To the Graduate Council:

I am submitting herewith a thesis written by A. Allison Swann entitled "Floating Debris on Lakes and Rivers: Effects on Operation, Use, and Safety of Lakes and Dams." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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FLOATING DEBRIS ON LAKES AND RIVERS: EFFECTS ON OPERATION, USE, AND SAFETY OF LAKES AND DAMS

A Thesis
Presented For The
Masters of Science
Degree
The University Of Tennessee, Knoxville

Alisa Allison Swann
May 1999

ACKNOWLEDGMENTS

I would like to thank Dr. Bruce A. Tschantz for his guidance and patience with this thesis. I would also like to thank Susan R. Jacks for her encouragement and the example she set for me. I am grateful for the assistance provided by the National Performance of Dams Program (NPDP) and the Association of State Dam Safety Officials (ASDSO). I want to thank Liz Etnier for being a last minute hero. I want to thank Bill and Liz Brady for their friendship beyond the call of duty. I want to thank my Dad, Mom, and Richard for being such great parents. I would like to thank my husband, Alva for his constant encouragement, his faith in me, and his love. I want to thank all of the people who prayed for me. Finally, I want to thank God for everything.

Abstract

Floating debris on reservoirs can cause a variety of potential hazards to dam and lake safety. Debris-related hazards can adversely impact navigation, recreation, flood control, and safe operation of lakes and dams. Owners and agencies involved with dam safety often neglect the concerns associated with floating debris because the dam safety community generally does not view floating debris as an 'imminent danger.'

This thesis emphasizes that floating debris represents a national concern to dam safety. It demonstrates the inconsistencies in federal and state administration of dam safety including a lack of inspection and dam maintenance regulation. The attitudes of state and federal agencies toward dam safety further reinforce the negative effects and ramifications of current policy and practice relating to floating debris. This thesis also includes responses to a survey of federal and state dam safety representatives and analyses collected information, addressing federal and state requirements for maintenance and disposal of reservoir debris. It illustrates possible damage- and failure-scenarios, and presents historical dam incidents, which validate the hazards associated with debris. Finally, this thesis recommends strategies for addressing debris-related problems.

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CHAPTER 1

Introduction

1. Introduction

To increase energy output at Great Falls Dam, one of the 54 Tennessee Valley Authority (TVA) dams, facility operators kept the head elevation just below the top of the gate. This increased elevation, coupled with slow operator response times, resulted in overtopping of the spillway during significant rainfall events. Consequently, floating debris, primarily large logs such as those shown at TVA's Wheeler and the Army Corps of Engineers' (ASCOE) Cheatham dam sites in Figure 1, lodged in the gate mechanisms inhibiting proper function. Inoperative gates posed a serious risk to the safe operation of the dam (TVA, 1995a and TVA, 1997a). A similar problem occurred in Wisconsin at Fairwater Dam, a facility owned by the Village of Fairwater. The gates at this dam were not operated in a timely manner and debris clogged the gates, rendering them inoperative and causing damage to the dam's embankment and roadway. The repair cost was approximately $400,000 (NPDP, 1998). These and other incidents of this type are indicative of a larger problem and suggest the need for further investigation of the causes and effects of floating debris as it relates to dam safety.

1.1. Scope and Objectives

In light of these and other incident, the main objective of this thesis is to demonstrate that floating debris is a national problem for dam safety. To accomplish this objective, the scope of this thesis addresses the issue of floating debris, US dam and lake

(a) Wheeler Dam – Illustrates the potential size of debris at dam sites (Jones et al., 1997)

(b) Cheatham Dam – Illustrates size of logs removed at Cheatham (Sadler, 1999a)

Figure 1. Size of Debris Removed from TVA and ASCOE Dam Sites

incidents caused by floating debris, and both federal and related state policies and attitudes that affect dam and lake safety. Additionally, this objective is accomplished by illustrating that legislation, hydraulic scenarios, past dam events, operation and maintenance of dams, and the attitudes of state and federal agencies toward floating debris all contribute to dam and lake safety problems. Other objectives and scopes of this thesis are as follows:

(1) to demonstrate the effects of floating debris on dam and lake operation, maintenance, use, and safety by:
   (a) showing a variety of potential "debris-related damage and failure scenarios" to dams, hereafter called damage- and failure-scenarios
   (b) presenting collected data on past debris-related incidents.
   (c) showing the various maintenance practices for the collection and elimination of debris.
(2) to illustrate that federal and state attitudes toward floating debris and the complex organizational framework of dam safety adversely affect dam and lake safety by:
   (a) highlighting the inconsistencies in the dam safety communities' priorities, policies, and practices.
   (b) showing the various dam safety agencies phlegmatic view toward floating debris. This is accomplished by:
      (i) showing their responses to a survey questionnaire.
      (ii)examining the scarcity of US literature that emphasizes the floating debris hazards on dam safety.
(3) to recommend strategies for addressing debris-related problems by:

(a) suggesting future research.

(b) proposing the hazards of floating debris be emphasized in dam safety publications and conferences.

(c) suggesting increases in federal resources to encourage federal, state, and owner responsibility.

1.2. General Description of Floating Debris and Its Hazards

For the purposes of this thesis, floating debris refers to lake or reservoir material, such as logs, branches, trash, ice, snow, plant life, and various other materials that accumulate at or above dams. It may also include docks loosened from their moorings, loose barges, log, branch, and organic debris (due to beaver activity, ice and snowstorms and fires), and the waste from forest clear-cutting operations. Floating debris normally does not include sediment matter or debris slides. The concerns associated with floating debris are:

- Lodging in spillway and other outlet works gate mechanisms
- Damaging gates, spillway supports, and trashracks
- Damaging rip-rap protection
- Blocking spillways
- Blocking intakes

Some of these incidents can change the flow of water over or through the dam by reducing the capacity of the spillway and outlet works, potentially reducing the dam's factors of safety. Engineers design dams to operate under certain flow conditions and, therefore, reducing spillway capacity can compromise the integrity of the dam.

CHAPTER 2

Floating Debris Concerns

2. Floating Debris Concerns

Concerns associated with floating debris include the blocking of critical dam facilities, such as spillways and outlet works; the damaging of gates, locks, and penstock openings; the clogging of auxiliary apparatuses, such as fishscreens and trashracks; and the lodging of debris material in gate mechanisms. The following sections demonstrate the various potential hazards of floating debris on the safe operation and use of dams and lakes. These sections also present historical debris-related incidents that further validate the concern over these potential hazards. In addition, these sections show the various maintenance practices for the collection and elimination of debris.

Classifications for dams by construction material consist of masonry, earthfill, rockfill, steel, timber, and inflatable (Morris, 1963). Although US dams include a wide variety of construction types, this thesis discusses dam scenarios based on two of the most common types of dams found in the US, a concrete gravity dam and an earthfill dam. There are several other means for classifying dams and these are discussed more thoroughly in Chapter 3.

2.1. Potential Damage- and Failure-Scenarios

Dam designers incorporate outlet works, principal and emergency spillways, gates and locks, and auxiliary apparatuses which, when not operating properly, pose potential concerns to the dams and/or downstream communities.

The two methods used to release waters from behind a dam are outlet works and spillways. Outlet works regulate the flow of water from the reservoir to the downstream side of the dam and are located below the minimum reservoir operating level. This location is necessary to maintain the required head in order to facilitate the release of water for a needed flow rate. Outlet works operate as free flow or under pressure. Spillways release excess flood flow that cannot be safely stored behind the dam. Principle spillways are designed to release a specific flood event while emergency spillways "are provided primarily to avoid an overtopping of the main dam embankment because of an emergency condition" (USBR, 1987). In order for a spillway to operate safely, a spillway must have sufficient capacity. Typical layouts of outlet works and spillways are shown in Figure 2 (State of Illinois, 1980).

Floating debris can interfere with the normal release of reservoir waters or floodwaters. If debris becomes stuck in a spillway, the hydraulic capacity of the spillway is diminished and the water elevation increases, thereby increasing the chance of overtopping during flood events that are less than the designed spillway capacity. Other ways debris can interfere with the capacity of a spillway are by damaging gates, bending spillway supports, and lodging in gate mechanisms, rendering the gates inoperative. Interference by floating debris to the discharge facilities (spillways, power intakes, low-level outlets, etc.) can affect their ability to pass large flood events (Brown and Nielsen, 1992). This reduction in flood capacity endangers the safety of the dam. Since different failure modes exist for concrete-gravity and earthfill dams, debris-related hazards affect

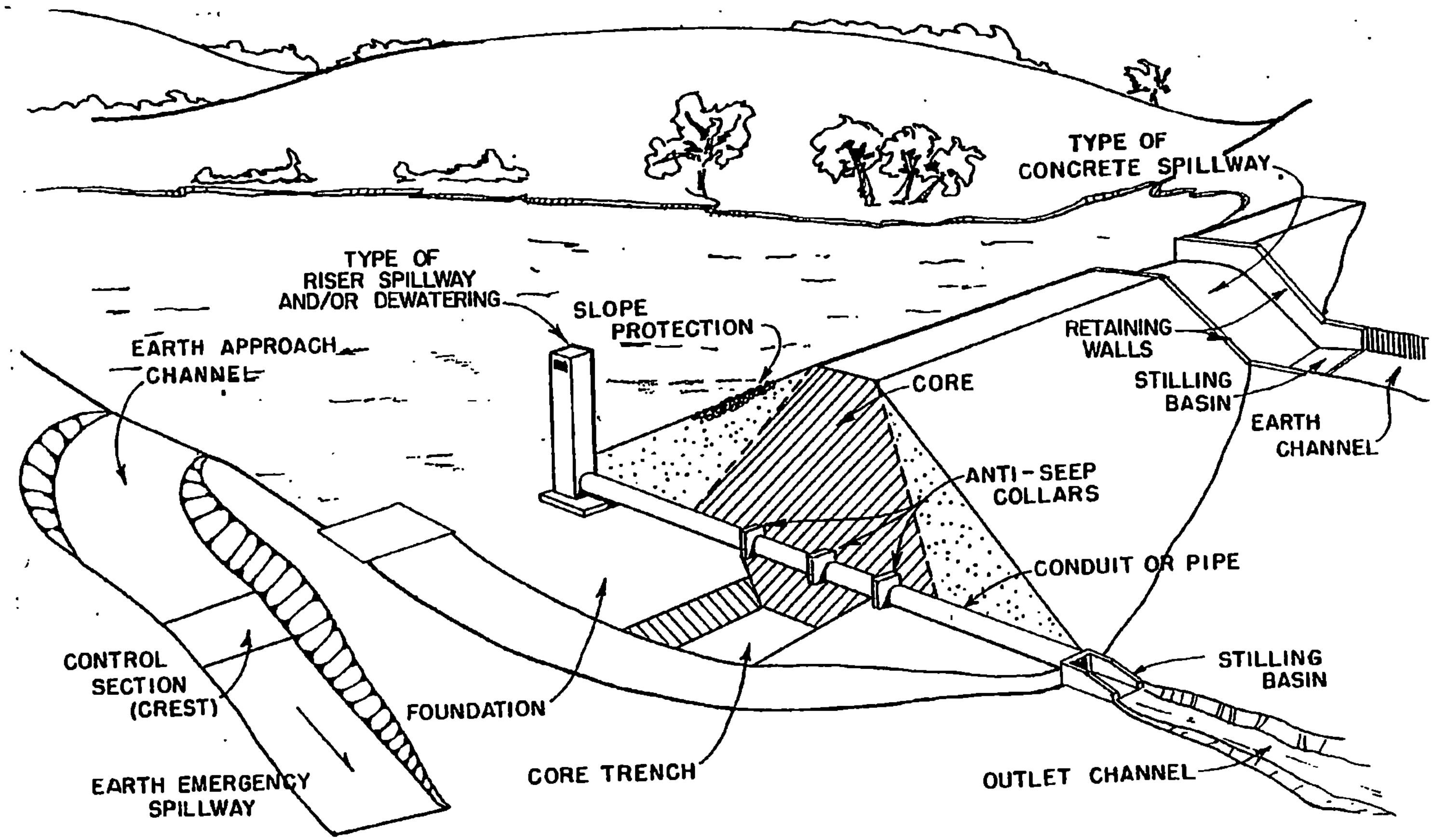


Figure 2. Typical Dam Components (State of Illinois, 1980)

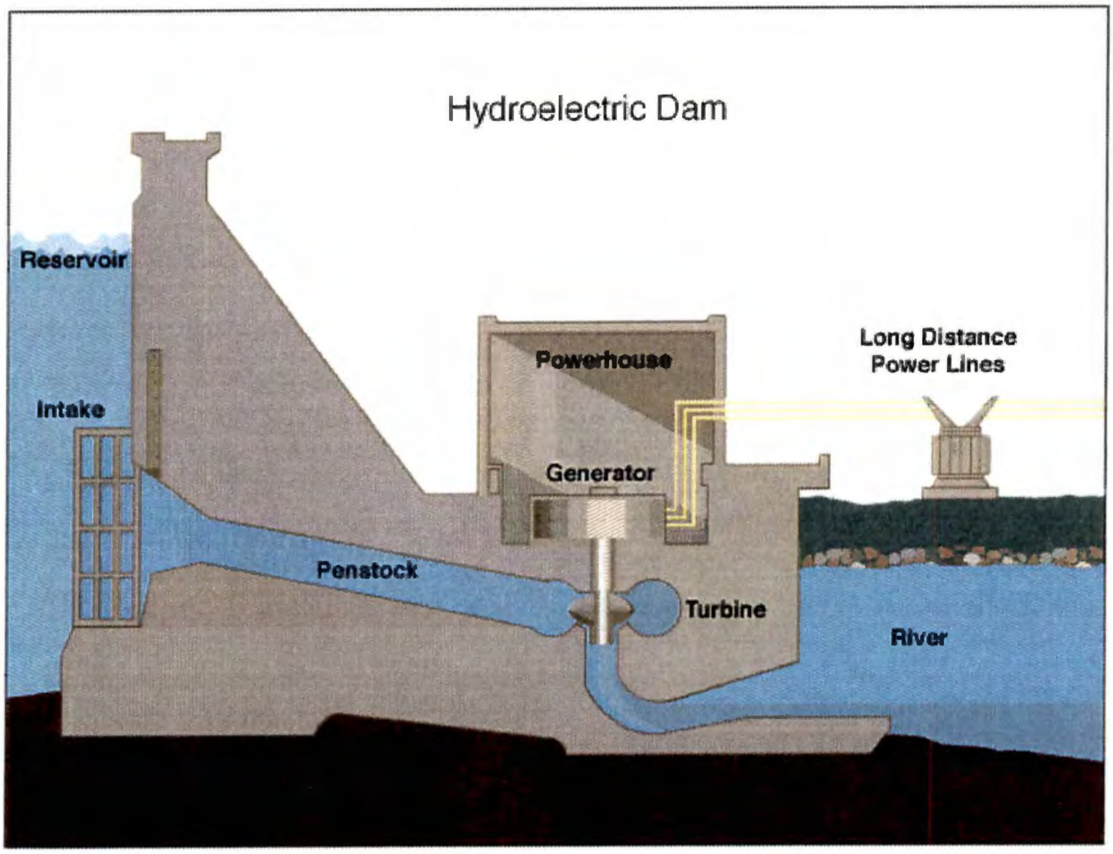
each type of dam differently. The discussion that follows analyzes the potential failure modes for these types of dams when debris hinders the hydraulic capacity of the spillway.

A dam might overtop due to the debris-related decrease in spillway capacity, but this is sometimes acceptable for a concrete dam. There are, however, other detrimental effects caused by the increased water elevation. Higher reservoir levels mean larger horizontal and uplift loads (Zipparro and Hasen, 1993). This increases the overturning moment and makes the dam more susceptible to overturning. Additionally, the increased horizontal force increases the shearing stress, which decreases the sliding stability of the dam. Finally, the increased horizontal and uplift loads decrease the compressive stress at the face of the dam, which increases the vulnerability to cracking or overstressing.

While overtopping is not a great concern for concrete dams, 81% of US dams (NPDP, 1999) are earthfill, which if overtopped can significantly damage the dam. When an earthfill dam is overtopped, erosion of the dam's embankment will occur due to the sheer stress of water on the soil (Henderson, 1995). Another detrimental effect of increased water elevation is an increase in the seepage force that acts on the pervious soil foundation. When the seepage force exceeds the resistive force of the soil, piping occurs. Piping is "the progressive removal of soil particles from a mass by percolating water leading to the development of channels" (USBR, 1987). Additionally, this increase in water elevation increases the shearing force that acts along the dam slope. If this shearing force exceeds the shearing resistance then sliding occurs along a shear surface, leading to stability failure. Finally, when the pressure acting on the soil is high enough, the resultant body force on the soil becomes zero (i.e. critical hydraulic gradient) and the "soil will have no strength. The soil is then said to be in a quick condition" (Craig, 1992). The water will move the soil particles when the critical hydraulic gradient is exceeded, which could lead to dam failure.

In addition to the potential failure hazards to dams, there are other debris-related concerns, such as repairs to damaged dam facilities, mechanisms, and auxiliary apparatus, as well as the loss of energy output on hydropower dams. Designers normally incorporate various debris-control devices, such as log booms and auxiliary apparatuses into the dam design. The design basis for each dam's floating debris control system is dependent on the land surrounding the reservoir, land use in the area, reservoir use, and the type and hazard category of the dam. The characteristics of the land surrounding the reservoir can influence the amount of potential debris entering the reservoir. For instance, a dam in a large, dense vegetative region might employ the use of log booms to dissipate the potential energy from large floating logs that impact and cause damage to the dam. However, in sparsely vegetated regions where this type of large debris material is not present, there is no need for this degree of protection.

For instance, other types of debris-control devices, like trashracks and fishscreens, affect the flow of water and cause energy losses. The energy losses come from "the amount of head loss due to the resistance of the rack" (Chow, 1959). This resistance increases as trash accumulates. If 50% of the rack area clogs, the velocity of water through the racks doubles (USBR, 1987). Increases in velocity through penstocks can have negative effects such as "erosion, corrosion, cavitation, and impingement" (Ahlgren et al., 1997). Hydropower dams incorporate trashracks and fishscreens, in part, to protect the turbines. Figure 3 shows a typical layout of a hydroelectric dam with a trashrack over the intake. Usually dam operators are concerned with the loss of hydrogenation efficiency that results from the clogging of trashracks. This loss in efficiency costs the operational agency money through loss of potential energy output capacity. Additionally, debris can also damage a trashrack enough to necessitate its replacement. A failed trashrack at TVA's Wilson Dam cost $250,000 to replace. This involved removal of the trash rack, logs, and debris, installation of the new rack, removal of additional debris, and the disposal of waste steel and debris. "The loss of energy and capacity from the unit was estimated at an additional $400,000" (Jones et al., 1997).



Reference: (TVA, 1999)

Figure 3. Typical Hydroelectric Dam Layout

2.2. Incidents Caused by Floating Debris

Existing records of debris-related incidents confirm the profound and tangible threat the previously described damage- and failure-scenarios represent to dams and downstream communities. Similarly, evidence from other past incidents verifies that floating debris interferes with the safe usage of lakes and reservoirs. This section presents data on debris-related incidents in order to demonstrate the concerns of floating debris on safe dam and lake operation.

2.2.1. Dam Incidents

Information on US dam incidents is archived at the Stanford University's Center for the Performance of Dams. Engineers from Stanford and ASDSO developed the *Guidelines for Reporting the Performance of Dams*, which establishes the definition of an incident and standards for reporting dam incidents. In general, "a dam incident is an event of engineering interest that provides insight to the structural and operational integrity of dams" (McCann, 1997). Additionally, Dr. McCann includes the following to define events of engineering interest (McCann, 1997):

- "the performance of a dam (satisfactory or unsatisfactory, anticipated or unanticipated) during periods of extreme loading such as produced by a nearby seismic event or a large inflow flood,
- misoperation resulting in uncontrolled release from a reservoir,
- implementation of an emergency action plan,
- signs of distress that are indicative of a potential loss of structural/operational integrity of a dam or its appurtenant structures,
- extreme deterioration of concrete, steel or timber structures that jeopardizes their structural integrity and safety, and
- dam safety modifications that are required to satisfy regulatory requirements and repairs to remedy damage caused by a dam incident."

The National Performance of Dams Program (NPDP) has compiled a list of 76 dam incidents within the US involving debris dating from 1916 to 1998 (NPDP, 1998). Of the reported incidents, 10 incidents were removed from this study because floating debris was not clearly a factor in the incident or was not of the same type as defined in this thesis (i.e., ash sediment, volcanic debris, landslides, and debris flow).

The data provided by NPDP is significantly low by at least 58% and possibly 94%. These percentages are deduced from additional information gathered from the survey responses. Chapter 3 and Appendix A presents and discusses this survey in more detail. The percentages also include information from Lessons from Dam Incidents USA (ASCE, 1975). Information from the NPDP (66 incidents), Lessons from Dam Incidents USA (1 incident), and the survey responses (62 incidents) did not provide enough data to prove or disprove that an overlap exists between 24 of the incidents. There was one (1) definite overlap between the information. If it is assumed that all 24 possible overlaps are accurately interpreted, there are 38 additional incidents reported in the Lessons from Dam Incidents USA and the survey results than NPDP reported. This represents an increase of 58% to the original NPDP reported incidents, which would result in 104 total incidents. If the 24 incidents are separate and individual, the increase is 94%. The total number of incidents in this situation is 128 incidents. The possibility exist that this number is still a low estimate because many agencies responded by telephone from their memory of past dam events and did little research to find if there were other incidents. Additionally, it is apparent from the survey results that many state dam agencies did not report incidents listed in the NPDP database. Appendix B gives the complete incident table provided by NPDP.

The first relationship developed from these data relates dam incidents involving floating debris and the hazard category ranking of the corresponding dam. This analysis demonstrates that almost one-half of the relevant dam incidents are in the high hazard category, as shown in Figure 4; 67% are in the high or significant categories. The second relationship shown is between floating debris and the dam type; Figure 5 shows the breakdown between dam types as a percent. In order to clarify the abbreviations in Figure 5, Table 1 is presented and is taken from the National Inventory of Dams (FEMA, 1995-1996). Fifty of the sixty-six debris-related incidents involved a type of earthen dam. This represents a total percentage over 75% (68.2%+1.5%+1.5%+4.5%).

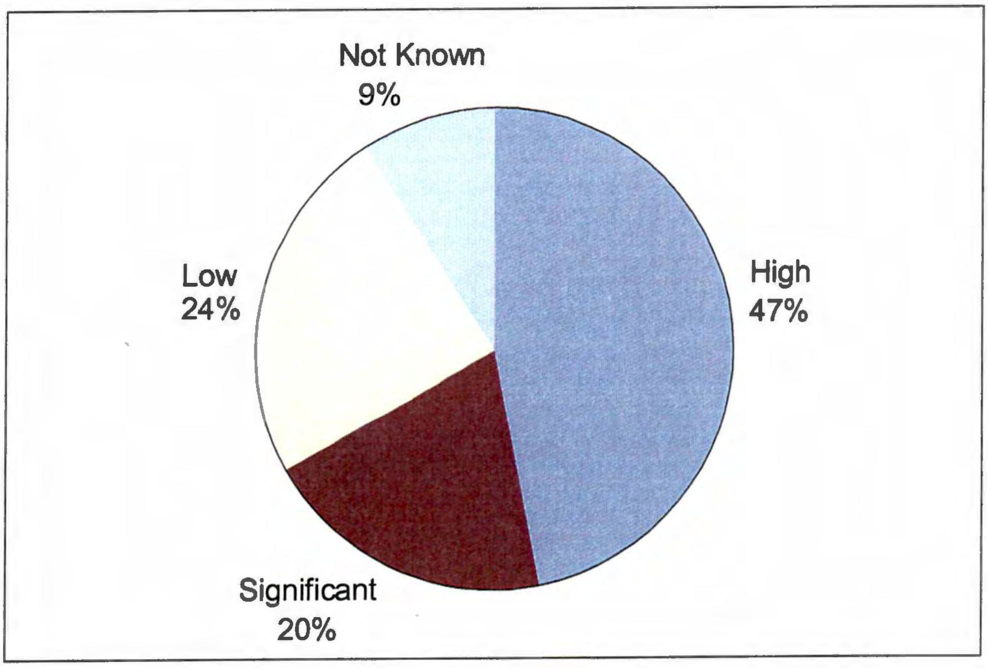


Figure 4. Dam Incidents by Hazard Category

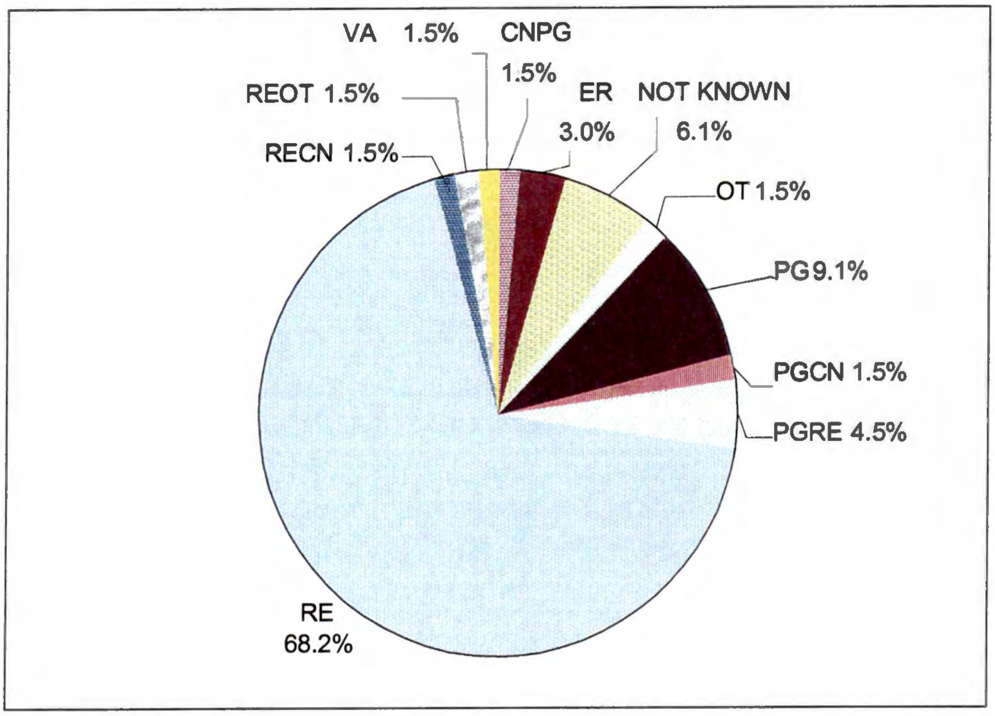


Figure 5. Debris-Incidents by Dam Type

Table 1. Codes Indicating the Type of Dam

RE = Earth	ER = Rockfill	PG = Gravity
CB = Buttress	VA = Arch	MV = Multi-Arch
CN = Concrete	MS = Masonry	ST = Stone
TC = Timber Crib	OT = Other	

Another statistic from the NPDP data is forty-five of the sixty-six incidents, or 68.2%, cited debris as blocking, clogging, lodging, plugging or obstructing dam facilities, mechanisms or apparatuses. Furthermore, forty of the incidents cited some type of impact to outlet works or spillways in the description of the incident. These incidents confirm that debris may normally affect discharge facilities in a way similar to the damage- and failure-scenarios presented earlier in the paper. This analysis shows that overtopping is of great concern since over 75% of the historical dam incidents involved a type of earthen dam, which are prone to fail if overtopped. Of the sixty-six incidents used in this study, 14 (21%) caused a failure to occur. Additionally, the dangers to downstream communities are important since 67% of the incidents involve a high or significant hazard category. These incidents prove that the previously described potential damage- and failure-scenarios are a real and tangible threat to the safety of dams.

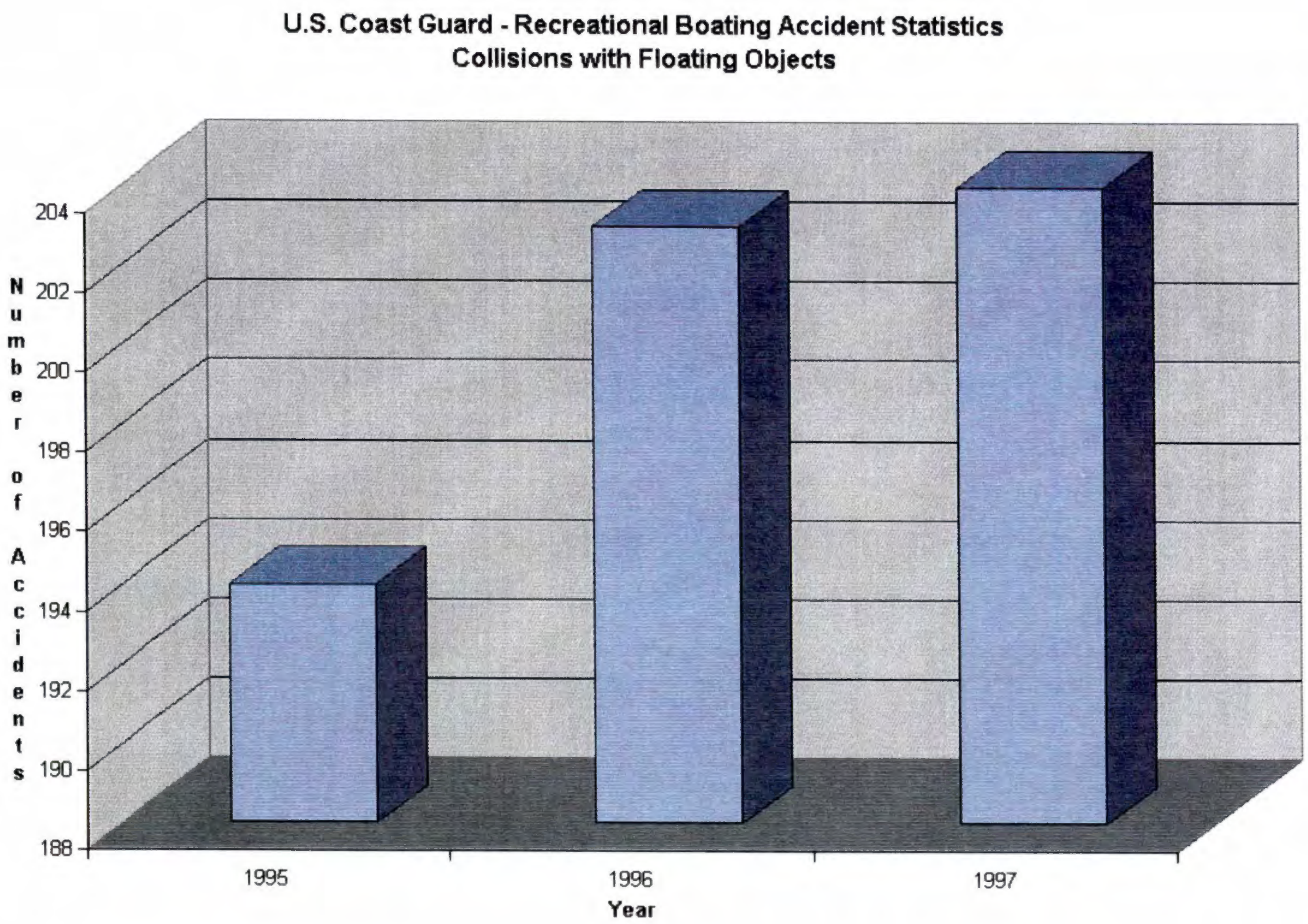
2.2.2. Lakes and Reservoirs Recreational and Navigational Hazards and Incidents

The purpose of many dams is to impound water to form lakes for recreation and navigation. According to the National Inventory of Dams, recreation and navigation serves as the primary purpose for 36.0% of dams (FEMA, 1995-1996). These lakes provide several benefits including boating, fishing, and swimming. Floating debris can affect the safety of these activities if floating debris inundates recreational lakes and waterways. Inundation could be the result of large rainfall events that wash debris into the reservoir. Another source of debris formation could come from trees not being clear-cut before the impounded water formed the lakes. These hazards can produce deadly results, like an incident at Neely Henry Lake, in Alabama, when trees were not clear-cut causing the fatality of one skier who "struck a stump" in 1988 (Bryant, 1997).

Furthermore, boaters might experience problems while navigating through debris-infested waters. Debris-related obstacles can easily damage boats. The number and severity of these types of accidents are hard to quantify because "many accidents [are] never reported" (USDOT, 1997). In addition to the cost of property damage in boating accidents, the graver consequence is not monetary, but the potential for fatalities. Of the over 800 recreational boating-related deaths in 1997, 13 are directly attributed to collisions with floating objects other than boats or vessels (Schmidt, 1998). See Appendix C for a complete list of type of boating accidents. The USDOT ranked recreational boating as the fifth largest category in transportation fatalities in 1995, while other waterborne vessels accounted for less than 0.1% of the total transportation fatalities (USDOT, 1998). Open motorboats and personal watercraft accounted for over 80% of injuries and almost 60% of fatalities for recreational boating accidents in 1995 (US Coast Guard, 1998). According to the US Coast Guard's Recreational Boating Accident Statistics (Schmidt, 1998), the number of accidents caused by collisions with floating objects is rising, as reflected in Figure 6. This figure was developed from the US Coast Guard's Recreational Boating Accident Statistics (Schmidt, 1998). Additionally in 1997, 135 boating accidents resulted from a boat striking a submerged object and resulted in six deaths (Schmidt, 1998).

2.3. Maintenance Practices

The previously discussed damage- and failure-scenarios and incidents emphasize the importance of integrating these concerns into the regular maintenance of dams and



Developed from the US Coast Guard's Recreational Boating Accident Statistics (Schmidt, 1998

Figure 6. Boating Accidents Caused by Floating Debris

reservoirs. Insufficient dam maintenance threatens downstream communities and involves financial repercussions for the dam owner. Therefore, dam owners must pay careful attention to debris maintenance, both its collection and elimination, in order to minimize debris-related hazards. This section shows the various maintenance practices involved in the collection and elimination of debris.

2.3.1. Collection of Debris

There are various practices for the collection of debris. A dam owner can collect debris within reservoirs, at banks along reservoirs, or at dam sites. At different dam locations, operators can employ different methods of collection. For instance, using boats to tow or push debris towards the banks of lakes or reservoirs can clear waterways and facilitate the removal of debris. Another example is when a flood event occurs debris might accumulate on the upstream side of a lock, 30 to 40 yards deep, which will hinder the ability of a vessel to enter the lock. In this situation, lock operators use work boats to push the debris toward the spillway (Hood, 1999). Operators can use cranes and clamshells to lift debris out of reservoirs on its bank, from barges, or from the dam itself. An example of this is seen in Figure 7 (Jacks, 1999). In addition, weed harvesters can remove aquatic plant life as shown in Figure 8. Some larger dam operators, such as TVA, also employ volunteer community groups to gather trash and debris on their lands. This sort of cooperation benefits both the community and TVA: the community receives a safer, more aesthetically pleasing recreational environment, while TVA gets the real benefit of free labor, which reduces maintenance cost. TVA used another practice through the early 1970's called "strand trash," in which reservoirs were raised and then lowered

Reference: (Jacks, 1999)

Figure 7. Shows Debris Removal using Barges, Cranes, and Clamshells


Reference: (TVA, 1997d)

Figure 8. Weed Harvester

within a week. The intent of this practice was to strand the debris along the banks allowing easier collection. Since this procedure created a better habitat for mosquito breeding and the debris ended up back in the reservoir if not collected and removed, TVA eventually abandoned this practice (Jacks, 1999). TVA now allows trash and woody debris to build up at the face of a dam. A crane removes the larger debris and operators flush the remaining debris through the spillway gates (Jacks, 1999). The frequency of collection might also vary according to dam sites. For example, at selected TVA dam sites, litter collection is scheduled periodically (once or twice per year), while at other locations collection would occur on an as needed basis (Jordan, 1999). For the last ten years, TVA has used drawdowns in October in cooperation with the Tennessee River Rescue to facilitate cleanup. Additionally, for the Chickamauga and Nickajack Lakes operators submit a request in October to lower lake levels by one foot to facilitate cleanup. Finally, TVA uses a wood chipper mounted on a barge to chip wood and then workers blow it back on the shoreline to decompose or workers haul it to a disposal site. This helps prevent large trees from being washed back into the reservoir (Clark, 1999).

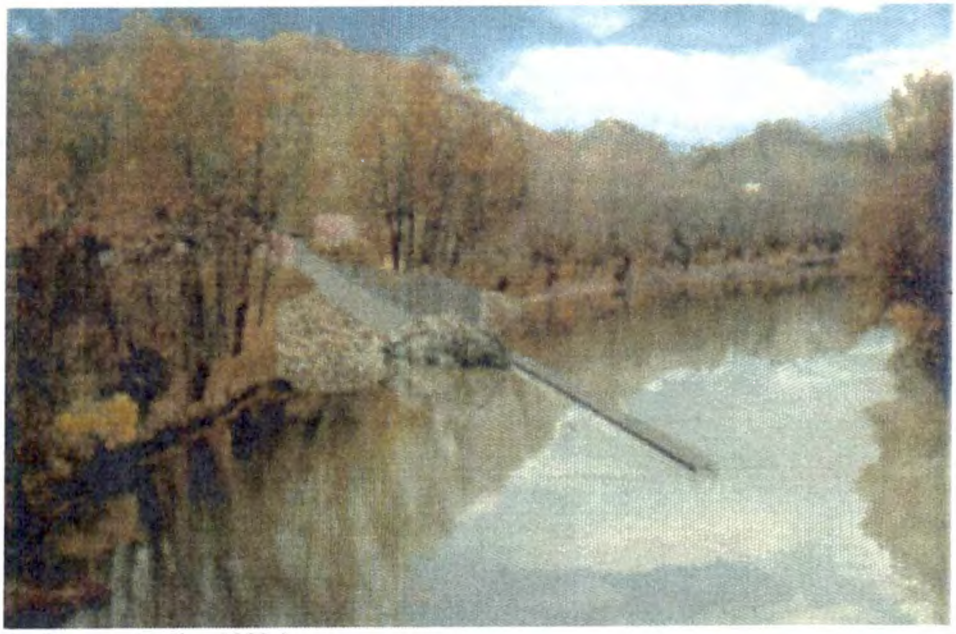
At dam sites, the means for collection include various types of mechanical equipment, such as trashracks and logbooms. Trashracks prevent debris from entering sensitive sections of dam facilities, such as penstocks, gates, intakes, drains, and spillways. Booms represent another type of collection tool "designed to retain floating debris before it reaches the trashracks or screens," and they "may also be used in the active collection of debris from lakes and reservoirs" (USBR, 1992). Figure 9 shows an example of a boom used to protect debris from entering aeration pumps at TVA's Douglas Dam after the flood of 1974 (Jacks, 1999). For lock operations an "air-bubbler" can blow air at the pivot point of the gate to generate a current that pushes the debris away from the gates (Hood, 1999). To properly eliminate debris, the dam owners must maintain and clean collection equipment. Trashrakes facilitate this equipment cleaning by scraping the debris from trashracks.

There are many costs associated with the collection of debris. Any equipment will require substantial capital cost. For example, the USACOE's experimental "trash gate" located on the Cumberland River in Kentucky cost $3.25 million. The gate is designed to prevent garbage and fallen trees from going over Cumberland Falls and reaching Lake Cumberland (Swope, 1999). Figure 10 is a computer generation of what the trashgate will look like when completed. Even after an initial outlay of capital, future maintenance,

(a) Douglas Dam – Shows debris accumulation and location of aeration pumps (Jacks, 1999)

(b) Douglas Dam – Shows booms around aeration pumps (Jacks, 1999)

Figure 9. Debris Surrounding Booms used to Protect Aeration Pumps



Reference: (Sadler, 1999a)

Figure 10. USACOE's Computer Simulated Trashgate on the Cumberland River

upkeep, and repairs on equipment will require further expenses. For example, Bay County Utility Service pays divers $960 four times a year to clean and remove debris at the two pumping stations intakes on Deer Point Lake in Florida (Olson, 1999). Additional expense is manual labor cost associated with gathering and sorting the debris. There is an inherent danger when workers have to clear debris from spillways during high flood events. This situation may exacerbate Workers' Compensation, used to cover labor-related injuries.

2.3.2. Elimination of Debris

Ideally, floating debris should be eliminated before it ever reaches the dam. However, dam owners should weigh environmental effects of floating debris eradication,such as clear-cutting the reservoir and using herbicides, against their possible negative environmental repercussions. Organizations that maintain the lands and waters around dams can use herbicides to reduce aquatic plant life, such as hydrilla and Eurasian watermilfoil, which might collect on dam structures in dangerous quantities. See Figure 11 for examples of quantities and depth potentials of aquatic plants on reservoirs. While herbicides reduce some of the debris that could be potentially harmful to a dam, these applications often release unwanted chemicals into the water supply. Fluctuating the water levels of a reservoir also reduces the aquatic plant life in and around the reservoir (Bates and Smith, 1994). Dam operators draw down reservoir water levels in winter; killing unwanted aquatic plants by exposing them to cold weather. Both small agencies, such as the Florida's Bay County Utility Service, and larger agencies, such as TVA, employ this method of reducing aquatic plant life (Olson, 1999 and Bates, 1994). Other departments or organizations besides a local dam safety office are sometimes responsible for maintaining some aspects of the lands and waters above the dams. For instance, Florida's Bureau of Invasive Plant Management is responsible for administrating that state's aquatic plant control program, which uses herbicides to control plants. Another method to reduce the amount of debris accumulation is clear-cutting the reservoir and removing the debris before filling the reservoir with water. Unfortunately, 'clear-cutting' can radically decrease the number of habitats available to fish and wildlife.

An additional procedure to eliminate debris from entering reservoirs involves state legislation prohibiting littering and dumping into and around lakes and reservoirs. Often these laws are either too difficult to enforce or not enforced at all, because "enforcement of litter and illegal dumping laws is not considered a high priority among local law

(a) Shows depth of aquatic plant life (TVA, 1997d)

(b) Shows Potential Amount of Accumulation of Aquatic Plant Life on Reservoir (TVA, 1997d)

Figure 11. Aquatic Plants at Gunterville Reservoir

enforcement agencies" (NCEDR, 1999). In general, "[t]here has been a collective failure by government, industry, and the public to develop and accomplish effective litter control" (NCEDR, 1999). Finally, many agencies also allow the flushing of debris through spillways as a means to eliminate floating debris from the reservoirs, which does not dispose of the excess, but merely transfer the problem elsewhere.

In the past, the most convenient and often used method of destroying debris after collection was burning. However, current air pollution and public fire hazard concerns have sparked legislation to require burn permits. Not all forms of debris can be burned. Items such as tires, appliances, barrels, boat dock remnants and other non-organic trash must be disposed of in a landfill. More volatile and hazardous debris must first go through costly tests to determine whether it is hazardous waste, which cannot be disposed of in a conventional landfill. Landfill disposal costs for TVA is between $28 and $30 per ton (Jacks, 1999). One incident from NPDP's data showed that the cost associated with debris removal at one dam site was $80,000, with an additional $20,000 in repair costs (FEMA, 1986). TVA's 1990 memo on strategies for reducing debris and trash states: "The estimated annual cost of 3.8 million dollars is realistic, with the majority going for disposal fees at landfill" (TVA, 1990).

2.4. Summary

Floating debris presents a variety of potential hazards to the safe operation and use of dams and lakes. Interference by floating debris to the normal operation of dams has the potential to endanger the integrity of a dam by increasing the forces acting on the dam. This can reduce the factors of safety and increase the chance of overtopping. These scenarios can damage and destroy dams, dam mechanisms, property, and human life. Additionally, floating debris poses a threat to lake safety with regard to navigation and recreation of boaters, swimmers, and skiers. By analyzing potential damage- and failure-scenarios and observing past dam and lake incidents, the dam safety community can recognize and address the associated dangers to normal dam operation and defend against the hazards. Among the variables to consider in the maintenance decisions are the equipment available and the capital cost of the equipment, local permitting and disposal laws, cost of disposal, and the effects on the environment and downstream communities.

CHAPTER 3

Organizational Framework and Agency Viewpoints Affecting Floating Debris

3. Framework and Viewpoints

The potential for an occurrence of any of the previously discussed floating debris hazards is reduced when the agencies that are responsible for dam safety establish and implement appropriate policies and practices. This section illustrates that dam safety agency's disregard of floating debris and the complex organizational framework of federal and state dam safety oversight adversely affects dam and lake safety. Additionally, this section summarizes survey results compiled from various federal and state agencies in an effort to substantiate inconsistent organization and lack of regulation of floating debris.

3.1. Inconsistencies in Dam Safety Management

Dam safety in the United States is a complicated and fragmented political and institutional system that has developed for protection and management of water resources (FEMA, 1998a). Agencies involved in dam safety have different legislation, priorities, and views of dam safety. The starting point for these differences is found within the definition of a dam. The federal government defines a dam in the National Dam Safety Program Act of 1996. The purpose of this Act "is to reduce the risks to life and property from dam failure in the United States through the establishment and maintenance of an effective national dam safety program to bring together the expertise and resources of the

Federal and non-Federal communities in achieving national dam safety hazard reduction" (US Public Law, 1996). The Act defines a dam as follows:

> "(A) means any artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or control of water, that-
> (i) is 25 feet or more in height from-
> (I) the natural bed of the stream channel or watercourse measured at the downstream toe of the barrier; or;
> (ii)if the barrier is not across a stream channel or watercourse, from the lowest elevation of the outside limit of the barrier;
> (II) has an impounding capacity for maximum storage elevation of 50 acre-feet or more; but
> (B) does not include-
> (i) a levee; or
> (ii)a barrier described in subparagraph (a) that-
> (I) is 6 feet or less in height regardless of storage capacity; or
> (II) has a storage capacity at the maximum water storage elevation that is 15 acre-feet or less regardless of height; unless the barrier, because of the location of the barrier or another physical characteristic of the barrier, is likely to pose a significant threat to human life or property if the barrier fails (as determined by the director)."

The criteria that define a dam vary from state to state, and although "the majority of states use portions of the Corps (federal) dam definition," these state definitions can deviate from federally defined parameters (FEMA, 1998a). While the definition of a dam may deviate from state to state, the Association of State Dam Safety Officials (ASDSO) Model State Dam Safety Program, published by the Federal Emergency Management Agency (FEMA), bases its definition on the federal definition. State agencies can use this document to establish their legislation and regulations, permitting, inspection, enforcement, emergency response, program staffing and funding, education and training, and public relations plan.

Another method of dam classification involves hazard categories based on the potential for property damage and loss of life to downstream communities. Generally, the hazard categories are classified as high, significant, and low. The use and interpretation of these categories can vary between state and federal agencies. For instance, Connecticut uses five categories rather than three to classify the hazard potential of its dams. Of the 75,187 dams on the National Inventory of Dams (NID), which include both federal and state dams, 23,927 structures (32.7%) are in the high or significant categories (FEMA, 1995-1996).

3.1.1. Federal Role in Dam Safety

US dam safety has evolved through changing cultural, social, and economic conditions. For example, Congress created TVA largely for economic reasons during the Great Depression, making TVA the single largest power producer in the nation (TVA, 1998a). By the late 1960's, TVA's primary responsibilities had expanded beyond navigation, flood control, and the production of electric power to encompass improvements in recreation and water quality (Schaffer, 1990).

After several major US dam failures during the 1970's, the federal government began to place more emphasis on the safety of existing dams. For example, in 1979 President Carter made the director of FEMA responsible for coordinating dam safety activities. FEMA's mission is:

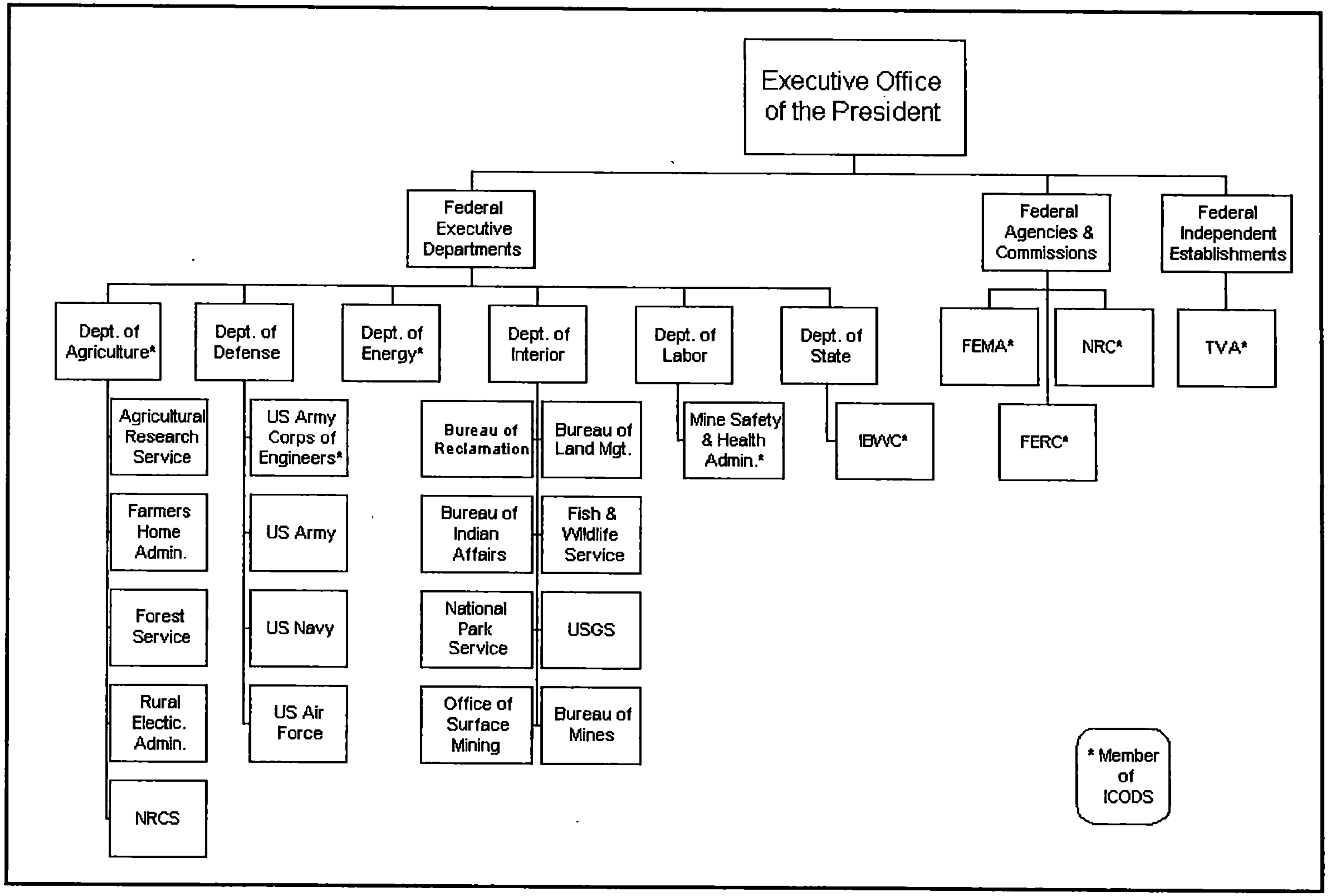
> "to reduce loss of life and property and [to] protect our nation's critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program of mitigation, preparedness, response and recovery" (FEMA, 1998a).

This placed FEMA in the complex role of acting as the coordinating agency in both federal- and state-level dam safety communities. Figure 12 shows a basic organization for the federal agencies involved in dam safety and the agencies that are members of ICODS.

The limited nature of FEMA's authority complicates the agency's role because it "has no regulatory responsibilities relating to dams" (FEMA, 1986). While FEMA fulfills the role of coordinator in a broad spectrum of activities regarding dam safety, the indirect responsibility of FEMA and various state and federal agencies hinders the effectiveness of FEMA's capacity in ensuring dam safety. Beyond FEMA's federal coordination responsibilities, FEMA assists state agencies in establishing their programs through the Model State Dam Safety Program. FEMA also administers the National Dam Safety Program funds, which provides "seed money to states to assist them with improving their dam safety programs" (ASDSO, 1998a). Additionally, FEMA has the obligation of coordinating the report on the Review of State Non-Federal Dam Safety Programs.

3.1.2. State and Regional Role in Dam Safety

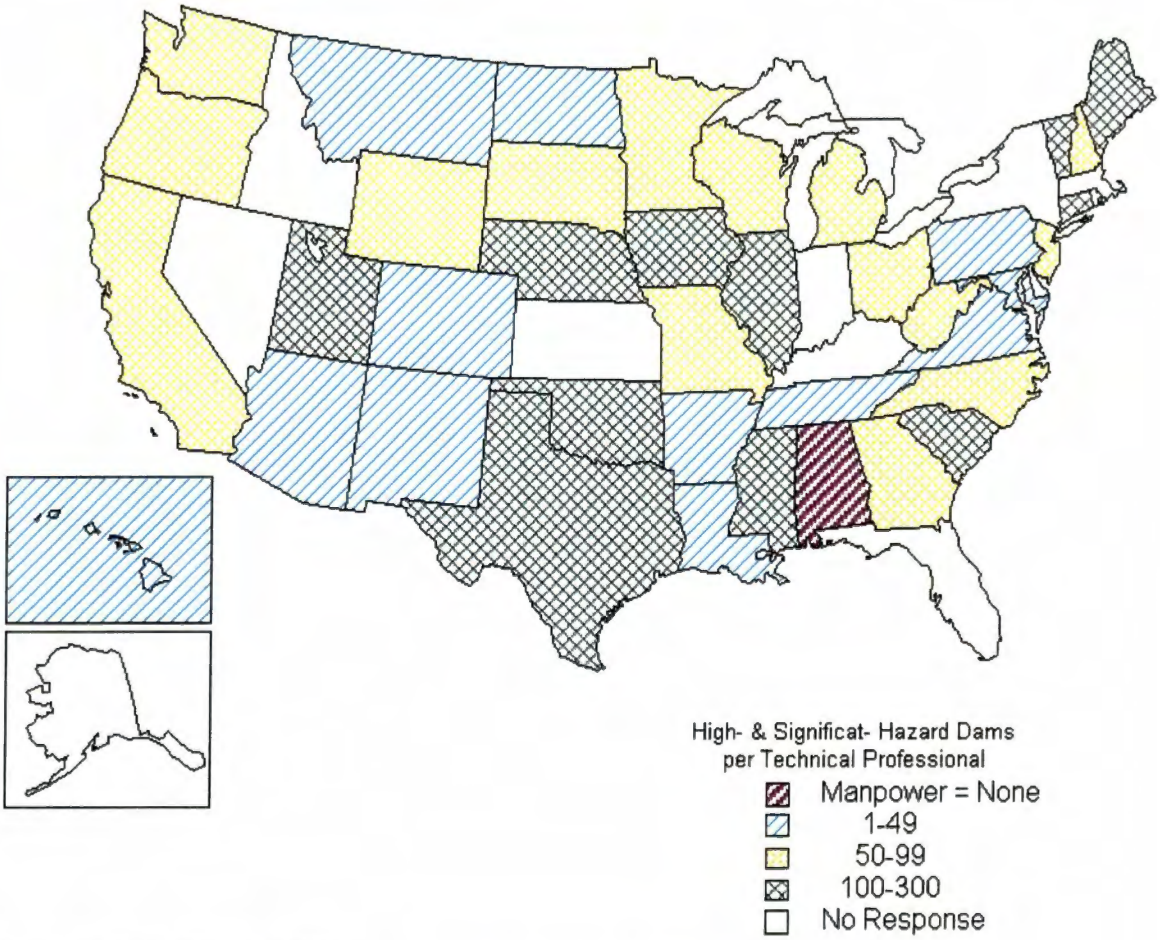
Of the almost two million dams in the US (Ungate, 1997), which include Natural Resources Conservation Service (NRCS) ponds, over 75,000 are covered by the National Inventory of Dams (FEMA, 1995-1996). The National Inventory of Dams is "a joint venture involving 67 States, Territories, and Federal agencies under the leadership of FEMA" (FEMA, 1995-1996). Of the 75,187 dams ninety-five percent (95%) are state regulated (FEMA, 1995-1996). This is significant because it indicates that most dam safety programs for dams in the US may involve a wide variety of state legislative policies, various budgeting, and differing priorities, precluding central and consistent



Developed from (Federal Web Locator, 1998; FEMA, 1992, 1986; NRSC, 1999

Figure 12. Federal Agencies Involved in Dam Safety

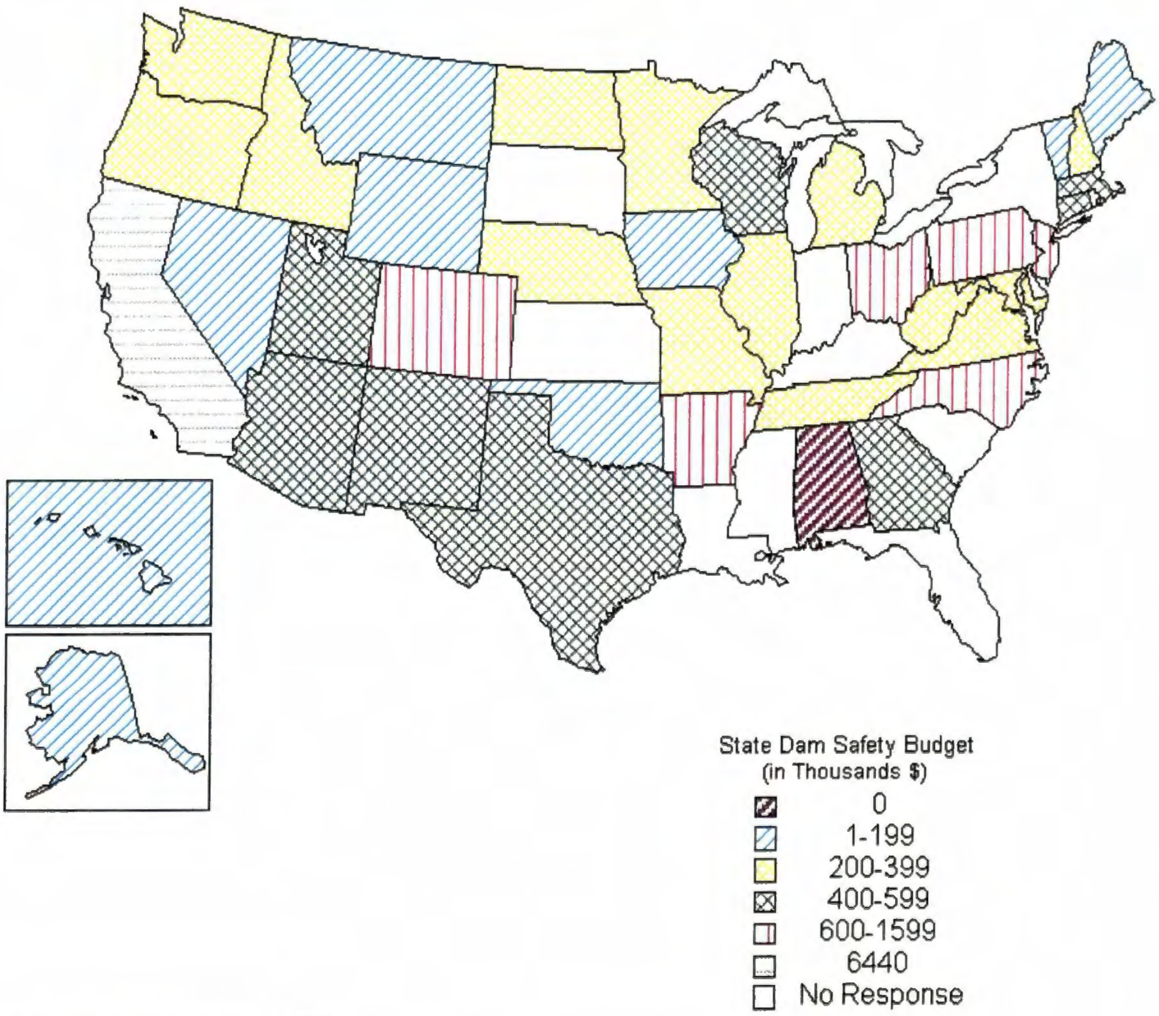
management of the various facilities. Additionally ASDSO provides a list of dams that includes total state regulated dams which includes over 95,000 dams (ASDSO, 1999). This number is greater than the total US dams found on the National Inventory because of the varying state laws on which dams are included under their jurisdiction. FEMA reports that "the degree to which states focus manpower and resources toward dam safety varies greatly from state-to-state" (FEMA, 1998b). Figure 13 illustrates this point by comparing the number of high or significant hazard dams under the responsibility of one technical professional in each state (FEMA, 1998b). Dam owner's priorities may result in dam



Developed from (FEMA, 1998b)

Figure 13. Varying Technical Manpower by State

safety problems when they focus manpower and resources on their primary objective and neglect dam safety concerns. Many agencies, both federal and state, provide insufficient funding and manpower to ensure dam safety (DeSena, 1998a and FEMA, 1992). The dam safety community has had to establish higher priority items besides debris maintenance because of a lack of resources allocated for dam safety. "The lack of resources is evidenced by small budgets, low numbers of staff, support for continued staff training, and owner education and public relations program" (FEMA, 1998b). Figure 14 shows the wide variety in state budgets allocated to dam safety.



Developed from (FEMA, 1998b)

Figure 14. Dam Safety Budget by State

Regional agencies have been able to implement more effective and inclusive debris management strategies within a larger, watershed-management agenda. For instance, TVA's watershed-management programs have dealt with floating debris issues as an inherent aspect of their guidelines of general resource management. TVA has more resources to effectively analyze and deal with debris hazards. For example, in 1999 TVA budgeted $600,000 for cleaning up dump sites along TVA reservoir shorelines, as well as funding of other shoreline problems, such as bank erosion (Jordan, 1999). Another hydroelectric company, B.C. Hydro, which consist of 60 dams at 43 locations, spends between $660,000 and $1,320,000 per year to clear debris and protect its hydroelectric facilities (Brown and Nielsen, 1992). However, the same efficiency, resources, and care have not been broadly available or properly handled at a national level. As stated by Martin McCann, director of Stanford University's National Performance of Dams Program, "the number one issue is how to make sure dams are maintained, given the great disparity in wealth of dam owners -- for example, a farmer who is relatively poor versus a large electric utility" (DeSena, 1998a). Even so, larger dam controlling agencies, even at the federal level, often overlook the potential hazards caused by floating debris to dams and in reservoirs.

3.1.3. Dam Oversight Roles and Responsibilities

Current policy places accountability for the safety, operation, and maintenance of each individual dam on the owner, regardless of who regulates or operates the dam. Nonetheless, federal and state governments have recognized their responsibilities to protect citizens. Federal and state governments often have different agencies with different responsibilities, which can include agencies to oversee the regulations, finance, planning, design, construction, and maintenance phases of a project. Table 2 itemizes the federal agencies type of involvement with dams. A single agency is not always responsible for what flows into and through the reservoir. Within large dam operating agencies such as TVA, US Bureau of Reclamation (USBR), and USACOE, departments other than the dam safety office are responsible for reservoir management (for instance the Land Management office at TVA). Moreover, the dam safety objectives of a specific controlling agency are frequently secondary to its primary mission and objective (Adler, 1995). For most federal agencies, "dam safety is peripheral to the main thrust of their activities" (FEMA, 1992). For example, the Mine Safety and Health Administration (MSHA), while deficient in implementing some of the Federal Guidelines for Dam Safety, selects "other high priority items to place on its Regulatory Agenda" (FEMA, 1992).

3.1.4 Coordination of Federal and State Dam Safety Policies

In order to combat some of the problems associated with dam safety, the dam safety community and the government have begun sharing information between various dam safety organizations. Section 7 of the National Dam Safety Program Act reflects this shift in operating procedures. It states that the duties of the Interagency Committee on Dam Safety (ICODS) are:

> "[To] encourage the establishment and maintenance of effective Federal and State programs, policies, and guidelines intended to enhance dam safety for the protection of human life and property through coordination and information exchange among Federal agencies and State dam safety agencies; and coordination and information exchange among Federal agencies concerning implementation of the Federal Guidelines for Dam Safety."

Table 2. Relationship of Federal Agencies to Dams

AGENCY	OWNER	REGULATOR	OTHER
US Dept. of Agriculture (USDA):			
Agricultural Research Service (ARS)			✔
Farmers Home Administration (FmHA)			✔
Forest Service (FS)	✔	✔	
Rural Electrification Administration (REA)			✔
Natural Resources Conservation Service (NRCS)			✔
Department of Defense (DOD):			
USACOE	✔	✔	✔
US Army	✔		
US Navy	✔		
US Air Force	✔		
US Dept. of Interior (DOI)			
Bureau of Indian Affairs	✔		
Bureau of Land Management	✔		
Bureau of Mines			✔
Bureau of Reclamation	✔		
Fish and Wildlife Services	✔		
Geological Services	✔		
National Park Service	✔		✔
Office of Surface Mining		✔	
US Dept. of Labor (DOL)			
Mine Safety and Health Admin. (MSHA)		✔	
Dept. of State			
International Boundary and Water Comm. (IBWC)	✔		
FEMA			
Federal Energy Regulatory Commission (FERC)		✔	
Nuclear Regulatory Commission (NRC)		✔	
TVA	✔		

Note: * Other = Could include: designed, constructed, financed, researched, etc.

Developed from: (FEMA, 1986; USACE, 1999; FEMA. 1992)

In addition to ICODS, the Association of State Dam Safety Officials (ASDSO) is active in improving the communication among state dam safety agencies and with federal agencies. Their purpose is "the improvement of dam safety through research, education and communication" (ASDSO, 1998b). Within this cooperative environment, agencies share knowledge and information that helps to improve dam and reservoir safety efforts. Although communication efforts between agencies have improved the refining of dam and reservoir safety, most industry intercommunication focuses on the engineering and structural integrity, flood capacity capability, and management practices relating to the operation of dams, often overlooking the issue of floating debris above dams.

3.2. Federal and State Agency's View of Floating Debris

As previously discussed, the development of dam safety management in the US has created multiple agencies and organizations involved in dam safety. However, the complicated framework of the dam safety community creates inconsistency in agency's priorities, practices, and policies. Although dam safety issues are garnering more attention, no established safety standards exist for debris maintenance. The deficiency of consistent debris management policies within the US allows agencies to form their own conclusions about the importance or lack of importance of debris management. Rules governing floating debris vary from dam to dam, owner to owner, state to state, and agency to agency.

Each agency that is responsible for dam safety decides how important the issue of floating debris is to their agenda. They base their viewpoints on many sources including preconceived ideas, the amount of money available in their dam safety budget, examples set by larger dam safety agencies, available technical data, and their exposure to the hazards of floating debris on dam safety. If floating debris is not considered an important issue then it further adds to the problems associated with dam and lake safety. Agencies that do not view floating debris as an actual and significant issue neglect their responsibilities to dam safety. A review of national and international literature as well as the results of a survey conducted by the University of Tennessee, Department of Civil and Environmental Engineering, are presented below as additional evidence that floating debris is not adequately considered a dam safety concern in the US.

3.2.1 Literature Review

Most dam safety officials and researchers publishing in current literature have not treated floating debris as a major concern because they focus their attention on what they consider more 'imminent dangers'; floating debris management is viewed as merely a routine of the operation and maintenance of dams. The scarcity of literature addressing floating debris as a safety problem further reflects the dam safety community's lack of concern for with the problem.

Most literature that specifically addresses floating debris as it relates to dam safety are authored and reviewed internationally, rather than domestically, demonstrating that the international community has a higher regard for floating debris as dam safety issue. An article from British Columbia addressed the dangers of floating debris on dam operations by presenting Canadian case histories (Brown and Nielson, 1992). One case was the Alouette Dam where a large tree lodged in the concrete panel overflow weir. A concrete panel shifted or was damaged due to this obstruction. This resulted in leakage and then severe erosion along with scouring of the underlying foundation. This ultimately led to the collapse of the spillway. The article further examined sources for debris. It also confirmed the dangers from debris to public safety during recreational use of the reservoir. It further discussed what B.C. Hydro had learned from these past incidents and steps it was taking to manage dam safety and environmental aspects of debris, such as guidelines to estimate the quantities of debris entering a reservoir and guidelines for preparation of reservoir debris management plans.

Another article summarized a project carried out in 1990-1991 by the Norwegian Hydrotechnical Laboratory (Godtland and Tesaker, 1994). In this study, models were used to determine conditions under which drifting trees and tangled trash may cause clogging of free overflow spillway and to determine the anchor forces required to hold back tangles of trash from reaching the dam crest. The study found that spillway capacity was reduced by the clogging of flood spillways by trash, and suggested guidelines for the design of an overflow spillway. A Swedish article presented the results from a hydraulic model study that tested gated overflow spillways and how floating debris affected the gate operation as well as the spillway discharge capacity. It examined the ability to pass debris in relation to the number of spillway openings and the length of trees with respect to the width of spillway openings. This study found that overflow height in relation to spillway opening width is not an important factor in trees plugging a spillway. (Johansson and Cederström, 1995)

In contrast, articles produced by US authors and agencies often focus on the reduced efficiency of hydropower production caused by trash accumulation at the intakes to turbines and the cost of replacing failed trashracks. One article emphases the need for online trash rack monitoring at hydro units. The main validation for the expense is the costs associate from high repair costs from a failed trashrack, revenue loss due to downtime, increased maintenance cost by accelerating the wear on bearings, and the cost of replacement power (Jones et al., 1997). Another article focused on detecting the amount of submerged debris at trashracks in order to plan and budget for trash removal. Two additional reasons given for mapping the debris at trashracks were "economics, turbine efficiency and safety, excessive loads on trashracks" (Edwards et al., 1993). One final US published article emphasized lost revenues from lower power generation capability caused reduced efficiency from trash and debris accumulation on turbine intakes at hydroelectric powerplants. It discussed the design, assembly, field experience, and cost of a self cleaning trashrack system at the Cheatham Powerhouse (Sadler, 1993). Other nationally authored articles addressed floating debris dangers but focused on bridge piers and the scouring of the streambeds and not on dam and reservoir safety (Diehl and Bryan, 1993; Saunders and Oppenheimer, 1993).

While articles addressing some of the hazards associated with floating debris exist, they normally appear from an international platform. US debris articles often focus on cost associated with debris clogging trashracks on hydropower operations, while the specific dangers that debris imposes on structures are frequently limited to bridge piers instead of dam safety. This scarcity of US interest and focus on the seriousness of the debris-related hazards represents a shortsightedness of the US dam safety community.

3.2.2 Survey Findings

In order to have a clearer understanding of federal and state attitudes, a survey addressing common regulations, practices, and problems was sent to all federal and state agencies. This survey was conducted by the University of Tennessee, Department of Civil and Environmental Engineering in October of 1998. Appendix A includes a copy of the survey sent to federal and state agencies involved with dam safety and their detailed responses. The survey attempted to evaluate the policies and procedures of these agencies toward floating debris and some of the historical dam incidents by asking the following questions:

1) Does your organization or organization(s) under your jurisdiction have regulations or procedures on the collection, management and/or disposal of floating debris at dams and in reservoirs? If so, what are they? If not, how is the debris managed? (Please be as specific as possible)

2) Does your organization or organization(s) under your jurisdiction allow floating debris to be flushed through spillway gates or locks as a means for controlling such materials? If so, have there been any problems relating to this practice?

3) Has your organization or organization(s) under your jurisdiction experienced interference by floating debris with regard to:
   a) dam operation and maintenance?
   b) lake navigation and recreation?
   c) the safe operation or the safety of dams?

   If yes, please describe any problems?

4) Has your organization or organization(s) under your jurisdiction had any debris caused damage or failure to dams? Name and briefly describe the incident(s).

All of the nine federal agencies with dam safety responsibilities and forty-eight of the fifty state agencies replied to the survey. The information gathered from surveying federal and state agencies was used to summarize agency policies and/or procedures regarding floating debris. The results of the survey reveal floating debris problems encountered by these agencies. The data analysis from this survey facilitates an understanding of federal and state concern regarding the hazards of floating debris to dam and reservoir safety. The analysis emphasizes the need to more intensely address the issues involved with floating debris in order to maintain and regulate the safety of lakes and dams. The following discussion is based on the responses to the primary survey questions, which are found in Table 3 and Table 4.

Table 3. Federal Survey Responses

Federal Agency	HAS REGULATIONS OR PROCEDURES FOR DEBRIS	ALLOWANCE OF FLUSHING DEBRIS THROUGH SPILLWAY	INTERFERENCE WITH DAM O&M
USBR	No	****	Yes
USDA	Yes	No	Yes
FERC	No	Yes	Yes
USACOE	Yes	Yes	Yes
DOE	No	****	No
NRC	No	No	No
MSHA	No	N/A	No
TVA	Yes	Yes	Yes
IBWC	Yes	Yes	Yes

Note:
1) '****' indicates no response or question was not directly answered.
2) USBR= US Bureau of Reclamation, USDA= US Department of Agriculture, FERC= Federal Energy Regulatory Commission, USACOE= US Army Corps of Engineers, DOE= Department of Energy, NRC= Nuclear Regulatory Commission, MSHA= Mine Safety and Health Administration, TVA= Tennessee Valley Authority, and IBWC= International Boundary and Water Commission.

The survey revealed that only four state agencies and four federal agencies claim to have regulations or procedures for floating debris management, as seen in Figure 15. Some agencies consider the use of trashracks or logbooms their debris management regulation, while other agencies, which answered 'No' to this question, also use these mechanisms, but do not view their use as debris regulated. Often owners and operators consider floating debris more of a nuisance than a serious safety issue, which is reflected

Table 4. State Survey Responses

STATE	HAS REGULATIONS OR PROCEDURES FOR DEBRIS	ALLOWANCE OF FLUSHING DEBRIS THROUGH SPILLWAY	INTERFERENCE WITH DAM O&M
AK	No	Yes	Yes
AL	No	N/A	N/A
AR	No	Yes	Yes
AZ	No	Yes	No
CA	No	Yes, Not Prohibited	No
CO	No	No	Yes
CT	No	No formal regulations	Yes
DE	No	N/A	N/A
FL	Yes	Yes	Yes
GA	No	Yes	Yes
HI	No	Yes	****
IA	No	Yes, Not Prohibited	Yes
ID	No	Yes	Yes
IL	No	Yes	Yes
IN	No	Yes, Not Prohibited	Yes
KS	No	N/A	No
KY	No	Not Known	Yes
LA	Yes	No	****
MA	No	No	Yes
MD	No	Yes	Yes
ME	No	No	No
MI	No	Not Known	Yes
MN	No	Yes	Yes
MO	No	Yes – Small; No – Large	Yes
MS	No	Not Allowed or Disallowed	No
MT	No	Yes	Yes
NC	No	No	Yes
ND	No	Yes	Yes
NE	Yes	Yes	Yes
NH	No	Yes	Yes
NJ	No	Not Known	No
NM	No	No	Yes
NV	No	Yes	No
NY	No	Yes, Not Prohibited	Yes
OH	No	Yes	Yes
OK	****	****	****
OR	No	No	Yes
PA	****	****	****
RI	No	No	Not aware of any
SC	No	Yes	Yes
SD	No	****	****
TN	No	Not an Issue	Yes
TX	No	Yes	Yes
UT	No	Yes	Yes
VA	No	Yes, Not Prohibited	Yes
VT	No	Yes, Not Prohibited	Yes
WA	No	Not Known, Outside	Yes
WI	No	Yes, Not Prohibited	Yes
WV	Yes	Yes, Not Prohibited	Yes
WY	No	Yes	Yes

Note:
1) ' ****' indicates no response or question was not directly answered.

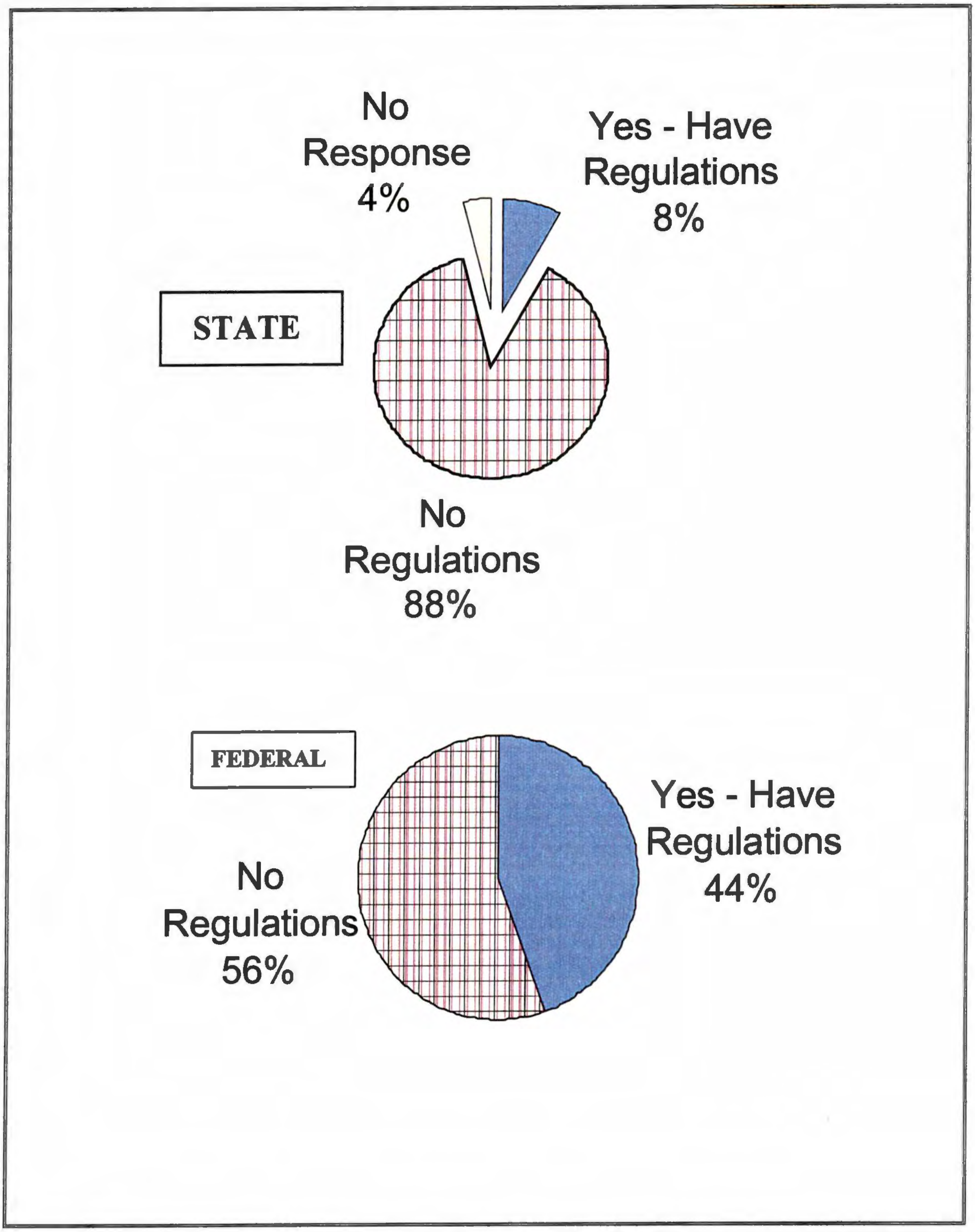


Figure 15. Percentage of Dam Safety Agencies having Debris Regulations

in the lack on policies addressing floating debris. Figure 16 shows that the majority of state agencies, 58.0%, allow the practice of flushing floating debris over a spillway. Forty-four percent (44.4%) of federal agencies also allow this practice. Finally, Figure 17 shows that 66.7% of the federal and 70.0% of the state agencies surveyed have experienced interference from floating debris with regard to dam operation and maintenance. This data shows that although most agencies have problems with debris, they do not address these debris issues with specific policies or procedures and further complicate the hazard by allowing dangerous practices.

Dam owners can combat debris contamination sources with efficient maintenance practices. Operational agencies are painfully aware of the cost and time associated with the collection and elimination of debris, but they do not view floating debris as an 'imminent danger'. Many regulatory agencies and dam owners view floating debris as a non-safety issue and instead regard it as a general maintenance matter. Because dam owners and dam safety agencies often consider floating debris as just a maintenance matter, dam safety agencies and dam owners do not adequately address the potential for dam failure. Most state agencies consider legislation stating that 'dams must be operated in a safe manner' as adequate policy for managing debris in lakes and reservoirs. In addition, state agencies rely heavily upon dam inspections to address problems on a site-specific basis. However, Alabama does not provide any dam inspections, while California "inspects annually but more or less frequently as needed on a case-by-case basis" (ASDSO, 1994). Assuming equal inconsistency among other states, this may leave many dams in greater jeopardy than other dams. Further, the *US Water News* reports that

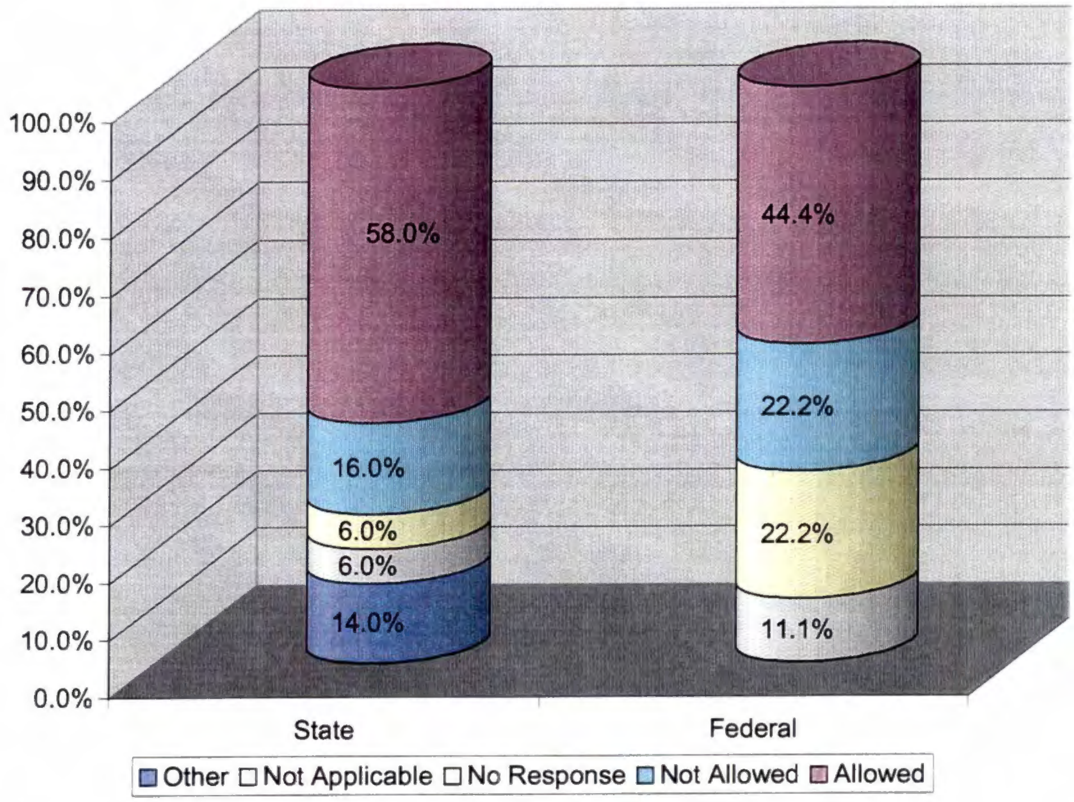
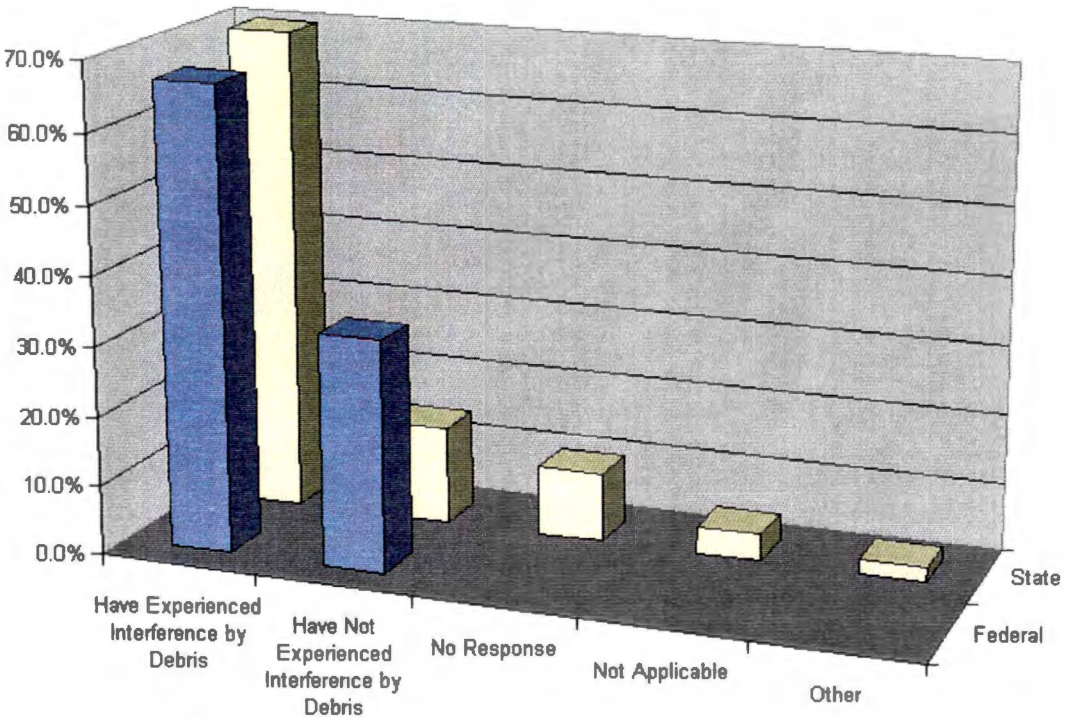


Figure 16. Percentage of Federal and State Agencies that Allow Debris to be Flushed through Spillways



	Have Experienced Interference by Debris	Have Not Experienced Interference by Debris	No Response	Not Applicable	Other
Federal	66.7%	33.3%			
State	70.0%	14.0%	10.0%	4.0%	2.0%

Figure 17. Federal and Non-Federal Agencies Experiencing Floating Debris Interference with Dam Operation and Maintenance

"almost half of the most potentially dangerous [dams] have not been inspected in the last five years" (DeSena, 1998a). This leads to the inevitable conclusion that debris could accumulate and 'back-up' for more than five years.

3.3. Summary

The lack of a comprehensive federal and state dam safety management program has created a large number of oversight organizations and inconsistent nationwide dam safety priorities, practices, and policies. The priorities and policies established by the agencies impact the effectiveness of maintaining the safe operation and use of lakes and dams. When an organization begins to prioritize its goals and objectives, it must evaluate the availability of its resources. An organization must carefully allocate its time, money, and manpower in order to meet its desired objectives and goals. These resources are exhaustible and organizations must often neglect lower priority items in order to accomplish their main objectives. Agencies create their policies in order to achieve their objectives. Therefore, their policies reveal their priorities. Unfortunately, most agencies that are responsible for dam safety do not view their primary priority as dam safety. For instance, the changing priorities of NRCS "has reduced the available input into dam safety" (FEMA, 1992).

As this thesis illustrates, the safety of a dam is dependent on dam safety agency's views toward floating debris. The results of the survey indicate that, many agencies only consider debris as a maintenance issue and not as imminent danger. This view can hinder an agency's ability to make adequate debris maintenance decisions.

The sheer number of autonomous agencies involved in dam safety produces a variety of regulatory inconsistencies, such as state inspections, which vary from annually to not at all. Other inconsistencies include but are not limited to an agency's operation and maintenance practices, as well as budgetary policies. Many legislative and economic indicators illustrate the priorities of federal and state dam safety agencies, such as budgeting, dam safety legislation, and various agencies' stated goals, regulations, policies, and procedures. The results of the previously presented survey further illustrate the inconsistent approaches of different agencies. By demonstrating their agendas and practices, the survey revealed the absence of real concern toward floating debris as it relates to dam safety by showing:

- most agencies followed the ill-advised practice of allowing floating debris to pass through spillway, which may be dangerous to dam safety as shown in Chapter 2.
- most agencies did not have specific regulations regarding floating debris, which shows they do not view it as a priority even though the majority of federal and state agencies had experienced interference by floating debris.

CHAPTER 4

Summary, Conclusions, and Recommendations

4. Summary and Conclusions

While many dams currently have measures in place for controlling floating debris, there are a variety of debris-related incidents which have prove these methods insufficient, resulting in loss of life and property. These past incidents and the potential scenarios present in Chapter 2 illustrate that floating debris is a national concern to both dam and lake safety. The problem is complicated further by dam agency's views toward floating debris and the lack of concern placed on the problems of floating debris. Additionally, the inconsistencies in priorities, policies, and practices of agencies responsible for US dam safety management increase the problems associated with this national concern. Once agencies realize the seriousness of floating debris hazards, the issue of how to manage and maintain floating debris effectively becomes the agency's next concern.

Federal and state agencies involved in dam safety must take the hazards presented by floating debris more seriously and recognize the necessity of facing these problems with consistent, adequate, debris management regulations or policies. Dam design and maintenance protocols should address the hazards of debris. Determining who is responsible for dam safety remains a complicated issue. However, the responsibility for dam safety still rests in the owner's hands. By removing debris in a timely manner owners could incur the costs of manpower to inspect dam sites, removal of debris and the associated manpower and machinery costs if needed, and disposal costs of the collected debris. However, by not removing debris in a timely manner dam owners risk:

- Repair cost to dams, dam mechanisms, facilities, and apparatuses
- Removal and disposal cost of dam parts and residual debris after damage occurs
- Risk of dam failure
- Cost to property and human life
- Loss of power production (if hydropower)
- Loss of recreational and navigational benefits

While the threat of floating debris may not appear as urgent as other dam safety issues, the danger it presents must be addressed and remedied effectively by the entire dam safety community.

4.1. Recommendations

The lack of a comprehensive approach to watershed management has resulted in the establishment of inconsistent regional, state, or agency specific policies relating to dam safety issues. This inconsistency has allowed states to assign their own views about the importance of dam safety and more specifically, debris safety. Couple these inconsistencies with the general lack of importance placed on floating debris as a dam safety issue, and the lack of monetary resources available to many owners and agencies, and there results a potentially serious threat to dams and lake users, owners, and downstream communities. Therefore, there should be a concerted effort by FEMA, ASDSO, state dam safety agencies, and all other agencies responsible for leading dam safety efforts to stress the dangers floating debris poses to dam safety and the importance of properly controlling debris through appropriate practices. Publications produced by coordinating agencies, such as FEMA and ASDSO, should emphasize these dangers and suggest acceptable, environmentally correct practices of collecting and disposing of debris. Additionally, dam safety representatives, FEMA, and ASDSO need to emphasize these concerns in their conferences. State dam safety agencies should suggest regular timelines for dam owners to inspect their dam for debris. These timelines could be monthly or after a certain storm event.

Because of the potential safety risk to dams when debris is allowed to pass over spillways, federal and state agencies need examine the risk associated with this practice on a case-by-case basis. Additionally, the dam safety community needs to conduct more US research on:

1) estimating the potential amounts of debris entering a reservoir given:
   a) different storm events.
   b) land characteristics.
   c) changes in upstream development.
2) designing and developing better debris control equipment.
3) identifying the most effective debris control policies.
4) correlating where (County or City) the incidents took place and the local availability of waste disposal.
5) effectiveness and total cost of different types of debris control equipment, including:
   a) collection and elimination cost
   b) varying types of debris found in different reservoirs.

For example, some reservoirs might have high quantities of hydrilla while other have logs in the magnitude of thirty feet long while still others find floating packs of ice and snow as their main floating debris problem. The effectiveness of debris prevention equipment is dependent on the topography of the surrounding reservoir.

6) optimizing the debris control equipment given the types of reservoir and dam

For example, an 8-ft earthen dam would probably not require the same heavy equipment and machinery to collect and dispose of debris as a larger concrete structure owned by the Corps or TVA.

7) developing a book or short computer program that takes into account all the different factors affecting the potential for debris accumulation and then optimize the best practices in dealing with debris.

Another important factor is for dam safety agencies to report their dam incidents to NPDP. This would facilitate identifying the magnitude of the hazards posed by floating debris. It also would help further researchers with an accurate database. Finally and most importantly, the funds required to make dam safety a top priority of agencies need to be provided for research, inspections, rehabilitation, technical manpower, and education. Agencies could advertise more the publications available for dam safety and the importance of reporting incidents to NPDP. If adequate funds are not available, floating debris will continue to be a national problem for dam and reservoir safety.

In summary, there needs to be an inclusive, consistent approach to floating debris management. This approach should address the degree to which floating debris affects the following:

* Dam Safety

* Hydropower Generation

* Navigation

* Recreation

* Operation and Maintenance Practices

* Environment

* Aesthetics of the Reservoir and Surrounding Lands

The manner in which debris accumulates in reservoirs predicates the need for a comprehensive watershed-management system that integrates land and water resource policy into a coherent and symbiotic legislative structure. A nationally regulated management protocol, including specific mandatory inspection and maintenance time frames, would create consistency in laws and regulations governing dam safety.

List of Abbreviations

ARS	Agricultural Research Service
ASDSO	Association of State Dam Safety Officials
BLM	Bureau of Land Management
Corps	US Army Corps of Engineers
DOD	US Department of Defense
DOE	US Department of Energy
DOI	US Department of Interior
DOL	US Department of Labor
DOT	US Department of Transportation
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FmHA	Farmers Home Administration
FS	Forest Service
ICODS	Interagency Committee on Dam Safety
IWBC	International Boundary and Water Commission
MSHA	Mine Safety and Health Administration
NCEDR	National Center for Environmental Decision-Making Research
NID	National Inventory of Dams
NPDP	National Performance of Dams Program
NRC	Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
REA	Rural Electrification Administration

TVA	Tennessee Valley Authority
USACOE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USCOLD	US Committee on Large Dams
USDA	US Department of Agriculture
USGS	US Geological Survey

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Appendices

Appendix A. Survey Questions and Responses

October 16, 1998

Dear Sir or Madam:

The University of Tennessee is conducting a study concerning the impact of floating lake debris on the safety of dams and we would like to have your input. Part of this study involves inventorying how the collection and disposal of debris is managed at regulated dams. Please reply by one of the following three ways:

- E-mail: SwannDavis@aol.com
- Fax: A. Allison Swann, c/o Susan Jacks at (423)632-4670
- Mail: A. Allison Swann, 113 Linda Marie Lane, Panama City Beach, FL 32407

1) Does your organization or organization(s) under your jurisdiction have regulations or procedures on the collection, management and/or disposal of floating debris at dams and in reservoirs? If so, what are they? If not, how is the debris managed? (Please be as specific as possible)

____

____

____

____

2) Does your organization or organization(s) under your jurisdiction allow floating debris to be flushed through spillway gates or locks as a means for controlling such materials? If so, have there been any problems relating to this practice?

____

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____

3) Has your organization or organization(s) under your jurisdiction experienced interference by floating debris with regard to:
   a) dam operation and maintenance?
   b) lake navigation and recreation?
   c) the safe operation or the safety of dams?

If yes, please describe any problems?

____

____

____

4) Has your organization or organization(s) under your jurisdiction had any debris caused damage or failure to dams? Name and briefly describe the incident(s).

____

____

Table 5. Detailed Detailed Survey Responses

Note: N/A = Not Applicable
N/R = No Response

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
AK	No	Inspection--3-5yr; new dams required to submit O&M manual in application process.	Yes	Not Known	N/A
AL	No	AL has no Legislation	N/A	N/A	N/A
AR	No	Inspection and O&M manuals	Yes	Unknown	N/R
AZ	No	Logbooms and flush through spillways	Yes	No	N/A
CA	No	Inspection annually, trashracks, logbooms etc.	Yes, Not Prohibited	Yes	Large wooden log might damage boom and need reconstruction.
CO	No	O&M required in design of log boom for protecting of spillway.	No	Sister agencies - Fish habit -memorandum for opening sluice gates.	N/A
CT	No	Site specific, inspection on smaller dams, O& M manual on larger	No formal regulations	N/R	N/R
DE	No	DE does not regulate dams.	N/A	N/A	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
FL	Yes	FL 373 of Florida statues, O&M unique to dam	Yes	Yes	Aquatic island (floating mats) during high flow events have the potential for overtopping.
GA	No	Passes over and collects at reservoir and cleans	Yes	Not Known	N/A
HI	No	During routine dam inspections, excessive or potentially disruptive debris are noted and removal recommended to the owner.	Yes	Yes	Larger trees have obstructed the primary discharge structures.
IA	No	Inspections, owner responsible	Yes, Not Prohibited	None Aware of	N/A
ID	No	Inspections, 5 yr. outlet inspections 2yr general inspection, site by site, owners responsible	Yes	None Aware of	N/A
IL	No	As a portion of the design and maintenance considerations.	Yes	Not Known	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
IN	No	Inspection (every 2 yr.) notification of owner	Yes, Not Prohibited	None Aware of	N/A
KS	No	O&M manuals	N/A	N/A	N/A
KY	No	Dam owners responsibility to keep the riser inlet and emergency spillway clear of drift.	Not Known	N/A	N/R
LA	Yes	District maintenance Forces collect the debris for the twenty (20) Publicly Maintained Dam as Required.	No	N/A	N/A
MA	No	Fish and Wildlife Services contact them when debris needs to be removed or annually.	No	N/A	N/A
MD	No	Inspection, dam owner responsible	Yes	Yes	Gate values and stem guide beat to death

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
ME	No	N/R	No	N/R	N/R
MI	No	Inspection, dam owner responsible	Not Known	N/A	N/A
MN	No	Flush through gates or haul to side	Yes	None Aware of	N/A
MO	No	Agency will request or order debris to be removed	1) Yes (small dams); 2) No (large dams)	N/R	N/R
MS	No	Dam owners responsibility to remove and dispose of floating debris.	Not Allowed or Disallowed	N/R	N/R

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
MT	No	Dam owner are required to have and follow a maintenance plan. The plan usually includes the management of debris on a regular basis.	Yes	N/R	N/R
NC	No	Inspection—During Inspections by our staff, if debris is obstructing a spillway or other appurtenant feature of a dam, our staff notifies the owner by letter of the need to remove the debris.	No	N/A	N/A
ND	No	Owner responsible	Yes	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
NE	Yes	Notify dam owners and they select a process for removing the debris.	Yes	No	N/A
NH	No	Inspection and notification and order. Law states dams be maintained in a safe manner.	Yes	None Aware of	N/A
NJ	No	N/R	Not Known	N/A	N/A
NM	No	Inspection, notify dam owner, issue and order if serious.	No	N/R	N/A
NV	No	N/R	Yes	No	N/A
NY	No	Regulatory environmental effects disposal	Yes, Not Prohibited	Yes	Ice and trash through sluice gate
OH	No	Inspection	Yes	None Aware of	N/A
OK	N/R	N/R	N/R	N/R	N/R
OR	No	Logbooms, detaining structures, check during inspection	No	N/A	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
PA	N/R	N/R	N/R	N/R	N/R
RI	No	Responsibility of dam owner to operate dam in a safe condition	No	N/A	N/A
SC	No	N/R	Yes	None Aware of	N/A
SD	No	N/R	N/R	N/R	N/R

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
TN	No	There is nothing in the Safe Dams Act or regulation specifically mentioning debris. The reg's require trash racks on principal spillways for new dams. The department does have authority to make owners maintain and operate their dams properly and can require removal of debris when needed.	Not an Issue	No	N/A
TX	No	N/R	Yes	No	N/A
UT	No	Inspection, suggest when needed	Yes	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
VA	No	Annual inspection with scheduled checklist, O&M as needed	Yes, Not Prohibited	Yes	Major debris build-up in 1995 and had to call for assistance from state emergency service and they contracted with the Corps to remove with heavy machinery. It took 2-3 days to remove.
VT	No	Routine practice with maintenance plan; also will recommend when needed.	Yes, Not Prohibited	No	N/A
WA	No	Trashracks or log booms are used in the design manual	Not Known, Outside Jurisdiction	N/A	N/A
WI	No	Guidance Document that clarifies state statutes used to have debris removed.	Yes, Not Prohibited	N/R	N/R
WV	Yes	Trashracks required	Yes, Not Prohibited	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
WY	No	Inspection	Yes	None Aware of	N/A
US Bureau of Reclamation	No	Site specific	N/R	N/A	N/A
Engineering Division - USDA/NRCS	Yes	O&M manual that states dam must be safe and to remove debris from intake structure that could interfere with operation.	No	N/A	N/A
Federal Energy Regulatory Commission	No	Inspection annually	Yes	Not Known	N/S
US Army Corps of Engineers	Yes	Site specific	Yes	Yes	Blue Stone Dam, WV
US Dept. of Energy	No	Clean as needed; site specific	N/R	N/R	N/R
US Nuclear Regulatory Commission	No	N/A	No	N/A	N/A
Mine Safety and Health Administration	No	Trashracks	N/A	N/A	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Regs or procedure?1a	What or how managed?1b	Allow flushing over spillway?2a	Problems with this practice?2b	What problems?2c
Tennessee Valley Authority	Yes	1) Pass through spillway (trashway); 2) Collect & dispose: internal review, permit to dispose use firewood	Yes	No	N/A
International Boundary and Water Commission	Yes	N/A	Yes	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
AK	Yes	Having to clear peat	Yes	N/R	Potentially	N/R
AL	N/A	N/A	N/A	N/A	N/A	N/A
AR	Yes	Logs on front of dam face	N/R	N/R	No	N/A
AZ	No	N/A	No	N/A	No	N/A
CA	No	N/A	No	N/A	No	N/A
CO	Yes	Logged in spillway	No	N/A	Yes	Logged in spillway
CT	Yes	Clogged drop inlet structure	Yes	Limited	Yes	Site 15, Debris boom, beaver built dam in inlet, water impounded without flood, overtopped, failed
DE	N/A	N/A	N/A	N/A	N/A	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
FL	Yes	Aquatic island (floating mats) during high flow events have the potential for overtopping.	Yes	N/R	Yes	Aquatic island (floating mats) during high flow events have the potential for overtopping.
GA	Yes	reduced capacity of storage	Not Known	N/A	No	N/A
HI	N/R	N/R	Yes	Hindered by excessive growths of water hyacinths.	N/R	N/R
IA	Yes	Collects around trashracks and clogs spillways and elevation increases	Yes	Unknown	Yes	Elevation raises to emergency and overtopps or flows through emergency spillway and erodes
ID	Yes	Beavers built in spillway	N/R	N/A	Yes	Debris obstruction in conduit
IL	Yes	Trashracks have not been cleaned regularly or after each storm event.	N/R	N/R	Yes	The accumulated debris on the trash racks impacts the ability of the spillway system to function adequately.

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
IN	Yes	During one flood event had officers constantly monitoring and in water collecting debris to keep out of spillway.	Yes	Different office, Conservation Office responsible	Yes	Failure
KS	No	N/A	No	N/A	No	N/A
KY	Yes	Debris has blocked the principal spillway inlet on some structures and it is a continual maintenance on most structures with forest above the structure.	Yes	Debris is a navigation hazard on most lakes after a storm	Yes	If the problem with drift in and on the riser is not corrected it could present a safety problem for a dam.
LA	N/R	N/R	N/R	N/R	N/R	N/R
MA	Yes	Clearing logs in gates.	No	N/A	Yes	Logs in gates.
MD	Yes	Gate values and stem guide beat to death	Yes	N/R	Yes	Minor non-emergency problems

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
ME	No	N/A	No	N/A	No	N/A
MI	Yes	Beavers	Not Known	N/A	Yes	Getting in spillway
MN	Yes	Clogging	Yes	During spring flooding	Yes	log gets jammed in gates and can't operate
MO	Yes	Plugged pipes	Not Known	Reservoir use issue not involved	Yes	Plugged pipes
MS	No	N/A	No	N/A	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
MT	Yes	Floating logs, etc. collect on upstream face of the dam and the wind and wave action causes erosion of the upstream face.	No	N/A	Yes	Floating debris have clogged the principal spillway channel causing dam overtopping
NC	Yes	Debris that has obstructed a principal spillway has resulted in excessive erosion in an emergency spillway (This has occurred at more than one dam.)	N/A	N/A	Yes	There have been instances when debris has completely clogged a principle spillway riser pipe causing the dam to overtop resulting in damage or failure of the dam.
ND	Yes	Hung in main spillway, reduce flow capacity, rerouted flow causing downstream erosion	Yes	N/R	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
NE	Yes	Debris has damaged rock riprap protection. Debris has destroyed trash racks. Debris has completely filled and obstructed intake structures.	No	N/A	Yes	Debris has damaged rock riprap protection. Debris has destroyed trash racks. Debris has completely filled and obstructed intake structures.
NH	Yes	N/R	Yes	N/R	Yes	N/R
NJ	No	N/A	No	N/A	No	N/A
NM	Yes	it is manageable, logs in intakes	No	N/A	Yes	Logged in intake and morning glory spillway
NV	No	N/A	No	N/A	No	N/A
NY	Yes	Inhibit hydraulic capacity	Not Known	N/A	Yes	Clogged rack openings, structural impact damage, prevent gate from closing, stepped spillways deterioration, spillway pier damage
OH	Yes	blockage of spillway, overtopped, raise elevation	Not Aware of any Problems	N/A	Yes	Restricted flow, Overtopped, severely damage
OK	N/R	N/R	N/R	N/R	N/R	N/R
OR	Yes	Trash logged in riser	Not Known	N/A	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
PA	N/R	N/R	N/R	N/R	N/R	N/R
RI	Not aware of any problems	N/A	No	N/R	Not aware of any problems	N/A
SC	Yes	We have experienced some problems that were at least partially caused by floating debris. Several small dams have had their riser system completely blocked by debris during periods of high flow following an unusual rainfall event, causing the dam to over	N/R	N/R	Yes	Several small dams have had their riser system completely blocked by debris during periods of high flow following an unusual rainfall event, causing the dam to overtop. At least one dam has failed due to overtopping, caused at least partially by floating
SD	N/R	N/R	N/R	N/R	N/R	N/R

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
TN	Yes	Principal spillway risers have gotten blocked by debris which contributed to higher lake levels or to overtopping.	N/R	N/R	Yes	Principal spillway risers have gotten blocked by debris which contributed to higher lake levels or to overtopping.
TX	Yes	Trash Racks on small and intermediate sized dams have been plugged, forcing engagement of emergency spillways.	N/R	N/R	Yes	Trash Racks on small and intermediate sized dams have been plugged, forcing engagement of emergency spillways.
UT	Yes	Clogging spillway	None Noticed	N/A	Yes	Clogging spillway with debris, ice, snow, boy scout rock throwing, beavers

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
VA	Yes	Clogging spillway	Yes	Needs to be stressed to remove debris	Yes	Clogging spillway
VT	Yes	Having to remove debris	Not Aware of any Problems	N/A	Yes	Collection on spillway
WA	Yes	Maintenance of downed timber during floods, but not a big issue because of "cattle guard" guard spacing design to release only small debris.	No	N/A	Yes	Maintenance of downed timber during floods, but not a big issue because of "cattle guard" guard spacing design to release only small debris.
WI	Yes	Clogging of a huge 150' trip gate section prevent flood from passing	Not Aware of any Problems	N/A	Yes	Clogging of a huge 150' trip gate section prevent flood from passing
WV	Yes	Having to clean clogged spillway, risers	No	N/A	Yes	Clogged spillway and riser.

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
WY	Yes	Blocked principle spillway which results in water flowing through emergency spillways which will erode.	Not Aware of any Problems; they don't get involved with	N/A	Yes	Blocked spillway
US Bureau of Reclamation	Yes	Environmental problems because they left the debris in the lake too long	N/R	N/A	No	N/A
Engineering Division - USDA/NRCS	Yes	Clogging of structures	N/R	N/R	N/R	N/R
Federal Energy Regulatory Commission	Yes	Plugs spillway outlet works	No	N/A	No	N/A
US Army Corps of Engineers	Yes	Barges stuck in spillway	Yes	Nav, no rec	Yes	Barges stuck in spillway
US Dept. of Energy	No	N/A	No	N/A	No	N/A
US Nuclear Regulatory Commission	No	N/A	No	N/A	No	N/A
Mine Safety and Health Administration	No	N/A	No	N/A	No	N/A

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Interfere with O&M?3a1	Describe problem?3a2	Interfere with nav&rec?3b1	Describe problem?3b2	Interfere with dam safety?3c1	Describe problem?3c2
Tennessee Valley Authority	Yes	Reduce efficiency of turbine or sluiceway	Yes	N/R	Yes	Sinking trash see 3a
International Boundary and Water Commission	Yes	N/R	No	N/A	Yes	N/R

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
AK	Not Known	N/R	N/R	N/A	Lower Fire Lake-Floating peat island- spillway ice problems.
AL	N/A	N/A	N/A	N/A	AL has no state legs.
AR	No	N/A	N/A		
AZ	No	N/A	N/A	N/A	Q3 problem have been minor and easily cleared
CA	No	N/A	N/A	N/A	
CO	No	N/A	N/A	N/A	
CT	Yes	Cantebury		Beavers built in overflow spillway and dam overtopped and failed	
DE	N/A	N/A	N/A	N/A	Delaware does not regulate dams, or debris, so we have no information of record. I do know of a log several years ago that lodged in a riser, restricting flow. As I recall it was a small riser, something like 48" or 30" barrel through the dam

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
FL	Yes	Kissimi River	1960	Overtopped and washed out hwy 50	
GA	No	N/A	N/A	N/A	
HI	No	N/A	N/A	N/A	
IA	No	N/A	N/A	N/A	
ID	No	N/A	N/A	N/A	
IL	None aware of	N/A	N/A	N/A	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
IN	Yes	Bean Blossom Dam	1992 or 1993	Clogging of principle spillway caused overtopping and failed	
KS	No	N/A	N/A	N/A	
KY	Yes	N/R	N/R	No failures but damage caused to principal spillway riser structures due to drift(mostly to the trash racks)	
LA	No	N/A	N/A	N/A	N/A
MA	No	N/A	N/A	N/A	
MD	Yes	Eden Mill Dam	1994	Gate values and stem guide beat to death	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
ME	Yes	The Apple Valley Lake Dam	Apr-96	Due to high flows and a blocked discharge culvert. Blockage was caused by accumulated floating debris.	N/R
MI	Yes	Lancing Club Dam	N/R	Floating tree got stuck	Michigan usually contracts out and doesn't collect data on this, most from his memory.
MN	Yes	N/R	N/R	Damage, not costly	
MO	Yes	Town and Country Trailer Park Dam, Eldon, MO	1998	Primary spillway pipe plugged and forced water through and overtopped. Floating dock, floated into concrete chute - 50% spillway capacity and logs forced out emergency spillway.	
MS	No	N/A	N/A	N/A	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
MT	Yes	1)Canyon Creek Dam; 2) Colgas Dam	N/R	1) Logs plugged the spillway approach channel and overtopped; 2) Sediment build up in spillway caused overtopping	
NC	Yes	1) Evans Lake Dam; 2) N/R	1) N/R; 2) September 15, 1989	1)Cumberland County, NC (see 3c2). I am certain that there are other instances, but I do not know the names of the dams.; 1) Fayetteville, NC: 18' embankment dam from overtopping during 6" - 8" rainfall event. The only outlet structure was a riser which	From Q2, I am not aware of any regulations which allow or prohibit flushing debris through spillway gates. However, I am also not aware that this has ever been a problem or that any complaints have been files regarding this issue.--Our regulations do
ND	No	N/A	N/A	N/A	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
NE	Yes	N/R	N/R	Debris has damaged rock riprap protection. Debris has destroyed trash racks. Debris has completely filled and obstructed intake structures.	
NH	No	N/A	N/A	N/A	
NJ	No	N/A	N/A	N/A	
NM	No	N/A	N/A	N/A	
NV	No	N/R	N/R	N/R	Debris can clog trashracks and spillways.
NY	Yes	N/R	N/R	Impact damage, spillway hydraulically inhibited, overtopping failure because racks too small.	
OH	Yes	N/R	N/R	No emergency spillway, spillway got blocked, lake level raised.	
OK	Unknown	N/A	N/A		
OR	Yes	N/R	N/R	Riser	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
PA	N/R	N/R	N/R		
RI	None aware of	N/A	N/A	N/A	
SC	Yes	N/R	N/R	Due to overtopping, caused at least partially by floating debris that collected during a period of high flow. IN 1990, we counted over 80 dams that had overtopping problems, and I would estimate that accumulated trash contributed to the overtopping in at least 1/3	
SD	No	N/A	N/A	N/A	South Dakota does not have any regulations addressing floating debris. I don't know of any problems either. I know the Corps of Engineers has cleaned their trash racks for the power tunnels on Oahe Dam, but they are submerged (150+feet)

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
TN	Yes	N/R	N/R	Contributory cause	
TX	Yes	Nix Lake Dam	1989	A Factor. A plugged fish screen may have contributed to overtopping of dam.	This is an area we have not previously studied and will likely remain a lower priority item.
UT	Yes	Knox Lake -UT00073; Crystal Lake: UT00316, Trial Lake: UT 00301; Indian Creek: UT00145	N/R	clogging of spillway on earthen dams caused overtopping; 1st 3 snow & ice; last debris--not enough freeboard	Utah is a high mountainous region with much snow and ice. They try to eliminate by painting spillway black to melt ice and absorb sun.

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
VA	Yes	N/R	N/R	Minor gate stems and trashracks beat	
VT	Yes	N/R	N/R	N/R	
WA	Yes	N/R	N/R	Principle metal grating accumulated 4" sticks and debris, caused erosion damage	
WI	Yes	Hatfield Dam	1993	Multiple problems, failure of power canal, debris partly the cause by clogging gates.	
WV	Yes	N/R	N/R	Rising water level caused flow over emergency spillway.	

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
WY	N/R	NR	N/R	N/R	
US Bureau of Reclamation	No	N/A	N/A	N/A	A slide gate was damaged during reconstruction of Jacson Lake Dam due to a submerged log. At Palisades, sownstream, they used to collect debris to keep it from plugging the powerplant intakes.
Engineering Division - USDA/NRCS	Yes	N/R	N/R	Failed due to pipe clogging and embankment overtopping.	
Federal Energy Regulatory Commission	Yes	Hatfield FERC#10855	N/R	Debris built up against flashboard system	
US Army Corps of Engineers	Yes	N/R	N/R	N/R	
US Dept. of Energy	N/R	N/R	N/R	N/R	
US Nuclear Regulatory Commission	No	N/A	N/A	N/A	NRC regulates only 19 low hazard dams. Floating debris has never been identified as a problem at any of these dams.
Mine Safety and Health Administration	No	N/A	N/A	N/A	Q1, our guidelines say that trashracks should be used on spillway inlets.

Table 5. Detailed Survey Responses (cont.)

Agencies or State	Damage to or failure of dams?4a	Name?4b	Year	Describe accident?4c	General Comments
Tennessee Valley Authority	Yes	N/R	N/R	Trashracks bent due to excessive head differential across the rack caused by debris accumulation.	
International Boundary and Water Commission	No	N/A	N/A	N/A	See survey response.

Appendix B. Dam Incidents Involving Debris

Table 6. NPDP's Dam Incidents Involving Debris

Information by NPDP, Stanford University

Key: "*" = Identifying information is not available at this time.
"?" = Available documentation is contradictory and/or inconclusive.

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
*	*	*	RE	62	HIGH	6/28/94	Modification/Repair	No	Repair of sluice gates, removal of existing silt against bulkhead, straightening bent panels and replacing seals on bulkhead removable panels, air vents in gatewell cleaned, and remove debris in conduit.
NY01489	Alder Pond Dike	NY	RE	15	HIGH	1/7-12/98	Flood	No	A combined ice storm and flood event occurred at the site on January 8, 1998 after several days of constant rainfall and snow melt. The peak flow of 11,150 cfs occurred at 5:30 P.M., January 8, at Elevation 1131.4 feet msl. The spillway was overtopped by 5.4 feet with one foot of freeboard. Staff implemented the EAP Dam Failure Watch (slowly developing failure) notification on January 8. On January 10, the flood flows began to decrease. The EAP notification was called off on January 11. The unit was operating at full output during the flooding period. There was no significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a direct result of project operation nor from the overtopping releases of the spillways.
AK00004?	Annex Creek Dam, FPC No. 2307	AK	OT	25/20?	LOW	1935	Flood	Yes	The dam failed due to logs which rammed the dam during a flash flood in 1935.
*	*	*	RECN	20	SIGNIFICANT	4/16/97	Seepage/Piping	Yes	The breach in the dam was estimated to be 20 feet wide. At least four road crossings along the outlet stream, Tannery Stream, received significant damage. No injuries have been reported Not sure of how it failed. It appears to have been a sequential, rather than catastrophic, failure. The dam was not observed or reported as failing. The best guess at this time is that a beaver dam or other debris got lodged in the spillway. The earthen portion adjacent to the spillway failed.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NY00615	Batavia Kill Watershed, Site 1	NY	RE	74	HIGH	10/11/88	Equipment Breakdown	No	Annual O&M Inspection Reports revealed there have been continual problems with the proper operation of the 24 inch non-rising stem slide gate at Site 1 since its installation in 1976. The Reports indicate that the gate had operated properly when cleaned and lubricated, but has for the most part been unreliable and nonfunctional. The gate binds, sticks, and leaks excessively. An investigating committee inspected the reservoir drain gate system on 10/11/88. The gate stem is not aligned properly, the upper cowling may be installed incorrectly, and the wedges are loose and ill-fitting. The stem is coated with corrosion in the threaded portion and may have suffered some damage from debris impact Furthermore, there is a high probability that the thrust nut and stem are worn or damaged and in need of replacement. The lack of gate maintenance has contributed to the development of the problems described above.
MD00080?	Big Millpond Route 50	MD	RE	10/9?	LOW	2/25/79	Flood	No	Rain and snowmelt flooding. Debris impact and scour may have contributed to total failure.
NY00635	Black River Power Dam	NY	PG	25	LOW	1/10/98	Flood	No	Flood in excess of 100 year flows. Flood -end around and overtopping. Minor gulley was formed. Dam left side raised to prevent overtopping and the flow went around the end. Temporary fill was breached within four days of flood event to gain access to control gates for debris removal. A second DIN (and DIDR) was received on 7/7/98: Note, the incident date on the second DIN is indicated as January 7-22, 1998. A combined ice storm and record flood event in exceedance of the 100-year event (estimated at 55,000 cfs) caused power outages and the Black River to overflow its banks. Reservoir status: Flashboard elevation 536.0 feet USGS exceeded and failed flashboard. Limited powerhouse inundation in basement. Damaged outlet regulating gate. Overtopped left retaining wall and backfilled berm area at gate section. Limited access road washout. No downstream or upstream damage.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NC00008	Blanchard Dam No. 2	NC	RE	21	HIGH	3/12/98	Erosion	No	The following conditions were noted during an inspection of the dam on 3/12/98: The dam has a severely eroded spillway channel; and several fallen trees are obstructing the channel.
NC02974	Blanchard Dam No. 4	NC	RE	37	HIGH	3/15/95	Seepage/Piping	No	Excessive seepage is present on the downstream slope and toe of the dam. The reinforced concrete pipe at the right end of the dam (looking downstream) is partially clogged with debris. Two plastic pipes have been inappropriately installed on the left end of the dam to replace the old concrete pipe at this location. Dense vegetation has been allowed to grow on the slopes and along the toe of the dam.
NY00692	Blenheim-Gilboa Lower Dam	NY	RE	100	HIGH	1/19/96	Flood	No	Continuous rainfall from morning of 1/19 to the morning of 1/20 with a total recorded rainfall of 4.22 inches. Warm temperatures melting snowpack contributed to an additional flow of 7 inches. Flood impacts were: scouring of stilling basin immediately downstream of tainter gates, floating debris accumulation on upstream headpond area of tainter gates, discoloration of creek waters, and clogging of intake filters.
NY00691	Blenheim-Gilboa Upper Dam	NY	PG	110	HIGH	1/19/96	Flood	No	Continuous rainfall from morning of 1/19 to the morning of 1/20 with a total recorded rainfall of 4.22 inches. Warm temperatures melting snowpack contributed to an additional flow of 7 inches. Flood impacts were: scouring of stilling basin immediately downstream of tainter gates, floating debris accumulation on upstream headpond area of tainter gates, discoloration of creek waters, and clogging of intake filters.
*	*	*	RE	10	HIGH	May, 1988	Flood, Dam Operations & Reservoir Incident	Yes	Beavers plugged the principal outlet, working and washing out the emergency spillway. Estimate of $80K to clear the debris, temporarily repair the dam, and make final repairs years later. Also, it will cost approximately $20K to repair a road crossing downstream. Reservoir status: incident not reported.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
CO00551	Boxelder Creek Watershed Structure B-5	CO	RE	80	SIGNIFICANT	10/24/79	Trash Rack Debris	No	This dam has a history of trash rack plugging since its completion in September, 1977. The incident date is based on Jack Stevenson's trip report dated October 31, 1979. The trash rack experiences some plugging problems whenever runoff occurs. During the first high runoff producing storm, the trash rack became plugged with trash. This plugging prevents the draining of the sediment pool which is a violation of the state's water laws. The trash rack is considered inadequate, and its basic design is substandard.
CO02238	Boxelder Creek Watershed Structure B-6	CO	RE	74	SIGNIFICANT	10/24/79	Trash Rack Debris/Rilling	No	This dam has a history of trash rack plugging since its completion in September, 1977. The incident date is based on a trip report dated October 31, 1979. The trash rack experiences some plugging problems whenever runoff occurs. During the first high runoff producing storm, the trash rack became plugged with trash. This plugging prevents the draining of the sediment pool which is a violation of the state's water laws. The trash rack is considered inadequate, and its basic design is substandard. Recent rains have resulted in rilling of the upstream face. The upstream zone of the dam consists of a coarse, cobbley, gravelly sand. Most of the rills are 6 to 8 inches or less deep and generally limited to the looser surface material. Significant armoring is apparent as the smaller material has eroded. In the gutter areas, deeper rills, as much as two feet, have developed. No immediate hazard to the dam exists. Most of the rilling will likely armor out and cause no problem. The deeper rills in the gutte
NC00092	Broughton Hospital Dam	NC	RE	70	HIGH	5/24/95	Deterioration	No	The dam is overgrown with trees and brush and must be cleared. Erosion is occurring on the downstream slope due to off-road vehicle usage. The spillway joints are showing signs of deterioration. The lake bed is becoming overgrown and it appears the bottom drain has clogged several times.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
None	Cecil Hollow Lake Dam	OH	RE?	25-30	Not Known	3/2/97	Flood	Yes	The spillway system did not function or was plugged. During a site visit by inspectors, no spillway system was noted. The dam overtopped and breached. The breached area through the dam measured approximately 12 to 15 feet in height, 10 to 12 feet bottom width, and 20 to 25 feet top width. A portion of the embankment still remained from the bottom of the breach to the downstream toe which appeared to be approximately 5 to 8 feet in height. This remaining 5 to 8 feet of dam embankment still retained water with a surface area of about 0.25 acre. A storage-volume calculation of the dam showed that the previous storage was about 10 acre-feet of water. Any dam with less than 15 acre-feet of storage is exempt from the Ohio Dam Safety Laws. A recommendation was made that the remaining portion of the dam embankment below the bottom of the breach should be removed to eliminate any potential for water to be impounded. Residents downstream suffered flood damage to trailers and personal property.
NC03079	Chowan College Dam	NC	RE	20	HIGH	5/17/95	Debris/Scarp	No	Debris has accumulated in and around the riser. An escarpment has formed on the upstream slope of the dam. This escarpment could possibly be attributed to either wave erosion or animal burrows.
•	•	•	RE	17	LOW	Summer, 1995	Hydrologic/Flood Event	No	According to the lake manager, a trailer home was washed into the reservoir during a storm event and plugged the spillway, causing it to overtop. An asphalt road ran along the crest. This road was washed out where overtopping had occurred.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
OR83006	Clearwater No. 2	OR	Not Known	Not Known	Not Known	2/5/96	Landslide (Appurtenant Structure)	No	Landslide damaged power canal and flume. A debris flow occurred on the slope above a portion of the Clearwater No. 2 canal near Flume No. 9. Flow debris blocked the canal and crushed the upstream end of the steel lined Flume No. 9. The concrete canal lining was severely cracked by large boulders. A geotechnical consultant retained by the licensee determined that the debris flow was started by the failure of a rock face at the top of the slope. Damaged sections of the canal and flume were replaced in kind and no plans or specifications were issued. Construction was completed by April 23, 1996 at a cost of approximately $381,000. The uphill slope above the canal was modified with a berm to deflect any minor sliding that might occur in the future.
MD00097	Conowingo	MD	PG	102/94?	HIGH	6/22-24/72	Flood/Storm	No	The incident involves the trash racks over the power intakes. As a result of tropical storm "Agnes," 33% of the trash racks failed when a large amount of debris was piled up on the racks. No details on the trash racks. Plant generation was shut down. Twenty new trash racks were installed; the remaining trash racks were repaired.
*	*	*	RE	34	LOW	1/10-11/98	Flood/Riser Failure	No	Heavy rainfall led to flooding which caused the riser to fail. The top of the pipes became plugged. Water level rose to approximately 3 to 4 feet above inlet of 8 foot CMP riser. Possible vortex resulted from flow through the riser which collapsed the 8 foot CMP near the bottom of the riser. The entire lake drained in hours. The riser, which served as principal/emergency spillway, completely collapsed resulting in drainage of the reservoir. Reservoir status: empty. No downstream or upstream damage.
CA00630	Crater Lake	CA	RE	36/20?	LOW	1928	Inadequate Spillway	Yes	Spillway became clogged with drift, causing the dam to be overtopped and breached. Inadequate spillway capacity, possibly due to obstruction by debris.
CA00431	Dam No. 5	CA	VA	60	SIGNIFICANT	3/10/95	Flood	No	No. 8 intake grating destroyed by debris from flood flows.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NC01793	Davis Pond Dam	NC	RE	22	SIGNIFICANT	3/7/95	Deterioration & Seepage	No	The primary spillway riser pipe appeared to be partially clogged and was not visible during this inspection. The outlet end of the primary spillway barrel pipe through the dam has deteriorated from rust. There was seepage noted on the downstream slope and toe of the dam. Soil erosion is also occurring in the new emergency spillway. Muskrats are burrowing in the dam, along the waters edge on the upstream slope.
CA00343	De Sabla Forbay	CA	RE	52	LOW	1/8/95	Other	No	Canal destroyed by debris flow.
CA00343	De Sabla Forbay	CA	RE	52	LOW	2/8/89	Other	No	Power canal overflowed in three areas, caused by tree falling in canal and blocking flow of ice.
NY00310	Denley	NY	CNPG	25	LOW	1/7-12/98	Flood	No	Ice laden river levels peaked on January 9, 1998 after days of continuous rainfall and snow melt under mild temperatures. The Moose River overtopped its banks No apparent damage to the dam or appurtenant structures. No downstream or upstream damage. No dam safety related damages. Experienced approximately two inches of flooding on the powerhouse floor. From second DIDR: A combined ice storm and historic flood event with a peak flood of 14,000 cfs occurred at the site on January 9, 1998 after several days of constant rainfall, warm temperatures, and high snow melt. Only the powerhouse was impacted by minor flooding on the floor. There was no other significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a direct result of project operation nor from the overtopping releases of the spillways.
None	Drew Smith	KY	RE	30	Not Known	Not Known	Deterioration & Seepage/Piping?	No	Principal spillway for this dam was an 8 inch steel pipe. The pipe had rusted and been plugged at the downstream end with a log. Flow from the rusted pipe saturated the embankment, weakening the dam. The owner attempted to breach the dam with a full reservoir. KY Division of Water provided siphons to drain the lake, then breaching resumed.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
WI00130	Fairwater	WI	PGRE	20	SIGNIFICANT	5/30/89	Flood/Dam Operations	No	Severe damage to embankment and roadway. Approximately a 50 year rainfall event. Failed to operate gates timely, debris clogged gate and could not be operated. Reservoir status: drawndown until reconstructed. Approximately $300K to reconstruct dam, $100K to repair road and utilities.
NC00748	Forest Lake Dam	NC	RE	25	SIGNIFICANT	1/20/95	Piping	No	Beaver debris clogged CMP riser in reservoir. Weight from beaver debris likely deformed riser/barrel connection in upstream embankment, causing piping of upstream embankment and a depression.
NY00305	Forestport Dam	NY	PG	27	HIGH	1/7-12/98	Flood	No	A combined ice storm and flood event occurred at the site on January 8, 1998 after several days of constant rainfall and snow melt. The peak flow of 11,150 cfs occurred at 5:30 P.M., January 8, at Elevation 1131.4 feet msl. The spillway was overtopped by 5.4 feet with one foot of freeboard. Staff implemented the EAP Dam Failure Watch (slowly developing failure) notification on January 8. On January 10, the flood flows began to decrease. The EAP notification was called off on January 11. The unit was operating at full output during the flooding period. There was no significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a direct result of project operation nor from the overtopping releases of the spillways.
*	*	*	RE	17	LOW	9/16/94	Flood	Yes	Flood caused full breach at emergency spillway. The dam is a 17 foot earthen structure with a CMP whistle tube outlet. The outlet evidently became plugged with debris, the dam overtopped and washed out taking with it a sizable section of a state highway. Reservoir status: drawn down. Property damage.
VA16301	Goshen Dam	VA	RE	38	HIGH	6/22/95 - 7/1/95	Flood	No	Emergency measures were required to alleviate a potentially hazardous situation. Heavy rains brought the water elevation up to within about 6 feet of the top of the dam. Debris partially blocked the spillway entrance and damaged some of the gate stems. Over a period of 3 1/2 days, the debris was removed and the dam brought to a stable condition.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NM00211	Hatch Valley Arroyos Watershed, Site No. 3 (Reed-Thurmond Dam)	NM	RE	26	LOW	11/15/82	Deterioration (Erosion)	No	As a result of an investigating committee's 11/15-19/82 site visit, several problems were revealed: 1. Reservoir sink holes near the inlet to the principal spillway. 2. A hole in the embankment undemeath the downstream end of the principal spillway conduit. 3. Rill erosion at the top of the embankment on the downstream slope. 4. A depression in the top of the embankiment above the principal spillway conduit. 5. Gully erosion on the north side of the emergency spillway exit channel but outside of the design emergency spillway flow area. 6. Gully erosion and a deep headcut along the dike at the south edge of the emergency spillway but outside of the design emergency spillway flow area. Also, erosion in the approach channel. 7. Plugging and breaching of the principal spillway outlet channel (disposal channel). No single incident or "failure" has occurred for separate identification. There has been no failure of the structure, per se. Some minor incidents have been reported in relation to each of the p
WI00016	Hatfield	WI	PGRE	97	HIGH	6/20/93	Flood/Deterioration/Seepage	Yes	One hundred plus year flood event, large canal failed (piping?), several tainter gate chains failed, debris clogged other gates, embankment developed seepage, major downstream damage. Reservoir status: drawndown for several months. Several millions $ damage to dam and powerhouse, levee downstream failed, inundating approximately 90 homes. Approximately $23 million for evacuations and rescues.
•	•	•	RE	10	HIGH	8/9-11/97	Flood	No	Intense thunderstorms occurred. The rainfall approached the 100 year event. Intake structure to the basin was clogged with debris, resulting in only one foot of storm flow into the basin. As a result of the rainfall, there was one fatality and $4 million in damages. No apparent damage to the dam or appurtenant structures.
NC02756	Hutton Dam	NC	RE	16	HIGH	4/26/94	Spillway Obstruction	No	A periodic safety inspection was also conducted on 5/31/95. Trees and bushes are growing on the dam. There are obstructions (growth and debris) in the emergency spillway.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
MO31988	ISP Minerals Inc. Plant	MO	Not Known	Not Known	Not Known	6/3-4/92	Overtopping	Yes	Tailings pile failed. Pipe became clogged, water filled the pond and overtopped the dam. Eventually, the dike was overtopped by the water/waste material and flowed into Big Creek.
NY00729	Kamargo Dam	NY	PG	12	LOW	1/10/98	Flood	No	Flood in excess of 100 year flow. Debris, return flow scour downstream of power channel structure. Actually two dam, diversion ogee with flash boards and intake gates on south side of an island, overtopping of closure structure at head of island. A second DIN (and DIDR) was received on 7/7/98: Note, the incident date on the second DIN is indicated as January 7-22, 1998. A combined ice storm and record flood event in exceedance of the 100-year event (estimated at 55,000 cfs) caused power outages and the Black River to overflow its banks. Reservoir status: Flashboard elevation 563.8 feet USGS exceeded and failed flashboard. Non-overflow structure at Poors Island, separating dam from canal headworks, overtopped. Access road on Poors Island was inundated and blocked by downed power lines and fallen trees. Washout from the non-overflow earthen structure dredged from canal headworks area. No downstream or upstream damage.
NY00308	Kayuta Lake Dam	NY	OT	26	HIGH	1/7/98	Flood	No	A combined ice storm and flood event occurred at the site on January 8, 1998. The peak flood occurred on January 9, after several days of constant rainfall and high snow melt. The peak flow of 5,837 cfs occurred at 2:00 A.M., January 9, at Elevation 1145.8 feet msl. The spillway was overtopped by 4.1 feet with two feet of freeboard. Staff implemented the EAP Dam Failure Watch (slowly developing failure) notification on January 9. On January 10, the flood flows began to decrease. The EAP notification was called off on January 11. The unit was operating at full output during the flooding period. There was no significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a direct result of project operation nor from the overtopping releases of the spillways.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
*	*	*	RE	20	LOW	July, 1992	Flood, Dam Operations & Reservoir Incident	Yes	Debris plugged principal outlet, working and washing out emergency spillway. Dam washed out in area of emergency spillway. Deposited large amount of sediment downstream.
*	*	*	RE	31	HIGH	2/28/97 - 3/4/97	Flood	No	Investigation on 3/5/97. Flood waters overtopped the left end of the dam for about 60 feet along the crest. The principal spillway was clogged with logs. The downstream slope had 12 inch deep erosion gullies.
NC04956	Lakewood Acres Dam	NC	RE	21	HIGH	August/September 1995	Flood	No	Dam overtopped; spillway capacity inadequate for high intensity rainfall events. Inlet to corrugated metal pipe at bottom of dam is almost clogged shut with some unknown material. Water flowing through culvert pipe severely eroded area of downstream slope. Outlet end of primary spillway barrel pipe through dams is deteriorated from rust.
NC01269	Leonard Phillips Dam	NC	RE	28	HIGH	1/21/98	Dam Operations (Riser Obstruction)	No	The following condition was noted during an inspection of the dam on 1/21/98: The riser appears to be submerged and obstructed causing flow through the emergency spillway.
NJ00283	Long Pine	NJ	RE	8	SIGNIFICANT	Circa 1982	Inadequate Spillway	No	The dam nearly overtopped because of the spillway becoming clogged.
OR00612	Lost Creek	OR	ER	345	HIGH	6/1/78	Wave Action	No	Erosion of the upstream face of the embankment occurred as a result of a short duration windstorm with wave heights of about 2 to 4 feet. The damage consisted of a terrace 4 to 8 feet wide along the full length of the embankment at about elevation 1871. Floating logs and debris contributed to the erosion. To avoid similar incidents in the future, adequate size riprap has been placed for slope protection.
NY00017	Lower Saranac North Dam (Treadwell Mills)	NY	PGCN	24	SIGNIFICANT	11/8/96	Flood	No	Record flooding occurred between 11/8-9/96 on the Saranac River. Flooding caused outages to both units on 11/9/96 due to debris build-up. Flood waters caused minor to moderate erosion to various project properties.
NY83107	Lower Saranac South Dam	NY	PG	17	SIGNIFICANT	11/8/96	Flood	No	Record flooding occurred between 11/8-9/96 on the Saranac River. Flooding caused outages to both units on 11/9/96 due to debris build-up. Flood waters caused minor to moderate erosion to various project properties.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
TX00987	Max Starcke Dam	TX	PG	99	SIGNIFICANT	December, 1991	Flood	No	Debris from flood in late December 1991 caused gate damage. The gates were still operable. Pier modification was to put stoplogs on gates so that the gates could be worked on. Modification of the spillway gate piers from a slanted front face to a straight vertical pier with a rounded front face in order to mate with a floating bulkhead. Construction began on 10/15/95, and was scheduled for completion in mid-December 1995.
None	Midway (Middle Fork of Porcupine)	MT	RE	40	Not Known	3/20/39	Flood	Yes	Spillway was plugged with ice and debris when the dam was (apparently) overtopped by a flood wave.
CA00110	Morena	CA	ER	181	HIGH	1916	Flood	No	The dam overtopped, but did not fail. Spillway became obstructed with floating debris. Heavy precipitation. Original construction - 1895; Constructed - 1912; Rebuilt - 1932.
*	*	*	RE	10	LOW	2/27/98	Deterioration	No	The culvert apparently became plugged by chunks of wood, thereby threatening the dam with overtopping. There was an emergency drawdown and installation of a new culvert. Reservoir status: level restrictions imposed. Dam raise and spillway design is underway. A passerby had first noticed the problem.
*	*	*	PG	68	HIGH	5/17/97	Flood	No	Higher than normal snowpack resulted in flows of about 11,000 cfs (about 10 feet of depth over the ungated spillway). The flows and river borne debris broke a cable supporting floating platforms used to pass debris over the dam. The Emergency Action Plan (EAP) provides for implementation at about 10 feet of flow over the ungated spillway (about 1/2 spillway capacity). At this flow, the downstream powerhouse could start to flood, and City personnel are notified. Since depth of flow over the spillway was about 10 feet, and debris could block the spillway, resulting in a higher reservoir level, the EAP for a potentially hazardous situation was initiated. No apparent damage to the dam or appurtenant structures. No downstream or upstream damage

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
CA00812	Nacimiento	CA	RE	270/215?	HIGH	2/24-27/69	Spillway/Gate	No	On 2/24/69, water went over the spillway. On 2/27/69, it reached a maximum depth of 3.5 feet. The high level outlet slide gate became clogged with debris and failed. The erosion was caused by the discharge of the spillway. The spillway was damaged.
NM00120	Navajo	NM	RE	388	HIGH	August, 1964	Erosion/Deterioration	No	Erosion of exposed concrete was noted in 1964. Underwater inspection revealed major erosion of the floor, walls, and wedges. The basin was then unwatered, cleaned out, and repaired. After one season of operation the repaired basin was found eroded to a critical state. At this time, major modifications were made to the stilling basin. This incident points out the need to maintain basins free of rock and construction debris.
NC03482	North Lake Subdivision Dam	NC	RE	21	HIGH	2/28/94	Seepage & Erosion	No	Area of extensive seepage located 10 feet to the right of the 6 inch steel pipe. Severe soil erosion has occurred beneath the 10 inch PVC pipe primary spillway. Trees and bushes are growing on the dam. Primary spillway riser pipe appears to be partially clogged. Muskrats or other animals appear to be burrowing in the dam along the waters edge on the upstream slope.
None	North Fork of the Toutle River	WA	Not Known	Not Known	Not Known	1980	Other?	No	Following the eruption of Mt. St. Helens, the US Army Corps of Engineers constructed a 38 foot high retention dam on the North Fork of the Toutle River to keep the downstream channel clear of volcanic debris. A month after completion, ash sediment and rock in the flow eroded and failed the shotcrete-lined gabion spillway.
*	*	*	Not Known	Not Known	Not Known	6/13-30/98	Flood	No	The drop-inlet was blocked by beaver debris, thereby preventing outflow from the primary spillway. The water level reached within inches of the top of the dam and was discharging through the emergency spillway which was a 36 inch culvert. This culvert started to collapse due to piping failure. Flow was diverted to an emergency spillway that was constructed by excavating a low area near the left abutment. A failure of the dam was averted.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
MS01476	Persimmon Creek Subwatershed, Site No. Y-21-50	MS	RE	24	LOW	11/5/86	Emergency Spillway Breached (Beaver Debris)	No	Field reviews were made on 11/5/86 and 11/14/86. The emergency spillway breached (exact date of the incident is unknown). It had breached down to the floodplain elevation. The breached width is approximately 15 feet at the bottom and 70 feet at the top of dam elevation. Property downstream from channel is being damaged by floodwater and sediment deposition. Approximately 400 acres is being affected and damage is moderate. The problem of the emergency spillway breaching was the direct result of beaver debris restricting the riser inlet, thereby causing frequent and prolonged flow through the emergency spillway. Beaver activity was present before at least August, 1975. Field review on 9/17/86 revealed the emergency spillway had eroded into the permanent pool area lowering the water level well below the principal spillway riser grated inlet.
None	Pillar Rock Dam	WA	PGCN	25	Not Known	1/27/70	Flood	Yes	Sudden failure of logging road fill, due to plugged culvert, released the impounded water downstream one-half mile, where 25 foot concrete-gravity dam in turn failed. Water supply cutoff to four occupied homesites and two homes destroyed and one home dislodged. All three unoccupied in the small village of Pillar Rock.
NC04345	Pisgah Forest Farm Dam	NC	RE	35	HIGH	2/9/96	Erosion	No	The trashguard on the riser appears to be damaged. The entrance to the twin 18" cmp emergency spillway pipes is partially obstructed with debris. The left cmp pipe has separated on the downstream side of the dam. Erosion noted from pipe outlet.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NC04345	Pisgah Forest Farm Dam	NC	RE	35	HIGH	2/13/98	Dam Operations	No	The following conditions were noted during an inspection of the dam on 2/13/98: Trees and bushes are growing on the dam; the entrance to the twin 18" CMP emergency spillway pipes is partially obstructed; and the left CMP pipe has separated on the downstream side of the dam. (These pipes drain onto the backslope of the dam which has caused a slope failure in the past and covered the outlet of the barrel with rock and debris.)
NY01428	Port Leyden	NY	PG	39	LOW	1/7/98	Flood	No	The DIN indicated that the incident occurred during 1/7-12/98. Ice laden river levels peaked on January 9, 1998 after days of continuous rainfall and snow melt under mild temperatures The Moose River overtopped its banks. No apparent damage to the dam or appurtenant structures. No downstream or upstream damage. No dam safety related damages. Experienced approximately two inches of flooding on the powerhouse floor. From second DIDR: A combined ice storm and historic flood event with a peak flood of 14,000 cfs occurred at the site on January 9, 1998 after several days of constant rainfall, warm temperatures, and high snow melt. Only the powerhouse was impacted by minor flooding on the floor. The unit was off-line during the flooding period. The generator and motor were wetted by flood water. There was no other significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a result of project
*	*	*	RE	17	LOW	7/17/96	Flood	Yes	More than 10" of rainfall in 24 hours. A section of approximately 30' of the dam embankment was completely washed away. The upstream outlet pipes were found partially clogged with debris. The emergency spillway was intact. Reservoir status: empty.
NY00240	Rainbow Falls	NY	CNPG	19	SIGNIFICANT	11/8/96	Flood	No	Record flooding between 11/8-9/96 on the Au Sable River. Flooding caused an outage due to trashrack differential. The powerhouse was flooded with about 2' of water. Flood waters deposited debris and mud in the lower turbine level of the powerhouse.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
WV07910	Ranch Lake Estates Dam	WV	RE	25	HIGH	1/29/96	Deterioration (Sinkhole)	No	Not sure if this incident is the result of a periodic safety inspection. This is possibly a piping incident. A sinkhole was discovered on the crest of the dam, approximately two feet from the top of the upstream face of the dam. The sinkhole appeared to be in line with the center of the outlet pipes.The depth of the sinkhole increased from 18 inches on 1/29 to 36 inches on 2/7, and to 48 inches on 2/9. The material in the deeper portion of the sinkhole was extremely wet, and had the consistency of a slurry. An indentation in the shoreline is visible along the line of the outlet pipes to the riser box. A small depression was observed approximately 2 feet from the sinkhole at the top of the upstream face slope. A significant amount of floating logs and debris has been washed to the riser box. The flow over the weir is not evenly distributed around the perimeter of the weir box. It appears that the structure has settled or tilted in the direction of the dam to cause this situation. There was erosion vi
NY12231	Rock Island	NY	CNPG	18	LOW	1/7/98	Flood	No	The DIN indicated that the incident occurred during 1/7-12/98. Ice laden river levels peaked on January 9, 1998 after days of continuous rainfall and snow melt under mild temperatures. The Moose River overtopped its banks. No apparent damage to the dam or appurtenant structures. No downstream or upstream damage. No dam safety related damages. Experienced approximately two inches of flooding on the powerhouse floor. From second DIDR: A combined ice storm and historic flood event with a peak flood of 14,000 cfs occurred at the site on January 9, 1998 after several days of constant rainfall, warm temperatures, and high snow melt. Only the powerhouse was impacted with minor flooding on the floor. There was no other significant damage to the civil works of the project. Trash and ice debris did not adversely impact the trashrack intake structure. Downstream inundation impacts were not a direct result of project operation nor from the overtopping releases of the spillways.

Table 6. (continued)

NATDAM ID	NAME	STATE	DAM TYPE	DAM HEIGHT (FT.)	HAZARD	INCIDENT DATE	INCIDENT TYPE	FAILURE	INCIDENT NOTES
NC01260	Scomp	NC	RE	28	HIGH	11/9/95	Spillway Obstruction	No	Trees on the front slope and back slope which are less than 6 inches must be removed from the dam. The spillway trashguard must be cleared of debris. The emergency overflow spillway should be cleared of brush and trees (high vegetation restricts the capacity of the spillway).
None	Shook Lower Dam	NC	Not Known	Not Known	HIGH	1/8/98	Flood, Erosion & Seepage	No	A request was made to inspect the dam (not a periodic inspection) because it was reported that the dam had overtopped. During the inspection, it was noted that the dam had been overtopped, causing severe erosion of the embankment. The dam had two pipes serving as its principal spillway. The two pipes were clogged with beaver debris, thereby restricting outflow from the dam. Significant seepage was occurring along the two pipes and at the right (facing downstream) abutment contact. The owner was instructed to make an emergency breach of the dam on January 8, 1998. On January 8 and 9, and emergency breach was made to the dam. An emergency breach of the Shook Upper Dam was not made because it was felt that if the Shook Lower Dam was breached, the lake area could provide some storage should the Shook Upper Dam fail. Subsequent inspections of the breach section in the Shook Lower Dam indicated that the breach section is becoming obstructed due to beaver activity. This will likely require that the breach s
NC04847	Stafford Pond Dam (Concrete Shed Dam)	NC	RE	13	HIGH	3/21/95	Spillway Clogged	No	The emergency spillway on the left side of the dam was activated due to increased water elevation in the lake. The spillway riser pipe was not visible. This pipe is clogged with debris or damaged to prevent proper operation, resulting in a higher water level and continuous flow through the emergency spillway.
*	*	*	Not Known	Not Known	Not Known	3/1/97	Flood	Yes	The dam overtopped and failed due to a reported 8 to 10 inches of rainfall. Reservoir status: 80 to 90% empty. The dam has almost completely breached. The 28 foot high dam breached aproximately 18 to 20 feet. The spillway was clogged with debris. The foundation was poorly constructed. A road downstream and underground powerlines were destroyed. Three homes received flood damage.

Table 6. (continued)

NATDAM ID	*NAME*	*STATE*	*DAM TYPE*	*DAM HEIGHT (FT.)*	*HAZARD*	*INCIDENT DATE*	*INCIDENT TYPE*	*FAILURE*	*INCIDENT NOTES*
•	•	•	REOT	16	HIGH	July, 1990	Flood/Dam Operations	No	Eight (plus) inches of rain in six hours. Failure to operate gates in a timely manner. Water pressures prevented gate mechanism from operating (debris and logs). Estimate of $500K to reconstruct the dam. Approximately $300K in damages to cars, boats, and sewage treatment plant. Reservoir status: drawn down until repairs can be made.
TN15745	Tompkins Lake	TN	RE	22	SIGNIFICANT	December, 1987	Flood	Yes	Partial failure due to overtopping, attributed to inadequate spillway blocked by debris and trees. Presence of numerous large trees on the downstream slope also contributed to the failure The owners failed to repair the dam at this time, and, as a result, a complete failure occurred in November 1988.
MO30204	Wappapello Dam	MO	RE	114	LOW	6/5/92	Erosion/Overtopping	Yes	Erosional failure occurred at large tailings pile. Decant pipe became clogged and water overtopped a berm.
WI00725	White River	WI	PGRE	30	LOW	9/1/26	Other	No	Due to debris at gates, the pipeline was dynamited to allow added flow. The sandstone foundation was found to be eroded.
NC010517	Willowhaven (No. 1?)	NC	RE	20	HIGH	6/3/79	Flood/Inadequate Spillway	No	The dam overtopped during a heavy storm. It was reported that a local 5 inch rain gauge overflowed during the storm. The estimated storm frequency is between a 25 year and 50 year storm. The incident was probably caused by a combination of an inadequate spillway and spillway obstruction by debris.

Appendix C. Types of Recreational Boating Accidents

Table 7. Types of Recreational Boating Accidents

Type of Accident
Capsizing
Collision with Fixed Object
Collision with Floating Object
Collision with Vessel
Fall in Boat
Falls Overboard
Fire/Explosion (Fuel)
Fire/Explosion (Other than Fuel)
Flooding/Swamping
Grounding
Not Reported
Other
Sinking
Skier Mishap
Starting Engine
Struck by Boat
Struck by Motor/Propeller
Struck Submerged Object

Reference: US Coast Guard, 1998

Appendix D. ASDSO's 1998 State Dam Inventory Data

Table 8. ASDSO: 1998 State Dam Inventory Data

Please Note: Inventory sizes vary from state-to-state because of number of dms, but also because state laws vary on which dams are included under their jurisdiction

State	Total National Inventory[1]	Total State Regulated[2]	State High-Hazard[3]	State Reg. Unsafe[4]	Government Ownership[5]
Alabama	1570	1704	184	150	25
Alaska	99	87	18	0	55
Arizona	315	214	73	23	173
Arkansas	927	427	98	25	363
California	523	1238	392	0	536
Colorado	1648	1808	292	189	428
Connecticut	707	3230	236	NR	251
Delaware	73	98	9	NR	75
Florida	572	NR	NR	NR	15
Georgia	4853	3311	366	57	634
Hawaii	129	129	56	0	29
Idaho	343	431	100	13	80
Illinois	1232	1232	157	NR	387
Indiana	1463	1414	243	NR	317
Iowa	2465	2514	66	2	1437
Kansas	6077	9899	200	51	1363
Kentucky	955	924	147	0	NR
Louisiana	381	311	12	0	90
Maine	617	694	23	59	57
Maryland	273	361	56	6	162
Massachusetts	1528	2921	333	21	685
Michigan	909	1191	83	NR	378
Minnesota	932	852	40	NR	532
Mississippi	3191	3328	238	10	121
Missouri	4032	614	195	20	206
Montana	3517	3219	153	13	795
Nebraska	2029	2029	92	0	1027
Nevada	323	577	106	8	74
New Hampshire	613	3148	88	NR	364
New Jersey	806	1580	183	32	350
New Mexico	501	521	162	6	182
New York	1633	5645	372	57	676
North Carolina	2699	4646	874	40	199
North Dakota	770	1308	26	5	191
Ohio	1766	2703	502	450	505
Oklahoma	4510	4380	145	5	150
Oregon	833	3733	122	0	186
Pennsylvania	1315	2886	735	7	501
Puerto Rico	36	36	33	0	31
Rhode Island	185	506	17	0	80
South Carolina	2252	2242	149	3	283
South Dakota	2392	2252	48	4	140
Tennessee	1044	593	136	28	382
Texas	6838	7247	818	403	2734
Utah	654	1948	214	41	198
Vermont	343	1001	51	NR	141
Virginia	1581	482	103	50	360
Washington	653	865	94	13	238
West Virginia	537	354	248	49	233
Wisconsin	1291	1080	192	NR	618
Wyoming	1216	1332	64	3	221
Total	76151	95245	9344	1843	19258

1 - Includes federal and non-federal dams over 25' in height or 50-acre-feet in volume, or anything above 6' in height with downstream damage potential should it fail
2 – Includes all dams under state regulatory control
3 – High-Hazard by state definition derived from state inventory in column 2
4 – Dams with identified deficiencies by state definition (varies state to state) derived from state inventory in column 2
5 – Derived from national inventory in column 1

NR = Not Reporting Some states do not keep data on "high-hazard" and/or "unsafe" categories.

Reference: (ASDSO, 1999)

Appendix E. Additional Pictures

Reference: (Bentley, 1999)

Figure 18. Tree Growing in a Riser Pipe

Reference: (Bentley, 1999)

Figure 19. Debris in an Outlet (Greenbrier)

Reference: (Bentley, 1999)

Figure 20. Beaver Debris built in a Spillway Outlet (Ridgetop)

Reference: (Bentley, 1999)

Figure 21. Other Side of Beaver Debris (Ridgetop)

Reference: (TVA, 1998b)

Figure 22. Debris Accumulation at Melton Hill Dam

Reference: (Sadler, 1999a)

Figure 23. Debris at Cheatham Dam

Reference: (Sadler, 1999a)

Figure 24. Debris gathered at Face of Cheatham

Reference: (Sadler, 1999a)

Figure 25. Trash, Tires, and Barrels at Cheatham Dam


Reference: (Sadler, 1999a)

Figure 26. More Debris at Cheatham

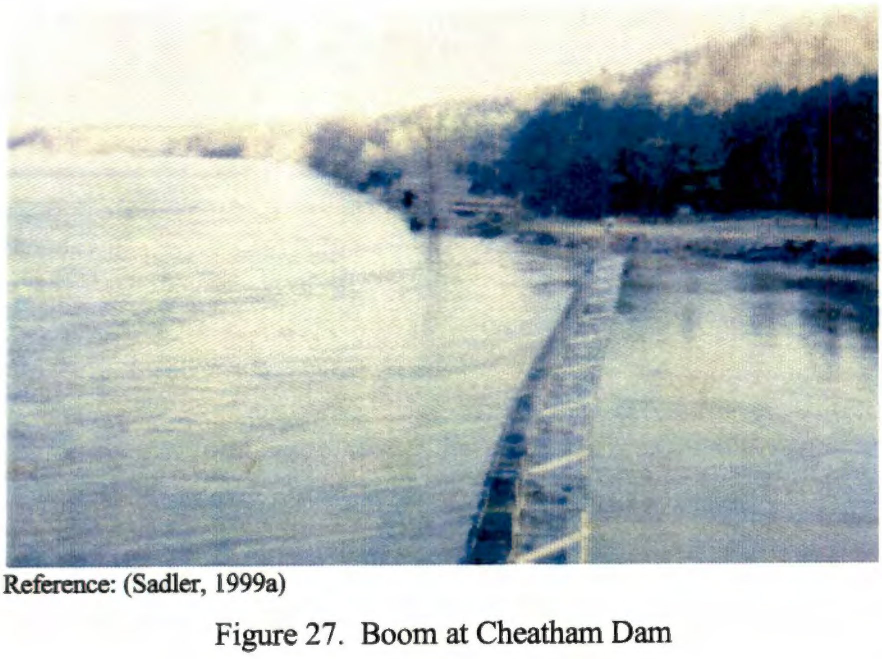
Reference: (Sadler, 1999a)

Figure 27. Boom at Cheatham Dam

Reference: (Sadler, 1999a)

Figure 28. Debris accumulated at Boom at Cheatham Dam

Reference: (Sadler, 1999a)

Figure 29. Debris being removed at Cheatham with Crane and Barge

Reference: (Sadler, 1999a)

Figure 30. Removal of Debris at Cheatham

Reference: (Sadler, 1999a)

Figure 31. Trashracks Removed from Cheatham Dam

Reference: (Sadler, 1999a)

Figure 32. Testing of Self-Cleaning Trashracks

Reference: (Sadler, 1999a)

Figure 33. Self-Cleaning Trashracks being installed at Cheatham Dam

Reference: (Sadler, 1999a)

Figure 34. Installation of Trashracks at Cheatham Dam

Reference: (Sadler, 1999a)

Figure 35. Cheatham Dam Self-Cleaning Trashracks

Reference: (Sadler, 1999a)

Figure 36. Debris at Bridge on Cumberland River

Reference: (Sadler, 1999a)

Figure 37. Debris on Cumberland River at Bridge

Reference: (Sadler, 1999a)

Figure 38. Debris at Huntsville Springs Branch Pier

Reference: (Sadler, 1999a)

Figure 39. Debris at Piers on Huntsville Springs Branch

Reference: (Sadler, 1999a)

Figure 40. Debris on Huntsville Springs Branch

Reference: (Sadler, 1999a)

Figure 41. Layout of Trash gate and Collection Area on Cumberland River

VITA

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