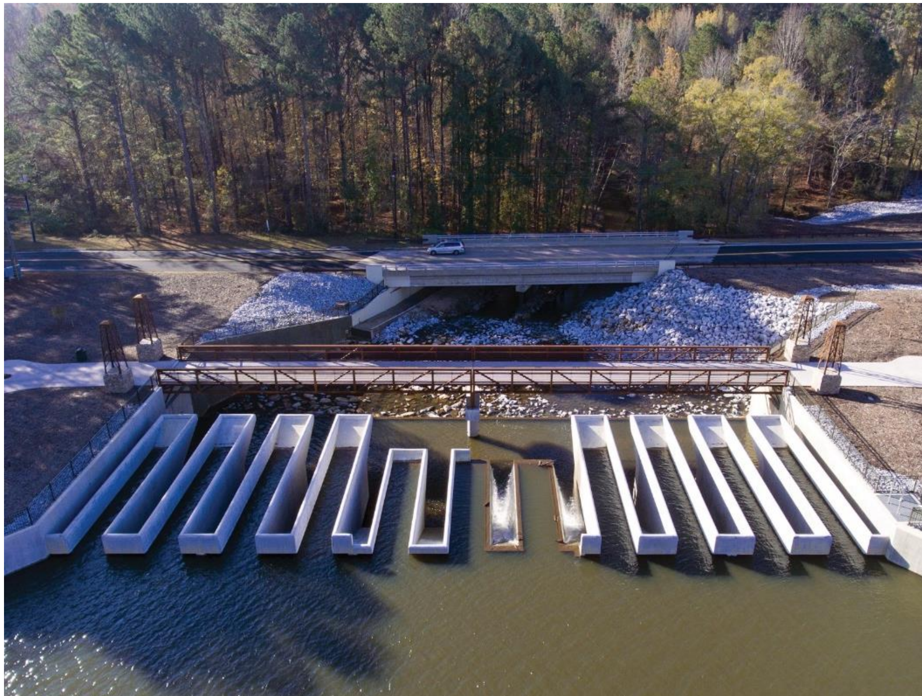
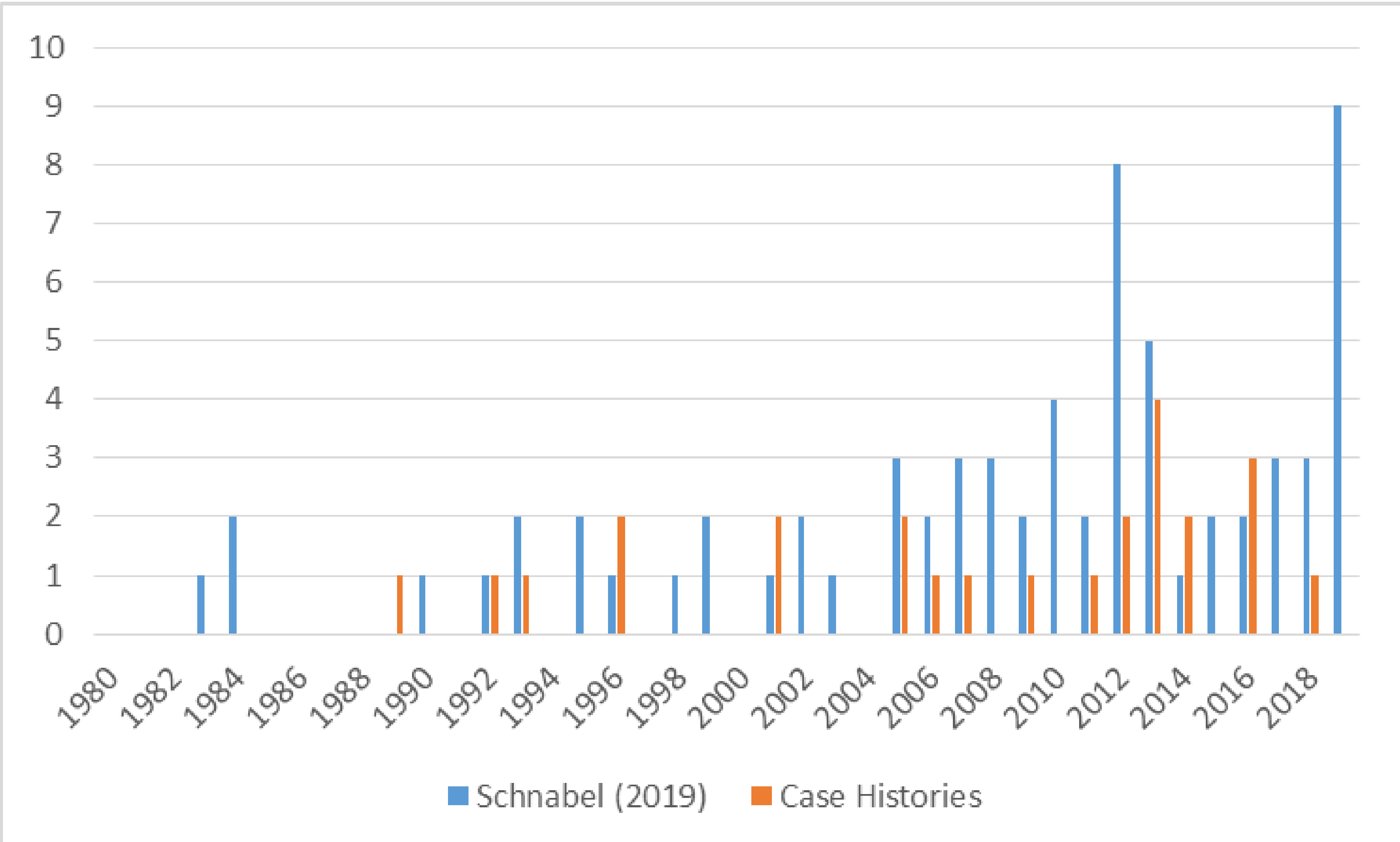

USA Experience



Labyrinth Spillways in USA

Labyrinth Spillways in USA



BALANCING SITE CONSIDERATIONS WITH HYDRAULIC EFFICIENCY FOR LABYRINTH SPILLWAYS

Greg S. Paxson, P.E.[1]
Joseph S. Monroe, P.E.[2]
Brian M. Crookston, Ph.D[3]
Dave Campbell, P.E.[4]

ABSTRACT

Labyrinth spillways are relatively common in the rehabilitation of dams that do not meet spillway design flood requirements. While hydraulically efficient (high discharge per unit width of spillway for a given head) designs are desirable, hydraulic optimization is not always prudent due to increased construction costs and site constraints. As designers, we acknowledge and accept a diminished hydraulic efficiency when the reduction is balanced against construction costs.

This paper presents a review of key geometric parameters related to the design of labyrinth weirs and describes how each parameter can impact construction cost and hydraulic performance. Several labyrinth spillway projects are highlighted to illustrate the influence of site conditions on the design.

While labyrinth spillways are hydraulically most efficient at low headwater ratios (H/P), it is common practice in design for the maximum H/P to be greater than 0.7 but less than 1.0, which approximates the limit of historic physical model data sets used in readily available publications. The results of recent hydraulic modeling have revealed that weirs with H/P ratios well above 1.0 can be used without significant incremental loss of hydraulic efficiency. Constructability and cost evaluations are also presented with regard to the impacts of nappe interference and disturbance length limits suggested by Falvey (2003). Applying these restrictions can lead to larger upstream-downstream dimensional requirements and larger sidewall angles. Similar cost evaluations are performed to consider cycle width (W/P) ratios lower than recommended by common design methods. While not as hydraulically efficient, high head labyrinths and compact plan-form labyrinths can meet hydraulic design criteria in many site settings at lower overall cost.

ICOLD 2013 (Seattle, USA)

Common Applications

Common Applications

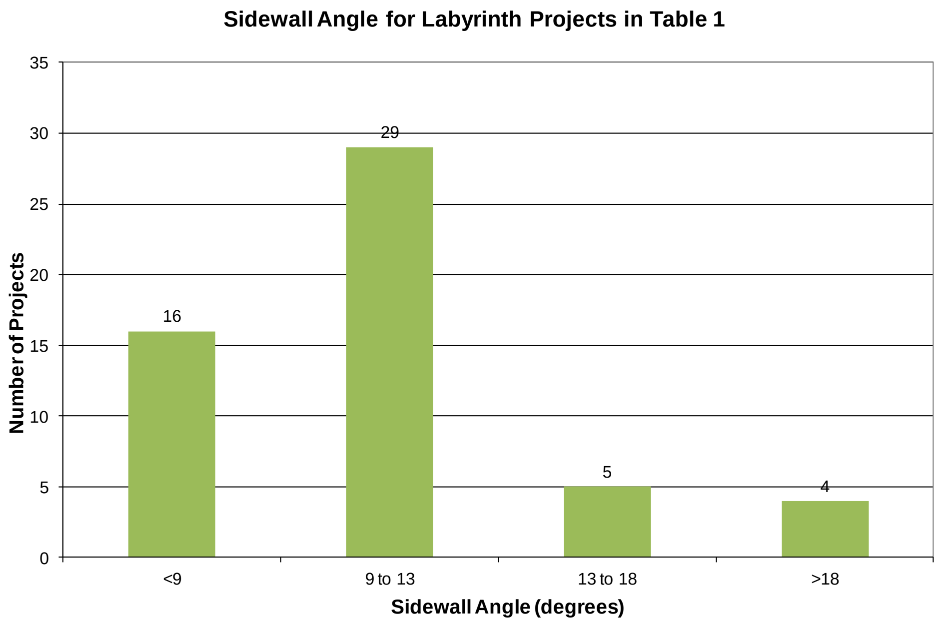
ID	Project Name	State	n	P (ft)	nxW (ft)	α	W/P	Max H/P
1	Roy F. Varner Reservoir Dam	GA	8	10	160	13.9	2.0	0.70
2	Dog River - original	GA	8	15	240	13.0	2.0	0.60
3	Lake Sovereign Dam	GA	2	5	50	12.6	5.0	0.80
4	Concourse Lake Dam	VA	2	10.9	24	10.5	1.1	0.32
5	Accord Pond Dam	MA	2	1.7	7	12.5	2.1	0.88
6	Hollis G Lathem Reservoir Dam	GA	3	15	90	12.6	2.0	0.53
7	Unicoi State Park Dam	GA	3	16	115	10.3	2.4	0.94
8	Whitewater Creek Dam	GA	12	13	360	13.3	2.3	0.31
9	Yahoola Creek Dam	GA	5	15	130	8.9	1.7	0.87
10	DRA Detention Structure[1]	GA	4	13.5	81	16.7	1.5	0.30
10	DRA Detention Structure[2]	GA	4	15.5	81	16.7	1.3	0.13
11	Waterford Lake Dam	NC	3	10	60	8.6	2.0	0.50
12	Lake Upchurch Dam	NC	6	12	120	8.6	1.7	0.42
13	Capital City Country Club Dam	GA	1	10.2	23	23.8	2.3	0.78
14	Pine Lake Dam	GA	2	7.5	30	6	2.0	0.53
15	Pye Lake Dam	GA	3	13	36	7.0	0.9	0.08
16	Dog River – raised	GA	8	25	240	12.2	1.2	0.36
17	Huntington Hills Dam	SC	3	12.5	78	9.7	2.1	0.15
18	Linville Land Harbor Dam[3]	NC	4	15	120	12.2	2.0	0.60
18	Linville Land Harbor Dam[3]	NC	4	19	120	12.2	1.6	0.47
19	Pine Run Dam[1]	PA	0.5	6	11	9.1	3.7	0.75
19	Pine Run Dam[2]	PA	3.5	7.9	77	9.1	2.8	0.33
20	Lake Townsend Dam[1]	NC	2	20	84	12.8	2.1	0.75
20	Lake Townsend Dam[2]	NC	5	21	210	12.8	2.0	0.67
21	Leaser Lake Dam[1]	PA	0.5	12	12.5	14.0	2.1	0.67
21	Leaser Lake Dam[2]	PA	1.5	13.5	37.5	12.3	1.9	0.79
22	Greystone Development Dam	GA	1	8	35	8.7	4.4	0.59
23	Indian Run Dam[1]	PA	0.5	9	16	10.9	3.6	0.89
23	Indian Run Dam[2]	PA	2	11.5	64	10.9	2.8	0.48
24	Upper Norton Dam	VA	3	10.5	63	12.1	2.0	0.43
25	Upper Owl Creek Dam[1]	PA	0.5	8.5	9.75	10.1	2.3	0.94

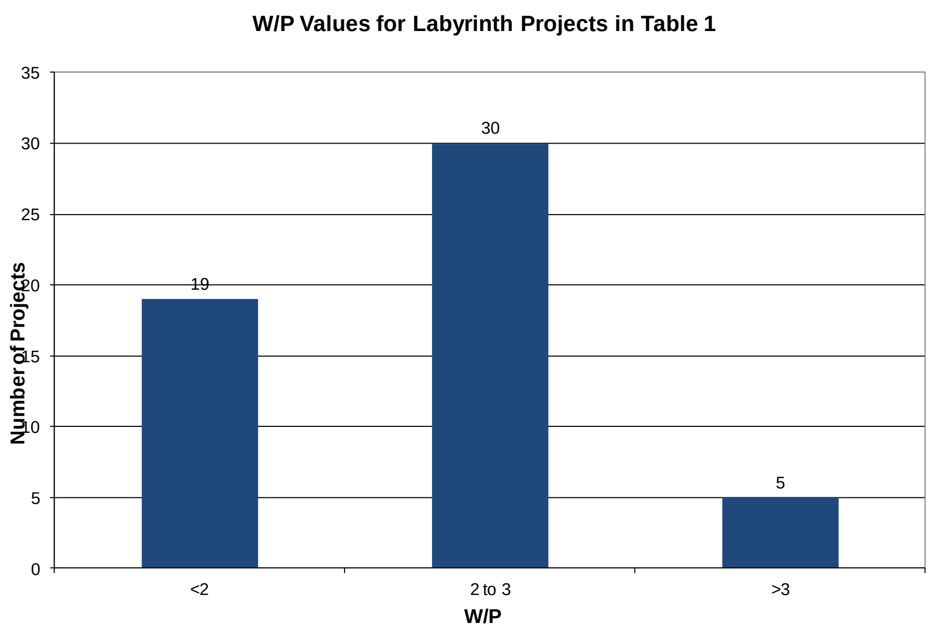
ID	Project Name	State	n	P (ft)	nxW (ft)	α	W/P	Max H/P
25	Upper Owl Creek Dam[1]	PA	0.5	8.5	9.75	10.1	2.3	0.94
25	Upper Owl Creek Dam[2]	PA	2.5	11	48.75	10.1	1.8	0.50
26	Lake Natalie Dam	GA	4	10.5	84	9.8	2.0	0.76
27	Charter Colony, LTC 20/25[1]	VA	0.3	10.7	3.54	7.0	1.1	0.36
27	Charter Colony, LTC 20/25[2]	VA	1.7	13.5	20.06	6.2	0.9	0.07
28	Kauffman Dam[1]	PA	0.5	5.5	9	8.6	3.3	0.91
28	Kauffman Dam[2]	PA	4.5	8	81	8.0	2.3	0.31
29	South River No. 29	GA	3	13	78	10.5	2.0	0.77
30	Tired Creek Dam	GA	3	13	78	9.0	2.0	0.72
31	Beaver Creek Dam	PA	30	6.25	300	10.1	1.6	0.96
32	Charter Colony, LTC 30	VA	4	12	72	8.8	1.5	0.28
33	Charter Colony, LTC 5	VA	2	12	37	8.2	1.5	0.23
34	Dees Pond Dam	GA	2	12	56	19.2	2.3	0.40
35	Ford Road Dam	GA	1	17.75	14	18.2	0.8	0.34
36	Hard Labor Creek Dam	GA	4	15	128	7.9	2.1	0.80
37	Lake Carroll Dam	GA	4	12	86	10.6	1.8	0.50
38	Long Island Drive	GA	1	12.75	13	18.4	1.0	0.47
39	Minsi Lake Dam[1]	PA	5	10	125	11.4	2.5	0.75
39	Minsi Lake Dam[2]	PA	5	12.5	125	11.8	2.0	0.44
40	Mountain Cove Dam	GA	1	8	22	7.7	2.8	0.63
41	Pilot Mountain State Park Dam	NC	2	8	17.5	8.8	1.1	0.50
42	South River No. 4	GA	2	13.5	54	10.3	2.0	0.78
43	Upper Dam	ME	4	14	112	10.4	2.0	0.28
44	Yellow River No. 3	GA	2	13	62	7.7	2.4	0.27

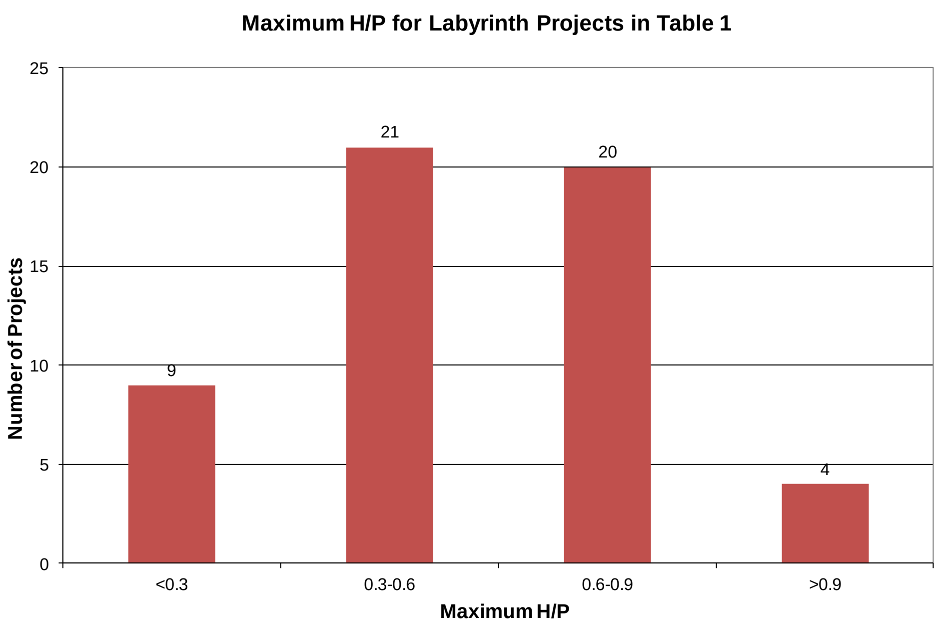
For each of the projects listed in Table 1, various alternative geometric layouts were evaluated for the authors. These figures summarize different geometric parameters selected for the projects in Table 1.

Through these designs, the authors have found the following general trends:

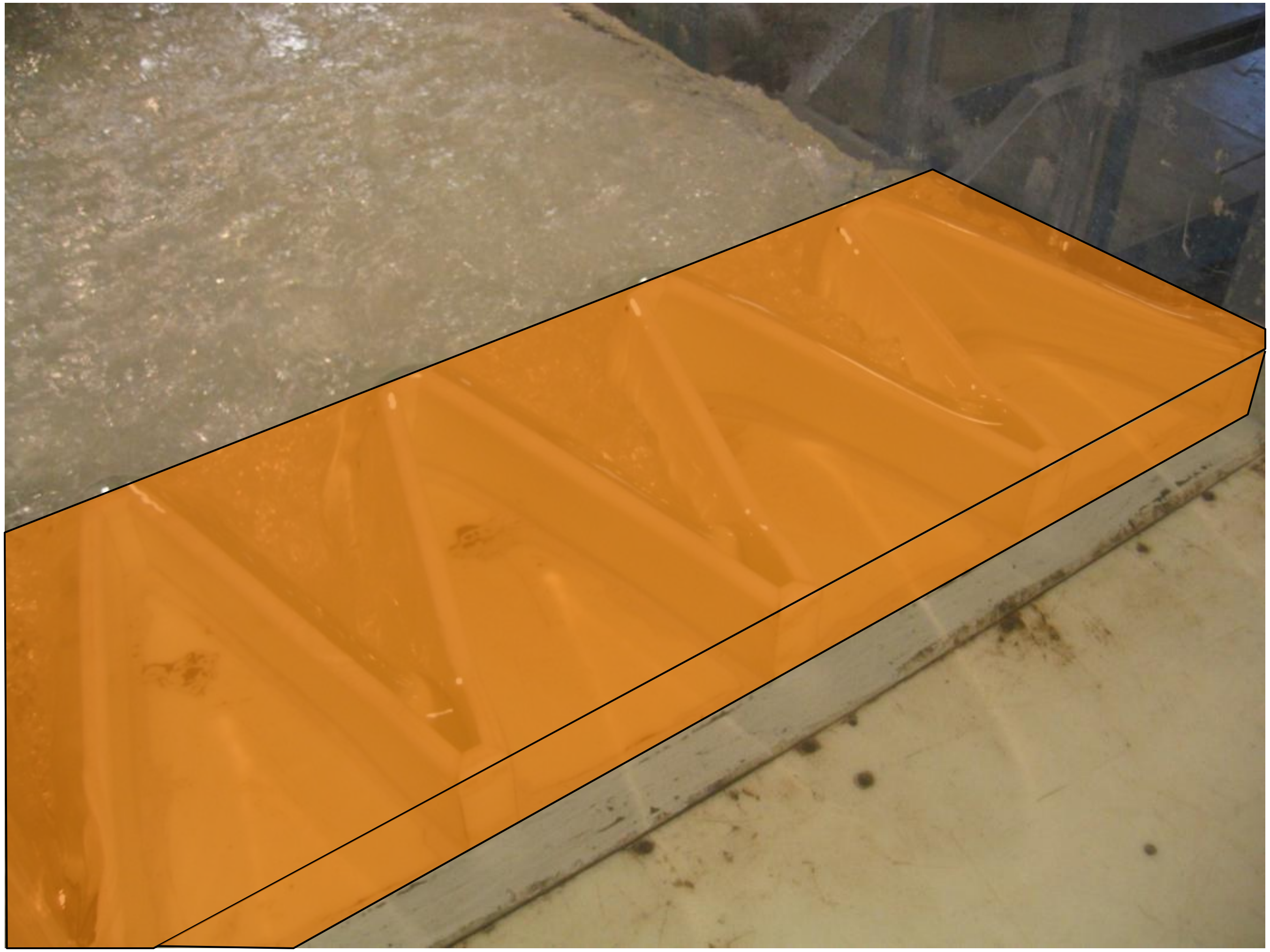
- Decreasing the sidewall angle typically reduces the total project cost.
- While lower W/P values generally result in less efficient hydraulic designs, lower W/P values have been found to result in more economical labyrinth spillways.
- For most projects, the designers have maximized the H/P ratio within the range of the design guidance.



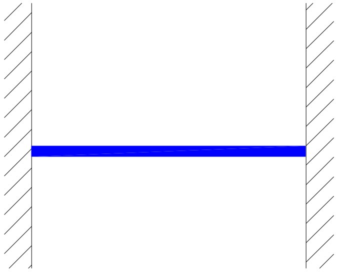


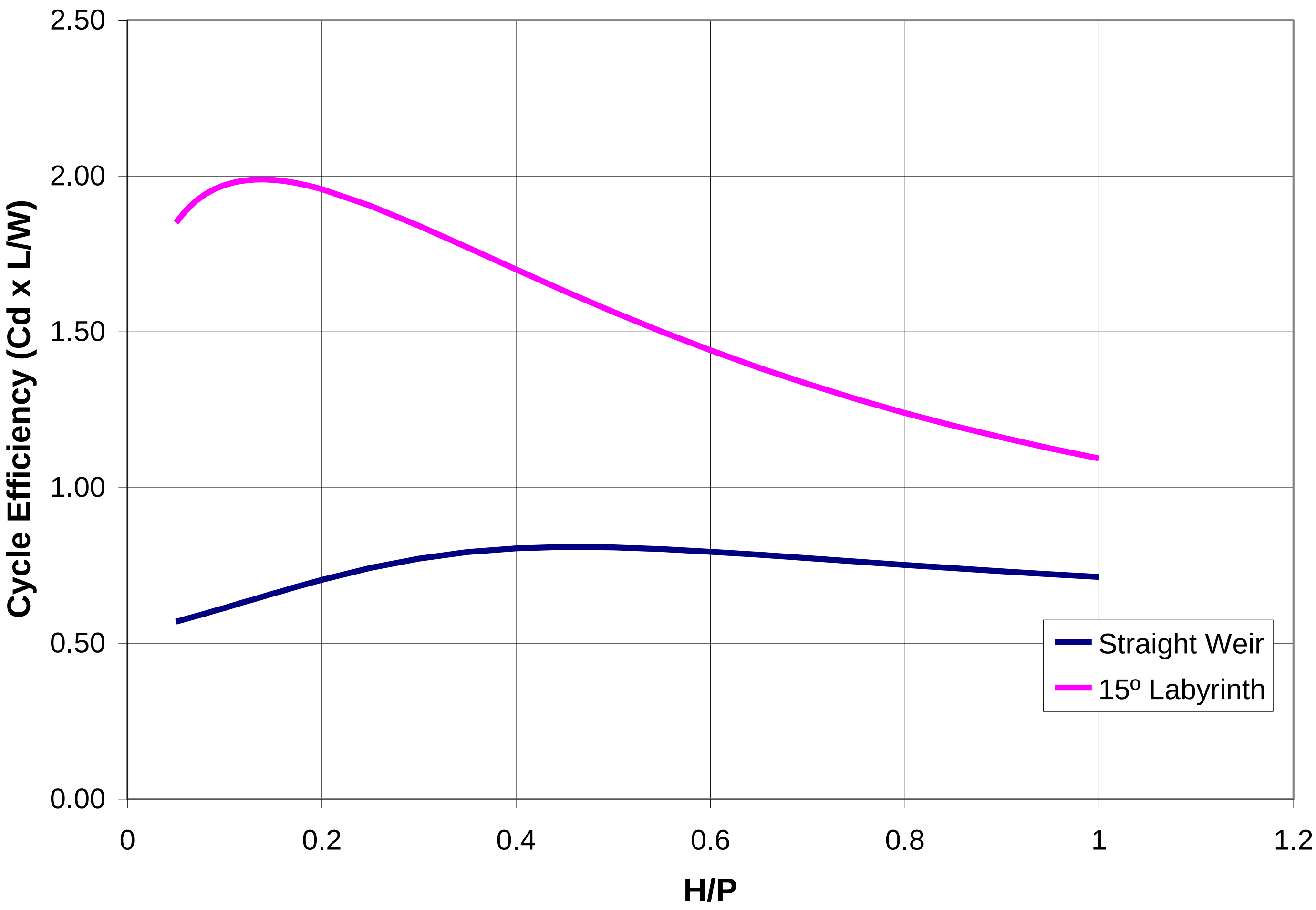


Large H/P Values

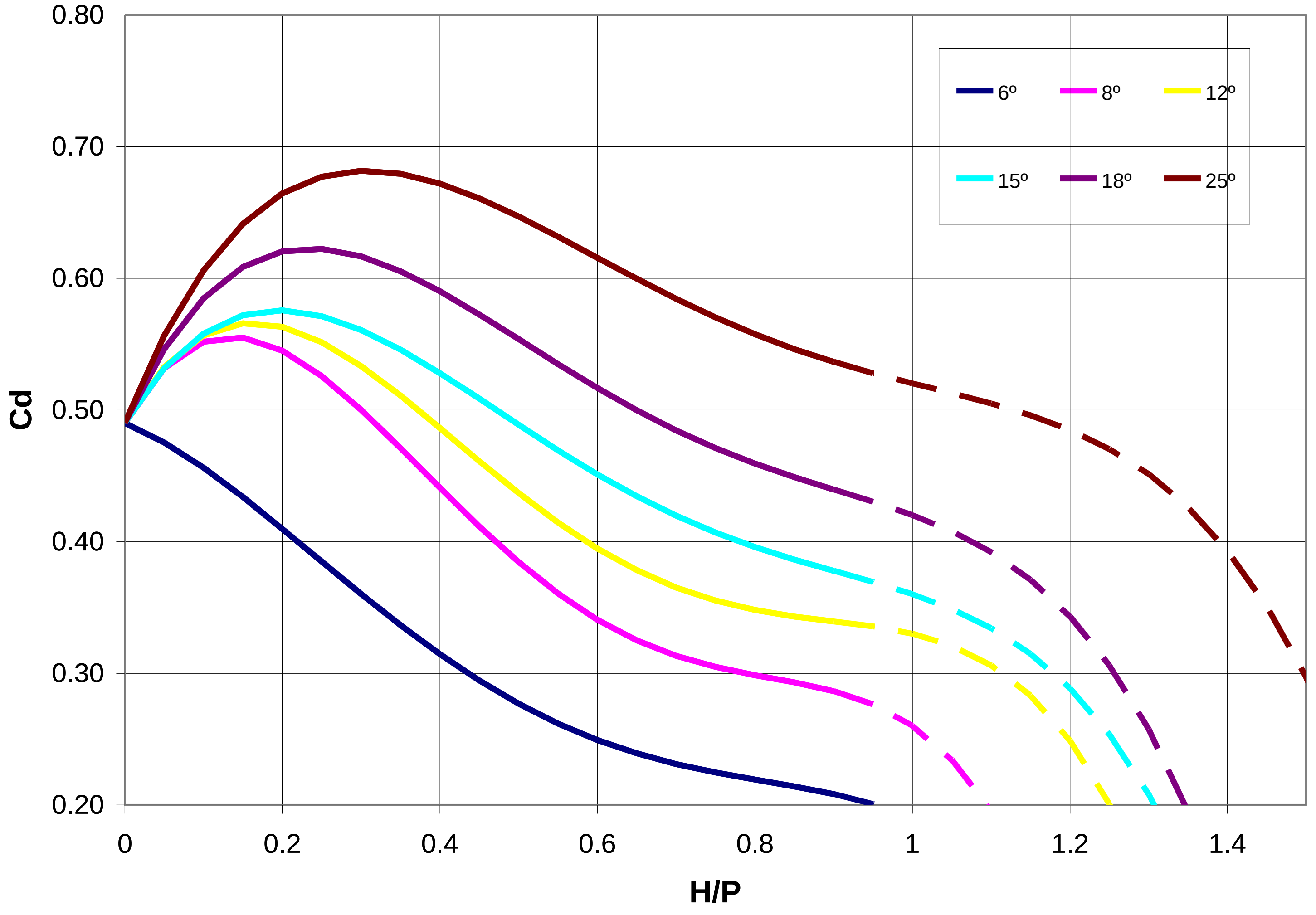


Purpose of Study

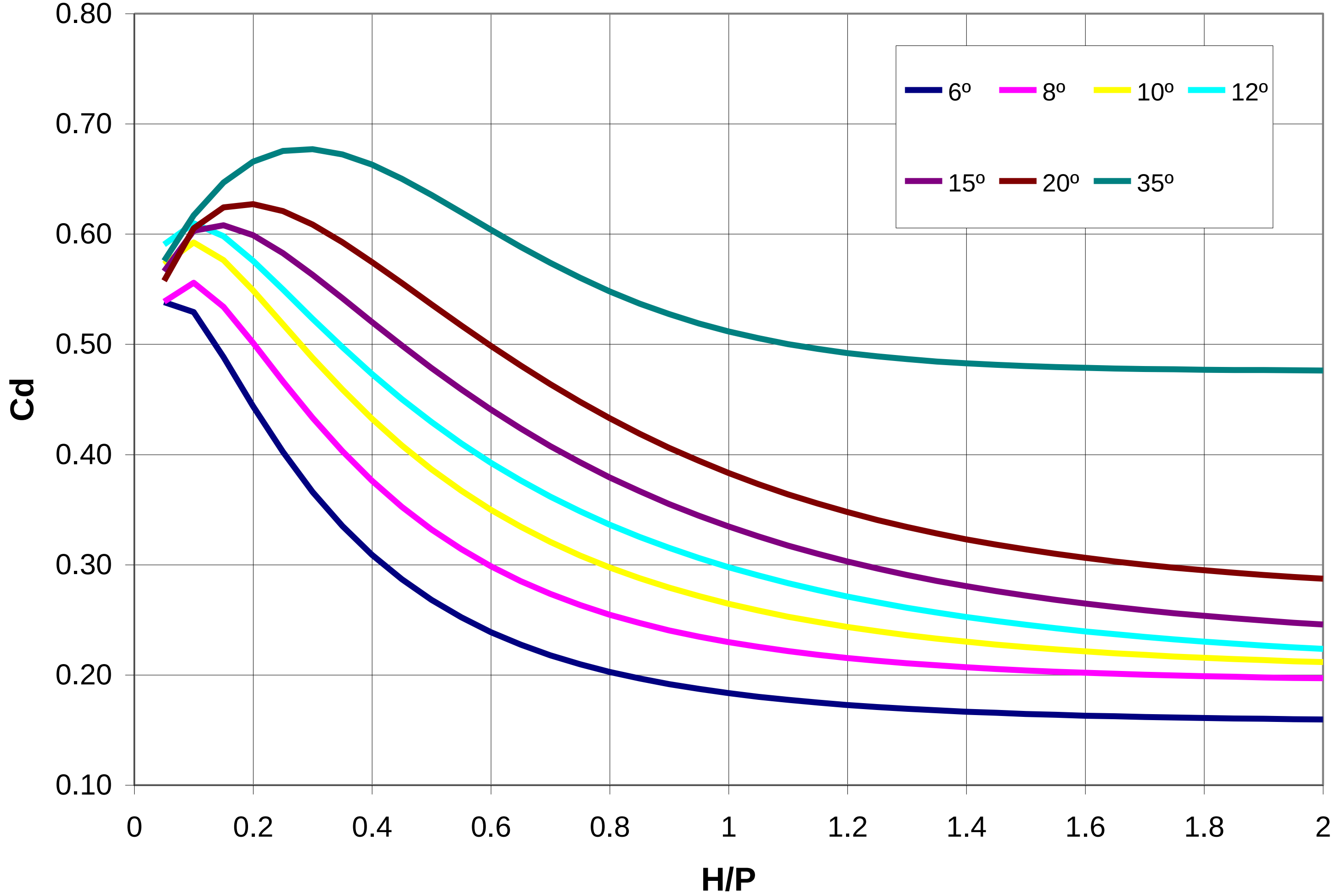




Tullis et al (1995): Polynomial Equations

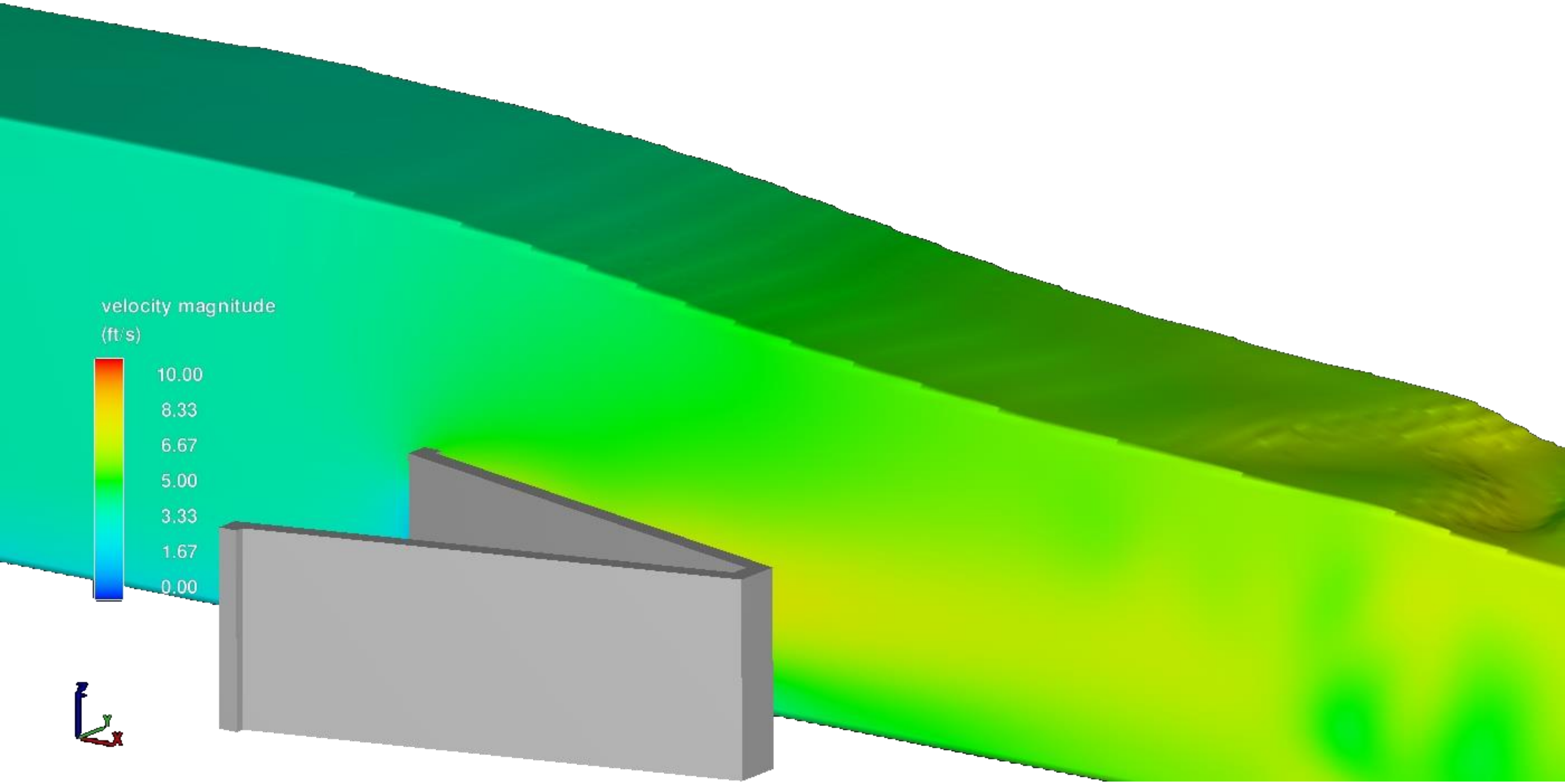


Crookston (2010) Equations

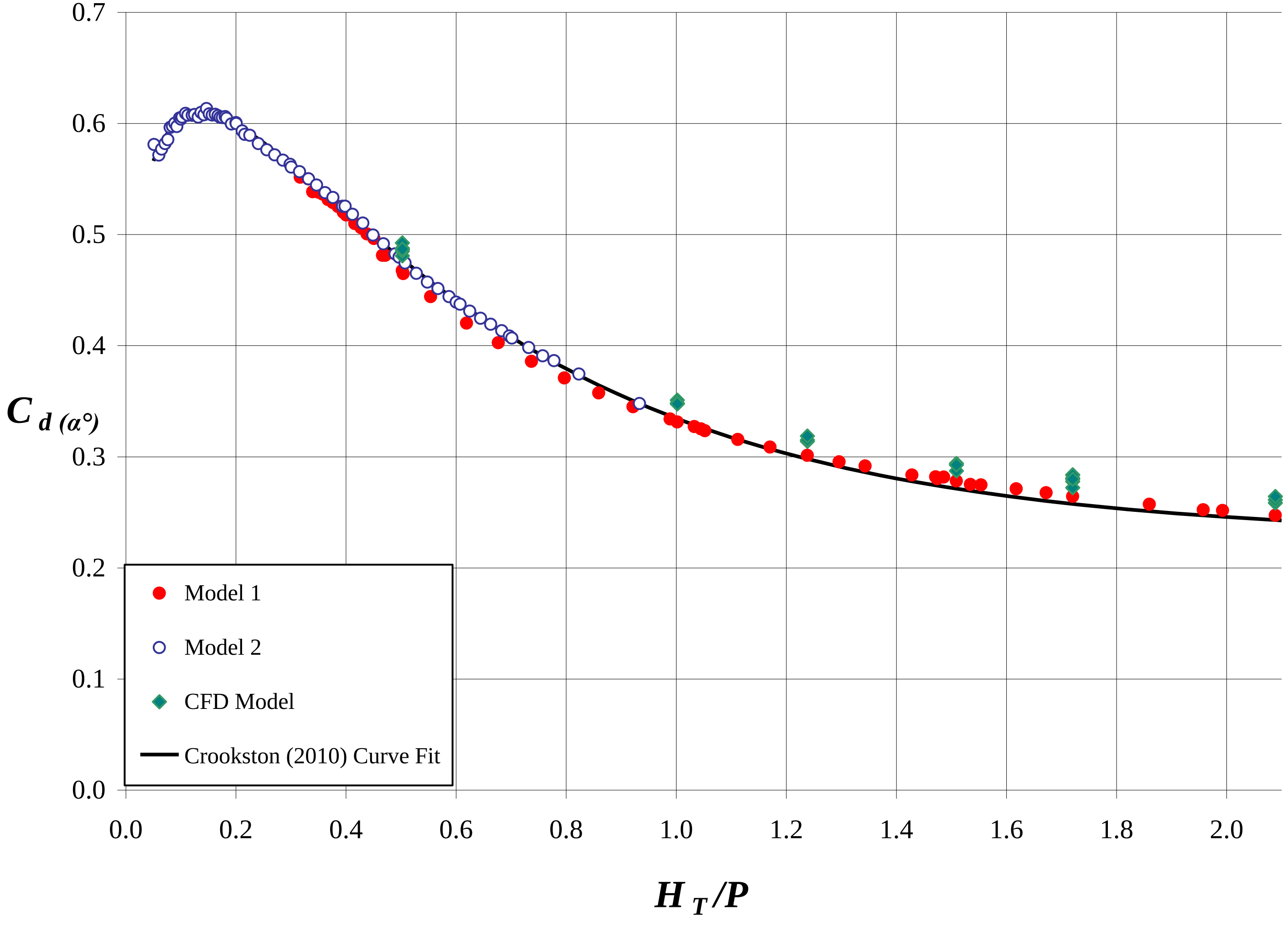


Physical Modeling

Numerical Modeling

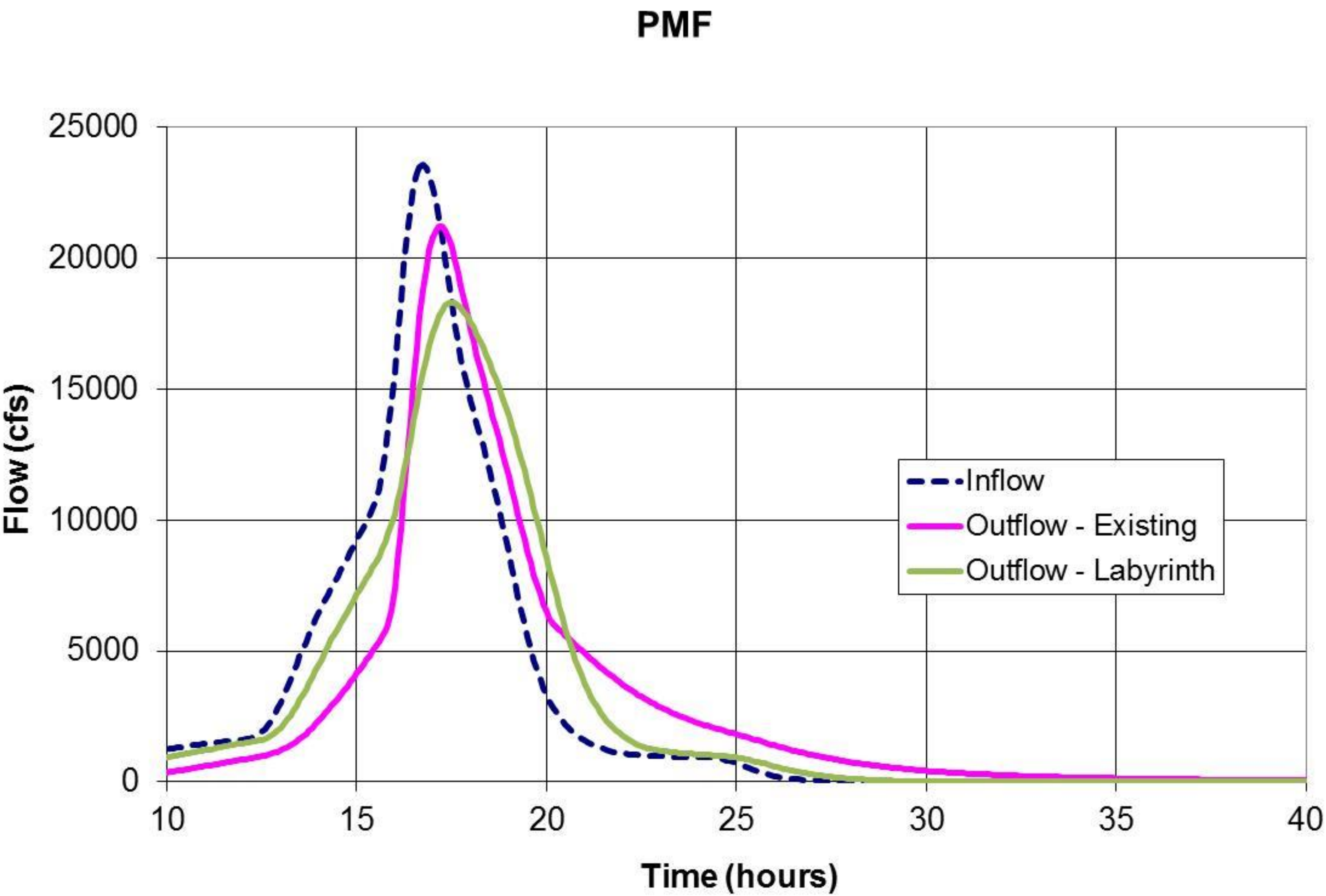


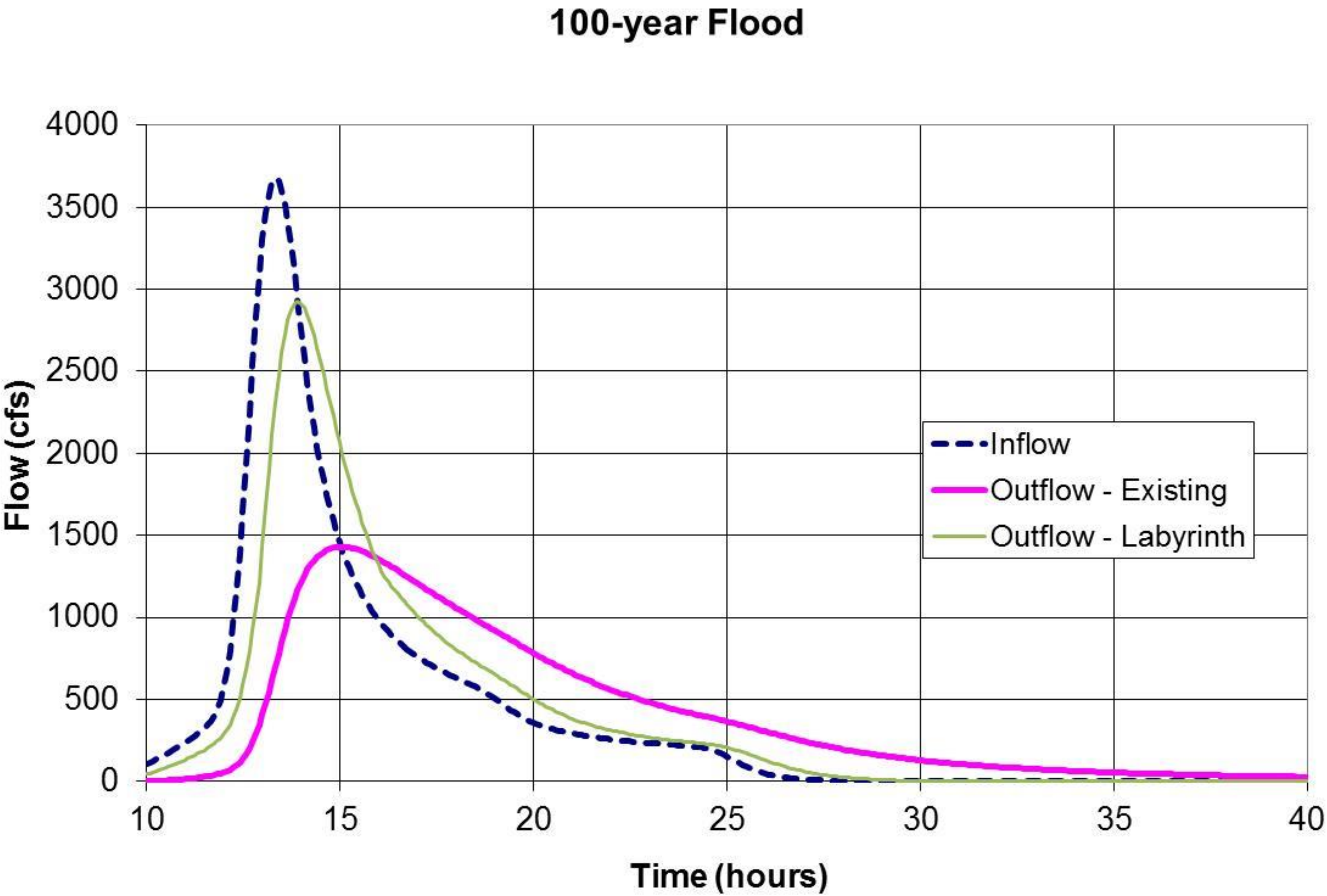
Results (15° Labyrinth)



Spillway Capacity

- Systems Approach
  - Passing the Peak
  - Flood Storage Reserve
  - Hydraulic Efficiency
- Spillway Replacement (Primary/Auxiliary)
- New Dams


PMF
25000
20000
15000
10000
5000
0
Flow (cfs)
10
15
20
25
30
35
40
Time (hours)
Inflow
Outflow - Existing
Outflow - Labyrinth


100-year Flood
Flow (cfs)
4000
3500
3000
2500
2000
1500
1000
500
0
10
15
20
25
30
35
40
Time (hours)
Inflow
Outflow - Existing
Outflow - Labyrinth

Staged Weirs

Gated Spillway Issues

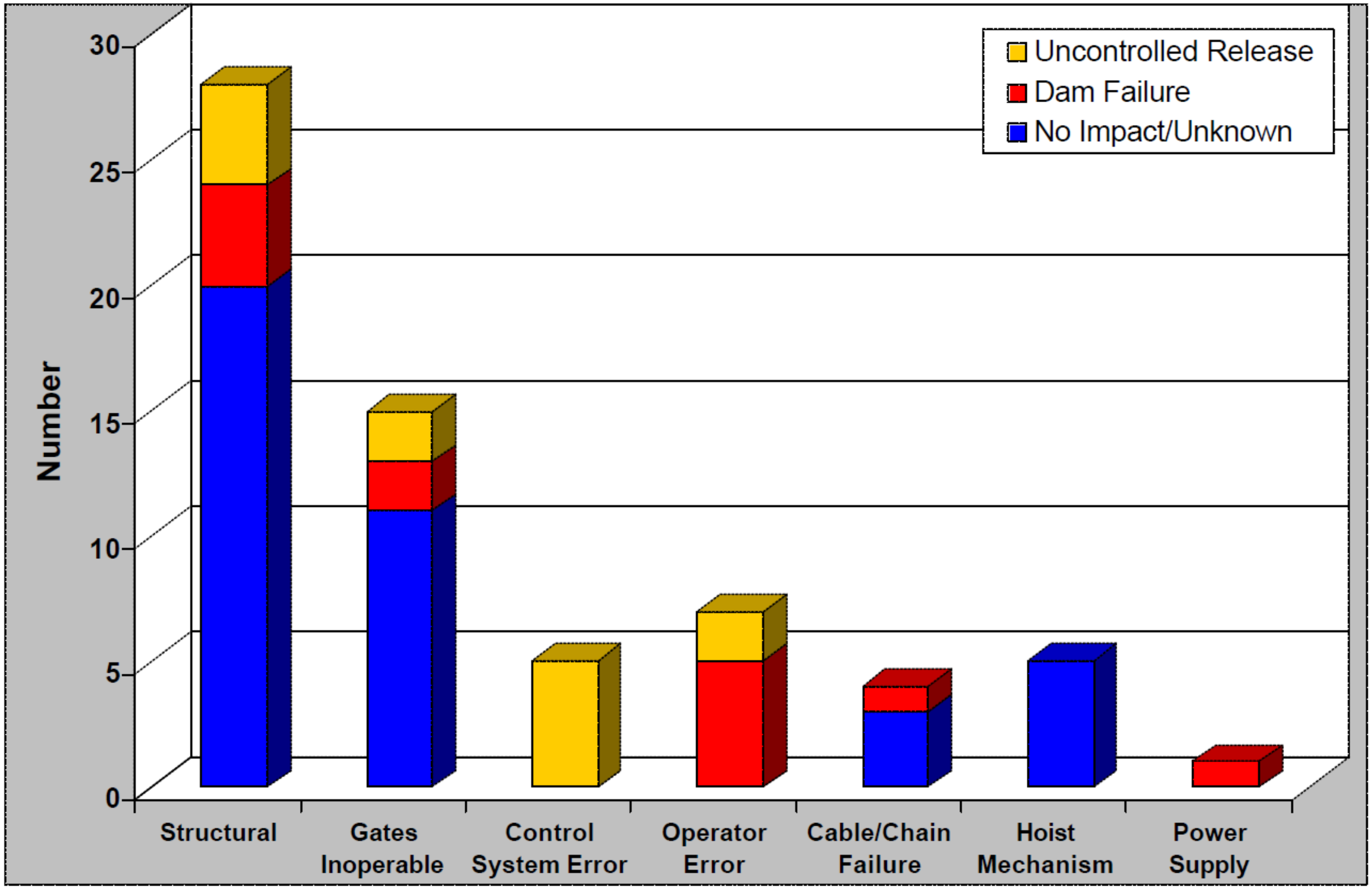


Figure 2 Dam gate system events and the consequences that resulted.

Source: *Performance of Hydraulic Systems*, National Performance of Dams Program, www.npdp.stanford.edu.

Gated Spillways

- Dam and Gate Failures

Gated Spillways

- Flooding…from gate operations?

Flood Gates Opened at the J. Strom Thurmond Dam

Posted: Jul 11, 2013 6:14 PM EDT
Updated: Jul 11, 2013 6:35 PM EDT

By Tyrone McCoy, WJBF Photojournalist CONNECT

Columbia County, GA - Minutes later, about 27,000 cubic feet per second of water rush over the spillway gates and into the downstream areas of the Savannah River. And while water doesn't seem like something we have a shortage of lately, Billy Birdwell tells us this test is to ensure water control at the dam

He explains, "without this dam and all of this water that will be coming down, spilling up behind the dam will be coming down in an uncontrolled way. And that will be devastating to the folks downstream."

And while this breath taking sight hasn't been seen here since 2007, the Army Corps of Engineers is urging anyone who gets close to this water downstream to tread lightly.

Something Angela Kelly says she's already doing at her home at Water's Edge. She says the deck to her dock is already under water.

"My concern is that it's going to make that go up a foot, two foot more and it's already up 10 foot higher than it's supposed to be," Kelly says.

10/13/2014

10 boys rescued after floodgates opened at Tenughat dam - The Hindu: Mobile Edition

THE HINDU

Home Sections Subscription

10 boys rescued after floodgates opened at Tenughat dam

Jun 21, 2014 12:36 PM , By PTI | 0 comments

Ten teenagers, who had gone fishing in Damodar river, were trapped for over eight hours when a sluice gate at the Tenughat dam was opened leading to sudden rise in water level, before they were rescued.

The boys escaped drowning by climbing atop a concrete platform built by the Chandrapura Thermal Power Station on Friday.

The incident at Pachaura village came close on the heels of the tragedy in Himachal Pradesh in which 24 engineering students from Hyderabad and a tour leader were washed away in the river when Larji hydropower project authorities suddenly released water from the barrage.

Bokaro Deputy Commissioner Uma Shankar Singh said, "The incident occurred when all the boys in the age group of 15/16 went to the river for fishing yesterday afternoon.

Larij Hydropower Project (2014)

File Photo: Largi Hydropower Project Downstream

25 Hyd Students Feared Swept Away As Larji Dam Releases Water Without Notice

Inquiry Report: *There are no standard operating procedures related to release of water...*

The warning system is also inadequate. All this constitutes a systemic failure due to wrong and entrenched faulty procedure and practices…

Tenughat Dam (2014)

THE HINDU

Home Sections Subscription

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Bokaro Deputy Commissioner Uma Shankar Singh said, "The incident occurred when all the boys in the age group of 15/16 went to the river for fishing yesterday afternoon.

"As the water swelled following opening of one sluice gate at the Tenughat dam in Bokaro district, they climbed atop a concrete platform built by the Chandrapura Thermal Power Station yesterday."

The boys, who were residents of nearby villages, were rescued by police at around 11.30 p.m. on Friday, said.

In the US...

Ad

Transportation

Laurel officials, businesses say WSSC should pay for Duckett Dam's flood damage

A | 0

Advertisement

All seven gates of the Duckett Dam are seen releasing flood water into the Patuxent River on May 1 in Laurel. (Ricky Carioti/The Washington Post)

AUDIO | DATA | DOCUMENTS

Near-Catastrophe During Flooding Highlights Issues at Dam in Austin

DECEMBER 10, 2013 | 12:10 PM

BY MOSE BUCHELE

AUSTIN ENERGY

Pompton Lakes dam served its purpose during Hurricane Irene, report finds

Print (http://blog.nj.com/ledgerupdates_impact/print.html?entry=/2012/04/pompton_lakes_dam_served_its_p.html)

(http://connect.nj.com/user/saugenstein/index.html) By Seth Augenstein | The Star-Ledger (http://connect.nj.com/user/saugenstein/posts.html)

Email the author | Follow on Twitter (https://twitter.com/SethAugenstein)

on April 12, 2012 at 12:15 PM, updated April 12, 2012 at 12:16 PM

Residents call for new dam outflow schedule

Josh O'Leary, Iowa City Press-Citizen 11:20 p.m. CDT September 15, 2014

(Photo: David Scrivner / Iowa City Press-Citizen)

Residents on Monday questioned the U.S. Army Corps of Engineers' handling of July's flooding, while the corps defended itself against charges of both:

- Not releasing enough water from the Coralville Reservoir before the flood.
- And later releasing too much water when there was dam capacity to spare.

Two months after Johnson County endured another summer flood, corps officials and representatives from local governments and the University of Iowa hosted a panel discussion at the Iowa City Public Library.

"I've always said our floods are man-made, because there's somebody controlling something, and that there are times I think something can be done to better control it," Cathy Wilcox, a Taft Speedway resident, told the panelists.

The discussion centered largely around the corps' management plan for the reservoir, which determines the schedule for when and how much water is released from the dam — a schedule that all seem to agree is due to be reevaluated. The plan was last revised more than a decade ago, but the corps'

In the US…

Residents question decisions made with released water

Tim Smith, tcsmith@greenvillenews.com 7:43 p.m. EDT October 14, 2015

(Photo: Exterior Genie)

COLUMBIA – George Dawn had just finished a late morning shower evacuation request by a fireman going through their Pine Glen neig

It had been raining since the day before, but the Dawns had never s of living there.

So Dawn said he grabbed only one set of clothes and left one of the assuming they would be back the next day and all would be fine.

It wasn't.

By the end of the day, a wall of water spread through much of the neighborhood, which is located within abou River, drowning homes almost to the roof. Some residents had to be rescued by boat.

The water tore apart homes, displaced families and overturned lives.

And now, residents question if some of that water came as a result of releases from the Lake Murray Saluda were adequate.

Lawsuits mount against SCE&G after dozens lose homes during floods

By Rachel Ham (http://coladaily.com/author/rachel/) on October 27, 2015

ColaDaily.com is your source for free news and information in Columbia and the Midlands. (http://coladaily.com)

Flooding destroyed numerous houses in the Coldstream and Pine Glen neighborhoods near Irmo during heavy rainfall and flooding earlier this month. After losing family mementos, pets and furniture, several families are filing lawsuits against SCE&G.

SCE&G announced Oct. 4 that officials would be opening the spillway gates to lower the levels in Lake Murray and alleviate pressure on the dam. A warning about "a significant increase in water flow in the lower Saluda River" was issued at that time.

Attorney Jake Moore said he is working about 50 lawsuits on behalf of clients after the Saluda River flooded their homes. Moore said he has no plans right now to create a class action suit.

"They gave us no warning," she said. "The
"This all started because SCE&G decided to flood our neighborhood. They say it's not their fault, but they knew the rain was coming. They could have let the lake down before it hit."
hydroelectric plant was releasing water…

Lake Townsend Dam

Considerations in Labyrinth Spillway Design

- Siting & Sizing
- Head/Discharge Requirements
- Downstream flow conditions
- Existing spillway hydraulics

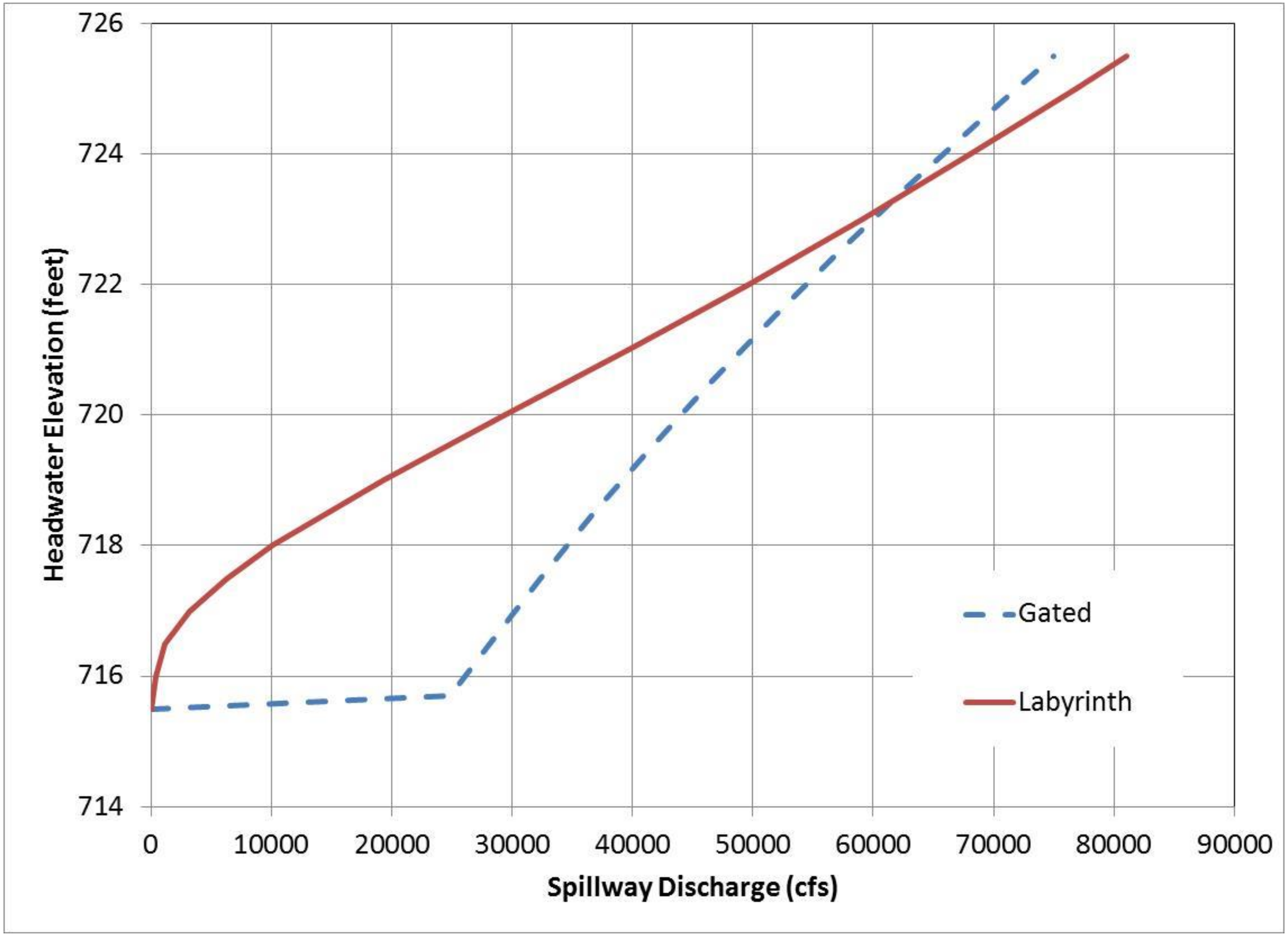
Spillway Capacity Design

- Replace gated spillway with labyrinth weir with similar capacity (82,000 cfs)* at top of dam (H=10 ft)

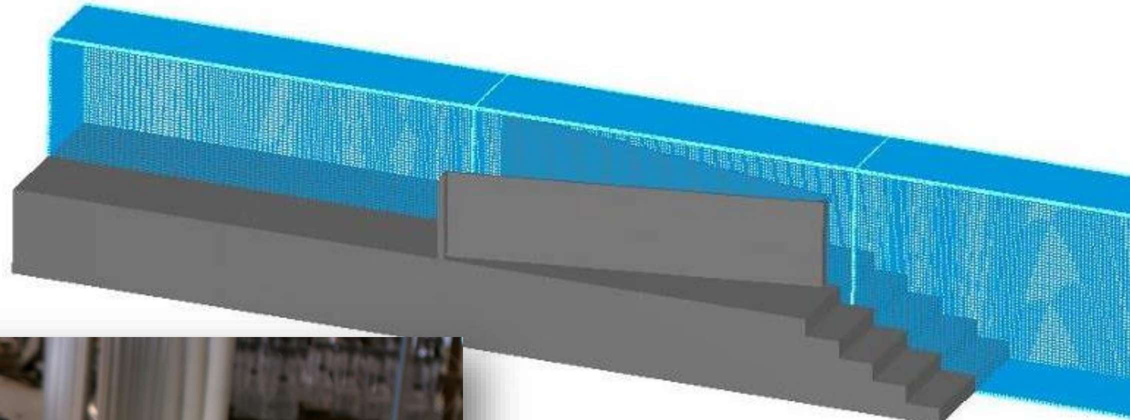
- Armor Embankment to safely pass SDF plus failures of upstream dams (Q_{in}=213,000 cfs)

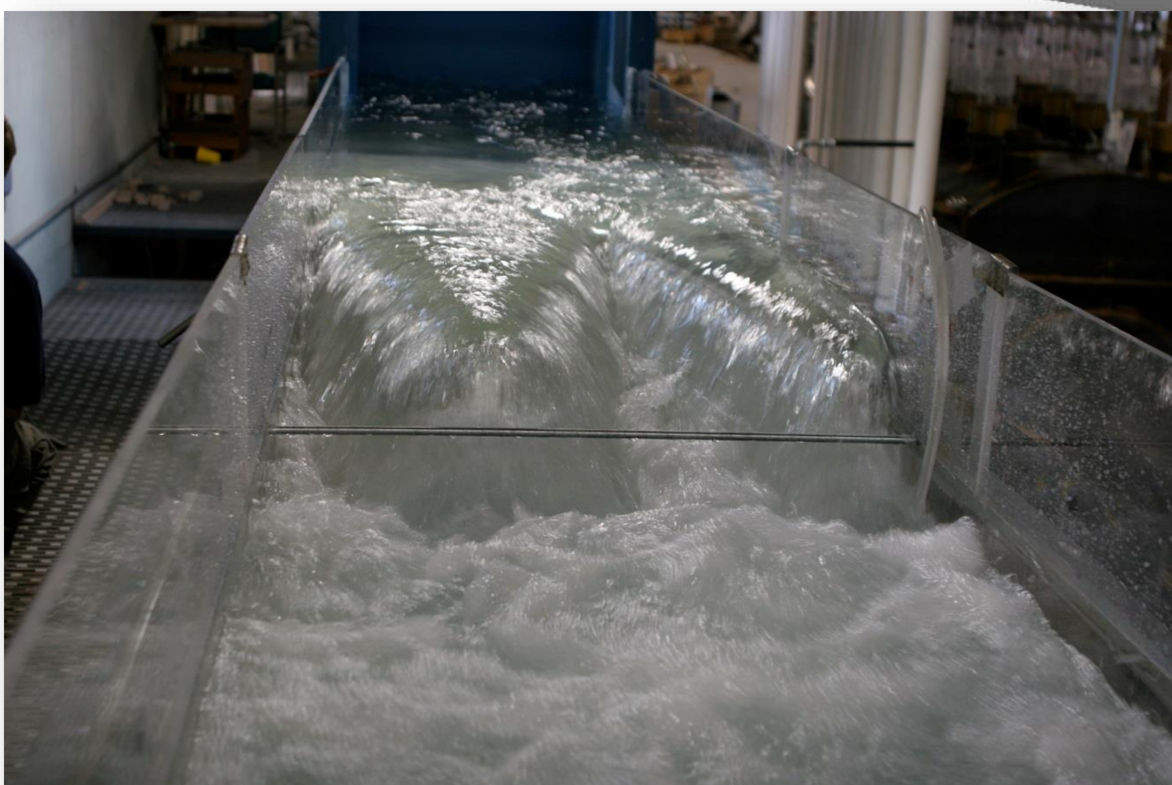
* Assumes gates are fully operational

Gates vs. Fixed Crest



Hydraulic Modeling





Linville Land Harbor Dam

Linville Land Harbor Dam

Linville Land Harbor Dam

Linville Land Harbor Dam

A Tale of Two Spillways:

The First Two Piano Key Weirs Constructed in the United States

J RYAN COLLINS

SAMUEL KEES

GERALD ROBBLEE

RANDALL BASS

INTRODUCTION

Non-linear weir structures can greatly increase the discharge capacity as compared to linear weirs within the same channel width. Labyrinth weirs have been constructed in the United States for decades. Research of the hydraulic performance of labyrinth weirs has been performed to better understand geometric effects of the weirs on the discharge capacity. Some notable studies include "Weirs with oblique and Zig-Zag Crests" (Gentilini, 1941), "Performance and Design of Labyrinth Weirs" (Hay and Taylor, 1970), "Discharge Characteristics of Labyrinth Weirs" (Lux, 1984), "Design of Labyrinth Spillways" (Tullis et al., 1995), and "Labyrinth Weirs" (Crookston, 2010), though there are many more.

A Piano Key Weir (PKW) is another variation of a non-linear weir, which has not been used before in the United States. The PKW has been used in France, Vietnam, Australia, and other parts of the world, but has not yet gained the same level of popularity in the United States. This article describes Schnabel Engineering's first PKW projects at two locations in the Southeastern United States (Peachtree City, Georgia, and Cedar Grove, North Carolina).

ADVANTAGES OF PKWs

PKW spillways provide unique hydraulic advantages, particularly when the available footprint dimensions are limited. The rectangular configuration of the "keys" provides a significant increase of weir length within a given channel width. The short base length and cantilevered apex geometry allow for even greater weir length within a relatively small footprint, making the use of PKWs convenient as a retrofit over an existing gravity section or where conventional labyrinth weirs would otherwise not be feasible due to available base length limitations. Figure 1 (Paxson, Laugier 2014) depicts typical geometric parameters of both labyrinth weirs and PKWs.

The PKW was introduced by Lempérière and Oumane in 2003 (Paxson, Laugier, 2014). The first known PKW installation was at the Goulours Dam in France in 2006 (Laugier, 2007). Since then, hydraulic engineers and researchers have continued to study the effects of the PKW geometry on the discharge capacity in an effort to optimize design parameters and better predict the head-discharge relationship of PKW spillways. Some of the impactful geometric ratios considered in the studies include the total hydraulic head to

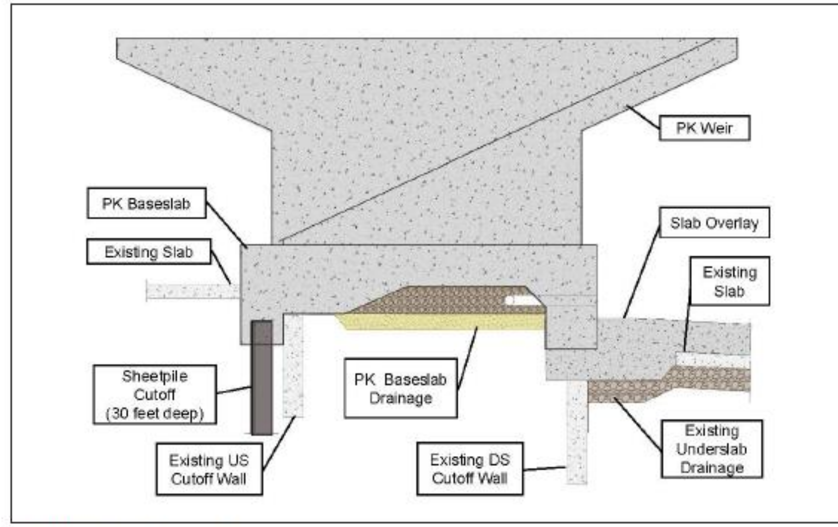


Figure 11: Proposed PK Weir Cross Section

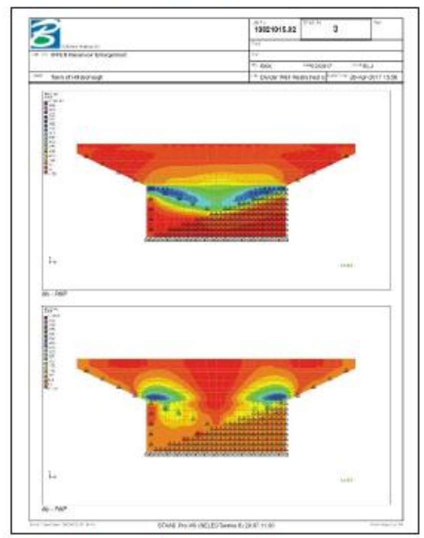


Figure 12: PK Divider Wall STAAD FE Model Output

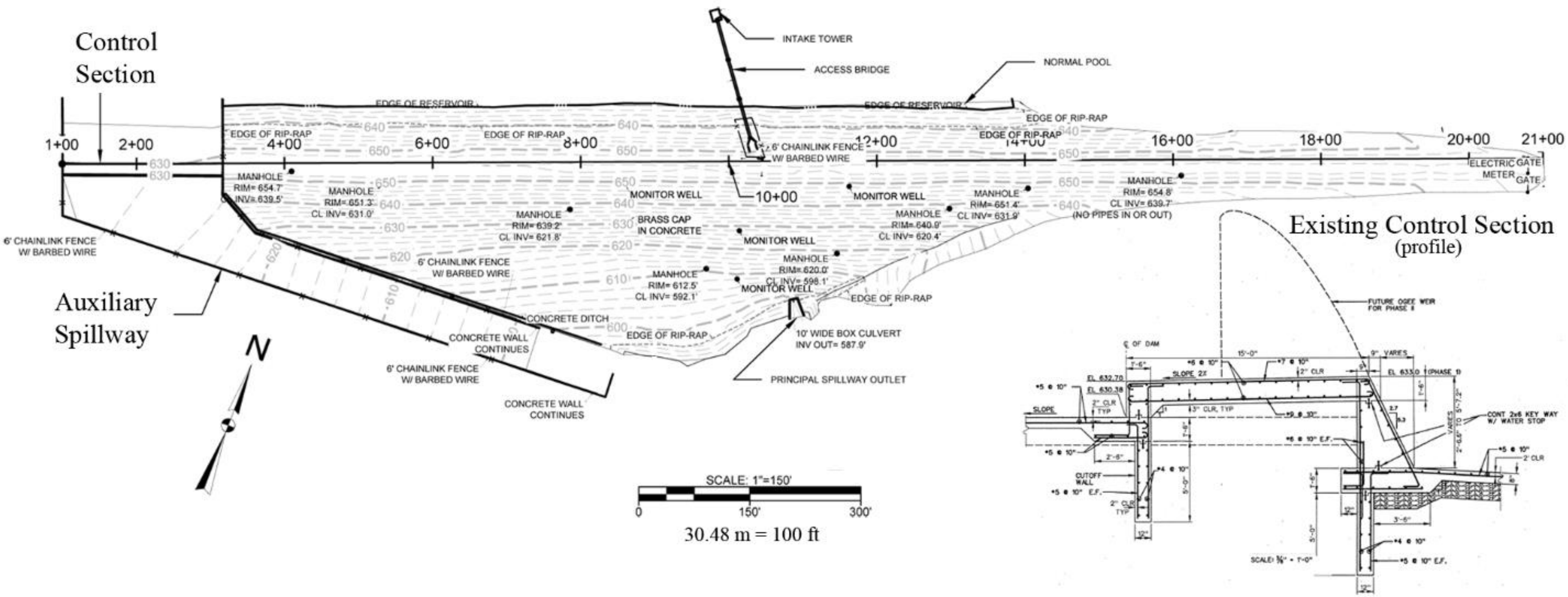
Figure 13: WFER Construction Progress as of January 8, 2019

pushing the divider walls away from the inlet ramp). To reduce these deflections, adjacent divider walls are structurally connected at the inlet ramps with full horizontal reinforcement across the joints. The detailing of the reinforcement included form savers at these connections to resist tension in the joints between the inlet ramps and divider walls. Smooth dowels are included for the connection between the outlet ramps and divider walls as water contained in the inlet ramps would push the divider walls into the outlet ramps and the upstream joints were in compression.

Piano Key Weirs in USA

Water Supply – Pool Raise

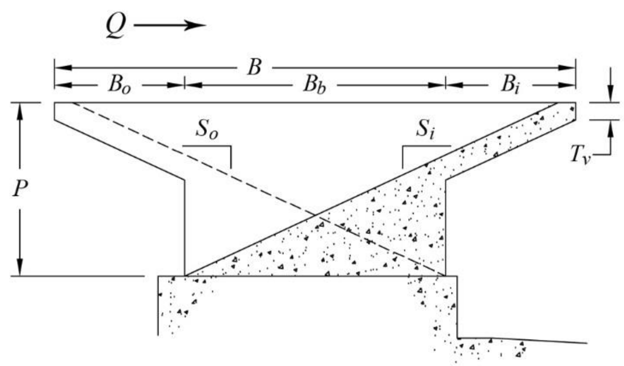
Hillsborough -WFER

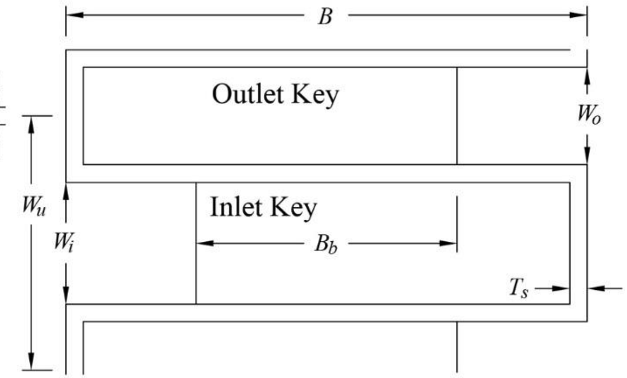


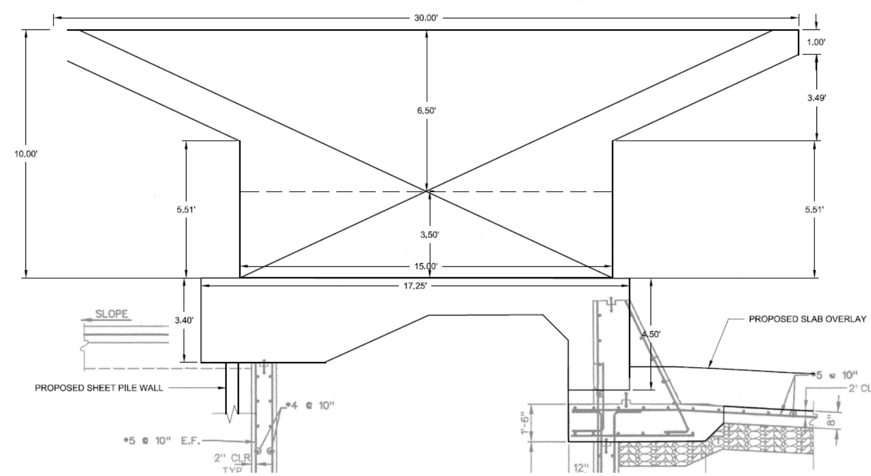
Existing Auxiliary Spillway

Spillway Alternative	Normal Pool EL (ft)	100-year Storm		¾ PMP (SDF)	
		Peak Q (cfs)	Peak WS EL (ft)	Peak Q (cfs)	Peak WS EL (ft)
Existing	632.3	1,750	633.7	18,590	641.7
Proposed Ogee Weir	642.2	1,420	643.8	17,840	649.6
Proposed PK Weir	642.2	2,180	643.5	15,720	649.7

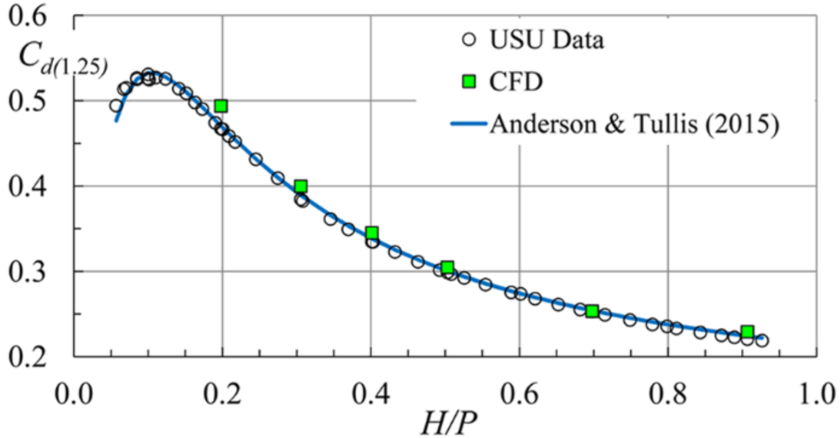
Hillsborough - WFER

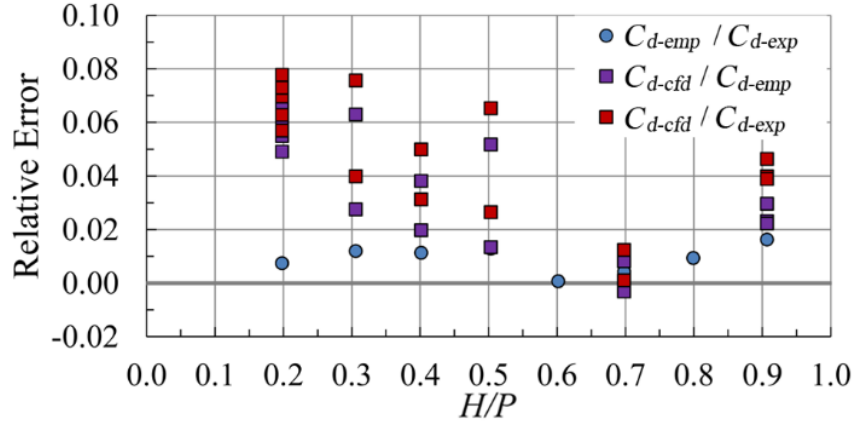




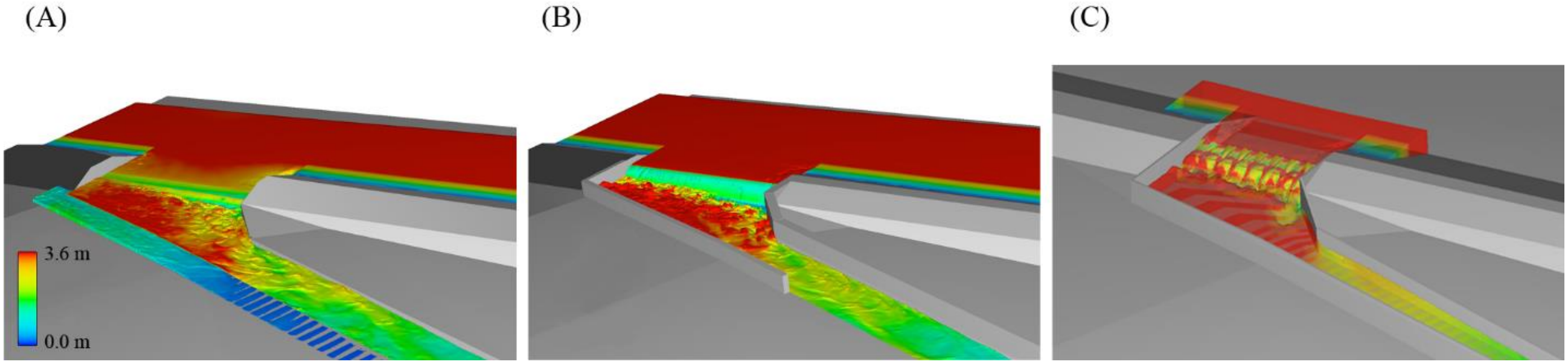


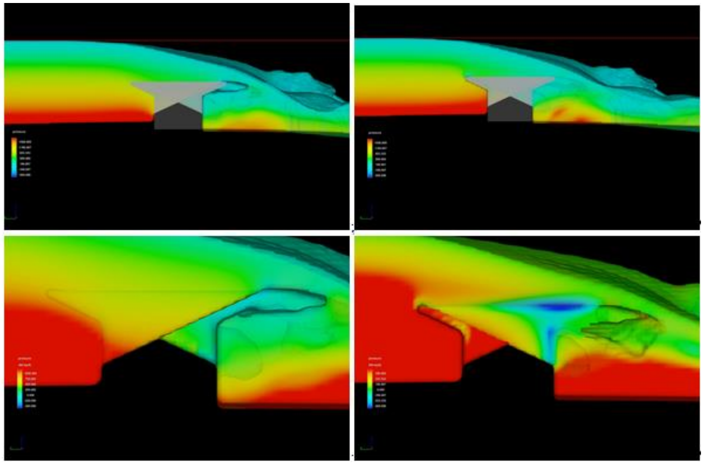
Hillsborough -WFER

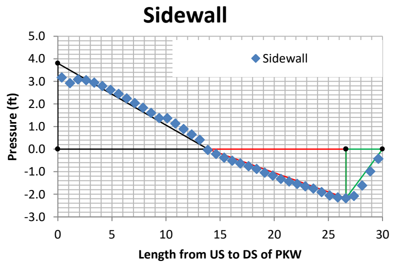


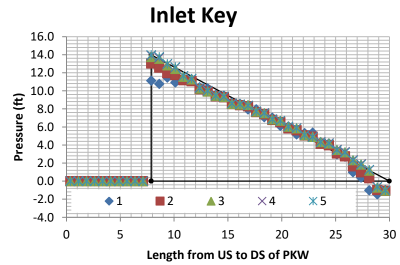


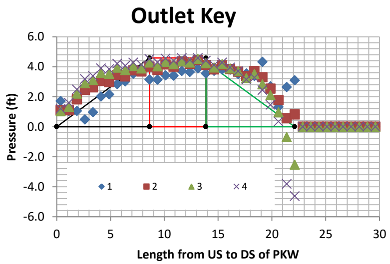
Hillsborough -WFER











Questions/Discussion

Pipestem Dam, North Dakota
(model at US Bureau of Reclamation)

Lake Isabella Dam, California