INVESTIGATION ON FACTORS AFFECTING TONGGUAN ELEVATION AND MEASURES TO LOWER IT

Case study I

Application of mathematical simulation to Sanmenxia Reservoir

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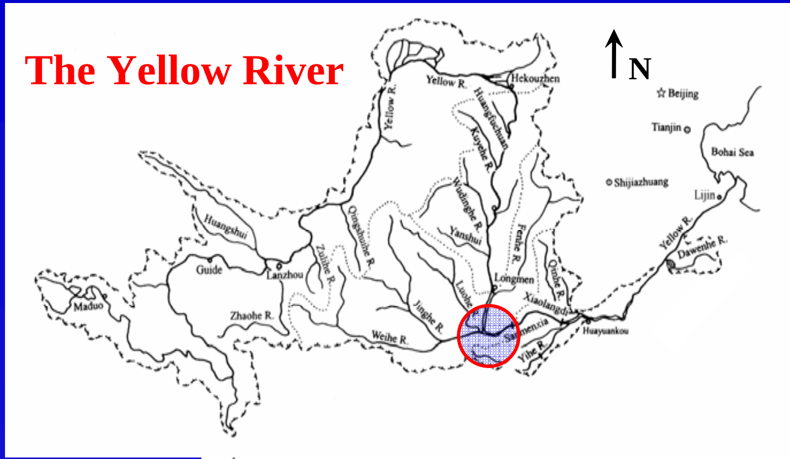
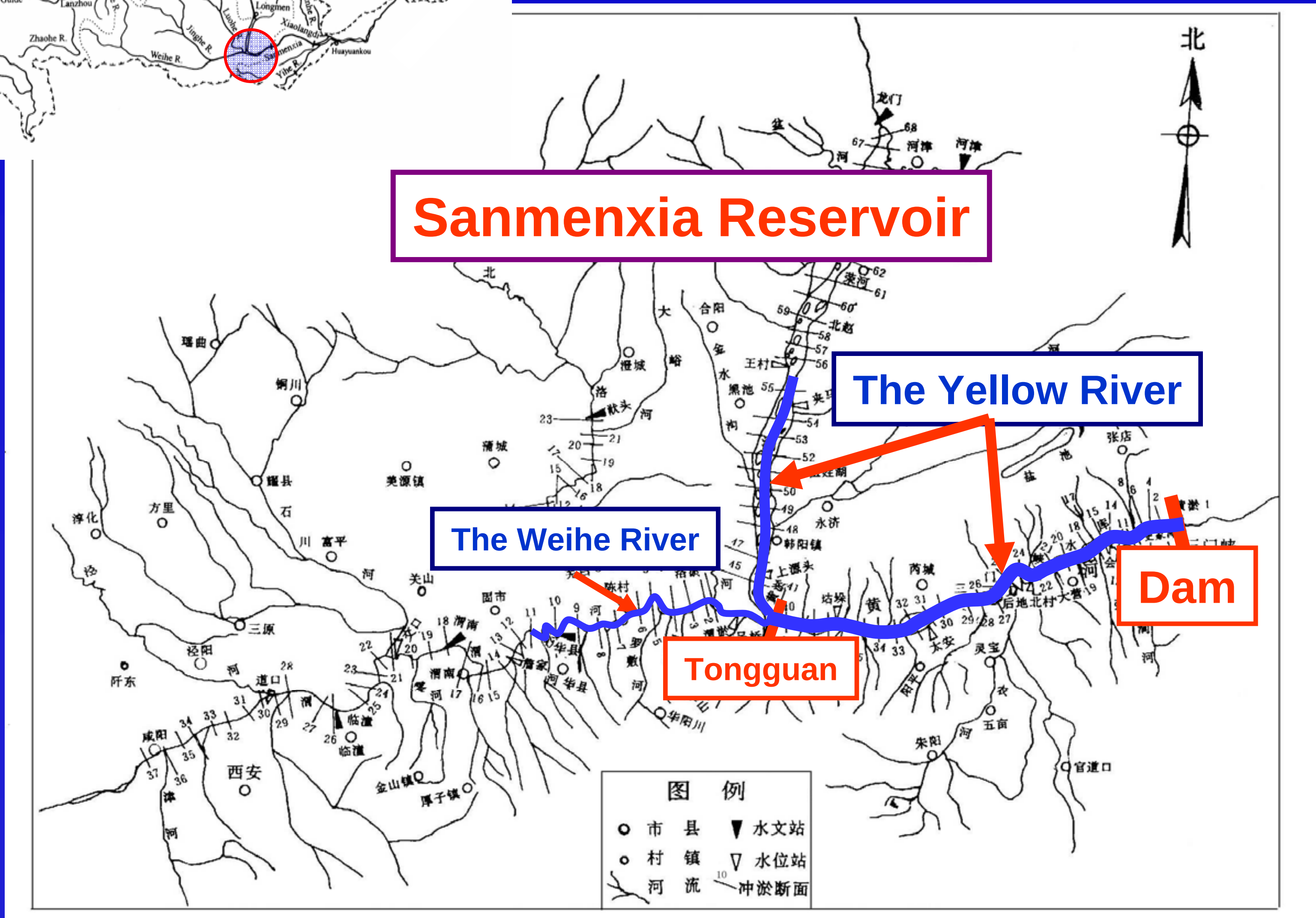
Objectives


The Yellow River
N
Beijing
Tianjin
Bohai Sea
Shijiazhuang
Lijin
Hekouzhen
Yellow R.
Lanzhou
Guide
Maduo
Zhaohe R.
Weihe R.
Longmen
Huayuankou

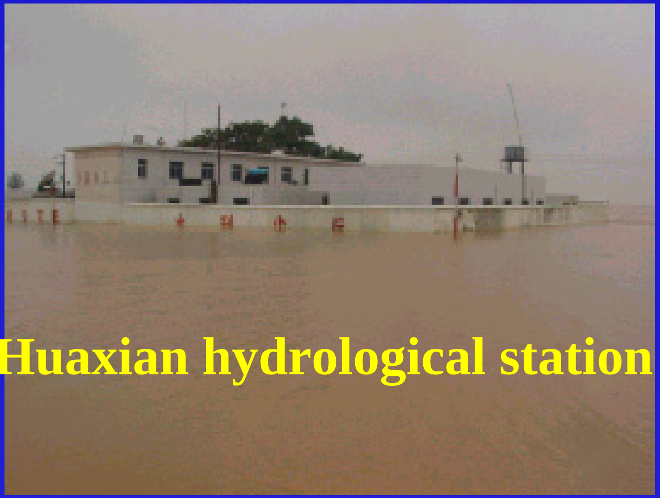

Sanmenxia Reservoir
The Yellow River
The Weihe River
Tongguan
Dam
北
西安
图 例
市 县
村 镇
河 流
水文站
水位站
冲淤断面

Objectives

This rising of TG resulted in many problems to Weihe River:

- Continuous rising of Weihe River bed
- Shrinkage of the main channel
- Decrease of flood conveying capacity
- Worse situation of flood control
- Rising of ground water level
- Soil salinization in the central Shaanxi plain
- Reduction of agricultural production
- Deterioration of eco-environment in reservoir area

Huaxian City



Huaxian hydrological station

Objectives

To alleviate the negative effects of TG elevation on Weihe River basin, the factors affecting TG elevation and the feasibility to lower it are investigated.

Sanmenxia Reservoir and TG Elevation


Sanmenxia Reservoir: the first large dam project on the Yellow River
Catchment area: 688,000 km^2, control 89% runoff, 98% sediment
Purposes: flood control, irrigation, power generation, water supply,
sedimentation reduction for the lower Yellow river, other purposes
Built: 1957, Finished: 1960, Operated: Sept., 1960

Sanmenxia Reservoir and TG Elevation

Due to the underestimation to sediment problem during the planning and design at that time, severe sedimentation has happened after the operation of the Sanmenxia reservoir in Sept. 1960.

To control the continuous sedimentation, the project has experienced three operation modes and two times of re-built to outlets.

Sanmenxia Reservoir and TG Elevation

Three operation modes

Operation mode		Duration	Minimum WL	Highest WL
1	Storing water and detaining sediment	Sept. 1960 to Mar. 1962	324.04m	332.58m
2	detaining flood and discharging sediment	Mar. 1962 to Oct. 1973	298.03m	325.9m
3	storing clear water and discharging muddy flow	after Oct. 1973	300.0m	318.0m

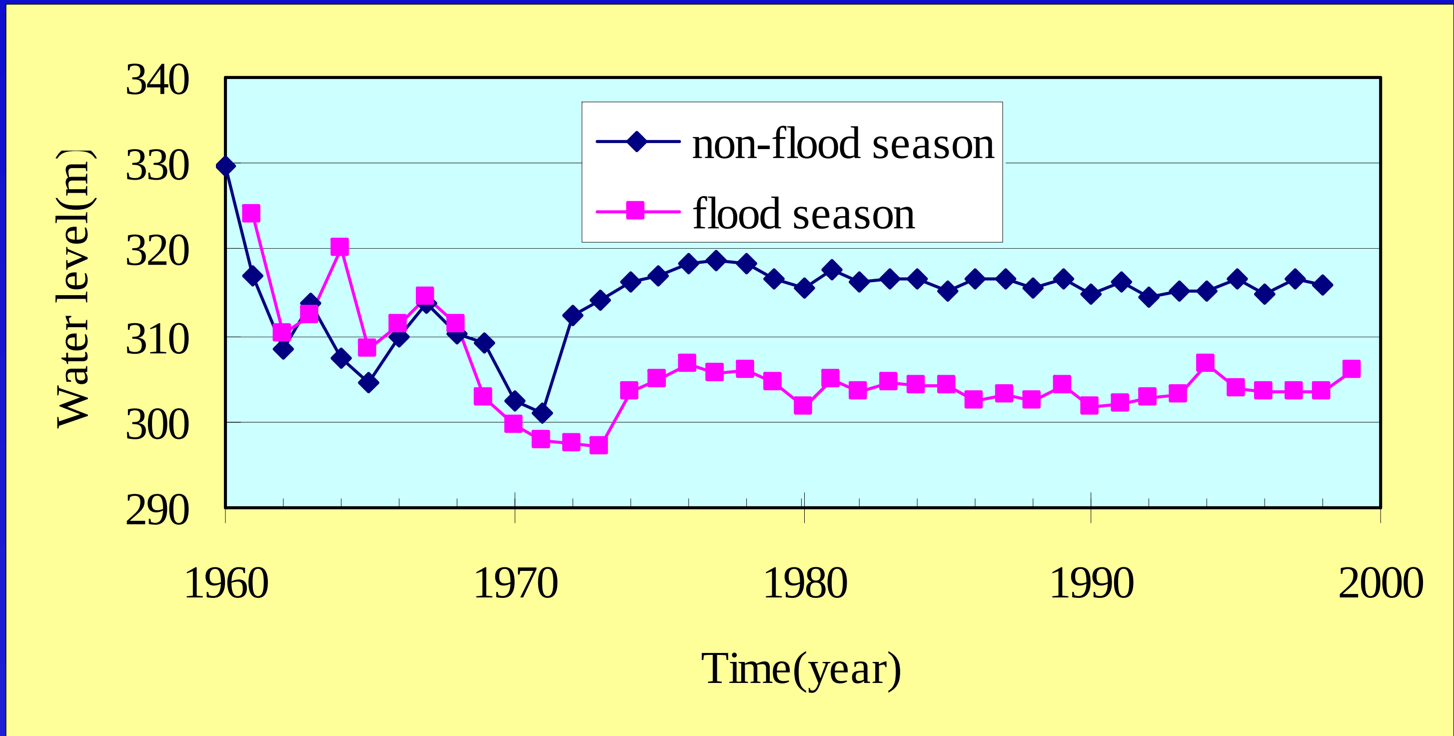
Sanmenxia Reservoir and TG Elevation

Two times of re-construction to outlets

Reconstruction		Duration	Discharge at WL 315m
1	Build two additional flood tunnels and change 4 power penstocks into flood outlets	1965 to 1968	3084 to 6102 (m^3/s)
2	Reopen diversion outlets 1#-8# Reopen bottom outlets 1#-12# Change a few more penstocks to flood outlets	1969 to 2000	6102 to 9701 (m^3/s)

Sanmenxia Reservoir and TG Elevation

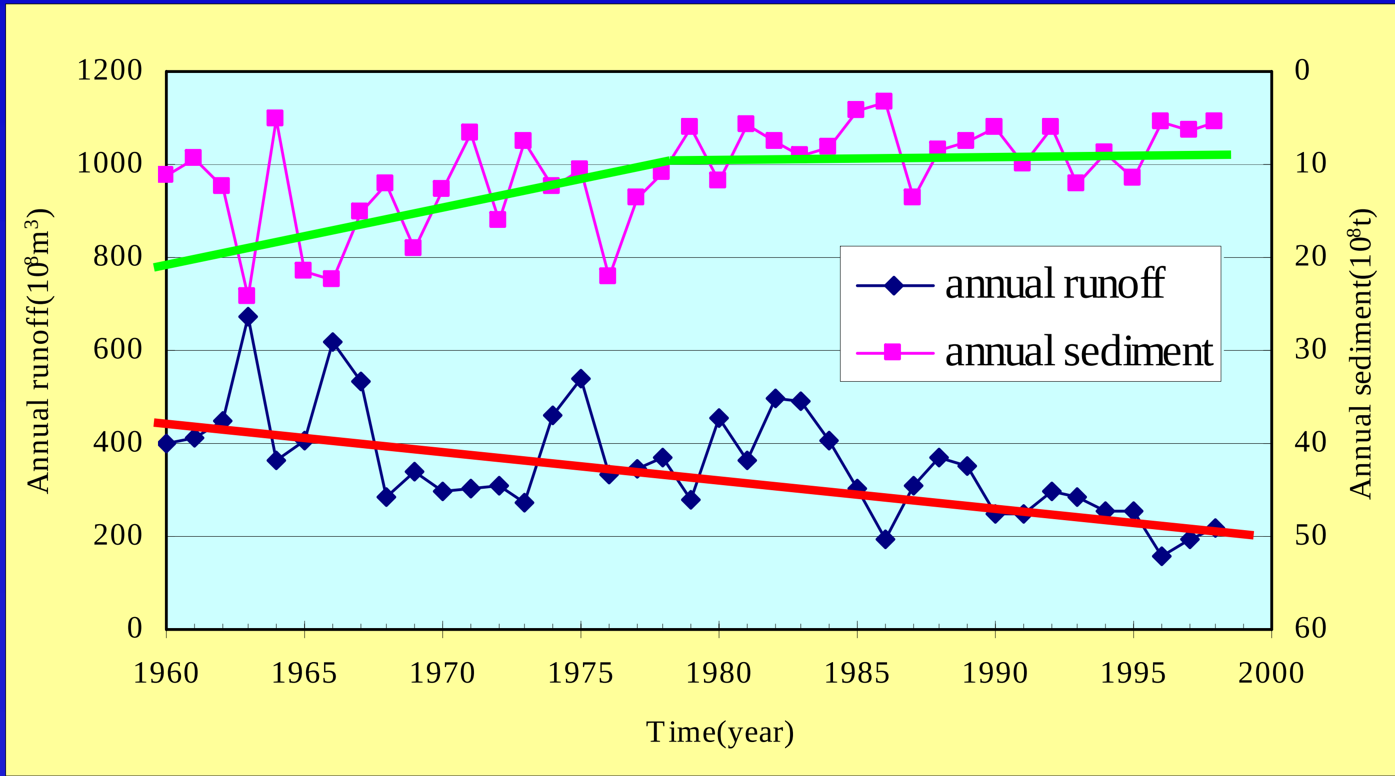
Operation water level of Sanmenxia Reservoir



Very high(330m) → very low(298m) → stable(304m/316m)

Sanmenxia Reservoir and TG Elevation

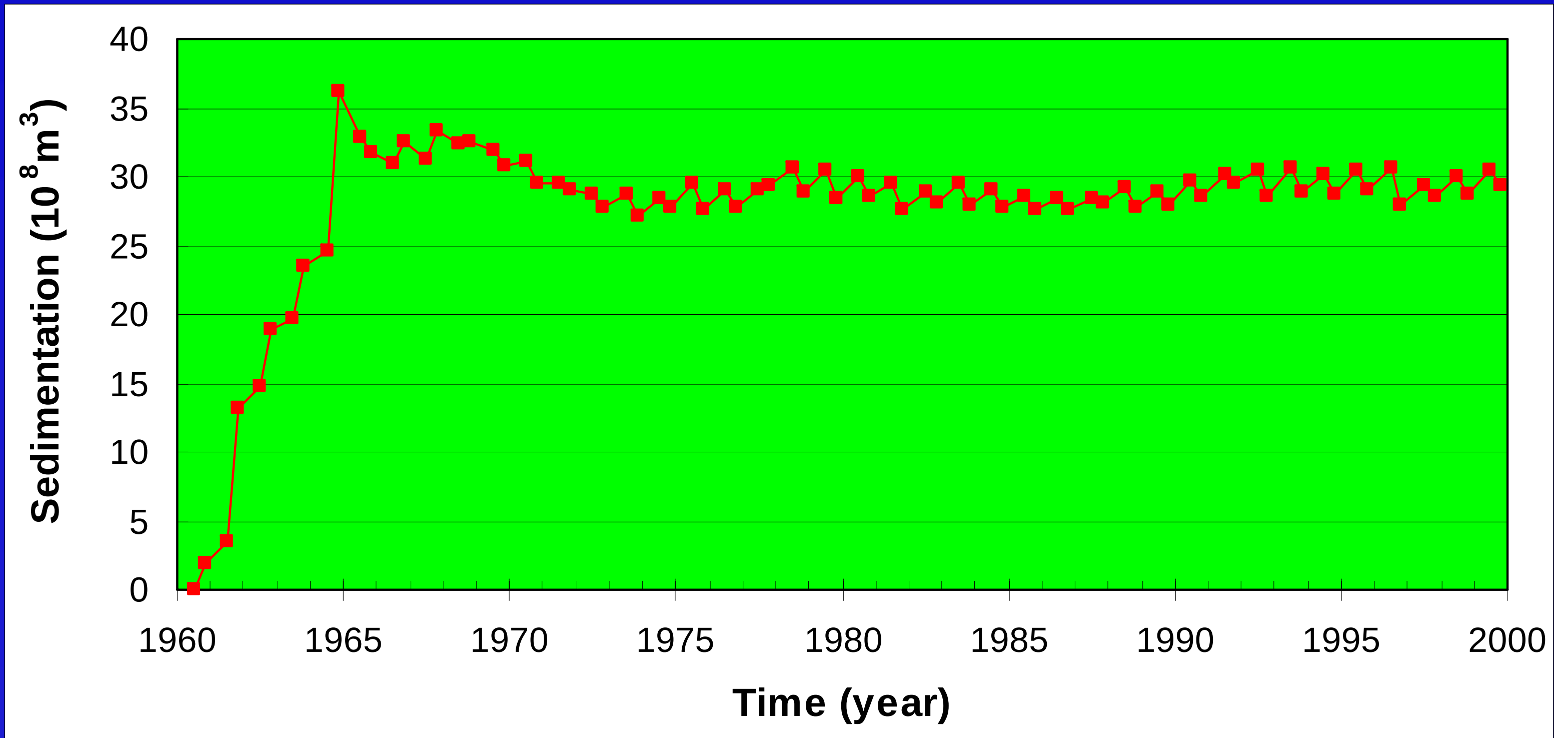
Incoming runoff and sediment to Sanmenxia Reservoir



Annual runoff: decrease from over 40 bm^3 to 20bm^3
Annual sediment: decrease first, then stable

Sanmenxia Reservoir and TG Elevation

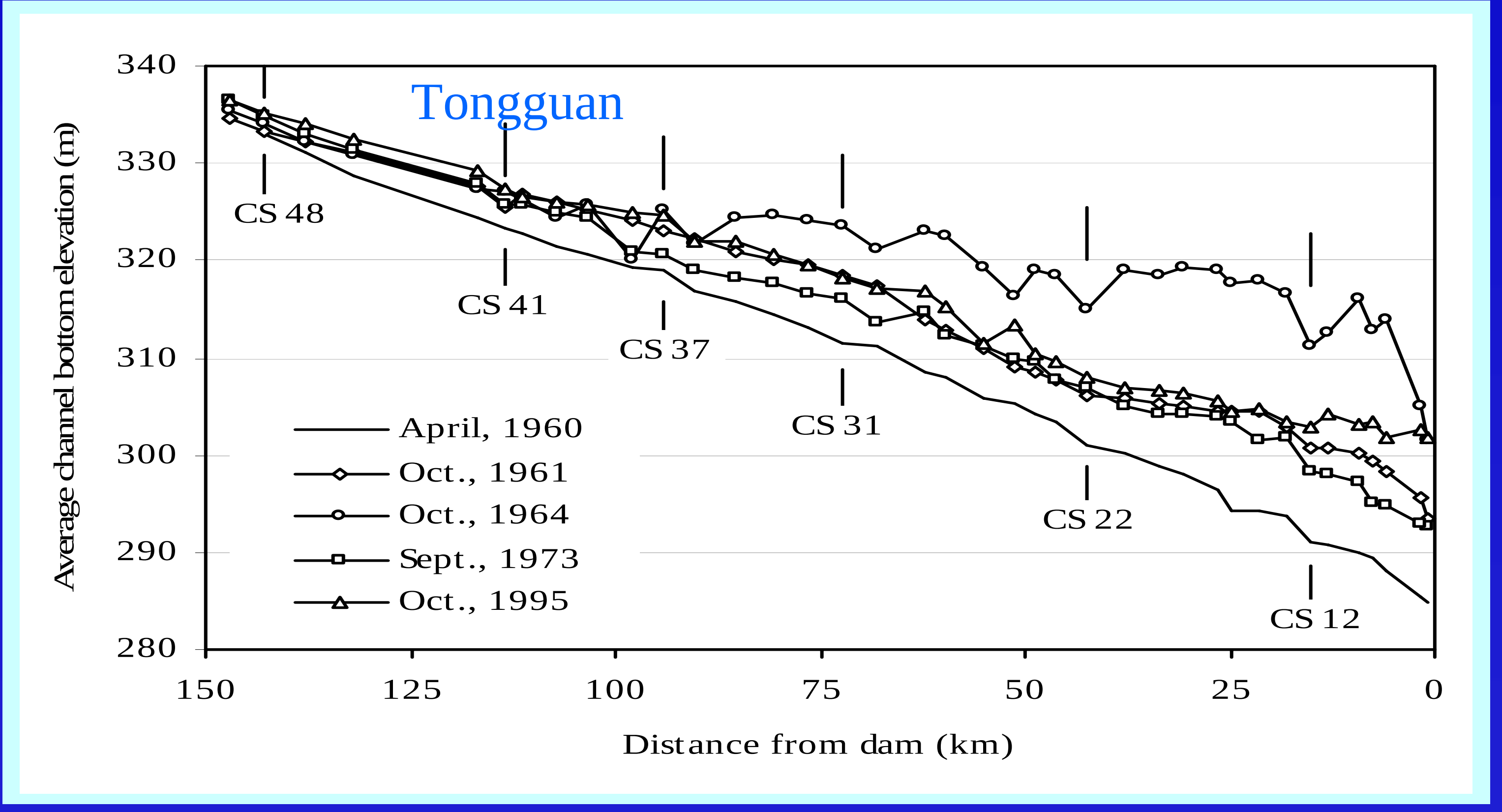
Sedimentation in Sanmenxia Reservoir (TG to Damsite)



The reservoir sedimentation has experienced three stage
Rapid deposition → erosion → nearly stable

Sanmenxia Reservoir and TG Elevation

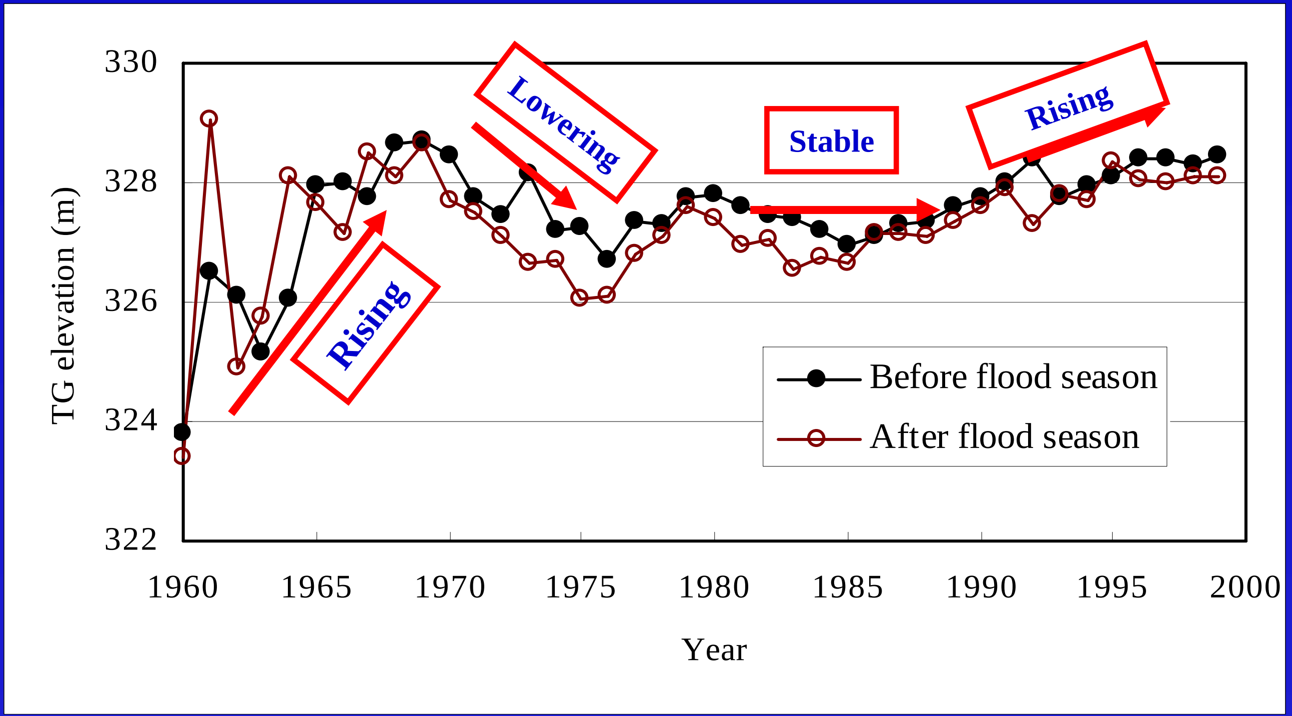
Sedimentation in Sanmenxia Reservoir (TG to Damsite)



Longitudinal profile for different periods

Sanmenxia Reservoir and TG Elevation

Variation process of Tongguan elevation



TG elevation: rapidly rising (1960-1969)—lowering (1969-1973)—stable (1973-1985)—slowly rising again (after 1985), which is closely related to the three operation modes (operation water level) and the incoming runoff and sediment.

Mathematical model

- **Governing equations**

Flow,
$$\frac{\partial H}{\partial x}+\frac{1}{2g}\frac{\partial}{\partial x}\left(\frac{Q}{A}\right)^2+\frac{1}{g}\frac{Q}{A^2}q_x+\frac{n^2Q|Q|}{A^2R^{4/3}}=0$$

Sediment,
$$\frac{\partial hUS}{\partial x}=-\alpha\omega\left(S-S^*\right)$$

Bed Deformation,
$$\rho'\frac{\partial Z_b}{\partial t}=\alpha\omega\left(S-S^*\right)$$

H=Water level; Q=flow discharge; q_x=lateral flow discharge; A=flow area; U=Velocity; S=Sediment concentration; S^*=Sediment-carrying capacity; α=Restore saturation coefficient; ω=settling velocity; R=Hydraulic radius; C=Chezy coef.; ρ'=dry density; h = Flow depth; and Z_b= Channel bed elevation.

Mathematical model

- **Sediment size computation**

Deposition:

$$P_{i+1,j} = P_{i,j}(1-\lambda_i)^{\left(\frac{\omega_j}{\omega_{c,i}}\right)^{\theta-1}}$$

Erosion:

$$P_{i+1,j} = \frac{1}{1-\lambda_i}\left(P_{i,j} - \frac{\lambda_i}{\lambda_i^*}R_{i,j}\lambda_i^{*\left(\frac{\omega_j}{\omega_{c,i}}\right)}\right)$$

here:

$$\lambda_i = \frac{S_i Q_i - S_{i+1}Q_{i+1}}{S_i Q_i}$$

$$\lambda_i^* = \frac{\Delta h_i'}{\Delta h_0 + \Delta h_i'}$$

ω_c **can be determined by:**

$$\sum_{j=1}^{L} P_{i+1,j} = 1$$

<u>Mathematical model</u>

- <u>**Sediment-carrying capacity**</u>

$$S^* = k_0 \left[1 + \left(\frac{\rho_s - \rho_0}{\rho_0 \rho_s} \right) \frac{S}{\beta} \right]^m \frac{1}{\left(1 - \frac{S}{\rho_s \beta} \right)^{(k+1)m}} \left(\frac{U^3}{h \omega_0} \right)^m$$

This formula is valid not only for the flow with low sediment concn. but also the hyper-concn.

S* is related not only to the hydraulic and sediment factors, but to the concn. of the incoming flow.

Mathematical model

- **Determine the related coefficients**

Semi-theoretical expression for sediment-carrying capacity coefficient k_0**.**

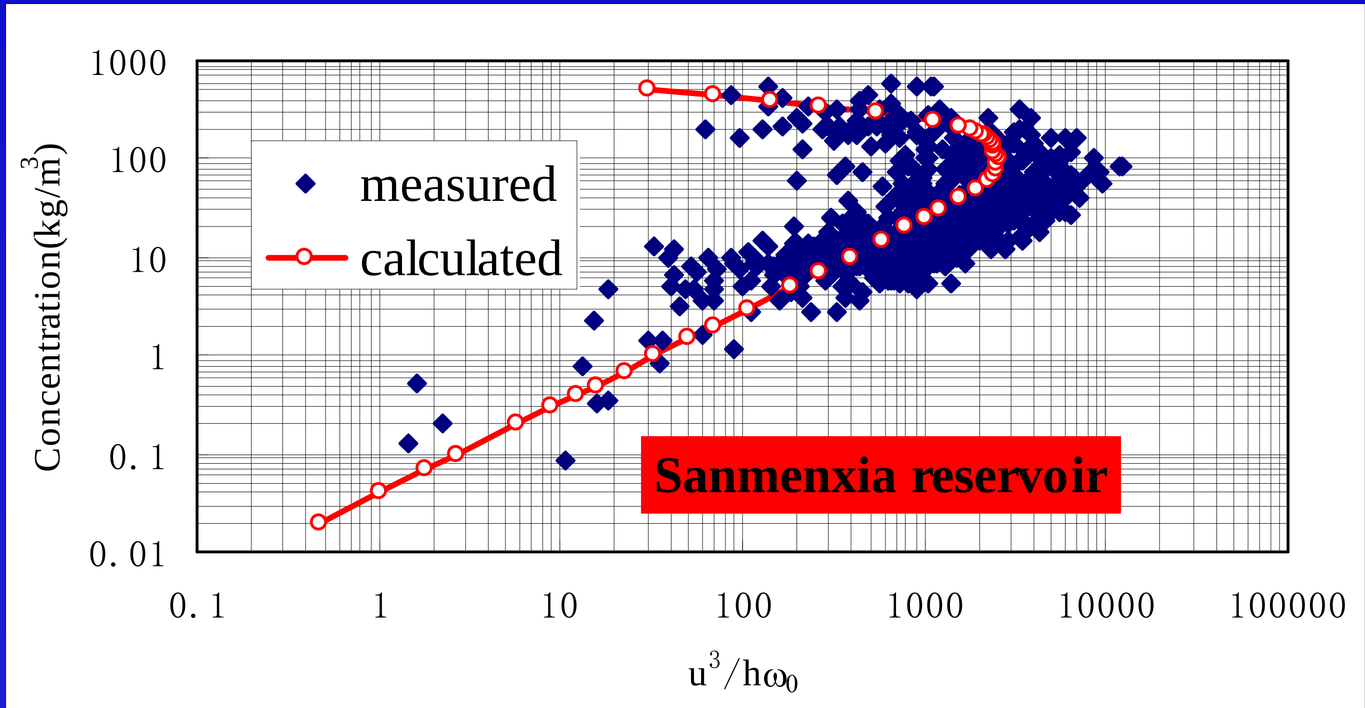
$$k_0 = \frac{\rho_0 \rho_s}{\rho_s - \rho_0} \frac{B_r}{C^2}$$

For natural rivers, B_r**=0.025, and Chezy coefficient C=30~60, So coefficient** k_0 **can be given as 0.011 to 0.045.**

Many applications of the sediment-carrying capacity formula show that the exponent m **can be given a constant value 0.92**

Mathematical model

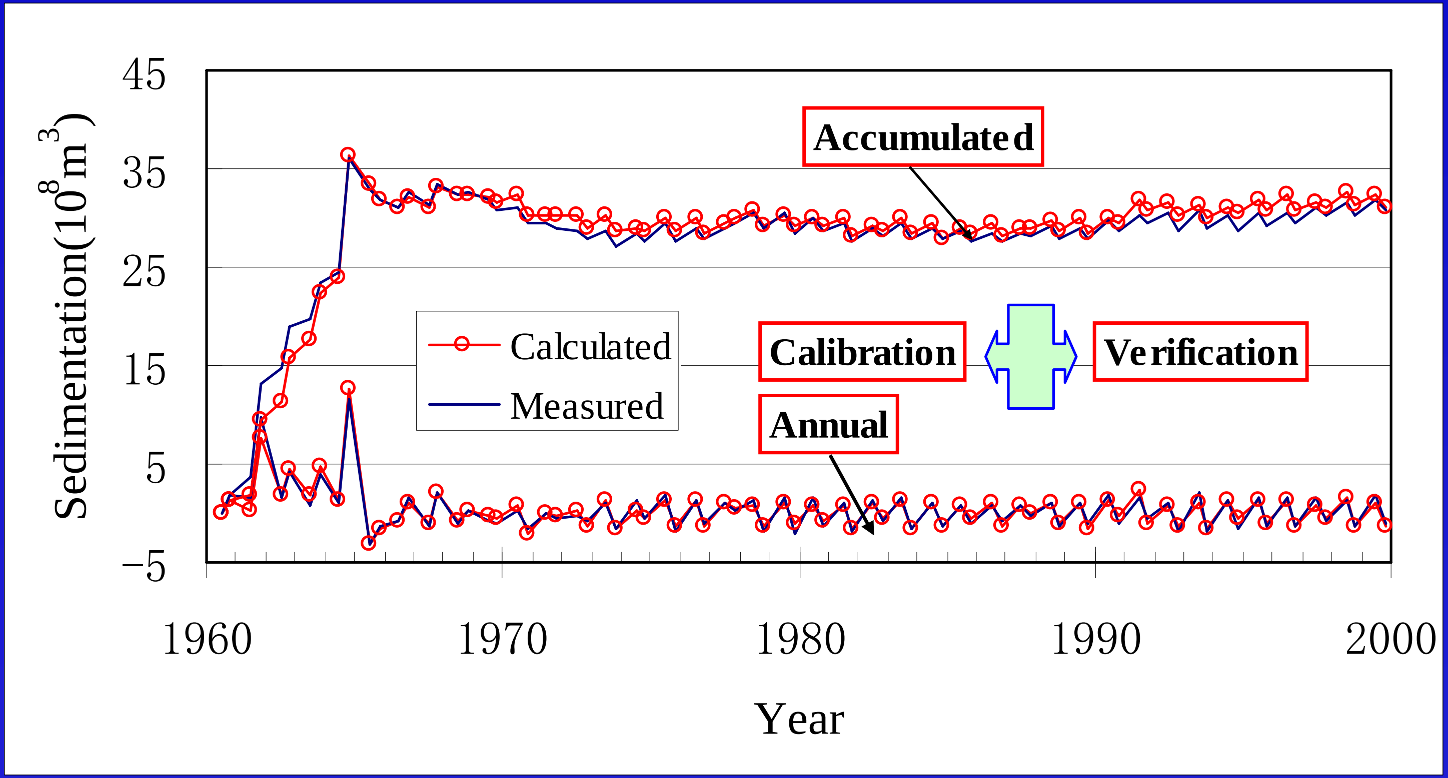
- **Determine the related coefficients**



Coefficients k_0 and m for the Sanmenxia Reservoir with high concn. can be given as 0.04 and 0.92, respectively.

Mathematical model

Calibration & Verification of the model

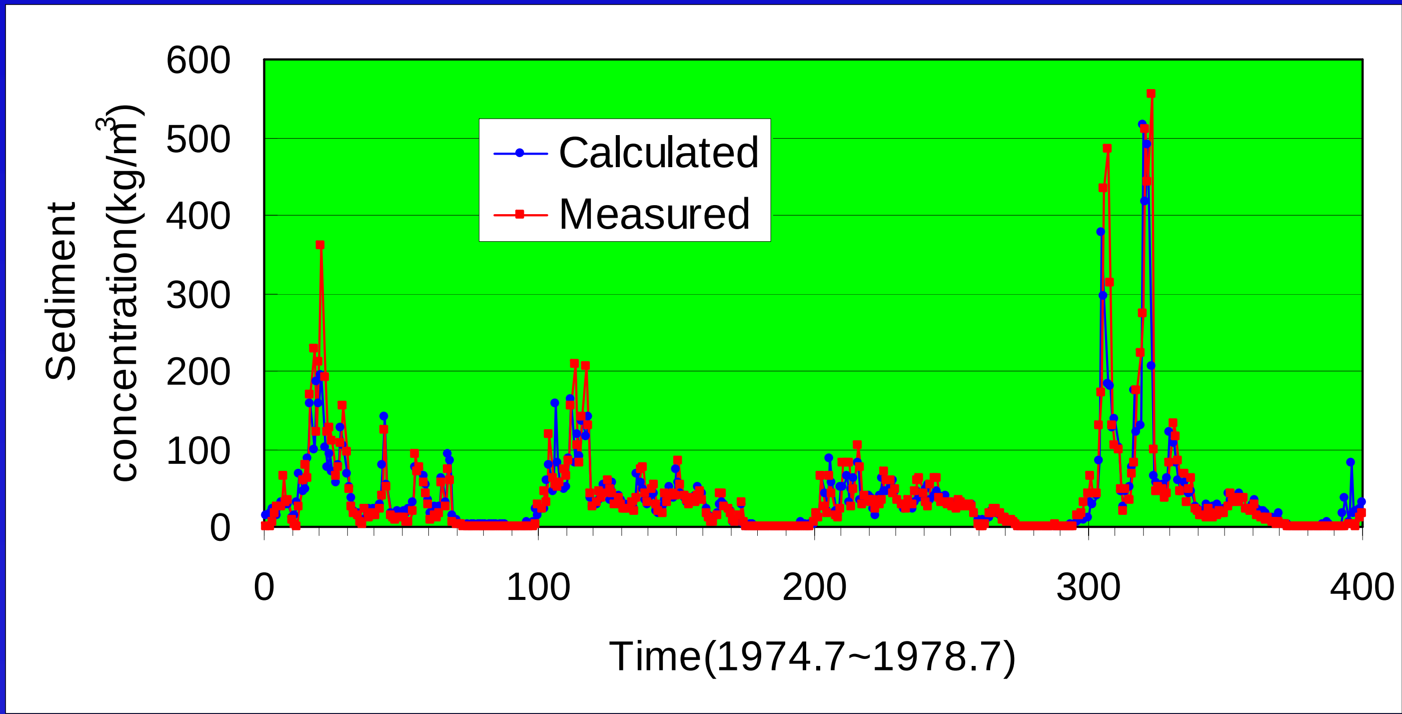


Calibration: using data from 1960 to 1988

Verification: using another set data from 1989 to 1999.

Mathematical model

Calibration & Verification of the model



Comparison between the calculated and measured sediment concentration

Feasibility to lower TG Elevation

There are two major approaches to lower TG elevation: one is to lower the operation water level of the Sanmenxia Reservoir and the other depends on the incoming flow and sediment conditions.

To investigate the effects of these two ways to lower TG elevation, a calibrated and verified mathematical model (Guo et al. 2003) is used to simulate the change of TG elevation under two different flow and sediment series and eight different reservoir operation modes..

Feasibility to lower TG Elevation

Incoming flow and sediment Conditions

Two flow-sediment series with 14 years duration are used (Unit: runoff-$10^8 m^3$; sediment-$10^8 t$).

Series		Yellow river	Feng River	Weihe River	Bailuo River	Total income
Series I	Runoff	235.1	6.286	55.94	6.375	303.7
	Sediment	5.795	0.049	2.904	0.754	9.502
Series II	Runoff	201.1	5.221	46.65	6.675	259.6
	Sediment	5.063	0.034	2.697	0.823	8.617

Feasibility to lower TG Elevation

Incoming flow and sediment Conditions

Time interval: the daily flow and sediment data are used, including flow discharge Q, sediment concentration S, size gradation at the inlet; flow discharge and operational water level at the dam site. During flood season (July 1st to Oct. 31th), the time step is one day. But in the non-flood season, a time step is about 10 days.

Initial channel bed: the total 32 measured cross sections in 2001 are used. The distance between two CS is about 3.5km.

Feasibility to lower TG Elevation

Operation modes

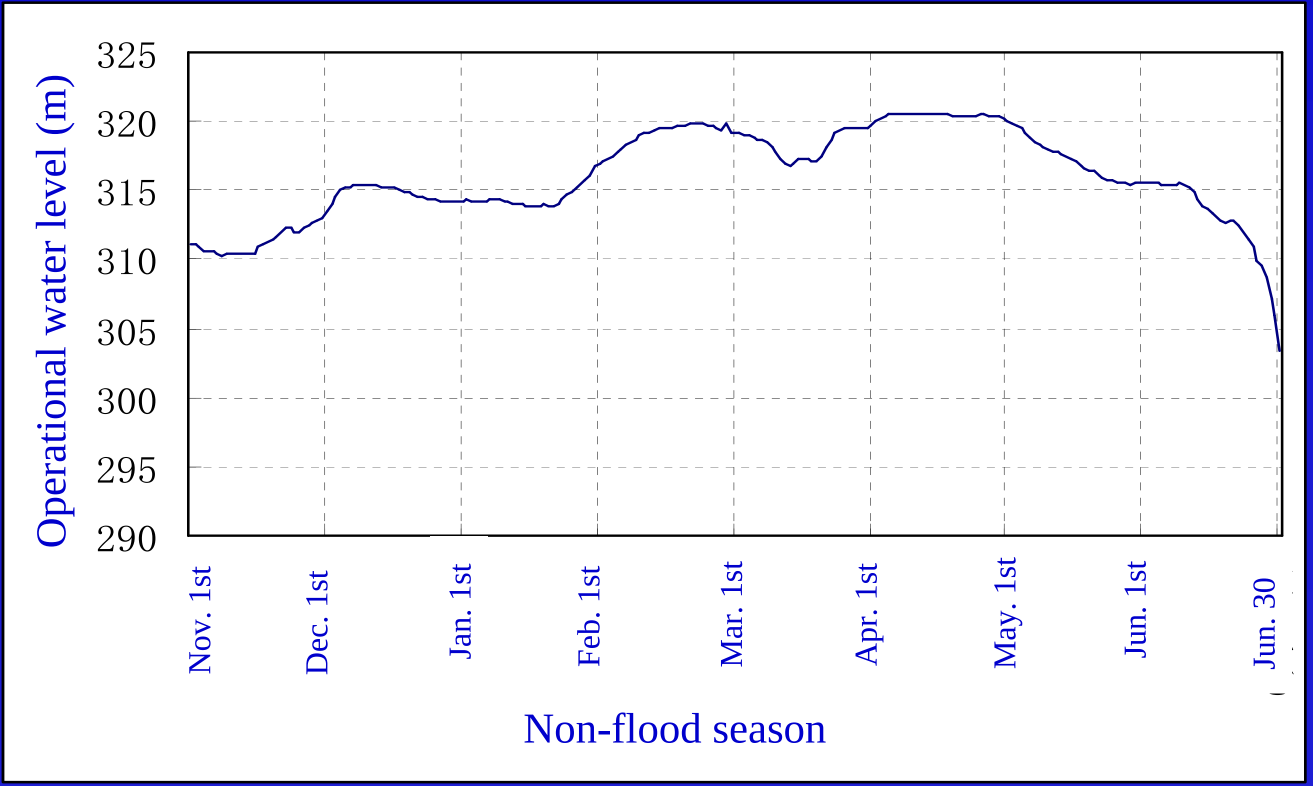
Eight reservoir operation modes (OM in short) are used, including the present operation mode, the un-gated operation, the un-gated operation in flood seasons and control operation in dry seasons, etc.

Operation modes	Operation modes of Sanmenxia reservoir
OM 1	Present OM: storing clear water and discharge muddy flow.
OM 2	Un-gated OM all year around
OM 3	Flood season: un-gated. Dry season: water level ≤ 318m.
OM 4	Flood season: un-gated if Q>1500m^3/s, otherwise 305m. Dry season: ≤318m.
OM 5	Flood season: un-gated OM. Dry season: water level ≤ 315m.
OM 6	Flood season: un-gated if Q>1500m^3/s, otherwise 305m. Dry season: ≤315m.
OM 7	Flood season: un-gated OM. Dry season: water level ≤ 310m.
OM 8	Flood season: un-gated if Q>1500m^3/s, otherwise 305m. Dry season: ≤310m.

Feasibility to lower TG Elevation

Operation modes

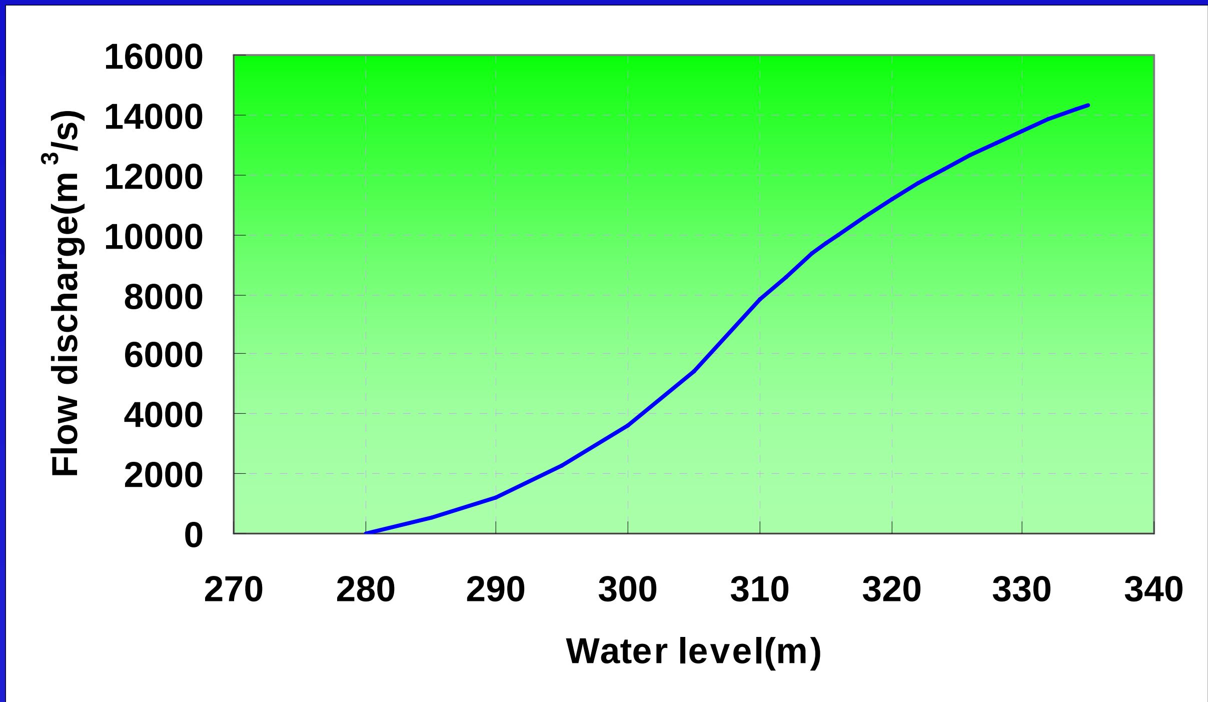
The operational water level in non-flood season for OM1



Feasibility to lower TG Elevation

Operation modes

Relation between the released flow discharge and water level



Feasibility to lower TG Elevation

Computational results

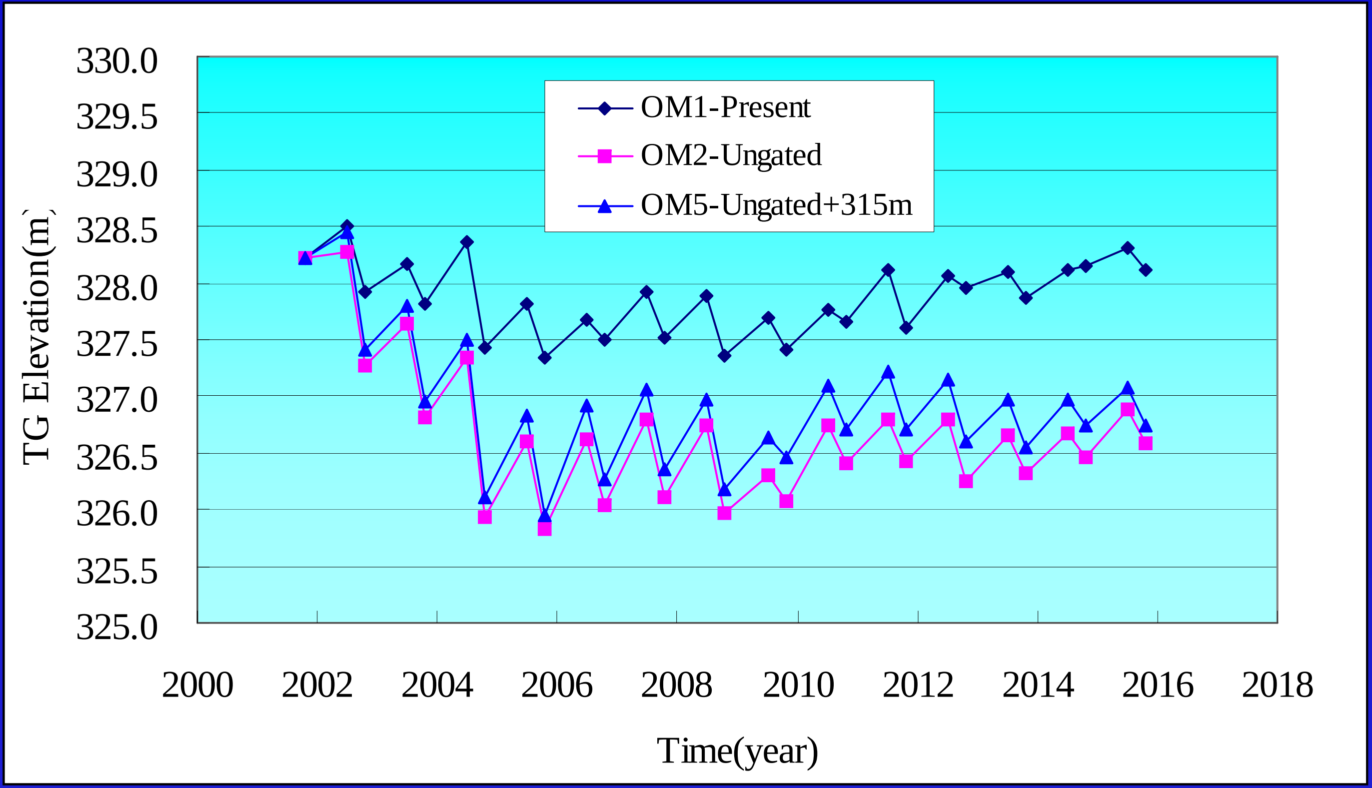
The simulated TG elevations under the two flow/sediment series and eight reservoir operation modes based on the initial channel bed condition in September 2001 are listed in the Table.

Series Operation mode	Flow/sediment Series I			Flow/sediment Series II		
	The lowest	End value	Change	The lowest	End value	Change
Present	/	328.23	/	/	328.23	/
Operation mode 1	327.35	328.12	-0.11	327.65	328.33	0.10
Operation mode 2	325.82	326.59	-1.64	325.90	327.14	-1.09
Operation mode 3	326.01	326.86	-1.37	326.06	327.44	-0.79
Operation mode 4	326.07	326.97	-1.27	326.11	327.53	-0.70
Operation mode 5	325.95	326.75	-1.48	326.00	327.34	-0.89
Operation mode 6	326.03	326.85	-1.38	326.08	327.45	-0.78
Operation mode 7	325.89	326.63	-1.60	325.95	327.22	-1.01
Operation mode 8	325.98	326.74	-1.49	326.04	327.35	-0.88

Feasibility to lower TG Elevation

Computational results

The change of TG elevations with time under the series I



Conclusions

(1) **Two major reasons affected TG elevation: the reservoir operation mode and the incoming flow/sediment condition. The operation mode was the main reason to cause TG elevation rapid rising at the initial operation stage of Sanmenxia reservoir, but after 1974 both reservoir operation and the incoming flow/sediment condition take the main place to affect the variation of TG elevation.**

(2) **Low operation water level of Sanmenxia reservoir and good incoming flow/sediment condition may result in an obvious lowering of TG elevation; otherwise TG elevation is hard to be lowered.**

Conclusions

(3) If the present operation mode in 2000, storing clear water and discharging muddy flow, is continuously used, TG elevation can be maintained around the initial value after 14 years, just a slight lowering in good flow/sediment conditions and a slight rising in dry flow/sediment condition.

(4) The un-gated operation all year round will result in an obvious lowering of TG elevation, 1.09~1.64m. The partial un-gated and partial controlled operation modes (OM 3 to OM 8) may also lower TG elevation and the averaged lowering value of TG elevation is about 1.0m.

Conclusions

(5) Simulated results of all eight operation modes and two different flow/sediment series show that even under the disadvantage flow/sediment condition and partial un-gated operation during the flood seasons, TG elevation can still be lowered by 0.7m. Therefore, for general case, it is possible that the un-gated operation for whole flood season can lower TG elevation by around 1.0m and the un-gated operation all year round can lower TG elevation by 1.4m or so.

Thanks