Introduction to reservoirs

- Basic facts.
- Function of Reservoirs
- Impacts on environment and society-
- Reservoir Sedimentation—Negative effect, Control, and Sedimentation Profiles

Introduction to reservoirs

Basic facts

- The total number of reservoirs with dam height over 15m is 49697. They are distributed in over 140 countries.
- The total water storage capacity is 18640.6 GM^3 and the total hydropower installation is 728.5 GW.

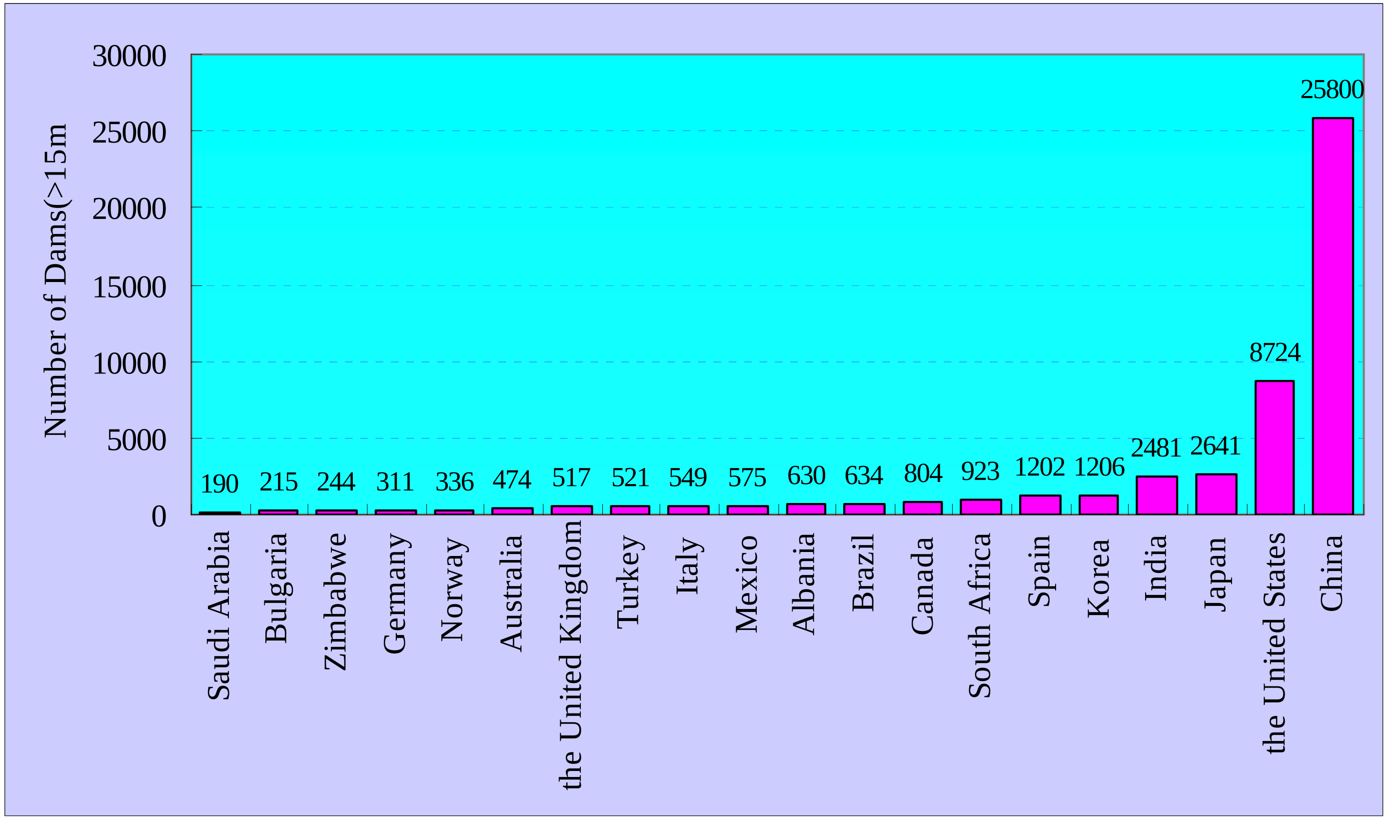
Number of reservoirs with dam height over 15m in the world (by 2003, source: ICOLD)

Over 15m	>30m	>100m	>150m
49697	12600	670	155

Introduction to reservoirs

Basic facts

The top 20-country's dam construction



Number of dams in top 20 countries (height over 15m)

Introduction to reservoirs

Basic facts

The six biggest water storage capacity reservoirs(GM^3)

Country	Reservoir Name	River	Water storage capacity
Russia	Bratskoye Reservoir	The Angara River	169.3
Egypt and Sudan	Aswan High Dam Reservoir	The Nile River	162
Zambia and Zimbabwe	Lake Kariba	The Zambezi River	160
Ghana	Volta Lake	The River Volta	148
Canada	Manicouagan Reservoir	Manicouagan River	142
Venezuela	Guri Reservoir	Caroni River	135.7

(Source:http://www.ilec.or.jp/database/index/idx-lakes.html)

Introduction to reservoirs

Basic facts

The four biggest hydropower installation countries (GW)

China	USA	Brazil	Canada
82.7	75.5	67.1	64.0

The four biggest hydropower generation countries by 2002 (TWh)

Canada	USA	Brazil	China
353	308.8	300	280

Introduction to reservoirs

Basic facts

The highest dams for various styles in the world (m)

Country	Dam Style	Height (existing)	Under construction
Switzerland	Concrete gravity dam	285	
Russia	Arched concrete dam	271.5	292 (China)
Russia	Earth rock dam	335	
Russia	Concrete gravity arch dam	245	
Mexco	concrete-faced rockfill dam	187	233(China)
Colombia	RCC Gravity Dam	188	216(China)
Canada	Concrete buttressed dam	214	

Introduction to reservoirs

Basic facts

The world's 8 greatest Hydropower Stations:

Country	Hydropower Stations	River	Total installed capacity (MW)	Elect. generation (Twh /year)
China	Three Gorges	Yangtze River	18200	84.68
Brazil and Paraguay	Itaipu	Parana River	12600	71
USA	Grand Coulee	Columbia River	10830	20.3 (initial stage)
Venezuela	Guri	Caroni River	10300	51
Brazil	Tucurui	Tocantins River	8000	32.4 (initial stage)
Canada	La Grande Stage II	La Grande River	7326	35.8
Russia	Sayano-Shushensk	Yenesei River	6400	23.7
Russia	Krasnoyarsk	Yenesei River	6000	20.4

Introduction to reservoirs

Basic facts

Current exploitation degree of the world

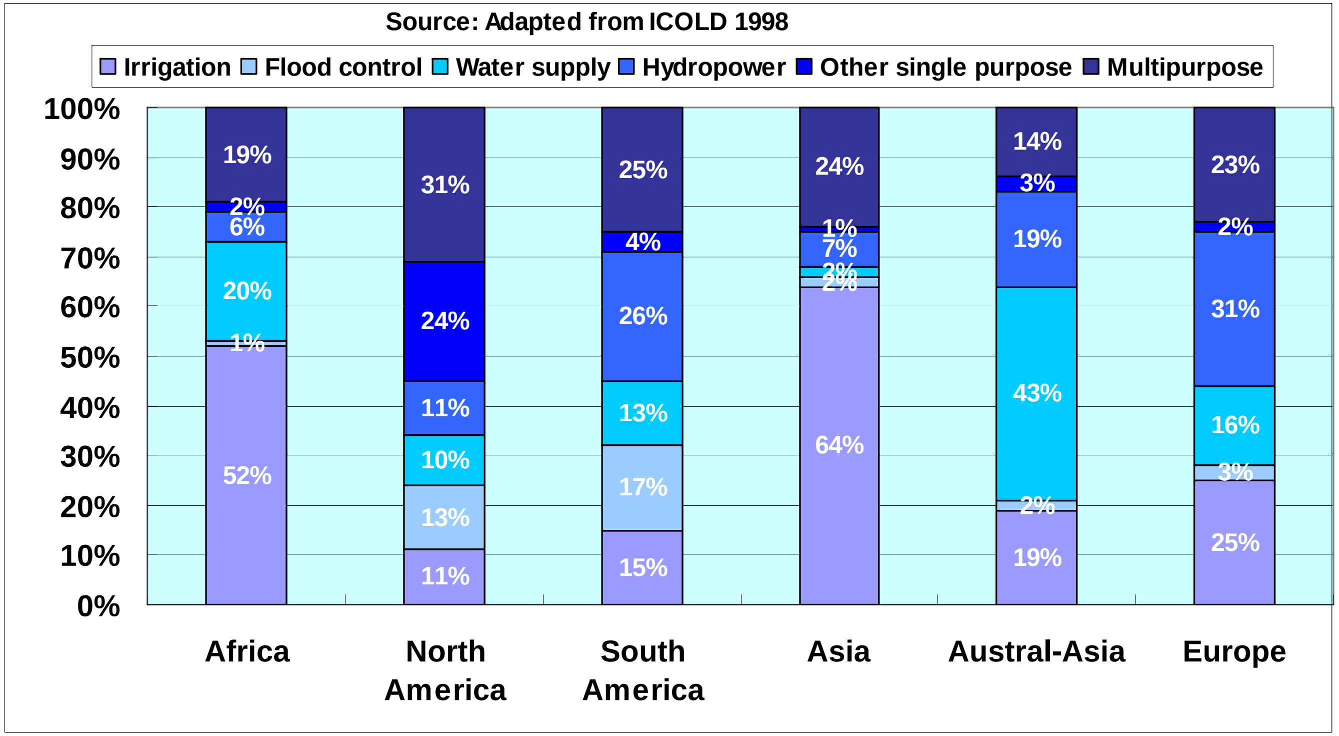
- Over 60%, France, Switzerland, USA, Canada
- 100% electricity used in Norway is hydropower
- In developing countries, the exploitation degree is relatively lower.

Country	Actual as % of economic potential	Hydro as % of total electricity
France	100	20
Switzerland	91	80
United States	77	10
Canada	65	63
Norway	56	100
Brazil	33	91.7
India	33	25
Indonesia	32	14
China	15	17
World total	36	<19
Sources: World Energy Conference, UN, MIT Energy Lab, Paul Scherrer Institute		

Introduction to reservoirs

Function of Reservoirs

Functions of reservoirs include Flood Control, Irrigation, Water Supply, Hydropower, Navigation, Recreation etc.



Distribution of existing large dams by region and purpose

Introduction to reservoirs

Function of Reservoirs

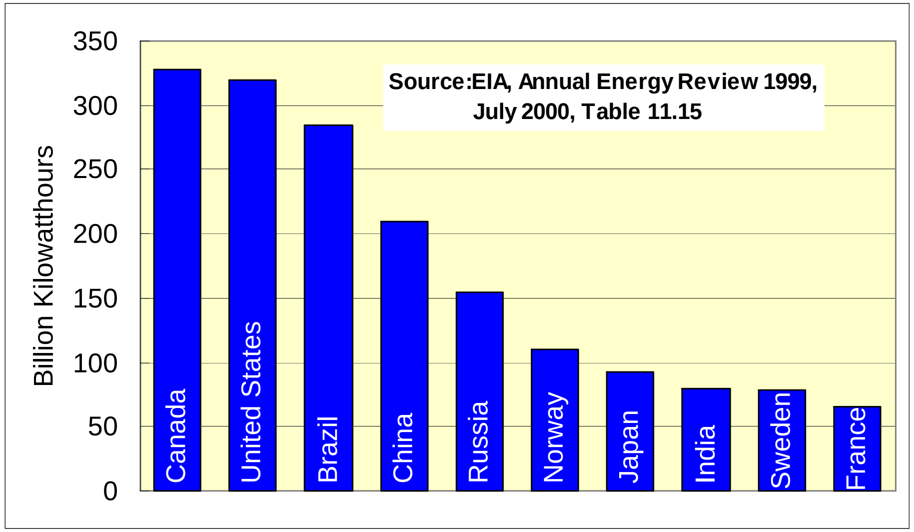
The 10 countries with the most large dams

By number of large dams		By function			
		Irrigation	Water supply	Flood control	Hydropower
1	China	China	United States	China	China
2	United States	India	Unite Kingdom	United States	United States
3	India	United States	Spain	Japan	Canada
4	Spain	Korea	Japan	Brazil	Japan
5	Japan	Spain	Australia	Germany	Spain
6	Canada	Turkey	Thailand	Romania	Italy
7	Korea	Japan	South Africa	Mexico	France
8	Turkey	Mexico	Brazil	Korea	Norway
9	Brazil	South Africa	France	Canada	Brazil
10	France	Albania	Germany	Turkey	Sweden
Note:This table shows that China, India and the United States have outpaced the world in building large dams based on ICOLD 1998 and WCD correction for China.					

Introduction to reservoirs

Function of Reservoirs

- **Hydropower advantage——Energy:**
  - ✓ **World-wide, about 20% of electricity generated by hydropower**
  - ✓ **Norway produces more than 99% of its electricity with hydropower**
  - ✓ **Brazil, New Zealand and Canada use hydropower for over 60% of their electricity**
  - ✓ **Long lifetime, 50 plus years**
  - ✓ **Usable for base load, peaking, and pumped storage applications**



Introduction to reservoirs

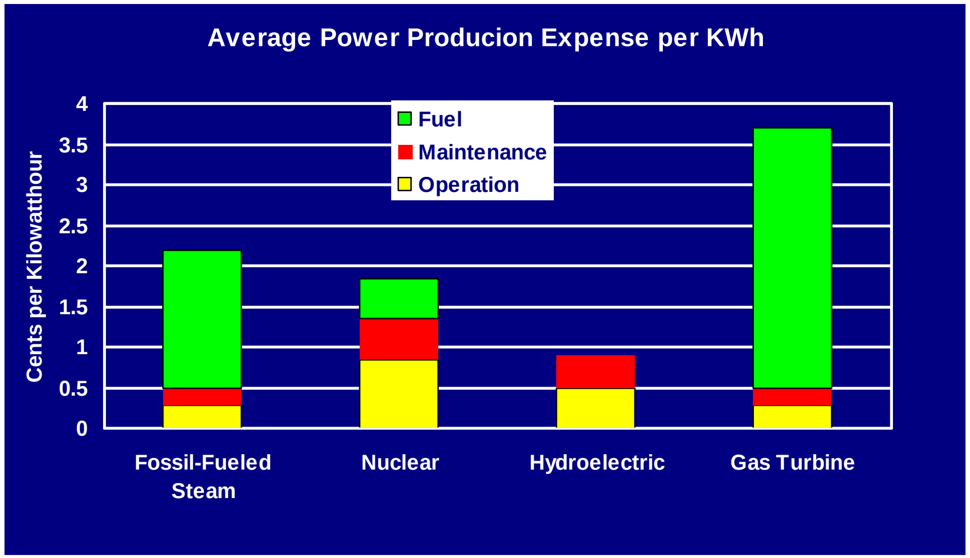
Function of Reservoirs

- **Hydropower advantage——Environment:**
  - **Hydropower is clean. It prevents the burning of 22 billion gallons of oil or 120 million tons of coal each year.**
  - **Hydropower is one of the electricity sources that generate the fewest greenhouse gases, i.e. 60 times less than coal-fired power plants and 18 times less than natural gas power plant.**
  - **Hydropower leaves behind no waste**

Introduction to reservoirs

Function of Reservoirs

- Hydropower advantage——Low cost:
  - ✓Low operating and maintenance costs
  - ✓Hydropower is the most effective way to generate electricity. Hyro-turbins can convert as much as 90% of the available energy into electricity.
  - ✓The cost of hydropower per kwh is about 50% the cost of the nuclear, 40% the cost of fossil fuel, and 25% the cost of natural gas.
  - ✓Hydropower does not experience rising or unstable fuel costs.



Introduction to reservoirs

◆Function of Reservoirs

➢**Hydropower advantage——Renewable:**

Hydropower is the leading source of renewable energy. It provides more than 97% of all electricity generated by renewable sources.

➢**Recreation:**

Reservoirs formed by dams provide many water-based recreational opportunities including fishing, water sports, boating, and water fowl hunting.

Introduction to reservoirs

◆Impacts on environment and society

- Land use—inundation and displacement of people
- Impacts on biodiversity
  - aquatic ecology, fish, plants, mammals
- Water chemistry changes
  - mercury, nitrates, oxygen
  - bacterial and viral infections
- Safety
  - seismic risks
  - structural dam failure risks
- Impacts on natural hydrology
  - increase evaporative losses
  - altering river flows and natural flooding cycles
  - sedimentation in reservoir and erosion downstream

Introduction to reservoirs

Reservoir Sedimentation

- **Reduce storage capacity: Reservoirs built in the upper and middle parts of a river basin can be used for multiple purposes, including flood control, irrigation and power generation. However, along with the impoundment of water in the reservoir, the cross-sectional flow velocity will dramatically decrease and the sediment-carrying capacity of the flow becomes very weak. Therefore large quantity of sediment deposit in the reservoir. The continuous sedimentation in the reservoir will greatly decrease the storage capacity, the function, and the life span.**
- **Retrogressive deposition: Deposition in the reservoir may extend sometimes to a longer distance upstream from the original backwater deposits occurred in the initial period of impoundment. More and more of the valley upstream would thus be subjected to inundation and salinization.**
- **Downstream erosion: The clear water released from the reservoir has abundant ability to carry more sediment and cause severe erosion downstream channel bed. This may bring negative affect to the irrigation system, water intakes and the stability of banks.**

Introduction to reservoirs

◆Reservoir Sedimentation

In the planning and design of the Sanmenxia Project, due to the inadequate knowledge to the sedimentation problems and the lack of operational experience, the unexpected severe sedimentation had occurred since its operation in 1960.

Introduction to reservoirs

Reservoir Sedimentation

During the initial period of impoundment, deposition in the reservoir was so serious that it amounted to nearly 1.5 billion tons by March 1962, retaining 93 % of the oncoming sediment load. By 1964, the total amount of deposition had reached 4.4 billion tons, and the backwater deposits had extended upstream to the tributary of Weihe River, thus endangering both the agricultural and industrial development and flood situation in the vicinity of the city of Xian and the vast alluvial plain on both banks of the Weihe River.

Afterwards, the mode of operation had to be changed from “storing water and detaining sediment” (Sept. 15, 1960 to Mar. 19, 1962) to “detaining flood and discharging sediment” (Mar. 20, 1962 to Oct. 1973) to “storing clear water and discharging muddy flow” (after Nov. 1973).

Meanwhile, two times of reconstruction were carried out. The level of flow discharge outlets were lowered and the additional flow and sediment discharge outlets were constructed. The capacity to discharge flow and sediment was largely increased.

With the change of the operational mode and two times reconstruction, the sedimentation has been efficiently controlled since 1973.

This experience was indeed a lesson not to be soon forgotten.

Introduction to reservoirs

◆Reservoir Sedimentation

- In China, according to the statistics of 43 large-/middle-sized reservoirs in Shanxi Province in 1974, 31.5% of the initial volume has been lost, the annual capacity lost is 50 million m3. Data from 192 reservoir with over 1 million m^3 volume in Shaanxi Province in 1973 also show that 31.6% of the total volume 1.5 billion m3 has been lost.
- In the United States, the total annual amount of deposition in reservoirs had reached 1.2 billion m^3.
- In Japan, up to 1979, from statistics on 425 reservoirs with a combined capacity exceeding 1 million m3, 6.3 % of the reservoir capacity had been lost due to deposition.
- In India, according to statistics presented in 1969, the annual rate of loss of reservoir capacity was 0.5-1.0 % for 21 reservoirs with a combined capacity greater than 1.1 billion m^3.
- In Russia, in the Middle Asian Region, the life span of reservoirs with dam height lower than 6m is 1~3 years; the life span of reservoir with dam height 7~30m is 3~13 years.

Introduction to reservoirs

◆Reservoir Sedimentation

Organized directly by the Ministry of Water Resources, an investigation on 20 key reservoirs, most of which had been operated less than 20 years, shows that the total amount of deposition was 7.8 billion m^3, or 18.6 % of their original capacity.

Sedimentation Dept., IWHR

Sedimentation in Some Reservoirs in China

	Reservoir	River	Drainage area 1000 km^2	Dam height m	Design Capacity $10^8 m^3$	Periods of statistics	Total deposition $10^8 m^3$	Dep./capa. %
1	Liujiaxia	Yellow	181.7	147	57.2	1968-78	5.8	10.1
2	Yangouxia	Yellow	182.8	57	2.2	1961-78	1.6	72.7
3	Bapanxia	Yellow	204.7	43	0.49	1975-77	0.18	35.7
4	Qintongxia	Yellow	285.0	42.7	6.20	1966-77	4.85	78.2
5	Sanshengong	Yellow	314.0	gate	0.80	1961-77	0.40	50
6	Tianqiao	Yellow	388.0	42	0.68	1976-78	0.075	11
7	Sanmenxia	Yellow	688.4	106	96.4	1960-78	37.6	39
8	Bajiazui	Puhe	3.52	74	5.25	1960-78	1.94	37
9	Fengjiashan	Qianhe	3.23	73	3.89	1974-78	0.23	5.9
10	Hesonling	Yeyuhe	0.37	45.5	0.086	1961-77	0.034	39
11	Fenhe	Fenhe	5.27	60	7.00	1959-77	2.60	37.1
12	Guanting	Yongding	47.6	45	22.7	1953-77	5.52	24.3
13	Hongshan	Xiliaohe	24.5	31	25.6	1960-77	4.75	18.5
14	Laodehai	Liuhe	4.50	41.5	1.96	1942	0.38	19.5
15	Yeyuan	Mihe	0.79	23.7	1.68	1959-72	0.12	7.2
16	Gangnan	Hutuohe	15.9	63	15.58	1960-76	2.35	15.1
17	Gongzui	Daduhe	76.4	88	3.51	1967-78	1.33	38
18	Bikou	Beilong	27.6	101	5.21	1976-78	0.28	5.4
19	Danjiankou	Hanjiang	95.2	110	160.5	1968-74	6.25	3.9
20	Xingqiao	Hongliuhe	1.33	47	2.00	14 yrs	1.56	78

Introduction to reservoirs

◆Negative Effects by Reservoir Sedimentation

- Decrease both the flood-control storage and the live storage of a reservoir. Affect the efficiency of flood control, electricity generation, navigation, irrigation and fishery.
- The decrease of the longitudinal slope results in the rising of water level in the upper reach and deposition extension headwater. As a result, nearby cities, factories, mines, and farm land have to face the threatening of flooding.
- The deposition extension headwater may also result in the rising of ground water, salinization of top-layer soil, and deterioration of eco-environment.

Introduction to reservoirs

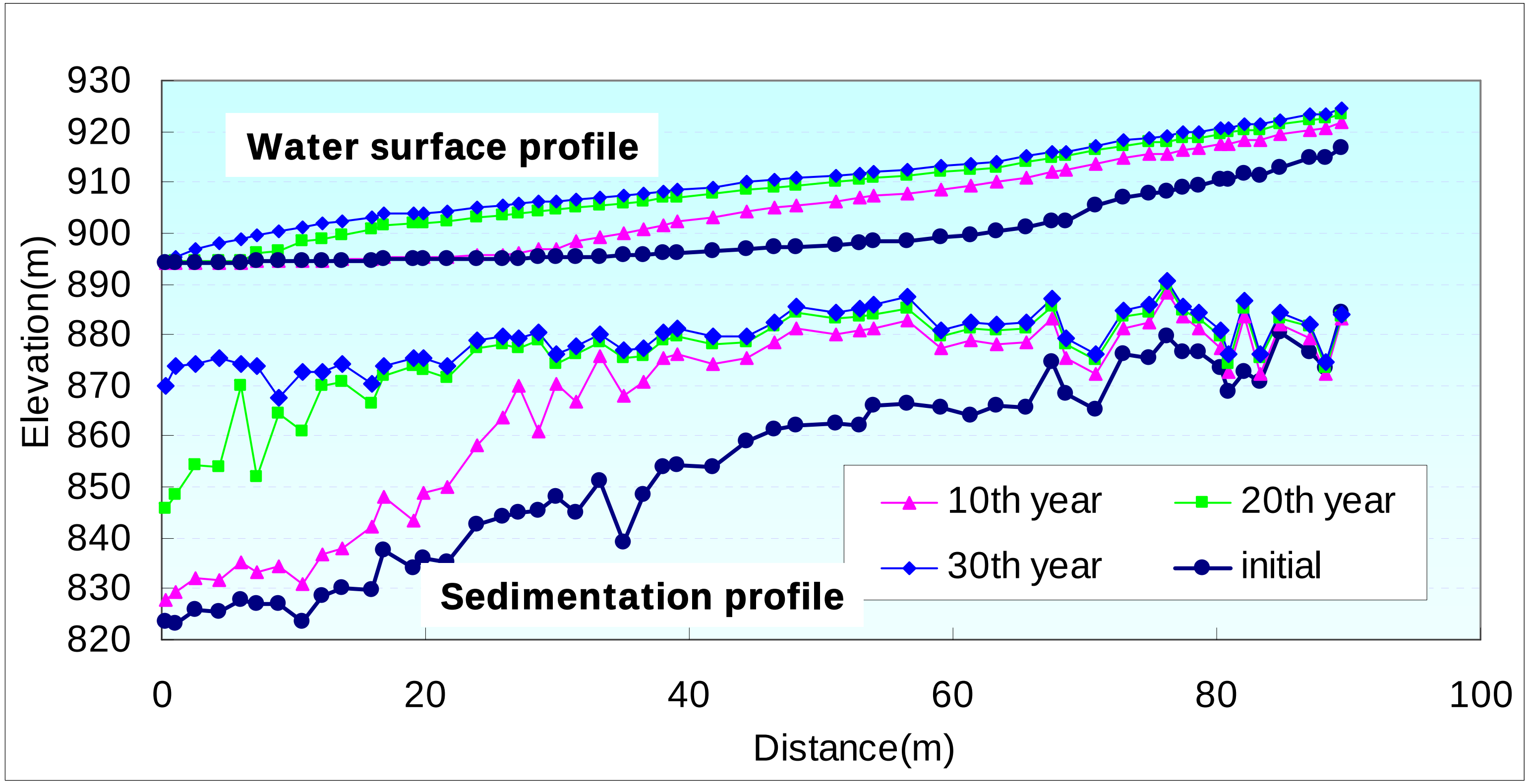
◆Negative Effects by Reservoir Sedimentation

- Negative effects of deposition in the movable backwater reach on the navigation.
- Sedimentation in the front area of the dam may affect the safe operation of the hydraulic project, including ship locks, navigation channel, the entrance of turbines, the entrance of water diversion intakes, the erosion of turbine blades, and the screen rack clogging.
- Pollutants attached in the surface of sediments may affect the water quality of the reservoir.
- Clear water released from the reservoir may cause severe erosion downstream and affect the channel stability and the applicability of existing hydraulic projects such as water diversion intakes.

Introduction to reservoirs

◆Negative Effects by Reservoir Sedimentation

Change of sedimentation profile and water surface profile



More land to be inundated and more people to displace

Introduction to reservoirs

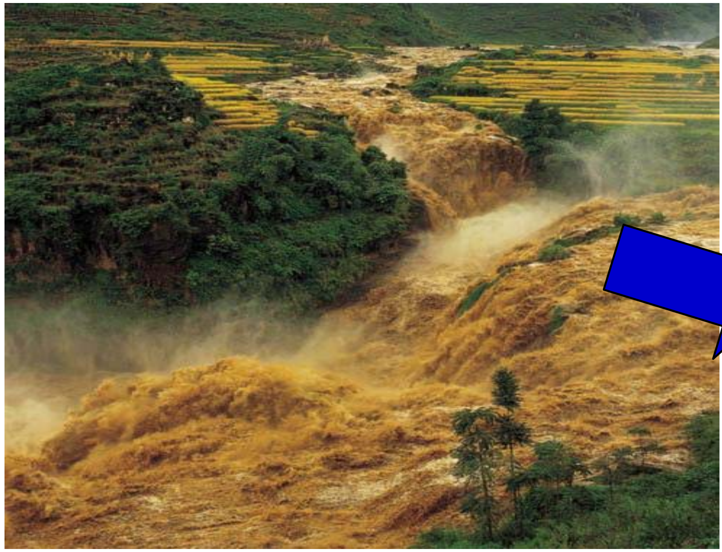
◆Control of Reservoir Sedimentation

Essential measures to alleviate the sedimentation of reservoirs are to reduce the sediment entering the channel and increase the sediment flushing rate. Some efficient measures are listed in follows.

Introduction to reservoirs

◆Control of Reservoir Sedimentation

- Using water and soil conservation and check dams to decrease sediment yield, to reduce sediment entering the channel, and finally to alleviate reservoir sedimentation.



Introduction to reservoirs

Control of Reservoir Sedimentation

- **Using the operation of storing clean water and discharging muddy flow to mitigate reservoir sedimentation. Low water levels are used during flood season to discharge more sediment, and high water levels can be operated during dry season**

Introduction to reservoirs

Control of Reservoir Sedimentation

- **Using density flow to discharge sediment. When the density flow happens, the sediment flushing gate should be lifted to let the density flow with high sediment concentration go through the dam.**
- **Ungated operation (Empty reservoir). When the sedimentation in a reservoir is very serious, an ungated operation can be used to flush a large quantity of sediment to the downstream. This operation has an obvious effect to restore storage capacity.**
- **Using big flood to flush sediment. Usually big floods carry large quantity of sediment. Therefore, according to hydrological forecast, lowering the operation water level can discharge the heavy sediment load out and efficiently alleviate sedimentation in the reservoir.**

Introduction to reservoirs

Control of Reservoir Sedimentation

- **Using by-pass channel to flush sediment. For some middle/small size reservoirs, by-pass channels are used to discharge floods with heavy sediment load.**

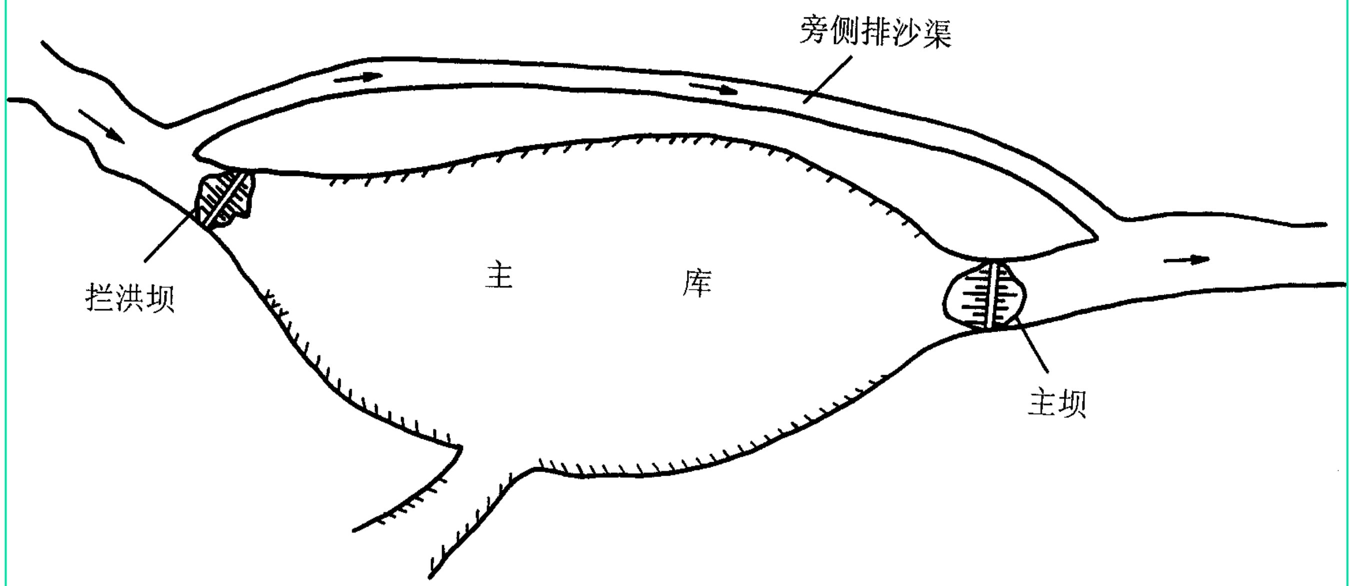


图 1 虎山水库旁侧泄洪排沙渠工程平面布置示意图

Introduction to reservoirs

◆Control of Reservoir Sedimentation

- Using high floodplain channel to wash floodplain surface. A low dam is constructed in the upper reach to divert flow to channels on the high floodplain. Then hydraulic erosion and gravity erosion formed by the steep between high floodplain and main channel are used to break up and transport sediment on the surface of the slope. Thereby the purpose of cleaning out sediment can be achieved.

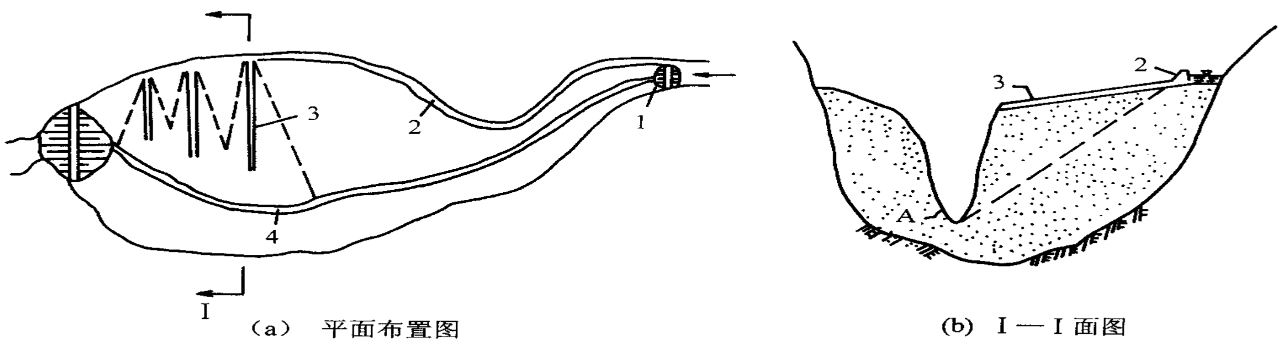


图 2 黑松林水库“高渠洩水冲滩”工程布置示意图

1—挡水坝 2—输水高渠 3—引槽 4—主槽

Introduction to reservoirs

Control of Reservoir Sedimentation

- **Mechanical cleaning and dredging. For large scale reservoirs, mechanical cleaning devices such as dredge boats are used to locally dredge sedimentation. For middle/small scale reservoirs, small-size power machines are used to clean deposition, such as air-driven pumps and hydraulic dredgers.**

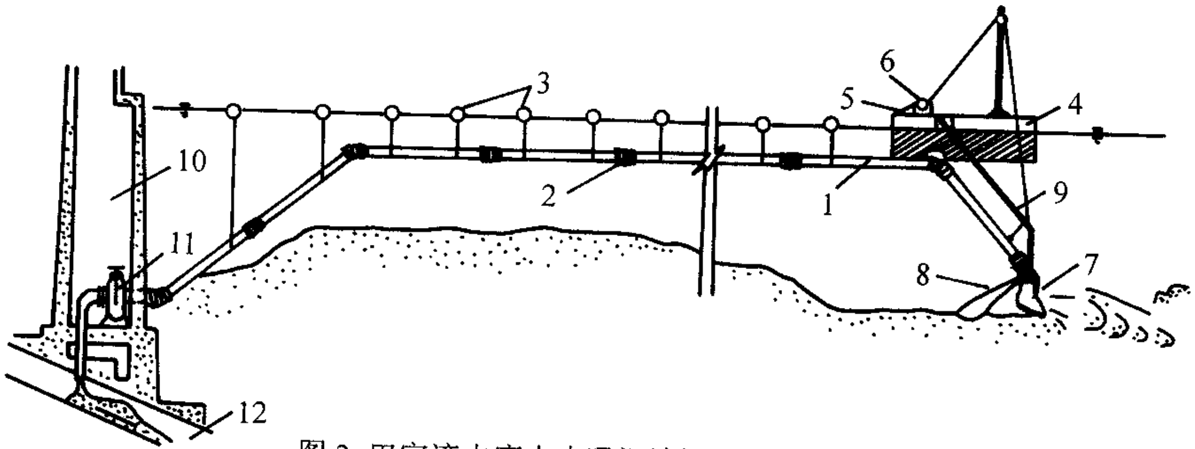


图 3 田家湾水库水力吸泥清淤装置布置示意图
1.输泥管；2.软接头；3.浮筒；4.操作船；
5.电机；6.卷扬机；7.吸头；8.方向舵；
9.拉杆；10.闸室；11.闸阀；12.卧管

Introduction to reservoirs

Reservoir Sedimentation Profiles

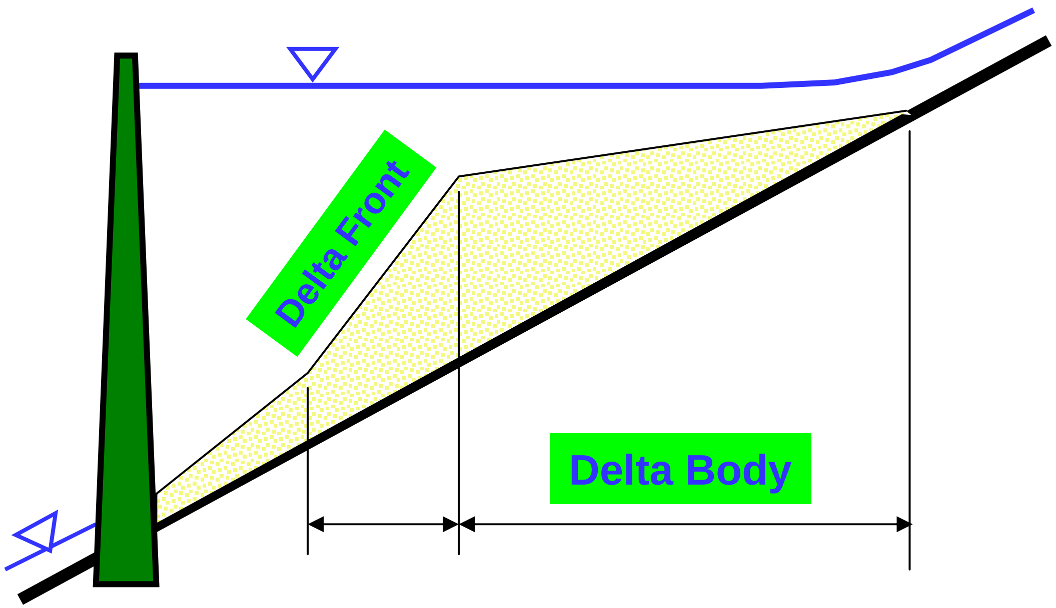
Reservoir Sedimentation Profiles generally include three types:

- Delta Sedimentation
- Conical Sedimentation
- Banded Sedimentation

Introduction to reservoirs

Reservoir Sedimentation Profiles

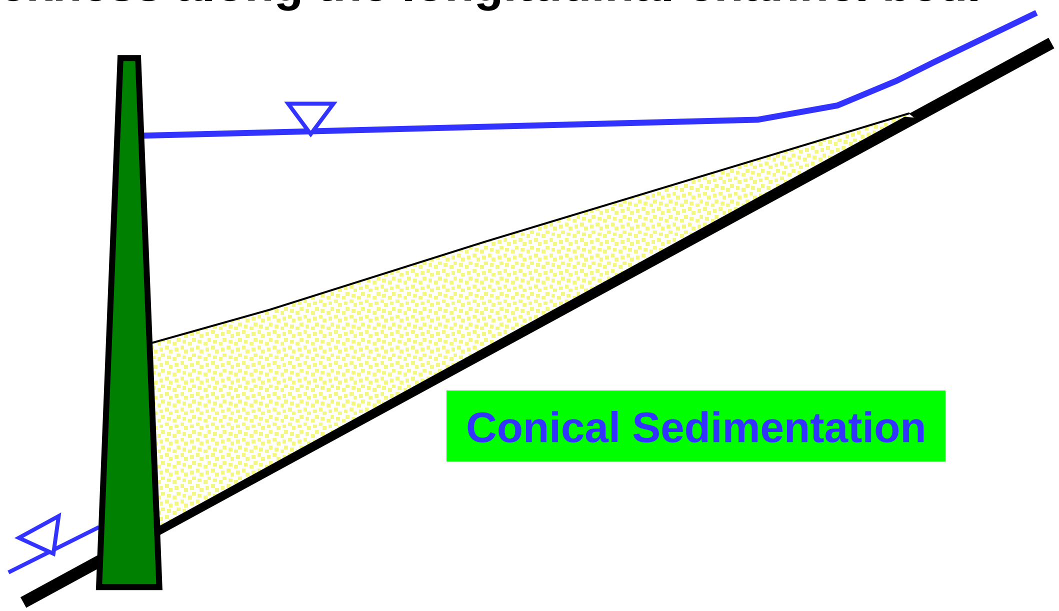
- Delta Sedimentation
  - ✓Formation Reasons: usually occurs in the reservoir with relatively stable and high operational water level, as well as a long backwater area.
  - ✓Characteristics: consists of two parts: delta body and delta front.



Introduction to reservoirs

Reservoir Sedimentation Profiles

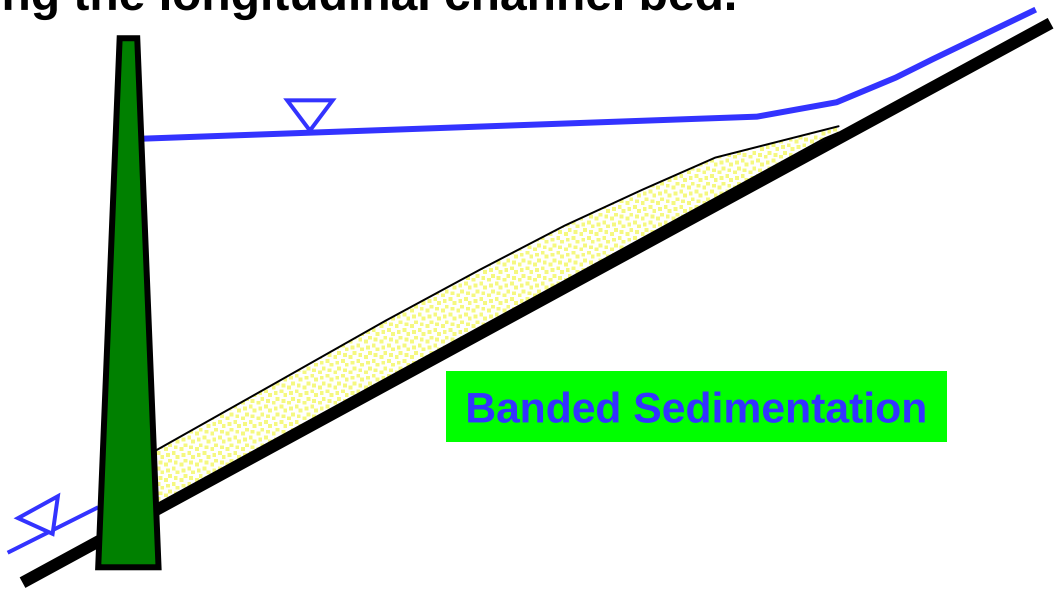
- Conical Sedimentation
  - Formation Reasons: small-sized reservoir, low operational water level, short back water area, hyper-concentrated flow, and very fine suspended sediment.
  - Characteristics: gradually increase of the sedimentation thickness along the longitudinal channel bed.



Introduction to reservoirs

Reservoir Sedimentation Profiles

- Banded Sedimentation
  - Formation Reasons: big variation of operational water level, long variable back water zone, the dual characteristics of river and reservoir in the variable backwater zone.
  - Characteristics: nearly uniform thickness of sedimentation along the longitudinal channel bed.



Thanks