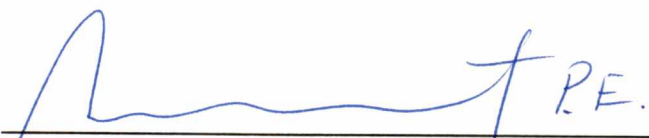
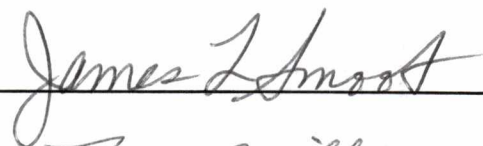
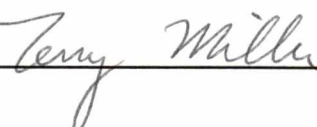


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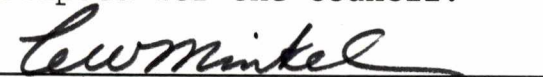
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RISK BASED PROCEDURE FOR MANAGING
A SPILLWAY GATE TESTING PROGRAM
FOR DAM SAFETY

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Julia Christina Ketron

May, 1994

DEDICATION

This thesis is dedicated to my parents

T. Hal and J. Sue Ketron.

Without their support, I could have never achieved
any of my goals.

This thesis is also dedicated to

Mark Raulston Madgett.

Without his motivation, I could have never
completed my dreams.

ACKNOWLEDGEMENTS

I would like to especially thank Dr. Bruce Tschantz for giving me the opportunity to work with him. His experience and guidance has helped me to focus my goals. I also wish to thank Sam Shipman for his understanding and patience in answering my many questions.

ABSTRACT

The Tennessee Valley Authority owns and operates fifty-four dams in a seven state region. The operation of discharge outlets to effectively release stored flood water is necessary to provide adequate safety measures for dams. Dams store a large volume of water behind the structure. Many dams are multifunctional and include flood control as one of the tasks. To ensure that spillway gates operate as close to 100% reliability as possible, a program must be implemented that requires periodic inspections and actual operational testing.

National recommended testing programs are reviewed to determine related guidelines and criteria to produce dependable outlet devices. The current TVA testing method is also discussed. Downstream damage and loss of water are the two main concerns for upgrading a spillway testing program to implement operating conditions into an inspection. Risk analysis is utilized to demonstrate that an increased testing program will not only benefit the reliability of spillway gates to pass water but also benefit TVA by lowering maintenance costs by detecting problems earlier and reducing spillway gate inoperability.

RISK BASED PROCEDURE FOR MANAGING
A SPILLWAY GATE TESTING PROGRAM
FOR DAM SAFETY

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The Tennessee Valley Authority currently maintains and operates fifty-four dams in a seven-state area in the Tennessee Valley region. Thirty dams provide hydroelectric power, and forty-seven of the dams have controllable water releasing devices. An important issue that TVA is dedicated to dam safety. The inspection of the spillway gates is necessary to ensure 100 percent reliability when needed because TVA assumes that all outlets work. The frequency of testing and the degree of inspection varies for each dam.

The Tennessee Valley Authority is a federal government agency. Although TVA is a government owned utility, it does produce power and collect monetary revenues for this power. TVA was authorized by the United States Congress in 1933. Many specific goals were to be achieved with the creation of the Tennessee Valley Authority. The TVA Act [14] states that its purpose is to provide navigation, flood control, and power to the multi-state region; however, navigation and flood control were the most important motives in establishing TVA. Power generation was less important. The TVA Act, therefore, establishes flood control as a higher priority than power generation. Because of this

prioritization, every effort must be made to ensure that the dams serve primarily as flood control devices. Power generation is a less important benefit.

TVA's dams are multifunctional. TVA's navigational interest is located mostly on the main channel of the Tennessee River. Nine main channel dams and one tributary dam are equipped with locks for the purpose of passing barges and other boats. The remaining dams are used for a combination of flood control and power generation. Thirty of the dams produce power for not only the Tennessee Valley region but also for portions of other closely located areas. The TVA power network includes all of Tennessee and parts of Kentucky, Virginia, North Carolina, Georgia, Alabama, and Mississippi. Approximately nineteen percent of the power output by TVA is generated by hydropower [19]. Table 1.1 compares the distribution of all types of generated power.

Table 1.1. Percent distribution of TVA's power generation[19].

TYPE OF POWER GENERATOR	PERCENT POWER GENERATED
Hydropower	19%
Fossil Fuels	68%
Nuclear	13%

For dam safety purposes, TVA's dams are classified by the potential hazard that the dam imposes. The potential loss of life was the most significant aspect that the Tennessee Valley Authority considered when it classified its dams. No size limits as to storage (acre-feet) or height of the dam (feet) were used to classify the dams. The three classifications for dams are high, significant, and low hazard dams. If a dam failure would endanger any human life, the dam was considered a high hazard dam and the spillway capacity must be designed to handle the probable maximum flood or PMF. The PMF is the probable maximum flood that could occur under a combination of meteorologic and hydrologic conditions in an area [8]. Low hazard dams are generally designed for the one-half PMF. In case of failure, these dams normally do not pose a threat to any significant amount of property beyond the area in which the dam is located. The damage is mainly to the dam itself. The last category is the significant hazard classification. This class lies between the low and high hazard divisions. The dams that did not readily fit into the high or low hazard category were judged by a case-by-case study by determining the economic consequences if a failure occurs depending on property, building damage, and other economic impacts. As can be seen, no specific guidelines were implemented in classification techniques; generally loss of life was the deciding factor [4]. Table 1.2 summarizes

Table 1.2. Classification of TVA dams.

HAZARD CLASSIFICATION	NUMBER OF TVA DAMS
High	31
Significant	1
Low	22

TVA's current dam inventory according to hazard classification.

With sixty percent of TVA's dams classified as high or significant hazard dams, any uncontrolled release of water may produce a high amount of damage to the downstream region. The dam may also be harmed. Destruction may occur to the spillway bays. Cavitation, erosion, and scour usually occur during a release of water.

TVA must also meet federal guidelines on dam safety [5]. The guidelines include organizational management, site investigation and design, and operation and maintenance. The operation and maintenance requirements include a periodic inspection program and emergency action planning. The inspection program is divided into three sections: informal, intermediate, and formal.

Spillway gate inspection is critical to the safety of all dams. If a gate does not operate to its needed height,

conditions may develop that put the dam in danger of overtopping or even failing during extreme events. Although a dam may be designed to pass the PMF, if a gate or several gates do not operate as expected, a much lesser event may seriously endanger the dam, embankments, power facilities, and downstream habitants and buildings.

Spilling devices must be able to withstand a tremendous load on the gates. Spillway gates, sluice gates, sleeve valves, and turbines control the flow of water in the event that water needs to be released. Reservoir levels are kept full during the late spring and through summer so that power and recreational needs can be met. During the winter, the water level is lowered to gain additional storage for flood events. During the winter and at other special times, TVA tests the gates in a "dewatered" condition. This method of testing is preferred due to its minimal loss of water. Because loss of water results in loss of power revenue, the "dewatered" or dry testing procedure is desirable. The water level is lowered to below the bottom of the gate or a device is used to stop the water from entering the spillway bay. This allows the gates to be opened to a full height, thus circumventing actual operating conditions.

1.2 STUDY OBJECTIVE

The main objective of this study is to utilize risk analysis methods to demonstrate that an increased testing

program will benefit the reliability of any outlet structure. This will be done by maximizing the optimum frequency of testing, while minimizing costs to TVA. The reliability will ensure as close to 100 percent operability as can be achieved. In the event that a large amount of water needs to be spilled, this will ensure the integrity of the dam. It will also be shown that TVA can benefit because additional assurance may be placed on the outlet devices. Increased inspection programs can reduce major and costly repairs to machinery and outlet devices by detecting problems in the early stages.

Frequency of use and type of outlet device are considered in the inspection procedures needed to achieve full reliability of spillway gates. The exercising of gates at each dam needs to be done on a periodic schedule. TVA requires that a portion of the spillway gates at each dam be inspected every two and a half years. The federal requirements suggest testing the spillway gates every one to two years, but allow testing to be delayed due to loss of water or damage to the downstream area [22]. Spillway releases are only required to keep the water elevation at a range of levels during heavy flows or to decrease the reservoir pool when floods are anticipated. The gates or valves may then be opened to allow stored water to be released.

A portion of the spillway gates of the TVA dams are

inspected every two and a half years. However, not every gate at every dam is tested during the inspection. Anywhere from two and a half to twenty-seven and a half years may pass before all gates at a dam are inspected. Although general guidelines are followed for the dams, most inspections are done as needed on a case by case basis. Testing generally does not involve operating the gates to their full design height or opening. Also, testing is seldom performed with normal water pressure (i.e., summer reservoir pool levels or wet); often, the gates are dewatered for inspection. Because of the importance of the proper spillway gate operation during a major event, the safety requirements must ensure 100 percent operational capability to full capacity. TVA had four gate operability problems when spillway releases were needed from 1989 to 1991 [3,13]. Although none of the problems resulted in a dam failure or overtopping, an updated testing and inspection program might have prevented the outlet inoperability and the costly repairs.

1.3 SCOPE AND APPROACH

A selection of nationally recommended testing programs, such as the Safety Evaluation of Existing Dams (SEED) [22] and the Federal Emergency Management Agency's Federal Guidelines for Dam Safety [5], are reviewed to determine other agency's guidelines and criteria. TVA's current

testing procedure is different for each dam because the type and the number of gates, as well as the downstream effect of testing vary for each dam. Spillway release records are utilized to determine the extent to which the gates have been operated in the past for necessary usage. The costs associated with the testing are being considered because any opening of a gate loses water, which is considered stored energy, and potentially lost revenue. Revenue loss is often a factor in testing procedures. A frequency-cost analysis will be performed to determine the optimum test frequency that can be achieved without introducing excessive costs to the program. The analysis for this paper will be performed on TVA dams which have radial or lift gates only. The radial and lift gates were chosen for this study because they are in use on 58 percent of the outlet devices in TVA's inventory.

CHAPTER 2

PROBLEM DISCUSSION

2.1 RELIABILITY CONSIDERATIONS

All TVA analysis concerning a dam's ability to handle incoming flood situations assume that every spillway gate and outlet controlling device are 100 percent operational when needed. Considering the average age of TVA's fifty-four dams is forty-two years, it is justified to assume that a 100 percent assurance level may be unreasonable because many mechanical features deteriorate with age.

Spillway gates and other appurtenances must be tested to ensure that water can be discharged as necessary. The general management issue concerning testing the operability of spillway gates and other outlet control devices is the large water volume releases that occur when gates are raised and lowered. When water is released, lost water and downstream damages become a concern. Potential power revenues are lost if the water is not used to produce power. Every dam should be evaluated to determine if spillway gate testing would cause excessive costs or downstream damages.

The importance of assurance that a gate will work properly when needed is undisputable. If a dam cannot function according to its' design specifications, the ability of TVA to properly control situations as they arise

could be severely hindered according to the number of available gates. Several TVA dams have many gates. For example, Wilson Dam has forty-nine lift gates, while Melton Hill Dam has only three radial gates. If one or two gates do not work properly at Wilson Dam, the consequences are not as drastic as when one or two gates fail at Melton Hill Dam. All high hazard dams are designed to pass the PMF.

Not every TVA dam is occupied by on-site personnel. Employees are present at all times at only thirteen of the fifty-four dams. All other dams are operated from off-site. It may be a long period of time before any problems are discovered at a dam which is not manned because problems may not be detected by sensors at the control site. The absence of on-site personnel heightens the importance of reliability testing procedures.

When a spillway release is necessary to control floods or relieve the water behind a dam, one or several of the gates are opened. Operational schedules have been developed by TVA's laboratory personnel in Norris, Tennessee, to determine the sequence in which the gates are opened. If only a small amount needs to be spilled, one gate may be fully or partially opened. If a larger amount needs to be spilled, every gate at a dam may be opened to some specific level. If the gates at a dam are unreliable, the operational schedules cannot be followed properly and flood control may suffer.

2.2 SPILLWAY RELEASE EXAMPLE

A typical scenario for a spillway gate opening at Fort Loudoun Dam is shown in Table 2.1. There are 119 gate arrangements for Fort Loudoun Dam. Gate opening settings range from 0 to 34. A setting mark of 0 represents a gate completely closed. If the setting is 34, the gate is fully open. The outflow is tabulated according to the headwater elevation. The headwater elevation is assumed at 802.0 feet above mean sea level. Table 2.1 shows gate arrangement 9. The corresponding discharge for headwater 802.0 feet and gate arrangement 9 is 9,370 cubic feet per second (cfs). Gate arrangement 30, as shown in Table 2.2, would produce a discharge of 30,700 cfs. Table 2.3 represents gate arrangement 100. The discharge for gate arrangement 100 is 168,000 cfs [6].

Manuals have been developed that relate the headwater elevation and the tailwater elevation with the gate settings to establish an outflow from the dam. Kentucky Dam has twenty-four three-section lift gates which operate according to seventy-two spillway gate arrangements. There are three settings for the lift gates at Kentucky Dam: upper leaf out (U), middle leaf out (M), and lower leaf out (L). The gate arrangements are dependent upon the headwater and tailwater elevations. An example is shown in Table 2.4. At headwater elevation 358.0 and tailwater elevation up to 338.0, the

Table 2.1. Gate arrangement 9 for Fort Loudoun Dam.
Flow discharge is 9,370 cfs.

GATE 1	GATE 2	GATE 3	GATE 4	GATE 5	GATE 6	GATE 7
0	0	6	0	6	0	6
GATE 8	GATE 9	GATE 10	GATE 11	GATE 12	GATE 13	GATE 14
0	6	0	2	0	0	0

Table 2.2. Gate arrangement 30 for Fort Loudoun Dam.
Discharge is 30,700 cfs.

GATE 1	GATE 2	GATE 3	GATE 4	GATE 5	GATE 6	GATE 7
8	6	8	6	6	6	6
GATE 8	GATE 9	GATE 10	GATE 11	GATE 12	GATE 13	GATE 14
6	6	6	6	6	6	6

Table 2.3. Gate arrangement 100 for Fort Loudoun Dam.
Discharge is 168,800 cfs.

GATE 1	GATE 2	GATE 3	GATE 4	GATE 5	GATE 6	GATE 7
30	26	30	26	30	26	30
GATE 8	GATE 9	GATE 10	GATE 11	GATE 12	GATE 13	GATE 14
26	26	26	26	26	26	26

Table 2.4. Gate arrangement 45 for lift gates at
Kentucky Dam.

GATE 1	GATE 2	GATE 3	GATE 4	GATE 5	GATE 6
M	M	U	M	U	M
GATE 7	GATE 8	GATE 9	GATE 10	GATE 11	GATE 12
M	M	M	U	M	M
GATE 13	GATE 14	GATE 15	GATE 16	GATE 17	GATE 18
M	M	M	M	M	M
GATE 19	GATE 20	GATE 21	GATE 22	GATE 23	GATE 24
M	M	M	M	M	M

discharge for gate setting 45 is 173,700 cfs. If the tailwater is between 344.51 to 345.5 feet, the discharge at gate setting 45 and headwater elevation 358.0 feet is 176,200 cfs. However, if the tailwater is 351.51 to 352.0 feet, the discharge is 141,600 cfs [11].

The manuals are located at TVA's reservoir operations forecasting room in Knoxville, at Chattanooga's office, and at each dam. The gate settings manual is also used to determine which gates to open for the even distribution of the outflow over the spillway apron so as not to concentrate too much water in one location. This is to help control vibration and to reduce erosion below the dam by spreading the flow over a larger area. Many of the gates are exercised a limited amount when a spill is performed. It is unlikely all the gates will be used at once or the gates will be opened to a very high opening because occurrences of flooding which require every gate are not frequent.

2.3 TESTING CONDITIONS

A gate testing program must consider several factors before initiating the program. To test spillway gates in accordance with required guidelines, actual operating conditions should be used if possible. Many testing considerations must be discussed when up to 14,660 cubic feet per second-days (cfs-days) of water volume may be discharged during a spillway gate test. Water loss is a

major concern for TVA. Stored water is considered an unused resource, or potential energy, for hydropower dams. Therefore, the loss of water, or potential energy, is a large part of the cost consideration for testing spillway gates to full open and closed positions.

However, water or power loss is not the only measurable cost associated with testing. Testing requires planning and manpower, hence, labor costs. Many other factors must be considered when planning a gate testing program, including public safety, loss of recreational benefits, potential downstream damage, environmental impact, navigational effects, and potential flood water storage with the water volume loss. These factors may add to the cost of testing or prevent testing during certain times or seasons of the year.

2.3.1 Water Loss

The need for stored water in the reservoirs is to produce power from the hydroelectric dams. TVA generally maintains high water levels in the summer because more power and recreational benefits are needed during the warm months. Air conditioning requires more energy than heating thus increasing the demand for electricity. Heat from gas is also used more in the winter reducing the dependence on electricity from TVA, except during periods of severe cold, thus allowing lower water levels. Recreation also benefits when the water level remains high. However, in the winter

the reservoirs are drawn down to provide extra storage for flood waters which are expected during the winter and early spring. Figure 2.1 shows the average operating cycle for Cherokee Dam, as an example of this seasonal cycle.

TVA requires the stored water to produce power. The hydropower produced at the dams generates an average of \$129,000 per day in net income from power revenues [20]. Accordingly, TVA has devised an economic plan to determine the cost of spilling water. Table 2.5 demonstrates the process used to convert flow, in cubic feet per second, to power value, or spilling cost, in dollars. The table is used to determine the revenue that the water would have generated had it been used for power generation instead of being spilled.

The two major factors influencing the spilling cost, or power value, are the hoisting equipment rate and the power factor. The hoisting equipment comprises the mechanical devices used to raise and lower the spillway gates. Fixed hoisting devices are used for most of the radial gates. The fixed hoisting devices have stationary motors and chains that are used to open and close the spillway gates. The lift gates are opened by gantry cranes or traveling hoists. One gantry crane or one traveling hoist can be moved to open all of the spillway gates. The faster that a gate can be opened and closed, the less water needs to be spilled to adequately test the spillway gates.

AVERAGE OPERATING CYCLE CHEROKEE DAM

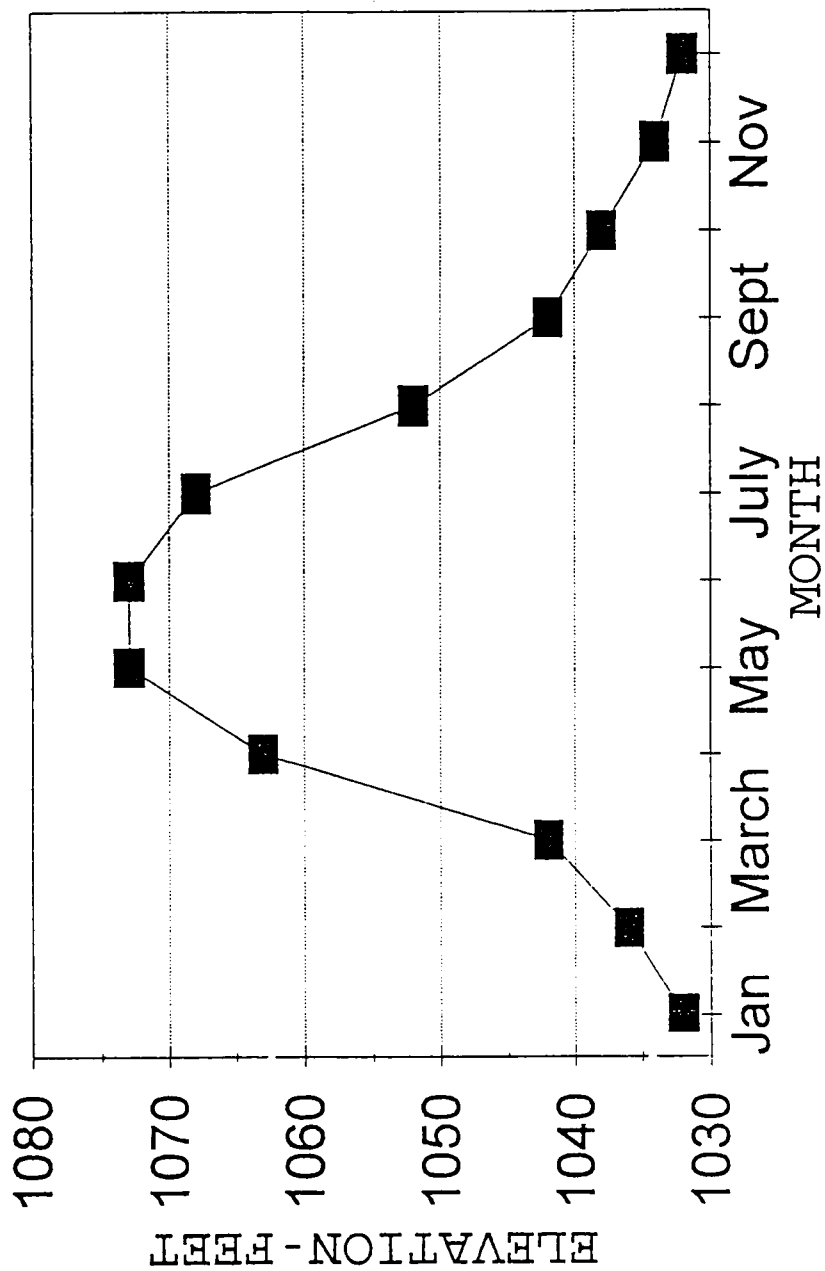


Figure 2.1. Operating cycle for Cherokee Dam.

Table 2.5. Table to determine the power value or spilling cost.

STEP	ACTION
1	Determine flow rate in cubic feet per second (cfs).
2	Determine duration to open and close the spillway gates in days.
3	Determine volume of water released in cubic feet per second-days (cfs-days).
4	Determine power factor in megawatt hours per cfs-days.
5	Determine power factor in megawatt hours (mwh).
6	Determine power rate in dollars per megawatt-hour (\$/mwh).
7	Determine power value i dollars (\$). Power value =power rate*power quantity.

The hoisting rate of the gates varies from 0.26 feet per minute (fpm) at Ocoee #2 to 10 fpm at Guntersville Dam. An attachment time is needed at the dams which have multisectional lift gates. The transfer or attachment time is the time needed to unattach the hoisting beam from one section of the lift gate and to attach the lifting beam to the next section of the gate. The attachment time requires an average of approximately thirty minutes for the process to be complete. Chickamauga, Guntersville, and Pickwick Dams have two-section lift gates; and Kentucky Dam has three-section lift gates. The other two dams with lift gates, Chatuge and Nottely Dams, have single section lift gates.

The power factor is dependent upon the elevation of the headwater. It is assumed to remain relatively constant with only minor seasonal changes. The power factor has units of megawatt-hours per day-second-feet (mwh/dsf) or megawatt-hours per cubic feet per second-days (mwh/cfs-day). This is used to determine the power quantity (refer to Table 2.5). The values used in determining the spilled water cost are the summer power factors which represent the worst case or the highest possible values. Variation of the power values should be minimal except at those dams where water levels fluctuate.

A typical radial gate discharge rating curve for Nickajack Dam is shown in Figure 2.2. This rating curve

DISCHARGE RATING CURVE NICKAJACK DAM

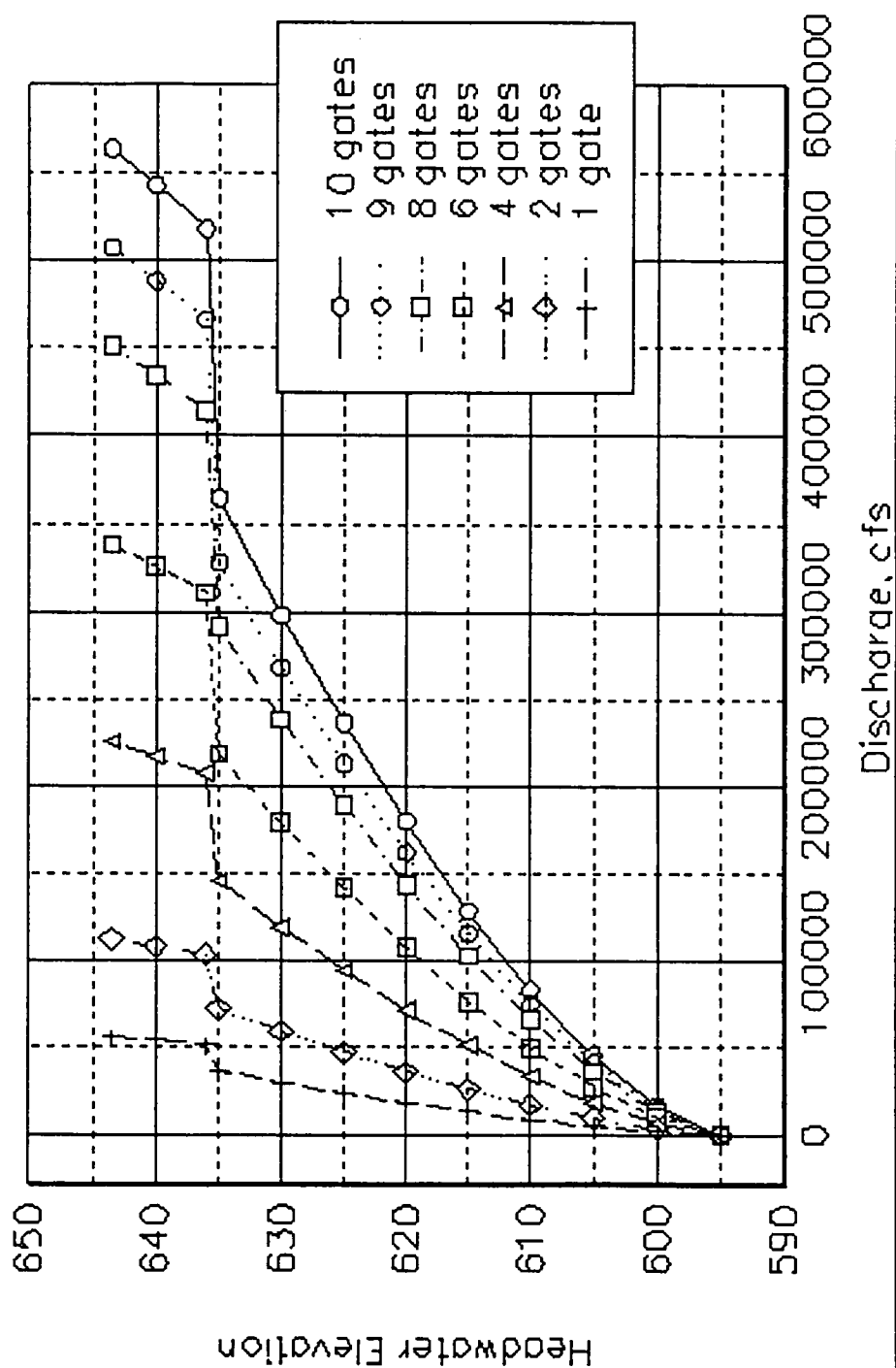


Figure 2.2. Discharge rating curve for Nickajack Dam.

represents a relationship between the discharge, in cfs, and headwater elevation, and the number of gates opened completely. The volume of spilled water for a full gate testing program is determined by integration of standard flow predicting equations. To determine volume of spilled water during a gate test, the equation for the flow rate was integrated with respect to the time required to completely raise the gate. This will be multiplied by two in order to account for the lowering of the gate.

$$Volume = 2 \int_0^t Q(t) dt \quad (1)$$

where: Q = flow, cubic feet per second, cfs
 dt = change in time

All calculations will be performed assuming that the water level is at the summer pool level. Most of the flows change from orifice flow to weir flow as the gate is raised. The exact transitional point between the change from orifice to weir flow was not determined but assumed to be at the summer pool level. Figure 2.3 represents the two scenarios of a gate with a summer pool level.

Figure 2.4 displays the open gate positions of the gates shown in Figure 2.3. Figure 2.4a has only orifice flow. Figure 2.4b has orifice flow as the gate is raised, then converts to weir flow.

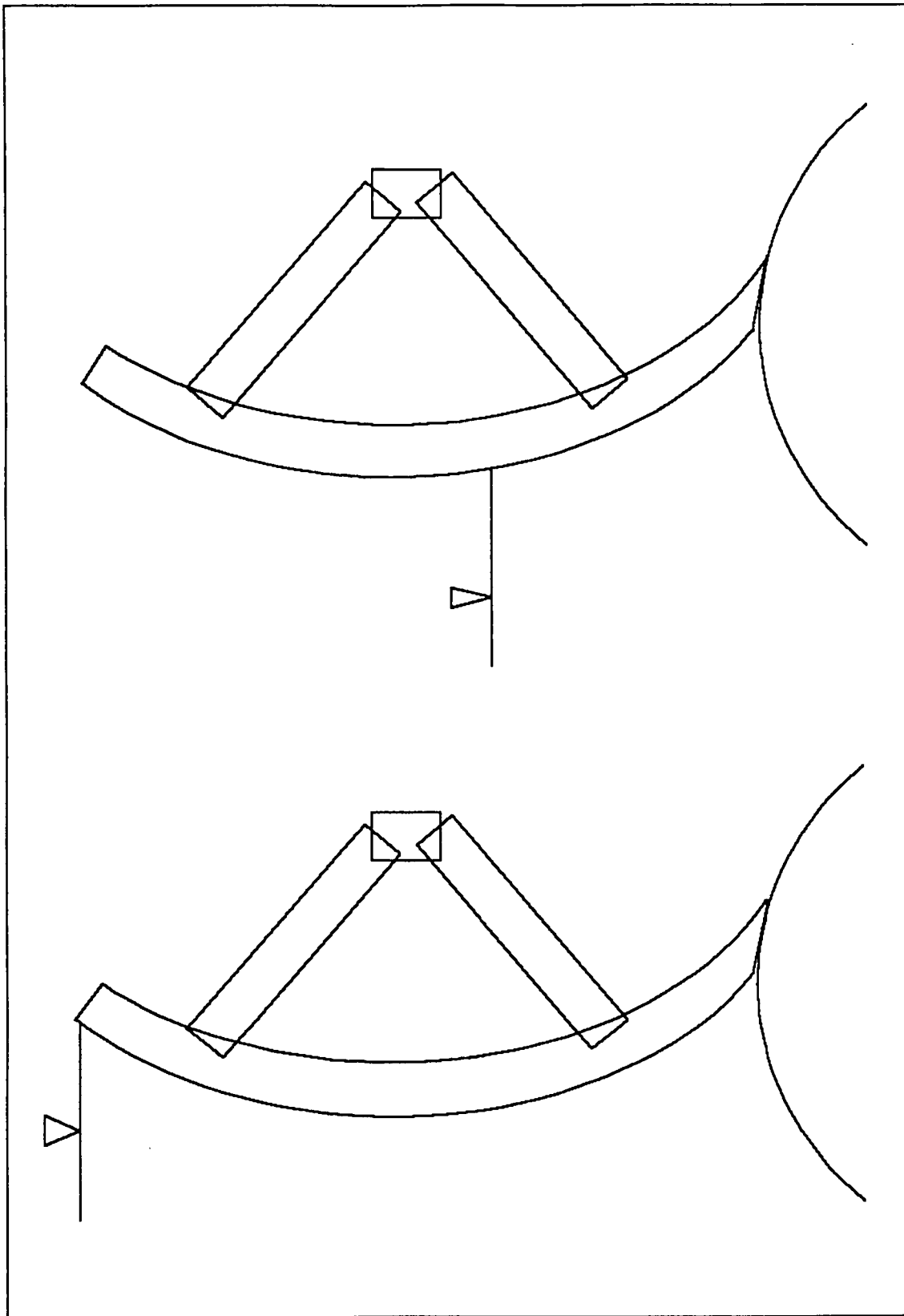


Figure 2.3. Radial gate with water level at a) top of gate and b) below top of gate.

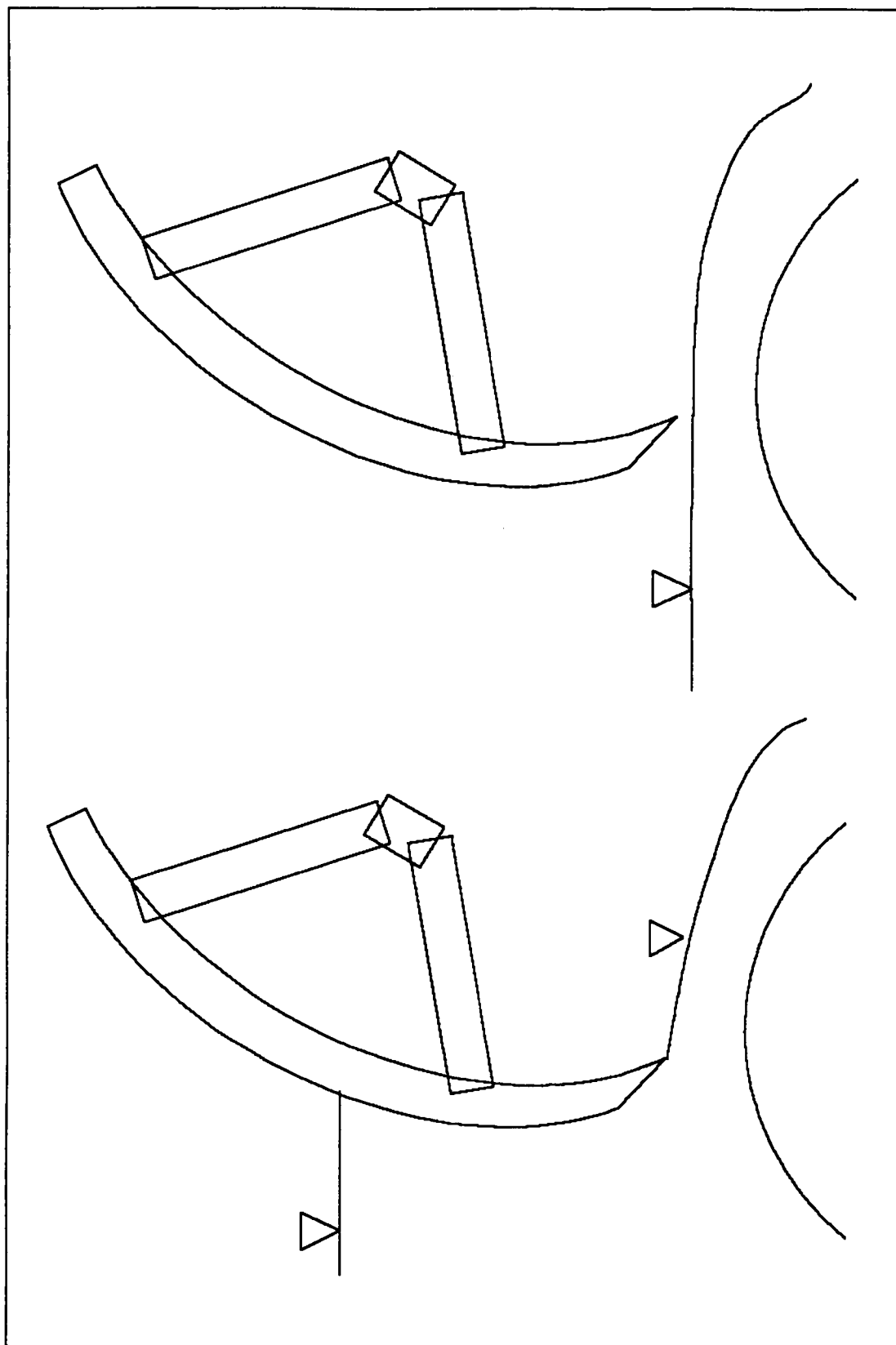


Figure 2.4. a) Orifice flow and b) weir flow of water as gates are opened completely.

For radial gates which exhibit characteristics like Figure 2.3a, the equation for volume may be derived by using the equation for orifice flow,

$$Q = CA\sqrt{2g}(H - 0.5h)^{1.5} \quad (2)$$

where: Q = flow, cubic feet per second, cfs
 C = discharge coefficient, assumed to be 0.69
 H = height from water level to crest of spillway, feet
 h = height of the opening of the gate, feet
 $H - 0.5h$ = average head through the orifice opening, feet
 A = area, square feet, $A = nwh$
 n = number of spillway gates
 w = width of each spillway bay, feet

The height of the opening is dependent on the rate of the hoisting equipment,

$$h(t) = R * t \quad (3)$$

where: $h(t)$ = height with respect to time
 R = rate of hoisting equipment, feet per minute
 t = time, minutes, to raise the gate to height, h

By substituting equation (3) and $A = nwh$, equation (2) for orifice flow becomes equation (5).

$$Q = Cnw h \sqrt{2g} (H - .5h)^{1.5} \quad (4)$$

$$Q = Cnw \sqrt{2g} (RtH^{.5} - .5R^{1.5}t^{1.5}) \quad (5)$$

The volume is determined by substituting equation (5) into equation (1) and integrating.

$$Volume = \int_0^t Q dt = Cnw \sqrt{2g} [RH^{.5} \int_0^t t dt - .5R^{1.5} \int_0^t t^{1.5} dt] \quad (6)$$

or

$$Volume = Cnw \sqrt{2g} [RH^{.5} \frac{t^2}{2} - .5R^{1.5} \frac{2}{5} t^{2.5}] \quad (7)$$

To obtain the correct units for volume for the power value, or spilling cost, time in equation (7) must be represented in minutes and days to obtain cfs-day (sfd).

$$Volume = Cnw \sqrt{2g} [.5RH^{.5} t_{\min} - .2R^{1.5} t_{\min}^1 .5] t_{\text{days}} \quad (8)$$

For radial gates like Figure 2.b, an equation for weir flow must be added to equation (8). The equation for weir flow is equation (9).

$$Q = nw C_d H^{1.5} \quad (9)$$

where terms are previously defined except C_d . C_d is the discharge coefficient, 3.6.

Since the water level does not change when weir flow is

determined by substituting equation (9) into equation (1) and integrating for weir flow.

$$\int_t^{t_2} Q dt = nWC_d H^{1.5} \int_t^{t_2} dt \quad (10)$$

$$Volume = nWC_d H^{1.5} (t_2 - t_1) \quad (11)$$

Volume for situations like Figure 2.3a can be represented by equation (8). The equation for volume for gates and water levels, like Figure 2.b, is the sum of equations (8) and (11) or equation (12).

$$Volume = Cnw\sqrt{2g} [.5RH^{.5}t_{\min} - .2R^{1.5}t_{\min}^{1.5}] t_{days} + nWC_d H^{3/2} (t_{2days} - t_{1days}) \quad (12)$$

Lift gates are slightly different. If the gate has only one section, the water behaves like Figures 2.4a or 2.4b and equations (8) or (12) may be used to determine flow. However, multiple section gates have a different arrangement. A two-section gate like those at Chickamauga may look similar to the gates in Figure 2.5.

When section 1 is removed, the volume may be found by either equation (8) or (12). An attachment process is then implemented which takes approximately thirty minutes. This process involves removing the lifting device from the first section and attaching it to the second section. During this time weir flow occurs over the top of the second section. Section two is then raised. During the lifting of the

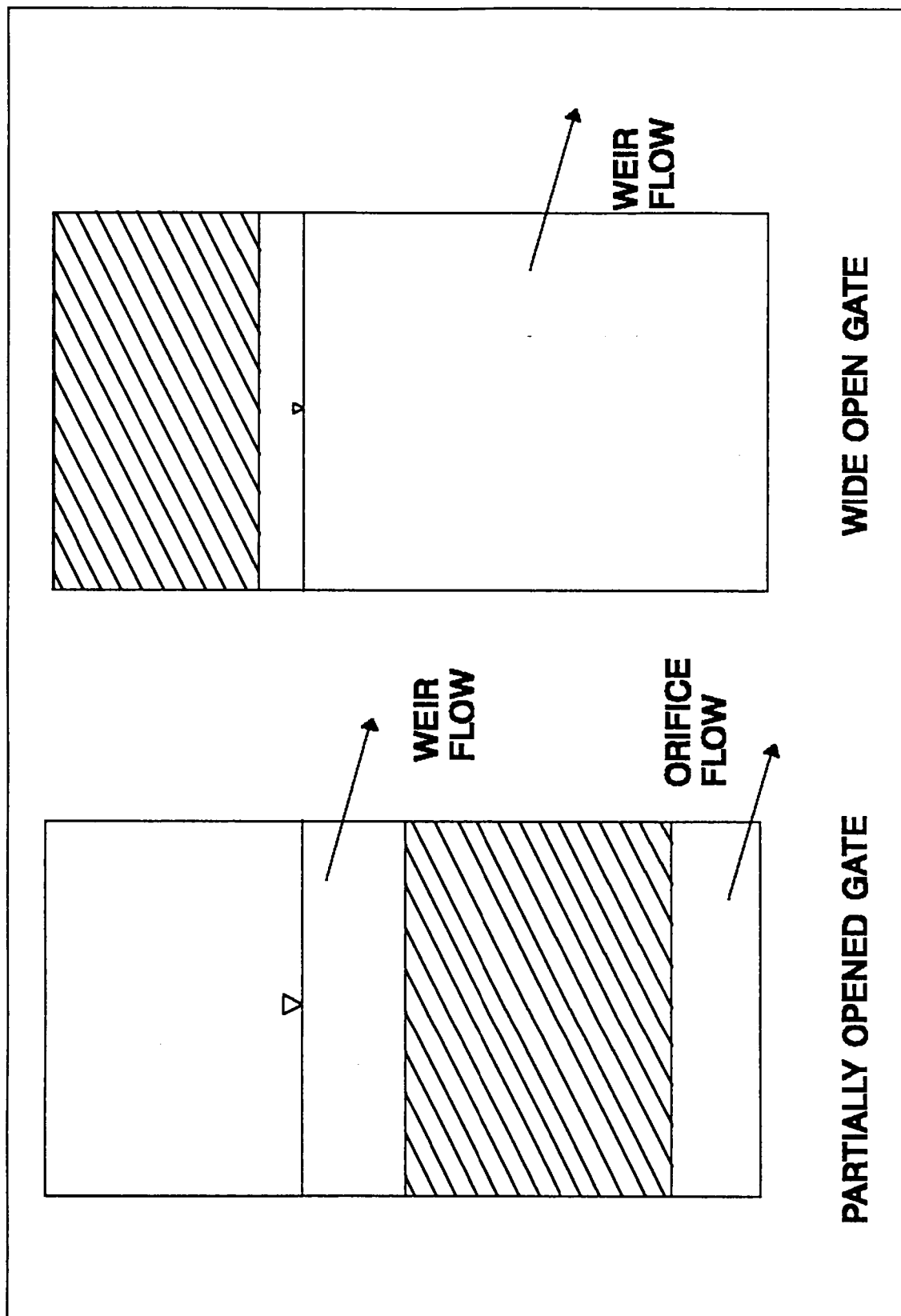


Figure 2.5. Raising process showing weir and orifice flows for lift gates.

second section, weir flow occurs on top of the first section of the gate, but it is being diminished. Orifice flow is increasing at the bottom of the gate as seen in Figure 2.5.

Once the top of the gate has reached the pool level, only orifice flow occurs under the gate section. As the gate continues to rise, the bottom of the gate reaches the pool level at t_2 . Weir flow occurs for the remaining time the gate is raised. The equation for the decreasing and increasing weir flow may be found by utilizing the general equation for weir flow, equation (9). However, height does change with time. By substituting equation (3) into equation (9), equation (13) derived. It gives the discharge in cfs for weir flow. By integrating equation (13), equation (14) gives the formula for volume.

$$Q = nWC_d R^{1.5} t^{1.5} \quad (13)$$

$$Volume = \frac{2}{5} nWC_d R^{1.5} t^{2.5} \quad (14)$$

The total volume spilled for a lift gate operation with two sections would be represented by equation (15). Either equation (8) or (12) would be used in equation (15) depending on the type of discharge, weir or orifice flow that is occurring during the lifting process.

$$TotalVolume = 2 * (eq8or12) + 2 * (30min. * Q_1) + 2 * (eq8or12) + 2 * eq14$$

(15)

where: Q_1 = weir flow at summer pool level with the first section out to compensate for the lost water during the attachment process.

2.3.2 Labor Costs

When a gate testing procedure takes place, several specialized personnel must be present. The gate testing personnel will visually examine the hoisting equipment and the spillway gates. Some degree of physical operation will be performed on the spillway gates to test the operability. Mechanical and electrical engineers inspect operating equipment such as motors, hoisting chains, gears, and electrical cabinets. Any abnormalities are reported, and a maintenance request is submitted. A gate operator who has been specifically trained to operate the machinery is needed to open and close the gates during inspections and needed spill operations. An electrician must be available to assist the electrical engineer. Any maintenance on the electrical devices would be performed by the electrician. A mechanic should also be at the dam during an inspection. He would remove any plates or guards needed to evaluate or inspect equipment. Table 2.6 represents the unit labor costs for all required specialized persons. All hourly wages are then multiplied by a factor of 0.429 to account for additional personnel benefit costs.

Table 2.6. Typical 1993 hourly wages for dam inspection personnel.

Mechanical Engineer	\$22.16/hour
Electrical Engineer	\$22.16/hour
Gate Operator	\$14.27/hour
Mechanic	\$17.60/hour
Electrician	\$17.84/hour
Total	\$94.03/hour X 1.429 \$134.37/hour

2.3.3 Planning

Planning an inspection must be coordinated with an engineer, usually the mechanical engineer from the inspection team, and the plant manager of the dam. Usually a week is needed to contact all personnel involved; however, the actual time spent on the coordination process is about four hours for the engineer and the plant manager. For a more detailed inspection, planning efforts may take up to a year. Such an inspection may require a reservoir drawdown that would need to be coordinated with the reservoir operations unit at TVA. Planning requires that the engineer and the local plant manager at a dam have the correct personnel available during the inspection. Any other special operations being performed during the inspection must also be taken into account. The plant or dam may need to lower the reservoir for mosquito control or may need to generate a high amount of energy which might limit testing.

Because of these and other special operating limitations, testing the spillway gates may need to be postponed to accommodate the special circumstances.

2.3.4 Public Safety

Generally, public safety is only a concern below the dam. Prior to and during testing, an inspector or other TVA employee inspects the downstream area for any people. He then warns fishermen, boaters, or other recreationalists to move away from the area. The gate may be pulsed or raised slowly to warn downstream inhabitants of the oncoming water. People who have been warned below the dam are responsible for their own safety; TVA is not liable because any people remaining in the area assume the risk while they are at the dam or on its waters. Upon evacuation, water may be spilled for the inspection.

2.3.5 Recreational Benefits

Since most recreational activities are normally curtailed below the dam during a spillway release, recreational benefits are not significantly affected by spillway gate testing. Most recreational activities take place in the reservoir or main body which is often a great distance away from the dam. Dams similar to Norris, Apalachia, and Hiwassee Dams may experience some inconvenience to trout fishermen, but the lost benefit is considered negligible or insignificant to the total inspection cost because of the small cost associated with

the benefit. Therefore, it is assumed that recreational benefits are not significantly affected by a spillway gate inspection associated with a spill procedure.

2.3.6 Downstream Damage

Since the inspection program only operates one gate at a time, downstream conditions would not normally be affected. There would be no damage to the stream bank or vegetation. Fish and other wildlife would not be impacted. Excessive sediment erosion or deposition would not occur. The spillway apron should also be able to withstand any damage. However, by only utilizing one gate at a time, some vibration may occur. This should be observed to determine if any adverse conditions affect the gates or the dam. During many spilling operations, more than one gate is operated. For this reason, multiple gate testing should be practiced occasionally to ensure that vibration is not occurring when more than one gate is utilized. Therefore, no damage to the downstream region or excessive cost is associated with spillway gate testing.

2.3.7 Environmental Damage

Releasing water through spillway gates could produce several negative environmental consequences. The first environmental effect is a potential fish kill. When a gate is opened, water released from behind the spillway may flow into the downstream water or it may strike the spillway apron with a violent force. With water entering the

downstream channel, most fish survive; however, if the water hits the apron, the impact could kill many fish. This problem occurs mostly at Nottely, Chatuge, and Blue Ridge Dams; it seldom occurs at the larger or main river dams. The fish primarily destroyed are shad and blue gill. These fish are in abundance and are present mostly in large groups. When a gate is opened, a large amount of fish may spill out to the downstream side. One method of limiting the amount of fish that wash through the spillway is to string chicken wire or other similar material over the spillway crest to hold them back. This is inexpensive and very effective. During a spill operation at Chatuge Dam, this method was utilized and found to prevent fish from spilling onto the apron. If a dam is likely to have this type of problem, measures may be taken to prevent any negative effects at little effort and expense. Besides using the wire to trap fish, testing with a spill could be performed in the late summer and winter when the fish are older and more likely to survive the spill.

Total dissolved gases have also produced negative effects at several of the dams. When a spill is taking place, the water may become supersaturated because of the temperature and the velocity change. When the spillway gate is opened and the total dissolved gases reach supersaturated conditions, nitrogen and oxygen levels become excessively high. Although this problem has been experienced at

Kentucky Dam, this is not a major concern in the southeast. The condition arises at dams which have a deep plunging flow when water is released. The main river dams seem to experience this situation the most. This affects the fish and may cause gas bubble disease. Although this has occurred at TVA dams, correction is limited because the structure of the dam causes the condition to take place. Therefore, it is an unavoidable side effect of testing. No real costs are determined for this problem.

Several dams are operated in conjunction with cold water fisheries. The tributary dams in this category are Apalachia, Norris, South Holston, Tims Ford, Wilbur, Watauga, and Chatuge. Problems occur when the water temperature changes a great deal. If water is released from the bottom of the dam, the colder water may decrease water temperature causing negative consequences to occur at the fisheries. This condition may occur when water is released by the spillway gates. Caution should be used to maintain the correct water temperature that will ensure no significant problems to the cold water fisheries. The time of year for spilling should be watched to insure that the water released does not adversely affect the downstream water temperatures.

Environmental concerns are not generally significant enough to limit testing of the spillway gates. By testing at dams which have problems with fish spilling onto the

spillway apron in late summer or winter, the effects are diminished. Year round testing can be accomplished, but more attention would need to be paid to protecting the fish. The dissolved oxygen effects are uncontrollable, but the effects are not considered significant enough to prevent spillway releases. Cold water fisheries may pose the most serious problem. Caution should be used to ensure that temperatures remain at a satisfactory level. It is assumed that no significant effects of environmental concerns should limit testing of spillway gates or other outlet devices; however, Further investigation into these concerns is presently being undertaken by TVA.

2.3.8 Navigational Impacts

There are ten dams in TVA's system which contain locks for navigational purposes. The nine main river dams which have this capability are: Chickamauga, Fort Loudoun, Guntersville, Kentucky, Watts Bar, Nickajack, Pickwick, Wheeler, and Wilson Dams. Melton Hill Dam is the only tributary dam which has a navigational lock.

During a spill, barges which are traveling the river have a more difficult passage because the current will increase during the release of water. Most of the dams can still pass barges during a normal spill operation. However, a concern is the fluctuation of the water level downstream during testing. This may make navigation more difficult. If a barge is full or heavy, fewer problems will be

experienced because it is easier to maneuver a heavy barge. Light or empty barges may encounter more significant difficulties as they attempt to navigate during a spillway release.

The tailwater elevation is an important factor on the amount of water which may be spilled. An approach wall to the lock helps to guide the barge into the lock. If the tailwater is at or above the top of the approach wall, the barge is in danger of hitting the wall. This could cause major damage to the wall, lock, and barge. It is recommended that the tailwater elevation remain at least one foot below the top of the approach wall. Considering the approach wall and difficulties associated with a high tailwater or headwater, Table 2.7 represents the maximum elevations at which navigational operations may continue to operate without risking any danger to the barge or other dam features. No discharge limits have been set which restrict navigational purposes.

Water flow may vary below the dam during an inspection because of raising and lowering one gate at a time. It is necessary to incorporate a Notice to Navigational Interest. This will inform traveling barges of the testing process and what to expect, including higher water levels and fluctuating flows. This will need to be coordinated between TVA, the United States Army Corps of Engineers, and the United States Coast Guard. Some barge operators may decide

Table 2.7. Navigational limits for testing [16].

DAM	MAXIMUM ALLOWABLE HEADWATER ELEVATION, FT	MAXIMUM ALLOWABLE TAILWATER ELEVATION, FT
Chickamauga	684.0	657.0
Fort Loudoun	814.6	771.0
Guntersville	596.5 (Main) 595.5 (Auxiliary)	583.0 577.0
Kentucky	374.0	341.0
Melton Hill	798.0	753.0
Nickajack	637.0	621.0
Pickwick	418.0 (Main) 418.0 (Auxiliary)	401.0 399.0
Watts Bar	744.6	705.0
Wheeler	556.5 (Main) 555.0 (Auxiliary)	516.0 516.0
Wilson	508.0 (Main) 508.0 (Auxiliary)	439.0 428.5

not to continue travel; however, as long as water levels do not exceed the maximum headwater or tailwater elevations, there should be no problems. To ensure adequate navigational capabilities during gate testing, the inspection team should notify the navigation unit at TVA with the day and duration of testing which incorporates spilling water.

2.3.9 Flood Storage Impacts

Storage benefits for flood control for inspections were also considered; however, they were determined to be negligible. The amount of water spilled during the spillway gate testing program is a very small amount compared to the reservoir volume which stores the flood water. When a gate is tested and spills water, more storage is available in the reservoir behind the dam for flood waters. TVA uses a value of \$160 per acre-foot of usable permanent storage above Chattanooga and \$7 per acre-foot below Chattanooga. If the permanent storage value is converted to temporary storage, the value decreases. Assuming a life of fifty years at 8 percent interest, the yearly value for temporary storage is \$10.54 per acre-foot per year or \$0.22 per acre-foot per week. Spilling time is normally less than an hour per gate, and the volume is very small; therefore, storage benefits are not substantial. Even if the storage benefit values were large enough to use, unless storage is needed behind the dam for an incoming storm, it is not a benefit.

2.4 GATE FAILURES

The history of dam gate failures is not a well documented type of incident. Therefore, it is difficult to determine the extent of damages caused by the gate failures. Many organizations do not include the inoperability of gates and related valves as an inadequacy. Strassburger [25] believes that few cases of gate failures are reported because the inoperability seldom results in a serious consequence. He compiled a listing of dam incidents which involved inoperable outlets including gate and valve malfunctions [25]. The list includes incidents in the United States during a 116-year period between 1868 to 1984. Of the 1,192 reported cases, only twenty-six were gate or valve failures. Strassburger believes this number is significantly lower than the actual number because gate and valve failures are not reported as often as the failures occur [25].

Every two years an interagency progress report on dam safety issues is published by FEMA for federal agencies. The agencies include the Bureau of Reclamation, the United States Army Corps of Engineers, Federal Energy Regulatory Commission, Forest Service, International Boundary and Water Commission, Soil Conservation Service, and TVA. TVA reported in The Dam Safety Program, 1988 and 1989 [3] that seven dam safety problems occurred including two which were gate failures.

On January 13, 1989, a slide gate was unable to be raised during a flood at Bear Creek Dam because of a worm gear failure. Water was passed over the spillway. The condition was not considered threatening to the safety of the dam.

On June 20, 1989, at Chickamauga Dam, the lifting beam did not operate properly and a gate was lodged in an awkward position. The backup lifting beam had also been damaged. Buildup from sandblasting and painting had caused the lifting beams to deteriorate. Repairs were done and a new inspection program suggested measures should be undertaken to ensure against this incident in the future. The Chickamauga situation was discussed by then-TVA Chairman Marvin Runyon in the Knoxville Journal in 1989. He advised updating an inspection schedule for testing the spillway gates. The inoperability of flood control gates was and still is a concern to TVA. This study is a response for the need of a revised testing program.

TVA reported in The National Dam Safety Program, 1990 and 1991: Progress Report on Dam Safety [12] that Hiwassee Dam encountered problems with concrete growth. This expansion caused at least two spillway gates to become inoperable. Since Hiwassee only has seven radial gates, this problem is of great concern. Slots have been cut in the dam to relieve the expansion. More slots have been planned in the future.

In December 1990, a spillway gate indicator would not function at Normandy Dam. The gate worked properly but the flow release was not known. The discharge uncovered a power line and damaged the downstream channel.

CHAPTER 3

TESTING PROGRAM

3.1 CURRENT TESTING PROGRAM

TVA's current testing program incorporates engineering inspection at each dam generally every two and one-half years. The plant personnel also test a portion of the gates normally on an annual basis; however, the engineering inspection is more detailed. It can take up to twenty-seven and a half years to inspect all the gates at a dam. This is because of the time consuming operating procedure at dams with lift gates. However, the majority of the dams can have every gate inspected in five years or less.

For radial gates, testing conditions can be done with or without water pressure or head acting behind the gates. Blue Ridge, Cherokee, and Douglas Dams have their gates raised to full height when there is no water pressure pushing on the gates. This "dry", or no water condition, is accomplished by testing in the winter when water levels are significantly lower. Ocoee #3 alternates wet and dry conditions by testing when the reservoir is high for a "wet" condition and low for a "dry" condition. A "wet" test is performed with water pressure acting on the spillway gates. Water is spilled during this type of testing procedure. Several dams use bulkheads or stoplogs to obtain "dry"

testing conditions. These devices are used to obstruct the spillway opening so that no water is release. Fort Loudoun, Melton Hill, Nickajack, Tims Ford, Watts Bar, and Wheeler Dams have the capability these devices. Every five years the bulkhead or stoplog is placed in front of the spillway opening to dewater the gate and allow testing at full height under dry conditions. These plants, like Ocoee #3 alternate the wet and dry testing conditions. The remaining dams test the gates only with water pressure, or wet conditions. However, for the water pressure testing, the gate is only hoisted approximately one-foot. The one foot raise, or partial opening, is used to test the hoisting machinery because the greatest load is present at the beginning of the lifting process. Table 3.1 represents characteristics of formal inspections for dams with radial gates.

The lift gate inspections are somewhat more difficult. Because most lift gates have more than one section, raising a gate takes much more time. The current inspection and testing program for lift gates only raises the upper leaf of multisectional lift gates. Generally, only two to three lift gates can be tested a day. The lift gate testing procedure is also influenced by the number of gates at the dam. Dams with lift gates generally have more spillway gates than those with radial gates. Therefore, dams with lift gates take longer to test. Gantry cranes are used at all dams with lift gates except Wilson Dam which has fixed

Table 3.1. Current radial gate testing criteria.

DAM	NUMBER OF YEARS TO TEST ALL GATES	TESTING CONDITION
Apalachia	2.5	Wet-partial
Blue Ridge	2.5	Dry-full
Boone	2.5	Dry-full
Cherokee	5.0	Dry-full
Douglas	5.0	Dry-full
Fontana	2.5	Dry-full Wet-partial
Fort Loudoun	7.5	Dry-full Wet-partial
Fort Patrick Henry	2.5	Wet-partial
Great Falls	12.5	Wet-partial
Hiwassee	2.5	Wet-partial
Melton Hill	2.5	Dry-full Wet-partial
Nickajack	2.5	Dry-full Wet-partial
Ocoee #2	2.5	Wet-partial
Ocoee #3	2.5	Wet-partial
Tellico	2.5	Wet-partial
Tims Ford	2.5	Dry-full Wet-partial
Watts Bar	5.0	Dry-full Wet-partial
Wheeler	5.0	Dry-full Wet-partial
Wilbur	2.5	Wet-partial

hoists. Since the gantry cranes must be moved from each spillway bay, it takes longer to move the equipment to get the lift gates raised. Table 3.2 represents characteristics of formal inspections for dams with lift gates.

3.2 REVIEW OF NATIONAL PROGRAMS

Many federal organizations and agencies, other than TVA, have dams which must be inspected. Several agencies were contacted and asked to contribute information to this study concerning the guidelines which have been incorporated into their own testing programs. The agencies which responded were: the United States Army Corps of Engineers (USACE), the Bureau of Reclamation (BurRec), the International Boundary and Water Commission (IBWC), and the Federal Energy Regulatory Commission (FERC). Several nonfederal power generators were also contacted, including: Pacific Gas and Electric Company, Georgia Power, Idaho Power Company, Montana Power Company, Portland General Electric and Gas Company, and Washington Water Power Company. Each of these power companies follow testing procedures set forth by the licensing agency, Federal Energy Regulatory Commission.

The USACE responded by sending several documents: *Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures* [18], *Structural Evaluation of Existing Spillway Gates* (draft form) [26], and *Structural*

Table 3.2. Current lift gate testing criteria.

DAM	NUMBER OF YEARS TO TEST ALL GATES	TESTING CONDITIONS
Chatuge	10	Dry-full
Chickamauga	20	Dry-full Wet-partial
Guntersville	20	Dry-full Wet-partial
Kentucky	15	Dry-full Wet-partial
Nottely	10	Dry-full
Pickwick	27.5	Dry-full Wet-partial
Wilson	5	Wet-partial

Inspection and Evaluation of Existing Welded Lock Gates

(draft form) [27]. The inspection interval is not clearly stated in any of the USACE documents. They recommended an initial inspection when dam construction is completed and before it is filled with water. A second inspection should be performed when the reservoir reaches the normal operating pool. The remaining inspections should be done yearly for the next four years, then every two years for the next four years, then every five years if the structure has no problems. During these inspections gates should be inspected for structural and operational adequacy. The USACE suggests testing with water pressure if no problems such as downstream damage and excessive water loss arise. No specifications were developed on height requirements for raising the gates.

The Bureau of Reclamation sent several documents including: *Emergency Closures of Guard Gates with Unbalanced Heads* [7], *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs* [9], and *Guidelines for Safety Evaluation of Mechanical Equipment* [10]. Also included was the *Review of Operation and Maintenance Program* [21] provides the best explanation of the Bureau's inspection program. Gates and valves which regulate flow are tested annually under balanced and unbalanced head. A balanced head test is performed when the pressure on both sides of the gate is equal. This is accomplished by testing

in an unwatered condition or when no water is acting on the gate or valve. It can also be done with equal water pressure on both side. An unbalanced head test is performed when the pressure is not equal on both sides of the gate or valve. This means that a net water pressure is acting on the gate or valve. Emergency or guard gates should be tested at least every six years with an unbalanced head; however, a balanced head test should be performed at least annually.

The Bureau suggests alternative testing procedures for dams with high water levels. These guidelines were developed because operation with a high water level would cause a substantial release of water and damage downstream. A partial raising should be performed with a high reservoir level. Steps should be taken to gradually raise the gate to 10 percent of total height. Full height testing should be done annually with an unwatered condition. If the reservoir level does not permit testing annually, stoplogs should be utilized. Full height testing should be done every six years. The Bureau warns that a partial opening test will not ensure that the gates are reliable for full travel.

The International Boundary and Water Commission sent a letter, inspection checklist, and two brochures. This agency operates a total of six dams, four jointly with Mexico and two independently.

Amistad and Falcon Dams are operated by the

International Boundary and Water Commission to provide irrigation. Amistad Dam has sixteen radial gates. Four gates are inspected annually including raising the gates. Falcon Dam has six counterbalance gates. Budget determines inspection, but generally two gates are inspected and operated each year. Anzalduas and Retamal are flood diversion dams. Anzalduas has six drum gates. Two are inspected yearly. Retamal has two radial and one balance beam gate which are inspected annually. There were no specifications concerning raising and lowering the two diversion dams' gates. The subject of wet and dry operations for the reservoir dams were not discussed. However, from the lack of water in the Texas and Mexico region, it can be determined that reservoir conditions during testing are probably at low levels.

All nonfederal hydropower dams must be licensed by the Federal Energy Regulatory Commission (FERC). Inspections are done by FERC during and after construction. FERC sent the *Operating Manual for Inspection of Projects and Supervision of Licenses for Water and Power Projects* [15] and the *Code of Federal Regulations, Number 18* [1]. Section 12.44 of the *Code of Federal Regulations* requires that each spillway gate must be operated, either by testing or actual use, each year. Raising gates to full design height must be accomplished at least every five years. No specifications are developed concerning wet or dry testing. However, they

stress the importance of evaluating the reliability of proper gate operations during inspections. The subsequent failure or nonfailure of a project may change any specific dam's inspection criteria for spillway gates and other outlet control devices.

The United States of the Interior published a book entitled The Safety Evaluation of Existing Dams (SEED) [22]. This book examines principles and concepts which should be used to ensure that a dam is safe and properly maintained. TVA uses SEED as a guide for the examination of its dams. SEED explains that onsite examinations should include a full operation of mechanical and electrical equipment under actual operating conditions. Gates are included as mechanical equipment since a hoisting device is used to operate them. SEED suggests that regular examinations should be performed at least every two years and a six year inspection which is more specialized should be conducted. Auxiliary power should also be checked for proper operation.

A SEED seminar manual [23] reaffirms the concept of testing to a full open position under actual operating conditions. However, it does establish provisions for the delay or revision of testing because of time, costs, or water conditions (ie., full reservoir pool level). Revised testing may include operation of a gate to only a partial lift, or opening or delaying testing until the water level

drops.

The Federal Emergency Management Agency (FEMA) [5] recommends operating a gate or other outlet device through full range at least annually to ensure proper reliability. However, testing is suggested to be performed when the reservoir level is down to reduce the chance of downstream destruction when large volumes of water are released.

FEMA recommends in the Federal Guidelines for Dam Safety [5] that inspections be performed on three levels. Informal inspections should be scheduled depending on a dam's size and hazard classification. This inspection is performed by a plant employee, or inspector, who checks for abnormalities at the dam and outlet devices. An intermediate inspection should be performed at least every two years, but it is preferable to do so annually with an engineer inspecting the dam and outlet devices. A formal inspection should be performed at least every five years. Current design requirements need to be reviewed to determine if the dam meets the guidelines. During this inspection the dam and outlet devices are inspected by a group of specialized engineers in geology, concrete, and other important areas. No details were discussed concerning the specific guidelines that gates and other appurtenant devices were measured against.

The International Commission on Large Dams released a manual, *Operation of Hydraulic Structures of Dams* [12].

This manual details general spillway testing. Intervals and inspection criteria are not specified. It is stated that most spillway gate testing is performed with the reservoir level down so that little or no water is released; however, this does not replicate actual operating conditions and may give a false sense of reliability that the gates will work properly during actual "wet" operating conditions. Although dry testing eliminates water releases, it may damage the seals on the gates thus potentially causing more problems in the future. The seal could dry out and crack when water is not used to lubricate the seal. Then, when the gate is lowered or closed, cracked seals could allow water to pass. The additional water may corrode the gates or valves contributing to further difficulties. Damaged seals might prevent the gates from complete closure which would allow additional water to be uncontrollably released. The limiting components which prohibit "wet" testing are the large releases of water to downstream areas which might cause damage and the squandered water that would be used to supply to the population or provide hydropower.

Most inspection programs suggest testing outlet devices annually. Table 3.3 is a general summary of testing procedures listed by Federal agencies, dam safety publications, or other organizations. The agencies generally advise that gate testing be done under wet or with water pressure conditions; however, exceptions are

Table 3.3. Summary of general testing procedures by national agencies or publications.

AGENCY/ PUBLICATION	TESTING INTERVAL	TESTING CONDITIONS
TVA	2.5 years	Dry-full height Wet-1 foot raise
Corps of Engineers	Annually-1 st 4 years Biennially-2 nd 4 years 5 years	Water pressure if possible.
Bureau of Reclamation	Annually- Regulating valves and gates Annually- emergency outlets 6 years emergency	Wet and dry Dry Wet
International Boundary and Water Commission	1-4 years	None given
Federal Energy Regulatory Commission	Annually 5 years	Partial-wet or dry Full height
Safety Evaluation of Existing Dams	2 years	Actual operating conditions-if possible.
Federal Emergency Management Agency	Annually 2 years	Dry None given
International Commission on Large Dams	None given	Dry

allowed for testing under dry conditions. Most often the cost of spilling stored water, or potential energy, and the downstream destruction are reasons given to delay testing or to test without water pressure acting on the gates or valves. Although there are cases where these reasons are valid, many dams are not affected by these limitations. Although some dams may need testing performed in a restricted manner, many which could test to full open and close positions with water pressure acting on the gates unjustifiably do not. Costs do increase, but most agencies require wet testing unless there is a restricting feature which prohibits the spilling of water. Therefore, if one dam has limitations on spilling during testing programs so that it does not release water, all dams that the agency owns may be tested the same to achieve a uniform testing program. This may help the inspectors, but it does not adequately justify limiting the testing program. An effective inspection regime should test the outlet devices as close to actual operating conditions as possible unless there are limiting costs or potential damages.

CHAPTER 4

DATA ANALYSIS

4.1 BENEFIT OF TESTING

If one of a dam's gates does not operate properly, the needed outflow may be obtained by using more gates or by opening the working gates to a higher level. However, if a gate does not work, discharges could become very large and exceed the reduced capacity of the other outlet devices. To ensure that TVA's dams operate correctly, each dam must be inspected for signs of deterioration or inoperable equipment. Required testing is a necessity because TVA has a responsibility, which is outlined in the Federal Guidelines for Dam Safety [5], as a government agency to confirm the safety of each of the dams.

Spillway releases are important not only during floods, but also when floods are predicted. The majority of the outflow should be through the spillway because the spillway can discharge very high flows. Some additional water may be passed through the turbines, sluices, or valves. When a large spill is needed, the gates are needed to release the desired volume of water. If the gates do not work properly, damage may occur to the dam or to the surrounding areas.

By changing testing procedures to incorporate testing with water pressure, spillway gates will become more

reliable. Actual operating conditions are most closely experienced when testing is done with water pressure acting on the gate thus, reliability can be assessed more accurately. Although several of the TVA dams test with "wet" conditions, or by spilling water, the height that the gate is raised is approximately one foot, only a fraction of the gates full height. A true testing procedure should allow the gate to be raised to full height with water pressure to most closely simulate actual operating conditions. A one-foot raise tests the hoisting devices used to lift the gates but does not test the gates completely. Raising a gate higher may expose many potential problems. Degradation of the track, which could limit the height that the gate could be raised, may be exposed. The cables or chains might show additional wear that visual inspections might not notice until the chains or cables are unwound. The additional pressure that the water has on the gate may cause the gate to bind as it is raised or lowered.

If a spillway gate does not operate correctly during a spillway release requiring a discharge from each spillway bay, the dam may be threatened by the dangers of overtopping. Overtopping of a TVA dam with radial or lift gates will not destroy the dam; however, the high water level may harm other aspects of the dam or cause damage to upstream landowners and it may do so even if overtopping does not occur.

At dams which have many spillway gates--like Kentucky Dam which has twenty-four lift gates--a singular gate failure is not as serious as such an incident at dams which have only a few gates, such as Melton Hill Dam which has three radial gates. If one radial gate at Melton Hill Dam does not function correctly, only 67 percent of the design flood, the probable maximum flood, can be accommodated.

TVA will gain many additional benefits by increasing testing and inspection intervals because problems may be detected earlier. This could avert major repairs by preventing the problems progression to a serious dilemma. If a major repair is needed, the reservoir level would need to be lowered to facilitate work on the gate. The drawdown could affect power generation, navigation, or recreational benefits adversely. Preventive maintenance could reduce the number of times that a reservoir would have to be lowered or drawn down for repair.

4.2 COST CONSIDERATIONS

The two major reasons that gates are not tested according to actual operating conditions are potential downstream damage and the cost of the stored water, or potential energy, that is lost. None of the fifty-four dams which TVA owns and operates would experience downstream damage from the expected discharge from testing spillway gates. When the spillway gates are tested, only one gate at

a time is raised and lowered. The spill release lasts only for as long as the gate can be opened and closed.

A cost is associated with spillway testing when water is discharged. The spilling cost is the value that the water would have produced had it been used to produce power instead of being discharged through the spillway. The dams with radial gates have lower spilling costs than lift gates. The reason that the dams with multisectional lift gates have a greater spilling cost than the dams with radial gates is that the multisectional lift gates have an attachment time to move the hoisting equipment from one section to the next section of the gate. The attachment time is the time required to unhook the gantry crane or traveling hoist from one section of the gate and to then reattach to the next section of the gate. The average spilling cost for the testing of every gate at normal summer pool levels for the eighteen dams with radial gates is \$2,785 per dam, compared to \$8,236 per dam for the seven dams with lift gates. The spilling cost can only be determined for dams which produce hydropower because the lack of production is equivalent to the lack of value.

For each inspection, planning must be done. Planning for an inspection is done by the engineer and the plant operations manager. The engineer contacts the manager and decides on an appropriate time. Normal inspections usually are planned at least a week in advance, but more detailed

inspections, which might include reservoir drawdowns, may take a year to coordinate. For normal inspections, the total time for planning is approximately four hours for the engineer and the manager. The time may be spread over a week to contact everyone involved. The cost for planning is \$253 per dam (1993 dollars). The manager must be able to ensure that all necessary personnel (gate operator, mechanic, and electrician) are available and that no special circumstances prevent the inspection. Inspection could be delayed if other maintenance or special operating conditions are being planned for that same time period.

The personnel involved in the inspection also represent a cost; mechanical and electrical engineers must be present along with a gate operator, mechanic, and electrician. These people do the actual onsite inspection of the mechanical components of the dam. All outlet devices are checked. Hoisting equipment is tested for oil levels and other important features. The cost for the five people is \$1,075 per day. The number of days for an inspection at a dam is dependent upon the number of spillway gates and the type of gates. Table 4.1 lists the number of days needed for an inspection to fully test each radial or lift spillway gate to full open and closed positions at a dam. Radial gates can be tested faster than lift gates because they have fixed hoisting devices. Lift gates require more time to

Table 4.1. Number of days to inspect all gates.

DAM	NUMBER OF DAYS TO INSPECT ALL RADIAL OR LIFT GATES AT THE DAM
Apalachia	1.5
Blue Ridge	2.0
Boone	1.5
Chatuge	2.0
Cherokee	3.0
Chickamauga	7.0
Douglas	3.0
Fontana	1.5
Fort Loudoun	3.5
Fort Patrick Henry	1.0
Great Falls	2.0
Guntersville	7.0
Hiwassee	1.5
Kentucky	12.0
Melton Hill	1.0
Nickajack	2.0
Nolichucky	<1.0
Normandy	1.0
Nottely	2.0
Ocoee #2	1.0
Ocoee #3	2.0
Pickwick	9.0
Tellico	1.0
Tims Ford	1.0
Watts Bar	2.0
Wheeler	3.0
Wilbur	1.0
Wilson	6.0

open completely because of their multiple sections and because they have gantry cranes which take longer to position before the gates can be moved. For the multiple section lift gates that use a gantry crane, only two to three gates can be opened and inspected a day.

4.3 INSPECTION AND TESTING COSTS

When a gate is tested to full open and closed positions, a large volume of water can be spilled. Of the twenty-eight dams with lift or radial gates on the spillway, twenty-five dams produce hydropower. The spilling cost is equal to the value the water would have produced had it been used for power generation, instead of being spilled. Therefore, only the 25 dams which produce hydropower have a spilling cost associated with the opening and closing of the spillway gates. The spilling cost is the major expense of the inspection program. The spilling cost for all the 18 dams with radial gates that produce hydropower is \$50,128. This compares to \$43,227 for the cost of personnel and planning costs for the dams with radial gates. Fifty-four percent of the total cost is from the spilling costs.

Dams with lift gates are also affected by the spilling cost. It costs \$57,651 in lost revenue for the water spilled at all seven dams with lift gates that produce power. The cost of the personnel and the planning combined is \$51,475. Fifty-three percent of the total cost is from

the spilling cost.

The spilling cost, however, may be reduced by testing and inspecting during a spillway release. Dams with radial gates may decrease their spilling cost by 35 percent in this manner. Costs may be cut to \$32,460 from the original spilling cost of \$50,128. Apalachia, Great Falls, Nickajack, and Ocoee #3 Dams could be tested while they are spilling water. The inspection and testing program can be held in conjunction with a spillway release if the inspection team is granted a minimum of one week advance warning to make the necessary arrangements.

The same process can be accomplished at dams with lift gates, where spilling costs may be reduced by 99 percent from \$57,651 to \$29. The savings are substantial because all dams with lift gates that produce power, except Nottely and Chatuge Dams, spill frequently. This enables inspections and gate testing to be conducted during normal spill operations. Since the water needs to be discharged, the spilling cost is not affecting the cost to inspect, except at Chatuge Dam. Chatuge Dam does not spill often enough to allow testing during a spillway release. The reservoir level at Nottely Dam is too low to spill water during a test because the summer reservoir level does not reach the spillway gates. Therefore, the total cost decreases by 53 percent from \$109,126 to \$51,475 for the dams with lift gates.

Considerations for testing procedures are summarized in Table 4.2. The ability to test the spillway gates to full open and closed positions with water pressure acting on the gates is listed. If the gates cannot be tested to full height with water pressure, the reason is discussed. The ability for a testing program to be held in conjunction with a spill event is also listed. Special considerations which could influence testing procedures are similarly noted.

The decrease in the cost of gate testing during a spill event is a savings which can be incorporated into the inspection program. The decreased cost may enable testing to be conducted more frequently. One drawback to the gate testing during a spill event is the time needed to get to the dam. An advanced warning of one week is necessary to allow the engineers enough time to organize an inspection team and to obtain current drawings and the last inspection report.

Another important component of the spillway gate testing program during a spill event is the safety of the inspectors. When a spill is needed to discharge excess water from a flood, the weather conditions could cause the dam site to be hazardous. Also, most flood events are in the winter months when conditions are colder. Ice and severe weather may inhibit the effectiveness of the inspectors because of safety considerations. However, such conditions are indicative of actual operating conditions.

Table 4.2. Considerations for testing procedures for dams with lift and radial gates.

DAM	CAN GATES BE OPENED FOR WET TESTING?	CAN TEST DURING A SPILL EVENT?	SPECIAL CONSIDERATIONS
Apalachia	Yes	Yes, spill often	Cold water fisheries, fish kill
Blue Ridge	Yes	No	None
Boone	Yes	No	None
Chatuge	No, low reservoir level	No	Cold water fisheries, fish kill
Cherokee	Yes	No	None
Chickamauga	Yes	Yes, spill often	Navigation
Douglas	Yes	No	None
Fontana	Yes	No	None
Fort Loudoun	Yes	No	Navigation
Fort Patrick Henry	Yes	No	None
Great Falls	Yes	Yes, run of the river, spill often	None
Guntersville	Yes	Yes, spill often	Navigation
Hiwassee	Yes	No	None

Table 4.2(continued). Consideration for testing procedures for dams with lift and radial gates.

DAM	CAN GATES BE OPENED FOR WET TESTING?	CAN TEST DURING A SPILL EVENT?	SPECIAL CONSIDERATIONS
Kentucky	Yes	Yes, spill often	Navigation, total dissolved gases
Melton Hill	Yes	No	Navigation
Nickajack	Yes	Yes, economic dispatch, spill often	Navigation
Nolichucky	No, environmental concern	No	None
Normandy	Yes	No	None
Nottely	No, low reservoir level	No	Fish kill
Ocoee #2	Yes	No	None
Ocoee #3	Yes	Yes, economic dispatch, spill often	None
Pickwick	Yes	Yes, spill often	Navigation
Tellico	Yes	No	None
Tims Ford	Yes	No	Cold water fisheries
Watts Bar	Yes	No	Navigation

Table 4.2(continued). Considerations for testing procedures for dams with lift and radial gates.

DAM	CAN GATES BE OPENED FOR WET TESTING?	CAN TEST DURING A SPILL EVENT?	SPECIAL CONSIDERATIONS
Wheeler	Yes	No	Navigaiton
Wilbur	Yes	No	Cold water fisheries
Wilson	Yes	Yes, spill often	Navigation

Safety should always be accounted for during an inspection program and all necessary precautions should be taken.

4.4 RISKS

Testing outlet devices at a dam increases the reliability of the spillway gates and when a discharge is needed it can be accomplished with little or no trouble. Eleven of the twenty-five dams with radial or lift gates averaged spilling more than thirty days per year during the last eighteen years (1975 to 1992), but ten of the dams averaged spilling less than five days per year [24]. Spillway gates at four TVA dams, Hiwassee, Boone, Chatuge, and Cherokee Dams, were not exercised for a spillway release at all during that period. Table 4.3 shows the average days of spill per year compiled from 1975 to 1992 [24]. The more a gate is used, the more reliable it is. Although a gate may have been used to spill water, it is unlikely that it was opened completely. Such an infrequently used spillway gate may develop problems, such as rusting, if the gate remains idle over an extended period of time. A risk is being taken if gates and other outlet devices are not exercised on a regular basis. A one-foot lift does not exercise a spillway gate enough for adequate assurance that the gate will work properly. An effective testing program for dam safety should stress fully opening and closing an outlet device on a regular basis.

Table 4.3. Average yearly spills for dams with radial or lift gates (1975 to 1992) [24].

DAM	AVERAGE DAYS OF SPILL PER YEAR
Kentucky	104
Nickajack	97
Great Falls	89
Guntersville	80
Ocoee #3	80
Tims Ford	69
Chickamauga	66
Pickwick	63
Wilson	33
Watts Bar	33
Apalachia	31
Wheeler	26
Fort Loudoun	23
Blue Ridge	10
Douglas	5
Fontana	4
Wilbur	2
Melton Hill	2
Fort Patrick Henry	2
Nottely	1
Hiwassee	0
Boone	0
Chatuge	0
Cherokee	0

Another risk involves the potential damage if a spillway gate is raised to discharge water and does not close properly; it may continue to drain the reservoir. This type of unintentional draining could be substantial in a small reservoir like Wilbur Reservoir. Therefore, if a spillway gate does not work properly, it could either discharge too little or too much water. This potential consequence often deters inspectors from opening a gate to full height.

If an outlet device does not open correctly and the desired discharge is not achieved, the reservoir level will continue to rise. This problem could become a critical situation if the water rises to an excessively high level, especially if it does so rapidly. The rate that the water rises in the reservoir could also become a critical factor. If the water is rising fast, there may not be enough time to repair a gate so that it can be opened. High water levels may overtop the dam or cause substantial damage to it or to upstream areas. The ability of a dam's emergency spillway to work properly is essential to allow the design flood to be discharged.

If an emergency situation does arise during a needed spill event, it would be expensive to bring personnel and equipment to the site to fix the gate. The ability of personnel to reach the site during an emergency would be hindered and working conditions may be dangerous because severe weather conditions would have caused the flood.

The failure cost used for this study is defined as the cost to repair a lift or radial gate at a TVA dam. Several different means of calculating failure costs were examined as alternatives. The cost of a dam failure was considered but not used because it controlled the results of the study. The dam failure cost was too large of an estimate of a gate failure because if a gate fails it does not destroy the dam. The cost to completely replace a lift or radial spillway gate was also examined; however, if a spillway gate fails, it is unlikely that it will need to be replaced. Therefore, the cost to repair a spillway gate was used as the best estimate of the failure cost.

The risk of failure cost is the cost associated with the failure of spillway gates. The risk cost of gate failure is equal to the product of the cost of replacing a spillway gate, the probability of failure for the inspection interval, and the number of spillway gates, as given by equation (16).

$$R=G*P*N \quad (16)$$

where: R= risk of failure cost, 1993 dollars
 G= cost of replacing gate, 1993 dollars
 P= probability of failure for the inspection
 interval
 N= number of gates

The replacement cost was determined by a survey to find

an acceptable risk of failure cost. The breakdown of repair costs was estimated for the lift and radial gates. Table 4.4 shows a list of the expected repair costs for the spillway gates. The repair costs were determined to be the average cost to repair a gate based on the breakdown. The repair cost is \$51,788 for lift gates and \$55,625 for radial gates.

The frequency or probability that a spillway gate at a TVA dam would not operate as expected when needed was determined by a consensus of four experienced TVA inspection, maintenance, and dam safety personnel. The consensus was developed through cooperation between the Water Resource Projects and the Reservoir Operations Planning and Development divisions. The spillway gate failure initial estimate was the opinion and judgement of a TVA dam safety employee. Then, three other inspection and construction engineers were contacted with the results to determine their reactions. Two of the three engineers recommended that the probabilities be used. The remaining engineer abstained and would not comment on the probabilities because the results of the probabilities would be published. The consensus is based on engineering judgment, because no records on previous failures were available to determine the failure probability. Table 4.5 lists the probability of gate inoperability or failure associated with the testing interval for radial and lift

Table 4.4. Breakdown of repair costs to lift and radial spillway gates.

	LIFT	RADIAL
<\$5,000	50%	24%
<\$12,500	8%	35%
<\$50,000	30%	35%
<\$100,000	10%	5%
<\$250,000	1%	1%
<\$500,000	1%	0%
>\$500,000	0%	0%

Table 4.5. Probability of spillway gate inoperability based on the testing and inspection interval.

Interval, years	Probability of failure for lift gates	Probabilty of failure for radial gates
0.5	2.0%	5.0%
1.0	3.5%	5.0%
2.0	5.0%	7.5%
3.0	7.0%	10.0%
5.0	10.0%	13.5%
7.0	12.0%	15.0%
10.0	15.0%	17.5%
15.0	17.0%	20.0%
20.0	20.0%	25.0%
30.0	25.0%	30.0%
50.0	35.0%	50.0%
75.0	40.0%	60.0%
100.0	50.0%	88.5%

gates. Figure 4.1 shows the data from Table 4.5 in graphical form for the two types of gates. A confidence interval was found on the estimated probability of failure for spillway gates. The upper range for the confidence interval was assumed by multiplying the estimated probability by two. The lower range was assumed by dividing the estimated probability by two. This technique of determining the upper and lower ranges of a probability estimate is commonly used in similar TVA's studies (29).

The probability of gate failure is dependent upon the type of spillway gate. The radial gates have a higher probability of failure for a given testing frequency than the lift gates. The radial gates have more areas or devices which could deteriorate and cause operating problems. A radial gate is hinged with a chain or cable attached to the top of the skinplate or upstream surface area. As the gate is raised, it moves along a track or guide. The motors used for raising and lowering the radial gates have push button activators that have shown signs of deterioration in the past and could cause inoperability in the future.

The lift gates operate according to a less complicated lifting process. They are raised by a gantry crane except, at Nottely and Chatuge Dams which use a traveling hoisting device. The lift gate is installed in vertical slots which are raised easier. The lifting process has fewer devices which could affect the probability of inoperability. The

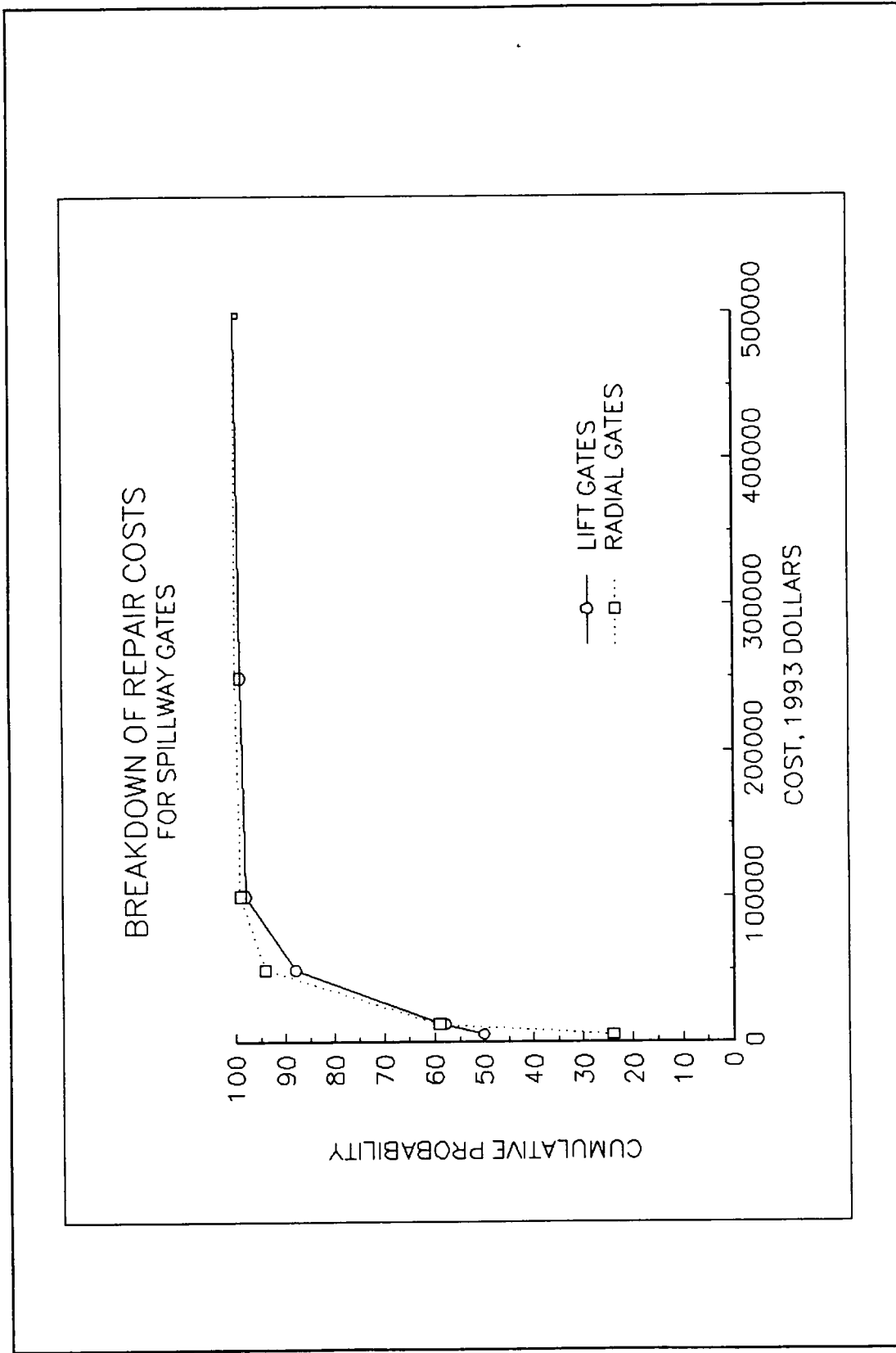


Figure 4.1. Breakdown of repair costs for radial and lift spillway gates.

lift gate is simple and travels only up or down, while the radial gates are more complex and move along a contoured guide.

The testing program that the probability is dependent upon utilizes the method of inspection base on the operation of the spillway lift or radial gate to full open and closed position with water pressure acting on the outlet devices. The inspection program is, therefore, closely related to the actual operating conditions.

4.5 FREQUENCY OF TESTING-FAILURE DATA

For every specified interval of testing, an inspection cost is determined to correspond with the testing interval. The annual inspection cost is divided by the testing interval in years. The inspection costs, as are all costs, are expressed in 1993 dollars and are not converted to future costs for the testing interval.

Table 4.6 lists the results for the total direct cost with respect to the testing interval. The corresponding graphs, Figures 4.2, 4.3, 4.4, and 4.5, show the optimum testing frequency based on the type of gate and the testing conditions.

From Table 4.6 and Figures 4.2, 4.3, 4.4, and 4.5, the results indicate that a yearly inspection program would benefit the reliability of spillway gates and ensure a safe dam release program. The radial gate results show that a

Table 4.6. Total direct costs with respect to the testing interval.

Interval, years	Radial	Radial with a spillway release	Lift	Lift with a spillway release
daily	\$34,074,940	\$27,516,254	\$39,830,988	\$18,788,374
0.5	\$754,087	\$718,749	\$458,548	\$343,246
1.0	\$660,731	\$643,062	\$529,644	\$471,993
2.0	\$897,740	\$888,906	\$655,304	\$626,478
3.0	\$1,165,868	\$1,159,979	\$877,412	\$858,195
5.0	\$1,550,583	\$1,547,050	\$1,223,306	\$1,211,776
7.0	\$1,715,461	\$1,712,937	\$1,457,367	\$1,449,131
10.0	\$1,995,148	\$1,993,381	\$1,811,314	\$1,807,369
15.0	\$2,275,723	\$2,274,545	\$2,049,793	\$2,045,950
20.0	\$2,841,542	\$2,840,659	\$2,408,419	\$2,405,536
30.0	\$3,407,361	\$3,406,772	\$3,007,341	\$3,005,420
50.0	\$5,675,617	\$5,675,263	\$4,207,367	\$4,206,214
75.0	\$6,809,744	\$6,809,508	\$4,807,380	\$4,806,611
100.0	\$9929995	\$9929818	\$6,008,499	\$6,007,922

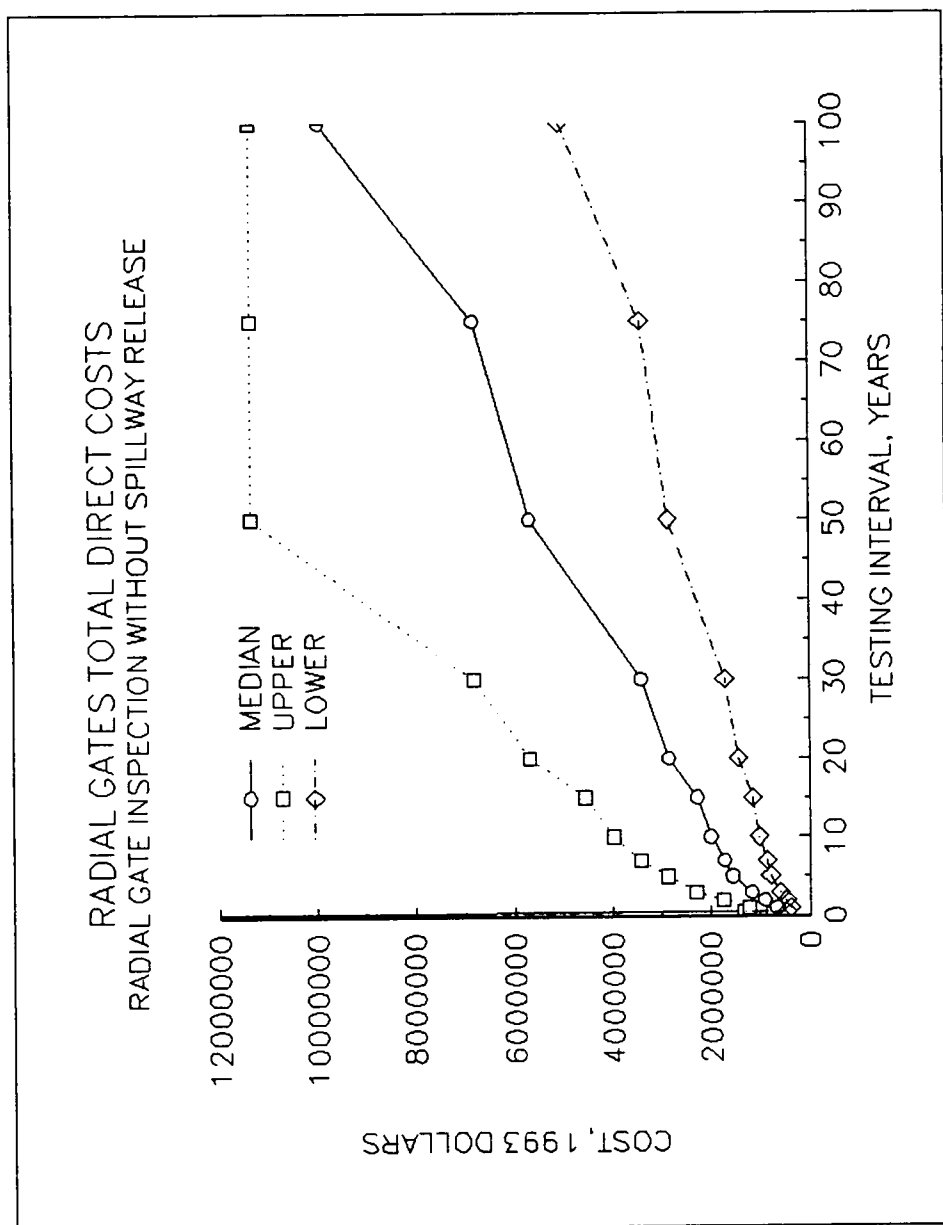


Figure 4.2. Optimum testing frequency versus cost graph for testing radial spillway gates without a spillway release.

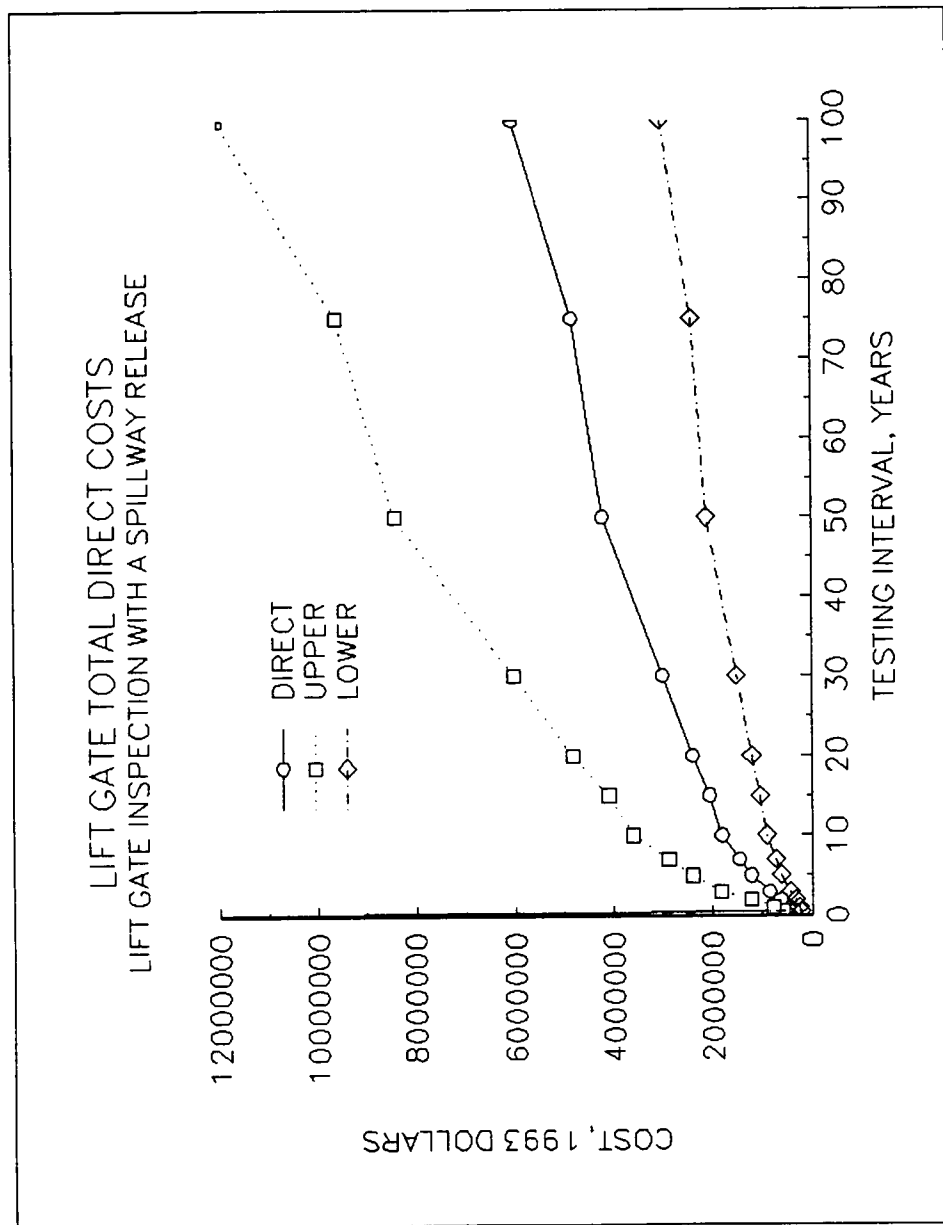


Figure 4.3. Optimum testing frequency versus cost graph for testing lift spillway gates during a spillway release.

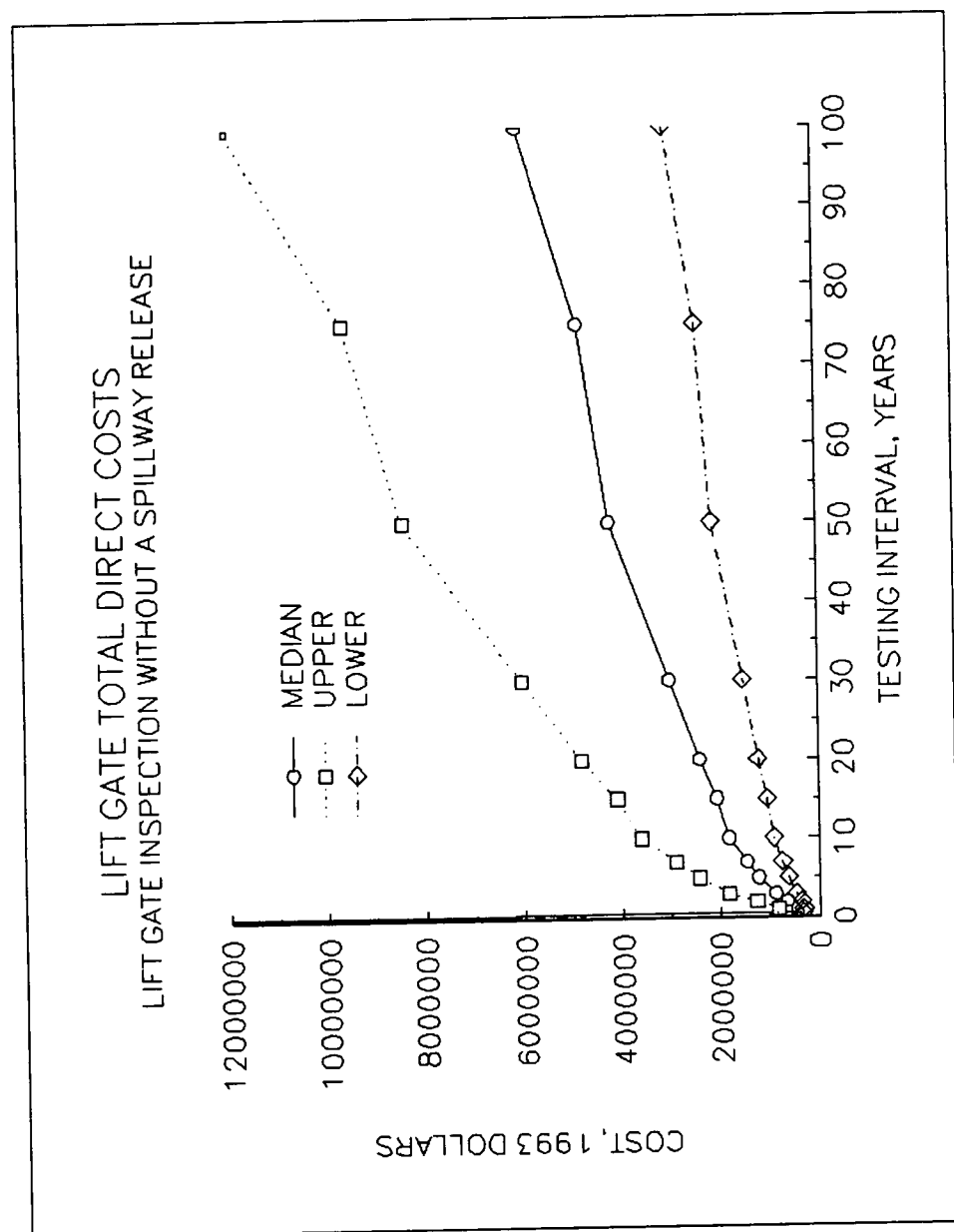


Figure 4.4. Optimum testing frequency versus cost graph for testing lift spillway gates without a spillway release.

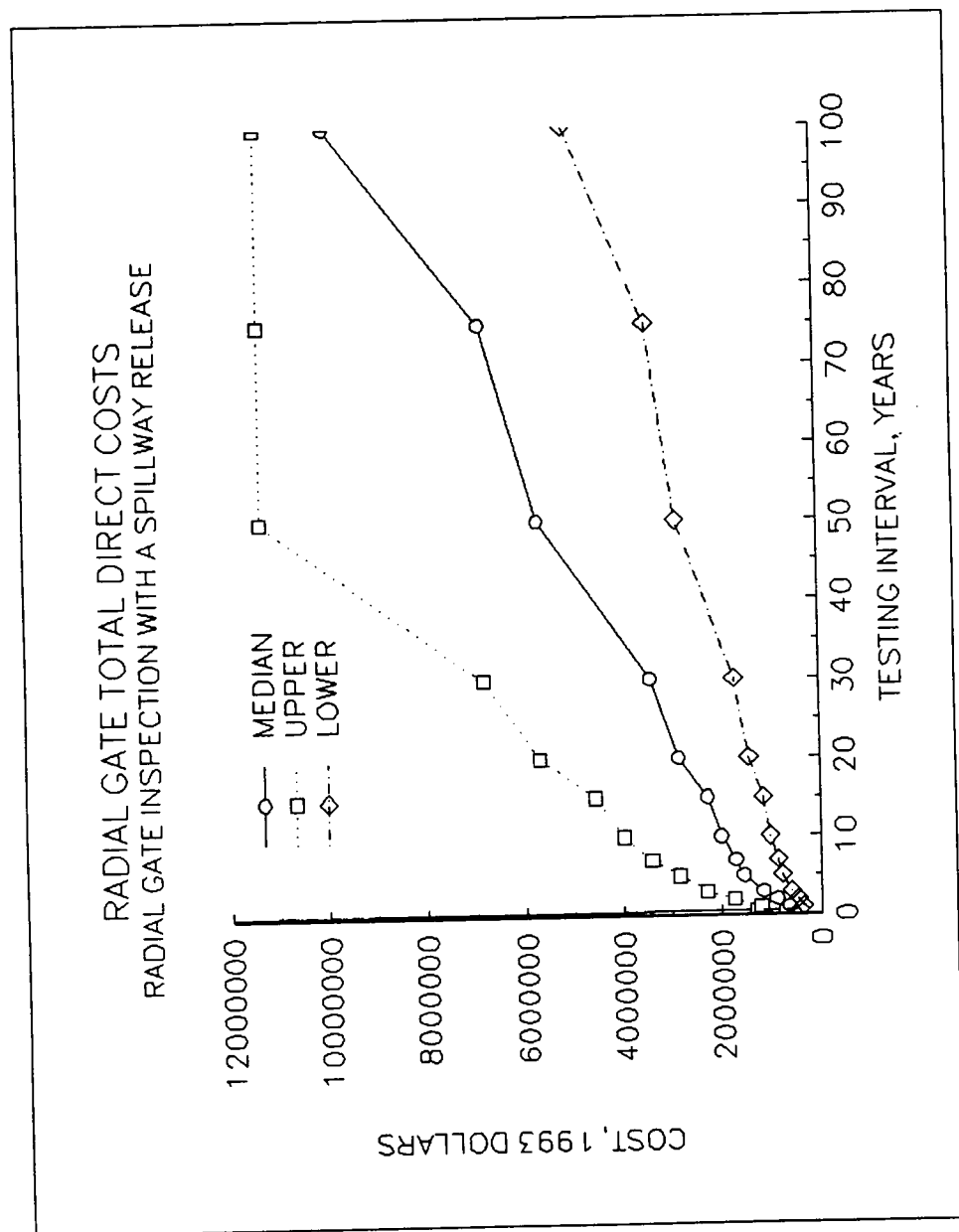


Figure 4.5. Optimum testing frequency versus cost graph for testing radial spillway gates with a spillway release.

one-year inspection interval represents the best choice for a more reliable spillway release program; however, a cost analysis of the lift gates produce less distinct results. Although a one-half year testing interval is the best option based on the results, a range of testing intervals is the best choice for the analysis because of the upper and lower ranges for the probability used in the study.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 RESULTS

The frequency of testing versus the cost data shows that the optimum testing frequency range are:

Radial gate	1 to 2 years
Radial gate with a spill	1 to 3 years
Lift gate	0.5 to 3 years
Lift gate with a spill	0.5 to 3 years

These results are based on costs for spilling water, labor, and planning, as well as the failure costs of the spillway gates.

Assurance in the results was established by confidence intervals for the probability of spillway gate failures. Upon discussion with a TVA economic specialist, a confidence interval was established and factored into the frequency of testing versus costs graphs and data. If factual probabilities and repair costs had been used, the confidence interval could have been narrowed, thus yielding more precise results. The results of the interval shows that the results are not very sensitive to the altered probabilities. The results are the same regardless of the which probability

is used.

5.2 LIMITATIONS OF RESULTS

The results of the optimum testing frequency appear reasonable; however, the results are dependent upon a consensus estimate for the probability of failure and an opinionated estimate of the breakdown of repair costs. First, the probability of a spillway gate failing based on the testing and inspection intervals must be estimated. Although the probabilities were considered acceptable by three engineers and inspectors, the probabilities are not based on any data such as inspection records. These records were not readily available since the data are located in Chattanooga and no database or comparable record keeping method has been used in storing the data.

Second, estimates for the failure cost were determined by a survey. The reasoning for the opinionated results is the same as that for the probability of gate failures. The cost data would be very difficult and excessively time consuming to obtain.

Methods used for the spillway gate study can be modified to determine testing intervals for other discharge devices. However, not all appurtenances can be tested as effectively, such as the three drum gates at Norris Dam. The drum gates are impossible to operate unless the water level is high enough to fill the drum or capsule. Thus, it

would be exceptionally difficult to test them in this manner.

Sluice or slide gates are also difficult to inspect because the gates are under water. Other water releasing appurtenances, such as valves, require a rigorous program to test. Visual inspection of underwater facilities is limited because of the depth of the appurtenances and may warrant extreme caution in exercising the equipment because of it's uncertainty.

The inspectors that test the spillway gates and other mechanical devices do not endorse updating the spillway gate inspection intervals or procedures. The opinion of Hydro Engineering Services in the Generating Group of TVA is that the current program provides adequate inspection of the mechanical features of the dam. According to the current program, unless a problem is found that could be common to all of the gates, only a portion of the gates are tested during each inspection. For example, when a spillway gate at Blue Ridge Dam would not work during subfreezing weather, testing was continued on all of the spillway gates to determine if the problem was typical at every gate. The inspectors believe that this method compensates for not testing each gate.

Another limitation of the inspection program can be compensated for by testing the spillway gates during spills. The ability of the inspection personnel to reach the

location of the dam on short notice may be difficult. For the dams to be tested, they need to be close enough for the inspectors to reach them in a reasonable amount of time. Of the nine dams with spillway gates which can be inspected during a spill, only three dams--Kentucky, Wilson, and Pickwick Dams--require travel which could delay testing. Kentucky and Pickwick Dams are main river dams which spill often for longer periods of time. Although the travel time is long, the duration of the spillway releases compensate for the additional travel time.

5.3 CONCLUSION AND DISCUSSION

Dam safety is an issue that needs to be addressed with the maintenance and inspection of all features of a dam. The spillway release devices are crucial to the ability to release flood waters and to pass expected incoming flood waters. The assurance that spillway gates and other appurtenances will work is necessary to ensure the safety of the dam.

If the spillway gates do not work properly, two scenarios could unfold. The spillway gates could fail in the closed position and it may become impossible by normal operating procedures to open the gates to allow water to pass. The upstream water level could continue to rise causing damage to landowners property and perhaps overtopping and failure of the dam itself. If the specified

gate sequence cannot be achieved, the order and opening height could be changed. Thus, the manuals that show the discharge dependent upon gate arrangement and headwater and tailwater elevations could not be used. Until detailed calculations could be made, the discharge from the dam would be unknown and downstream damage could occur. The discharge might be concentrated by the new gate arrangement causing scour to the downstream area.

The spillway gates could also become jammed or stopped in an open position. With the spillway gates remaining open, the reservoir might be drained before they could be fixed or before a bulkhead or stoplogs could be installed. This could affect benefits achieved through power generation, recreation, flood control, and navigation, not only for the reservoir that has the broken gate, but also for other upstream and downstream reservoirs in the system.

Forty-one of the fifty-four dams do not have onsite personnel. Most of the dams are operated remotely and a malfunction may not be discovered until sensors detect something wrong. The inoperability of spillway gates could result in more severe problems since personnel is not present at the dam. Personnel travel time would also slow the ability to fix the gate.

The method used to determine if testing spillway gates is justifiable can be repeated for any type of appurtenance. As discussed earlier, the sluice gates and other underwater

appurtenances, such as valves, may require more caution in inspecting because of the consequences that may occur if the devices do not work properly. A visual inspection can not be performed before the underwater appurtenance can be tested. However, the frequency of testing versus the cost curves and data could be repeated with the appropriate data to complete an optimum testing interval for the specific type of outlet device.

The consequences of the spillway gates not operating properly are serious. Because of the potential effects of the inoperability of a spillway gate, national inspection guidelines have been established. Upon review of these guidelines, most agencies suggest testing under normal operating conditions, if possible. No justifiable reasons have been discovered to prevent spilling water and raising and lowering the spillway gates completely during an inspection of the TVA spillway gates. Downstream damage does not occur and the spilling costs are less than one percent of the hydropower generating profits. Therefore, by considering costs and risks to TVA, there are no negative reasons not to completely raise and lower every spillway gate under normal operating conditions, if possible, during the suggested intervals to ensure as close to 100 percent operability as possible.

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APPENDIX

Table A.1. Height of spillway gate, hoisting rate and spilling cost for each dam.

DAM NAME	HEIGHT OF GATE	HOISTING RATE	SPILLING COST
Apalachia	23 feet	3 fpm	\$3812
Blue Ridge	20 feet	20 minutes to raise	\$1709
		20 minutes to lower	
Boone	35 feet	4 fpm	\$2277
Chatuge	6 feet	3 minutes to raise	\$29
		3 minutes to lower	
Cherokee	32 feet	8 fpm	\$1789
Chickamauga	40.44 feet	10 fpm + 30 minute attachment time	\$11415
Douglas	32 feet	8 fpm	\$1992
Fontana	35 feet	3.36 feet	\$6211
Fort Loudoun	32 feet	8-10 fpm	\$1637
Fort Patrick Henry	35 feet	4 fpm	\$1395
Great Falls	14 feet	4.86 fpm	\$569
Guntersville	40.44 feet	10 fpm + 30 minute attachment time	\$10896
Hiwassee	23 feet	5 fpm (or 10 fpm)	\$1516
Kentucky	50 feet	9.24 fpm +30 minute attachment time	\$17153
Melton Hill	42 feet	1.2 fpm	\$3614
Nickajack	40 feet	42.5 minutes-open	\$8820
		42.5 minutes-close	
Nottely	6 feet	2 fpm	\$0
Ocoee #2	10.8 feet	0.26 fpm	\$306
Ocoee #3	23 feet	3 fpm	\$2757

Table A.1. Height of spillway gate, hoisting rate and spilling cost for each dam.

DAM NAME	HEIGHT OF GATE	HOISTING RATE	SPILLING COST
Pickwick	40 feet	10 fpm +30 minute attachment time	\$14013
Tellico		39 minutes to raise	
		39 minutes to close	
Tims Ford	42 feet	1.13 fpm	\$4711
Watts Bar	32 feet	8-10 fpm	\$1710
Wheeler	15 feet	14 minutes to raise	\$5164
		14 minutes to close	
Wilbur	15 feet	3 fpm	\$142
Wilson	20.54 feet	4.5 fpm	\$4145

Table A.2. Inventory of TVA's Dams, hazard classification, outlets, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OF OUTLETS	YEAR OF DAM'S COMPLETION
Apalachia	High	Radial Lift Butterfly valve Slide	10	1943
			1	
			2	
			2	
Bards	Low	Slide	1	1966
Bear Creek	Low	Slide	3	1969
Beaver Creek	High			1965
Beech	Significant	Slide	1	1963
Blue Ridge	High	Radial Valve Caterpillar	8	1930
			1	
			2	
Boone	High	Radial Slide Wheeled Slide	5	1952
			2	
			6	
			2	
Cedar	Low	Slide	1	1963
Cedar Creek	Low	Slide Sleeve Bypass Valve	3	1979
			1	
			1	

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlets, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OF OUTLETS	YEAR OF DAM'S COMPLETION
Chatuge	High	Lift Sleeve Bypass Valve	50 1 2	1942
Cherokee	High	Radial Slide Roller Slide	9 16 4 2	1941
Chickamauga	High	Lift Wheel Slide Sliding type	18 1 2 3	1940
Clear Creek	High			1965
Columbia	High			Under construction
Crooked Creek	Low	Slide	1	1964
Doakes Creek	Low			1938
Dogwood	Low	Slide	1	1965
Douglas	High	Radial Slide Roller Slide	11 16 4 2	1943
Duncan	Low	Slide	1	1980

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlets, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OF OUTLETS	YEAR OF DAM'S COMPLETION
Fontana	High	Radial	4	1944
		Sleeve	1	
		Slide	1	
		Slide	12	
		Roller	3	
Fort Loudoun	High	Slide	2	1943
		Radial	14	
		Wheel	6	
		Slide	3	
Fort Patrick Henry	High	Radial	5	1953
		Wheel	2	
		Sliding	2	
Great Falls	Low	Radial	18	1916
		Broome	3	
Guntersville	High	Lift	18	1939
		Wheel	1	
		Slide	2	
		Sliding type	3	
Hematite	Low	Slide	1	1939

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlets, and year of completion

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OF OUTLETS	YEAR OF DAM'S COMPLETION
Hiwassee	High	Radial	7	1940
		Ring Seal	4	
		Roller	2	
		Slide	3	
		Lift	1	
Kentucky	High	Lift	24	1944
		Wheel	6	
		Slide	6	
Little Bear Creek	Low	Slide	3	1975
		Sleeve	1	
		Bypass valve	2	
Long Creek	Low	Slide	1	1965
Lost Creek	Low			1963
Melton Hill	High	Radial	3	1963
		Wheel	3	
		Slide	3	
Nickajack	High	Radial	10	1967
		Wheel	3	
		Wheel	1	
		Slide	6	
Nolichucky	Low	Lift	1	1913

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlets, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OF OUTLETS	YEAR OF DAM'S COMPLETION
Normandy	High	Radial	2	1976
		Sleeve	3	
		Slide (low)	2	
		Slide (high)	2	
Norris	High	Drum	3	1936
		Slide	16	
		Tractor	2	
Nottely	High	Lift	50	1942
		Slide	2	
Ocoee #1	High	Flap	4	1911
		Intake	10	
		Exciter	2	
Ocoee #2	Low	Radial	1	1913
		Sluice	5	
Ocoee #3	Low	Radial	7	1942
		Slide	2	
		Lift	1	
		Butterfly valve	1	
Pickwick	High	Lift	22	1938
		Lift	6	
		Slide	6	
Pin Oak	Low	Slide	1	1964
Pine	Low	Slide	1	1964

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlet, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OUTLETS	YEAR OF DAM'S COMPLETION
Raccoon Mountain	Low	Slide	1	1978
		Slide	1	
Red Bud	Low	Slide	1	1965
South Holston	High	Sleeve	1	1950
		Slide	2	
		Butterfly Valve	1	
Sycamore	Low	Slide	2	1965
Tellico	High	Radial	3	1979
Tims Ford	High	Radial	3	1970
		Slide	1	
		Valve	1	
		Roller	1	
		Slide	1	
Upper Bear Creek	Low	Slide	3	1978
		Sleeve	1	
		Bypass valve	1	
Watauga	High	Sleeve	1	1948
		Slide	2	
		Roller	1	

Table A.2 (continued). Inventory of TVA's dams, hazard classification, outlets, and year of completion.

DAM NAME	HAZARD CLASSIFICATION	TYPE OF OUTLET	NUMBER OUTLETS	YEAR OF DAM'S COMPLETION
Watts Bar	High	Radial	20	1942
		Lift	1	
		Wheel	6	
		Slide	2	
Wheeler	High	Radial	60	1936
		Lift	2	
		Lift	7	
		Slide	3	
		Lift	2	
Wilbur	High	Radial	4	1912
		Radial	1	
		Lift	3	
Wilson	High	Lift	49	1924
		Wheel/lift	1	
		Slide	12	
		Slide	6	
		Slide	3	
		Slide	9	

Table A.3. Upper and lower ranges for confidence range.

	LIFT GATES		RADIAL GATES	
INTERVAL	UPPER, %	LOWER, %	UPPER, %	LOWER, %
.5 Years	4	1	10	2.5
1.0	7	1.75	10	2.5
2.0	10	2.5	15	3.75
3.0	14	3.5	20	5
5.0	20	5	27	6.75
7.0	24	6	30	7.5
10.0	30	7.5	35	8.75
15.0	34	8.5	40	10
20.0	40	10	50	12.5
30.0	50	12.5	60	15
50.0	70	17.5	100	25
75.0	80	20	100	30
100.0	100	25	100	44.25

Table A.4. Upper and lower direct costs for testing spillway gates.

INTERVAL Years	RADIAL WITHOUT SPILL		RADIAL WITH SPILL		LIFT WITHOUT SPILL		LIFT WITH SPILL	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0.5	1321462	470399	1286124	435061	698845	338400	583543	223098
1	1228106	377043	1210437	359374	830015	319385	772364	261734
2	1748803	472209	1739968	463374	1256045	354933	1227219	326107
3	2300618	598493	2294729	592604	1838597	456894	1819380	437677
5	2855546	784627	2852012	781093	2424788	622565	2413258	611035
7	3417586	864399	3415062	861874	2899145	736478	2890909	728243
10	3980960	1002242	3979193	1000475	3615357	912024	3609592	906258
15	4545223	1140974	4544045	1139796	4092312	1028534	4088468	1024691
20	5678417	1423106	5677534	1422222	4811382	1206938	4808499	1204056
30	6811611	1705237	6811022	1704648	6011045	1505490	6009123	1503568
50	11349367	2838742	11349013	2838389	8412553	2104776	8411400	2103622
75	11348744	3405495	11348509	3405259	9613308	2404418	9612539	2403649
100	11348744	5022203	11348256	5022026	12015907	3004795	12015330	3004219

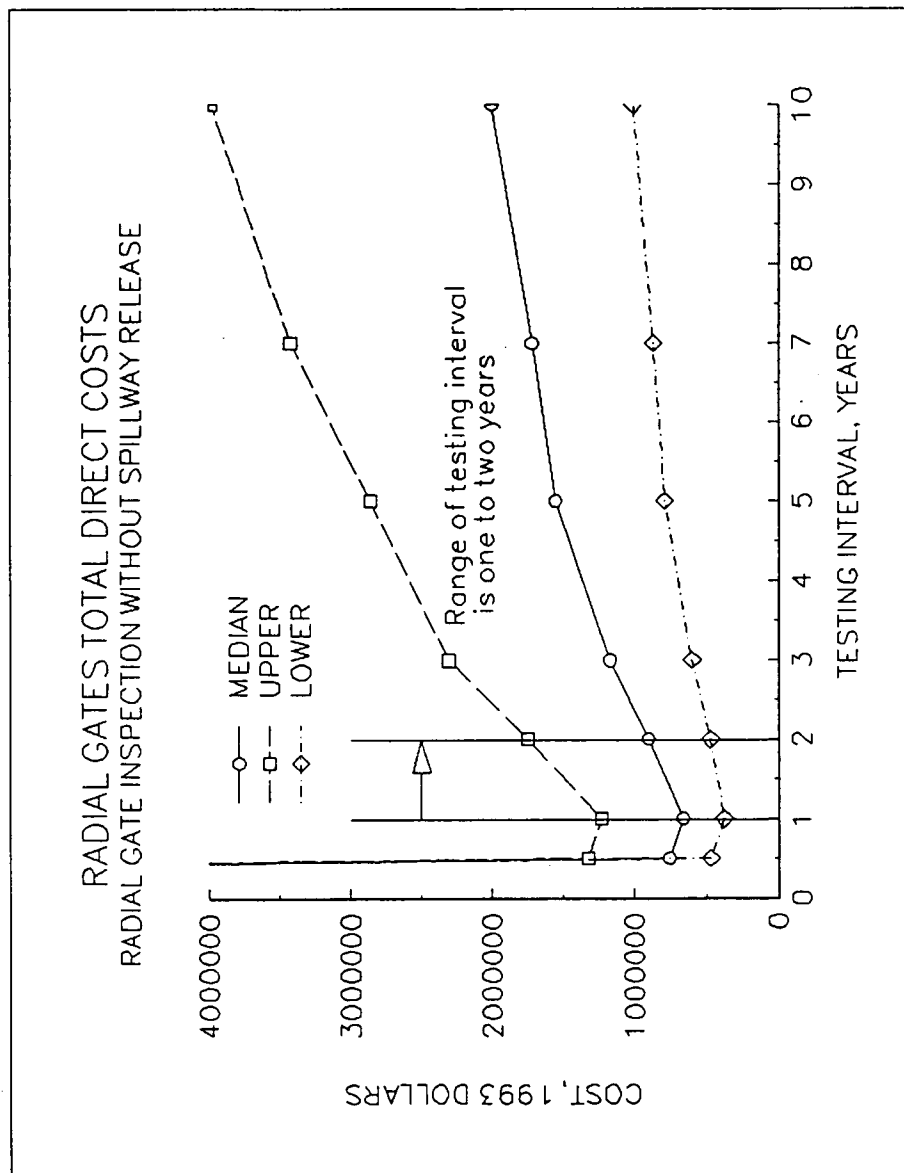


Figure A.1. Optimum testing frequency versus cost graph for testing radial spillway gates without a spillway release showing the first ten years.

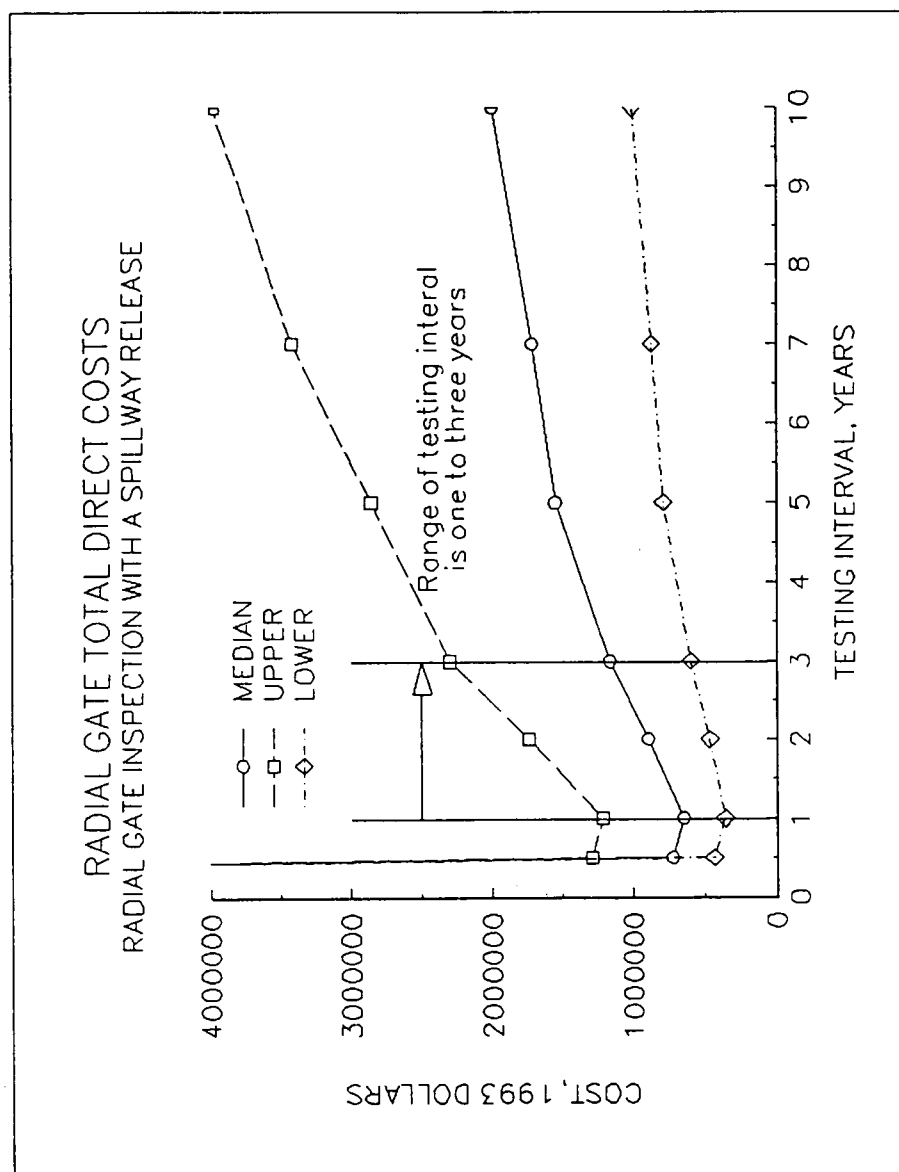


Figure A.2. Optimum testing frequency versus cost graph for testing radial spillway gates with a spillway release showing the first ten years.

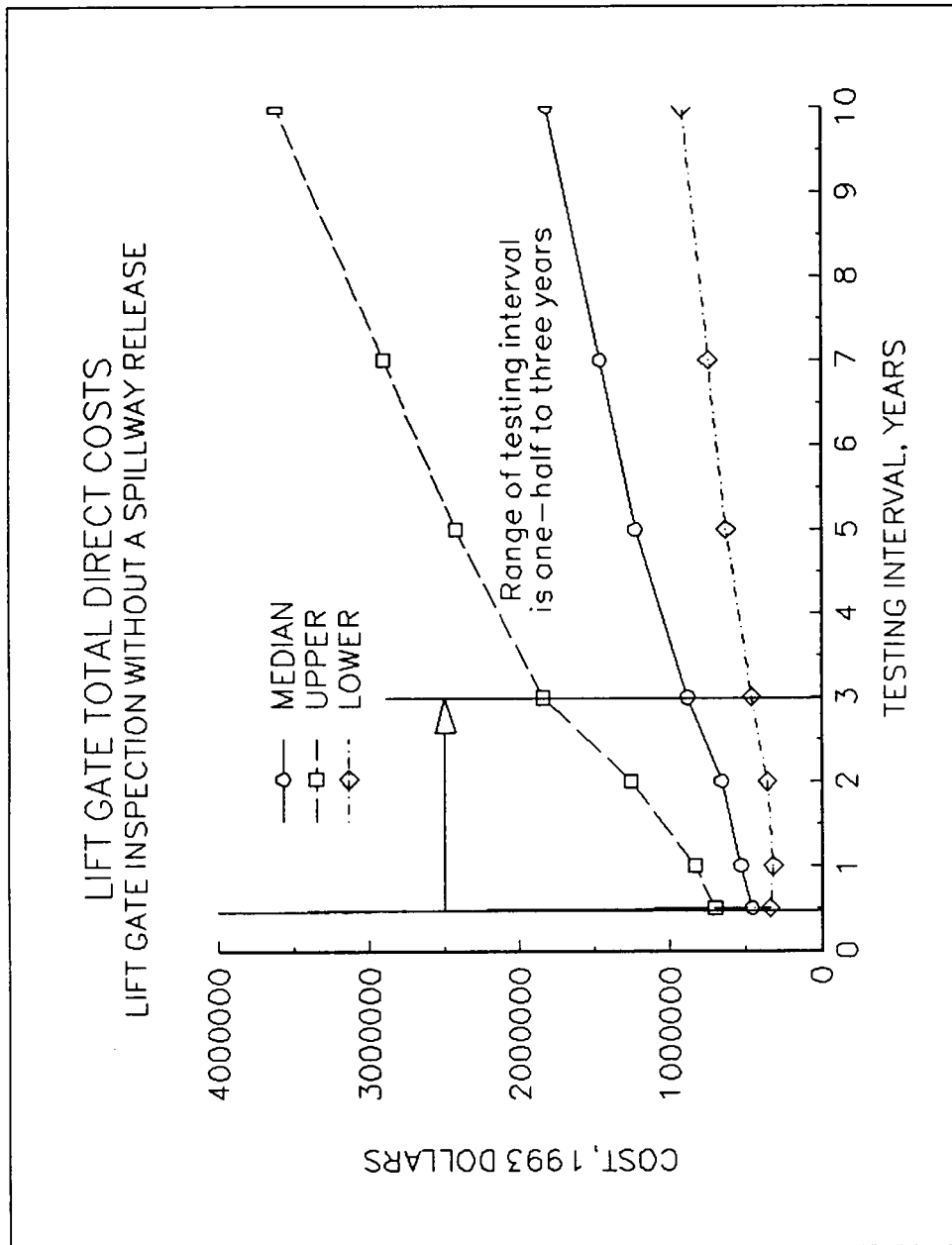


Figure A.3. Optimum testing frequency versus cost graph for testing lift spillway gates without a spillway release showing the first ten years.

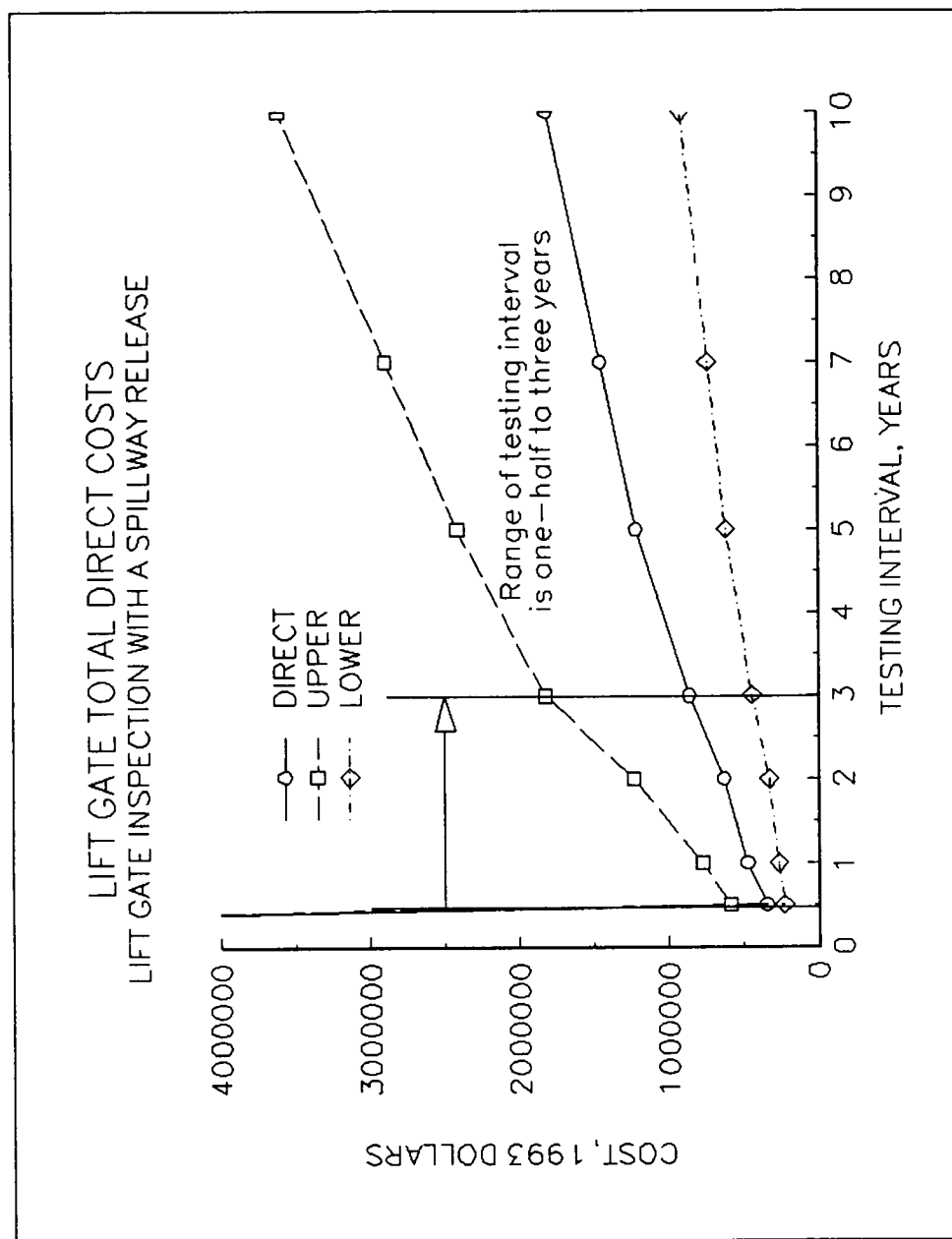


Figure A.4. Optimum testing frequency versus cost graph for testing lift spillway gates with a spillway release showing the first ten years.

VITA

The author was born in April of 1970, in Kingsport, Tennessee. She was raised in the Kingsport area, and graduated from Sullivan Central High School in 1988. She chose to pursue her undergraduate academic career in Civil Engineering at The University of Tennessee in Knoxville. Immediately after the completion of her Bachelor of Science degree in 1992, she decided to continue her education at The University of Tennessee and worked towards a Master of Science degree in Environmental Engineering, concentrating in hydraulics, hydrology, and water resources. The author is currently employed with Tennessee Valley Authority in the Reservoir Operations Planning and Development division in Knoxville, Tennessee.