Renovation of Shihmen Reservoir for Sustainability

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GT International

Presentation Outline

1. Environment Induced Water Challenges in Taiwan
2. Role of Reservoir and Condition of Siltation
3. Problems Caused by Typhoon Aere in 2004
4. Measures to Secure Potable Water Supply Following Storms
5. Measures to Secure Reservoir Volume for Sustainability
6. Concluding Remarks

1. Environment Induced Water Challenges in Taiwan

Geographic location of Taiwan

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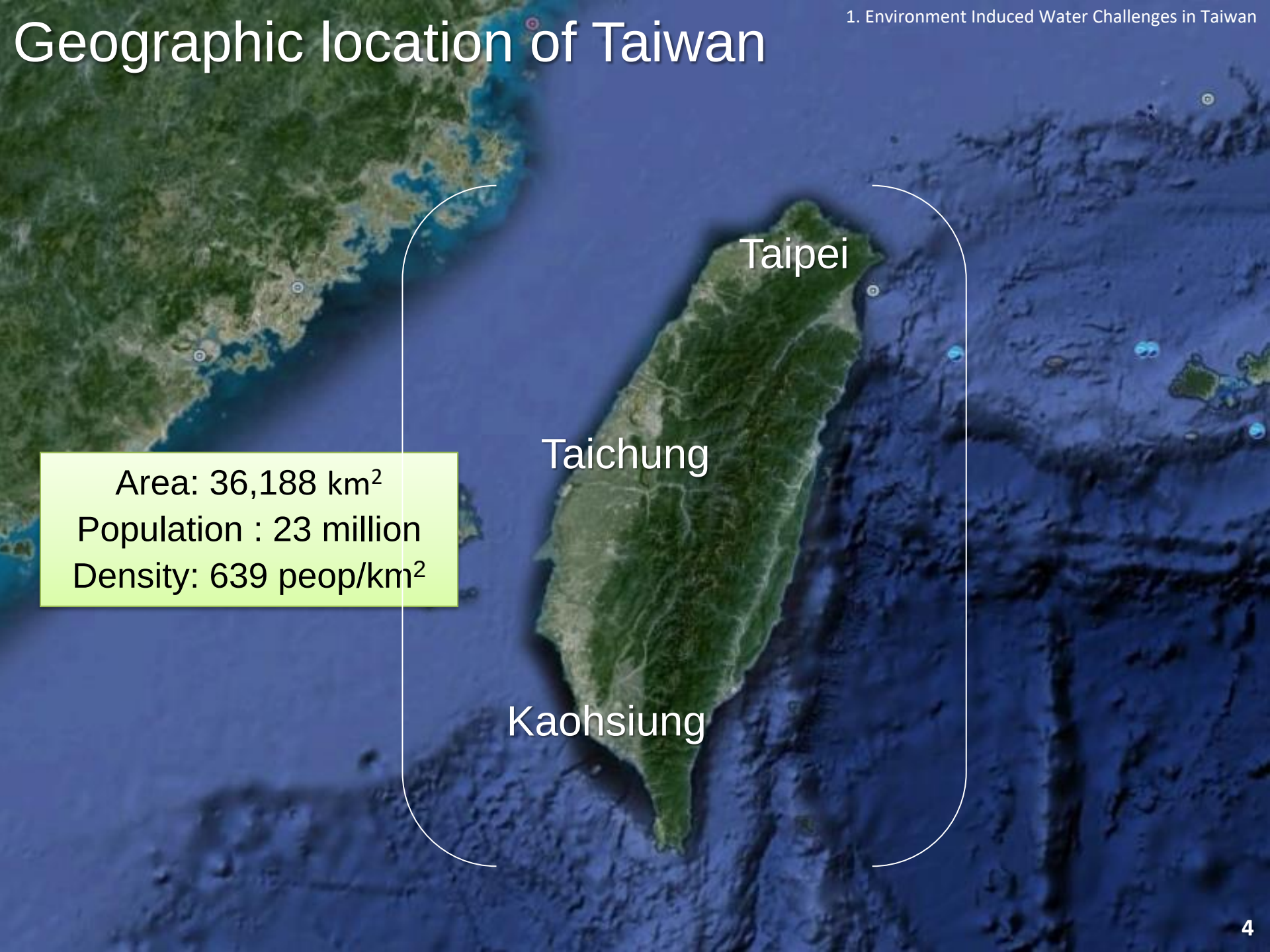
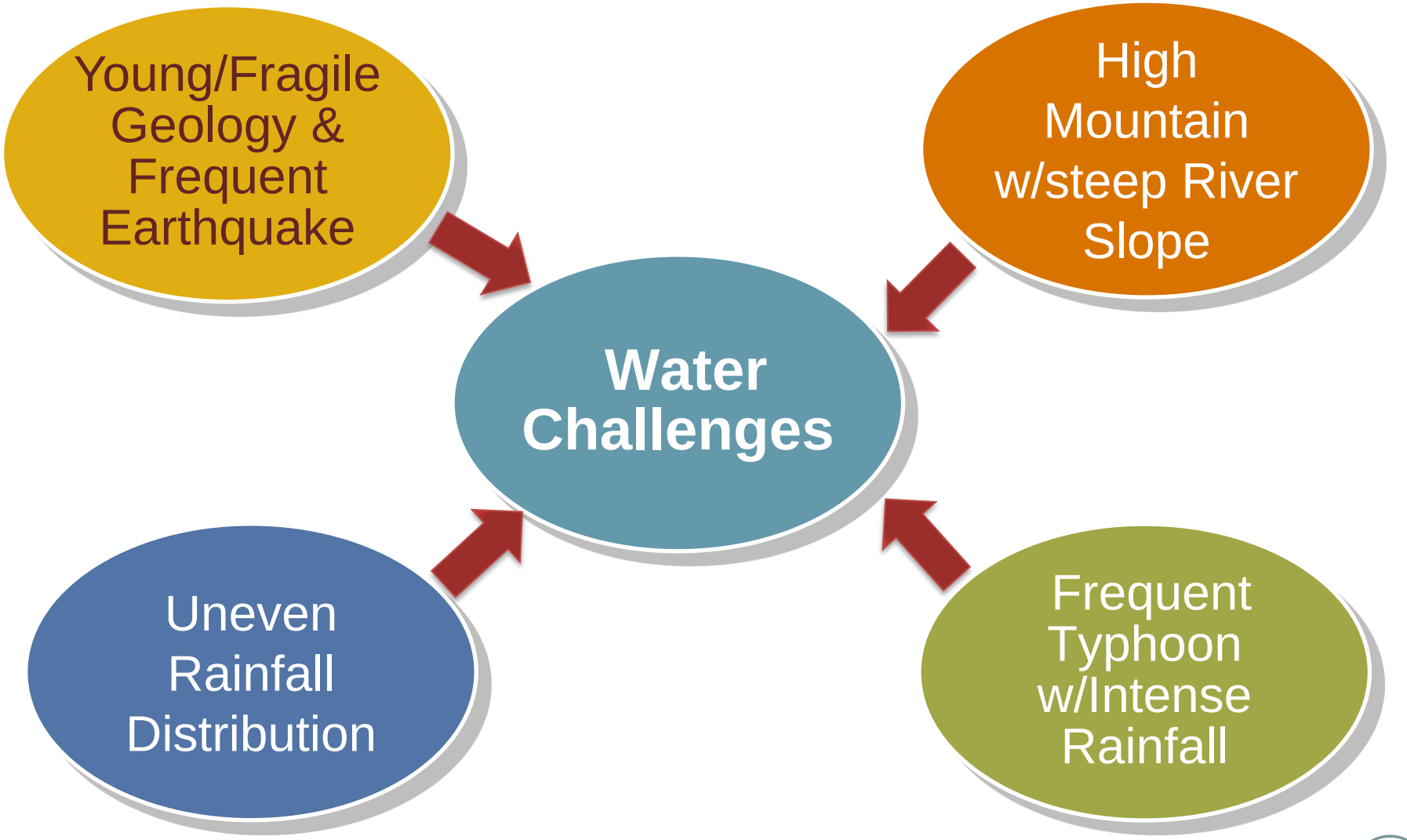


Area: 36,188 km^2
Population : 23 million
Density: 639 peop/km^2

Environment and Water Challenges

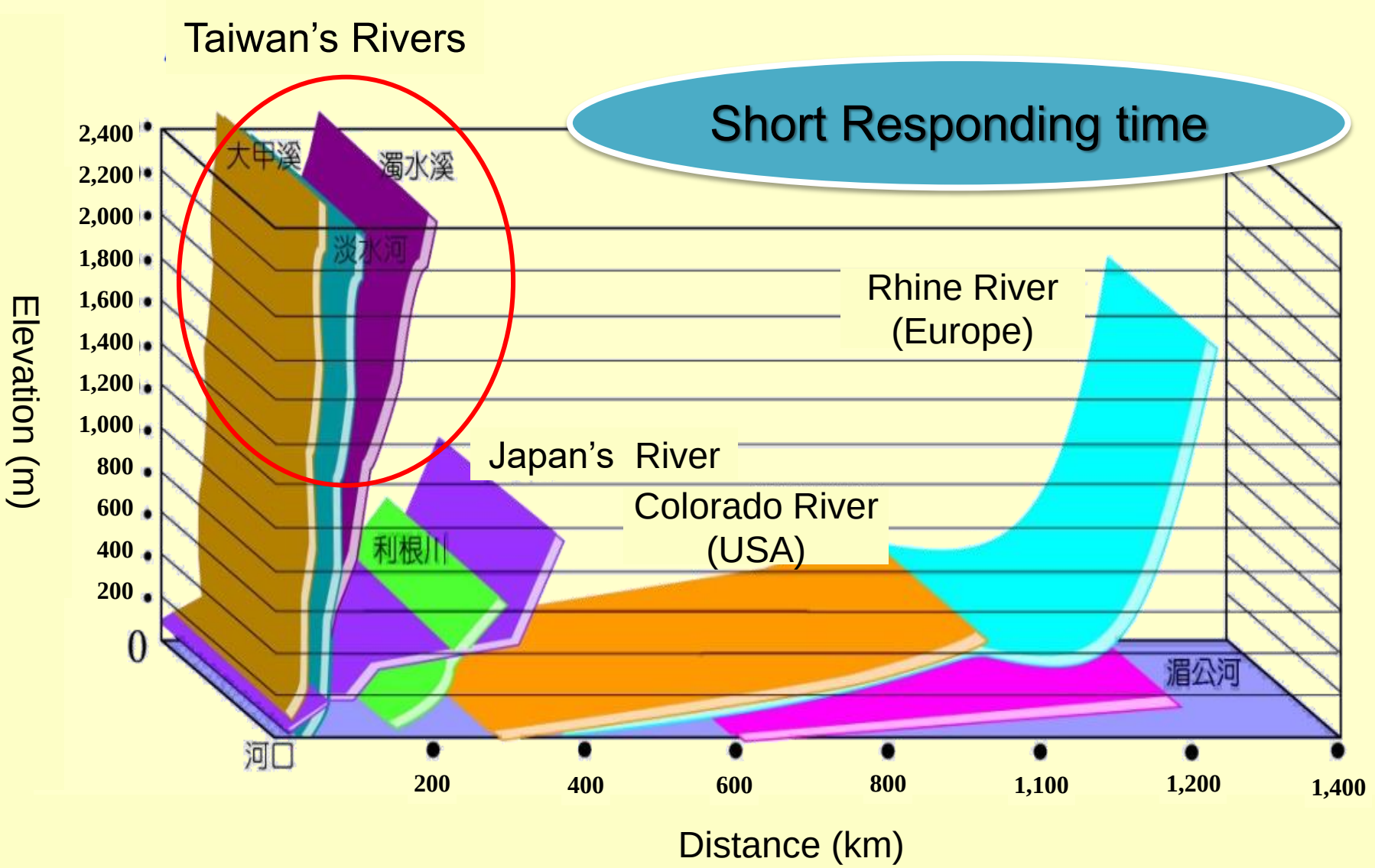


Challenge 1 – Young and Fragile Geology

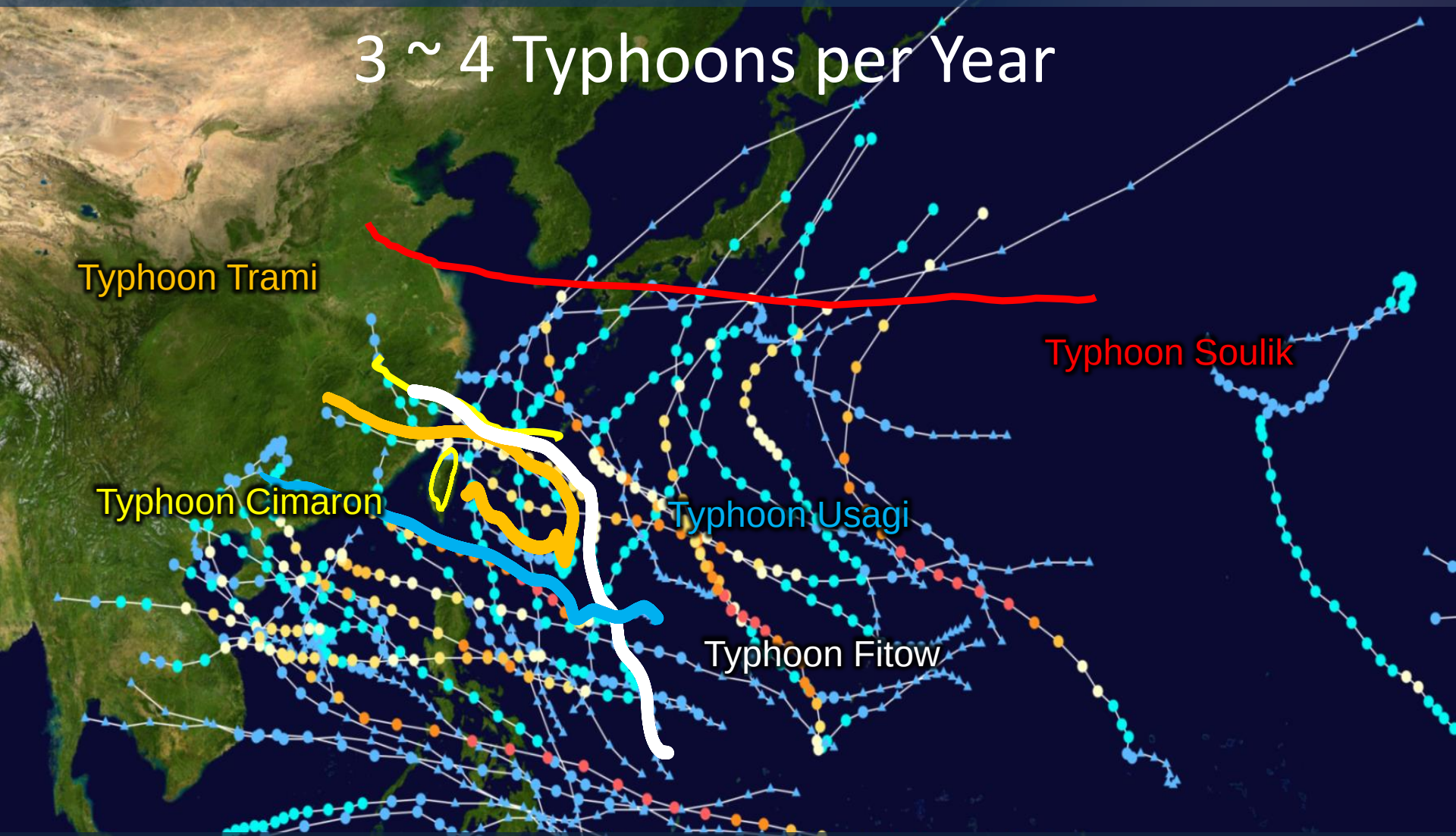
Stratigraphic age ≒2 million years

Challenge 2 – Steep Slope

Comparison of River Slope



Challenge 3 – Intense Rainfall



- 3~4 typhoons per year.
- High intensity, Long duration.

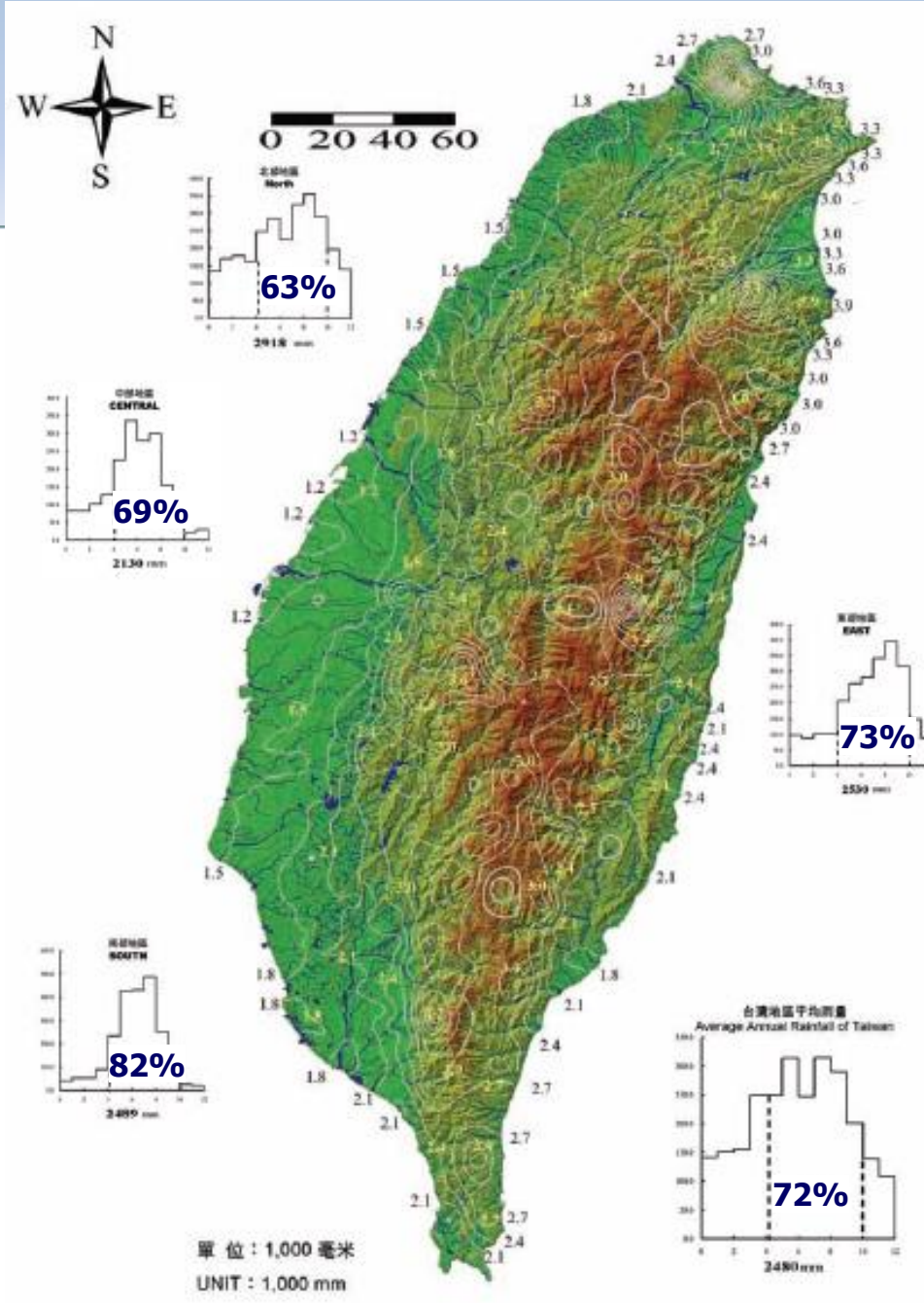
Taiwan Typhoon Rainfall Records

Rainfall			Typhoon	Location
Ranking	mm	Yr.		
1	3060	2009	MORAKOT	Chiayi County
2	2139	2001	NARI	New Taipei City
3	2162	1969	Tropical Storm FLOSSIE	Taipei City
4	1987	1996	HERB	Chiayi County
5	1834	1987	LYNN	Taipei City
6	1774	2012	SAOLA	Yilan County
7	1672	1967	CARLA	Yilan County
8	1611	2008	SINLAKU	Taichung City
9	1561	2005	HAITANG	Pingtung County
10	1546	2004	AERE	Miaoli County

Challenge 4- Uneven Rainfall Distribution

- Average Annual Precipitation in Taiwan (1949~2006): 2,515 mm

Region	Percent of Rainfall in Dry Season
North	37%
Central	31%
South	18%
East	28%



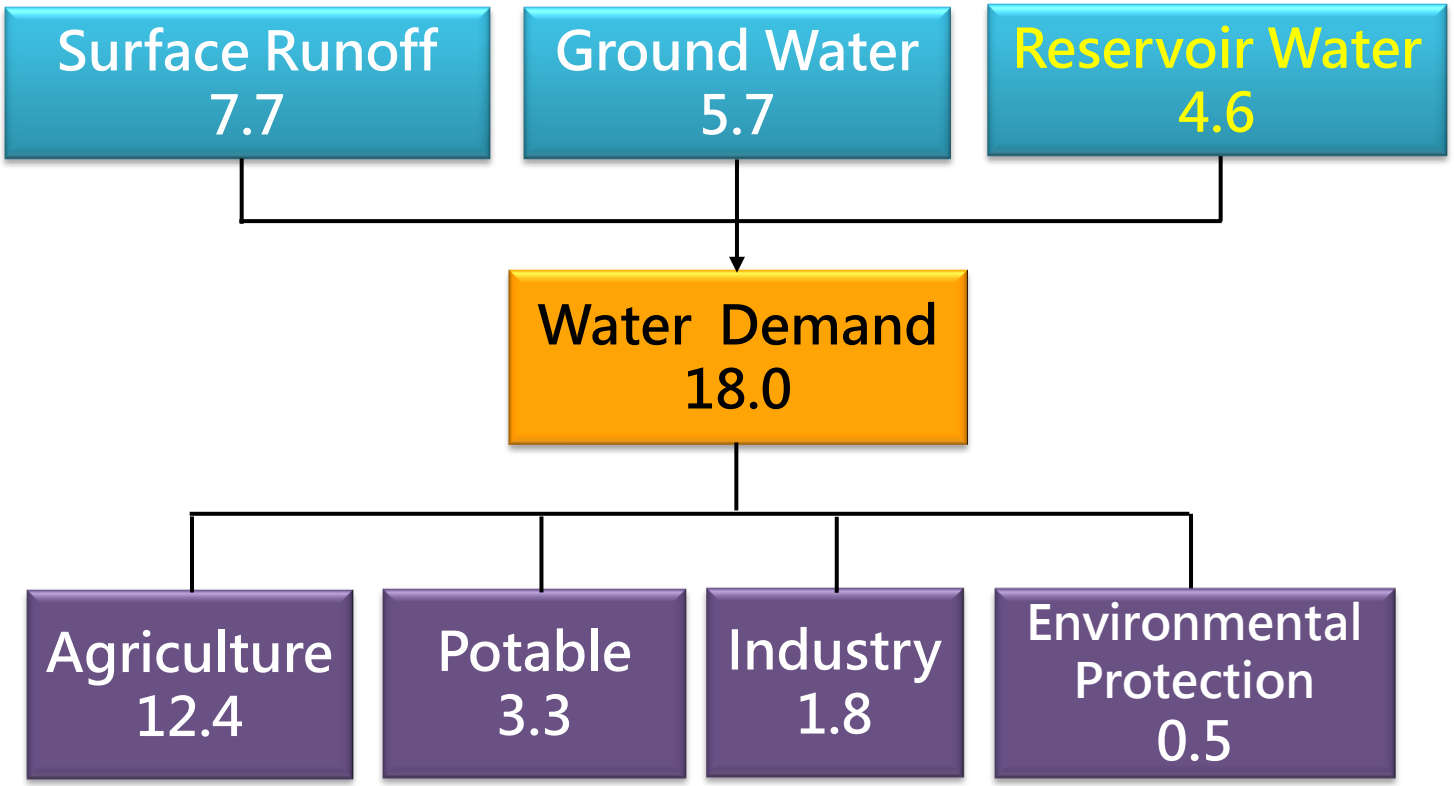
2. Role of Reservoir and Condition of Siltation

Water Use in Taiwan

Annual Rainfall Volume: $90\times10^9 m^3$

Total Reservoir Volume : $1.90\times10^9 m^3$

Unit: $10^9 m^3$

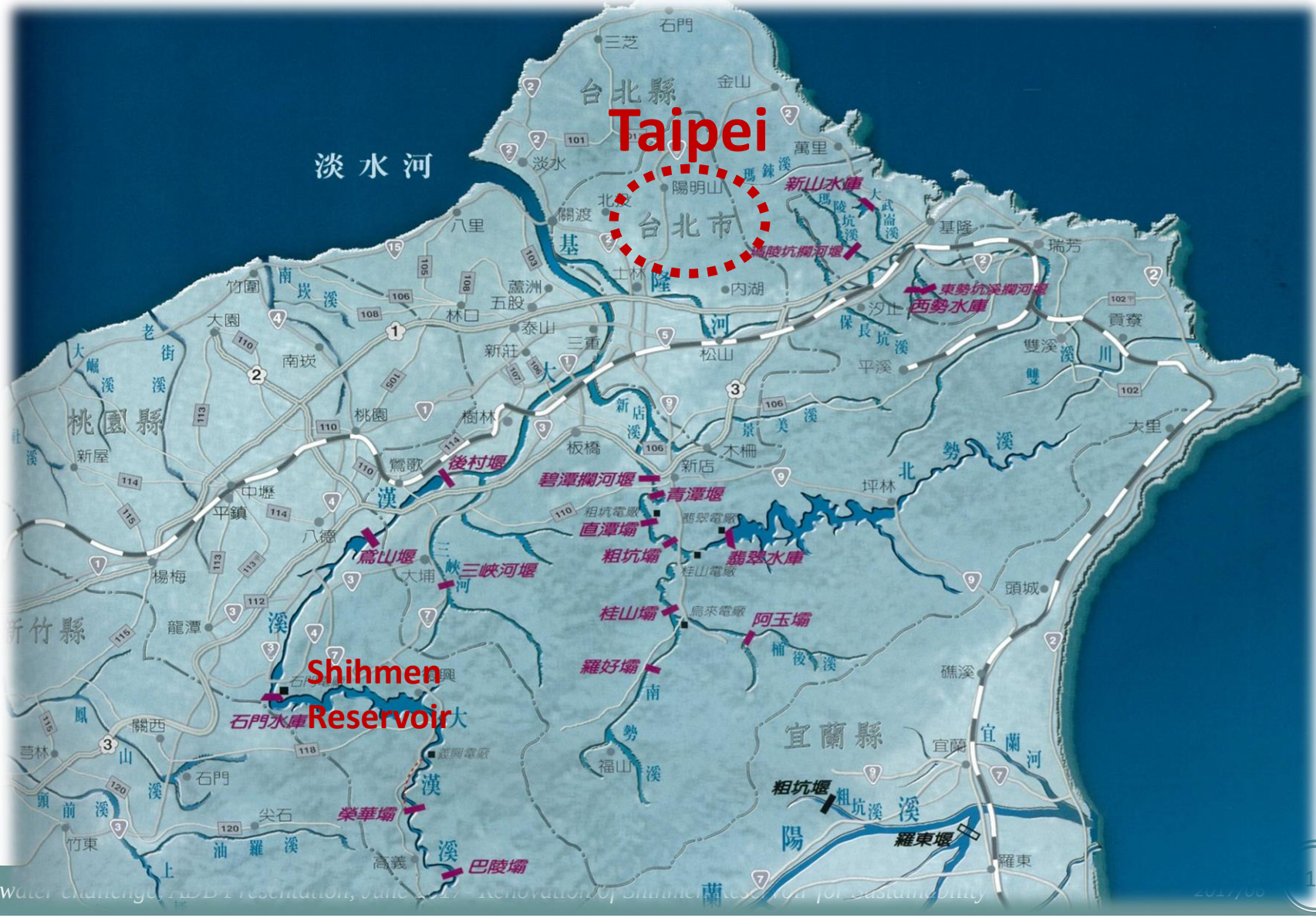


Volume of Main Reservoirs in Taiwan

Unit: $10^6 m^3$

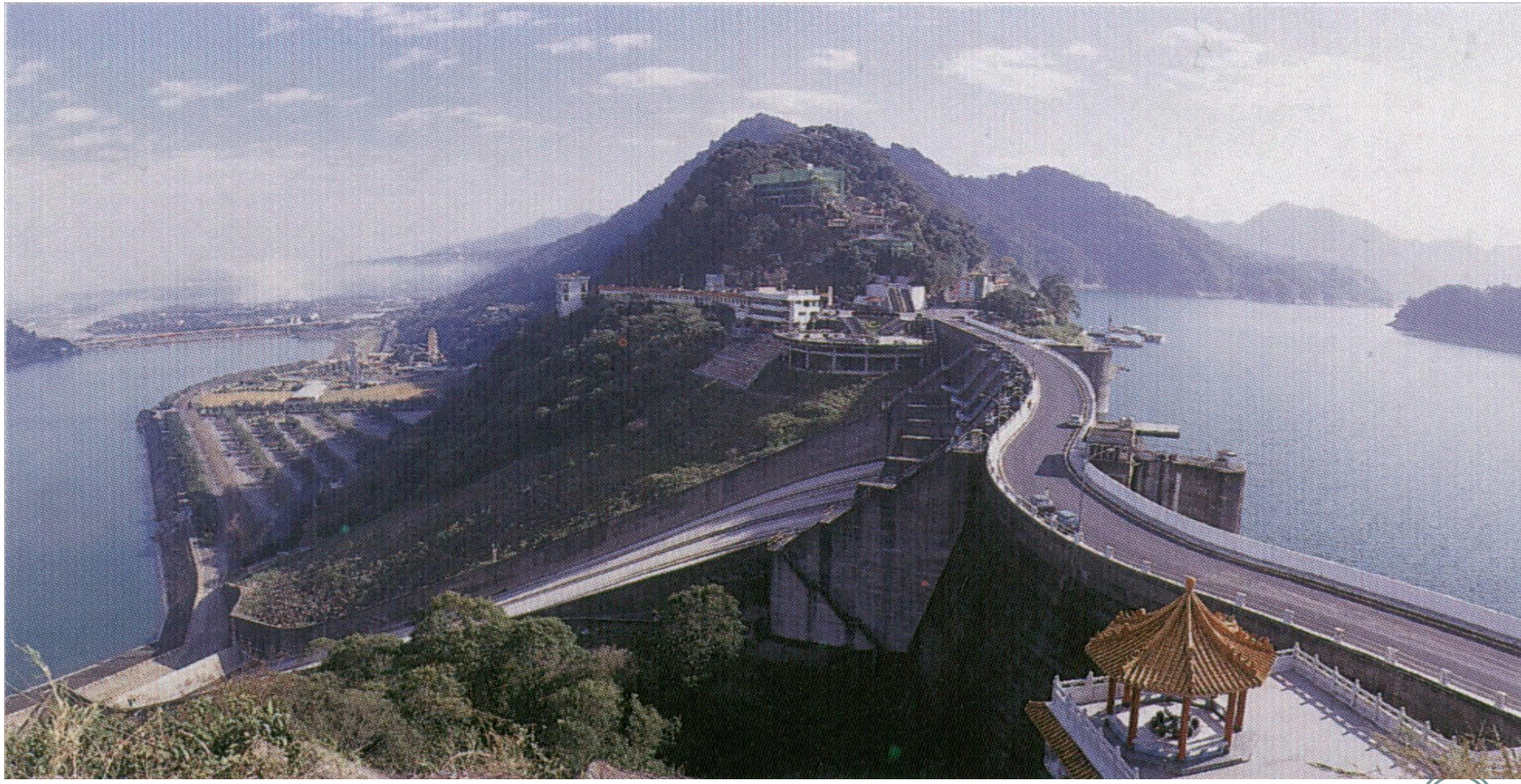
No.	Reservoir Name	Initial Volume	Current Volume
1	Shinshan (新　山)	10.00	9.97
2	Feitzai (翡　翠)	406.00	380.04
3	Shihmen (石　門)	309.12	204.71
4	Baoshan (寶　山)	5.47	5.50
5	Yuheshan (永和山)	29.58	30.23
6	Minder (明　德)	17.70	12.36
7	Dergi (德　基)	262.21	191.40
8	Wusher (霧　社)	150.00	44.86
9	Sunmoon Lake (日月潭)	171.62	142.56
10	Liyitan (鯉魚潭)	126.07	118.46
11	Zenyutan (仁義潭)	29.11	26.34
12	Lantan (蘭　潭)	9.80	9.80
13	Tsengwen (曾　文)	712.71	462.68
14	Nanhua (南　化)	154.41	95.00
15	Wushantou (烏山頭)	168.83	78.28
16	Mutan (牡　丹)	31.18	26.41
17	Chengkung (成　功)	1.08	1.21
SUM	-	2,594.89	1,839.81

Location of Shihmen Reservoir

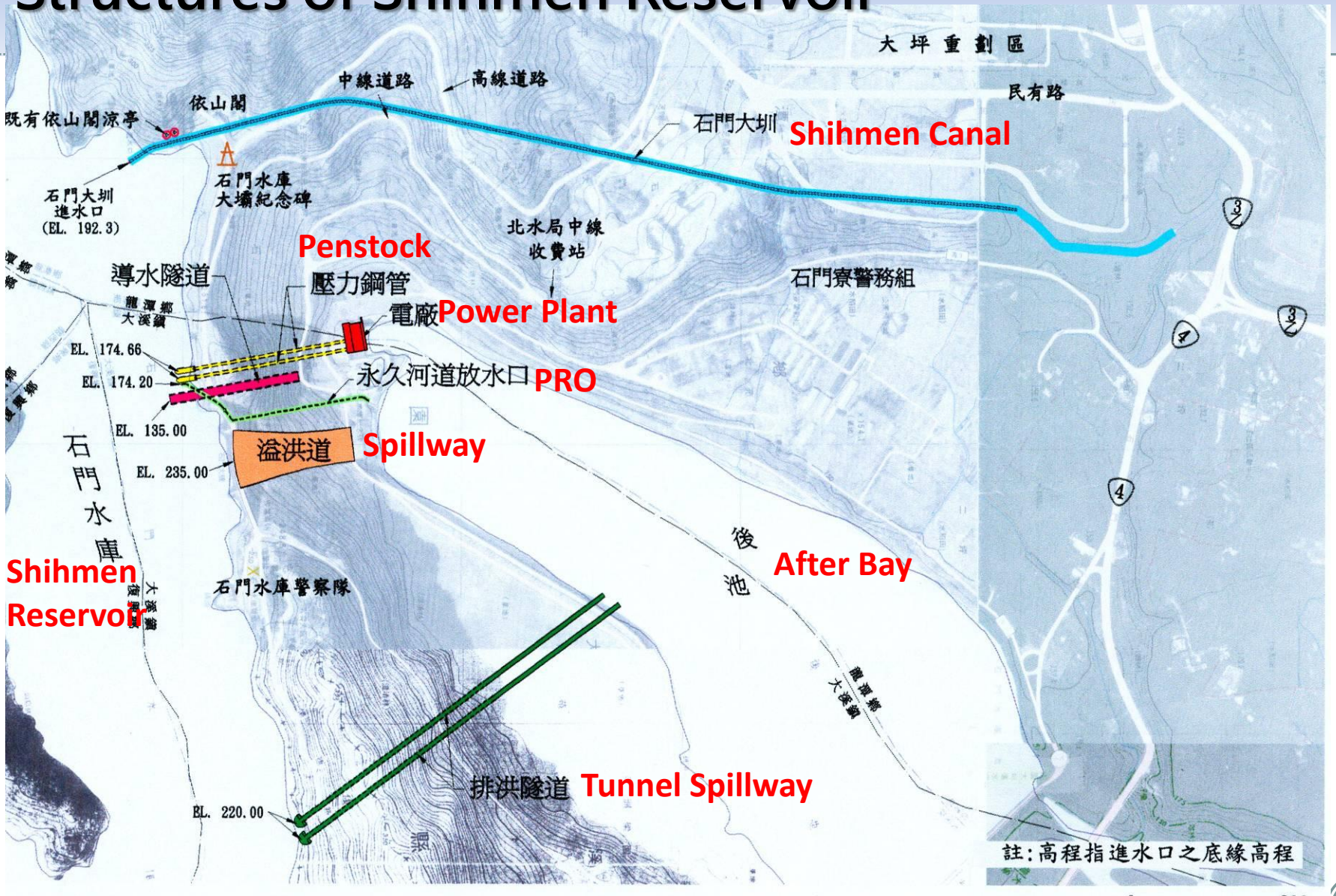


A View of Shihmen Reservoir

- Drainage Area: 763 km^2
- Completed: 1963



Plan View of Original Outlet Structures of Shihmen Reservoir



Current Water Budget of Shihmen Reservoir

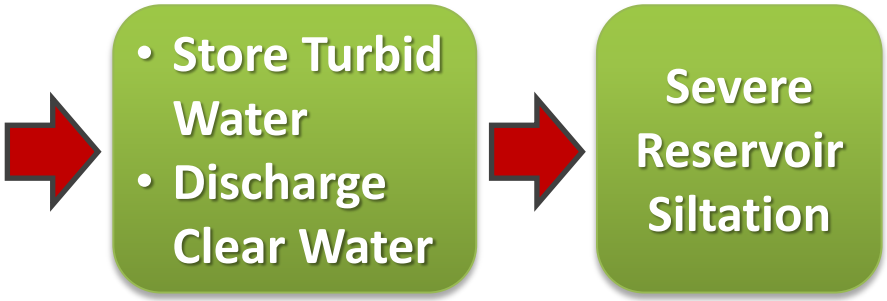
- Current Reservoir Volume: $200 \times 10^6 m^3$

Average Annual Inflow ($10^6 m^3$)	Average Annual Outflow ($10^6 m^3$)		
	Irrigation	Potable Water	Flood Discharge
1,560	456	400	710
	850		

Shihmen Reservoir Discharge Structures

- Designed Based on Traditional Approach
  - Small bottom outlet
  - Large spillway

Structure	Intake Elevation (m)	Design Capacity (cms)
Diversion Tunnel	EL. 135.0	4,700 (plugged)
Permanent River Outlet	EL. 169.5	34.0
Power Intake	EL. 169.5	2@68.6=137.2
Irrigation Canal	EL. 193.5	18.4
Tunnel Spillway	EL. 220.0	2@1,200=2,400
Spillway	EL. 235.0	11,400



3. Problems Caused by Typhoon Aere in 2004

Facts About Typhoon Aere

- Date of Occurrence: August 24 and 25, 2004
- Average Basin Rainfall: 973 mm
- Total Inflow Volume: 742 X $10^6 m^3$
- Peak Inflow Discharge: 8,600 cms
- Peak Outflow Discharge: 6,270 cms

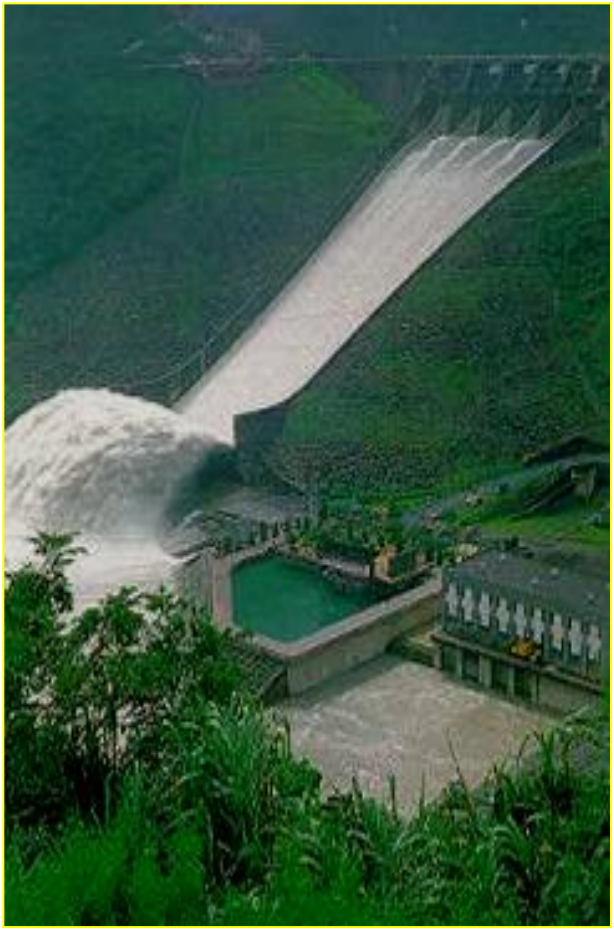
View of Turbid Reservoir After the Storm

View of Log Accumulation in Upstream Reach

View of Floating Debris in the Reservoir

View of Log Accumulation Near the Dam

Spillway Discharge During Aere

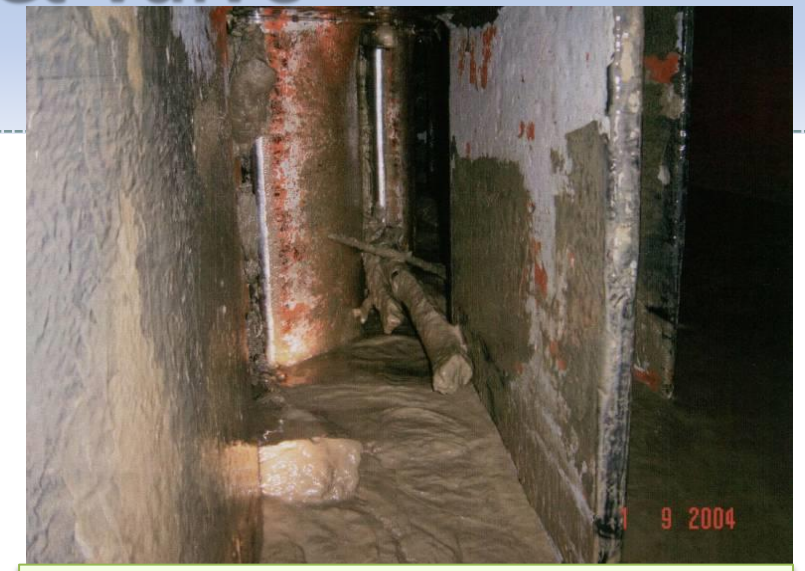


Mudflow in Penstock

No Tap Water After Typhoon Aere

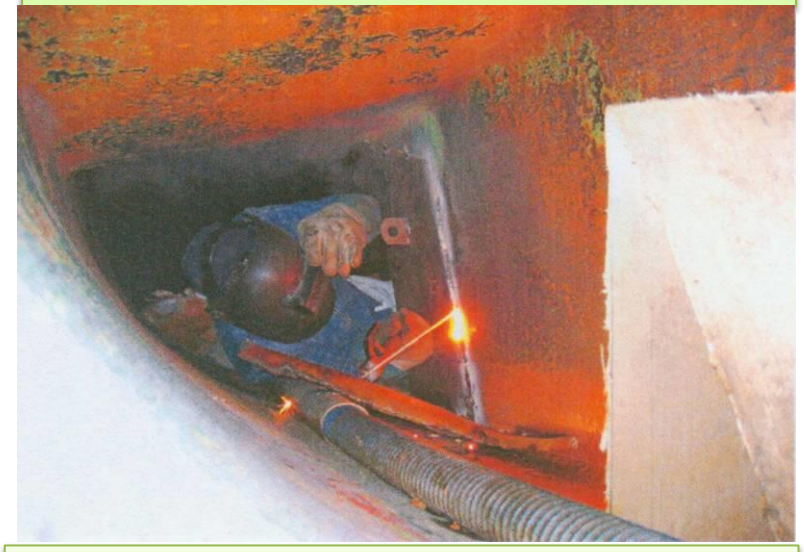
Problems with Turbine & Valve

Guide Vane



Wicket Gate

PRO Damage



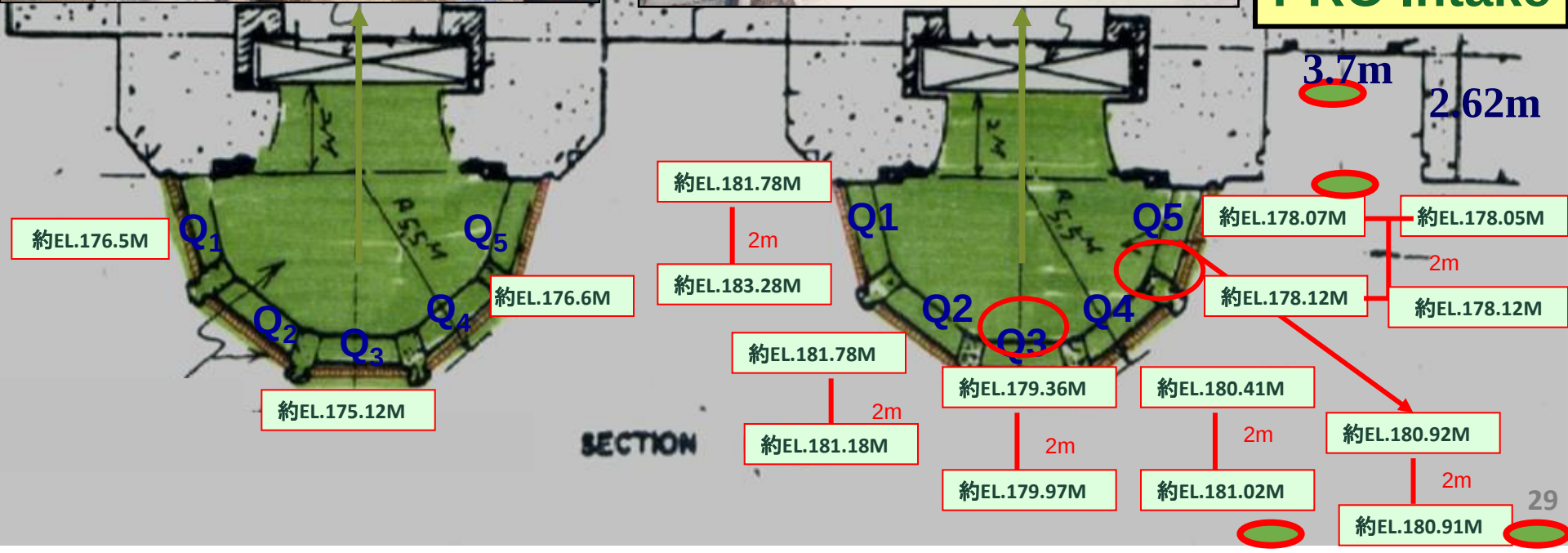
PRO Repair

Excavated Logs in Front of Power Intake

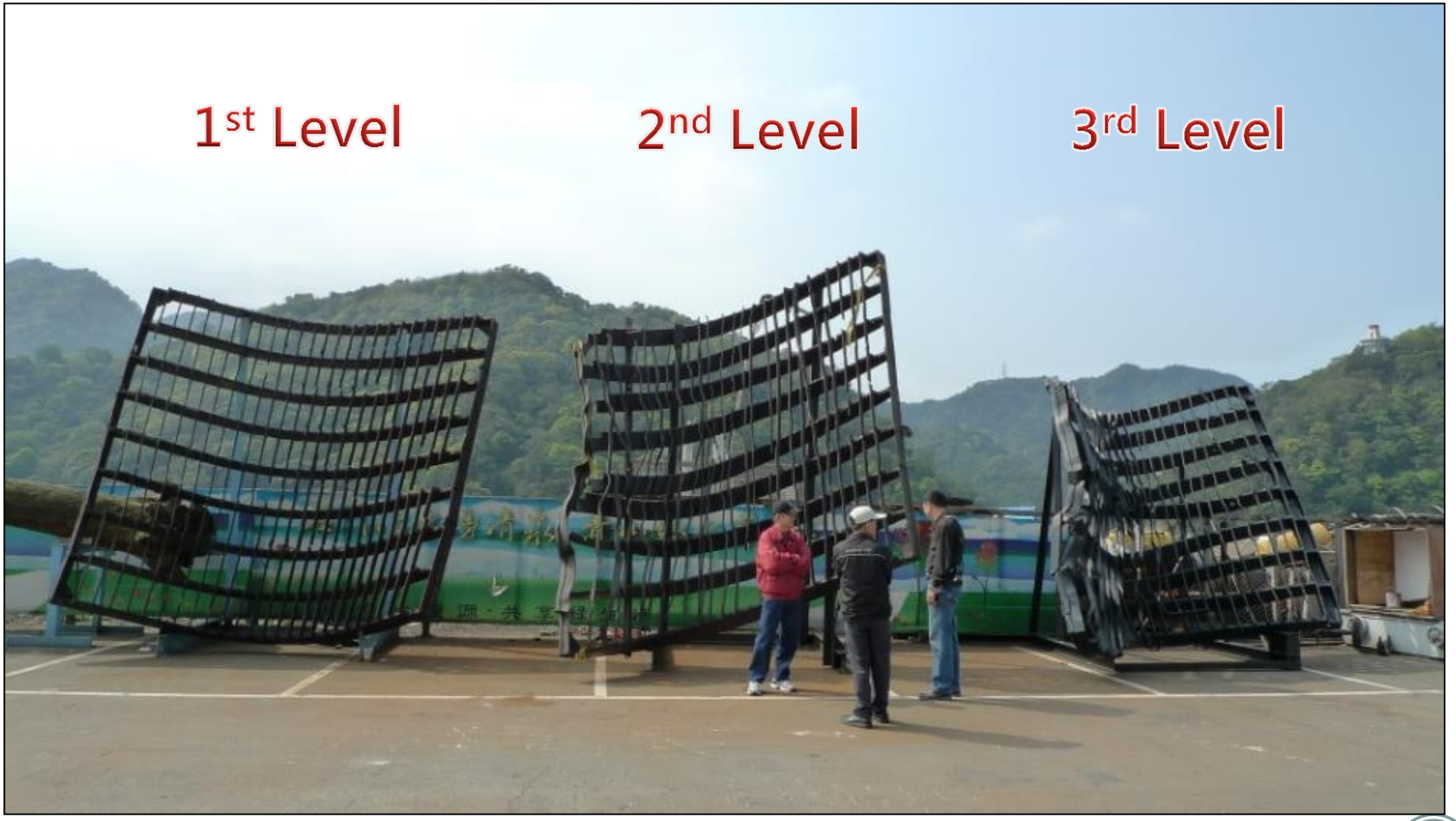
#1 Intake

#2 Intake

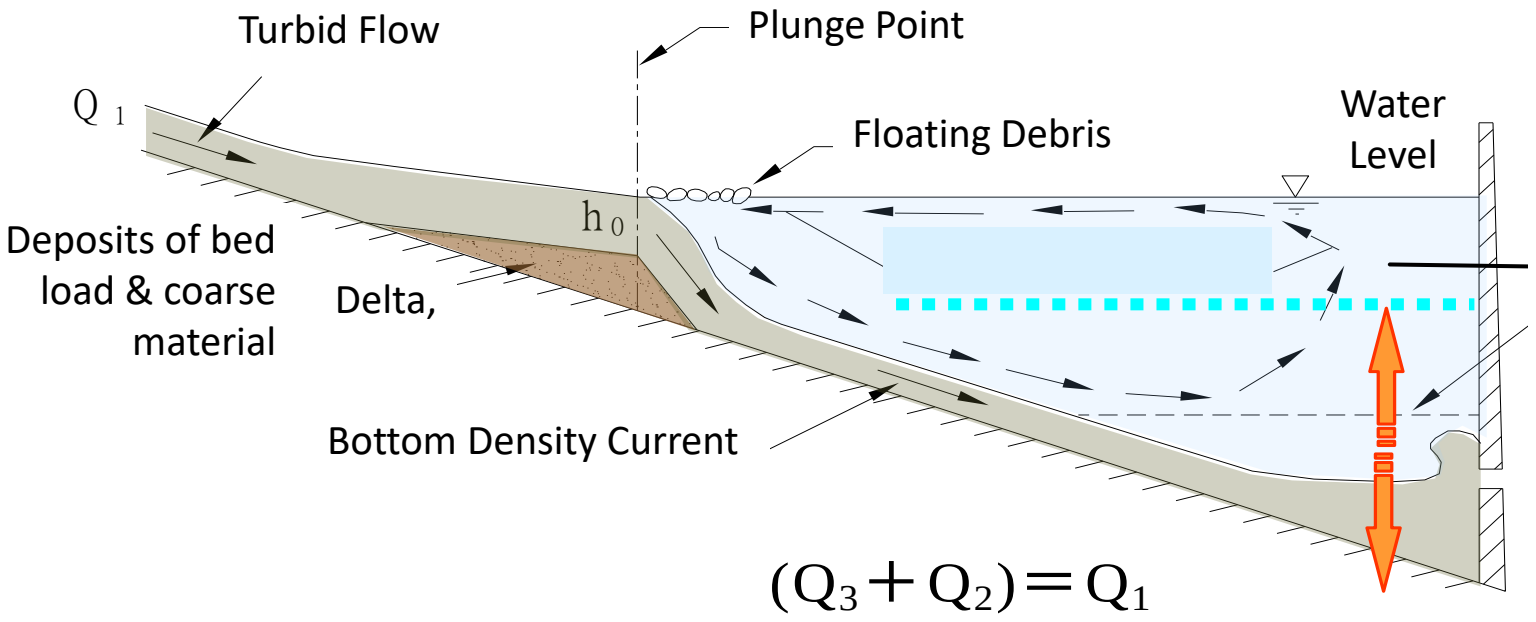
PRO Intake



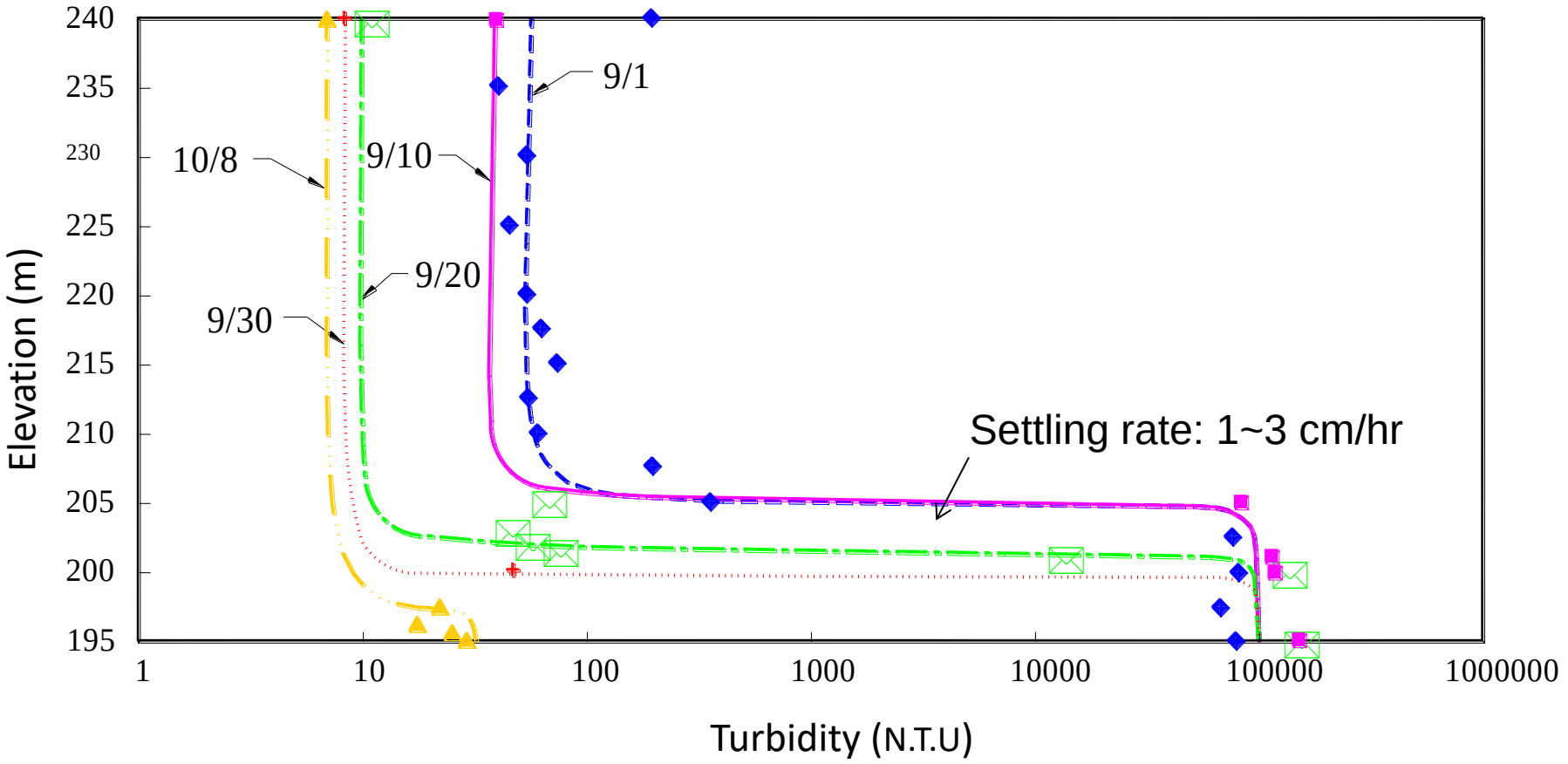
PRO Trashrack Damages Caused by Log/Mud Blockage



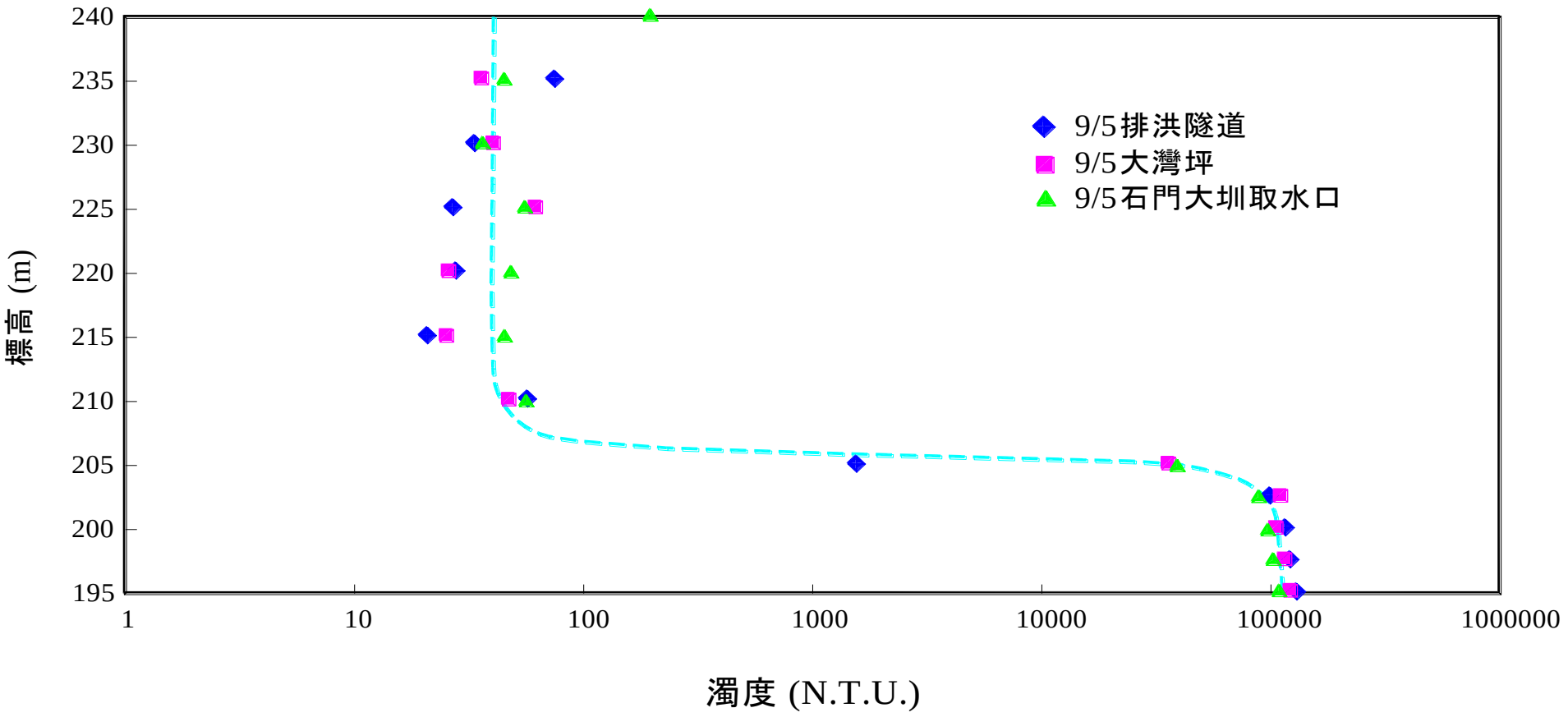
Density Current in a Reservoir



Turbidity Variation at Shihmen Canal Intake Following Typhoon Aere



Turbidity at Different Location in Shihmen Reservoir Following Typhoon Aere



Problems Caused by Typhoon Aere

- Turbidity of water at intake too high to be purified
- Reservoir siltation of $27.88 \times 10^6 m^3$, caused permanent reduction in water supply capability
- Submerged debris clogged intake structures affecting normal operations of intake and hydro units
- Discharge capacity can not handle PMF, causing safety concern

Siltation Caused by Major Typhoon Events

Yr. 年度	Typhoon 颱風名稱	Deposition 淤積量(m^3)
1963.05~1964.03	Gloria 葛樂禮	1,947
1969.05~1970.06	Elsie 艾爾西	503
1971.06~1972.12	Bess 貝　絲	523
1984.11~1985.11	Nelson 尼爾森	369.5
1995.11~1996.11	Herb 賀　伯	867
2004.03~2004.12	Aere 艾　利	2,788.4
2006.12~2007.12	Krosa 柯羅莎	962.4
Sum		7,960.3
Total Siltation		9,386.4
Sum/Total siltation (%)		84.8%

4. Measures to Secure Potable Water Supply Following Typhoon

Temporary Measure

- Constructed a floating pumping facility in the reservoir
- Constructed a large storage tank on the right abutment of the dam to receive flow from the pumping facility
- Constructed an above ground pipe with a head tank to link flow from the storage tank to existing water main
- The design discharge was 980,000 CMD

Floating Pumping Facility (1/2)

Floating Pumping Facility (2/2)

Overview of the Pumping Facility

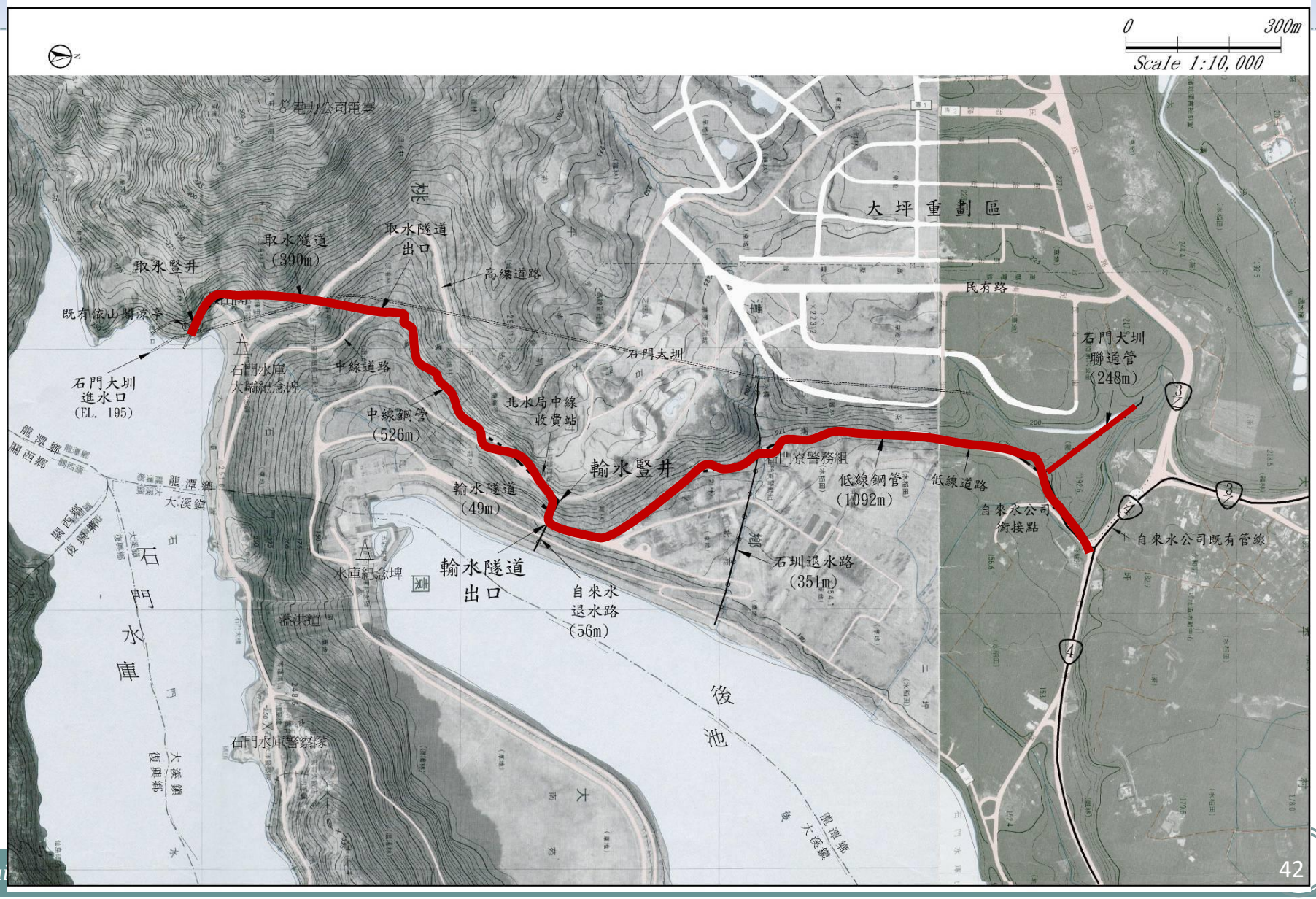
Head Tank

Above Ground Pipe w/Decoration

New Permanent Intake Project Design Guidelines

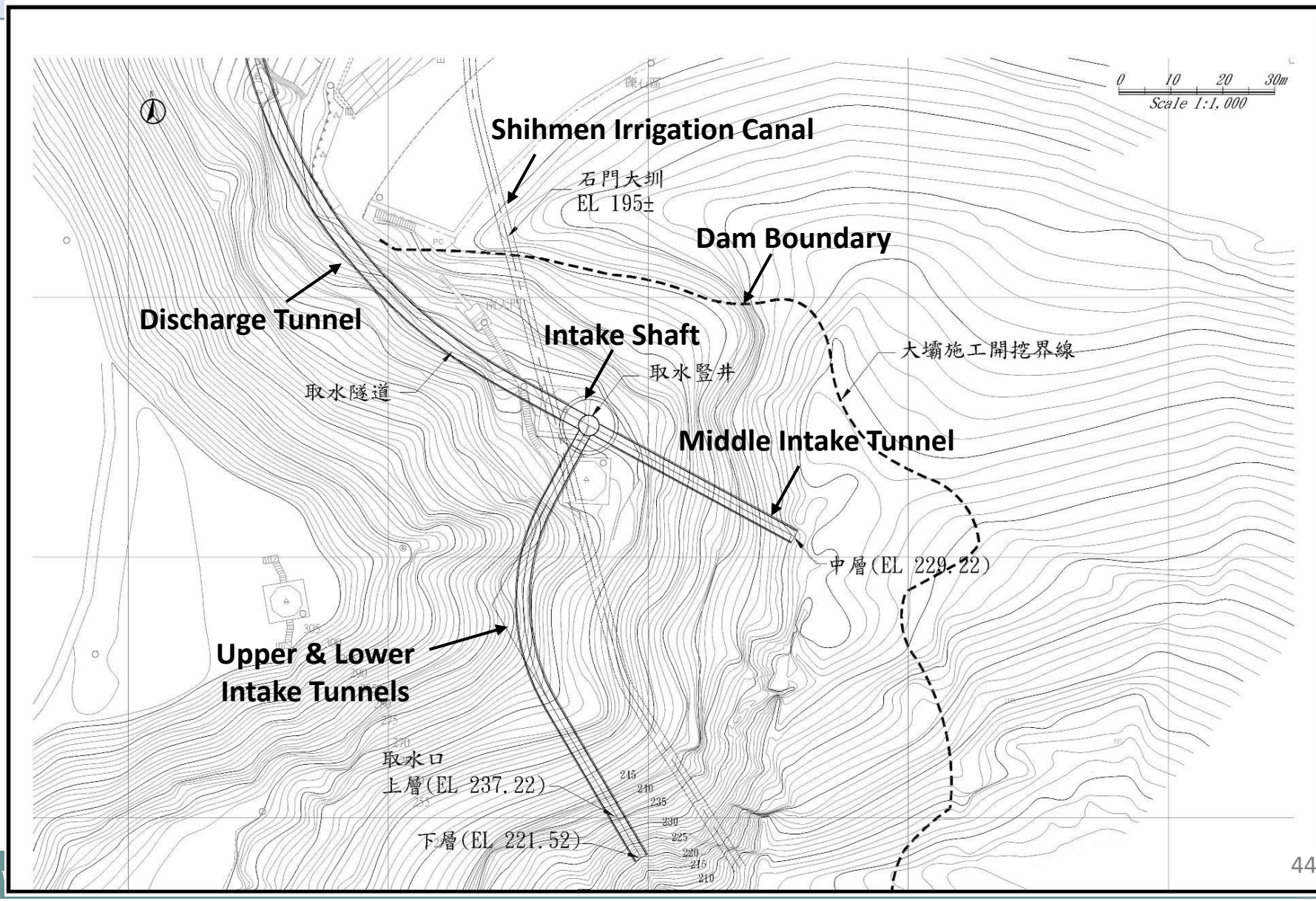
- Discharge Capacity: 140,000 CMD
- Intake Level: EL. 220、EL. 228、EL. 236
- Discharge Connections
  - Water Company's Pipeline
  - Existing Irrigation Canal
  - Afterbay

Overall Layout of New Intake Project

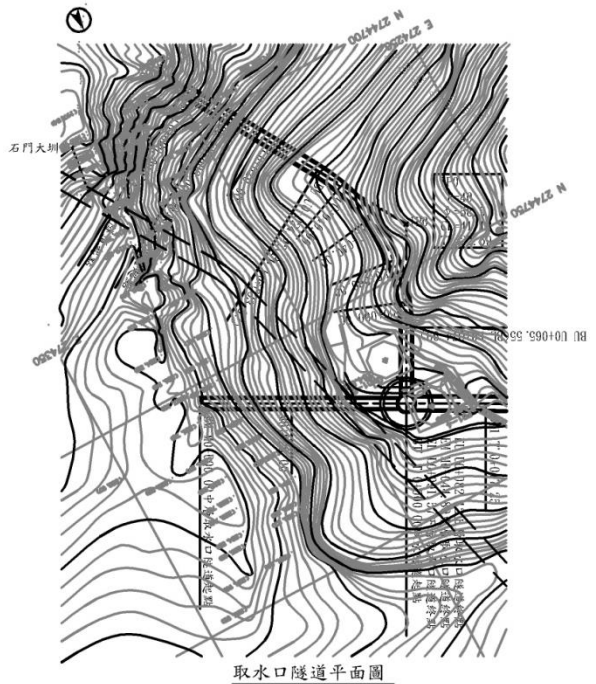


Original Landscape of The New Intake

Plan View of the New Intake



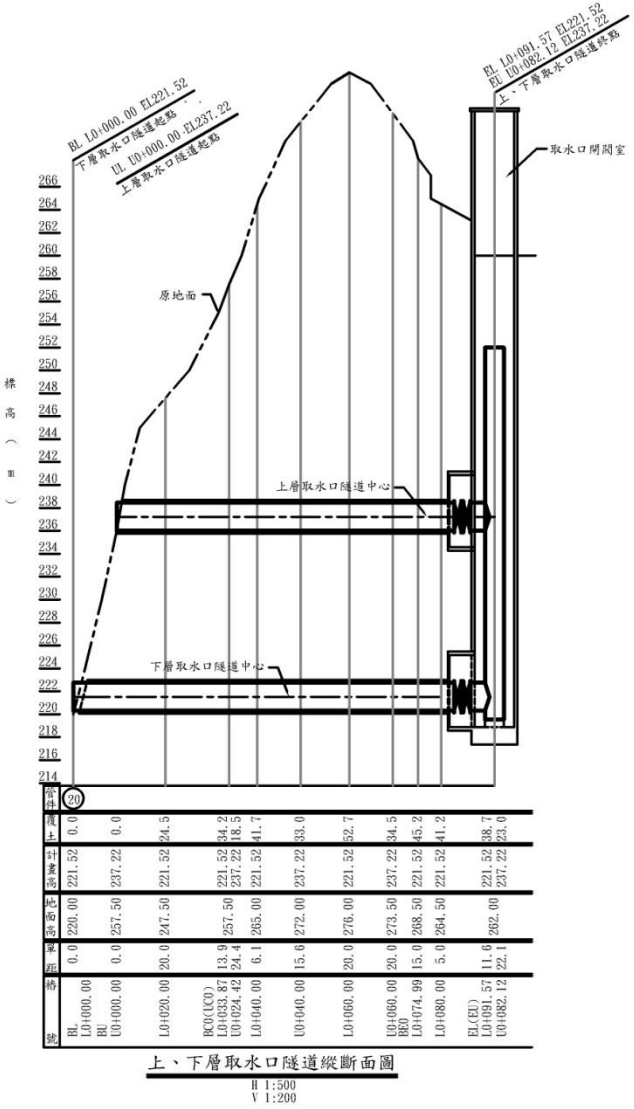
Section View of Intake Tunnels

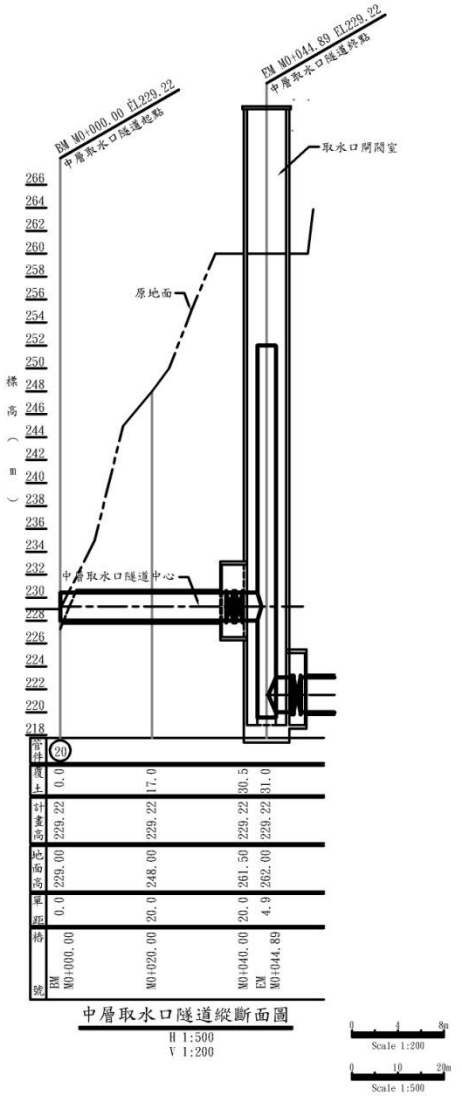


控制點座標詳表

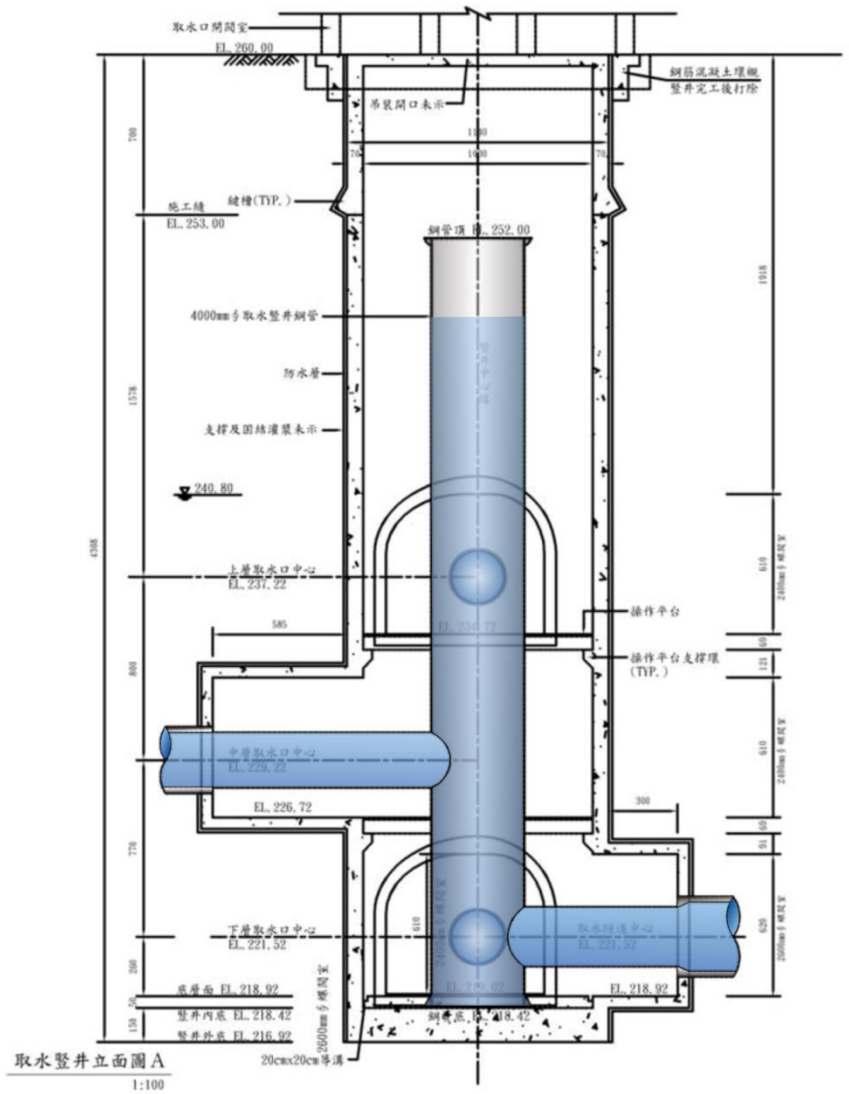
點號	N	E	水平角	垂直角
BU	2744700.4	274293.8		
EU	2744775.3	274288.6		
BM	2744754.0	274328.1		
BL	2744692.2	274298.6		
IP0	2744740.9	274270.0	58.9°	

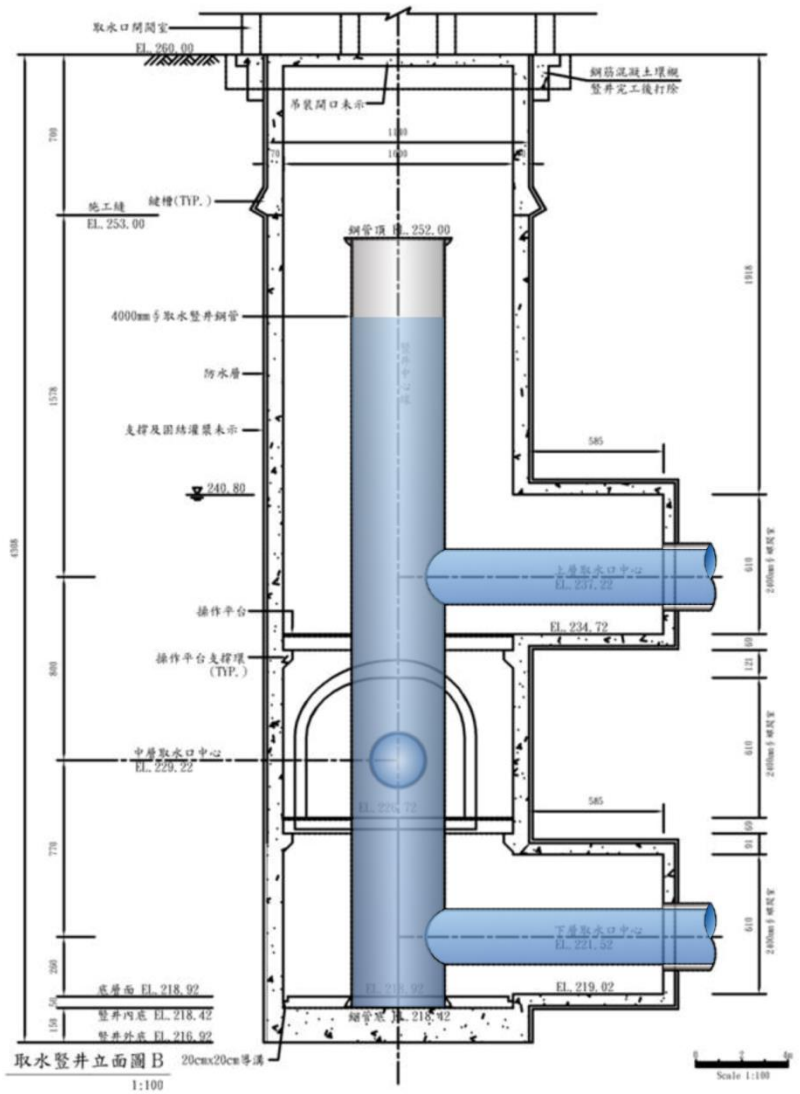
說明：1.本圖單位除註明外，其餘為m
2.計畫高為管線中心高





Section View of Intake Shaft

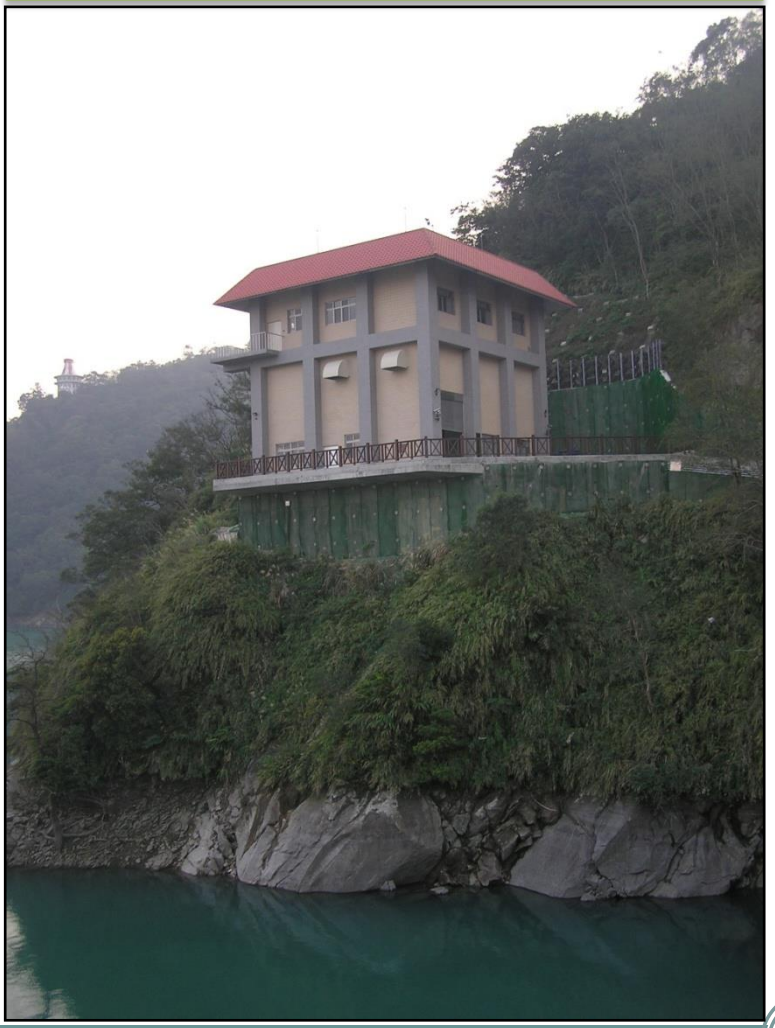




Photos of New Intake

Top Level Intake

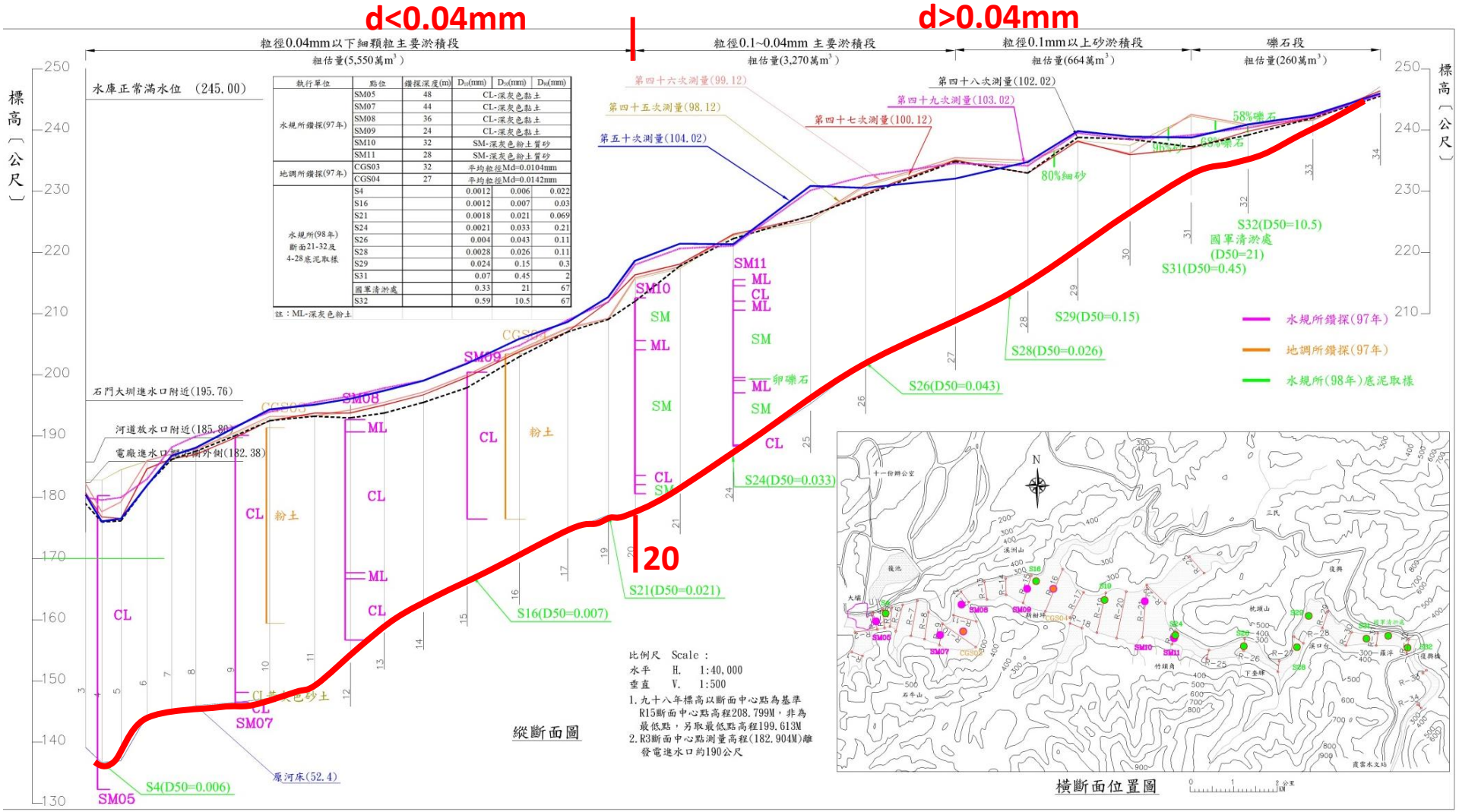
Control Room



5. Measures to Secure Reservoir Volume for Sustainability

- Existing Outlet Modification to Enhance Silt Sluicing
- New Silt-Sluicing Tunnel at Dawanping
- Dredged Sediment Sorting and Flushing Facilities at Amuping

Reservoir Siltation Profile and Separation of Material at about Section 20



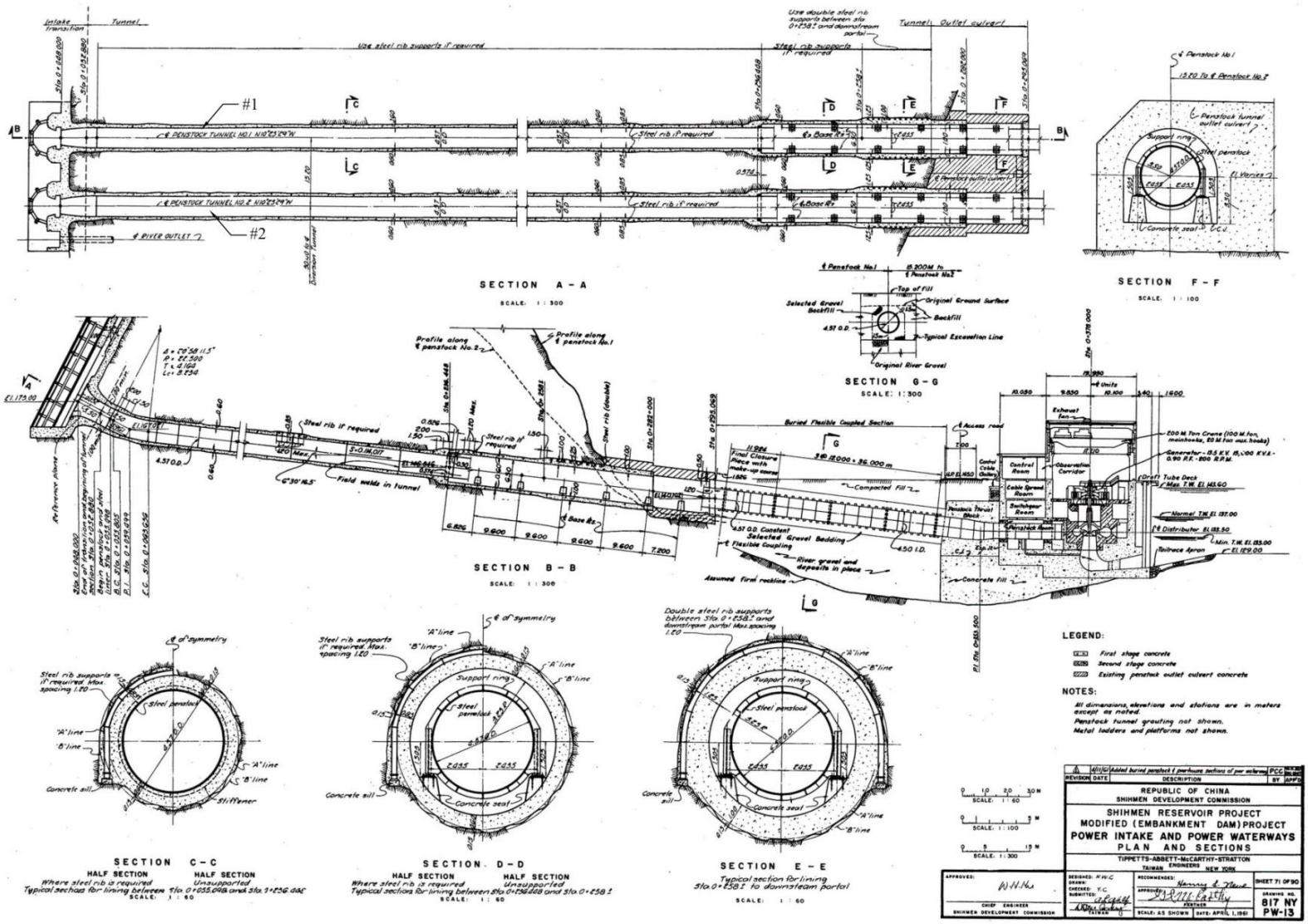
執行單位	點位	鑽探深度(m)	D_{10}(mm)	D_{50}(mm)	D_{60}(mm)
水規所鑽探(97年)	SM05	48	CL-深灰色黏土		
	SM07	44	CL-深灰色黏土		
	SM08	36	CL-深灰色黏土		
	SM09	24	CL-深灰色黏土		
	SM10	32	SM-深灰色粉土質砂		
	SM11	28	SM-深灰色粉土質砂		
地調所鑽探(97年)	CGS03	32	平均粒徑Md=0.0104mm		
	CGS04	27	平均粒徑Md=0.0142mm		
水規所(98年)斷面21-32及4-28底泥取樣	S4		0.0012	0.006	0.022
	S16		0.0012	0.007	0.03
	S21		0.0018	0.021	0.069
	S24		0.0021	0.033	0.21
	S26		0.004	0.043	0.11
	S28		0.0028	0.026	0.11
	S29		0.024	0.15	0.3
	S31		0.07	0.45	2
	國軍清淤處		0.33	21	67
	S32		0.59	10.5	67

註：ML-深灰色粉土

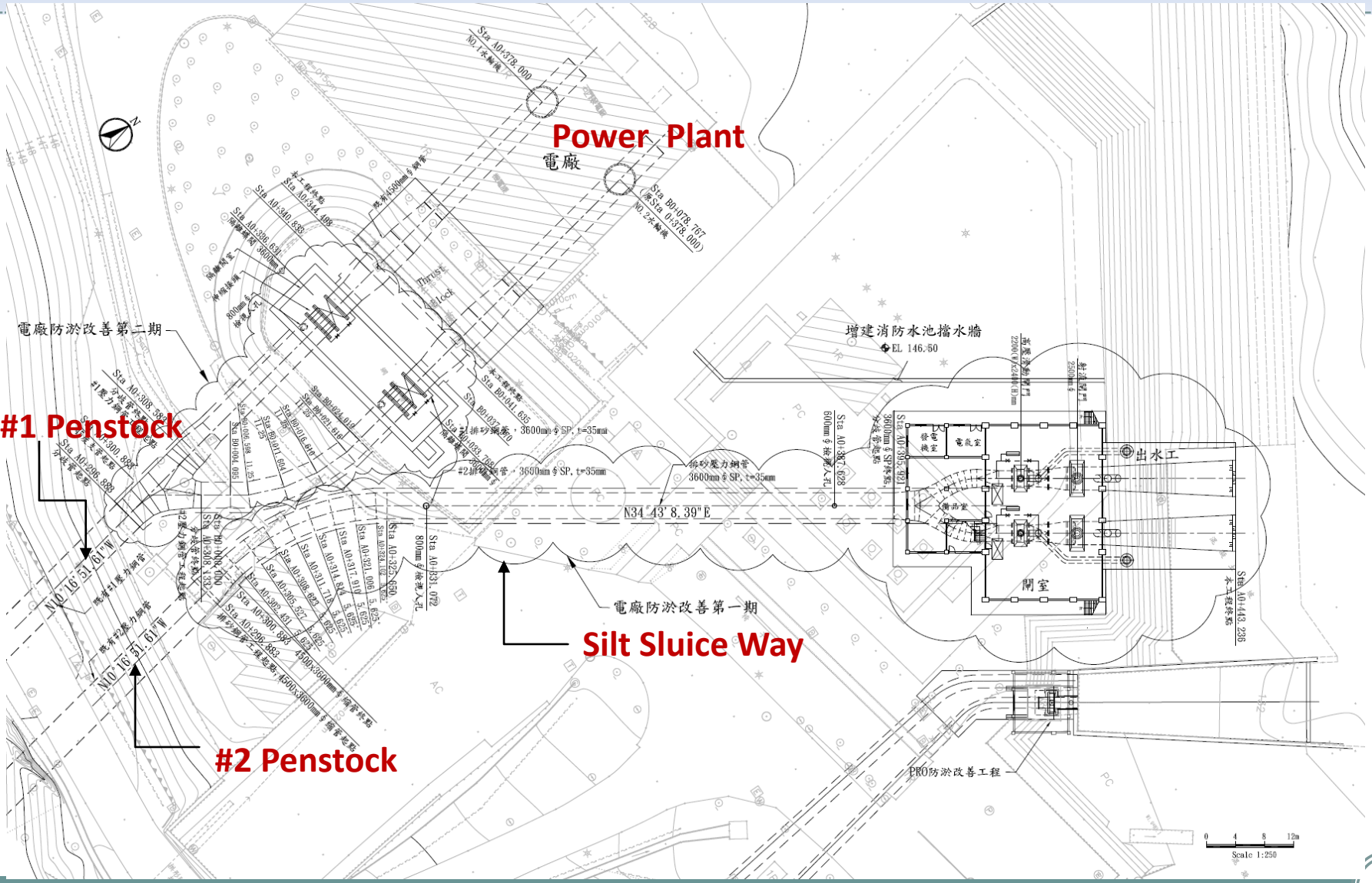
Shihmen Reservoir Existing Outlet Modifications to Enhance Silt Sluicing

Outlet	Design Q (cms)	Type of Modification
Shihmen Irrigation Canal	18	—
Permanent River Outlet (PRO)	33	Howell-Bunger Valve changed to Jet Flow Gate
Penstocks	2@68	Unit 1: Bifurcation to both units
		Unit 2: Convert to silt Sluice way Q=300 cms

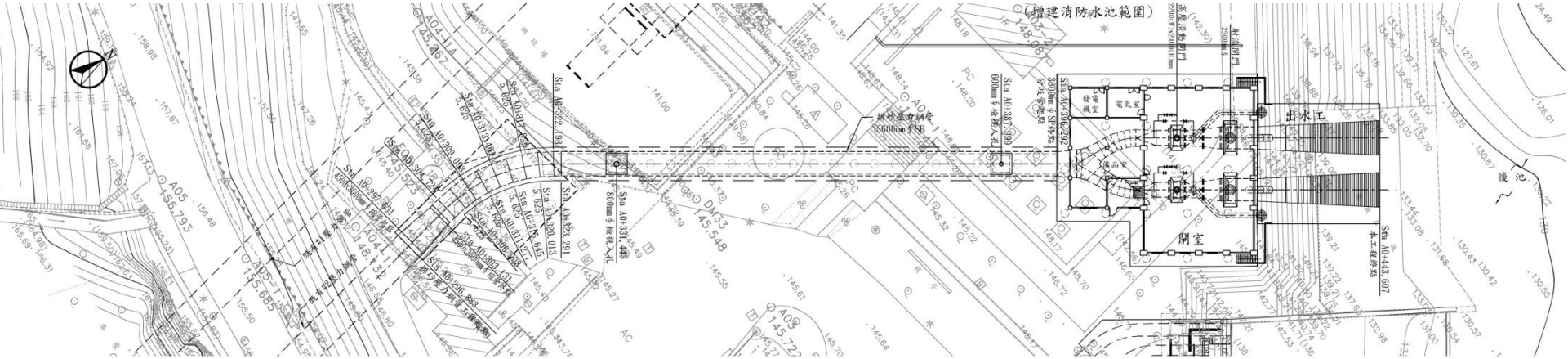
Plan & Elevation Views of Penstocks

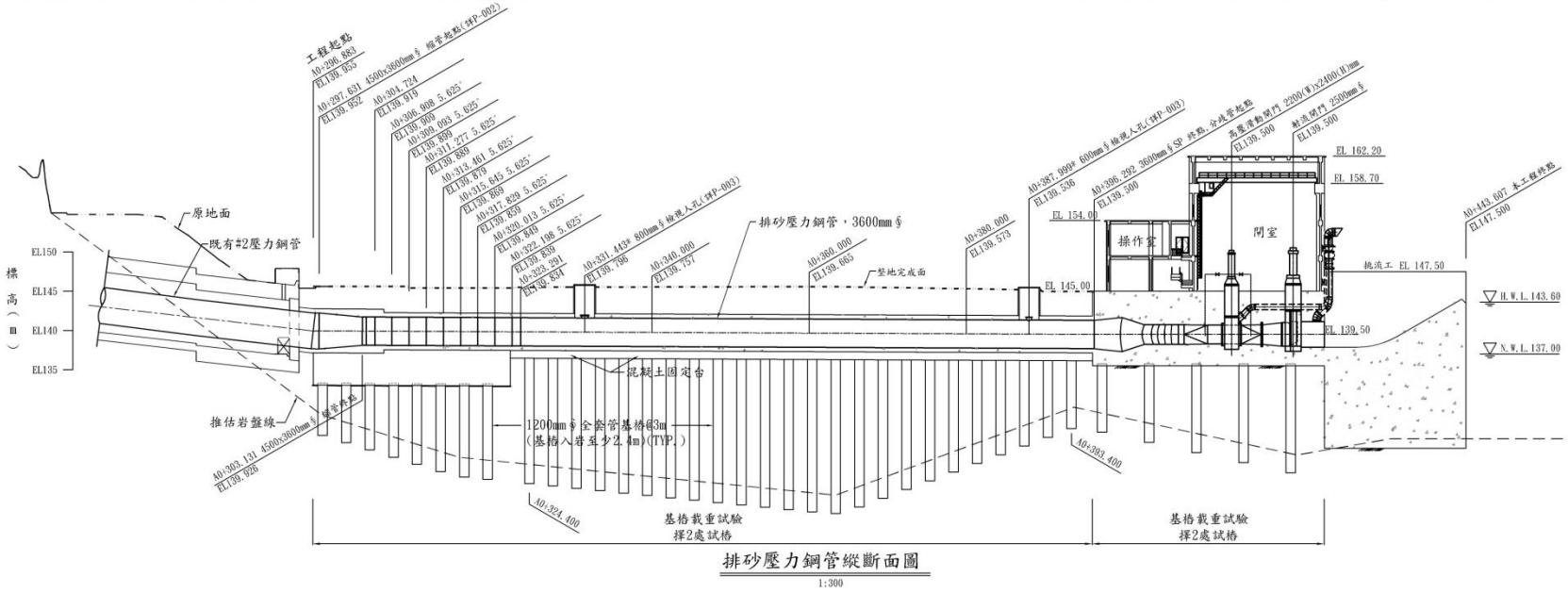


Penstock Modification as A Silt Sluice Way

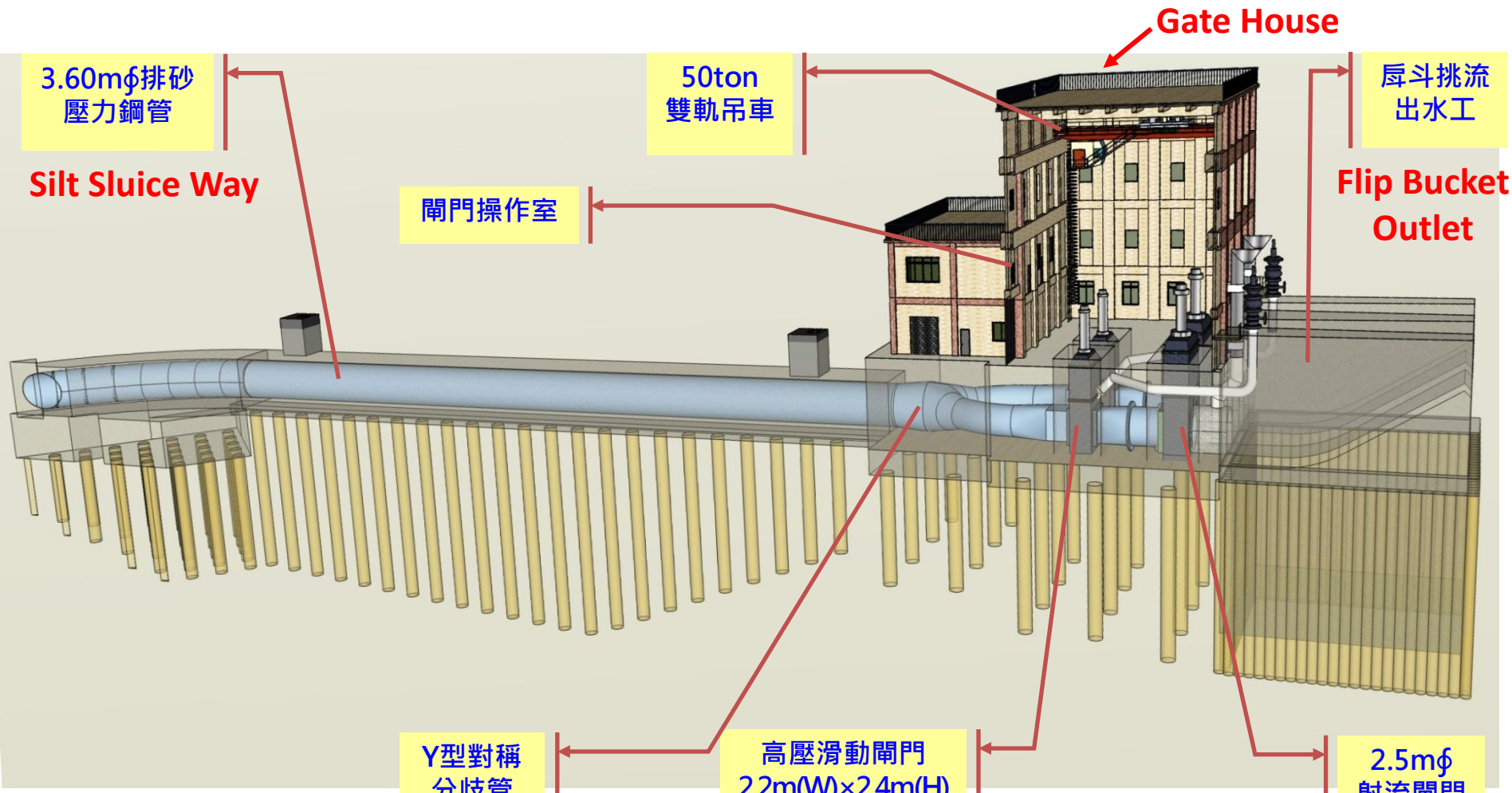


Silt Sluice Way Profile





3D View of Penstock Converted Silt Sluice Way

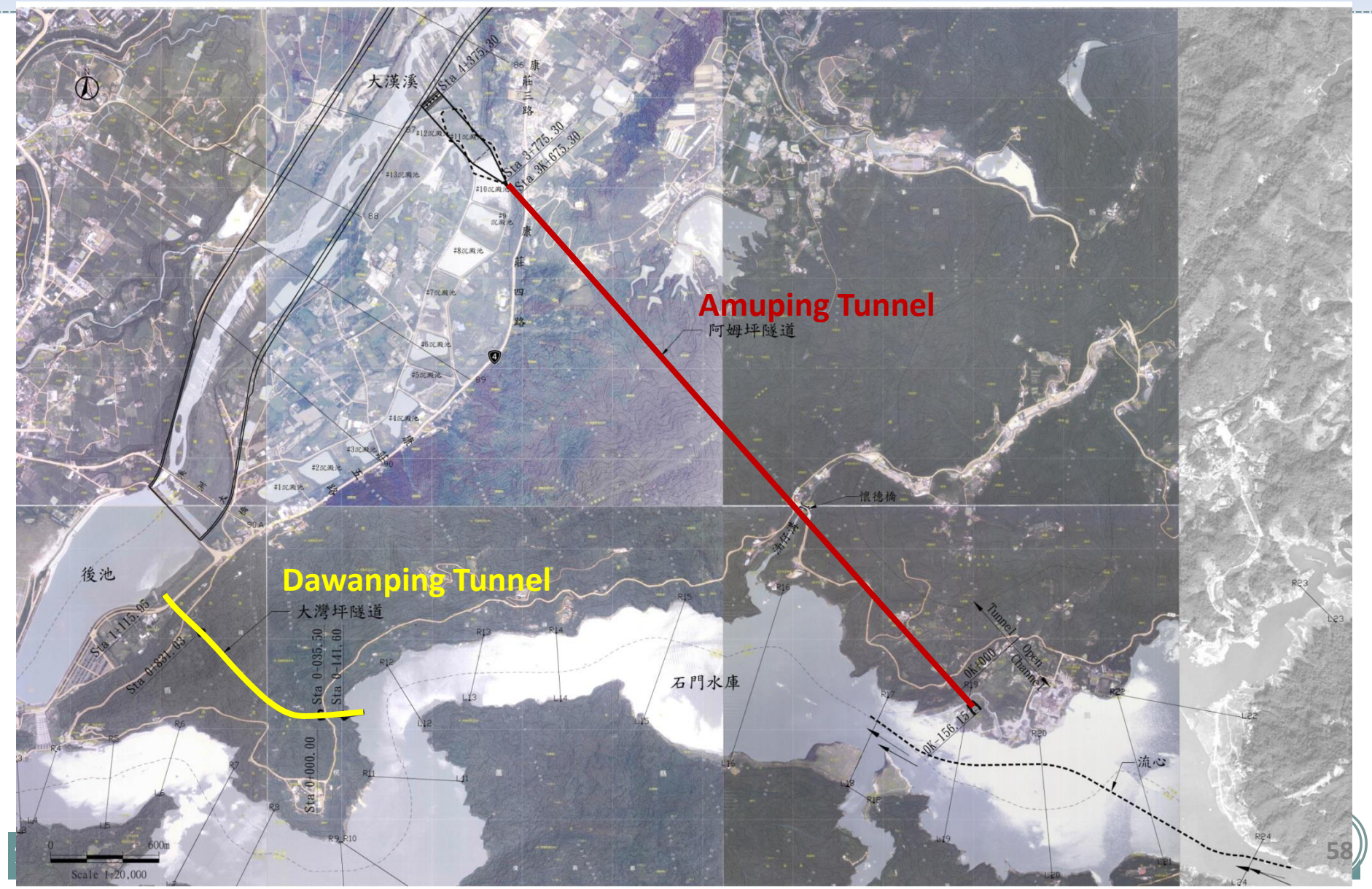


Construction Photos of Penstock Silt-Sluice Way

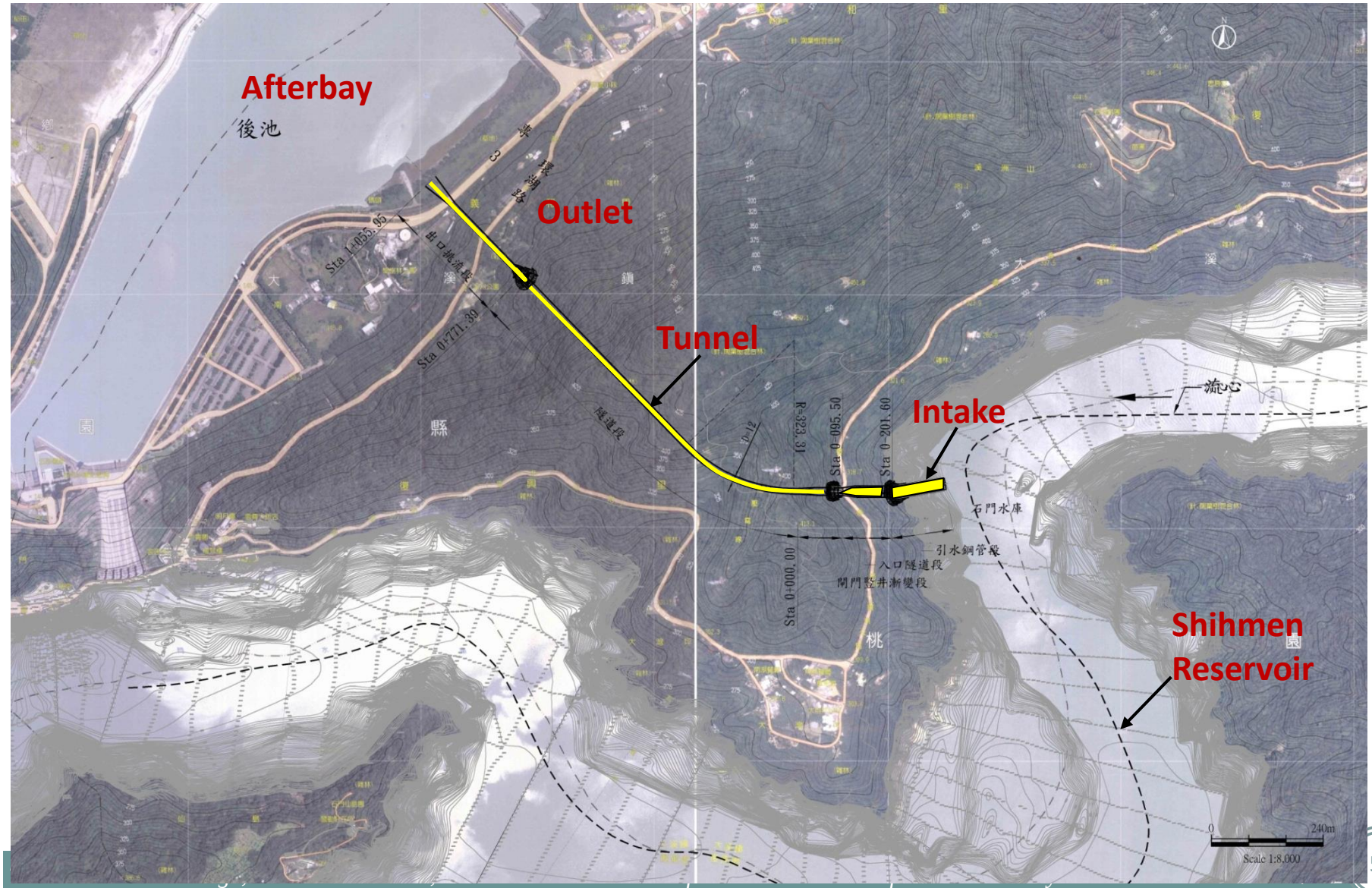
Operation of Spillway & Penstock Silt Sluice Way

2013 Typhoon Soulik in Shihmen Reservoir

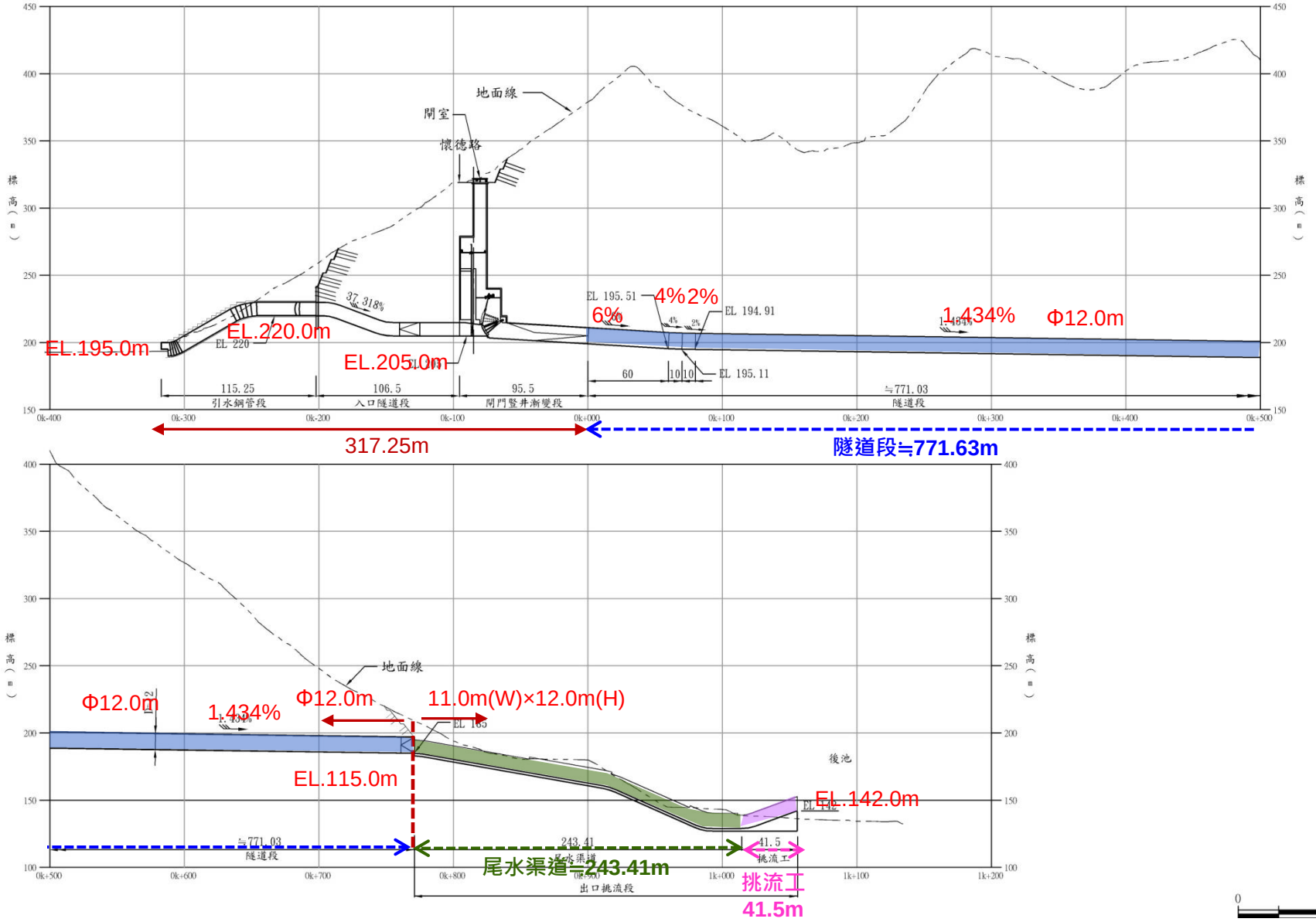
Location of Amuping & Dawanping Silt Sluice Tunnels



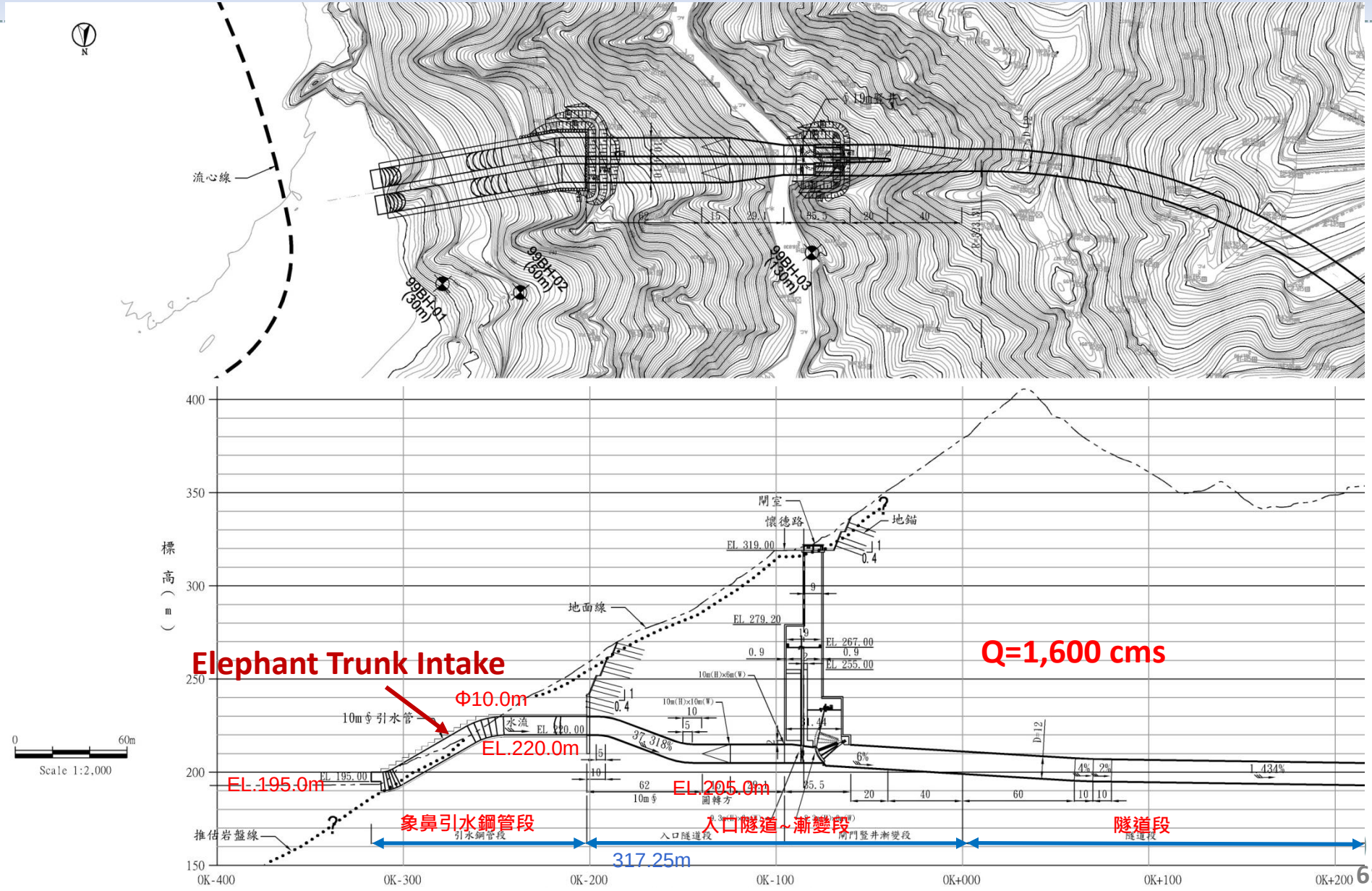
Plan View of Dawanping Tunnel (Q=1,600cms)



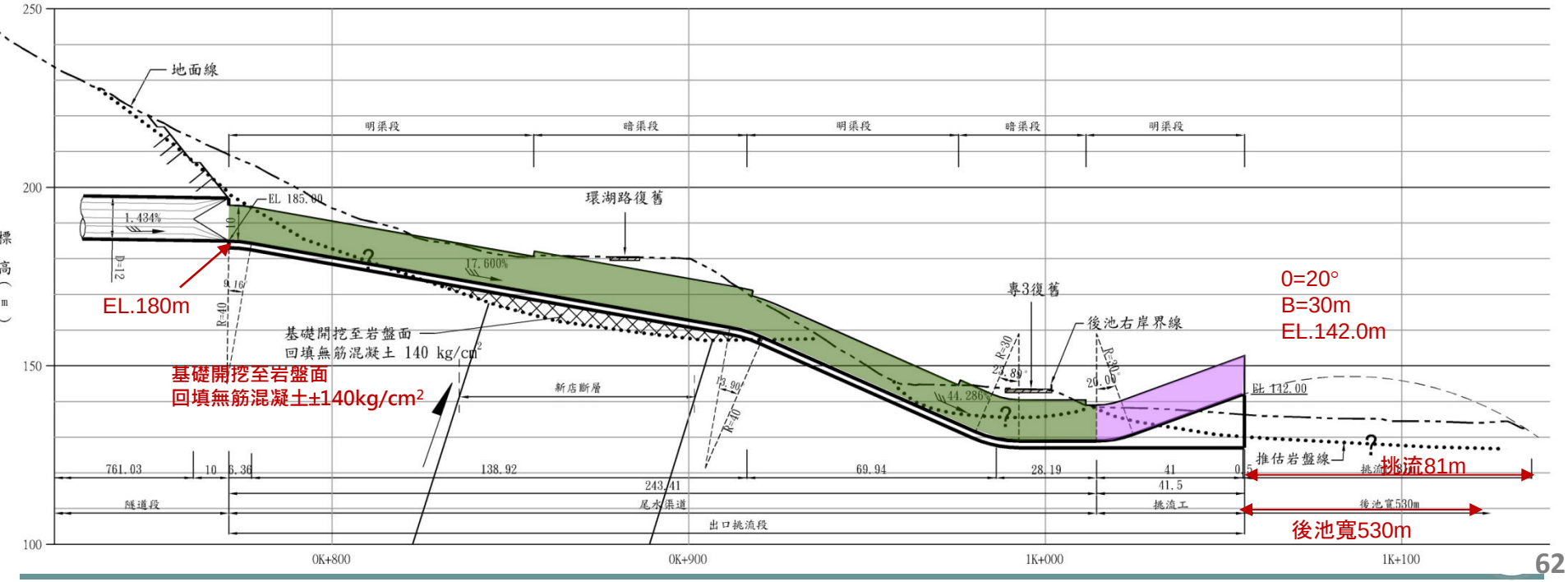
Profile of Dawanping Silt-Sluice Tunnel



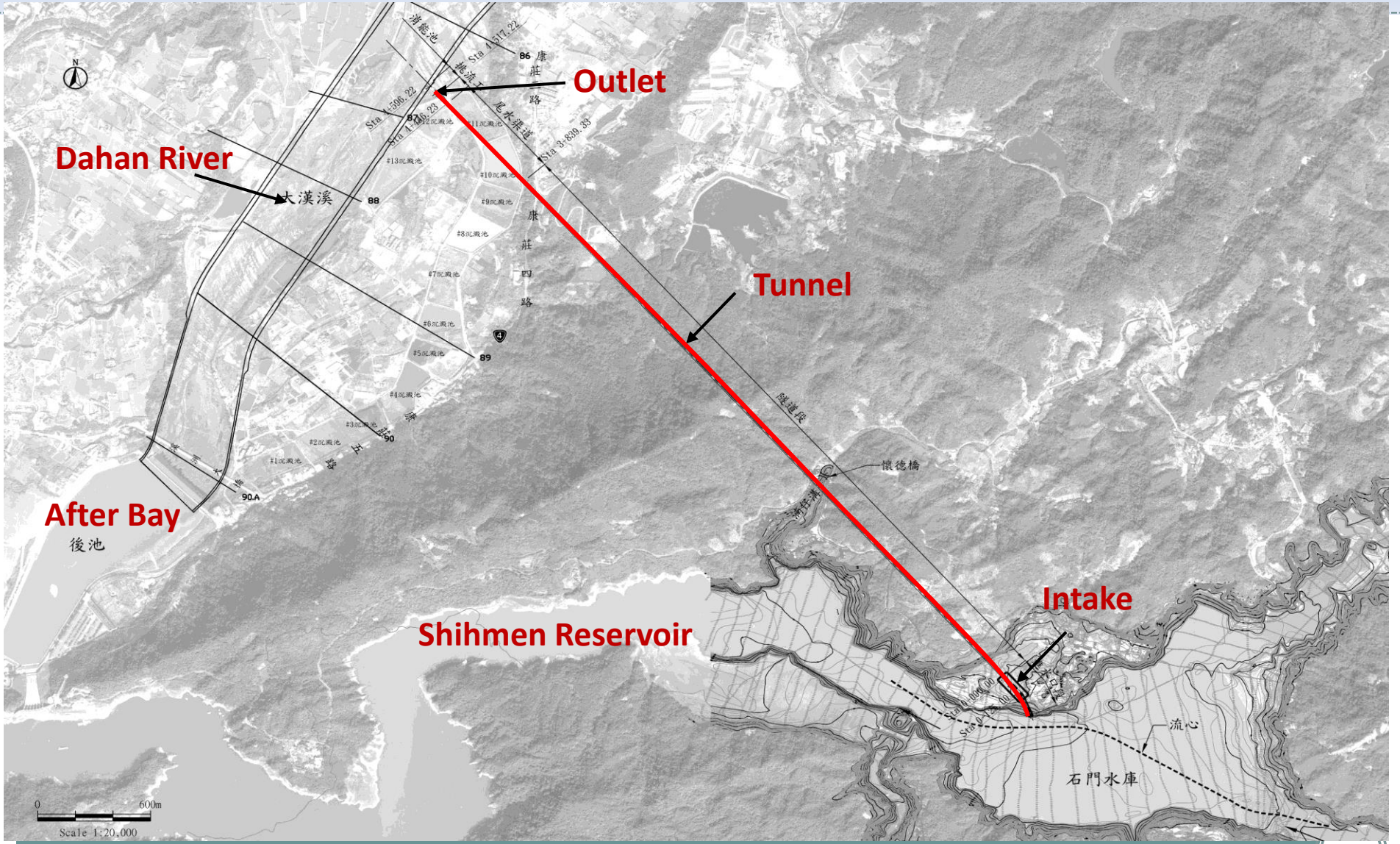
Dawanping Tunnel Intake



Dawanping Tunnel Outlet



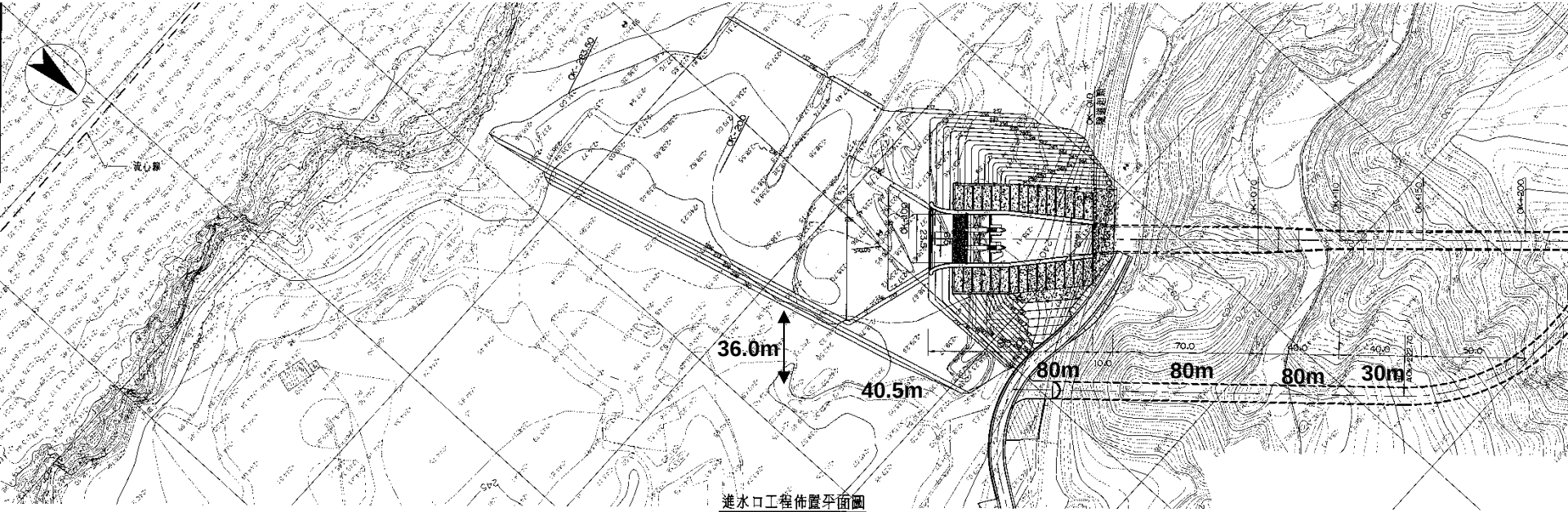
Plan View of Amuping Tunnel



Amuping Facility Design Concept

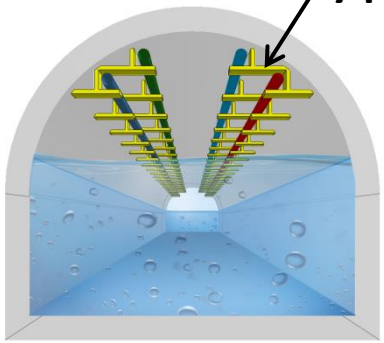
- Dredge material upstream from section 20
- Sediments deposited in this region is coarser
- Designed to remove 640,000 m^3 of deposits of per year
- Estimated that roughly half of the deposits can be used as concrete aggregates. Sorting facility will be used to segregate them from fines
- Fine materials shall be temporarily stored in a 200,000 m^3 detention basin. The material shall be flushed to the river by excess reservoir water prior to and during typhoon

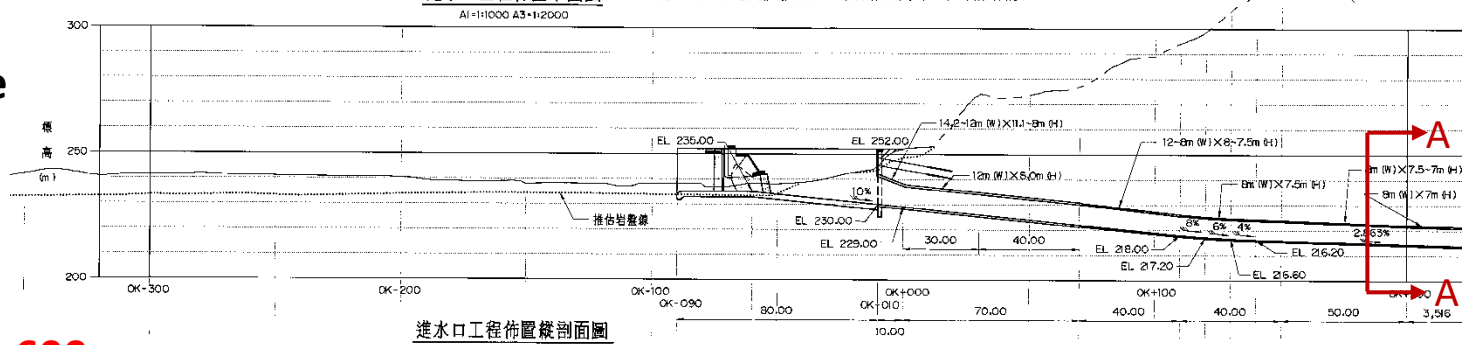
Intake & Cross-Section of Amuping Tunnel



進水口工程佈置平面圖

A1=1:1000 A3=1:2000





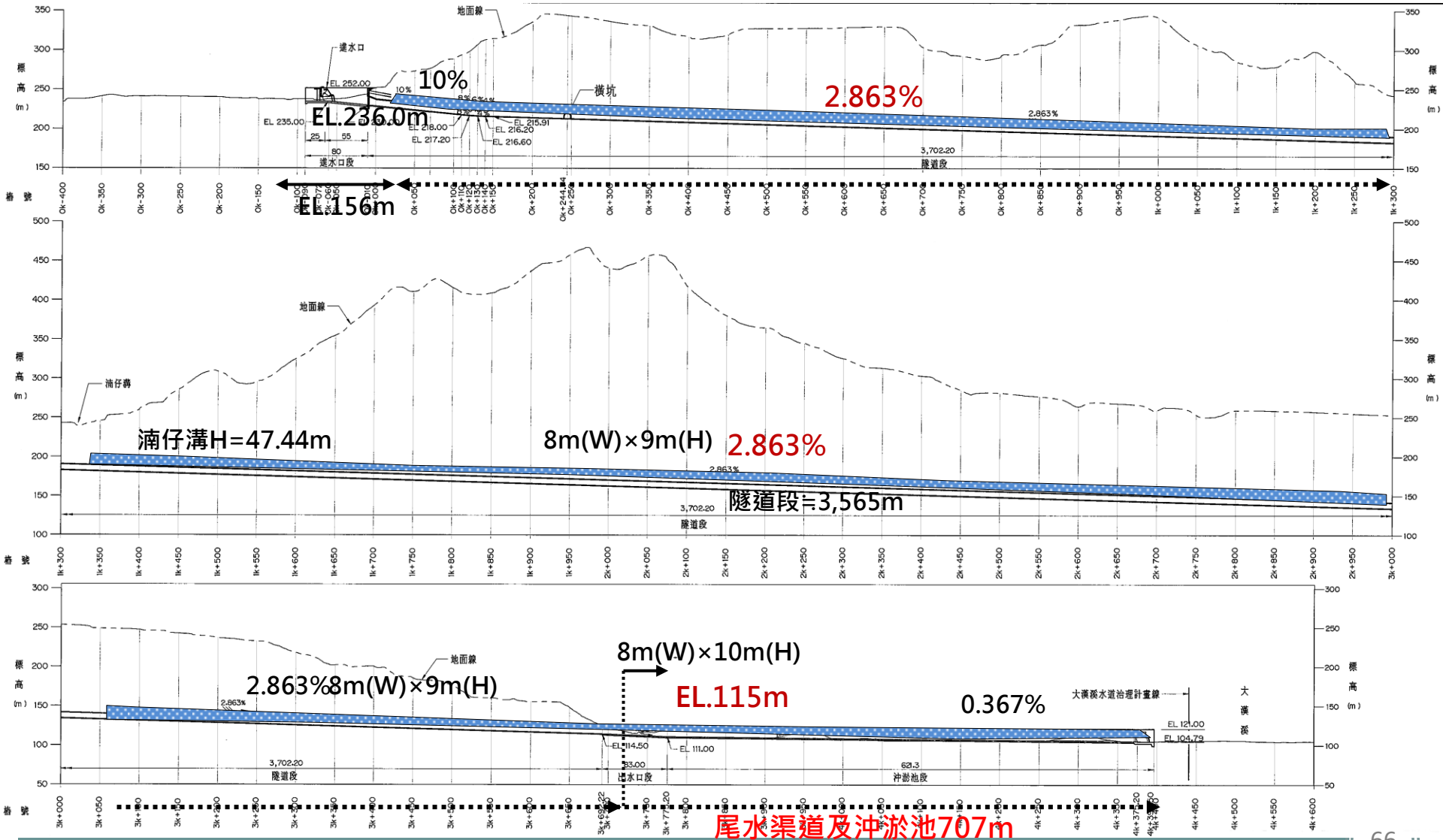
進水口工程佈置縱剖面圖

A1=1:1000 A3=1:2000

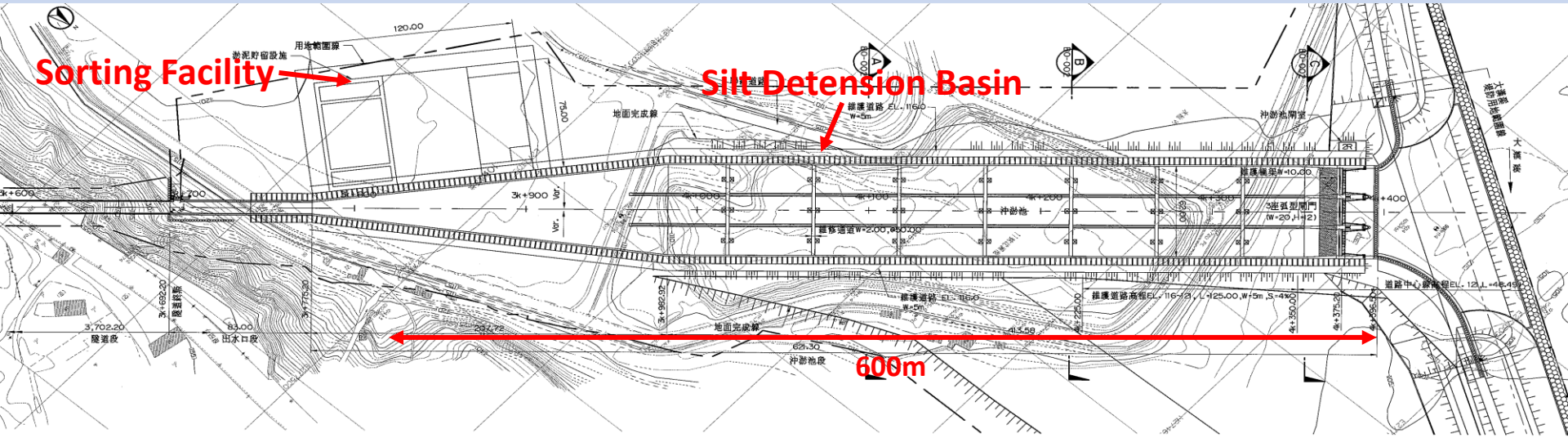
Q= 600 cms

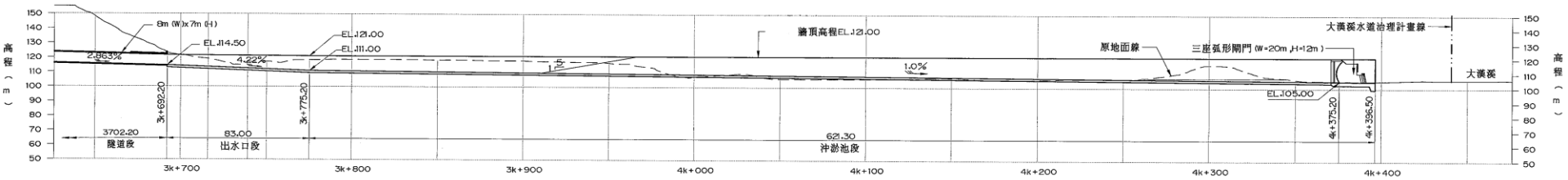
Profile of Amuping Tunnel

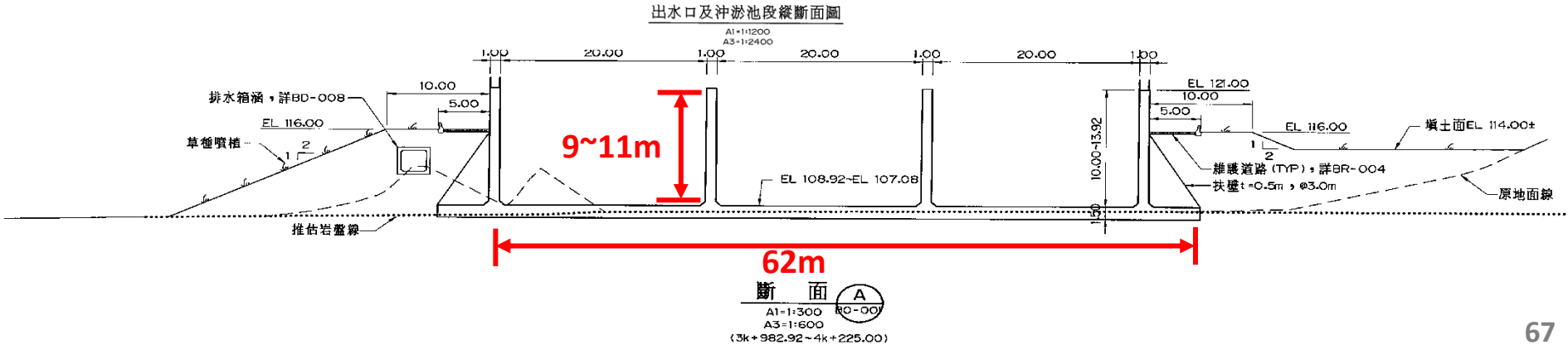
Total Length=4,530m



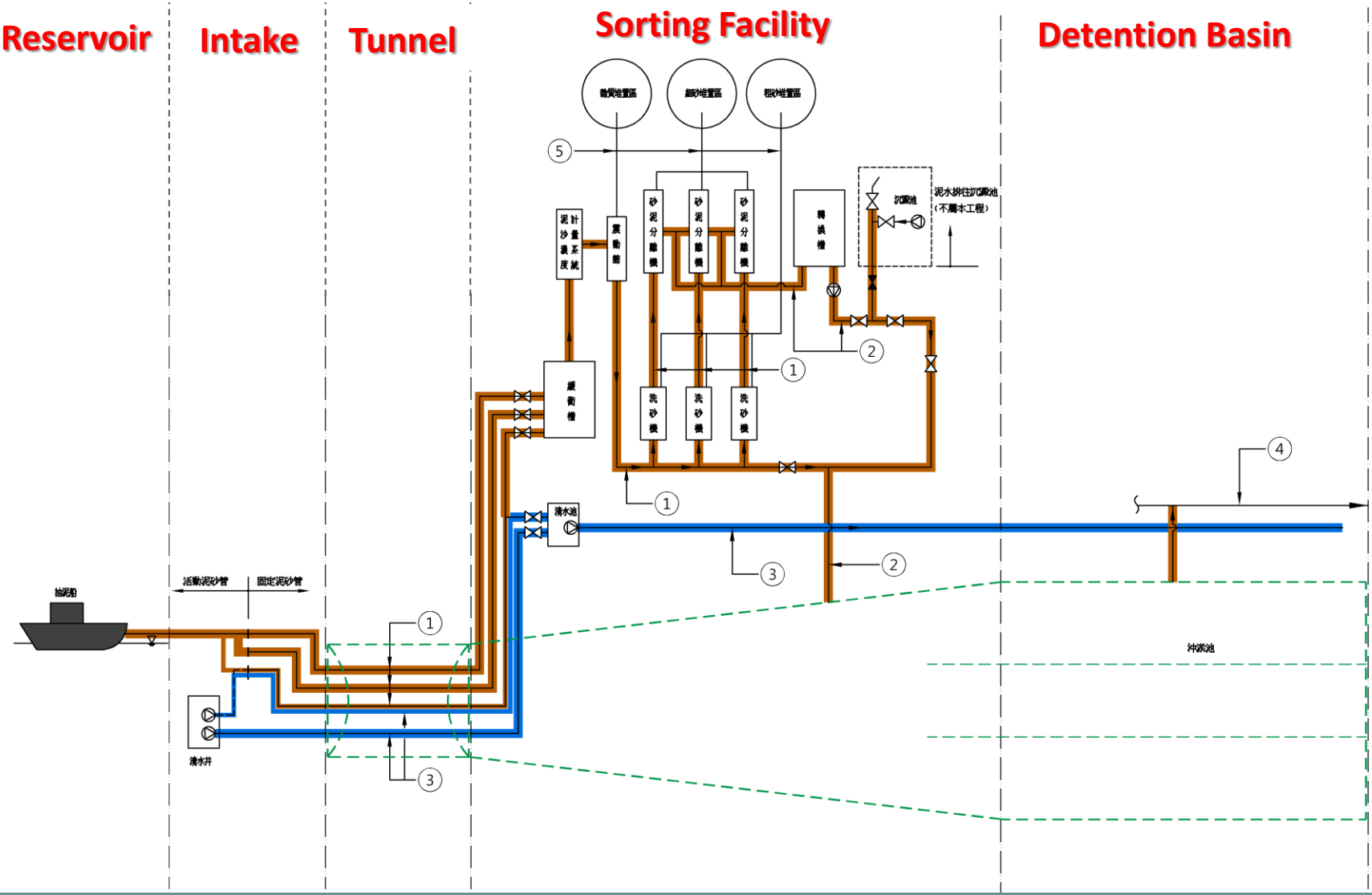
Outlet of Amuping Tunnel







Schematic of Amuping Sediment Removal System



Maintaining Reservoir Volume

Unit: $10^3 m^3$

Average Annual Sediment Inflow	Average Annual Sediment Outflow						
	PRO Sluice way	Power Plant Sluice way after Power Plant modification	Dawanping Silt Sluice Tunnel	Dredged Silt Through Amuping Tunnel	Dedging at Dam	Dredging u/s from Reservoir	Sum
3,420	150 (4%)	1,020 (30%)	710 (21%)	640 (19%)	500 (15%)	400 (12%)	3,420
	55%			19%	26%		100%

Sufficient Outflow Capacity for PMF

Yr.	PMF (cms)	Outflow Capacity (cms)					
		Spillway	Penstock Silt Sluice way	Tunnel Spillway	Dawanping Silt Sluice way	Amuping Tunnel	Total
1959 (original Planning)	**10,900**	11,400	–	–	–	–	**11,400**
1963 (After Typhoon Gloria)	**11,750**	11,400	–	2@1,200	–	–	**13,800**
2014 (3rd Dam Safety Analysis)	**14,500**	11,400	300	2@1,200	1,600*	600*	**16,300**

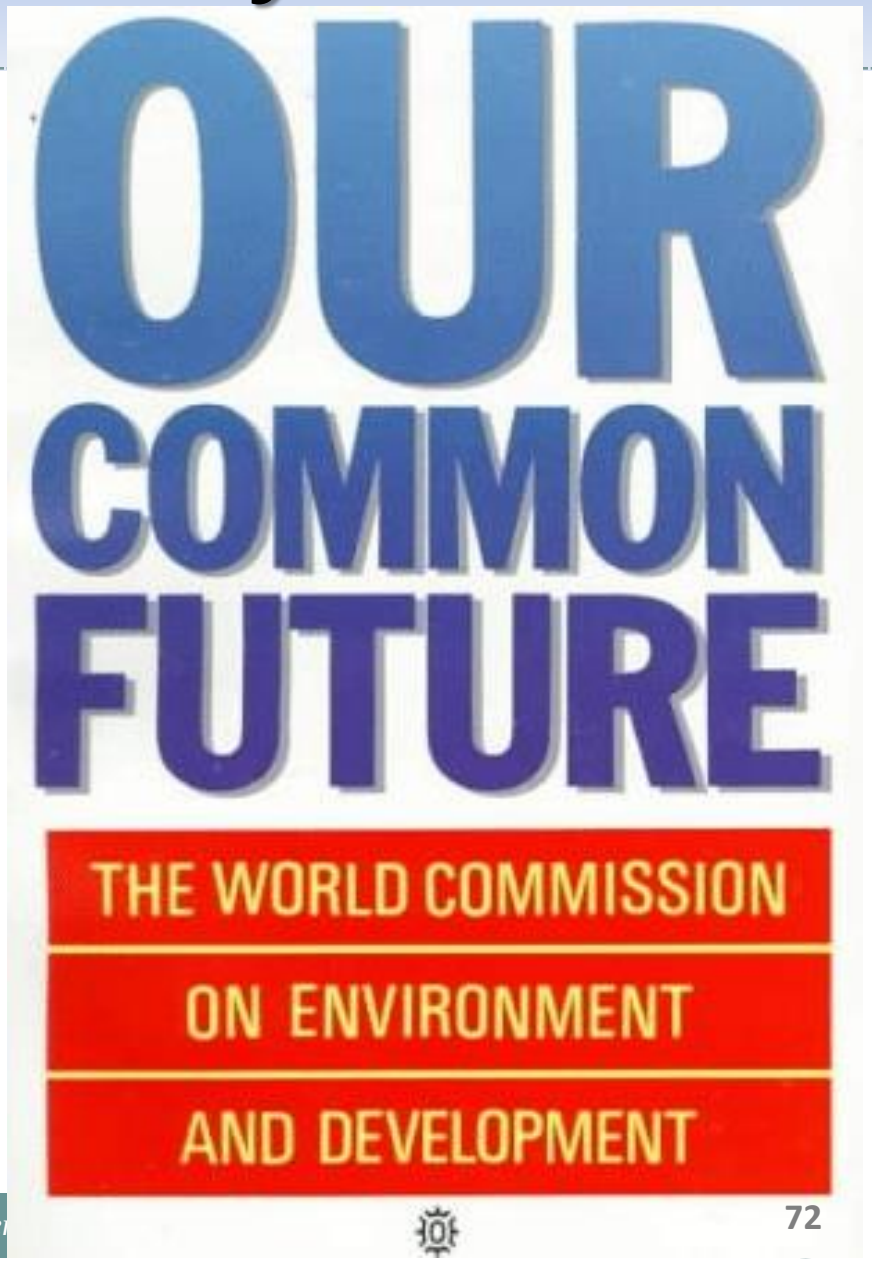
*Construction under planning

6. Concluding Remarks

Concept of Sustainability

The World Commission on Environment and Development ，**WCED** - Our Common Future,1987

” Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs. ”



What We Have Learned and Our Willingness to Share

- Reservoir sedimentation is a key issue on water resources management in Taiwan
- Traditional design of small bottom outlet with large overflow spillway will cause large sediment accumulation and make a reservoir unsustainable. The design approach should be modified
- In addition to Shihmen Reservoir, Taiwan is also doing renovation of other reservoirs in southern region
- Renovation experiences learned from these reservoirs can also be implemented to existing reservoirs in other countries
- ADB is invited to visit Taiwan to gain a deeper understanding of the renovation works