

# Fluid Dynamics

Prof. Il Won Seo

Dept. of Civil and Environmental Engineering

Seoul National University

# Lecturer

## 서 일 원 II Won Seo (IW Seo)

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[ehlab.snu.ac.kr](http://ehlab.snu.ac.kr)

### *Education*

1990, Ph.D., Civil Engineering, Univ. of Illinois at Urbana-Champaign, U.S.A.

1983, M.Sc., Civil Engineering, Seoul National University, Korea

1981, B.Sc., Civil Engineering, Seoul National University, Korea

### *Profession*

1990~91, Research Associate, Illinois State Water Survey, U.S.A.

1992~ present, Professor, Seoul National University, Korea

2007, Visiting Professor, UC Davis, U.S.A.

2014, Visiting Professor, Colorado State University, U.S.A.

### *Research Interests*

Diffusion and Dispersion in Surface Waters

Modeling Hydrodynamics and Contaminant Transport in Rivers

Design of Ocean Diffuser Systems

Data-based Modeling for River Flow and Water Quality

# Fluid Dynamics

## Course Information:

No. and Title: 457.561/Fluid Dynamics (3-3-0)

## Prerequisites:

Elementary Fluid Mechanics and Lab.

Hydraulics and Lab.

## Grade:

Class Participation	10%
Homework Assignments	20%
Term Project	30%
Final Exam.	40%

# Fluid Dynamics

## Objectives:

This course, which is a core course in the Hydraulic Engineering graduate program, deals with the advanced theories of hydrodynamics to be the basis of design and analysis of the social infrastructures such as river and hydraulic structures, dam, power plant, etc. Further, in this course, students will learn all the capabilities necessary for the modeling of the practical fluid phenomena in the river and for the analysis of numerical simulations of rivers and water resource structures.

# Fluid Dynamics

## Description:

This course deals with the physical concepts and fundamental equations of fluid dynamics in the advanced level. In the beginning of this course, the similarity of the fluid transport phenomena and stress-strain relations are discussed. Main part of this course will be focused on three-dimensional expressions of equations of continuity and motion for viscous fluids. Specific topics and applications in fluid dynamics are also treated. In the latter part of the course, dynamics of turbulent flow, turbulent boundary layer theory, and turbulence modeling are studied in detail.

# Fluid Dynamics

## Texts:

- Seo, I.W., Lecture Note of Fluid Dynamics, Seoul National University, 2020, Web: [ehlab.snu.ac.kr](http://ehlab.snu.ac.kr)
- Daily, J.W. and Harleman, D.R.F., Fluid Dynamics, Addison-Wesley, 1966.
- Kundu, P.K., Cohen, I.M., and Dowling, D.R., Fluid Mechanics, 5<sup>th</sup> Ed., Academic Press, 2012.
- Tennekes, H. and Lumley, J.L., A First Course in Turbulence, MIT Press, 1972.
- Rodi, W., Turbulence Models and Their Applications in Hydraulics, IAHR Monograph, A.A. Balkema, 1993.

# Fluid Dynamics

## Contents:

1. Fluid Characteristics
2. Kinematics
3. Fluid Transport
4. Continuity, Energy, and Momentum Equations
5. Stress-Strain Relations
6. Equations of Continuity and Motion
7. Boundary Layer Flows
8. Origin of Turbulence
9. Turbulent-Boundary Layer Flows
10. Turbulence Models

# Weekly Schedule:

Week	Lecture (File Name/No. of Slides)	Homework
1	Ch. 0 Introduction (LC0/50) Ch. 1 Fluid Characteristics (LC1/40)	
2	Ch. 2. Kinematics (I) (LC2/26) Ch. 2. Kinematics (II) (LC3/31)	HW #1
3	Ch. 3. Fluid Transport (LC4/32) Ch. 4. Continuity, Energy, and Momentum Equations (I) (LC5/24)	HW #2
4	Ch. 4. Continuity, Energy, and Momentum Equations (II) (LC6/26) Ch. 4. Continuity, Energy, and Momentum Equations (III) (LC7/36)	Term project title/HW #3
5	Ch. 5. Stress-Strain Relations (I) (LC8/27) Ch. 5. Stress-Strain Relations (II) (LC9/33)	HW #4
6	Ch. 6. Equations of Continuity and Motion (I) (LC10/28) Ch. 6. Equations of Continuity and Motion (II) (LC11/23)	
7	Ch. 6. Equations of Continuity and Motion (III) (LC12/32) Ch. 6. Equations of Continuity and Motion (IV) (LC13/35)	Term project proposal presentation
8	Ch. 6. Equations of Continuity and Motion (V) (LC14/20) Ch. 6. Equations of Continuity and Motion (VI) (LC15/33)	HW #5
9	Ch. 7. Boundary Layer Flows (I) (LC16/27) Ch. 7. Boundary Layer Flows (II) (LC17/32)	
10	Ch. 8. Origin of Turbulence (I) (LC18/20) Ch. 8. Origin of Turbulence (II) (LC19/22)	
11	Ch. 8. Origin of Turbulence (III) (LC20/31) Ch. 8. Origin of Turbulence (IV) (LC21/37)	
12	Ch. 8. Origin of Turbulence (V) (LC22/22) Ch. 9. Turbulent Boundary Layer Flows (I) (LC23/14)	HW #6
13	Ch. 9. Turbulent Boundary Layer Flows (II) (LC24/42) Ch. 9. Turbulent Boundary Layer Flows (III) (LC25/28)	
14	Ch. 10. Turbulence Models (I) (LC26/22) Ch. 10. Turbulence Models (II) (LC27/29)	
15	Ch. 10. Turbulence Models (III) (LC28/30) Final Exam	Term project final presentation



# Term Project

## A. Outline

	Proposal	Final Report
Presentation (PPT)	Week 7	Week 15
Presentation Time	5 min	15 min
PPT	PPT 6 pgs.	PPT 15 pgs.
Report	A4 2-4 pgs.	A4 10-20 pgs.

\* Term Project title (English) should be submitted on Week 4.

# Term Project

## B. Presentation (Recommended)

- (1) Title page: Presentation title and author
- (2) Introduction: Issue and necessity of research, research objectives
- (3) Theoretical research: Previous and current research trends
- (4) Methods: Research detail and methodology
- (5) Result and discussion: Analysis of research results
- (6) Conclusion: Summary and conclusion
- (7) References

# Term Project

## \* Remarks

- Introduce significant governing equation and BC& IC only.
- Introduce significant pictures and graphs only.
- Proposal and report must be written in English.
- Refer to Hydraulic Terminology Dictionary.
- Punctuality is important in presentation (Practice in advance).

# Term Project

## C. Outline of Proposal and Final Report

### 1. Proposal

- (1) Research title
- (2) Necessity and background of research
- (3) Objective and scope of research
- (4) Research methodology
- (5) Reference

# Term Project

## 2. Final Report (Recommended)

(1) Title

(2) Abstract (including keywords)

(3) Introduction - Necessity and objective of research

(4) Body- Research trends, theoretical studies, experiment/numerical simulations

(5) Summary and conclusion

(6) Reference

\* Remarks: Spacing between lines should be 1-1/2 space, unimportant pictures and graphs should be included in the appendix.

# Term Project

## ▪ Suggested Term Project Topics

### 1. Commercial Software

Modeling 2-D turbulent flows using TEACH-2E

Modeling 2-D incompressible viscous flows using ELOW

Modeling hydrodynamics of flow in a river Wando using RMA2/HDM-2D/FaSTMECH

Modeling pollutant transport in a meandering river using RMA4/CTM-2D

Modeling bed deformation in a river using Nays2DH/TELEMAC2D/CCHE2D

Modeling flood in a river and floodplain using Nays2DFlood

Numerical modeling of mass transport for 2-D trench using FLUENT/OpenFOAM

Analysis of flow characteristics of dam spillway using FLUENT/OpenFOAM

Analysis of flow characteristics of dam spillway using SSIIM

([www.bygg.ntnu.no/~nilsol/ssiimwin](http://www.bygg.ntnu.no/~nilsol/ssiimwin))

# Term Project

## 2. Numerical modeling

Numerical modeling of Navier-Stokes equation using SIMPLE method (Semi-Implicit Method for Pressure-Linked Equations)

## 3. Analytical study

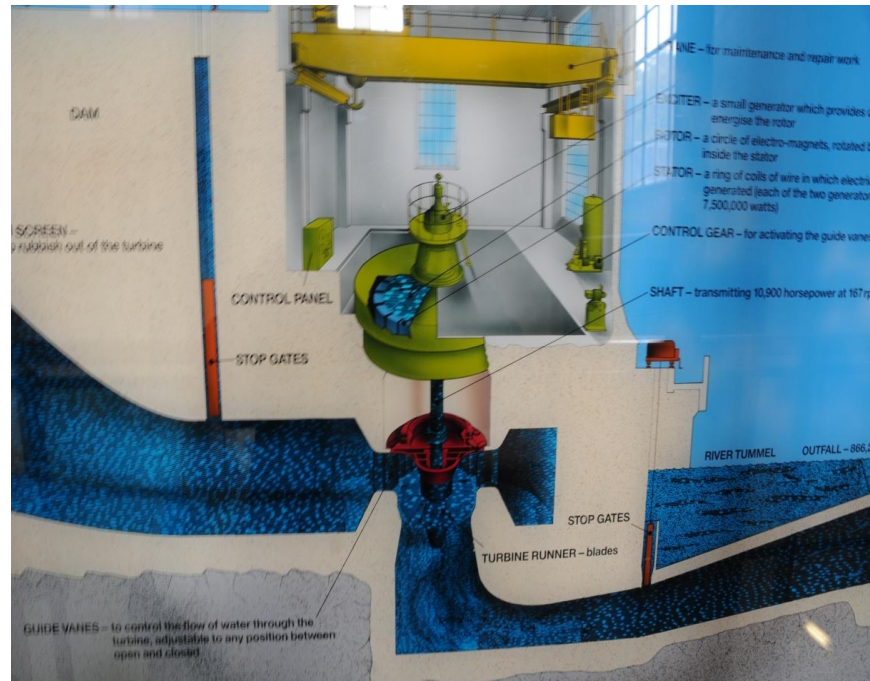
Analytical and numerical investigations of 2-D boundary layer equation  
Comparative study of turbulence models for Reynolds equation

## 4. Experimental study

Experimental study of turbulent flow over the weir in the open channel  
Experimental study of 2-D flow/pollutant transport around the weir in the open channel

# Fluid Dynamics

## Chapter 0 Why Fluid Mechanics?





# Chapter 0 Why Fluid Mechanics?

## Contents

0.1 Speculation of Leonardo da Vinci

0.2 Physics of Golf

0.3 Water Resources

0.4 Dams

0.5 Hydropower Plants

0.6 Flood Control

0.7 River Navigation

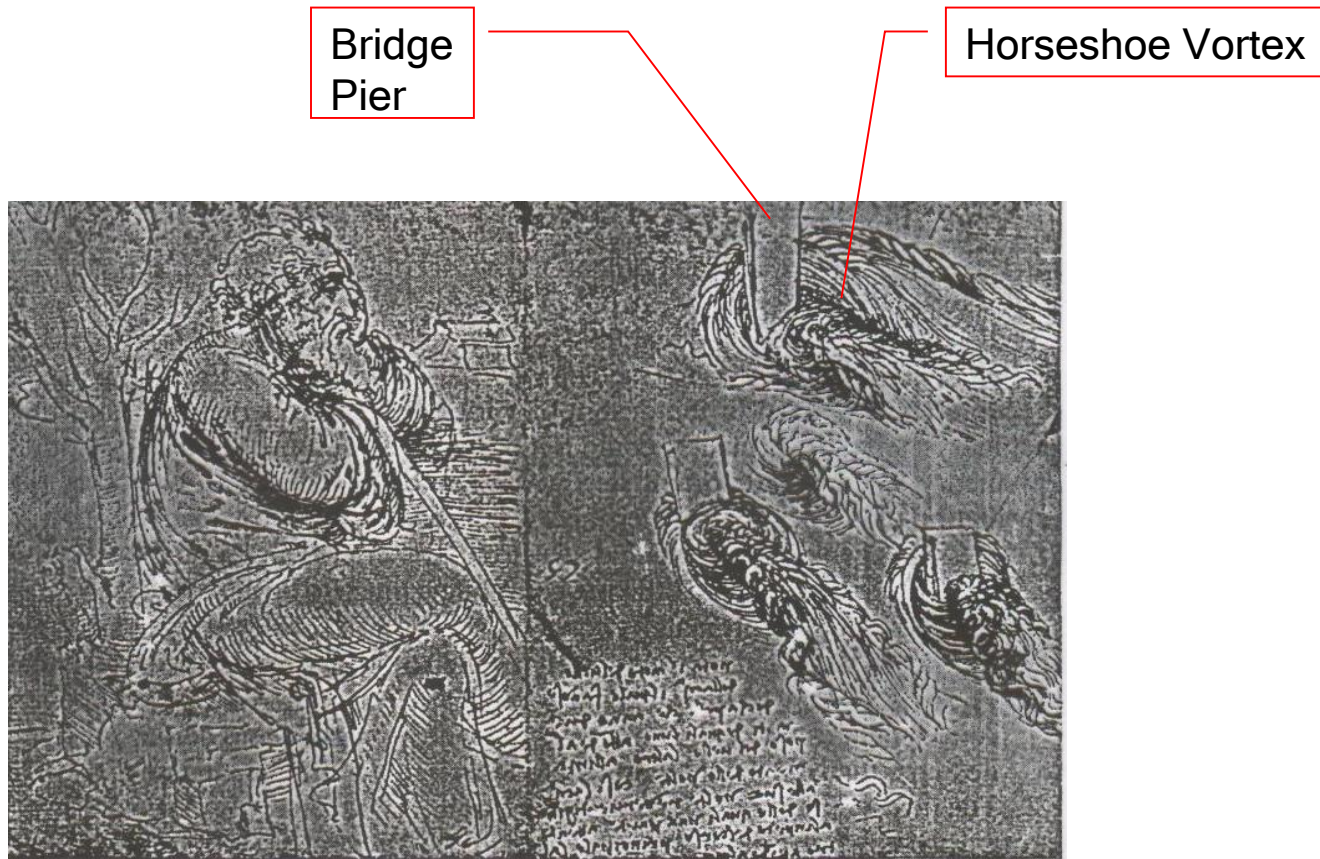
0.8 River Recreation

# Chapter 0 Why Fluid Mechanics?

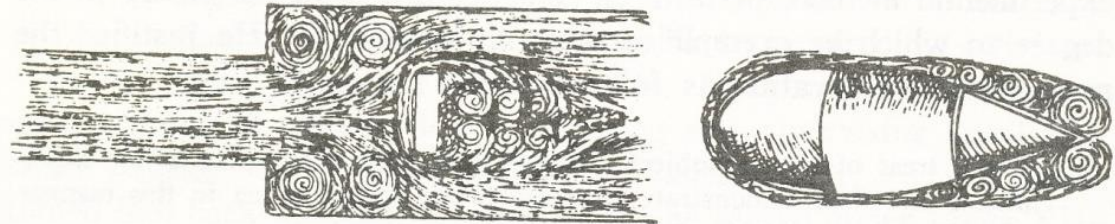
## Objectives

- Find your motivation to attend this class
- Introduce practical applications of fluid mechanics

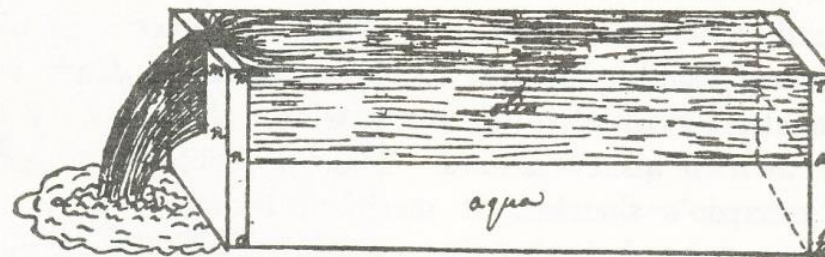
# 0.1 Speculation of Leonardo da Vinci



# 0.1 Speculation of Leonardo da Vinci



*Eddy formation in zones of separation.*



*Sketch by Leonardo of flow over a contracted weir.*



# 0.1 Speculation of Leonardo da Vinci



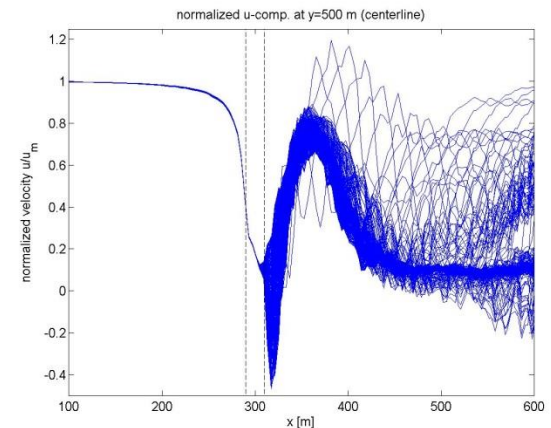
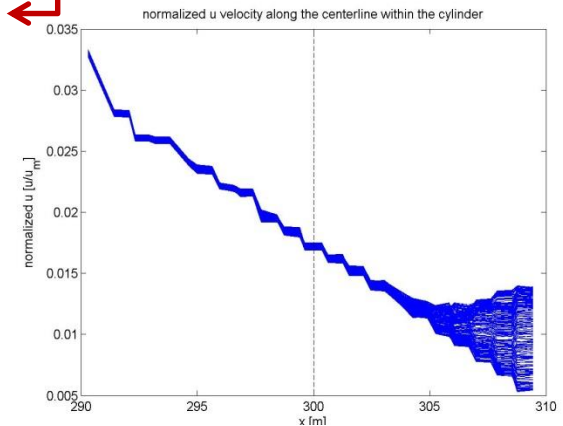
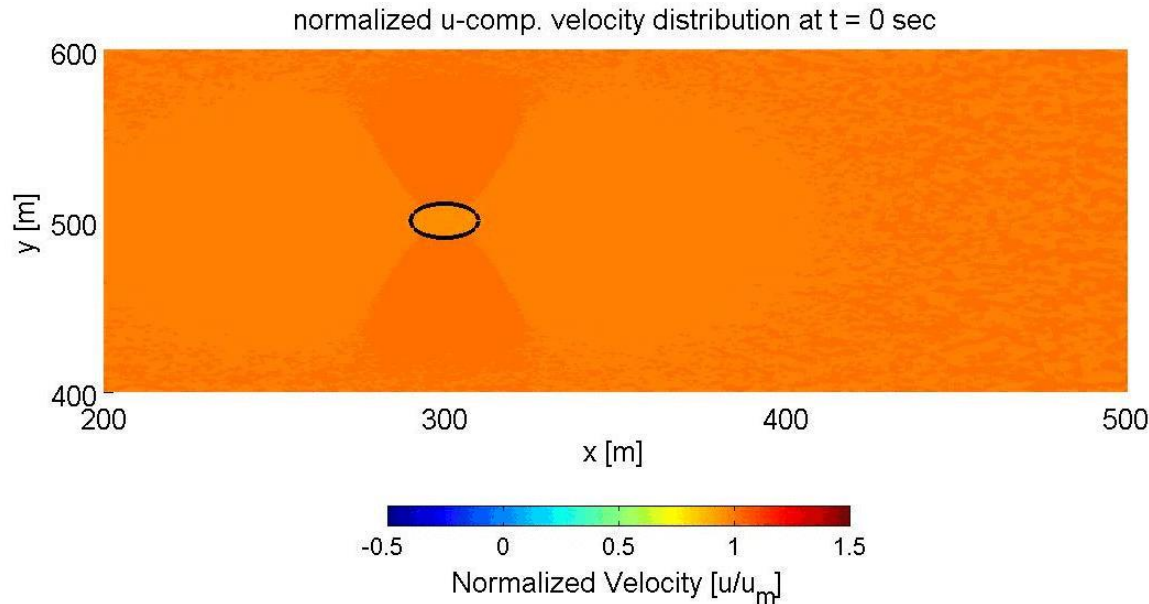
# Velocity field around/within a single cylinder

## □ Momentum reduction by quadratic drag law formulation.

- Governing equations including the drag law formulation.

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -g \frac{\partial h}{\partial x} + \nu_H \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - C_{DB} \frac{\sqrt{u^2 + v^2}}{H} u + F_{D,x}$$

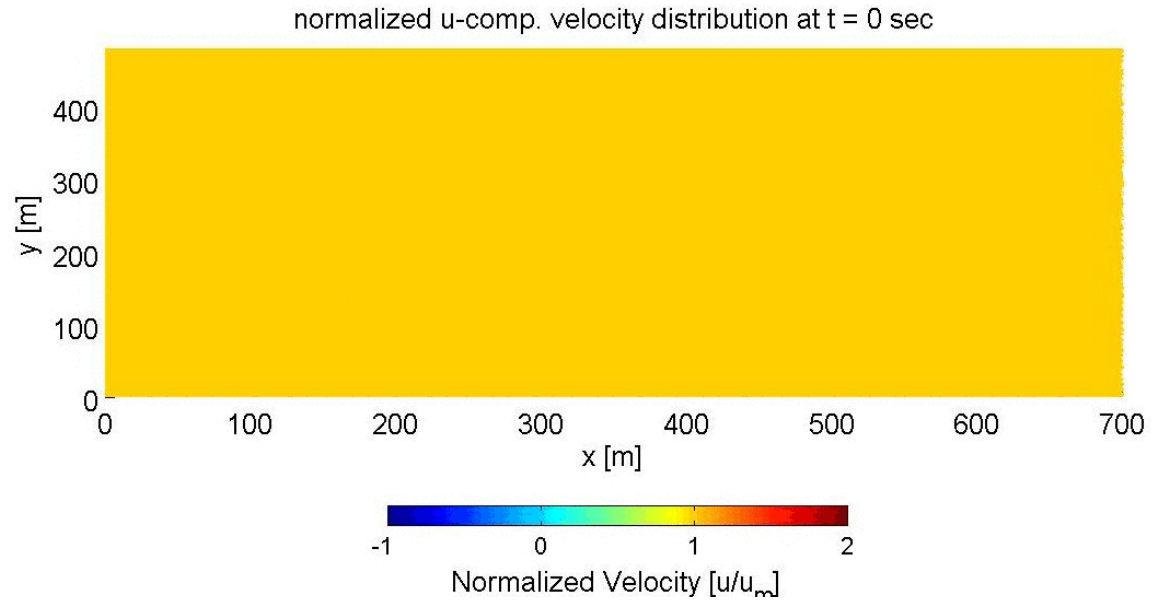
$$F_{D,x} = -\frac{\alpha C_D (u^2 + v^2)^{1/2}}{D} u,$$



# Velocity fields

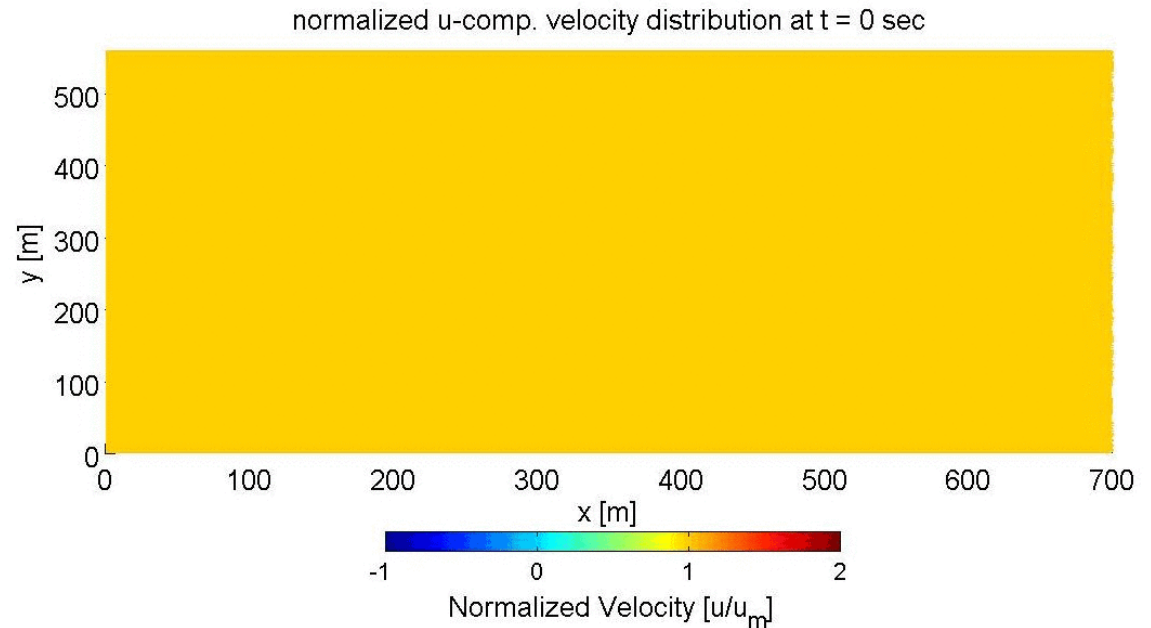
$$L_G/D = 2$$

$$L_T/D = 2$$



$$L_G/D = 2$$

$$L_T/D = 4$$

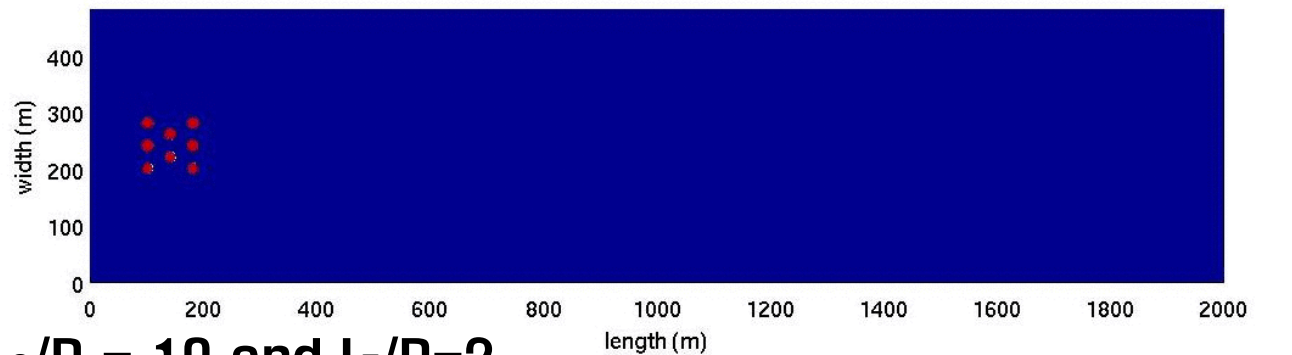


# Staggered array cases

## □ Mixing around staggered arrays

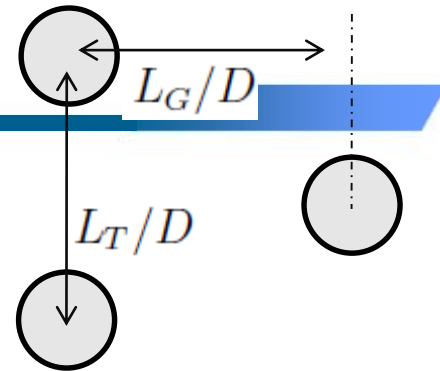
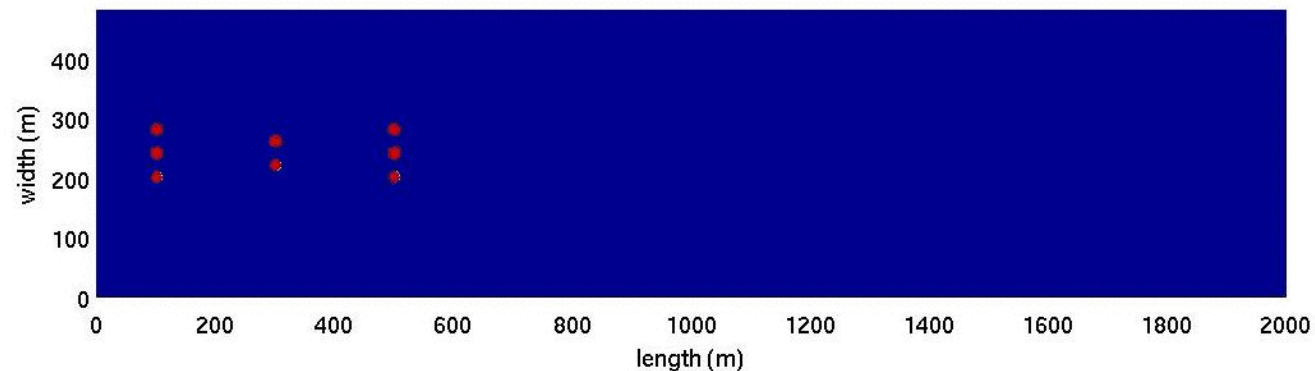
–  $L_G/D = 2$  and  $L_T/D = 2$

$t = 0.00$  sec



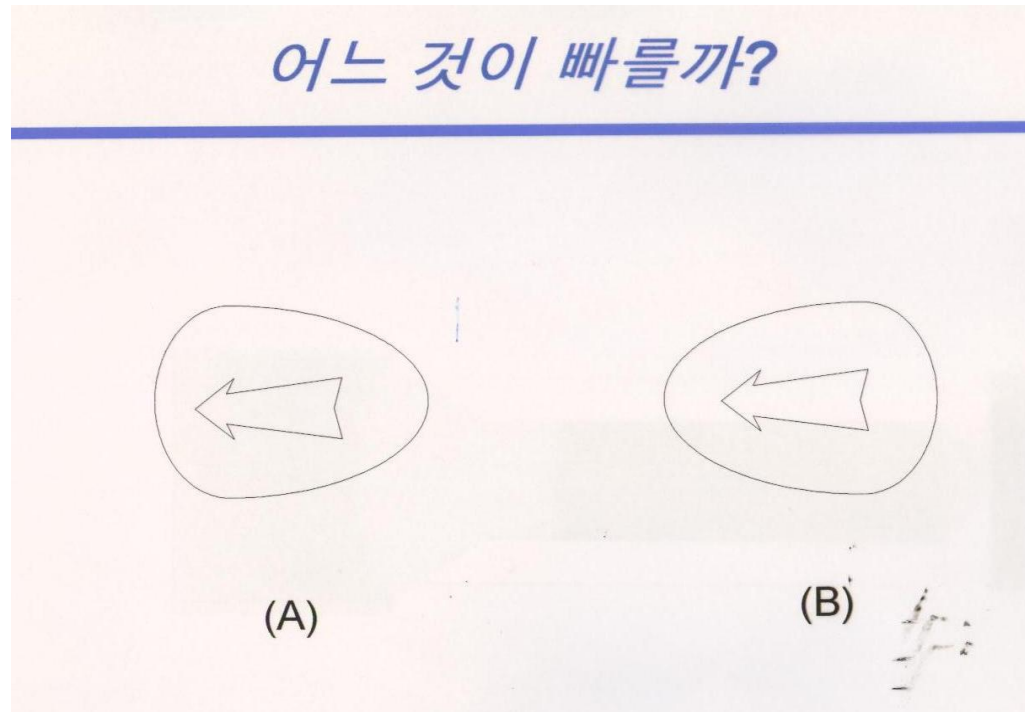
–  $L_G/D = 10$  and  $L_T/D = 2$

$t = 0.00$  sec

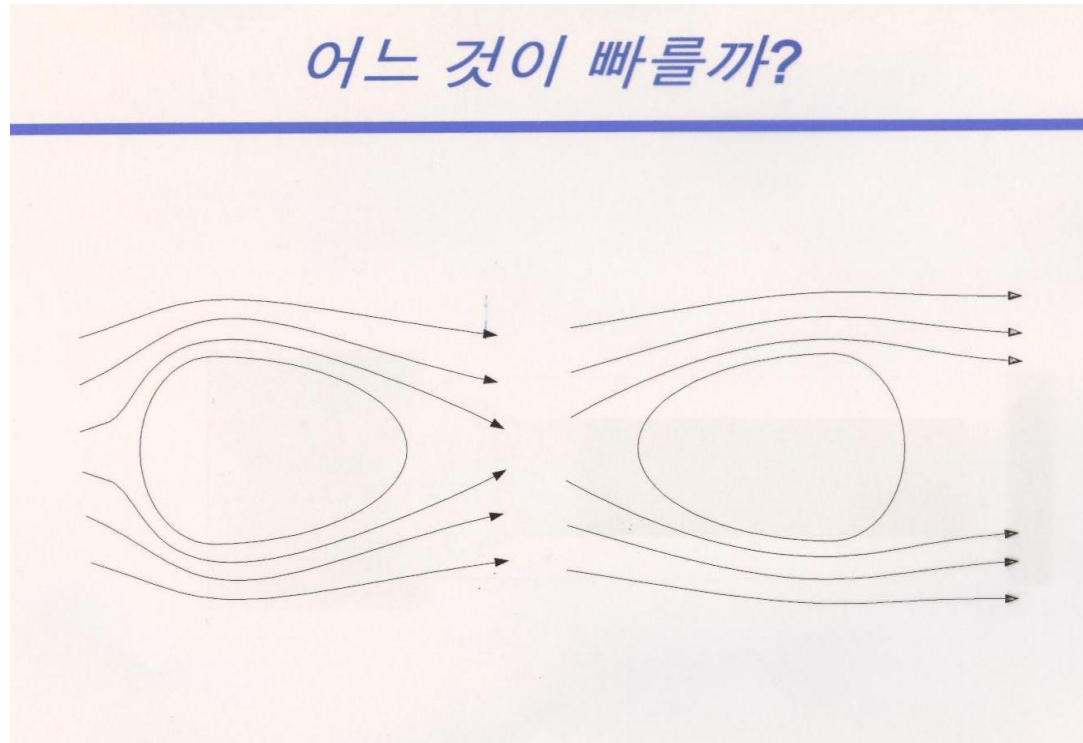




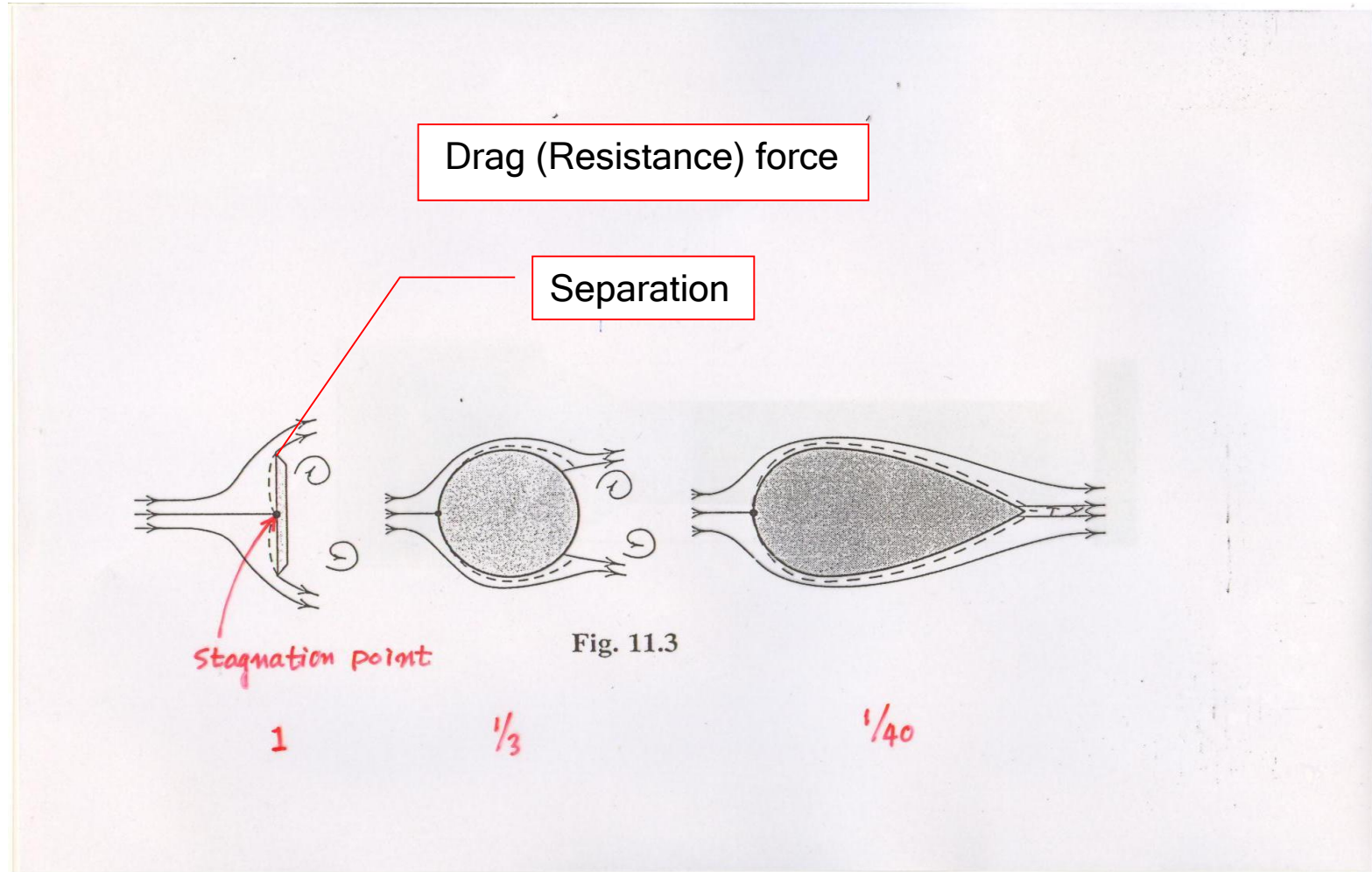
## 0.2 Physics of Golf



## 0.2 Physics of Golf

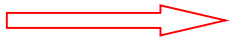


## 0.2 Physics of Golf

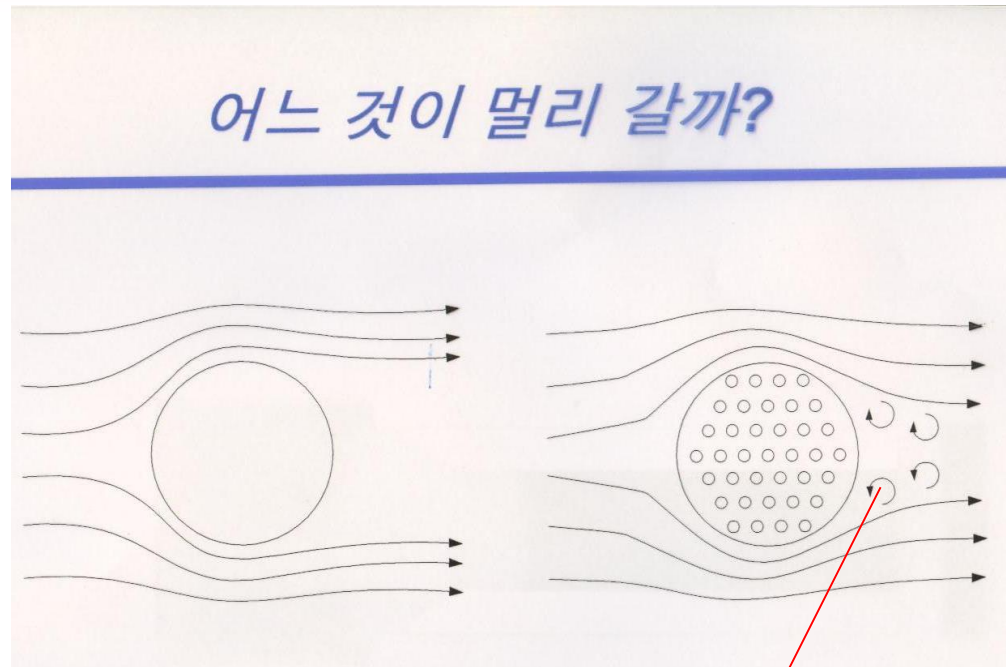


## 0.2 Physics of Golf

어느 것이 빠를까?



## 0.2 Physics of Golf



Turbulent  
Eddy

# 0.2 Physics of Golf

## Feathery Ball



Last feathery made by Robertson, in 1852

## Guttie Ball



Smooth ball made by Robertson in 1852



Red, hand-hammered guttie for use in snow



Hand-hammered Robertson guttie from the 1850s



Guttie ball stamped with a distinctive circle marking

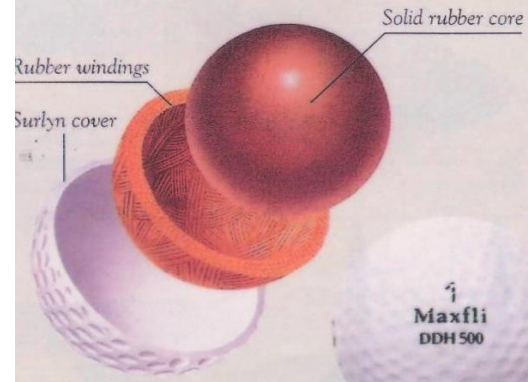


# 0.2 Physics of Golf

## Rubber-core Ball

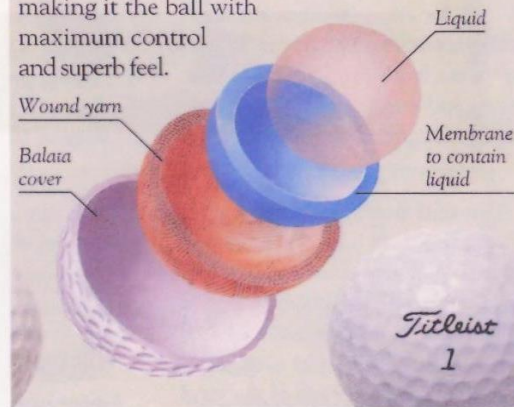
### THREE-PIECE (SURLYN COVER)

This version of the three-piece wound ball has a solid rubber core over which rubber yarn is wound for good control. The cover is made from Surlyn, a thermoplastic resin that is harder than balata and is thus considerably more durable; it is virtually uncuttable.

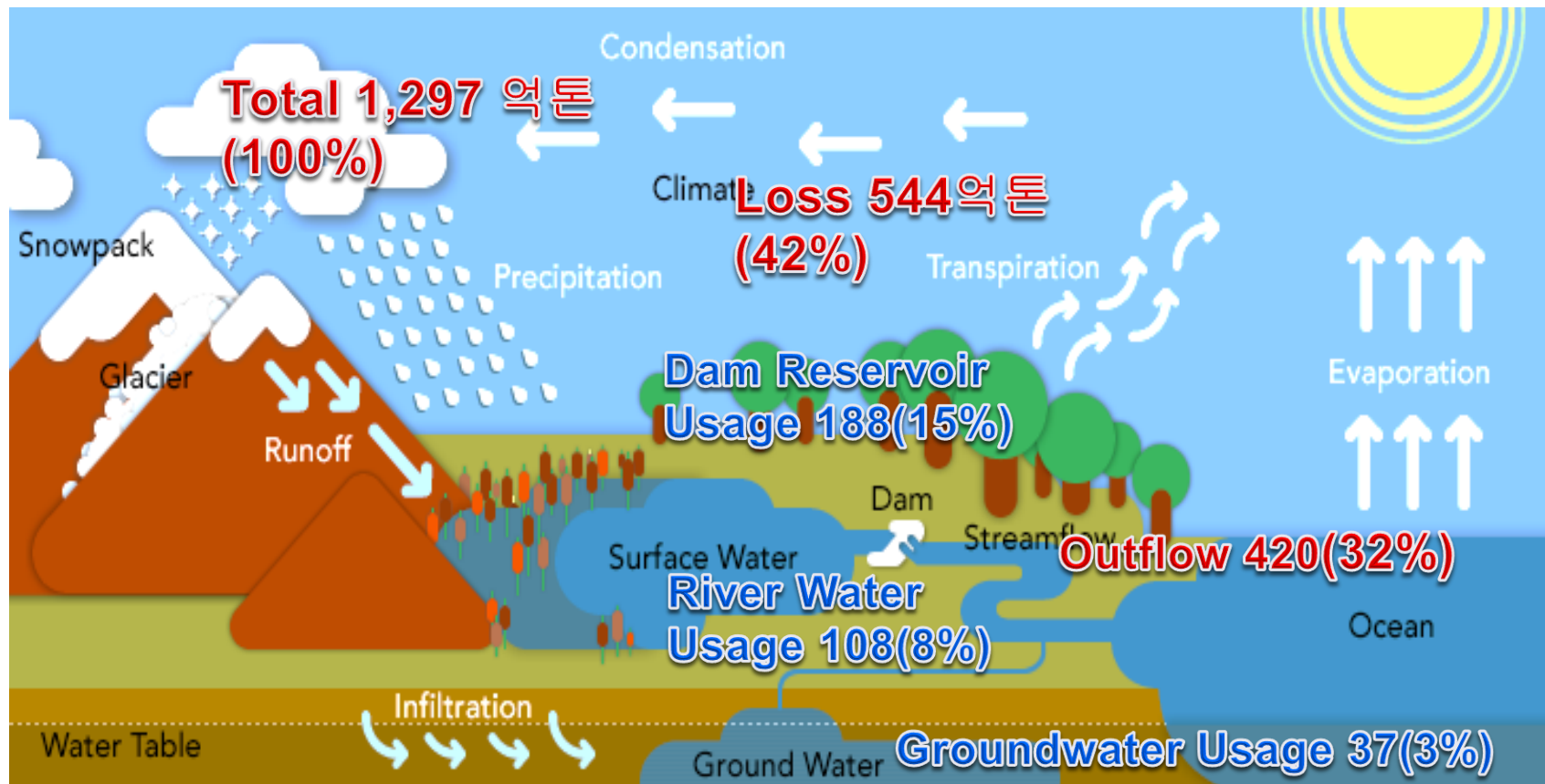


### THREE-PIECE (BALATA COVER)

The balata-covered, liquid-centred three-piece ball might be described as the most advanced of golf balls. The wound construction over a liquid centre, combined with a soft, synthetic balata cover, produces the highest spin rate, making it the ball with maximum control and superb feel.



# 03 Water Resources

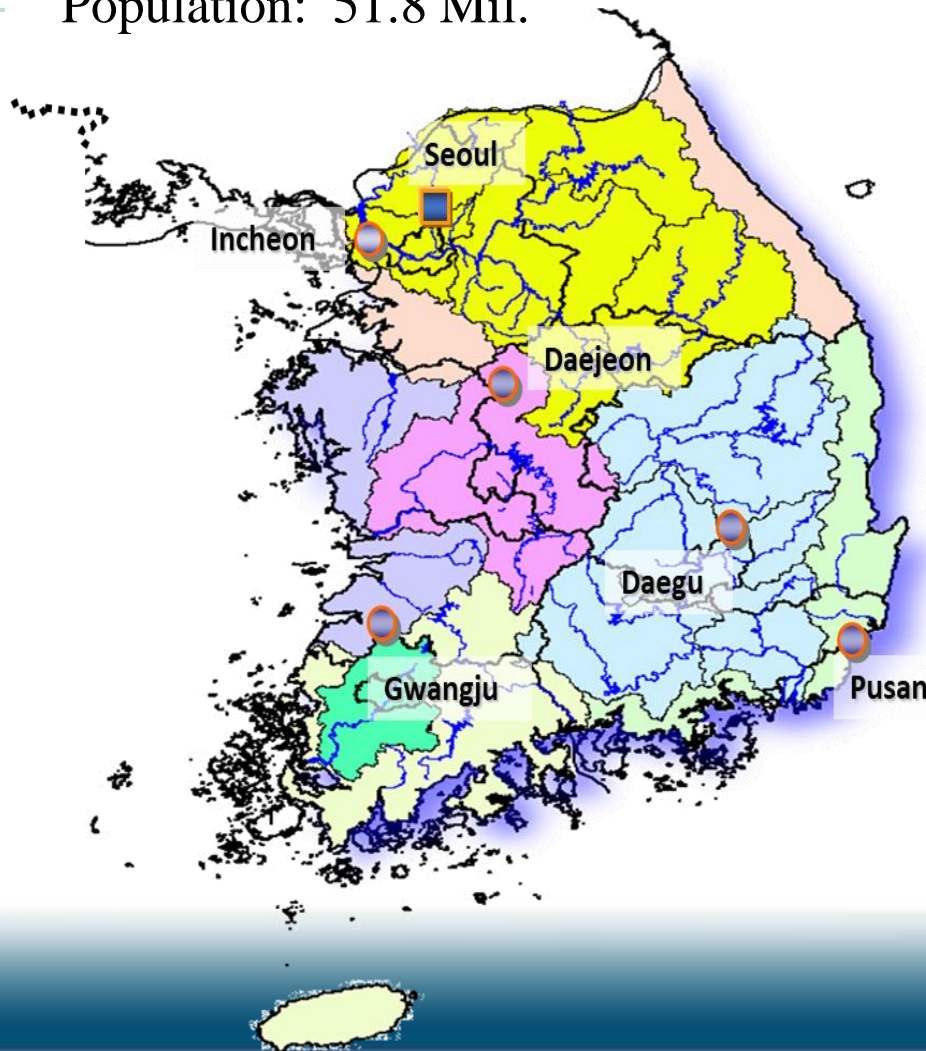


**Total water usage 333 억톤 (26%)**



# Water Resources in Korea

- Annual precipitation: 1,281 mm/yr
- Land area: 99,460 km<sup>2</sup>
- Population: 51.8 Mil.



Water Demand	억 m <sup>3</sup> (%)
Drinking	76 (20.4)
Industrial	23 (6.2)
<b>Agricultural</b>	<b>152 (40.9)</b>
River environments	121 (32.5)
Total	372

Water Supply	억 m <sup>3</sup> (%)
Dam reservoir	188 (56.5)
River	108 (32.4)
Groundwater	37 (11.1)
Total	333

## 0.4 Dams



### <Chungju Dam>

H 97.5 m; L 464 m

Storage: 2.75 billion m<sup>3</sup>

Power: 400,000 kW



## 0.4 Dams



<Daechung Dam>  
H 72 m; L 495 m  
Storage: 1.49 billion m<sup>3</sup>



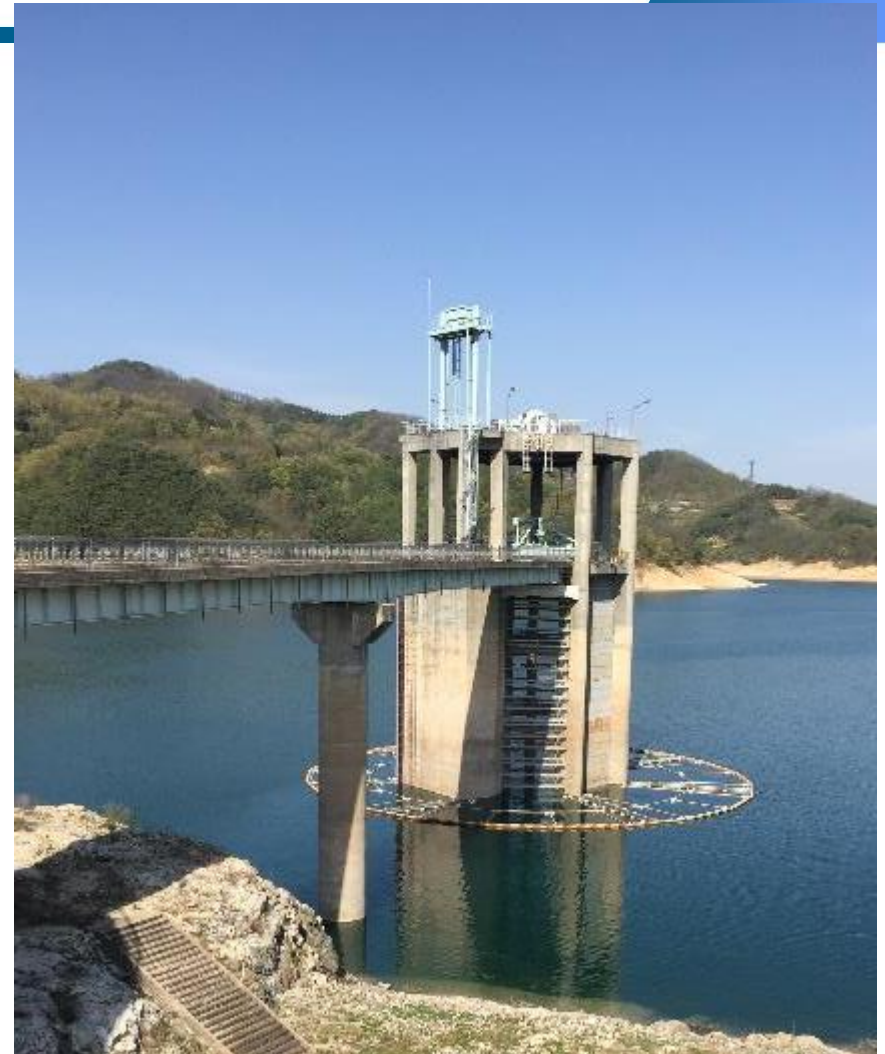
<Soyang Dam>  
H 123 m; L 530 m  
Storage: 2.9 billion m<sup>3</sup>



## Water Supply System




Paldang dam



Andong dam

# 0.5 Hydropower Plants



**Scottish Hydro**  
energy made better

## Welcome to Pitlochry Fish Ladder, Dam and the Scottish Hydro Electric Visitor Centre

Scottish Hydro Electric carefully manages the flow of water on rivers where there are hydro electric schemes, by releasing a regulated water flow downstream of its dams. This is called compensation water and it is used to help maintain the natural water environment.

Here at Pitlochry, you can see this care for the environment in action. Salmon and sea-trout migrate upstream in spring, summer and early autumn before spawning in the late autumn. Most male salmon die after spawning, around 20% of the females survive and attempt to migrate back to the sea. The majority do not survive to return another year.

At first, the dam appears to form an impenetrable barrier.


To overcome this, the series of pools in front of you form a fish pass that enables fish to safely migrate.

This fish pass, also known as a 'ladder' is 310 metres long. It comprises a series of 34 pools, including three 'resting pools', connected by underwater pipes. Each pool is 50 centimetres higher than the last.

There are three exit points from the top of the ladder into Loch Faskally so the fish can enter the loch regardless of the water level.

A counter records the number of fish that migrate through the pass. These are sophisticated devices that even distinguish which way the fish are swimming.

The Fish Ladder principle

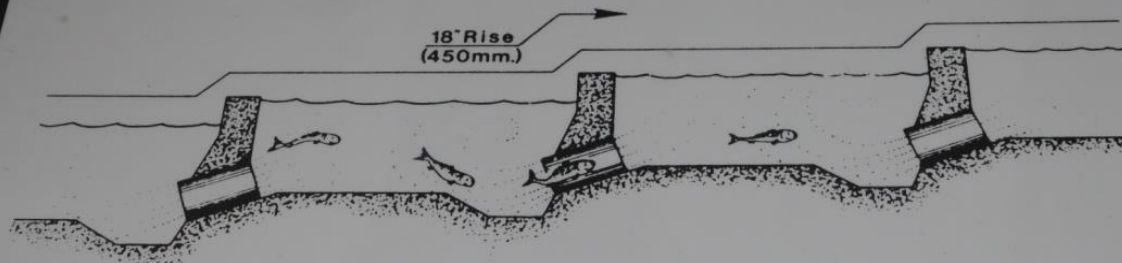


# 0.5 Hydropower Plants

## PITLOCHRY FISH PASS

Between April and October salmon return from their Atlantic feeding grounds to the rivers where they were born in order to lay their eggs. The flow of water from the bottom of the fish ladder attracts them into the first pool and from there they go in 18" (450mm) steps through connecting pipes from pool to pool until they have climbed the height of the dam.

Three resting pools, spaced among the other thirty-one, provide patches of slack water for a break in the struggle against the current.



## SECTION OF FISH LADDER

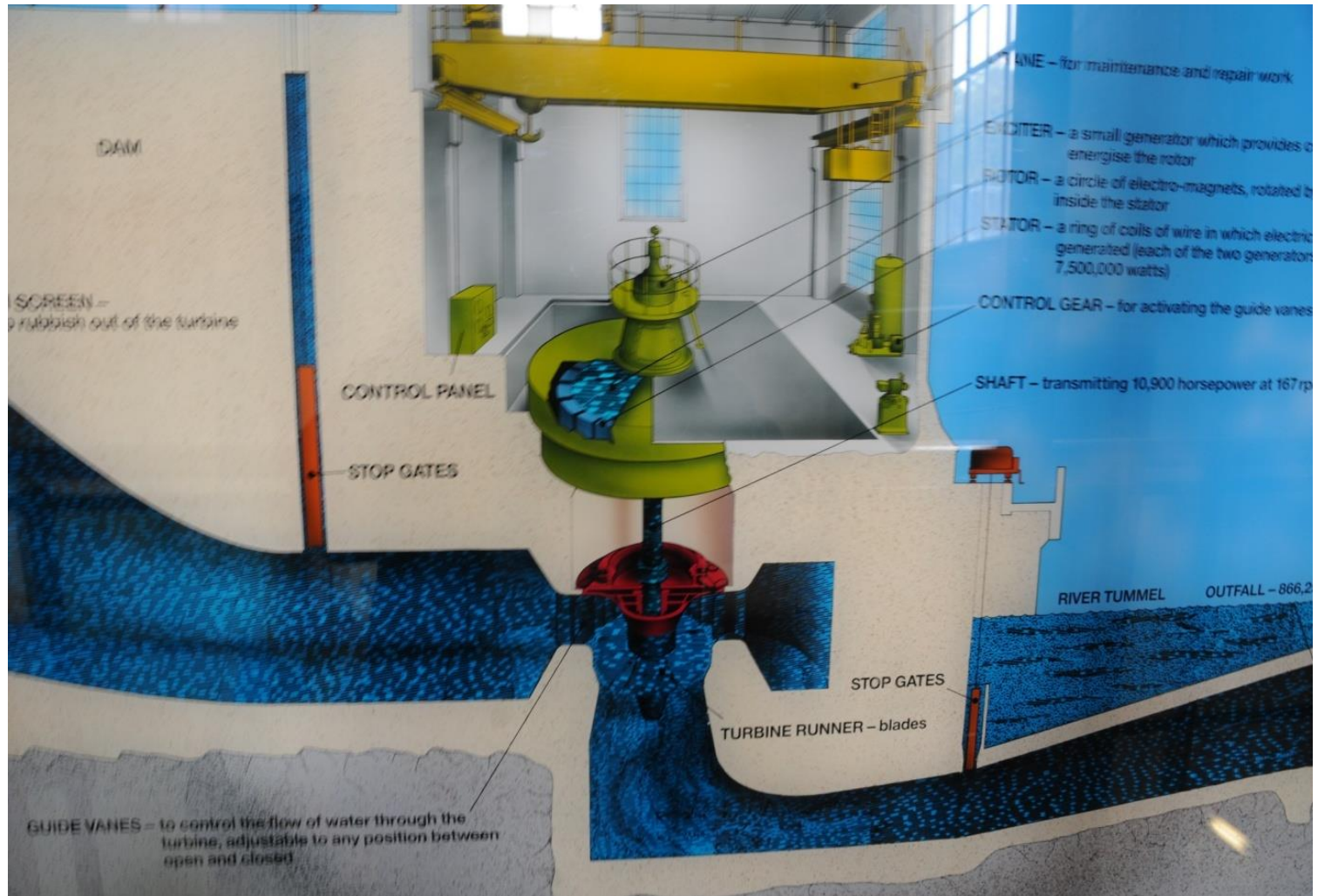
In late autumn the female salmon, with a male in attendance, makes a trough in the gravel of the river bed, lays her eggs and covers them with gravel. The young fish hatch in spring and wriggle up through the gravel in search of food. They live and grow in the river for one to four years before travelling downstream on their way to the sea.



# 0.5 Hydropower Plants



# 0.5 Hydropower Plants



Francis turbine





<Yubari Dam>

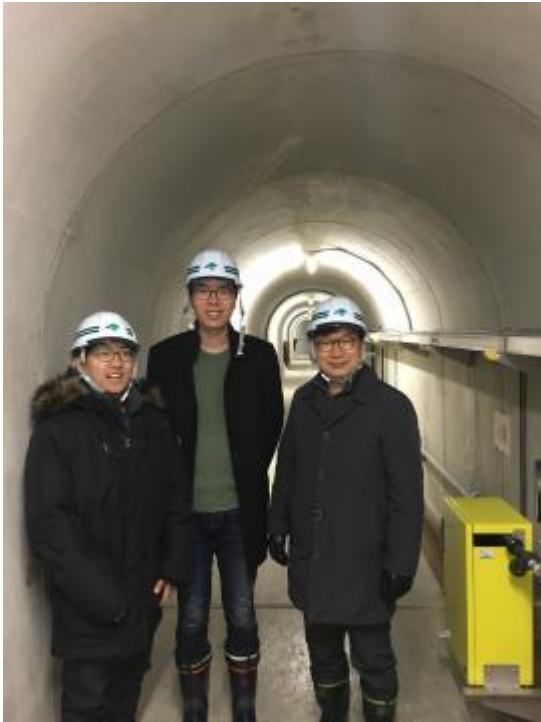
H: 110 m

L: 390 m

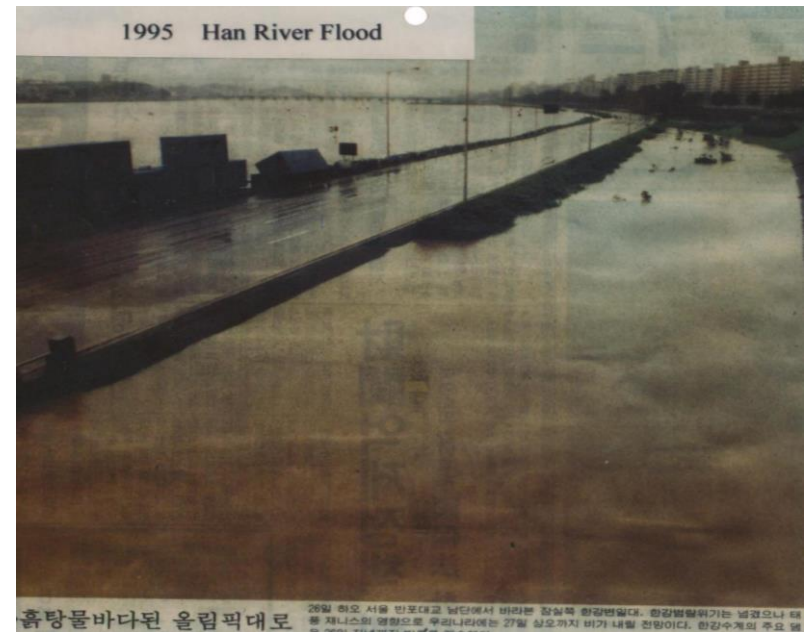
Storage: 0.43 billion m<sup>3</sup>

Power: 26,000 kW

< Yubari Dam, Hokkaido, Japan>



# 0.6 Flood Control





## 0.6 Flood Control

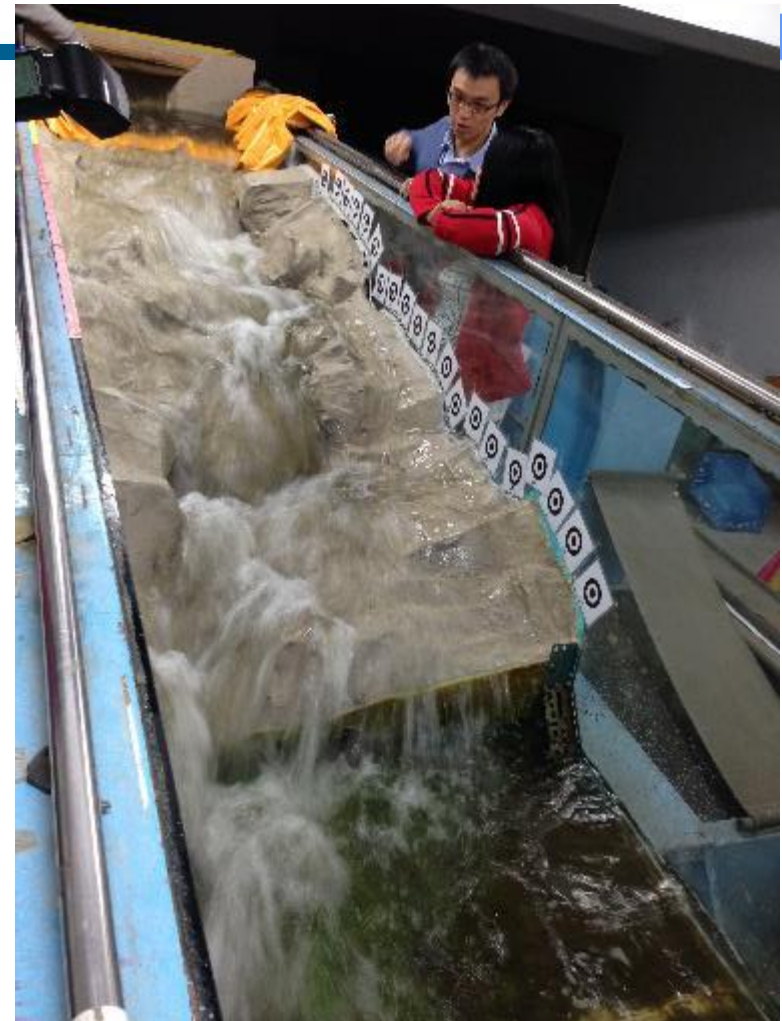


Flood on Sept., 2011





Flood way, Jeju, Korea



Flood test, NTU Channels



## 0.7 River Navigation



Mississippi River



Neckar River, Germany



Falkirk Wheel, UK

# Ara Canal

Canal:

L: 18 km; W: 80 m; H: 6.3 m







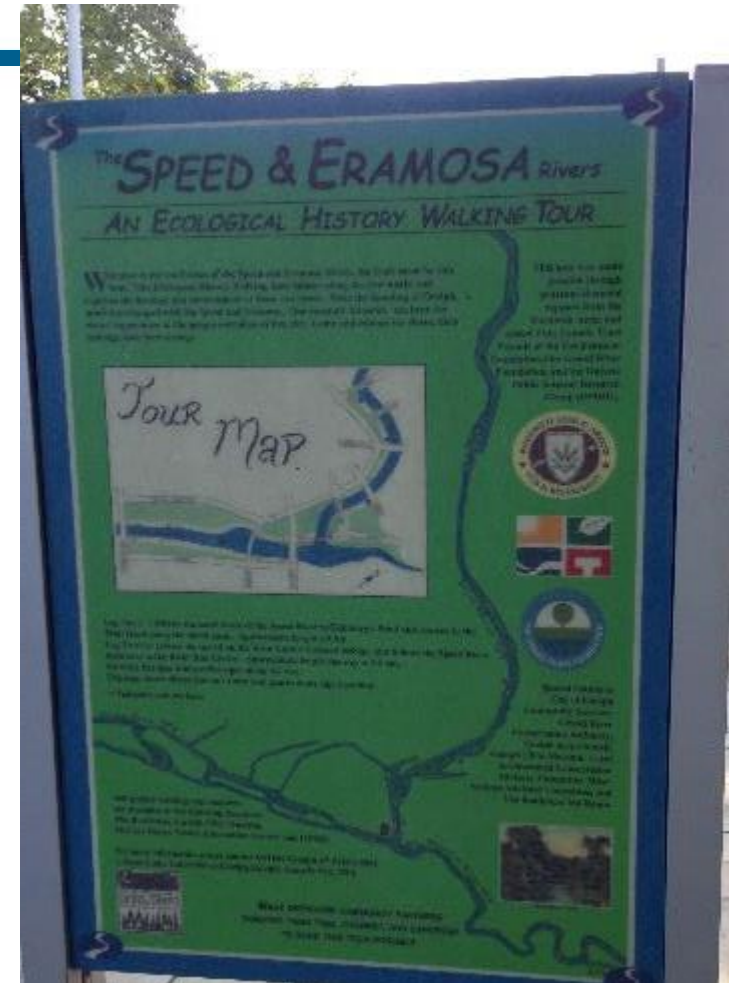


# 0.8 River Recreation



Cherry Creek, Colorado

## 0.8 River Recreation



Grand River, Canada