Hidden Dangers and Public Safety at Low-head Dams

BRUCE A. TSCHANTZ, PE

KENNETH R. WRIGHT, PE

ABSTRACT

Low-head dams, a.k.a. "killer dams" or "drowning machines," often present a safety hazard to the public because of their ability to trap victims in a submerged hydraulic jump formed just downstream from the dam. Most of these dams, normally producing vertical water surface drops ranging from one to a dozen feet, have been constructed across rivers and streams to raise the water level for the purpose of improving municipal and industrial water supplies, producing hydropower, and diverting irrigation water. Hundreds were built in the 1800s to power gristmills and small industries. Many have fallen into disrepair or been abandoned, posing dangerous conditions to the public. Kayakers, canoers, rafters, swimmers, and other water users are often unaware of the existence of hazards at low-head dams, and sometimes end up getting trapped and drowning in the strong recirculating currents. Although hundreds have been killed over the last four decades, few states regulate these dangerous structures because of their small heights. Moreover, state dam safety regulations focus primarily on structural integrity and prevention of failure, but they do not generally consider public safety issues at or around dams.

A recent study of accidents at these dams over the last four decades reflects a sobering reality of the problem from a national hazard perspective. The hydraulic action below low-head dams is reviewed to show how it creates a water hazard, threatening public safety. Structural and non-structural measures to reduce drownings are examined and a drowning case study is presented that the authors have investigated.

I. Introduction

Dam safety, or the safety of dams, has been in the public and technical topical forefront for almost four decades, since the Buffalo Creek tailings dam disaster and other notable dam failures including Teton and Kelly Barnes in the 1970s. The growing number of government actions, organizations, articles, workshops and conferences about dam safety demonstrate this nation's recognition of the need for policies, standards, regulations, and institutions to make dams safer and to reinforce a dam owner's responsibility to protect the public from property damage and loss of life in event of structural failure. Forty-nine states and all federal agencies having some responsibility for dam safety have programs to regulate the design, construction, operation, inspection, and maintenance of dams under their jurisdiction. Most states and federal agencies have emergency action requirements for warning the downstream public in event of failure. In addition, the National Dam Safety Program (NDSP) provides important support for the improvement of the state dam safety programs that regulate most of the approximately 84,000 dams in the United States included in the National Inventory of Dams (USACE 2010).

What is missing in this vast array of programs to regulate the structural safety of dams is a national, or coordinated, effort for protecting the public at and around certain dams– especially those smaller structures that are exempted because they fall below the state or federal jurisdictional size categories. While there are thousands of unregulated dams, one notable class stands out: the "low-head" dam. Low-head dams are run-of-the-river, overflow structures, usually defined to be in the range of 3 to 5 meters in height, constructed across rivers, with flow passing directly over the entire dam structure for the purpose of raising the water level to improve industrial and municipal water supplies, protect utility crossings, and enhance recreational opportunities. Low-head dams are also known as "killer dams" or "drowning machines" because of their capability to produce dangerous currents, hydraulic forces, and other hazardous conditions to anyone trapped immediately downstream from the overflowing water. The term "drowning machine" was first used thirty years ago to describe this phenomenon in a video that underscored the dangers at these structures (Borland-Coogan, 1980).

Hundreds of these low-head dams were built across the U. S. during the 1800s to power gristmills and small industries. Hundreds more have been constructed for irrigation and water supply diversion on rivers throughout the U.S. The number of low-head dams in most

ISSN 1944-9836 - Association of State Dam Safety Officials

states is unknown. Pennsylvania maintains an inventory of about 300 low-head dams and Virginia estimates having between 50 and 100. In Ohio, over 200 low-head dams are reported, New Jersey has 120, Illinois has about 250, and Iowa estimates having between 200 and 400 (Allen, 2008). Of 37 states that responded to a 2004 national survey, 17 estimated having almost 1700 low-head dams (Tschantz, 2004).

Hydraulic engineers are aware of the forces created by moving water and have a professional responsibility to design safe structures to control and contain these forces. But, as Professor Hans Leutheusser (1988) pointed out twenty years ago, “a safely designed and executed hydraulic structure does not, in itself, render a water flow harmless.”

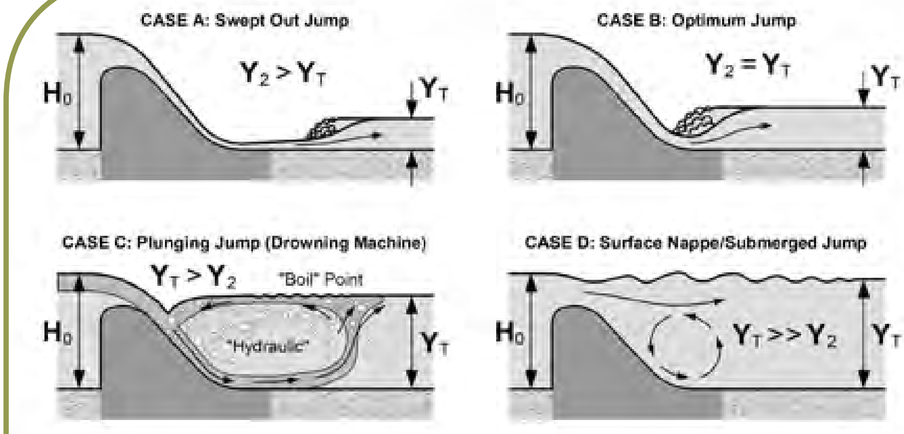

Figure 2. Different states of weir flow as a function of jump sequent depth, Y_2, and tailwater depth, Y_T.

Across the country, many older dams that no longer serve their original purposes have been abandoned and have fallen into disrepair, creating dangerous conditions for the public. Unwary swimmers, kayakers, canoers, boaters and anglers generally do not recognize this danger or understand the power of moving water at and below these dams. Some water users are actually attracted to the sporting “thrill” from a rushing cascade.

Figure 1 shows a dramatic June 30, 2009 rescue below a low-head dam on the Des Moines River, Des Moines, Iowa, where drownings have occurred.

II. Low-head Dam Hydraulics

Flow over a low-head dam can be characterized by the hydraulics of flow over a rectangular weir. Four distinct states of weir flow, as a function of relative hydraulic jump depth (Y_2) to tailwater depth (Y_T), just downstream from the dam, are presented in Figure 2.

Inspection of Figure 2 shows that an ideal hydraulic jump may form immediately downstream of a weir at the point of the overflow nappe impact when the local tailwater depth (Y_T) in a channel just matches the sequent depth (Y_2) as the jump changes from supercritical to subcritical flow (Case B). Because the sequent jump depth depends only on the unit discharge over the weir and the plunging nappe depth, but the tailwater depth depends on open channel flow hydraulics, jumps may be pushed downstream for low tailwater conditions ($Y_2 > Y_T$), finally reaching a point where the sequent and local tailwater depths match (Case A). For relatively high tailwater conditions ($Y_T > Y_2$) the jump may be forced upstream against the weir, thus forming a mildly submerged jump (Case C). The principles of momentum and specific force would determine the location of the jump in cases A and B as described by Bélanger (Chow, 1959). At flood conditions, for a combination of very high flows and high tailwater ($Y_T >> Y_2$), the weir and overflow nappe become fully immersed and the jump is wiped out, resulting in only undulating surface conditions (Case D).

Figure 1. Photo by Mary Chind, Copyright 2009, The Des Moines Register and Tribune Company. Reprinted with permission.

When the jump is submerged (Case C), the smooth-looking nappe plunges vertically into a deceptively quiescent tailwater surface. A strong underwater rotating current begins at the front of the plunging nappe. The underwater vortex formed by the submerged hydraulic jump is called a “hydraulic” by many kayakers and canoers. Case C, the most dangerous condition, is called a drowning machine because the rotating vortex can easily trap victims by forcing them downward at the overflow and keeping them circulating, first by downstream-directed underwater current and then by the relentless reversed surface countercurrent, until they become exhausted and drown. Because the plunging nappe entrains air, the rotating water becomes less dense and buoyancy is reduced, thus making it difficult for one to remain afloat. Reversed underwater currents that continuously pull objects back toward the overfall lower the chances of surviving.

The other three jump conditions usually do not represent the danger to people that Case C presents. For example, Case A occurs at low flows, accompanied by low velocities, low depths, and normally non-dangerous currents below a dam. Case B occurs for moderate flows that produce optimum jumps, high energy dissipation, and frothy water, but only localized turbulence. While Case D occurs for very high flows, this condition is not dangerous because the dam and overflow nappe are completely submerged and the hydraulic jump, together with entrapping countercurrents, is eliminated.

A submerged hydraulic jump occurs when the local tailwater depth (Y_T) in the channel exceeds the jump’s subcritical sequent depth (Y_2), a condition that often forms at low-head dam structures. Leutheusser and Fan (2001) described the submerged jump process

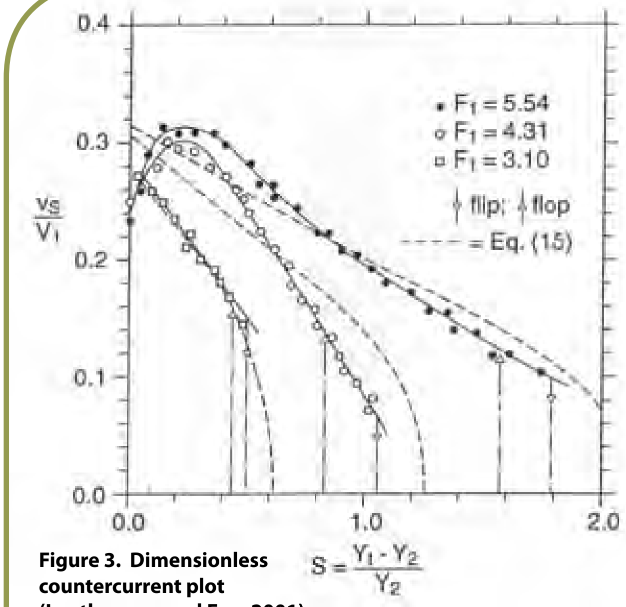

Figure 3. Dimensionless countercurrent plot (Leutheusser and Fan, 2001)

and reversed surface velocity characteristics of Case C based on results from their model tests as follows:

Once the jump is submerged, it becomes essentially a forced vortex featuring a significant upstream directed free-surface velocity. The velocity is highest for mild submergence where, for all hydraulic conditions, its magnitude is approximately one-third of the supercritical inflow velocity of the corresponding unsubmerged jump. The countercurrent velocity decreases with increasing submergence or tailwater depth, until it suddenly drops to zero. When this happens, the submerged nappe, moving along the channel bottom, suddenly "flips" to the free surface and, simultaneously, the vortex vanishes. The phenomena of nappe "flip" and its counterpart of nappe "flop," induced by a decrease of the tailwater depth, occur when the ratio of upstream depth (H_o) to tailwater depth (Y_T) is approximately 1.15 (Leutheusser and Fan 2001).

Leutheusser and Fan presented a dimensionless chart (Figure 3) for estimating the reversed surface velocity (V_s) as a function of its ratio to the supercritical inflow velocity, Vs/V_1, and a submergence factor $S = (Y_T - Y_2)/Y_2$, as defined by Roa and Rajaratnam (1963). Figure 3 shows that during each test, surface countercurrents (V_s) exist for a range of S from zero to a value where a rising tailwater and increasing S reach a critical point where the nappe flips (∇) to the free surface, the jump is drowned out, and the vortex vanishes simultaneously. At this point, a dangerous countercurrent surface velocity ceases to exist. On the other hand, a decreasing tailwater depth and lower S force the nappe to flop back (Δ), to begin to cause dangerous countercurrent conditions. In other words, a dangerous condition will always exist for S-values less than the flop (Δ) points for any Froude Number. The small range of S between flip and flop is explained in terms of incomplete ventilation of the nappe when the tailwater decreases. Important conclusions and findings from this work and other studies are as follows:

- In Figure 3, starting at about $V_s/V_1 = 0.25$ where $S = 0$, the test curves of different incoming Froude Numbers (F_1) peak at about $V_s/V_1 = 1/3$ at $S \approx 0.25$ to 0.30 and then drop gradually with increasing tailwater and S to their respective flip and flop points, which occur when the average tailwater depth (Y_T) to upstream depth (H_o) becomes approximately 1/1.15 or 87 percent.
- The longitudinal extent of the hydraulic zone, defined by the length of the zone of reversed surface velocity and countercurrent rotation, measured downstream from where the plunging nappe meets the tailwater, is between three and four weir or dam heights (Leutheusser and Birk,1991). Figure 4 shows this zone as CZ. The downstream end of the hydraulic zone is typically observed as a traverse band area across a channel called a "boil" (Figures 2C and 4) where the rotating current rises to the surface, marking a splitting point between upstream and downstream currents.

The dynamic impact force of the falling nappe is estimated to be "in the neighborhood" of 1.5 times the weight of a mature person (Leutheusser, 1988). This force can be estimated by applying the principle of impulse-momentum to falling water impacting a victim's body section

$$F = pAV^2$$

where F = force in pounds, ρ = mass density of water (62.4/g), A = cross-sectional body area (ft^2), and V = nappe overflow velocity (ft/sec) the point of impact.

Computed surface countercurrents (Vs) of up to 6 feet per second are easily achieved under certain overflow and tailwater conditions. Such velocities are difficult to overcome for victims who fall into the countercurrent zone, and they challenge even the most highly trained swimmers to escape the pull toward the overflowing nappe.

Example

A simple example applied to flow over a typical low-head dam illustrates the difficulties that a victim faces in the water under Case C conditions. Consider the situation shown in Figure 4.

Countercurrent surface velocity V_s can be estimated from the previous discussion. For example, assume that the height (P) of a low-head dam is 6 ft with water flowing over the crest at a head (H) of 2 ft. The tailwater depth for this flow is $Y_T = 4.1$ ft. The overflowing nappe produces an incoming supercritical flow depth (Y_1) to form a hydraulic jump. Characteristics of the initial conditions of the jump can be deduced from experimental data and dimensionless curve solutions of the weir nappe energy equations developed by Leutheusser and Fan (2001) for H/P = 0.333 as follows: Incoming Froude Number $\mathbf{F_1} = 4.75$, initial depth $Y_1 = 0.50$ ft, and initial velocity $V_1 = 19.1$ ft/sec. A form of Bélanger's momentum equation relates the initial and sequent depths, Y_1 and Y_2, to the incoming Froude Number $\mathbf{F_1}$ of a hydraulic jump as follows:

$$Y_2/Y_1 = 1/2[(1 + 8\mathbf{F_1}^2)^{1/2} - 1]$$

For this example, the subcritical depth after the jump is $Y_2 = 3.13$ ft. Note that the higher tailwater depth of 4.1 ft will thus force the jump upstream against the weir and cause it to be mildly submerged (Case C). The submergence ratio $S = (4.1 - 3.13)/3.13 = 0.3$ can be seen in Figure 3 to cause a maximum countercurrent velocity V_s/V_1 ratio equal to about 0.31 for $\mathbf{F_1} = 4.75$. Thus maximum surface velocity toward the dam is $V_s = V_1 [V_s/V_1] = 19.1(0.31) = 5.92$ ft/sec, or almost 6 ft/sec*.

**If the tailwater for this flow had risen to approximately 87 percent of the headwater depth Ho = 8 feet, or about 7 feet, S would increase to a critical "flip" point (approximately 1.2 in Figure 3) where the jump would be completely drowned out and would no longer produce dangerous countercurrents, as represented in Case D of Figure 2. It can also be demonstrated for this example that tailwater depths within the range, $3.3 < Y_T < 4.7$, would produce reversed current velocities in excess of 5 ft/sec.*

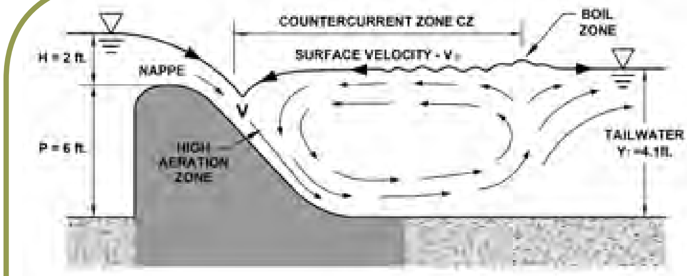

Figure 4. Schematic showing example of drowning machine elements.

In this example the length of the countercurrent zone (CZ) shown in Figure 4 would be 3 to 4 dam heights long, or about 18 to 24 feet. Any floating body or object within this zone would be pulled back toward the dam and its overflow at about 6 ft/sec. Most struggling victims caught in the middle of a wide channel or river would find it difficult or impossible to avoid being pulled back to the overflow.

Reports of canoers and kayakers being pulled back to the falling nappe and capsizing are common. Stalled boaters, including rescuers, have fallen victim to the same countercurrents and capsized upon reaching the overflow. Once struggling victims reach the nappe, they experience a dynamic force falling over their head and torso areas, forcing them downward into the circulating current. In the above example, if a victim is positioned under the falling nappe at a point represented by "**V**" in Figure 4, the downward force (F) from the penetrating water is estimated to be $F = \rho AV^2 = (1.935)(.81)(15)^2 = 350$ lbs, assuming a traverse surface area of 750 cm^2 (0.81 ft^2) for an average male body cross-section (Leutheusser, 1988) and an overflow velocity of 15 ft/sec at an overfall distance of 3.9 ft, based on Rouse's nappe profile measurements (Rouse, 1950). This downward force is approximately double the weight of most adult males and capable of pushing the victim downward into the circulating current.

Where dams and waterways are not marked with warnings, boaters are often unaware of, or do not appreciate, the potentially extreme forces and vortices at low-head dams and, for different reasons, unwittingly or purposefully glide over a seemingly innocuous overfall, capsize in the falling water, get trapped in the hydraulic or "keeper," and drown in the strong circulating currents. The downstream turbulence, accompanied by high aeration as evidenced by foaming or "whitewater" conditions, decreases the water density and therefore the buoyancy of objects by as much as twenty to thirty percent, causing personal flotation devices or lifesavers to be less effective and making it hard for even a neutrally buoyant victim to stay afloat (Wright, 2008). Heavy logs and other debris trapped in the hydraulic maintain a strong rotating pattern and create an additional hazard to already helpless, panicking, quickly tiring and disoriented victims. A kayaker who drowned in 2000 was reported to have been stripped of his life vest in the swirling waters below a low-head dam on the Musconetcong River in New Jersey (Meyer, 2000). Temperature of the water is often cool enough to add hypothermia to the mix of life-threatening hazards. Adding to all of these is the dynamic force of the water dropping over the dam that can exert hundreds of pounds on a person's body.

In summary, the hydraulic forces in conjunction with the factors described above combine to create what has been described as a nearly perfect drowning machine.

III. Case Study: Island Farm Weir Dam, Somerset County, New Jersey

Island Farm Weir Dam was constructed across the Raritan River, as shown in Figure 5, in 1995 to raise the water level to improve water supply drafting during low flow conditions. The Raritan River is classified by New Jersey as being suitable for recreational uses, including boating. No warning signs had been installed on the landings for boaters or other water users. On April 12, 1996, a canoer who had paddled over the dam crest and through the hydraulic was drowned in the recirculation flow of the reverse roller while attempting to rescue a comrade who had gone over the dam in his kayak and capsized. The kayaker and another person in the canoe eventually made it out with the help of a fisherman, but the victim's body was never found. The river discharge on this date was estimated to be about 2,000 cfs over the 200-foot-long, 8-foot-high, ogee-shaped low-head dam.

Hydraulic analysis shows that for a tailwater depth of 7.6 feet and a head of 2.4 ft over the 8-ft high dam, the Froude Number, initial hydraulic jump depth, and incoming velocity of the submerged jump were about 5.0, 0.6 ft, and 21 ft/sec, respectively. These conditions are capable of producing a sequent jump depth of about 4 ft and a tailwater submergence, $S \approx 0.9$. For this degree of submergence and surface water drop over the dam of only 2.8 feet, the reversed surface velocity toward the dam was almost 5 ft/sec. The length of the countercurrent velocity zone between the overflowing nappe and "boil" point is estimated to have been between 25 and 35 feet, or approximately 30 feet.

Figure 6 illustrates the dam and hydraulic characteristics at the time of the drowning. The strength of the countercurrent and overpowering nappe force, estimated at about 260 lbs, was apparently enough to drive the victim downward, entrap him, and ultimately cause his death.

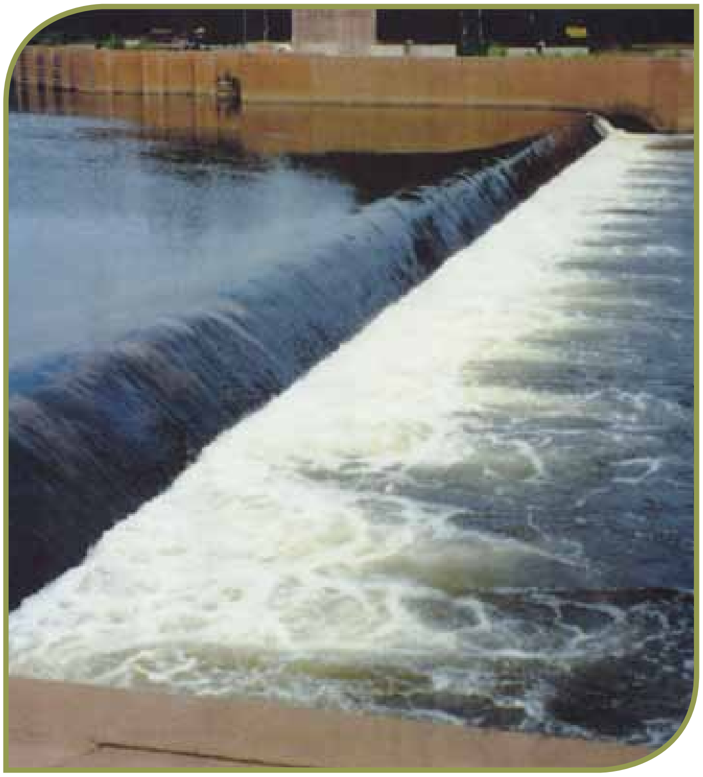

Figure 5. Original Island Farm Weir

ISSN 1944-9836 - Association of State Dam Safety Officials

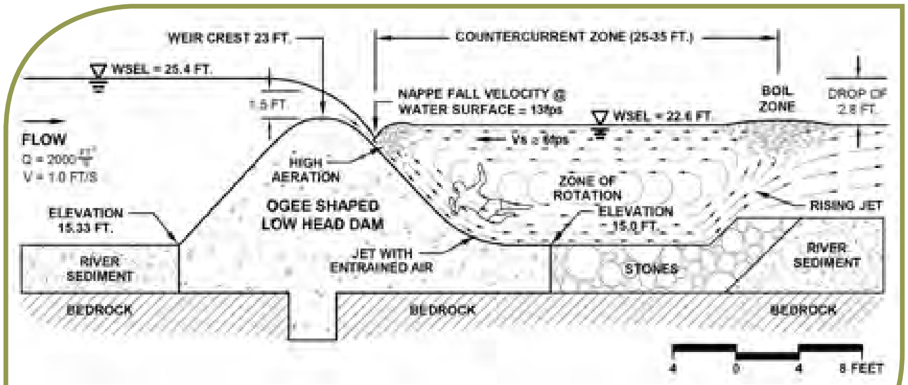

Figure 6. Island Farm Weir - Conditions on April 12, 1996. Adapted from Wright Water Engineers, Inc. (Wright, Andrews and Kelly, 2003)

A month after the drowning incident, during similar flow conditions, a jet skier attempted to travel up the overflow nappe of the dam, but fell off the ski, was trapped, and had to be rescued with a line-gun rope. In October 1996, a local television station camera crew visited the Island Farm Weir dam to film a story on high flooding during a storm event. While they were filming, a canoer unexpectedly paddled over the dam crest. He capsized against the nappe and fell into the water, and, as the victim and his canoe bobbed up and down, the whole episode of the victim's drowning was captured on tape for viewers of the evening TV newscast. The victim's body was found a week later.

The Island Farm Weir was modified in 1998 after four drownings and three near-drownings in only three years following its construction. The successful retrofit consisted of providing a series of steps on the downstream face (Figure 7) to dissipate energy and to eliminate the opportunity for a submerged jump and reverse roller to form below the dam structure.

Figure 7. Island Farm Weir stepped spillway modification.

IV. A National Problem

While accidents and drownings at low-head dams are reported regularly in the local and national media, little statistical data is available to assess the full national extent of the problem. Minnesota's Boat and Water Safety Section of the Department of Natural Resources reports 52 deaths and 50 injured or rescued people at low-head dams in that state between 1974 and 2002 (Minn., 2003). In Illinois, the Fox River has a notoriously dangerous segment of 15 dams in the 115-mile reach, just west of Chicago, between Wisconsin and its mouth at the Illinois River. At the 7-foot high Yorkville Dam (Figure 8), at least 12 people are reported to have drowned since it was rebuilt in 1960. Drayton Dam on the Red River in Minnesota claimed 12 lives between 1965 and 1995. On-going study by Tschantz of documented news articles and other data sources from 1970 through July 2010 reveals 155 injury and/or death related incidents at low-head dams in 30 states. In these incidents, there have been at least 48 injuries and 191 drowning deaths. These figures exclude 12 deaths reported at Drayton Dam on the Red River since being constructed in 1964. One hundred eight, or 57%, of 191 documented drowning deaths have occurred since 2000, as indicated in Figure 9.

Documented information shows that of the 191 drownings, use or non-use of personal flotation devices (PFDs) was known for only 56 victims. However, use of PFDs didn't appear to make a difference in the outcome: 28 were known to have worn PFDs and 28 were known to have not worn PFDs. Similarly, of 97 people who drowned after going over the dam, 18 were reported to have worn PFDs, while 19 were known to be without one. Reasons for the close split may be because PFDs often get torn off in the hydraulic turmoil, buoyancy is greatly reduced in highly aerated waters, and PFDs may become snagged on underwater objects.

The distribution of the drownings and injuries from low-head dam accidents across the country is shown in Figure 10.

Paddle sports and other water-based recreational activities have dramatically increased in popularity over the past twenty years. The American Canoe Association reported that about 50 million Americans participated in canoeing, kayaking and other paddle sports in 2002, and that watercraft recreation is expected to increase (Donahue and Earles, 2003). Paddler Magazine (May/June 2008) recently featured an article, "The Drowning Machines," where several examples of drownings around the country are discussed. However, as accidents continue to occur, it has become apparent that the special hazards created by low-head dams to boaters and other water users have fallen through the cracks of attention between the state dam safety and the boating safety communities.

Figure 8. Yorkville Dam on the Fox River.

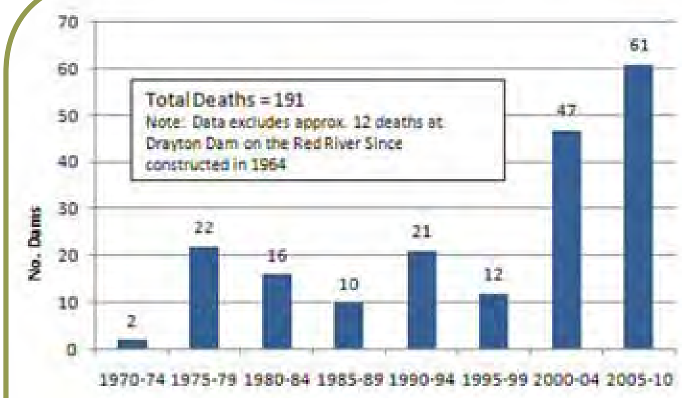

Figure 9. Documented Drownings at Low-head Dams in U. S. (1970 - July 2010).

Most states do not regulate the design, operation or safety of low-head, or run-of-the-river, dams because of their small heights and/or impounding capacities and low hazard potential to downstream property or life in event of failure. States tend to focus primarily on design, construction and operation of safe structures. Not surprisingly, over the last 30 to 40 years since the Buffalo Creek disaster and the failures of Teton and Toccoa Falls dams, warranted emphasis has been given by the dam safety community on preventing dam failures and protecting the public should failure occur. Considerable resources have been expended to inventory and classify dams, remediate or remove unsafe dams, promote owner responsibility, develop and improve dam safety technology, postulate the occurrence of failures and promote emergency action plans, and generally regulate the structural safety of dams. However, there are inherent residual hazards associated with safe dam and spillway structures that many design engineers tend to overlook. One paper presented at the 1988 ASCE National Conference on Hydraulic Engineering emphasizes this oversight in its title: "Dam Safety, Yes, But What About Safety at Dams?" (Leutheusser, 1988). In his paper, the author captures the irony of emphasis on structural safety at the expense of other public safety needs:

> Hydraulic engineers by their very calling are aware of the forces associated with the motion of water. Indeed, it is the containment and control of these forces which render their profession so very challenging and satisfying....
> [L]arge amounts of energy are released and dissipated, under fully exposed conditions, in structurally safe weir-and-stilling-basin assemblies. While the environmental dangers associated with these flow processes are well respected by hydraulic engineers, they are less so by the general public, and serious accidents may be the consequence.

All hydropower dams licensed by the FERC, including low-head types, are required to have a public safety plan that includes appropriate warning signs and other safety devices to protect swimmers, boaters and fishermen. However, in a survey of state dam safety programs, only a handful (KY, LA, MA, PA, & WI) of 42 responding states indicated a requirement that some type of warnings or buoys be placed near certain low-head dams (ASDSO, 2000). Some states (IN, IA, MN, & OH) said they recommend or encourage owners to post signs near dams. Pennsylvania, following several drownings at low-head dams, enacted its 1998 Act 91 (P.L. 702) requiring notified owners of low-head, run-of-the-river dams to warn the swimming, fishing and boating public of the hazards posed by such dams by marking upstream/downstream exclusion zones with warning zone signs and other specified markers. Pennsylvania's dam safety program is responsible for inventory and notification activities, and the Fish and Boat Commission is responsible for establishing and enforcing sign and warning regulations at such dams. In Ohio, after a rash of drownings, legislation was introduced in 2004 to require owners of low-head dams to install warning signs and buoys. The proposed bill failed after an ill-advised amendment, opposed by the Ohio Department of Natural Resources (ODNR), was added requiring that gates be locked at public boat ramps during dangerous water conditions.

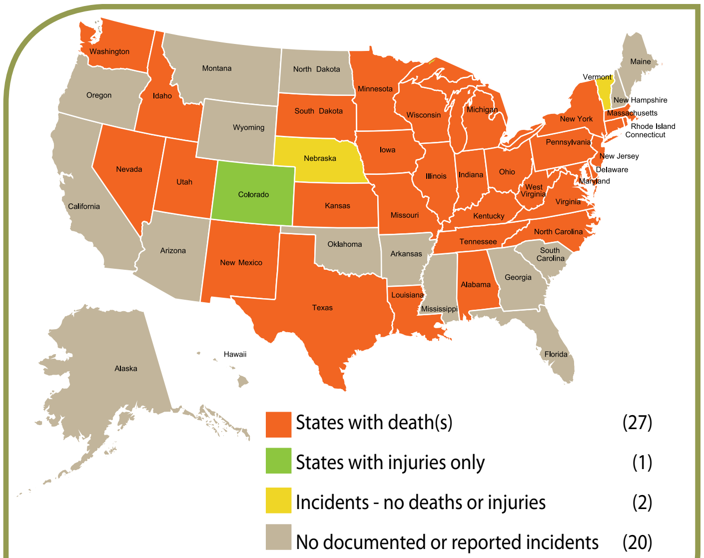

Figure 10. State distribution of known drownings and injuries at low-head dams 1970 - July 2010.

In a 2004 survey of state boating law administrators, through the National Association of State Boating Law Administrators (NASBLA), an organization of state officials responsible for administering and/or enforcing state boating laws, only three states (FL, PA, SC) were reported to have warning sign posting requirements at low-head dams, with only Pennsylvania and South Carolina having sign posting laws to mark hazardous conditions and prohibited access to dams (Tschantz, 2004).

More recently, Virginia enacted permissive legislation (effective January 2008), following a series of drownings, *allowing* owners of low-head dams to use signs and buoys to warn the public of the hazards of swimming, fishing, and boating activities near low-head dams. According to the Act, "Any owner of a low-head dam *may* mark the areas above and below the dam and on the banks immediately adjacent to the dam with signs and buoys of a design and content to warn the swimming, fishing, and boating public of the hazards posed by the dam. Any owner of a low-head dam who marks a low-head dam in accordance with this subsection shall be deemed to have met the duty of care for warning the public of the hazards posed by the dam. Any owner of a low-head dam who fails to mark a low-head dam in accordance with this subsection shall be presumed not to have met the duty of care for warning the public of the hazards posed by the dam" (Virginia, 2007). The original bill was amended shortly before becoming law by substituting weaker language ("may" for "shall") thus *permitting*–rather than *requiring*–owners to mark areas around a low-head dam. However, duty of care remains an important established force.

In April 2008, Iowa enacted a low-head dam public hazard program for establishing a low-head dam public safety program. The program includes compiling an inventory of low-head dams for purposes of publicizing hazards through maps and warning signage, recommending design templates to reduce drowning, developing criteria for removal, and establishing a prioritizing system for funding removal and hazard reductions (Iowa, 2008).

Clearly, the problem of drownings at low-head dams in the U.S. is widespread and growing. More state regulatory programs are needed to reduce the danger to the public.

V. Proposed Measures to Reduce Drownings

As the number of people attracted to water recreational opportunities increases, water-related accidents and deaths are inevitable, but engineers, state and federal officials, boating safety organizations, and recreational watercraft organizations need to work together to reduce or eliminate the environmental hazards at low-head dams. A five-step approach is proposed to reduce the risk to the public from dangerous conditions at low-head dams:

Miami Conservancy District (2011)

1. **Public awareness programs** that promote safety education and cognizance of the potential dangers at low-head dams. These programs would require the cooperation of several communities: the boating public, including national canoeing, rafting, kayaking and boating organizations; local clubs; design engineers; dam owners; public officials, including legislators and local, state and federal regulators; and boating safety and boating law administrator organizations to better educate swimmers and watercraft users. The Internet, print media, television, videotapes, CD/DVDs, workshops, and schools offer unlimited opportunities for reaching and educating the public about the dangers around dams. This effort presupposes the need to thoroughly understand the extent of the problem—identifying potential hazards and evaluating risks—on a state-by-state basis in order to put the issue into perspective and to prioritize the needs. Specific target audiences and potential organizations for promoting education and awareness need to be identified. Materials such as boating safety information and training videos, CDs, brochures such as distributed by the Minnesota DNR and the Miami Conservancy District (2011), maps showing low-head dams, public service announcements, on-line courses, and websites need to be inventoried to determine what is already available, what works, and what remains to be developed in order to promote effective educational programs.

Minn. Dept. of Nat. Resources (2008)

2. **Warning markers and effective legislation and regulation** at the state level requiring dam owners to install appropriate warning signs and buoys, escape, portage, safety and other devices at low-head dams. It is essential, from a public safety standpoint,

Pa. Dept. of Env. Prot.


WILL YOUR DAM OR LEVEE PERFORM WHEN IT'S NEEDED MOST?
JUST ASK GOLDER.

We provide engineering solutions from the ground up. As one of the world's leaders in the planning, permitting, and design of dams, reservoirs, and outlets works, we provide a complete spectrum of services. Whether it's investigating dam sites, designing diversion tunnels, or evaluating, upgrading, and rehabilitating older dams and levees, you can count on Golder.

A World of Capabilities Delivered Locally.

Atlanta Headquarters: 1.800.275.3281
www.golder.com

Golder Associates

that dams be marked to warn the public of their existence and potential hazard, especially as a result of changing flow conditions (Schweiger, 2006). All low-head dams should be inventoried and periodically monitored and inspected for safety compliance. Hazardous dams with a history of accidents should be identified and receive priority for warning and protecting the public. Existing state legislation and regulations related to public safety requirements at low-head dams should be researched, and model legislation and regulations should be developed. FERC guidelines and standards for safety signage, public safety, and warning systems at hydropower projects have provided a template for many other federal agencies to develop their own guidelines (FERC, 1992, 2001).

3. **Structural modification** of low-head dams. The physical hazard to boaters, fishermen, and swimmers around and below low-head dams needs to be reduced or eliminated wherever practical, given the reality of technical, legal, environmental, and financial constraints. A technical manual should be developed for design engineers to stimulate a range of practical alternatives such as full or partial dam removal; use of engineered structures like stepped spillways, gabion baskets, flat slopes, cascading pools, or dumped rock to dissipate energy and eliminate the hydraulic; chutes to accommodate boaters; and portage ways for boaters to safely bypass a dam. Ohio's dam safety program (Ohio, 2011) and the Heinz Center (2002) have developed excellent low-head dam removal frameworks for decision making and to discuss issues to consider prior to removing dams.

Minn. DNR Fast Water Rescue School demonstration.
Photo by Tim Smalley, Minn. DNR.

4. **Rescue training** programs to help state and local water rescue professionals understand and respond to the special hazards created at low-head dams. Many rescue personnel have died attempting to save others trapped inside a reversed current below low-head dams. The Boat and Water Section of the Minnesota Department of Natural Resources has a study guide and three training videos for Minnesota-based organizations that review conditions and rescue techniques at fast-water and low-head dams, including one called "The Drowning Machine" (Minnesota DNR, 1997). ASDSO, NASBLA, federal agencies, and the various national watercraft safety organizations should form a "core" team to coordinate the development of a standard state training program, perhaps modeled after Minnesota's program.

5. **Develop comprehensive national guidelines for public safety** at dams for identifying potential hazards and evaluating risks; changing operating practices; installing standardized warning systems, signage and safety controls; developing site-specific public safety plans and inspection and maintenance programs; and developing a continual review and improvement process for dam owners and operators, design engineers, and other stakeholders. The guidelines would also include some of the elements discussed above in steps 1 - 4.

The Canadian Dam Association (CDA) has drafted a manual, "Guideline for Public Safety Around Dams" and supporting technical bulletin, "Public Safety Signage Around Dams." (CDA, 2009). The CDA recognizes that an important aspect of dam safety management is protecting the public from hazards associated with the operations of dams throughout their lifecycle, particularly when spilling water or under rapidly changing flow conditions during power generation. Such thinking goes beyond the traditional interpretation of "dam safety" as being primarily concerned with protecting the public from catastrophic failure triggered by extreme events. The guideline recognizes that dam facilities may create dangerous hydraulic conditions–even for small unregulated low-head dams. The guideline outlines a comprehensive public safety plan for reducing or eliminating hazards at dams. The plan includes a systematic management approach for identifying hazards associated with the site, assessing the degree of public interaction around dams, establishing dam owner accountability, identifying measures for mitigating the hazard, installing physical barriers and warning systems, educating the public of the hazard, providing for emergency response, and reporting incidents. The guideline draft, currently undergoing discussion, presents an effective approach and template to the US dam safety community in developing responsible public safety programs around dams.

The US dam safety community would do well to follow Canada's example in developing comprehensive guidelines and standards for public safety to minimize the public risk around dams–especially for the unique low-head type. As it is now, hundreds and possibly thousands of low-head dams in this country expose water users to dangerous hydraulic conditions. As water recreation increases, a long-term effort by dam owners to structurally reduce or eliminate the hazard should be complemented by immediate measures by owners for warning the public and by state-wide programs for raising public awareness. States, acting through cooperation among all affected agencies involved with dam safety, boating safety, and recreation, need to inventory their low-head dams, assess their hazard, and begin to take action to save lives from this hidden menace by adopting effective legislation and regulation.

References Cited:

Allen, David (Dam Safety Program Manager) and Nate Hoogeveen (Water Trails Coordinator), telephone conversations on Iowa low-head dam inventories and estimates, Iowa Dept. of Natural Resources, Des Moines, February 28, 2008.

ASDSO, Annual Survey of State Dam Safety Programs response to question, "Does your state require posting of warning or barriers near low-head dams? Please describe or provide citation," September 2000.

Borland-Coogan, Filmspace Productions, *The Drowning Machine* (video), 1980.

Canadian Dam Association (CDA), *Guideline for Public Safety Around Dams* (DRAFT), scheduled for completion in mid-2009.

Chow, Ven Te., *Open Channel Hydraulics*, McGraw-Hill, Inc., Chapters 3 & 15, 1959.

Donahue, M. G. and T. A. Earles, *Recreational Use Considerations in Planning and Permitting Low Head Dams*, Proceedings, Dam Safety 2003, Annual Conference Proceedings (CD), Minneapolis, MN, Sept. 7-10, 2003, Association of State Dam Safety Officials (ASDSO), 7 pp.

Federal Energy Regulatory Commission (FERC), *Guidelines for Public Safety at Hydropower Projects*, Div. of Dam Safety and Inspections, March 1992, 21 pp. + 6 appdcs.

Federal Energy Regulatory Commission (FERC), *Safety Signage at Hydropower Projects*, Div. of Dam Safety and Inspections, October 2001, 43 pp.

Heinz Center for Science, Economics and the Environment, *Dam Removal, Science and Decision-making*, 2002, 221 pp.

Iowa Senate File 2380, Act for *Establishing a Low Head Dam Public Hazard Program*, legislation signed by Gov. Culver, April 11, 2008.

Leutheusser, H. J., and J. J. Fan, *Backward Flow Velocities of Submerged Hydraulic Jumps*, ASCE, J. or Hydraulic Engr., June 2001, pp. 514-17.

Leutheusser, H. J., *Dam Safety Yes, But What About Safety at Dams?*, Proceedings, 1988 National Conference, ASCE, Hyd. Div., Colorado Springs, CO, August 8-12, 1988, pp, 1091-96.

Meyer, Z., Suburban Philadelphia Inquirer article, *Missing Bucks Man is Feared Dead in Kayak Accident*, August 20, 2000.

Miami Conservancy District, *The Great Miami River - Play It Safe*, Boating Map & Guide; brochure, videos for safety at low-head dams, 2011 (see low dams at www.miamiconservancy.org).

Minnesota Dept. of Natural Resources (DNR), Boat and Water Safety Section, Boat & Water Safety Brochure: *The Drowning Machine (Kim Elverum, Tim Smalley,2008);* 3 videos: *Water Rescue (#387), Water: the Timeless Compound (#150),* and *The Drowning Machine (#172),* St. Paul.

Minnesota Department of Natural Resources, Boat and Water Safety Section, *1974-2002 Dam-Related Accidents*, Spreadsheet data table of 63 accidents provided to author, 3 pages, 2003.

Ohio Dept. of Natural Resources, Division of Water, Low Head Dam Inventory and Removal Program, Framework website (2011): http://www.dnr.state.oh.us/water/tabid/3357/Default.aspx

Paddler Magazine, *The Drowning Machines*, article by Christian Knight, May/June 2008. pp. 46-53.

Rouse, J., Editor, *Engineering Hydraulics*, Chapter VIII, Section 10, 1950.

Schweiger, P. and M. Morrison, Saving Lives at *"Killer Dams," Improving Public Safety at Low Head Dams*, Annual ASDSO Conference Dam Safety 2006 Proceedings, Boston, Mass, Sept. 10-14, 2006.

Tschantz, B. A., *The Hazards of Low-Head Dams: (How) Can We Make Them Safer?,* Annual Conference Proceedings (Abstract), National Association of State Boating Law Administrators (NASBLA), Chattanooga, TN, Sept. 11-15, 2004, p. 18.

U. S. Army Corps of Engineers, 2009 National Inventory of Dams (NID), EP 360-1-23, July 2010.

Virginia Acts of Assembly, 2007 Session, Chapter 664, An Act to amend and reenact § 29.1-509 of the Code of Virginia, *Duty of care and liability for damages of landowners to hunters, fishermen, sightseers, etc., relating to Low-head Dams*, Effective Jan. 1, 2008, Approved and signed by Gov. Kaine, March 20, 2007.

Wright, K. R., T. A. Earles and J.M. Kelly, *Public Safety at Low-Head Dams*, Proceedings, Dam Safety 2003, Annual Conference Proceedings, Minneapolis, MN, Sept. 7-10, 2003, Association of State Dam Safety Officials (ASDSO), 14 pp.

Wright, K. R., Earles, T. A. and B. A. Tschantz, telephone discussion, March 3, 2008. ≋

Bruce A. Tschantz, PE
Professor Emeritus
University of Tennessee
1508 Meeting House Road
Knoxville, TN 37931

865/531-5624

btschant@utk.edu

Bruce A. Tschantz, PE, is Professor Emeritus in the University of Tennessee's Civil and Environmental Engineering Department, where he taught water resources engineering for 37 years. Dr. Tschantz is currently a senior research associate for the Tennessee Water Resources Research Center and a consulting engineer in Knoxville. He established FEMA's Office of Federal Dam Safety where he served as the first Chief of Federal Dam Safety in 1980. Dr. Tschantz has made many presentations and written several articles on the hydraulics of and public safety at low head dams. He is an Honorary Member in ASDSO, an ASCE Fellow, and is a registered engineer in Tennessee, Ohio, Virginia and Alabama.

Kenneth R. Wright, PE
CFO and Chief Engineer
Wright Water Engineers
2490 West 26th Avenue,
Suite 100A\
Denver, CO 80211

303/480-1700

krw@wrightwater.com

Kenneth R. Wright, PE, is chief engineer and founder of Wright Water Engineers, Inc., Denver, Colorado. Mr. Wright is a member of ASDSO, a Distinguished Member of ASCE and has authored several papers on low-head dams. Mr. Wright is a registered engineer in 14 states and a Diplomate of Water Resources Engineering through the American Academy of Water Resources Engineers. He received the Order of Merit for Distinguished Service to the Republic of Peru, and several academic awards for paleohydrologic research at Mesa Verde National Park and at the Peruvian archaeological sites of Machu Picchu, Tipon and Moray.