Combining hydropower water intake and sediment bypassing for improvement of reservoir sustainability in a montane area: field tests

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Abstract

River-borne sediment is a primary issue on the operational application of reservoirs across a river channel. A cascade of loose sediment supplied from hillslope erosion processes usually transforms into river channel networks, leading to serious reservoir sedimentation problems nearby montane regions. Constructed in 1934, the Sun Moon Lake Reservoir (SMLR) in the Western Foothill Belts of Taiwan has been used for hydropower generation, domestic usage, irrigation, especially in recreation. However, this off-stream reservoir has suffered severe sedimentation, incurring the reduction in its storage and lake area in recent years. Till 2019, its accumulated loss of capacity is about 19% and the corresponding sedimentation is about 0.4 Mm^3 y^{-1}. To improve sedimentation problems in the SMLR, the field test (47 of totals) of hydropower water intake using sediment-laden flow was investigated to delineate sediment bypass action, addressing the domino effects of sediment bypassing on reservoir area, hydro turbines and its downstream environments. Results show that bypassed sediment concentration reached Chonggui Dam averaging 140 minutes after the beginning of water intake, causing its consequent sedimentation rate of 45.54%. This sedimentation rate could be decreased with hydropower generation time related to subsequent water discharge. Sediment concentration averaged 3.5 hours reaching

Shuili Branch, Water Cooperation Company in the downstream, with sedimentation rate of 4.82 %. Moreover, sampling tests indicate no apparent influence of sediment bypassing on the downstream, i.e., the mainstream of Jhuoshuei River. In other words, this study also evaluated sediment abrasion on hydro turbines during the tests and further estimated maintenance costs. These patterns suggest sediment bypass via the process of hydropower water intake is workable and could improve the benefits of sediment removal in the SMLR.

Introduction

Sun Moon Lake Reservoir (denoted by SMLR) is an off-channel reservoir located in Yuchi Township, Nantou County in Taiwan. Its water source is mainly supplied from Jhuoshuei River. Till today, this reservoir still plays a majorly important role in the water source supply for the central Taiwan, having been used for hydropower generation, domestic usage, irrigation, especially in recreation. Built in 1934, the reservoir capacity is about 170 Mm^3, however, having no suitable sediment removal facilities suffering severe sedimentation near 19% during last 86 years.

SMLR is also one of the top 13 reservoirs managed by the Ministry of Economic Affairs, Taiwan involved in sedimentation problems. To improve sustainability of the SMLR decreased by sedimentation. At first, traditional mechanical dredging has been used treated as the main countermeasure for sediment removal, but its corresponding dredging amount, restricted by sediment storage and transportation routes, is still less than the annual sediment amount entering the SMLR. Therefore, it is necessary to simultaneously combine with hydraulic desilting, e.g., sediment bypassing through a hydropower intake, to decrease the sedimentation of the SMLR.

The objective of this paper is to disentangle the workability of sediment bypassing through a hydropower intake in the SMLR. We investigate low-concentration sediment laden-flow transfer into a hydroelectric aqueduct via sediment sampling. Also, we address the domino effects on hydro turbines and its downstream environments.

Field test setting

The SMLR is located in the central Taiwan as shown in Fig. 1 and has an area of 8.16 km^2 on its full water level. To realize the effects of sediment bypassing via hydropower intake in the SMLR on reservoir area, hydro turbines and its downstream environments, a field test with sediment sampling was settled as listed in Table 1. In particular, the sediment concentration near the bed of the SMLR is considered under 810,000 ppm.

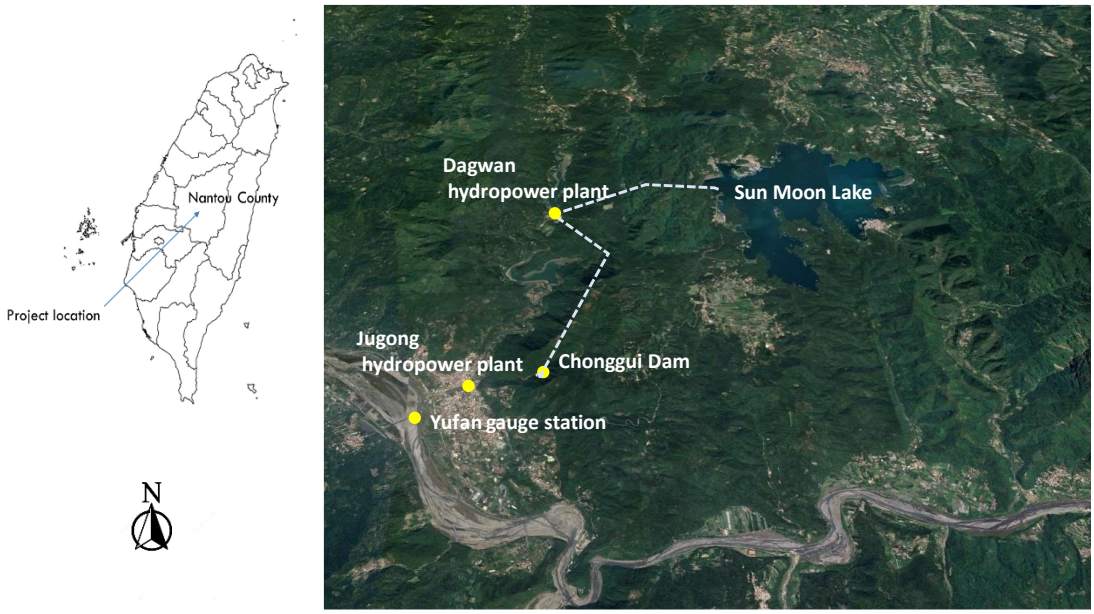

Fig. 1 the study area

Table 1. General information on sediment bypassing via hydropower intake for field test

times	Period (min)	Hydropower discharge (cms)	Mixed sediment concentration (ppm)	concentration of Sediment pumping (ppm)	Discharge of sediment pumping (cms)	Sediment volume (m^3)
1	20	15	213	40,000	0.08	5
2	40	15	213	40,000	0.08	9
3	60	15	213	40,000	0.08	14
4	80	15	213	40,000	0.08	19
5	100	15	107	40,000	0.04	12
6	120	15	107	40,000	0.04	14
7	140	15	107	40,000	0.04	17
8	160	15	107	40,000	0.04	19
9	20	15	427	80,000	0.08	9
10	40	15	427	80,000	0.08	19
11	60	15	427	80,000	0.08	28
12	80	15	427	80,000	0.08	38
13	100	15	213	80,000	0.04	24
14	120	15	213	80,000	0.04	28
15	140	15	213	80,000	0.04	33
16	160	15	213	80,000	0.04	38
17	20	15	640	120,000	0.08	14
18	40	15	640	120,000	0.08	28
19	60	15	640	120,000	0.08	43

20	80	15	640	120,000	0.08	57
21	100	15	320	120,000	0.04	36
22	120	15	320	120,000	0.04	43
23	140	15	320	120,000	0.04	50
24	160	15	320	120,000	0.04	57
25	20	15	853	160,000	0.08	19
26	40	15	853	160,000	0.08	38
27	60	15	853	160,000	0.08	57
28	80	15	853	160,000	0.08	76
29	100	15	427	160,000	0.04	47
30	120	15	427	160,000	0.04	57
31	140	15	427	160,000	0.04	66
32	160	15	427	160,000	0.04	76

Results and concluding remarks

Results show that bypassed sediment concentration reached Chonggui Dam averaging 140 minutes after the beginning of water intake, causing its consequent sedimentation rate of 45.54% as listed in Table 2. This sedimentation rate could be decreased with hydropower generation time related to subsequent water discharge.

Sediment concentration averaged 3.5 hours reaching Shuili Branch, Water Cooperation Company in the downstream, with sedimentation rate of 4.82 % as listed in Table 3. Moreover, sediment sampling tests during the period from March 4th 2020 to April 22nd 2020 show the river-borne sediment volume and peak sediment concentration on the downstream, i.e., the mainstream of Jhuoshuei River, has increases of 1.49% and 10.94%, respectively, suggesting no apparent influence of sediment bypassing on the downstream. In other words, examination of hydro turbines pre- and post- sediment bypass shows no apparent abrasion. Based on the equation proposed by Nozaki (1989), we also evaluate the annual abrasion depth of hydro turbines at two hydropower plants on the downstream. Under the condition of sediment bypassing, the annual erosion depth is 0.0207 mm and 0.01007 mm, respectively.

Although long-term, continuous observation is necessary to delineate the effect of sediment bypassing on the downstream evolution, these patterns still suggest sediment bypass is workable and could improve the benefits of sediment removal in the SMLR.

Reference

Taiwan Power Company. 2019. Planning of Desilting Engineering in Sun Moon Lake.

Nozaki Tsugio. 1989. Determination of the capacity and cross section of a sand basin, in view of water turbine abrasion. Electric Power Civil Engineering, 218: 143-152.

Table 2. Sedimentation of Chonggui Dam during field test

Date	Sediment amount (m^3)	Water discharge (cms) at Daguan	Peak sediment concentration (ppm) at Daguan	Sediment concentration reaching time (min) at Chonggui Dam	Sediment amount (m^3) at Chonggui Dam	Sedimentation of Chonggui Dam (m^3)	Sedimentation rate of Chonggui Dam (%)
2019/3/4	4	18.80	47.00	X	4.00	0.24	X
2019/3/5	3	15.80	46.00	100.00	4.00	0.58	X
2019/3/6	4	10.80	35.00	140.00	4.00	1.85	43.73
2019/3/11	46	16.80	421.00	100.00	53.00	27.52	44.62
2019/3/12	8	9.60	75.00	220.00	9.00	5.60	55.54
2019/3/18	57	8.20	465.00	180.00	57.00	43.67	76.62
2019/3/19	11	8.50	83.00	180.00	10.00	4.28	45.72
2019/3/20	7	10.00	67.00	180.00	6.00	1.34	30.19
2019/3/25	60	8.30	517.00	190.00	40.00	17.39	62.26
2019/3/26	53	14.60	292.00	120.00	52.00	28.51	55.80
2019/3/27	51	15.00	309.00	120.00	51.00	20.61	40.39
2019/3/30	64	11.70	436.00	120.00	64.00	42.92	67.14
2019/3/31	106	14.30	760.00	120.00	106.00	66.55	62.85
2019/4/8	105	12.00	441.00	45.00	103.00	78.53	76.78
2019/4/9	103	11.00	777.00	120.00	103.00	57.37	55.76
2019/4/10	112	14.30	893.00	130.00	119.00	72.62	58.58
2019/4/15	73	15.00	623.00	104.00	73.00	28.31	38.70
2019/4/16	68	15.30	830.00	120.00	74.00	19.65	19.60
2019/4/17	115	15.20	619.00	100.00	114.00	57.72	50.90
2019/4/22	41	14.60	268.00	150.00	41.14	-	-
2019/4/23	31	14.70	282.00	120.00	31.30	3.64	11.64
2019/4/24	27	16.40	200.00	150.00	27.39	3.23	11.80
2019/4/30	116	15.80	523.00	120.00	115.91	2.43	2.10
average	57.27	13.09	407.36	133.14	57.17	27.83	45.54

Table 2. Sediment load of Jhuoshuei River influenced by sediment bypass via hydropower water intake during field test

Date	Sediment amount (m^3)	Peak sediment concentration (ppm) at Yufan station	Peak sediment concentration influenced by sediment bypass (%)	Sediment transport amount (m^3) of Jhuoshuei River	Sediment amount influenced by sediment bypass (%)
2019/3/4	4	1381.00	1.56	2536.00	0.15
2019/3/5	3	2146.00	0.63	3860.00	0.09
2019/3/6	4	1278.00	0.56	2151.00	0.10
2019/3/11	46	2398.00	5.44	3173.00	0.80
2019/3/12	8	1300.00	1.17	2162.00	0.16
2019/3/18	57	1577.00	4.34	2667.00	0.50
2019/3/19	11	1242.00	1.72	1980.00	0.29
2019/3/20	7	678.00	5.43	1080.00	0.43
2019/3/25	60	1244.00	9.97	2007.00	1.13
2019/3/26	53	722.00	13.02	1066.00	2.20
2019/3/27	51	22337.00	0.42	12824.00	0.24
2019/3/30	64	683.00	18.16	1145.00	1.84
2019/3/31	106	1294.00	13.45	2383.00	1.66
2019/4/8	105	1794.00	10.37	2988.00	0.82
2019/4/9	103	692.00	41.04	1138.00	4.01
2019/4/10	112	1572.00	13.17	2260.00	2.05
2019/4/15	73	1214.00	15.47	2135.00	2.09
2019/4/16	68	1624.00	15.61	2401.00	2.26
2019/4/17	115	1320.00	17.22	1845.00	3.05
2019/4/22	41	1455.00	-	2007.00	-
2019/4/23	31	1579.00	5.53	2429.00	1.14
2019/4/24	27	1340.00	5.83	1868.00	1.29
2019/4/30	116	1520.00	31.12	2209.00	5.14
average	57.27	2318.59	10.94	2626.27	1.49

Note:1. Peak sediment concentration influenced by sediment bypass (%)= peak sediment concentration observed at Shuili Branch/ Peak sediment concentration at Yufan station. 2. Sediment amount observed at Jugong hydropower plant/sediment amount observed at the Yufan station of Jhuoshuei River