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An Analysis of Streambed Changes Downstream of Daecheong Dam

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Abstract

Riverbed change is greatly influenced by artificial factors such as dam construction, gravel collection, and river improvement. This study simulated a long-term bed change based on the GSTARS3 model using actual data from the area downstream of the Geum River Daecheong Dam and compared the estimation with a section of the actual measurement. As a result, it was found that the section of the actual measurement was far lower than the result of the simulation in terms of long-term bed change. While the area downstream of Daecheong Dam displayed approximately an average of 2.29 m of streambed degradation on average while the upper stream area showed approximately 0.63 m of bed degradation over 24 years. In the simulation of the area downstream of Daecheong Dam based on the GSTARS3 model, similar bed degradation was observed. However, a great difference was detected between the result and the actual measurement. According to the cause analysis, the riverbed in the area downstream of Daecheong Dam has continuously degraded due to the dam construction and mass collection of gravel. The mass collection of gravel was the main cause of riverbed change. It was found that about 76% of all riverbed degradation was caused by the mass collection of gravel.

Key words : Streambed Changes, Gravel Mining, Daecheong Dam, GSTARS3 Model

1. Introduction

The transport of sediment occurs when flow exceeds a certain threshold and becomes capable of moving the particles that constitute a river-bed. When the channel bed becomes mobile, erosion or deposition may occur. These bed changes depend on many parameters, including hydraulic conditions such as flow velocity and depth, bed composition such as the size of the particles that constitute the bed, and supply rates such as the amount and type of sediments entering the channel (Chih Ted Yang *et al.*, 2002).

The change of bed characteristics in rivers and streams has serious consequences as it may cause floods, water transport hazards, bridge collapse, bank erosion and failure, river migration and meandering, water quality degradation, loss of productive land, and habitat damage, among other issues.

Studies have been conducted by Laursen (1958), Krone (1962) and Meyer-Peter (1948) to gain an understanding of the characteristics of sediment deposition and the time needed for interaction between sediment and flow in natural bodies of water. A more specific and elaborate model to manage sediment compaction and the redistribution of sediment activity was developed by Bennet in 1977. More precise analytical research into a numerical method has been conducted over the past decade to estimate two-dimensional flow, sediment transportation, and river-bed changes. Molinas and Yang (1986) developed the GSTARS computer model which utilizes the stream tube concept, to simulate and predict hydraulic conditions using a one-dimensional approach along stream tubes and provides a semi-two-dimensional variation of the hydraulic conditions in rivers and reservoirs. Hydraulic conditions coupled with uneven aggradation and degradation processes along stream tubes can provide a semi-three-dimensional variation of the geometry of the channel and a longitudinal bed profile.

In this paper, a comparative study of the observed streambed elevation with an estimated downstream elevation of Daecheong Dam was examined using the GSTARS3 model. The effect on the change of the river-bed due to the construction of Daecheong Dam as well as gravel mining over the past several decades was also analyzed.

2. Area of Study and Model Input

2.1 Area of Study

The area of study was selected by the following criteria.

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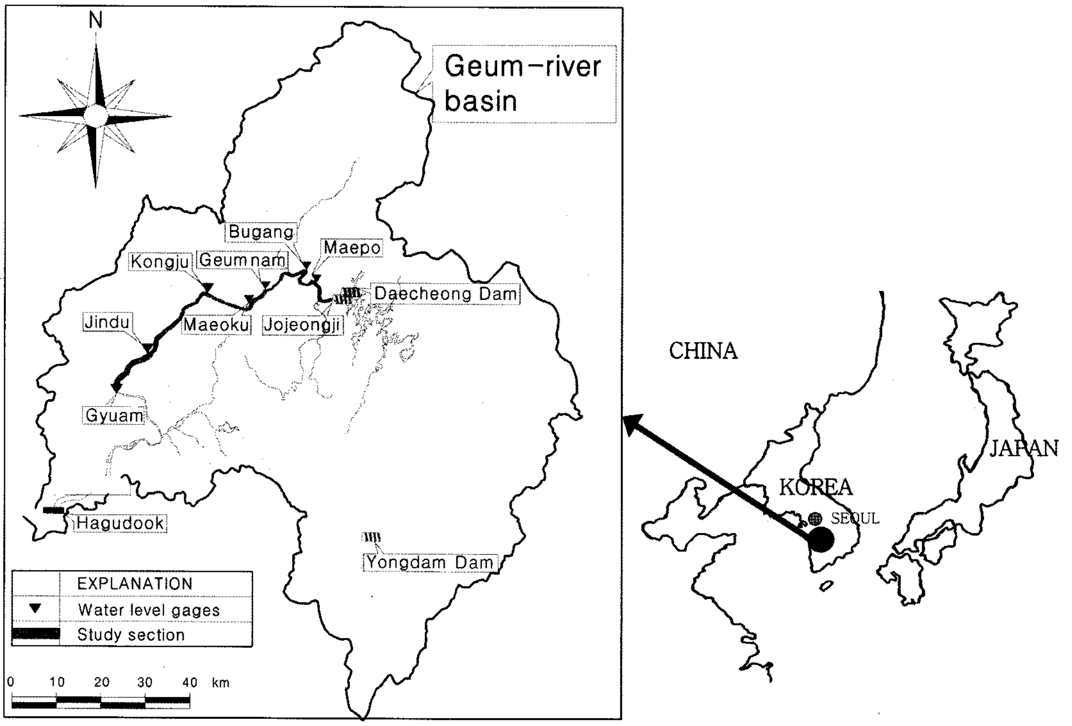

Fig. 1. Study area map

Firstly, the river bed must be expected to change. Secondly, reliable model input data and a history of river-bed change should exist for the site. In this study, the Geum River from Jojeongji which is a re-regulation pond of Daecheong Dam to the Gyuam Stream gauging station located 79.3 km downstream of Daecheong Dam was selected in order to predict river-bed change over a long period of time. The Daecheong Dam was constructed in December, 1980. It is the third largest dam in Korea and can accommodate more than 15 hundred million m^3 of water. Fig. 1 shows a map of the study area.

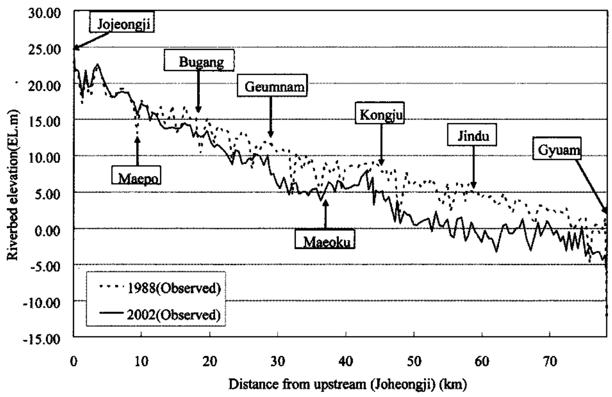

Fig. 2. Comparison of surveyed values in 1988 and 2002

2.2 Input Data

Channel geometry data for the acquisition and application of the area downstream of Daecheong Dam were used from the Geum River Management Plans (Ministry of Construction, 1974, 1975), Geum River Bed Change Investigation Report (Ministry of Construction, 1985), Geum River Basin Comprehensive Management Plan (Ministry of Construction, 1988) and Geum River Basin Management Plan (Ministry of Construction and Transportation, 2002). Reports published in 1974-1975 and 1985 were not used for the simulation because of the paucity of cross sectional survey data and missing data. Therefore, cross section data from a survey in 1988 was applied as the baseline cross section and was then compared with the observed data from 2002 and 2006. Fig. 2 shows the variation of the longitudinal river-bed elevation at the thalweg of the cross section. The longitudinal river-bed elevation is becoming lower as the distance from the upstream is becoming farther. Especially, for Marpo to Gyuam, where the elevation is deepest. There is, however, no significant difference between Jojeongji, which is located immediately downstream of Daecheong Dam and Maepo because of the armoring and stabilization that has taken place since 1988 (Korea Water Coporation, 2005).

Each cross section in a reach can be divided into several regions or channel divisions according to equivalent roughness. A compound channel with two flood plains might have three divisions, corresponding to the left flood plain, the main channel, and the right flood plain. Each one of these channel divisions would have its own roughness coefficient value. Therefore Manningís n-values of the main channel and two flood plains on the Geum_River were applied separately. The roughness coefficients were calculated using an inverse operation for the Manningís uniform flow formulation on each channel division. Table 1 shows

Table 1. Manning's nvalues for each channel division

Channel division Sections	Left flood plain	Main channel	Right flood plain
Jojeongji ~ Maepo	0.039	0.027	0.039
Maepo ~ Guemnam	0.034	0.027	0.034
Guemnam ~ Kongju	0.029	0.026	0.029
Kongju ~ Gyuam	0.028	0.026	0.028

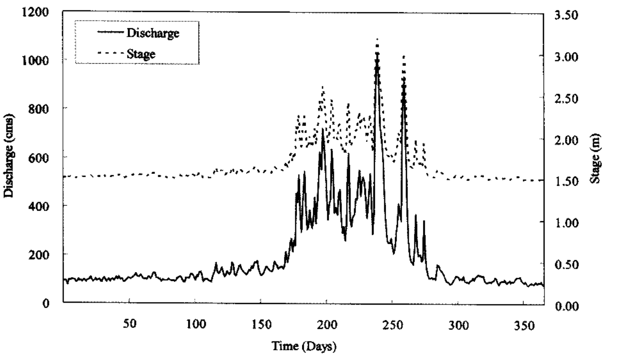

Fig. 3. Discharge and stage relationship used for the numerical simulation

Table 2. Bed material characteristics

Diameter (mm) / Division	Mean (d_m)	Effective (d_{10})	Maximum (d_{max})
Jojeongji ~ Daekyo	0.939	0.121	9.520
Daekyo ~ Jicheon	0.641	0.095	4.760
Jicheon ~ Gyuam	0.491	0.111	4.760

the value for each section and channel division, respectively.

Energy loss coefficients account for the hydraulic impact of bends, natural and man-made structures, etc., at or upstream from the cross section. Internally, the GSTARS3 establishes a coefficient of loss to 0.1 for contractions and to 0.3 for expansions. These values were used in this study. The theory of minimum stream power was not used because it requires a long period for calculation and the result was similar to the one that used minimum stream power.

The discharge and stage data used for the numerical simulation are shown in Fig. 3. A time interval of one day was chosen for a total of 6,445 time intervals or steps. The size of bed material is in general less than 1 mm, with a minimum of 0.001 mm and maximum of 9.520 mm. As shown in Table 2, gravel and sand (mean diameter: 0.939 mm) are distributed generally throughout the area from Jojeongji to Daekyo, while sand and silt (mean diameter: 0.641 mm) are distributed throughout the area from Daekyo to Jicheon. Sand (mean diameter: 0.491 mm) is distributed throughout the area from Jicheon to Gyuam.

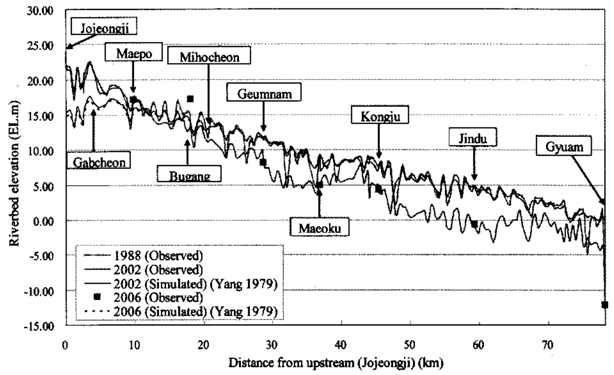

Fig. 4. Riverbed changes downstream of Daecheong Dam

3. Comparison of the Observed and the Simulated Values of riverbed change

Six formulas were used for the sediment transport equations in this study (Meyer-Peter and Muller (1948), Laursen (1958), Toffaleti (1969), Engelund and Hansen (1972), Yang (1979, 1984)) (Chih Ted Yang *et al.*, 2002). The period of long term bed change was simulated using cross sectional data surveyed from 1988 through 2002 and 2006. Three stream tubes were used for the simulation; however the streampower minimization process was not used.

The simulation results between 1988 (observed) and 2002 and 2006 (simulated) agreed reasonably well in all sediment formulas, although the model displayed a difference between Jojeongji and Maepo, as previously mentioned (due to armoring and stabilization). The agreement between 1988 (observed) and 2002 and 2006 (observed) displayed a significant difference. The observed elevation in 2002 was on average 2.45 m lower than the observed elevation in 1988. Consequently, it can be assumed that the simulation results did not expect the river bed changes in the area downstream of Daecheong Dam and it was a challenge, therefore, to decide which formula is best for simulating the river-bed change. To select the best formula for the scope of this study, the Development of a Guideline for the Selection of Sediment Transport Formulas Report (Korea Institute of Construction and Technology, 1989) was used along with Yangís formula (1979, 1984), which appeared to simulate reasonably well the river-bed changes in Korean rivers. Yangís simulation results (1979, 1984), were selected for this study.

Fig. 4 and Table 3 show the observed and simulated river-bed elevations in 1998, 2002 and 2006. The observed elevation on the North Guem River in 1988 was 11.44 EL.m while the simulation result for the same location in 2006 expected a slight agradation (11.72 EL.m). The surveyed elevation in 2006, however, was 8.17 EL.m. Furthermore, in the case of Kongju, the observed elevation in 1988 was 8.01 EL.m while the simulation result in 2006 expected a degradation of 7.60 EL.m. The surveyed elevation in 2006, how-

Table 3. Observed and simulated riverbed elevation

Distance from upstream (m)	Locations	Observed River-bed Elevation (EL.m)			Simulated River-bed Elevation from the Yang Formula (EL.m)	
		1988	2002	2006	2002	2006
0	Jojeongji	23.07	24.05	-	15.42	14.83
5,490	After Gabcheon Confluence	18.16	18.25	-	16.38	16.02
9,840	Maepo	17.55	17.23	17.16	15.84	15.58
18,120	Bugang	13.03	12.99	17.21	13.80	13.74
21,720	After Mihocheon Confluence	13.54	10.98	-	13.33	13.31
28,690	Guemnam	11.44	8.55	8.17	11.68	11.72
36,820	Maeoku	9.04	5.01	5.00	9.41	9.44
45,400	Kongju	8.01	4.10	4.36	7.63	7.60
59,360	Jindu	4.77	-1.02	-0.68	4.80	4.76
78,310	Gyuam	-12.84	-6.07	-12.17	0.00	0.00

Table 4. Variation of riverbed elevation compared with the value in 1974 (1975)

	Distance from upstream area (m)	Main Points	River-bed Elevation (Difference between 1974(1975), m)			
			1974 (1975)	1988	2002	2006
Downstream of Daecheong Dam	28,600	Geumnam	8.74	11.44 (+2.70)	8.55 (-0.19)	8.17 (-0.57)
	36,960	Maeoku	8.56	9.04 (+0.48)	5.01 (-3.55)	5.00 (-3.56)
	45,400	Kongju	7.65	8.01 (+0.36)	4.10 (-3.55)	4.36 (-3.29)
	78,310	Gyuam	-4.20	-12.84 (-8.64)	-6.07 (-1.87)	-12.17 (-7.97)
	Mean Degradation Depth		(0)	(-1.28)	(-2.29)	(-3.85)

ever, showed a remarkable degradation of 4.3 6 EL.m, which was 3.24 m lower than the simulation.

4. Cause and Effect Analysis

4.1 Riverbed change Caused by Dam Construction

Daecheong Dam was constructed in December 1980 and it is assumed that the river-bed changes began from that time. Fig. 5 shows the surveyed thalweg elevation for each cross section in 1974 and 1975, prior to dam construction, and in 1988, 2002, and 2006, follow dam construction. The river-bed elevation in 1988 and 2002 has degraded 1.28 m and 2.29 m on average respectively as compared to the elevation in 1974 (1975) (Table 4). The section between Jojeongji and Bugang showed degradation particularly from 1974 to 1988 but the other sections displayed a large degree of degradation from 1988 to 2002 (Fig. 5).

Fig. 6 shows the variation of the river-bed elevation upstream and downstream of Daecheong Dam between 1974 (1975) and 2002. Apparently that the degradation is more severe downstream than that in the upstream area since the dam construction encourages the interception of sediment. The slight upstream degradation that occurred was 0.61 m. It is assumed that the Yongdam Dam constructed in 2001 might have played a role in that phenomenon.

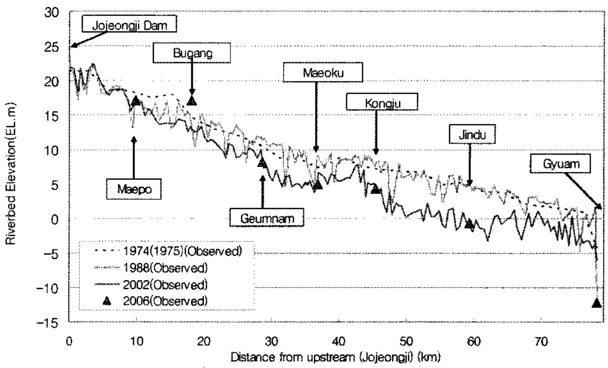

Fig. 5. Riverbed profile prior to (1974 & 1975) and following (1988, 2002, 2006) dam construction

4.2 Riverbed Change Caused by Gravel Mining

As part of the scope of this study, a gravel mining project was also carried out. The volume of gravel mining increased along with a boom in the construction business in 1990s, and large-scale mining was carried out from 1996 to 2001 as part of the comprehensive Guem River development project (Chungnam-do, 1995). For this reason, it may be said that large-scale gravel mining is one of the main factors influencing streambed degradation along with the interception of sediment caused by Daecheong Dam. Table 5 shows the record of gravel mining for each city within the study region (particularly the area downstream of Daecheong

Dam) from 1981 to 2005. The volume of gravel mining in Yeonki, Kongju and Buyeo between Bugang and Gyuam is a matter that needs urgent attention as significant degradation has occurring in these areas.

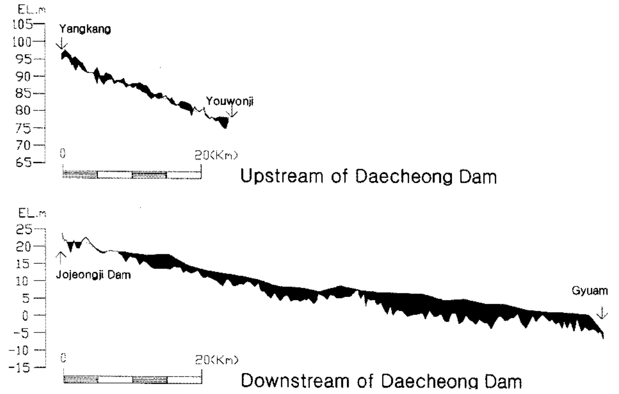

Fig. 6. Comparison of riverbed elevation with the upstream and the downstream areas of Daecheong Dam between 1974 (1975) and 2002

To visualized the change to the river-bed caused by a gravel mining, the surveyed same surveyed cross section data were compared to calculate the volume of degradation and deposition from Jojeongji to Hagudook between 1988 and 2002 (Table 6).

It was found that the volume of degradation and deposition during this period amounts to about 129 million m^3 and 44 million m^3, respectively. Therefore the volume of sediment that disappeared comes to 85 million m^3. Furthermore, the amount of gravel mining carried out in the scope of this study for the same duration comes to about 64.7 million m^3, which accounts for 76% of the total amount missing.

Considering these results, it is analyzed that there must be a high interrelation between the gravel mining and the degradation of river-bed change downstream of Daecheong Dam, and also, the gravel mining can be considered as the

Table 5. Gravel mining records for the area downstream of the Daecheong Dam region

(unit : 1,000 m^3)

Year \ Province	Cheongwan	Yeonki	Kongju	Cheongyang	Buyeo	Nonsan	Total
1981	-	100	-	-	-	-	100
1982	-	100	-	-	92	-	192
1983	-	100	-	-	256	-	356
1984	-	100	-	-	400	-	500
1985	61	561	-	-	131	-	753
1986	62	749	136	34	124	-	1,105
1987	21	676	222	40	135	-	1,094
1988	-	656	240	80	239	-	1,215
1989	12	771	450	115	528	-	1,876
1990	-	940	1,180	194	586	-	2,900
1991	-	841	2,574	384	874	-	4,673
1992	-	1,097	2,686	615	558	-	4,956
1993	-	1,791	2,740	656	630	-	5,817
1994	-	1,670	2,423	560	1,905	-	6,558
1995	-	1,670	2,863	740	1,623	182	7,078
1996	-	1,813	2,586	542	1,736	80	6,757
1997	-	1,282	2,824	704	1,184	135	6,129
1998	-	1,145	1,786	588	1,120	242	4,881
1999	-	1,689	1,214	451	1,356	292	5,002
2000	-	892	337	216	690	-	2,135
2001	-	832	943	124	704	-	2,603
2002	-	833	-	286	958	-	2,077
2003	-	801	-	125	252	-	1,178
2004	-	1,030	-	458	653	-	2,141
2005	-	329	-	231	787	-	1,347
Total	156	22,468	25,204	7,143	17,521	931	73,423

Source: Division of Flood Control and Disaster Prevention, Chungnam, 2006

Table 6. Degradation and deposition volume in the area downstream of Daecheong Dam

(unit : 1,000 m^3)

Section	Degradation Volume (a)	Deposition Volume (b)	(a) - (b)
Jojeongji ~ Hagudook	128,686	43,761	84,925

main reason of the degradation occurred during the period of 1988-2002.

5. Conclusions

River-bed change is caused by various factors such as floods, land-use alterations and man-made structures, among others. In this study, the cause of river-bed changes in the area downstream of Daecheong are analyzed in view of the construction of Daecheong Dam and the effects of gravel mining. The specific conclusions are as follows:

(1) The degradation in the reaches of the area downstream of Daecheong Dam is becoming more serious with the passing of time.

(2) It was found that an average degradation of a 2.29 m has occurred in the area downstream of Daecheong Dam while a degradation of 0.69 m has occurred upstream.

(3) This large-scale degradation has been caused by the interception of sediment after the construction of the dam and gravel mining projects carried out in the past.

(4) It was found that gravel mining was the main reason for river-bed changes in the area downstream of Daecheong Dam as the total amount of gravel mining occurring in the study accounted for 76% of the difference of the amount of degradation and the deposition volume.

Finally, it may be concluded that the effect on river-bed change from gravel mining is of greater impact than the effect of the construction of the dam. This extreme bed change represents the severity of unplanned gravel mining. Precise investigation and analysis should therefore be undertaken before future mining.

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