CHAPTER 3

DEVELOPMENT OF WATER CONTROL PLANS

3-1. Principles and Objectives

a. Water control facilities constructed by the Corps of Engineers, together with projects constructed by other Federal or private entities for which the Corps has responsibility for directing water regulation for flood control or navigation, constitute the major river regulation capability for the United States. Presently, there are approximately 560 dams and other water control structures constructed and operated by the Corps nationwide. There are approximately 88 non-Corps dams for which streamflows are regulated, at least in part, through the supervision and direction of the Corps. Also, there are several projects constructed through international agreements with Canada and Mexico, in which the Corps shares water regulation responsibility with boards or commissions that direct the management of the water control facilities. All of these projects have an effect on the control, management and use of the river systems of the United States, and the control that they provide constitutes the principal means for achieving water management goals for the greatest beneficial use of the nation's rivers. Management of these water resource developments is a major Federal responsibility, and the Corps, through its mandated responsibility for the planning, design, construction and operation of water resource projects on a national basis, must direct the water management activities on the basis of sound engineering practice. The Corps has many years of experience in water resource development and, as a result, has a sound technical background for carrying on water management programs that best utilize the Nation's water resources.

b. The development of water control criteria for the management of water resource systems stems from the earliest planning studies of river basin development and continues through the various steps in investigating, justifying, authorizing, designing, and constructing the water control projects. Even after the projects have been constructed, there may be further refinements or enhancements of the water control procedures, in order to account for changed conditions resulting from new requirements, additional data, or changed social or economic goals. Throughout the life of the project, it is necessary to define the water control criteria in precise terms at a particular time, in order to assure carrying out the intended functional commitments in accordance with the authorizing documents. For this reason, documents related to water regulation are prepared during the various stages of project development to assure that the projects are regulated in accordance with the design criteria and agreed upon procedures.

c. Throughout the nation, the variety of projects and conditions related to water control makes it impossible to develop a single set of water management rules which apply to all projects. Each region or river basin has its own unique requirements which need to be addressed. Furthermore, there is a wide range among projects. For example, the types of criteria required for a series of single purpose locks and dams designed for improving navigation, as opposed to the criteria required for large multipurpose reservoir systems involving several projects and complicated interactions among the various water uses. Nevertheless, for all projects there is an over-riding requirement that methods used in developing water control plans be performed in accordance with general principles and guidelines established as consistent policy for all projects. It is the purpose of this chapter to outline the various steps and technical considerations necessary to develop water control plans, whereby the engineers involved in these programs may apply them to their particular projects or systems.

3-2. Water Control Plans

a. General

(1) The water control plan addresses the needs and methods for determining a plan of regulation considering all water management goals (functional, environmental, social and aesthetic), as well as various techniques, organizations, systems and facilities involved in the regulation of water projects. The principle guides for scheduling project regulation are the basic criteria discussed in Section 3-3.

(2) The organization and staff required to carry out water control functions are also dealt with in the water control plan. Each river basin development and Corps office has it own unique circumstances and meets its own staffing and organizational requirements for water management activities. General guidelines are set forth in existing policies and regulations. For major river system regulation with multipurpose requirements, water management involves many activities which support the process of scheduling project regulation. These include specialized elements which develop project regulation procedures, system modeling, hydrologic analysis, and functional water use studies such as flood control, hydroelectric power, water quality, etc. These specialists perform evaluations and

studies of current operations which are used for updating annual operating plans and seasonal schedules.

b. Integration of Water Quality into the Water Control Plan

(1) Integration of water quality control into the initial water control plan requires carefully designed preimpoundment studies and extensive analysis of preproject conditions. These efforts are coordinated with State and Federal resource agencies and support the development of reasonably accurate predictions regarding the quality of reservoir inflows, storage, discharge and downstream impacts. Subsequently, a water quality control plan is developed.

(2) Predictions of reservoir inflow conditions are based on investigations of the watershed and the quality of surface waters and, perhaps, groundwater quality. Such investigations must consider past, present and future land use activities (agriculture, mining, industry, etc.) in order to identify all possible parameters that may impact reservoir storage conditions. Water quality data must include biological as well as physical and chemical measurements and must be collected during a reasonably complete range of hydrologic conditions including wet and dry. A comprehensive data base including water quality, hydrology and meteorology is essential for application of math modeling procedures.

(3) These preimpoundment studies along with coordination with the resource agencies must also consider downstream conditions, water use needs and resource management objectives. Water quality measurements and operating targets such as water supply, aquatic habitat or fisheries may need special studies. This data base will aid in development of the water quality control plan and support investigation of any post-impoundment impacts whether anticipated or not.

(4) Acceptable predictive techniques require application of an appropriate mathematical model or models. These techniques provide reasonably accurate predictions of the physical, chemical and biological characteristics of impoundments. These studies provide design criteria for water quality control structures such as selective withdrawal and predictions of discharge quality.

(5) Subsequently, the above studies and information will be used to develop a comprehensive operating plan that will best meet the overall water quality, environmental and resource management objectives. These objectives will include both downstream and reservoir users and benefits. In addition, a post-impoundment plan for monitoring inflow, reservoir and tailwater conditions will be developed. These monitoring activities will provide data for daily

operating decisions, evaluating long-term trends or changes in water quality conditions and tracking the effectiveness of the operating plan. This information will be included in water control manuals.

c. Annual Water Management Plans. Annual water management plans represent application in detail for the current operating year for multi-purpose regulation. They are used to define guide curves for water supply functions, such as hydroelectric power, irrigation, navigation, water quality, etc., based on the current conditions of water management for the current year. The annual water management plan may be used to develop an outlook for regulation for more than one year in advance, but the plan is revised annually. The methods of system analysis used in developing the annual plan are essentially the same as those used in planning and design studies.

d. Input from Other Water Regulation Interests

(1) Usually, management of water control systems by the Corps involves input from other agencies of the Federal government, as well as state and local authorities, public utilities, irrigation districts, fish and wildlife interests, and other groups that are involved in environmental and public use functions of project regulation.

(2) Hydroelectric power is an example of the need for integrating project regulation with other water management entities. The water control plan for a coordinated power system requires full knowledge of all elements of the system, including estimates of loads and resources for each of the operating utilities, project and power transmission operating characteristics, methods for scheduling, dispatching, and marketing power, and a myriad of details that affect system regulation. These requirements for coordinated regulation, data inputs, and technical evaluations for achieving power regulation goals can be met by establishing coordinating bodies or groups which are voluntarily agreed upon by the parties involved. The coordination groups provide for the exchange of data and the establishment of work groups for developing coordinated project power operating plans. The water control plan for Corps projects that include hydroelectric power include descriptions of this type of data exchange with other operating utilities or power marketing agencies, as appropriate.

(3) Other water use functions may similarly require data input and coordination between the Corps and special interest operating groups. Water releases for improving water levels for navigation or scheduling of lock closures, for example, must be coordinated with navigation companies. Scheduling water supplies for irrigation or M&I use require coordination and input from the using agencies to

define the specific requirements and scheduling procedures. Special water regulation may be requested by river user groups, and the water manager must appraise and recommend action based on information provided by these local groups and the effects of the proposed regulation on the overall regulation of the project. These special requests should consider all appropriate safety aspects prior to implementation.

(4) Regulation of projects must consider all aspects of the conditions of the rivers and projects, as well as at downstream locations. Many of the functional uses have far-reaching effects on water related systems involving major industries, utilities, and agricultural developments, which are dependent in some degree upon the utilization of the water resource. Furthermore, project regulation has significant effects on the use of the waterways by the general public in relation to environmental and aesthetic considerations.

e. Analysis of Drought Periods

(1) One of the principal objectives of water supply evaluations for a water resource system is to determine the regulation of the system during periods of drought. System studies for hydroelectric power, irrigation, navigation, and municipal and industrial use, singly or in combination, are largely made to determine the assured capability of projects to meet these uses during the most critical sequence of low water conditions that may reasonably be expected. These studies also may be used to determine the minimum instream flow that can be assured at downstream control points. In view of the multipurpose regulation that generally prevails for system regulation, the determination of minimum instream flow must be based on system studies which consider all of the project functions. In many cases, the functions are complementary to each other, and full use of the storage space to meet all functions provides the minimum instream flow requirements in conjunction with other uses. Streamflow augmentation in the interest of water quality is an adjunct to the minimum instream flow requirement.

(2) Determination of drought conditions, in relation to the conditions of streamflow, is usually based on the most critically severe sequence of low water conditions as determined from the historical period of record of streamflow for a particular river system. Inasmuch as the period of record of streamflow data varies widely between river systems, this criterion does not yield a consistent measure of drought severity. Hydrologic low-flow analysis may be necessary to yield consistent probabilities of low water sequences.

f. Water Control Procedures During Planning and Design. The first step in the preparation of water control procedures is accomplished in the planning and design phases of project development. Development of the water control plans should proceed with full knowledge of these planning and design studies, realizing that changed conditions may require adjustments from the operating criteria established during these studies.

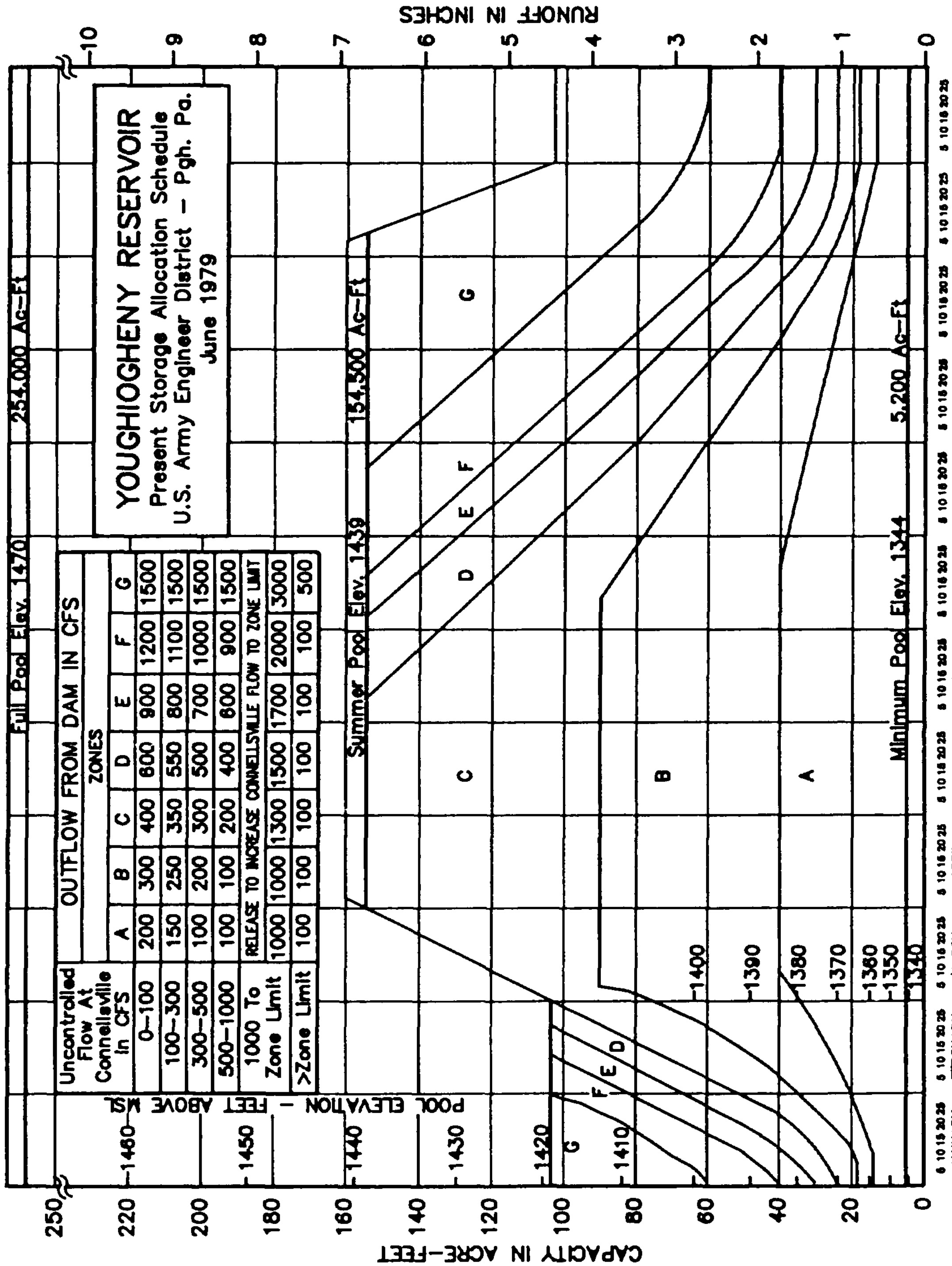
3-3. Development of Regulation Schedules and Water Control Diagrams

a. Definitions

(1) A water control diagram represents a compilation of regulating criteria, guidelines, guide curves and specifications that govern basically the storage and release functions of a water resource project. The diagrams indicate pool levels and limiting rates of project releases required during various seasons of the year to meet all functional objectives of the particular project, acting separately or in combination with other projects in a system. They are usually expressed in the form of graphs and tabulations, supplemented by concise specifications, and are used to help determine regulation (release) schedules. The diagrams are sometimes called guide curves. An example of a water control diagram is shown on Figure 3-1.

(2) The water control diagrams are an important element of the water control plan in that they provide the technical guidance and specific rules of regulation that are mandated as the result of studies and the review and approval process in the planning and design phases as well as in the operational phase. However, the diagrams are only a part of the overall water control plan, which provides for adjusting project regulation on the basis of other factors that may develop in actual operation as the result of unique hydrometeorological conditions, changing water control requirements, and other factors which may influence current project regulation.

(3) Water control diagrams must be documented in a manner to assure that project regulation is accomplished in accordance with the water control plan as developed from the project regulation and system analysis studies. Guide curves are used to define the seasonal and monthly limits of storage which guide the regulation for planned purposes. The regulation is in accordance with specific operational rules that define the requirements at the project and at downstream locations in order to meet project objectives. Physical operating limits are established that define the limiting discharges and water levels at the project and in some cases at downstream locations, together with rates of change of discharge and



Uncontrolled Flow At Connellsville In CFS	OUTFLOW FROM DAM IN CFS – ZONES A	B	C	D	E	F	G
0–100	200	300	400	600	900	1200	1500
100–300	150	250	350	550	800	1100	1500
300–500	100	200	300	500	700	1000	1500
500–1000	100	100	200	400	600	900	1500
	RELEASE TO INCREASE CONNELLSVILLE FLOW TO ZONE LIMIT						
1000 To Zone Limit	1000	1000	1300	1500	1700	2000	3000
>Zone Limit	100	100	100	100	100	100	500

Figure 3-1

water levels. Special limitations are also applied that define limits of operation of hydraulic water control facilities (spillways, outlet works, power generation equipment, navigation locks, fish passage facilities, etc.), as they may affect the scheduling of water releases. Detailed charts and diagrams are prepared that define flood control regulation as related to hydrometeorological conditions, storage, and system regulation. Similar types of charts and guides are prepared for control of diversion and by-pass structures, hurricane or tidal barriers, and interior drainage facilities for levee projects. For those projects that include hydroelectric power, detailed instructions are set forth that define the methods for scheduling power, controlling power facilities, dispatching power in an integrated power system, limitations of operation of the power facilities, and monitoring system operation.

b. Assessments of Changed Conditions from Planning and Design Studies

(1) General. Completion of a project may occur several years after the design phase and perhaps decades after the time that the original planning studies were made. Preparation of the water control plan and the documentation of that plan in the water control manual must be undertaken based on current knowledge of conditions regarding river basin management, and the manual should be completed by the time the project becomes operational. Furthermore, for many projects that have been operational for a number of years, the water control plans and water control manuals are out-of-date, and there is a need for revising them to make them applicable to current conditions. Many of the existing water control manuals were prepared prior to current concepts of system regulation and sophisticated computerized methods of analysis. Requirements for enhancing the multi-purpose use of projects has become important, particularly with regard to environmental and public use aspects of the projects. For all of the above reasons, there is a requirement to periodically review and update the regulation procedures.

(2) Additional or New Hydrologic Data. After a project is planned or designed, additional hydrologic data from existing or new data stations become available, which in combination with previously available data, are used to re-study system regulation schedules. These data may be in the form of streamflow, rainfall, snow accumulation, or other elements which are observed routinely to help define the hydrologic character of a drainage basin. These additional records not only extend the period of record of the basic data used in the initial water control studies, but also enhance the determination of regulation criteria and basin watershed characteristics that are used in modeling procedures. The new data may also include records of significant events of extreme conditions

of flood or drought which may require modification of the water control diagram. In some cases, the additional basic data warrants a complete system hydrologic analysis for refining the derived streamflows at the projects. In any case, it is important to fully utilize all available hydrologic data when revising the water control plan.

(3) Reevaluation of Water Control Requirements

(a) In addition to the basic economic functions for which the projects were originally authorized and constructed, water management goals now include environmental and social aspects of project regulation. This conforms to public laws dealing with water related activities that were enacted after the authorization of most water control projects. These laws require inclusion of certain aspects of environmental, fish and wildlife, and recreational uses in the management of the projects or improvement of the environment of the rivers downstream through project regulation. The specific uses are determined from river basin investigations and are incorporated into the regulation plan.

(b) Besides the new requirements for including environmental and social goals in project regulation, there needs to be reevaluations of the water control criteria for meeting single or multi-purpose uses for which the projects were authorized. In the span of time between the planning or design studies and the preparation of a detailed water control plan, there may be significant changes in policy procedures or other conditions which may affect the overall regulating criteria. Therefore, a study program is carried out in connection with the development of a detailed rule/guide curve (diagram) to further refine the regulating criteria through the use of additional basic data, water management requirements, and systems analysis techniques that have become available subsequent to the planning and design studies.

(c) A periodic review of flood control regulating parameters is often required because of changed conditions with respect to seasonal downstream channel capacities, possible downstream development adjacent to the river channel, and changed economic values for flood protection. In many cases there are encroachments in the flood plain that require a reevaluation of target control elevations for flood regulation, or controlled river levels during the post flood evacuation period. The studies may be used to refine guide curves in conjunction with the additional flood data described in subparagraph (1) above. System flood control studies for multi-purpose river basin developments are made using computerized system hydrologic and reservoir regulation models.

c. Basic Flood Control Regulation

(1) Principles and Objectives

(a) The objective of regulation for flood control is to reduce flood damages to the extent possible with available facilities. The best method of attaining this objective is often difficult to determine and depends principally on the location and types of damages to be prevented, location and amount of storage capacity, flood characteristics, flood frequencies, and extent of uncontrolled drainage area.

(b) In selecting the water control diagram (and plan) to be followed, a study should be made of the results of applying various regulation schedules to the past floods of record and selected hypothetical floods. Although there is sometimes a lack of the basic data needed for a comprehensive investigation and a short period of record may be a poor index of future events, the historical record of floods is the principal source of factual data that can be relied upon for deriving and testing flood regulation schedules.

(c) In order to achieve flood control objectives, it is necessary to establish and maintain existing nondamaging channel capacities. Every effort should be made to prevent encroachments downstream of the dams which would reduce existing reservoir release rates. This can be accomplished through a joint effort between water control managers and project operators. Stored floodwater can be released up to the maximum "nondamaging" downstream channel capacities, consistent with regulation procedures, provided the releases do not exceed peak inflow into the reservoir(s). Project operators continually monitor downstream conditions and notify water control managers immediately whenever development might adversely affect regulation procedures. Water control managers may visit the area with the project operator, contact the owner, and if necessary follow through with correspondence stating that the Corps will not reduce the existing maximum nondamaging release rate to prevent flooding of the site area. Correspondence is also forwarded to appropriate local and State agencies.

(2) Classification of Flood Regulation Methods

(a) General. Although various bases exist for a classification of methods of flood control regulation, no simple analysis can be made in the more complicated situations. A general plan has been adopted, however, which classifies flood regulation by three basic methods. These methods are described in the following paragraphs.

(b) Method A. Method A regulation is based on maximum beneficial use of available storage during each flood event. This method incorporates the concept of reducing damaging stages at the locations being protected as much as possible during each flood with the currently available storage space, thus disregarding the possibility of having an appreciable portion of the flood control storage capacity filled upon the occurrence of a large subsequent flood. Where the principal damage areas are agricultural, the nondamaging stages toward which regulation is directed may be established at higher levels during the non-growing season than during the growing season when potential damages are greater. The regulation to obtain maximum benefits in minor to moderate floods can be only as successful as the ability to forecast flow conditions at the control structures and the damage centers. The use of computerized system hydrologic models for real-time streamflow and project forecasting is intended to make use of this concept of regulation and thereby maximize the flood control effectiveness of project regulation. It is pointed out, however, that there are definite limitations to the period of effective use of this type of forecasting because of the inability to reliably forecast weather related parameters (rainfall, air temperature, etc.) more than a day or two in advance. The use of computerized models enhances the ability to forecast the hydrologic conditions that affect project regulation and provide the capability of analyzing statistical probabilities of future events that would affect project regulation.

(c) Method B. This method of regulation is based on control of the project design flood. At projects where a limited amount of flood control storage is available and where the primary flood control objective is to provide protection up to a specified project design flood, flood regulation based on continual releases, up to specified amounts, is often adopted. The regulation consists of releasing water at an established rate (as may be determined by associated flood conditions and/or reservoir contents) and storing all excess inflow as long as flooding continues at specified locations. The release rates are established so that all the storage capacity is utilized during hypothetical regulation of a project design flood when operating under the adopted schedules. The schedules are then followed at all times on the assumption that the result will be the best overall regulation of floods. While this method provides considerable assurance of satisfactory regulation of major floods, less satisfactory regulation of lesser floods which occur more frequently may result in a substantial loss of benefits and complaints from downstream communities. This is particularly true at damage centers where releases can be timed so that they do not combine with damaging flows from uncontrolled areas. When benefits are desired for a considerable distance downstream, general flood characteristics and the period of time that forecasts of river stages can be extended become increasingly important. Uncertainties which occur with the use of this method may result from being too optimistic about assumed project releases or the fact that each major flood is an individual event which may significantly alter the release patterns for control of a future flood. The effect of a possible increase in duration of downstream flooding may also be mistakenly overlooked.

(d) Method C. Method C is a combination of methods A and B, and quite often results in the most appropriate flood regulation. For instance, in protecting agricultural areas a regulation plan for maximum damage reduction during ordinary floods may be desirable during the main farming season, but may not be the most advantageous plan during the winter or severe flood season. Furthermore, it may be desirable to provide reserve (sometimes termed primary) storage to give increased assurance of protection for an important leveed area or a town which is endangered only by unusual floods. Thus, after the lower part of the storage is filled, a fixed schedule of releases would be followed to assure greater control of major floods at the expense of less regulation of moderate floods. A necessary increase in releases during emptying periods may cause difficulties by increasing the duration of flooding during flood recessions. In summary, each of the proposed methods for defining the plan for flood control regulation has inherent strengths and weaknesses, and the determination of the plan for a particular system must be based on the study effort carried out in the planning and design phase of project implementation, together with more detailed studies of project regulation performed in the operational phase. By use of computerized systems analysis models, various alternatives in methods of flood control regulation can be conveniently tested and evaluated in order to achieve the optimum regulation. Further, the experience gained in the application of these models for studying regulation plans can be applied in real-time regulation with the assurance of achieving an appropriate overall regulation.

(3) Flood Regulation Schedule for Single Reservoir

(a) In the case of a single reservoir built for the protection of the local area immediately downstream from the dam (small uncontrolled intermediate area), the regulation schedule is a simple matter. The release schedule would consist of passing all inflow up to the value of the channel capacity and is the same for all the methods discussed in Paragraph 3-3c(2), above.

(b) If benefits are to be obtained at remote locations only (appreciable uncontrolled intermediate area), regulation under method A consists of keeping the discharge at the damage center within bankfull capacity, or a minimum release from the project (controlled area) when above bankfull. Releases at the dam within the limits of available storage would be based on observed or forecast runoff conditions for the uncontrolled drainage area. The success of such regulation is dependent upon advantageous time relationships or the opportunity to make adequate forecasts. Releases would be based on observed and/or forecast conditions at the project site and downstream locations. A regulation schedule of method B would provide for releasing water at specified rates so that the design flood runoff could be controlled without exceeding flood storage capacity.

(c) Where primary flood control benefits are sought at downstream local and remote locations, the method of regulation and preparation of schedules becomes more complicated than for remote benefits alone, since additional restrictions on releases for successful regulation require more storage capacity. If method A is to be followed, the adequacy of the forecasts becomes of primary importance, and streamflow simulation models for forecasting river and reservoir conditions are mandatory in real-time regulation for making most efficient use of reservoir storage for flood control.

(4) Flood Regulation Schedules for Multireservoir Systems

(a) General regulation schedules for an integrated system of projects are usually developed first for the tributary projects operating as separate units. The adjustment of the individual regulation schedules for coordinated regulation of the various tributary and main river projects are generally based on system analyses of the basin development, design floods, and historical floods of record. The critical flood regulation plan may be determined by the occurrence of a succession of moderate floods rather than one severe flood, or an unusual flood event which is distributed in time or space differently than the normal flood occurrences. Also, in those cases where it is possible to forecast seasonal runoff volumes several months in advance (as, for example, snowmelt runoff), it is desirable to establish flood regulation criteria that considers the magnitude of expected runoff volume on a seasonal basis.

(b) Regulation based on method A is most commonly used for multireservoir systems. If channel capacities below the individual dams are limited and both local and remote benefits are obtained at locations, it is quite possible that sufficient storage will not be available for complete control during a critical basin-wide flood. Regulation based on maximum utilization of available storage probably would provide the most benefits for the system. However, to demonstrate this to be the case and to provide the necessary information for successful regulation on that basis, extensive data on seasonal channel capacities and damage areas should be determined and periodically updated. Stream profiles for various combinations of releases from different projects must be established and the areas flooded at successive elevations of the profiles must be determined. With these data presented in the form of stage-damage curves for various reaches, controlling stages can be established so that the flood control storage may be evacuated in a reasonable length of time, minimizing damage in the basin. These factors can be evaluated with computer simulation models, and through trial and error of various methods of regulation, the optimum plan of flood regulation can be formulated.

(c) The regulation schedules depend upon forecasting both controlled and uncontrolled river stages at all of the control points. If uncontrolled damaging stages are forecast or anticipated, reservoir releases are adjusted so that the streams will just reach flood stage or some lesser stage where the uncontrolled area is large and a margin of safety for unpredictable runoff is desirable. The process may be iterated several times to test various adjustments to reservoir releases between projects in order to achieve a balanced regulation. The results of the studies are used to prepare water control diagrams which define relative amounts of storage between projects and general guides to reservoir filling or evacuation. In actual real-time regulation, the same principles are applied, but the analysis of data is based on current forecasts of streamflow and reservoir levels rather than historical data. The forecasts change from time to time because of the changing conditions of weather variables, so that adjustments to reservoir regulation are being constantly applied to make best use of the residual flood control storage at each of the projects. Also, through the process of model simulation, various extremes of weather related factors can be tested and evaluated to be sure of retaining sufficient storage space for control of unusual rainfall or snowmelt events. In summary, the guide curves (water control diagrams) provide general guides for reservoir filling and evacuation in order to meet the flood control objective of maximum beneficial use of available storage. In actual operation, the analysis afforded by real-time model simulation and forecasting provides the projections for adjusting project regulation based on current hydrometeorological conditions and estimates of future events, in order to achieve the optimum balanced regulation from the best information that is available as operating decisions are being reached.

(d) Regulation based on method B may be feasible if channel capacities below the dams are relatively large and the remote flood control benefits are obtained at a few centralized locations. Regulation schedules are based on making fixed or variable releases that depend upon existing or forecast stages at downstream control points, and on the control of design floods at the individual projects.

(e) Normally, for major or complex river basin developments, method A or a combination of methods A and B will provide the most dependable benefits.

(5) Seasonal Variation in Flood Control Storage Requirements. Water resource systems are most commonly multipurpose. Although many Corps projects have been justified primarily for meeting flood control and navigation objectives, the other water management functions described in Chapter 2 have become increasingly important in order to achieve the full utilization of water resources. While flood control may represent the primary function for some particular projects, the capabilities of these projects to control floods can be assured along with other functional uses by seasonal allocations of project flood control storage space. The seasonal variation of the flood control requirements is determined by flood routing studies of floods of all magnitudes, distributed seasonally over the period of historic record. Synthetically derived floods may also be analyzed if the historical period of record is insufficient to provide an adequate sample of flood distributions. The seasonal guide curves (water control diagrams) that define the flood control storage space requirement are determined from these studies for each project or system of projects. These guide curves are drawn as enveloping lines of storage space required for the control of all historical floods as a function of the time of year, and they are usually drawn as straight lines on a monthly or seasonal basis. These curves represent the maximum allowable reservoir levels for which water may be stored for other multipurpose uses on a seasonal basis. For rain-fed rivers, the seasonal flood control storage reservation guide curves apply to all years, but for those rivers where snowmelt is a significant contribution to runoff, a family of guide curves representing the flood control storage reservation requirements may be derived which are based on the forecasts of anticipated seasonal runoff volume. Also, it is possible to designate flood control storage in different categories. For example, the upper portion of the flood control storage (termed primary) is assured on a completely firm basis, but the lower portion (termed secondary) is conditionally assured. The latter depends on time of year and other desired multipurpose uses that may partially utilize this portion of the storage space under certain pre-planned operation rules for regulation.

(6) Planned Control of Individual Floods. The water control plans for flood control, as described above, provide the general concepts and guidelines for flood control regulation. As noted previously, these plans are developed mostly from hindsight analysis

of historical flood events, and they are designed to achieve a generalized, optimally balanced plan of regulation for all floods, considering both minor and major floods of record as well as design floods. No two flood events are the same, and the history provided in the flood records cannot possibly represent all future events. The use of hydrologic modeling on a real-time basis provides the water control manager a means for completely analyzing the system regulation and adjusting it hourly or daily to fulfill the required flood regulation.

(7) Reservoir Evacuation. Post flood evacuation of water stored in reservoirs for rain flood regulation must be accomplished as soon as possible following the flood event. There are two general criteria for post flood evacuation: (a) releases made so that streamflows at downstream control points are at or below bankfull or non-damaging channel capacities, keeping in mind that nondamaging stages can vary seasonally in agricultural areas, or (b) releases made so that streamflows do not exceed the peak flows that occurred during the course of the flood event, where such peaks exceed bankfull capacity. The objective of release of water stored for flood control, where such floods are caused primarily by rainfall, is to provide storage for future control of subsequent flood events. In order to avoid the risk of a series of floods whose combined volume would exceed the reservoir storage capacity, it is desirable to evacuate the stored water as quickly as possible, consistent with downstream runoff conditions and weather forecasts. To meet this objective, evacuation plan (b) will provide the fastest evacuation of stored water. Release of stored water which results in above bankfull capacities prolongs the period of downstream flooding. Evacuation plan (a), on the other hand, may result in much delayed evacuation of stored water and therefore causes a greater risk of flooding from subsequent storms. In actual practice, usually a compromise between plan (a) and plan (b) is adopted, and the post flood evacuation results in river stages somewhat higher than bankfull, but lower than peak stages experienced during the flood due to the contribution from uncontrolled areas. The decisions made on adopting post flood evacuation criteria are based on flood routing studies of individual floods, damages which occur from prolonged above bankfull stages, and risks of future flood events.

d. Integration of Basic Seasonal Flood Control Guide Curves with Other Objectives

(1) General

(a) An increasing number of multipurpose projects have been constructed in connection with basin-wide development of natural resources. Therefore, development of the water control diagrams must be compatible with all water control objectives. For some projects, storage for low-water regulation, navigation, irrigation, power production, water supply, or recreation is provided by allocating storage capacity between particular levels for specific purposes, in addition to that required for flood control, and the regulation schedules for the various uses may be independent of each other. In many reservoir systems, the multipurpose functions are compatible for joint use of the reservoir storage space, and the allocated storage space and project capabilities for all joint use functions are determined from reservoir system analysis studies. The seasonal storage allocation for flood control, as discussed in Paragraph 3-3c(5) above, provides for flood regulation in a manner similar to single-purpose flood control projects, and the seasonal guide curves defining storage capacities for all functions are depicted by charts plotted with ordinates representing storage amounts, and abscissas representing time of year.

(b) Sufficient storage capacity or water supply available from storage release and natural flow often is not sufficient to provide fully for all the desirable functions. Development of regulation schedules under these conditions results in a semidependence between purposes and requires that secondary consideration be given to other related functions when schedules are being developed for a specific purpose.

(2) Development of System Analysis Studies for All Multipurpose Uses

(a) General. The basic concepts of reservoir system analysis studies that are performed in the planning and design phase apply to the development of guide curves (water control diagrams). The emphasis of the studies in the planning and design phase is to determine the project capabilities, such as firm or secondary power potential, peaking capability, unit sizes, irrigation capabilities, water supply potential, low flow augmentation, etc., based on the historical record streamflows and proposed regulation criteria. The emphasis in the operational phase is to develop the general framework of guide curves which account for changed conditions and refinements of planning and design studies. Further, the water control plan may call for specific guide curves based on the known conditions of project regulation in the current year. These studies are also based on computerized system analysis for multiproject or multipurpose systems.

(b) Hydropower System Operation. Regulation schedules for hydropower operation cover a wide range of requirements. The general methods for evaluating power capabilities and determining power regulation are described in EM 1110-2-1701, and the application of these methods determine the principles of regulation for a specific project. Power guide curves are derived and define the following criteria:

- the month-by-month reservoir schedule and operating limits for each project as required for system power regulation

- the plant and power system capability as related to the sale of electrical energy

- the regulation of each project in the system to meet its proportional share of the electrical power system load, in conjunction with all other water management requirements

(c) Irrigation, Navigation, Fish and Wildlife, Water Quality, M&I, and Other Functional Use Requirements. As is the case for integrating basic seasonal flood control reservoir guide curves (water control diagrams) with power operations, the water supply requirements for irrigation, navigation, fish and wildlife, water quality, M&I and other functional uses may be integrated with basic flood control guide curves. Inasmuch as the water supply functions could conflict conceptually with flood control for the assured use of reservoir storage space, there must be definite guide curves, which define the upper and lower limits of reservoir regulation for these water supply functions as well as for flood control. These limits are usually defined as seasonally variable guide curves, which are inviolate in actual operation except as necessary to meet the specific functional goals set forth in the planning and design phase. The definition of these guide curves becomes the means for balancing the relative use of storage space in reservoirs when conflicting multipurpose functions occur and for achieving a compromise as may be necessary to meet the project's functional commitments. The functional objectives of project regulation to provide water supply and methods for analyzing the water control plans to account for them have been previously described. These basic requirements are incorporated in the water systems analysis operational studies as discussed into this section, and the refinements in project regulation are incorporated into the seasonal guide curves. The guide curves are usually generalized for application to all years and would thereby account for future variable hydrologic and operating conditions anticipated from the system studies. In some cases, the guide curves are developed individually on a year-to-year basis in order to account for specific operating criteria as defined for that particular year.

(d) Environmental, Social and Aesthetic Requirements. For many river systems in the United States, the awareness of environmental, social and aesthetic values has focused on the importance of these aspects of project regulation. Some of the requirements are set forth in Federal legislation, while others result from local, state or regional input that may represent the desires of particular interest groups or the general public in preserving or enhancing these values. There is a wide range of desires that may be considered in connection with environmental, social and aesthetic considerations, some of which are easily accommodated in the general concepts of regulation for other purposes. Other desires may be almost completely infeasible or impractical from an economic point of view, considering the functional uses for which the project was authorized and constructed. The judgment on which to base consideration of these requirements or desires must be made with full knowledge of the history of project development, legislative actions, project justification, and the planning of project utilization. Various alternatives for meeting environmental and social goals should be tested in connection with water control plan studies in order to determine their effects on each of the water control functions, and recommendations for change should be made based on the judgment and analyses of the results of the studies. The regulation schedules which include environmental, social, or aesthetic values may be in the form of generalized relationships and rules which apply to all years of future regulation. Others are specifically developed for a particular year or season's and are changeable from year-to-year. The detailed regulation schedules may be in the form of: (1) guide curves of storage required on a seasonal basis in conjunction with other functional water uses; (2) minimum project releases which may vary seasonally or as a function of water in storage which is usable for downstream release and surplus to other needs; (3) rates of change of discharge or water surface elevation, either at the project or at a downstream control point; or (4) special short-term releases for a particular environmental or aesthetic need.

(3) <u>Solutions of Systems Analysis to Determine Optimal and Balanced Regulation</u>. The use of reservoir systems analysis techniques, discussed in Paragraph 3-3d(2), provides the basic means for developing and testing the detailed regulation schedules and water control diagrams in general. The studies may be used to simulate the regulation of projects on a foresight rather than hindsight basis by using derived or synthetic forecasts of project inflows. If it is not hydrologically feasible to forecast inflows, the observed conditions of runoff may be used, with the assumption that no reference is made to future hydrologic events in determining the regulation within the studies. Various assumptions for regulation criteria of each of the elements discussed in Paragraph 3-3d(2) can be individually tested in conjunction with all other elements, and the optimum and balanced regulation criteria and schedules may be derived by repetitive solutions of the simulation.

3-4. Testing Water Control Plans

a. General. Water control diagrams are usually developed on a "hindsight" basis, using historical streamflow data, and with full or partial knowledge of runoff events that may be used in adjusting the criteria to best achieve the water management objectives. The schedules may have been derived on only a portion of the historical sequence of streamflows which had been selected as the most critical sequences of either high- or low-flow conditions that would control the water management criteria for flood control and/or water supply functions. In actual operation, the runoff sequences will never duplicate those of the historical record. Therefore, it is desirable to test the guide curves and other criteria on the water control diagram using independent data, in a manner similar to actual operation. This concept applies to both flood regulation as well as regulation to meet water supply utilization for hydroelectric power, irrigation, navigation, and other water uses. The data used for input to the test regulations may be historical data, other than those used in developing the schedules, or it may be independently derived by statistical stochastic methods or from hypothetically derived streamflows, design floods, etc.

b. Short-Term Flood Control Analysis. Although the flood control regulation criteria are usually developed from studies of the maximum floods of record, it is desirable to test the criteria on all magnitudes of floods, including the infrequent design floods as well as more frequent floods of lesser magnitude. For this reason, a program should be established for making simulations of streamflow and project regulation for short-term analysis, using daily or shorter time period streamflows as may be appropriate, for testing the flood regulation criteria on independent data which encompasses the entire spectrum of flood conditions. Procedures using computer models simulate both natural and regulated streamflows at all inflow stations, projects and downstream control points in the system and perform the necessary routings through the structures and channel for modeling a complete river system regulation. Thus, these models may be used to simulate forecasts of streamflow and project conditions in real-time, or may be used to simulate system regulation using observed or derived streamflows.

c. Long-Term Water Utilization Analysis

(1) Testing regulation guide curves and other criteria on the water control diagram for long-term water utilization should also be performed for those projects or systems which involve hydroelectric power, irrigation, navigation, M&I, water quality, low-flow

augmentation, or other water uses. The tests are performed using system analysis techniques, and generally use mean monthly streamflow data and monthly regulation criteria. The system regulation should usually be tested on data independent from those used in establishing the regulation criteria. For those projects where the water control plan uses forecasts of seasonal runoff volume as one of the parameters, the simulations should be based on forecasts of runoff volumes which have been derived from available hydrometeorological data. The simulations developed from these tests will reflect the errors in forecasting seasonal runoff volume and accordingly provide a realistic appraisal of system regulation under actual operating conditions.

(2) Testing regulation criteria as described above provides the means for evaluating the effectiveness of the water control plans under actual operating conditions and for refining the water control diagram into a final document that can be used on a daily basis. Any serious deficiencies in regulation that are detected in the testing program should be dealt with by reformulating the plans.

3-5. Winter Navigation. The water control plan needs to include management of ice to minimize adverse impact on winter navigation. This plan will cover the river system and include the following:

- ice and related hydrometeorological data collection and monitoring
- ice forecasting
- communication system (between projects, water control offices, towing industry, and Coast Guard)
- regulation plan for river system
- decision matrix on when ice conditions are too severe to maintain project operation for navigation

This plan must consider all project purposes such as navigation, water quality, flood control, hydropower, recreation, and environmental protection.

3-6. Revision of Water Control Plans

a. General. The water control plans and manuals for many projects that have been in operation for several years are out of date, and there is a need to revise them to be applicable to current conditions. Also, delays in revision often result from budget and manpower constraints, and the high proficiency of water control managers in performing their duties; i.e., management often decides it can get by without updating the documents and, consequently, assigns this task a very low priority. Continual vigilance by responsible water control managers is required to overcome this unfortunate dilemma. Many of the existing water control manuals were prepared prior to current concepts of system regulation and sophisticated computerized methods of analysis. Requirements for enhancing the multipurpose use of projects has become important, particularly with regard to environmental and public use aspects of the projects. For these reasons and others that follow, there is a need to periodically review and update the regulation criteria and procedures.

b. Additional or New Hydrologic Data. In some cases it is important to fully utilize all available hydrologic data when revising the water control plan, especially when the period of record available for design was relatively short. After a project is designed or completed, additional hydrologic data from existing or new water data stations become available, which in combination with previously available data, are used to restudy system regulation schedules. The data may be in the form of streamflow, rainfall, snow accumulation, or other elements which are observed routinely to help define the hydrologic character of a drainage basin. These additional records not only extend the period of record of the basic data used in the initial water control studies, but also aid the revision of regulation criteria and basin watershed characteristics that are used in modeling procedures. The new data may also include records of significant events of extreme conditions of flood or drought which may require modification of the water control diagram. In some cases, the additional basic data warrants a complete system hydrologic analysis for refining the derived streamflows at the projects.

c. Reevaluation of Water Control Requirements and Objectives

(1) In additional to the basic economic functions for which the projects were originally authorized and constructed, water management goals now include environmental and social aspects of project regulation. This conforms to public laws dealing with water related activities that were enacted after the authorization of most water control projects. These laws require inclusion of certain aspects of environmental, fish and wildlife, and recreational uses in the management of the projects, or improvement of the environment of the rivers downstream through project regulation. The specific uses are determined from river basin investigations and are incorporated into the water control plan.

(2) In addition to the new requirements for including environmental and social goals in project regulation, there needs to be reevaluations of the water control criteria for meeting single or multipurpose uses for which the projects were authorized. Conditions may change. For example, a periodic review of flood control regulating parameters is sometimes required because of changed conditions with respect to seasonal downstream channel capacities, possible downstream development adjacent to the river channel, and changed economic values for flood protection. In many cases the are encroachments in the flood plain that require reevaluation of target control elevations for flood regulation, or controlled river levels during the post flood evacuation period. The studies may be used to refine guide curves and regulation schedules on water control diagrams, in conjunction with the additional flood data described above. System water management studies for multipurpose project and river basin development may now be made using computerized hydrologic and water control models.

d. Updating or Modifying Water Quality Control Procedures and Plans

(1) If the appropriate techniques are properly implemented, water quality conditions associated with initial impoundment and the first several years of operation will be anticipated. In most cases, unusual but predictable phenomena will occur for the first year or so after initial fill. For example, in stratified reservoirs, inundated vegetation will generate high concentrations of hydrogen sulfide which will flush out of the project by the second or third year of operation.

(2) The fact that changes will occur in terms of water quality and operating procedures must be anticipated. Land use changes, extreme or unusual weather events, etc., may induce abrupt or long-term changes in water quality conditions. Operating procedures may also be modified for other reasons such as water user needs or changes in management objectives. Operating experience may suggest alternative procedures or indicate need for major modifications.

(3) Monitoring and surveillance activities, which provide data for operating guidance, usually include watershed surveillance, inflow and discharge monitoring and water quality profiles in the reservoir. These actions also identify long-term trends as well as abrupt changes. In some instances, special studies of reservoir conditions will be required in order to develop guidance for modifying operating procedures or, perhaps, control structures. Such studies may be relatively simple in time and scope or may require

math modeling, reservoir system analysis or physical model applications.

(4) The above activities, information and data will also provide input for updating water control plans and manuals. Water quality data summaries will be included in project descriptions and used to identify changes in conditions. The operating experience will be documented in terms of success and/or failure in meeting water quality objectives. Results of studies will be documented particularly when used as a basis for modifying operating procedures.

e. Constraints on Water Control Plans. The physical size and capacity of water control structures, and other conditions that exist at the time of project design, certainly impose limitations and boundaries on water control capabilities, but are not considered to be constraints. A constraint is a condition that arises subsequent to project design that prevents (or is allowed to prevent) the achievement of a water control objective. Constraints may result from physical, social or economic impacts on residual, agricultural, industrial or environmental areas that are affected by the water control capabilities of a project. The purpose of the discussion here is to acknowledge some of the kinds of constraints that come to bear on water control projects. Other than possible compensating changes in water control procedures, however, their resolution is beyond the scope of this EM.

(1) Constraints due to Incomplete Project Development

- downstream channel capacity used for design is not provided, which may have been based on clearing and snagging, realignment, enlargement, dredging, or levee construction.

- inadequate, vague or complete lack of easement acquisition that prevents full use of storage space, or flowage downstream of water control structures.

(2) Impacts (Constraints) Beyond the Scope of Design

- encroachments in the flood plain downstream and in areas upstream of water control structures impose restrictions on utilization of authorized storage space and release schedules.

- attenuation of flows by control structures often permits and encourages low lying lands that were frequently flooded before project development, to be cleared and used, which reduces the nondamaging channel capacity.

- near bankfull flows and near constant (of higher than normal) pool levels for prolonged periods may increase erosion, requiring reduced or fluctuating releases and a change in pool levels.

- seasonal drawdown may be restricted due to development of mud flats in the reservoir area.

- the time of inundation of roads and railroads may be highly restrictive on transportation and prolonged inundation of boat ramps, docks and marinas may severely hamper recreation activities.

- the time required to notify the public may delay implementation of a release schedule during flood emergencies.

- earthquake potential or embankment boils may restrict or prevent use of authorized storage capacities, or structural deterioration may require reduced discharge capacities to ensure project integrity.

- structural rehabilitation may require significant changes in release schedules temporarily.

- point or non-point pollution and stratification can degrade water quality and render it unsuitable for fish and wildlife, water supply, and other conservation purposes.

- meteorological forecasts that are unauthorized (non-Federal) for Corps use may be inaccurate and may mislead the public re potential impacts on Corps projects.

- conservatively high (intentionally inaccurate) hydrologic forecasts issued by the NWS can mislead the public, our common constituency, causing the public to question Corps releases and to seek water control action that is inappropriate.

- frequency of filling and runoff volume may increase at impoundments over pre-project conditions, requiring higher release rates from reservoirs and additional pumping capacity at local protection (interior drainage) projects.

- an extreme low flow event may occur that is more severe than the hydrologic record when the project was designed, which detrimentally impacts conservation purposes by restricting releases for water quality, water supply, hydropower, etc.

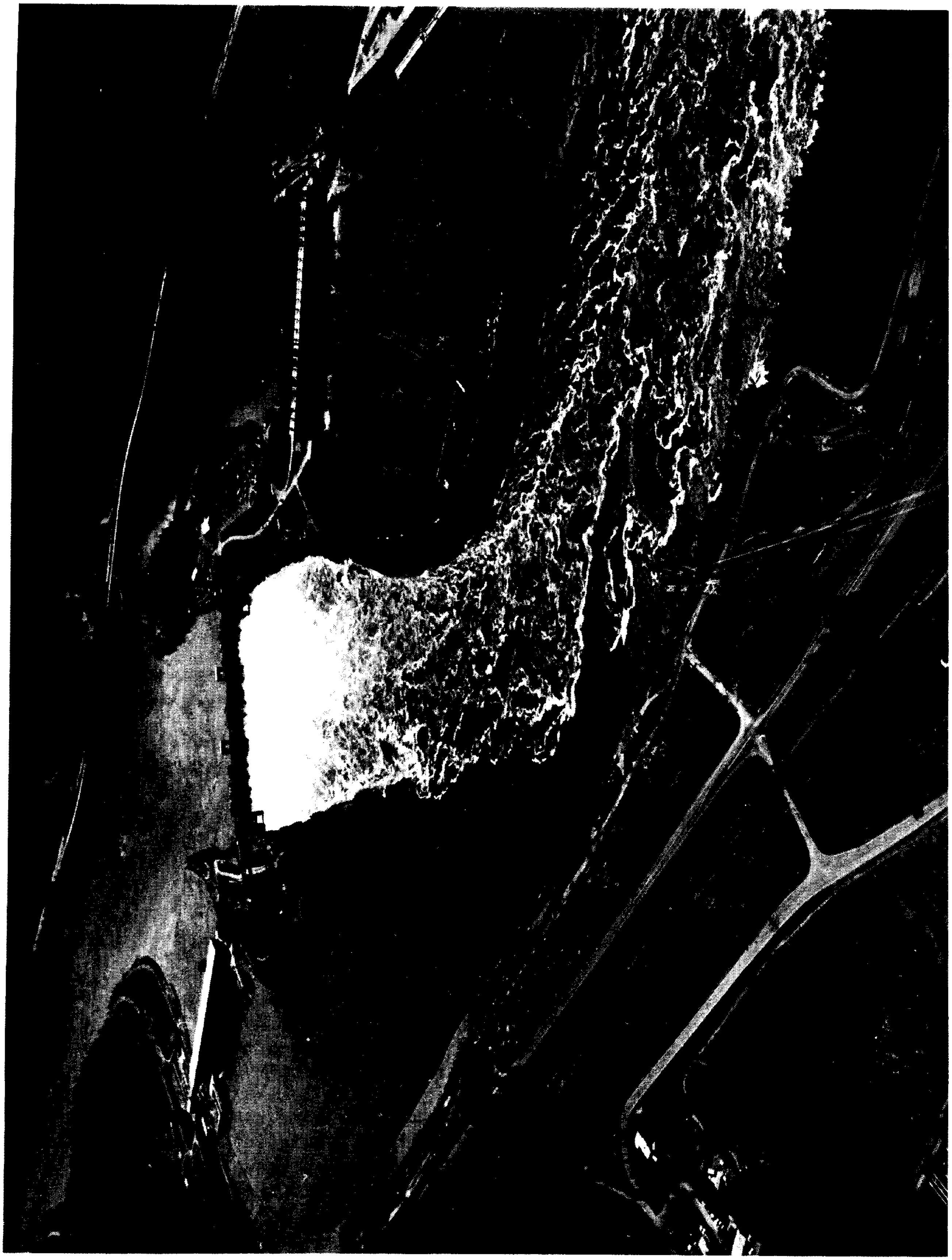


Figure 3-2. Bonneville Lock and Dam, Columbia River, Oregon.