation and functional management of these resources to meet all water management goals, including hydropower, is performed in accordance with instructions and schedules provided by the Reservoir/Water Control Center or other water regulation unit that has responsibility for scheduling plant operation. Individual units may be started and placed on line in accordance with operating schedules and the needs for power. The starting and stopping of individual units may be done manually by plant operators or remotely from the power plant control room or other designated project controller location. The units may be operated according to a specified load, or they may be placed under Automatic Generation Control (GC). When units are operated to meet a specifically scheduled load, it is termed "block loading." Such loadings are generally specified as hourly values, which reflect the anticipated needs for power generation and the needs for all other water demands. The changes as required in scheduled plant loadings are performed by the plant operator form the project control room or remotely from a designated project controller or central dispatch facility. Under certain conditions, units may be operated under "speed no load," in which the unit is rotating at the speed which is synchronized with the power system operation, but without load or significant generation of electric power. This type of operation may be necessary to help provide inductive or capacitive reactance to the power system operation and enhance system stability. It also provides for spinning reserve capacity which may be required for power system operation to meet unforeseen changes in plant or system loads. The methods of scheduling and coordinating the regulation or power plant operation are discussed later in this section.

f. Integration into Regional Power System. The electrical power produced at Corps of Engineers projects in the United States is integrated with electric power produced by other utilities. Under the terms of the Flood Control ct of 1944 (Public Law 78-534, dated December 22, 1944) and related legislation, the power produced by Corps of Engineers projects is marketed to the utilities and other direct service customers by five regional power marketing administrations (PM's) of the Department of Energy. In addition to marketing, some of the PM's also provide transmission and dispatching services. The regional electrical power networks in the United States are complex and highly integrated systems whose operation is made possible through formal agreements between utilities or through informal working relationships to enhance the overall capability of individual utilities.

g. Control Equipment. Units or plants at major hydroelectric power stations may be loaded on the basis of predetermined fixed schedules (block loading), or they may be loaded through use of load-frequency control equipment known as Automatic Generation Control (GC). In those cases where system control of hydroelectric power facilities represents a major portion of the system generation, this equipment is normally part of the control facilities provided in the power dispatching control center operated by the Power Marketing Agency (PM). The function of GC is to control power generation automatically at one or several plants in a system in response to the moment-to-moment load variations that are imposed on the system. It is also used to pro-rate generation automatically to several plants as required to meet a major portion of system loads, on the basis of predetermined functions which represent the proportional loadings of individual plants. These functions, known as "break point" settings, are individually determined for each plant from power system simulations that project the expected loads and resources into the future, usually for periods of one to five days. The "break point" settings may be changed daily as a function of system requirements. In actual operation, the plant loadings computed by the GC are converted to electrical signals, and they are received at each plant at approximately 1-second intervals. The power plant internal computer automatically apportions the plant load change among the generating units on-line at that particular time. The use of the equipment is a very important tool in the power scheduling and dispatching process. The "break point" settings determine the actual loadings of each plant as a function of the continuously varying power requirements, and they determine the resulting streamflows at each project under GC. It is vital that the water manager who has projects operated under GC be familiar with interrelationships between system controllers and the planned use of this equipment for scheduling plant operation for normal and emergency conditions. Although the planned and scheduled use of power plants is coordinated through the water managers, the ultimate plant operation is determined by the automatic generation control equipment for those plants under its control. It is, therefore, important that the plant operation be continuously monitored to assure that all of the water management goals are being met and to take corrective action when necessary.

h. Special Operating Problems. The problems of power operation vary widely among projects and systems, depending upon the importance of hydropower in relation to other project purposes, the methods of hydrosystem control, and the system integration of power regulation with other multipurpose water management requirements. The water manager is concerned with two basic types of problems:

- Project and system regulation on a seasonal basis, when power is a consideration in the water control plan

- Scheduling power regulation on a daily, weekly, or monthly basis to meet the power needs in conjunction with the other water uses

Both types of problems require a large degree of coordination with all users.

(1) Seasonal Reservoir Regulation for Hydropower. Chapter 3 describes the principles of hydropower system operation and the methods for developing reservoir regulation schedules for reservoir projects with hydropower facilities. The Annual Operating Plan (OP) is developed on the basis of each year's hydrologic conditions, system power requirements, and multipurpose requirements and goals for reservoir regulation. The studies required for developing the OP must be coordinated with other power interests and local or regional groups that have an interest in the multipurpose aspects of water regulation.

(2) Coordination. There is an imperative need for coordination between the Corps of Engineers and the Power Marketing Agency (PM) when formulating power production and power marketing strategies and when integrating the operation of power facilities within the regional power grid. This coordination involves many aspects of project operation and reservoir regulation at Corps projects, including the development of the operating plan to achieve the power operating goals, scheduling reservoir releases, and dispatching power under normal and emergency conditions. All coordination requires administrative procedures, technical evaluations, and detailed working arrangements to assure that the responsibilities of the two agencies are met. This is generally accomplished by executing formal Memorandums of Understanding, which define specific duties and responsibilities, establish coordinating groups composed of agency representatives which oversee the operations, and form work groups assigned to specific tasks. Similar arrangements are made with other operating utilities in the region. During operation, however, there are often circumstances which require unplanned minor departures from the operating plans in order to satisfy unforeseen requirements or desires for river regulation. For some cases, departure from operating plan schedules and guidelines may have a significant effect on meeting one or more of the water management goals, and the problem

may have to be referred to an appropriate administrative level for resolution. Chapter 8 deals with interagency coordination in greater detail.

(3) Scheduling and Dispatching Power. Scheduling and dispatching power from Corps projects are performed in accordance with the basic operating strategies and criteria contained in the Annual Operating Plan (OP) and Water Control Manual. As mentioned previously, the OP consists of guide curves and other operating guidelines that are generalized from power operation studies performed on the basis of mean monthly historical streamflow data and estimated load and resource evaluations. It is also necessary to base the actual operating schedules on current hydrologic and power data, together with forecast data. For small or relatively simple systems, the schedules can be determined manually from analysis of current data and estimated projections of future operations. For large integrated power systems, however, the schedules are usually determined by computerized simulations, which provide current analyses of all hydrologic and power generation data, load forecasts, interchange requirements, and plant and unit status conditions on a real-time basis and conform to the constraints of operating rule curves. Simulations cover in detail several days to a week in advance, and more general projections are made for periods up to 30 days or more in advance. The actual operating schedules are then derived from the simulations of project operation. The daily operating schedules are forwarded to the project office (usually by teletype) for plants not on centralized control, or they are inserted into the system controller at the power control center. They may indicate hourly generation values for block loaded plants and anticipated plant loadings, unit status, and "break point" settings for plants operating under control of the GC equipment.

(4) Power Dispatchers. The continuous operation of the power system is under control of the power dispatchers, who monitor all aspects of plant and system operation. The dispatchers are highly trained specialists who control the flow of power in the system under normal operating conditions. They also recognize any abnormalities or departures from planned system operation and take immediate action to correct the problem and restore the system to normal operation. Potential problems include unusual load demands, power outages, equipment failures, or loss of transmission. The dispatchers are in frequent communication with plant operators who control the operation of hydroelectric facilities at their respective plants. The plant operators are responsible for the operation of their plants in accordance with the operating schedules and other operating criteria that may affect water regulation and the operation of the physical facilities.

(5) Constraints on Peaking Operation at Hydropower Plants. Many hydroelectric plants are designed for meeting peaking and intermediate load requirements that result in a low load factor operation. Some plants generate only when peak loads occur, generally less than 8 hours per day, and their generation is scheduled to help meet the morning or afternoon peak loads. Other plants are scheduled for a more continuous operation but still respond to daily variations in system loads. While there are many advantages to operation at peak loads, fluctuating outflows resulting from this operation may cause water regulation problems. Environmental considerations, such as the effect of fluctuating water levels on fish and wildlife, aesthetics, navigation, and public safety, are all considered in the planning, design and operation of peaking power plants. In some cases, the water fluctuation problems related to peaking operation are completely met by constructing reregulating reservoirs immediately downstream from peaking power projects. Where it is impractical to construct reregulating reservoirs, specific operating limits for fluctuations in power production and/or water level in the river system below the projects are developed on the basis of studies made during the design phase. Pondage projects, which are developed in tandem on a major river, are operated as a system with regard to peaking power operation. The total system output is shaped to meet the fluctuating power loads, so that all plants share in loads and fluctuations in reservoir and tailwater water levels. The analysis of this type of system operation is accomplished through use of the various computer models available for this purpose. In actual operation, there may be requests for restrictions in peaking operation beyond those set forth in the design or operational studies. These requests are generally a result of changed environmental conditions or other unforeseen conditions. Requests of this nature must be carefully analyzed.

(6) Electrical Operating Reserves. An electrical power system is designed to guarantee reliable service to customers. This requires that reserve capacities be available to cover forced outages, maintenance outages, abnormal loads, and other contingencies. Typically, power system resource planning is based on providing about 20-percent reserve capacity above the expected annual peak load. This capacity is called the system planning reserve. In day-to-day system operation, an operating reserve of 5 to 10 percent of the load being carried must be maintained at all times. Half of this must be spinning reserve (capacity which is rotating but not under load; see Paragraph 4-10e, Plant and Unit Operation), and the remainder is standby reserve, which must be available in a matter of minutes. The spinning reserve is used to handle moment-by-moment load changes, while standby reserve is used to cover unexpected power plant outages.

(7) Load Forecasting. Load forecasting is one of the most important factors in scheduling and dispatching power. Normally, this is done by the PM, as part of their service in the scheduling process. When the federal plants are interconnected with private utilities and are operated under power exchange agreements for coordinated system operation, the federal plants may also provide interchange energy to help meet the utility system loads. System load forecasts prepared in conjunction with daily operation are short-term hourly and daily loads, as compared to generalized monthly load forecasts used in resource planning and annual operation planning. The actual daily load forecasts are prepared from analyses of recent weather and load data, forecasted weather data, and other variables such as time of day, day of the week, and time of year. The load may be separated into several components, such as industrial, commercial, and residential, and detailed computerized load forecasting programs have been developed. The load forecasts are then used to develop individual plant schedules.

(8) Emergency Control Procedures. The requirements for scheduling the use of power resources are based on normal operation of generation equipment, transmission and substation systems, and anticipated power loads which conform closely to the scheduled amounts. Unanticipated outages in system operation may arise and require immediate compensation in the electrical system to prevent a breakdown in the total system operation. Emergency actions by the dispatchers and power schedulers are required that may affect both the use of generation equipment at hydroelectric plants and conditions of streamflow and water levels at individual plants. In emergencies, changes in power system operation must usually be instituted in seconds or minutes, and the recovery of the system may require as much as an hour or more. In order to assure that normal operation can be achieved within the overall capabilities of the power system, the scheduling must allow for sufficient reserves of generation capacities to meet such requirements (see Paragraph (6), above). Short-term or disturbance-related power shortages are met by generation reserves. This unused generator capacity is available for use in the event of a failure in the power generation, substation, or transmission facilities. "Operating reserve" is generating capacity that can be made available and loaded within 10 minutes on a sustained basis. "Spinning reserve" is a component of operating reserve and is on-line, unloaded, and ready to pick up immediately on demand. In extreme emergencies, where the power system is unable to provide sufficient generation to match load, automatic devices institute a program of "load shedding." Coordinated automatic load shedding should be established to prevent the total loss of power in an area that has separated from the main network and is deficient in generation. Load shedding should be regarded as an "insurance program" and should not be used as a substitute for adequate system

design. The emergency conditions of power plant operation discussed in this paragraph are beyond the normal scope of coordination between the Corps of Engineers and the PM. It is mandatory that the water manager be informed immediately of any large scale interruption of the power system and take actions as necessary to preserve the water regulation goals and inform others regarding the emergency conditions.

4-11. Fish Passage Facilities and Use of Water Control Facilities for Fishery Enhancement

a. General Considerations. There are two classifications of fish life that are dealt with in the development of fish facilities for water control projects. These are:

- Anadromous (migrating) fish species such as salmon or shad, which basically maintain their habitat in the ocean and ascend from the sea into rivers to breed

- Resident fish such as bass and trout, which are bred, reared, and maintain their habitat in rivers

Specially designed facilities for fish passage and enhancement of fish life have been incorporated into many water control projects. These facilities may include fish ladders; fingerling fish bypasses; fish turbines, fish pumps, water conduits, or spillways or outlet works that provide water to attract fish into fish passage facilities; fish "elevators"; and facilities that release the desired quantity and quality of water to enhance fish life in downstream areas. In addition to these physical facilities, other fishery activities, facilities and operations which may be related to water management may include:

- Fish hatching and rearing to supplement natural fish runs and establish new runs

- Improving fish spawning grounds

- Transporting fish by truck and barge

- Modifying spillways to reduce nitrogen supersaturation during times of spill and adjusting or reducing spill to help mitigate nitrogen supersaturation

- Performing basic and applied research in fish biology, particularly in regard to the effects of dams and reservoirs

- Regulating water releases to meet the streamflow and water level fishery requirements in the water control plan

b. Fish Passage Facilities. Dams are designed to preserve anadromous fish runs, primarily the salmonoids. Fish ladders provide safe upstream passage of adult migrants past water control structures. Years of experience in the operation of properly designed fish ladders have shown them to be a proven method for passing upstream migrants through a series of dams whose hydraulic heights range from 50 to 150 feet. Passing the downstream migration of juvenile anadromous fish, however, is not accomplished with the same degree of reliability. Various methods, such as constructing fingerling bypass facilities at dams, transporting migrants by truck or barge, passing fish through spillways rather than power units by induced spill, and increasing streamflow through reservoirs during migration, have been tested. Multilevel intakes, usually considered a means to provide general water quality control, may have been justified primarily to meet the fishery requirements for control of water temperatures or other water quality parameters that affect fish life. Scheduling the operational use of multilevel intakes is usually based on the fishery needs, and the water manager must have full knowledge of the fishery management programs and the particular requirements for the river reaches affected by their use.

c. Fish Attraction Water. One of the objectives in the design of fish ladders is to provide the proper water currents in the channel area adjacent to and immediately downstream from the entrance of the ladder at the tailwater of the dam. These currents are essential in leading the upstream migrant fish into the fish ladder approach channels (including power plant tailwater fish channels) from the tailwater area or open river. "Fish attraction water" is the term applied to the water which is supplied for the specific purpose of creating these currents. The hydraulic design of fish ladder entrance conditions is usually based on hydraulic model studies. Relatively large amounts of water are required to create the currents (1,000 to 2,000 cubic feet per second), and these may be supplied by large capacity pumps, a hydroelectric unit whose draft tube discharges into the fish ladder approach channels, or by direct diversion of water from the headwater to the approach channels through gravity supply systems. These facilities must be operated during the season of upstream fish migration. The power output from fish turbines is fed into the power system and represents an element of the hydropower resource, but the output is proportionally less than the main units because of small discharges. Fish pumps simply recirculate the water in the tailwater area, but they require relatively large amounts of power to operate them. Direct diversion of water to supply fish attraction water is the least efficient method, considering the loss in energy that would otherwise be available by the use of the water for power production. In summary, fish attraction water is a necessary adjunct to the operation of fish ladders, and the use of water or power to supply it has a bearing on the efficient use of water for all purposes.

d. Fingerling Fish Bypass Facilities. The operation of fingerling fish bypass facilities of the type used in the dams in the lower Columbia River system require flows ranging from 300 to 600 cubic feet per second in the intake area, but about 80 percent of this amount is pumped back from the point where the water enters the bypass diversion channel. The remaining 20 percent (about 60 to 120 cubic feet per second) flows through the diversion channel or conduit to the tailwater, and this amount is lost to the functional utilization of water at the project. The intakes for these facilities are constructed in conjunction with the power unit intakes. Fish screens that are located in the power unit intakes divert the fingerlings up through the gate well slots, thence through orifices or weirs into the fishery bypass collection channels and bypass conduits. The hydraulic systems which comprise these bypass facilities are complex, and their operation must be carefully monitored to assure that the fish are being transported efficiently past the power structure. Changing conditions of pool levels and power discharges may affect their operation, and deficiencies in their effective passage of downstream migrants may require adjusting power plant operation or inducing spill as an alternative means for passing the fish.

e. Increased Streamflows to Aid Passage of Downstream Migrants. In view of the difficulties of passing downstream juvenile migrating fish past a series of large dams, particularly those with hydroelectric facilities, a number of alternative methods are being tested in order to achieve the most satisfactory and economic solution. The use of fingerling bypass facilities is still in the developmental stage, and until these facilities are proven fully effective and are installed at all plants, it may be necessary to enhance the passage of downstream migrants by induced spill of water at critical times. Further, due to longer travel times of fingerling migration that result from the impact of reservoirs in the river system, it is desirable to increase streamflows by releasing water stored in upstream reservoirs during the downstream fish migration. These two factors are considered in the daily management of the water control facilities in conjunction with all other project purposes. Although the annual operating plans may recognize and account for fishery requirements, under actual operation the many variables that affect the daily fishery needs cannot be foreseen more than a few days in advance. This is particularly true of the need for induced spill and increased discharge through the reservoirs during critical times in April and May. A mathematical modelling system to simulate and evaluate hydraulic and fishery conditions is now being used experimentally as an aid in scheduling the water regulation during the critical times of downstream fish migration.

f. Fish Hatcheries. Water intakes for the hatcheries may be from the reservoir or from the river channels downstream. Water quality characteristics including temperature, pH, dissolved oxygen, and nitrogen must be maintained within specified tolerances.

g. Control of Dissolved Gas Supersaturation

(1) Dissolved gas supersaturation occurs in rivers below dams as water plunges over a spillway into a deep stilling basin. Gas supersaturation may injure juvenile and adult fish through the occurrence of gas bubble disease. This condition results from long exposure to water supersaturated with dissolved air exceeding the tolerance level of the fish. The problem has been studied extensively and measures have been taken to partially alleviate the problem. Although it is possible to reduce gas supersaturation caused by spill at dams, there is no way to reduce it to complete non-damaging levels under all conditions of streamflow. Also, threshold levels at which gas supersaturation becomes damaging to fish life are uncertain. Nevertheless, specific efforts are being made to reduce supersaturation by modifying the structural shape of spillways, by adjusting the water regulation in the system to reduce spill, and by adjusting the distribution of spill.

(2) The design and construction of "flip lips" on the downstream ogee section of spillways has been accomplished for several Columbia and Snake Rivers dams. Prototype measurements have indicated a significant reduction of gas supersaturation at those projects, in the low to medium range of their spillway design capacity. These flows correspond to those experienced during normal flood runoff conditions. It is believed, however, that when spill occurs of the magnitude which would be experienced in major floods, the effects of the "flip lips" are drowned out, and they would have little or no effect on reducing gas supersaturation. Overall, the "flip lips" reduce the duration and frequency of gas supersaturation and are therefore beneficial in alleviating the problem. The use of upstream reservoir storage to reduce spill may also alleviate the problem. This solution must be considered with respect to all other aspects of reservoir regulation. Normally, the plan for system wide operation is also to lessen the spill at downstream locations and therefore is consistent with minimizing gas supersaturation. However, it is sometimes possible that the timing of the spill reductions could be scheduled to better coincide with the fish runs. These objectives can be incorporated on a long-range basis into the

annual operating plan, and on a short-range basis into the day-to-day scheduling.

(3) Probably the most direct way to reduce gas supersaturation through water management is by adjusting spill between projects under real-time operation. This can be accomplished by shifting power loads to maximize spill at those projects where the spill produces the least gas supersaturation. Also, it may be feasible to arrange for increased power loads on the hydropower system by transferring loads from thermal plants or other outside resources. Special computer programs are available which simulate the levels of gas supersaturation and can be used for analyzing and projecting the levels resulting from the scheduled spills in the system. These programs use current system data, which is essential for initializing and evaluating the effects of current conditions of spill.

h. Coordination of Regulation for Fishery. Detailed knowledge of the fishery resource and the responsibility for its management are shared by the state and federal fish and wildlife agencies, Indian tribes, and international organizations. These agencies represent the interests of sport and commercial fishing, Indian tribes whose treaties may involve rights for fishing, and the fishery interests of other countries who share in the responsibility for fishery management through treaties and compacts. Input from all of these organizations are important for determining the specific needs of the management of the fishery resource as it pertains to the management of water control systems. This requires a coordinated effort among fishery and water managers to include fishery needs in the water control plans and to carry out these requirements in the day-to-day management of the water and fishery resources.

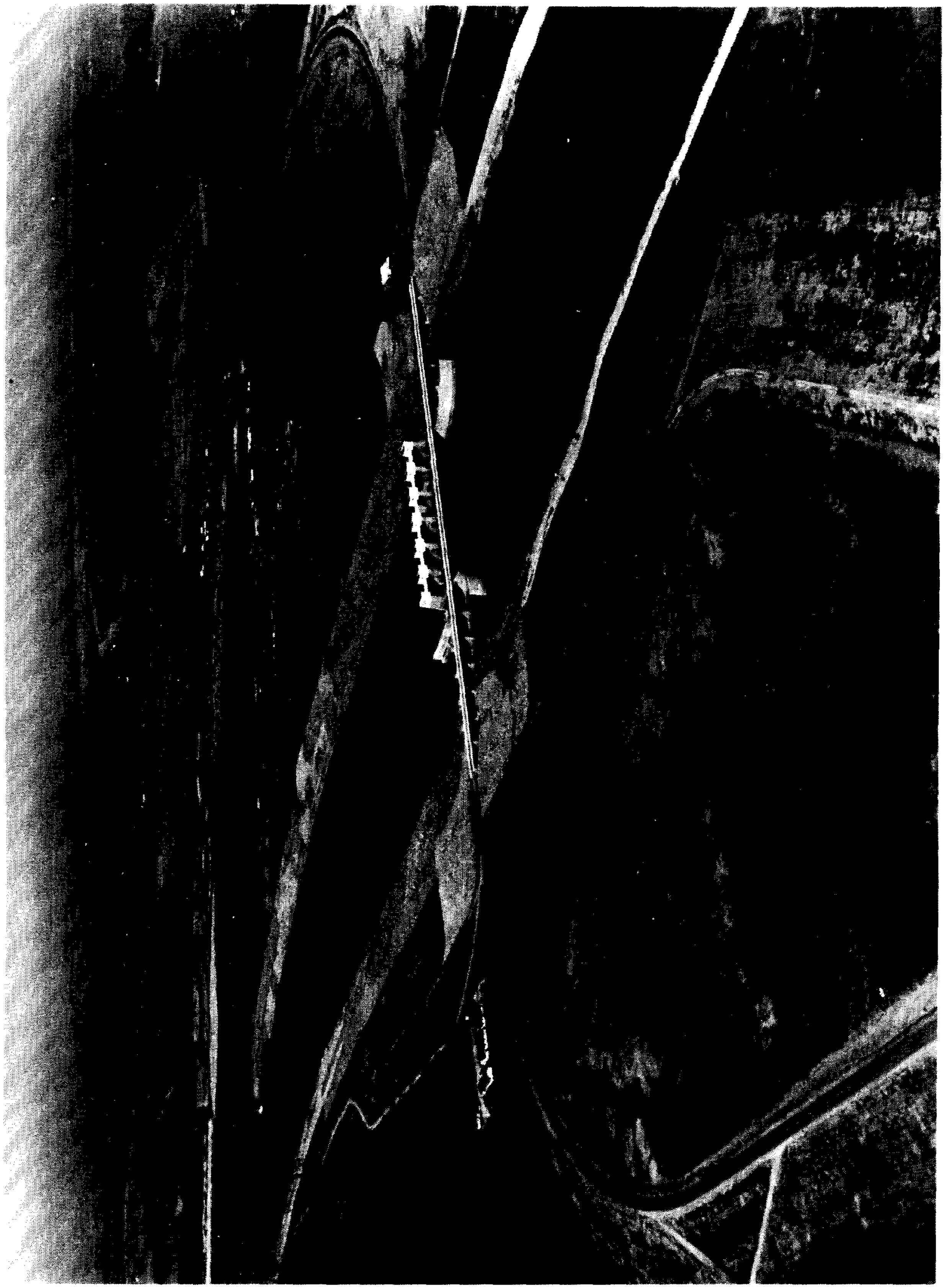

Figure 4-6. Old River Control Structures, Old River, Louisiana; New Orleans District