Current Conditions of Reservoir Sedimentation and Turbidity in Irrigation Dams in Japan

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Abstract

This paper describes results and analysis of some investigations on reservoir sedimentation and turbidity problems of irrigation dams in Japan. In general, the catchment area of the irrigation dam is smaller than that of the dam for electric power generation when the storage capacity is identical. As a result irrigation dams have unique characteristics on sediment management as follows; 1) C/I ratio and specific sediment rate of irrigation dams are comparatively larger than those of other ones. 2) As turnover rate of an irrigation dam is smaller and the water level fluctuation is larger than those of other dams, sediment movement is very active in a reservoir. These facts can be made sure by echo sounding exploration that is also introduced as a case study. Sedimentation problems and turbidity problems are in a contradictory relationship. In a case where it is judged to be necessary to discharge turbid water, discharging a specified quantity during a flood is recommended as a countermeasure.

1. Introduction

In order to predict future sediment trends including a study of the appropriateness of the initial plan, it is essential to clarify sedimentation and hydrological history, and catchment basin development trends to analyze trends in sedimentation in a relatively long time span extending from the opening of the dam to the present time. And to clarify the present state of sedimentation to select appropriate countermeasures backed up by progress in observation and exploration technologies, it is essential to carry out an emergency concentrated investigation of sediment routing. By the way, there are some distinguishing characteristics in reservoir sedimentation and turbidity problems of irrigation dams.

An irrigation dam provides multiple functions, but its basic function is to store water. The deposition of sediment in a dam effects its storage function, but the speed that this occurs varies according to the characteristics of the catchment basin and the reservoir management[1]. In this paper, appropriate sediment management for irrigation dams is studied. Current condition of reservoir sedimentation and turbidity are studied and introduced for the purpose of applying appropriate countermeasures in irrigation dams in the future. And a case study of sediment routing of an irrigation dam is also introduced.

2. Sedimentation characteristics of irrigation dams

In this chapter, the sedimentation characteristics of the irrigation dam reservoirs are discussed based on the investigation data.

2.1 C/I ratio

The ratio of C to I (C/I) is designated as C/I ratio in this paper, where C (m^3) is the storage capacity of the reservoir and I (m^3) is the annual inflow of water into the reservoir. C is one of the factors related to the reservoir factors, and I is one of the watershed factors. That is, the C/I ratio is a dimensionless value related to both factors. Moreover, the C/I ratio is a reciprocal number of the annual revolving rate (I/C) of the reservoir. It is obvious that the annual revolving rate of the reservoir markedly affects the reservoir operation or hydraulic conditions of the reservoir, the tributaries, the watershed, etc. Therefore, it is assumed that the C/I ratio is closely correlated with the reservoir sedimentation process. The analysis of reservoir sedimentation based on the C/I ratio is important to clarify the sedimentation factors and the sedimentation characteristics in the irrigation dams.

2.2 Catchment area and C/I ratio of irrigation dam

In general, water storage in an irrigation dam is designed in considering the annual revolving rate of the reservoir. As a result, suitable catchment area which can supply a sufficient volume of water as that planned, is selected. On the other hand, in a dam for electric power generation both the volume of water and the water level must be secured. The catchment area of the irrigation dam is smaller than that of the dam for electric power generation when the storage capacity is identical.

Fig.1 shows the relationship between the water storage capacity and watershed area of each dam. Sedimentation data of the irrigation dam were originally collected in this study and the previous data, mainly

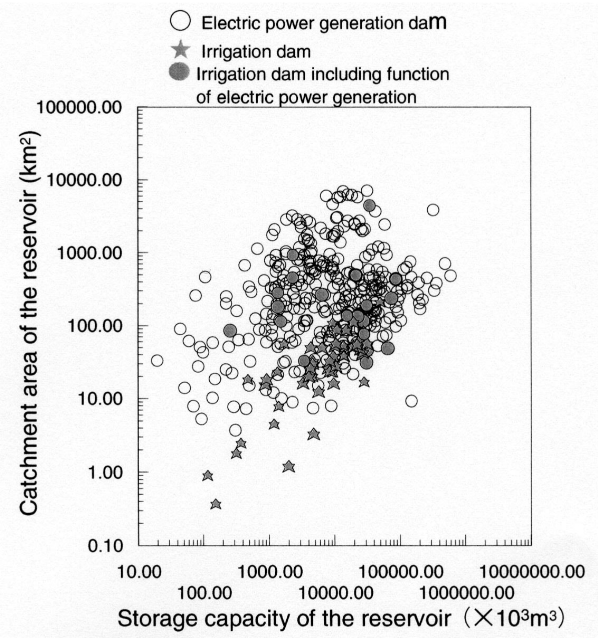

Fig. 1 Relationship between storage capacity and catchment area

data for electric power generation[4], were used in the analysis. The symbols in Fig. 1 indicate the kind of dams, either for irrigation or for other purposes. Fig. 1 shows that the dams for electric power generation have large catchment areas. Assuming that all the dams sampled had the same storage capacity, the watershed area F and the annual water inflow I of the irrigation dams would be smaller than those of the power generation dams. In fact, based on the same assumption, the C/I ratio of the irrigation dams is considered to be larger than that of dams for electric power generation.

2.3 C/I ratio and annual sediment deposit rate

Fig. 2 shows the relationship between the C/I ratio and annual sediment deposit rate of the dams[1,3]. The purpose of the reservoirs is indicated by the symbols. The annual sediment deposit rate is defined as the average percentage of storage capacity lost by sedimentation in a year (% year). As stated in the previous paragraph, the values of the C/I ratio of an irrigation dam are mainly included in the range of the value zone indicated in Fig. 1. Moreover, their distribution is in agreement with the general tendency observed in Fig. 2. Furthermore the plots of their distribution show a smaller value for the following reason. The annual sediment deposit is expressed as Q/Y/C, where Q is the total volume of accumulated sediment (m^3), Y is the number of years after dam construction, and C is the storage capacity (m^3). Assuming that A and B dams have the same degree of storage capacity C, if the annual revolving rate (I/C) of A dam is larger (C/I ratio is smaller) than that of B dam, the annual sediment deposit (Q/Y) of A dam is considered to be larger in general. It is generally assumed that the values of Q/Y/C of irrigation dams are relatively smaller than those of other dams, In other words, it is considered that in the irrigation dams the sedimentation stages are longer than in the power generation dams. Therefore, it is assumed that the irrigation dams are located in suitable sites for avoiding the sedimentation problems.

2.4 C/I ratio and specific sediment rate

The results can also be interpreted by paying attention to Q/Y which corresponds to the amount of annual sediments deposited in the reservoir. At first, it is assumed that all the dams sampled show the same values of F and Qin, where Qin refers to the annual sediment volume transported into the reservoir. As the irrigation dams tend to trap sediments effectively and Q/Y/F of an irrigation dam shows relatively larger values (Fig. 3).

Fig. 3 shows the relationship between the C/I ratio and specific sediment rate[1,3]. The purpose of the reservoir is indicated by the symbols. The specific sediment rate is defined as the total amount of accumulated sediments deposited in the reservoir per unit catchment area, averaged in a year ($m^3/km^2/year$). The distribution of the specific sediment rate of irrigation dams shows a similar pattern to that of other dams as depicted in Fig. 3 and larger values are recorded, especially when the C/I ratio is close to 0.1. The macroscopic tenden-

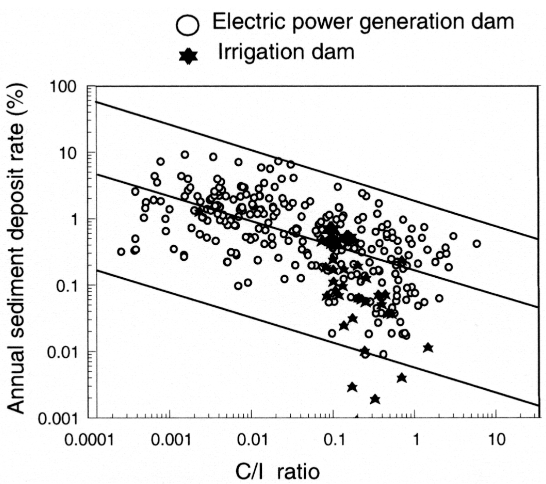

Fig. 2 Relationship between C/I ratio and annual sediment deposit rate

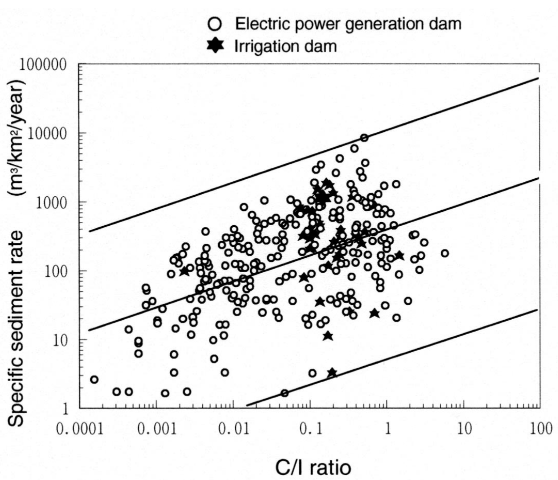

Fig. 3. Relationship between C/I ratio and specific sediment rate

cies mentioned above can be explained as follows. The specific sediment rate is expressed as Q/Y/F, where F is the watershed area (km^2). First of all, attention should be paid to the value of F and it should be assumed that these dams have the same storage capacity C. It was already indicated in Fig. 1 that the watershed area F of irrigation dams tends to be smaller than that of the power generation dams. Ashida et al.[2] observed that the specific sediment discharge rate shows a reverse correlation with the watershed area F. The difference between the specific sediment rate and the specific sediment discharge rate was disregarded here for simplicity, since the specific sediment rate (Q/Y/F) of the irrigation dams is considered to be larger than that of other dams. These observations are in agreement with the results indicated in Fig. 3.

3. Turbidity Problems in Irrigation Dams

This chapter describes the organization and analyses of the results of the investigation that were done to show trends in turbidity problems at irrigation dams and at the same time to consider appropriate future countermeasures and ways to properly manage dams to deal with turbidity problems at the drainage basin level and reports on the results of these studies.

3.1 Outline of the investigation of the state of turbidity at irrigation dams

3.1.1 Method

The questionnaire forms were distributed to dam managers through agricultural administration offices and regional development bureaus by the Construction Division of the Ministry of Agriculture, Forestry, and Fisheries. The dam managers were asked to answer the questions in the questionnaire. The forms were distributed in March 1995 and the answers were collected in about one month.

3.1.2 Respondents

The respondents were managers of organizations that actually manage dams in the field (national government, prefectural, land improvement district, etc.). The questions included some regarding the present state and causes of the problem of turbidity, but it is assumed that the answers reflect each respondentÅfs personal understanding and suppositions.

3.1.3 Districts investigated

Agricultural administrative bureaus selected major irrigation dams that were constructed as part of nation-

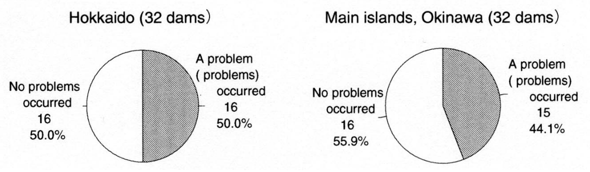

Fig. 4 Whether or not Turbidity Problems Occurred in the Districts that were Investigated

al land improvement projects and are still in operation. Dams in a total of 66 districts (35 districts by the Hokkaido Development Bureau and 4 districts by each of the Regional Development Bureaus) in Japan were investigated. In the remainder of this report, the dams will be represented by the numbers 1 to 66, with dams 32 to 63 located in Hokkaido. All are dams used for irrigation. Of the 66 dams, those with other purposes in addition to irrigation (electric power generation, disaster prevention, etc.) were located in 13 districts (19.7%) (below, these are categorized as agricultural use dams "that also have electrical power and disaster prevention functions"). They also include 21 districts where the dam has not been in operation for 10 years (32%).

3.2 Investigation results

3.2.1 Occurrence/non-occurrence of turbidity problems

"Turbidity problems" in this report refers to problems caused by a change or an increase in turbidity in the flowing water revealed by a comparison of the turbidity in the so-called natural river before construction of the irrigation dam with the turbidity after the construction. Therefore, it is predicted that places and dams where turbidity is considered to be a problem and its causes will be mixed in each case. Fig. 4 shows the breakdown of the results of the answers by district. It reveals that nationwide, turbidity problems have appeared in about half the districts.

3.2.2 Parties complaining of turbidity problems

If the parties complaining that turbidity presumably caused by a dam is a problem are clarified based on the results in Table-1 are obtained. Most of the sources of the complaints are fisheries associations, but they include farmers on irrigated land, residents, and nature conservation groups.

3.2.3 Principal geology of the drainage basins

Fig. 5 shows the relationship of the results of answers to question 4 concerning whether or not tur-

Table-1 Source of the Problem Causing the Turbidity and Details

Individuals or organizations that have made inquiries (or submitted complaints) regarding turbidity	Description of the inquiries (or complaints)	Number of districts investigated where this has occurred (multiple answers)
Fishing association related	Turbidity	11
Farmers	Turbidity, odors, blocking of irrigation systems, reduction of product quality	6
Water supply service related	Turbidity	2
Residents and nature conservation bodies etc.	Turbidity, odors	6

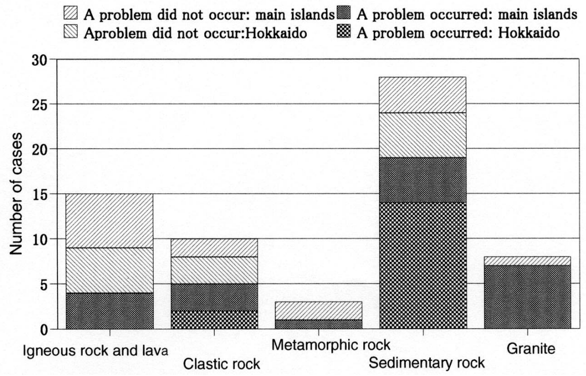

Fig. 5 Occurrence/Non-occurrence of Turbidity-Drainage Basin Geology Relationship

bidity problems have occurred with the principal geology of each dam's drainage basin. The results show a high rate of occurrence of turbidity problems in districts that include sedimentary rock geology and in districts including granite and clastic rocks.

3.2.4 Dam intake and discharge methods

Table-2 shows the relationship of the answer to question, whether or not problems have occurred, with the intake and discharge methods (whether or not ponded water is drained) of the dams. Here "draining ponded water" refers to artificially lowering the water level in the reservoir at the end of the irrigation period. The intake method was judged from sketches of the intake facility that respondents were requested to include with the completed questionnaire. Because many of the dams that were included in this survey use the floating type intake method (particularly in Hokkaido), many problems occurred at such dams, but no significant differences between the rate of occurrence of problems was found according to the intake method.

3.2.5 Factors causing turbidity (factors hypothesized based on respondents' answers)

Written responses concerning causes of turbidity hypothesized by the managers are categorized from A to I in Table-3 Legend. The turbid substances that originally caused the turbidity are sediment and the skele-

Table -2 Turbidity – Dam Intake Method and Ponded Water Drainage Relationship

Ponded water drainage after irrigation period / Intake method	Ponded water is drained		Ponded water is not drained	
	A problem occurred	A problem did not occur	A problem occurred	A problem did not occur
Intake tower, surface intake gate method	2	3	5	0
Intake tower, floating method	11	9	1	3
Selective intake gates inside the dam body	1	1	4	5
Inclined drain, bottom drain	1	3	4	1
Other	0	0	2	1

Table- 3 Period and Frequency of Turbidity and Causal Factors based on Hypotheses of Dam Managers

Duration of each occurrence of turbidity / Annual frequency of turbidity	1 day~1 week	1 week~2 weeks	2 weeks~1 month	1 month or more
Once	**42**(A,H) 65(A,B)			1(A), (A,B) 16(A)*, 19(C) 24(C), 28(B,D) **36**(E), **63**(A,B)
Twice	**51**(A,B,G)	**40**(G,H)	13(A,B,D,I)	12(A,F), **52**(A,B) **53**(A,B)
Three times	20(A,B,D)	**48**(A,B,G)		18(A,B,D)*, 66(A,B)
Four times or more	29(A,B)	**61**(A,D) **62**(A,D)		

Legend of factors hypothesized by dam managers to cause turbidity
A By rainfall (flooding) in the dam drainage basin
B By the geology or vegetation in the dam drainage basin
C By high temperatures or continuous dry weather in the summer
D By the fall of the reservoir level
E By work upstream from the dam
F By sedimentation inside the dam reservoir
G By the discharge of ponded water
H By the formation of humus or algae by fallen leaves
I By the agitation of the irrigation water
Note 1) 25 (A,B,D) indicates that it is dam No. 25 and the factors causing the occurrence of turbidity are A, B, and D.
Note 2) Numbers printed in bold are dams under the jurisdiction of the Hokkaido Development Bureau.
Note 3) The symbol "*" indicates dams with purposes other than irrigation (electric power generation, disaster prevention).

tons of living organisms produced inside the drainage basin and the reservoir. Their behavior is governed by the movement of the water that was the medium for their transport. There is a method of hydraulically and hydrologically analyzing the deposition and flow in a reservoir of sediment produced in the dam drainage basin as a "dam sedimentation mechanism." Because a turbidity problem is a problem concerning the transport of turbid substances including sediment, it is possible to hypothesize the causes of turbidity problems based on primary causes of the problem of dam sedimentation. Primary causes of dam sedimentation can be generally categorized as drainage basin primary causes and as reservoir primary causes[1). Among the reservoir primary causes, primary causes that are results of the characteristics of management that are particularly important in the case of an irrigation dam are considered, and part of the reservoir primary causes are categorized as management primary causes. Based on these concepts, the factors hypothesized by dam managers in Table-3 are categorized as (1) drainage basin primary causes A, B, C, and E, and as (2) management primary causes D, G, and I, and as (3) other reservoir primary causes F and H.

In Table-3, causal factors hypothesized by dam managers were categorized according to the annual occurrence frequency of turbidity phenomena, or in other words "frequency", and the duration of each turbidity phenomenon that has occurred. Frequency presumably differs according to each respondent's impression and feelings throughout the year. But the overall survey has shown that without doubt, most phenomena occurred with frequency of once or twice a year and continued for a long duration of more than a month. In addition, the results of this investigation have shown that the times of the occurrence of turbidity phenomena are mainly concentrated from July to September.

3.2.6 State of implementation of countermeasures in the field

Table-4 organizes the state of implementation of countermeasures taken to deal with turbidity problems by the district where turbidity problems occurred. Countermeasures have been taken (or are planned) in 16 districts, that is about half of all the 31 districts where problems occurred. No responses were received regarding many of the other districts, but in some cases, measures have not been taken (or cannot be taken) for a variety of reasons: there is no countermeasure method, the cost of countermeasures is too high, or the problem does not harm irrigation.

Countermeasure methods are broadly categorized into three types (1) measures to prevent turbidity in the drainage basin that is the source of the production of turbid substances, (2) measures to prevent turbid water from flowing into the reservoir or to remove turbid substances that have flowed in, and (3) measures to prevent the intake or discharge of turbid water by surface intake or by discharge etc. (study of intake and discharge operation methods as non-physical measures and improvement of systems as physical measures). These measures are taken in response to the hypothetical causal factors in Table-3, and are the grounds for the categorization of turbidity problems by phenomenon and by cause, but these are discussed below.

3.3 Considering the survey results

Based on the above section, the following predictions regarding turbidity phenomena have been made.

1) Because the total discharge from an irrigation dam is generally lower than at other types of dams, it is hypothesized that the absolute quantity of turbid water is small. It can also be stated that the quantity of water required to dilute turbid water is low, because it is in a water environment where the turbid water density rises easily.

Table 4 Description of the Implementation of the Measure

Category of countermeasure method	Specific method	Dam No.
Change of the intake or discharge methods	Surface intake/discharge	1,28*.29,**48**, **51,52,53**,65
	Bottom water discharge	1
	Change of the intake opening	**63,**66
	Advance drainage of ponded water before a flood	**61,62**
Improvement (reconstruction) of the intake or discharge system	Installation of a pipe filter	65
	Installation of a sludge outlet valve	64
	Enlargement of the discharge pipe diameter	16*
Purification inside the reservoir	Dredging work	2,**36**
	Installation of water purification system	24
	Replacement of the water	**63**
	Ensuring an alternate route for inflowing water	18*
River basin countermeasures	Construction of a sabo dike	**61**
	Adjustment of the work period	**33**

Note 1) Numbers printed in bold are dams under the jurisdiction of the Hokkaido Development Bureau.
Note 2) The symbol "*" indicates dams with purposes other than irrigation.

2) It is assumed that eutrophication occurs readily in a reservoir with a long retention time. At the same time, reservoirs of this kind generally stratify easily, resulting in a danger of a dense flow of muddy water causing high density turbidity.
3) As shown by A, B, in the Legend in Table-3, there are assumed to be close relationships between the geological and rainfall conditions of the drainage basin and the occurrence of turbidity. The impact of geology is extremely clear as already shown by Fig. 5. In the estimation equation of the specific discharge of flooding in drainage basins, as the area of the drainage basin increases, the specific discharge declines in proportion to the square of its reciprocal[5]. This suggests that because an irrigation dam has a smaller drainage basin area than that of other types of dams, the specific discharge of the drainage basin of an irrigation dam may be relatively larger than that of other types of dams. In this case, there is danger of suspended load or wash load that are the principal constituents of turbid substances being produced easily[1].
4) As shown by comparing an irrigation dam with an electric power generation dam, the turnover rate of an irrigation dam is small and the water level fluctuation is large. This means that there are many cases when water intake is also required when the water level is low. Normally, it is extremely dangerous to take in high concentrations of turbid water and turbid substances that have been left by surface intake and retained or deposited in the bottom layer. This is probably conspicuous during droughts.

4. Investigation of Sediment Routing in an Irrigation Dam Reservoir

In this chapter, a study conducted using sample cases to answer two questions is described. To what degree can information be obtained by observations at fixed intervals of several years of present sediment routing done as part of efforts to quantitatively predict future sedimentation and how can this information be applied?

4.1 Investigation methods

4.1.1 Investigation location

Dam A, an irrigation use rock fill dam with a catchment basin of 55km^2, has been an important source of water irrigating 7,118ha of land since it was completed in 1983. Its upstream basin is steep and its valleys narrow, it includes volcanic sediments produced by mud flows and pyroclastic flows, and sediments flow easily through its topographical and geological environment, and judging from the results of continuous observations of the quantity of sediment made in recent years, there is a danger that continued sedimentation will reduce the storage capacity of its reservoir.

4.1.2 Investigation method

The progress of sedimentation of a dam is governed by the quantity of sediment produced in its catchment basin and its transport mechanisms. The annual advance is generally slow, but in the case of Dam A that was investigated, intensive rainfall in the year before the investigation (two day rainfall in the entire river basin including the dam catchment basin of 220mm) deposited unstable sediment in the upper and middle parts of the reservoir, and later this flowed continuously into the reservoir.

The investigation was continued according to this timing. From the following year of 1996 until 1998, topographical measurements of the sediment were performed during the bank full stage (May and June) that is an effective time for sounding in order to clarify minor fluctuations of the sedimentation over a wide area from year to year. Specifically sounding of the reservoir bed (3 times), lateral measurements on land (2 times), and exploration of the bottom sediments with an acoustical sounder (1 time) were done. The reservoir bed topography was measured within the same range as once a year for a total of 3 times. The sounding was done using the Small Investigation Boat Sounding System Combining DGPS and Acoustical Explorer[6] .

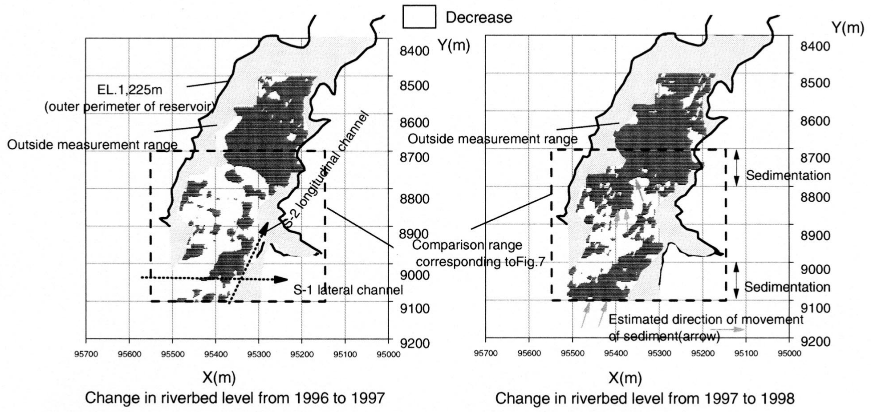

Fig. 6 Plane Distribution of Annual Change of the Riverbed Level in the Sounding Section

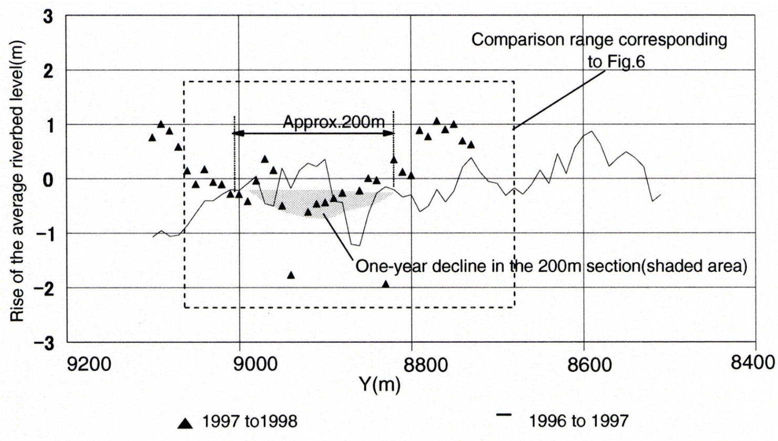

Fig. 7 Annual Change of the Average Riverbed Level of Each Section

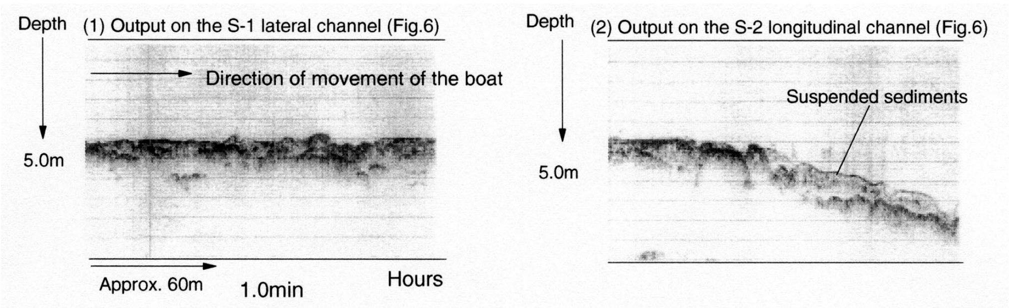

Fig. 8 Output of the Bottom Sediments Exploration

4.1.3 Lateral measurements on land

These were done twice, once a year in 1997 and 1998, on the land where sounding is impossible. The survey section was set at intervals of about 100m to perform lateral measurements using an optical distance measuring device.

4.1.4 Exploration of bottom sediments

This was done once in 1996. An acoustical explorer with output of 5 to 10 kHz (Senbon Denki Co., Ltd., SH-20) and a GPS transceiver were used for exploration in the same range as the reservoir bed sounding.

4.2 Considering the sediment routing

The data obtained by the three year exploration were data for year-to-year change equal to three times at the most but, characteristically, it is spatially dense information.

4.2.1 Direction of movement of the sediment

Fig. 6 shows the results of calculating the change of the riverbed level at points in each mesh based on the results of the three years of sounding. Downstream from Y = 8,700m (upward on the figure) is the range of one-way sedimentation on the reservoir bed throughout the year. So upstream from there, the direction of plane movement of the sediment is considered focussing on the range until Y = 9,100m (part enclosed by the dotted lines in the figure).

The difference between the way the riverbed level changed between 1996 and 1997 and between 1997 and 1998, can be categorized in four patterns: (1) two years continuous sedimentation, (2) change to sedimentation in the second year, (3) change to erosion in the second year, and (4) two years of continuous erosion. Pattern (1) corresponds to the filling range and pattern (4) corresponds to a range where a large erosion channel formed. The area at the site where large scale relatively stable erosion channels are mixed with multiple constantly moving small erosion channels almost corresponds to (3) and (4). It is, therefore, assumed that sediment flowed into areas (1) and (2) (sedimentation range) from areas (3) and (4) (erosion range), so it is possible to draw arrows showing the direction of the movement of sediment as in the right side of Fig. 6.

4.2.2 Quantity of movement of sediment

In order to consider this issue in greater detail, the quantity of movement of sediment is considered. Fig. 7 shows the degree of change each year of the average riverbed level at each lateral riverbed section from Y = 8,500 to 9,100 m. Because the locations of change of the sediment within the part of Fig. 7 corresponding to Fig. 6 (part of the figure enclosed by the broken line) are originally based on the same riverbed fluctuation data, the trend is the same as that shown by the results of considering Fig. 6. It is assumed that the quantity of decline of sediment in the part where the riverbed fell between 1997 and 1998 (approximately 200m section near Y = 8,900 ~ 9,100) is equal to the quantity that moved downstream to calculate the quantity of movement of sediment during a single year. If the area of the shaded part of Fig. 7 that corresponds to the above-mentioned approximately 200m part is assumed to be approximately a triangle, it is 220m X 0.5m X 1/2 = 50m². If the lateral width of the riverbed in this part is assumed to be approximately 200m, ultimately, it is possible to estimate that the annual quantity of sediment that moves is the value of approximately $50m^2$ X 200m = $10{,}000m^2$.

4.2.3 Considering the results of the bottom sediment exploration

Fig. 8 shows the results obtained from the bottom sediment exploration on the two channels S-1 and S-2 shown in Fig. 6. Near S-1, the area downstream from sediment deposited by the intensive rainfall of 1995 assumed to be the area where great longitudinal and lateral erosion occurred. In the lower layer of the section, a striped pattern thought to be traces of an old channel is observed. It is assumed that after coarse grain materials were transported and deposited, relatively fine grain sediment was deposited on the old channel. And the relative flatness of the riverbed section is also thought to have been caused by continued lateral erosion accompanying the constant change of the channel and by the endless supply of sediment from upstream.

In S-2, it appears that as the riverbed gradient changes abruptly, the quality of the sediment changes. The relationship of these changes in the sedimentation and erosion environments with the existence of points of change on the riverbed and other output from the exploration is a future challenge.

5. Conclusion

Generally speaking, sedimentation problems and turbidity problems are in a contradictory relationship. For example, aggressively discharging turbid water that is one cause of sedimentation is disadvantageous from the standpoint of turbidity, but restricting the increase in the production of sediment is beneficial from the standpoint of sedimentation problems. It is, therefore, assumed that in order to resolve these problems at the drainage basin level in the future, as a general theory, restoring the quantity and quality of the water in a river, the quantity of sediment it transports and other natural conditions in the river to their original states in order to discharge a suitable quantity of sediment at an appropriate concentration is considered. But at dams where there is little danger of the quantity of sediment increasing during the service lifetime of the dam, it is more appropriate to either maintain the reservoir level at a low level without draining ponded water (low water management) or to restrict the production of turbid water by surface discharge. In a case where it is judged to be necessary to discharge turbid water, discharging a specified quantity during a flood is recommended. Reasons for selecting "during a flood" include three facts: it is possible to discharge in a short time, it can bear the role of the dilutant that tends to be short supply, and the discharge does not abruptly change the turbidity of the river water. The problem at this time is setting the appropriate quantity of turbid water to be discharged, but this is a yardstick for the quantity of turbid material retained in the reservoir over years. The quantity of water necessary to discharge sediment from an irrigation dam is ideally and rationally provided from water overflowing the spillway or from discharged ponded water. If this is done, it is possible to safely reduce the factors causing turbid water and sedimentation a little each year without greatly altering the river environment in order to maintain the sediment hydraulic environment of the reservoir and the drainage basin. It is necessary to develop related economical physical technologies, but equipment that is too large considering the required quantity of sediment discharged is inappropriate.

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References

1) Taruya, H. & Kitada, T.: Sediment factors of existing irrigation dam reservoirs. J. JSIDRE, 64 (10), 57-65 (1996)
2) Ashida, K. & Okumura, T.: Study on sedimentation in reservoirs. Annu. Disas. prev. Res. Inst., Kyoto Univ., 17B, 555-570 (1974)
3) Kira, H.: On the sediment problems of reservoirs. J. Hydraul., Coast. & Environ. Eng., 193, 23-33 (1971)
4) Kira, H. et al.: Fundamental problems on sedimentation in reservoirs. Sci. Rep. Fac. Agric. Kobe Univ., 11, 301-318 (1975)
5) Ministry of Agriculture, Forestry and Fisheries, Agricultural Structure Improvement Bureau: Land improvement project planning and design standards and design (dams), p. 83 (1981)
6) Okushima, S. & Taruya, H.: Sounding system using a small exploration boat combining DGPS and an acoustical sounder. "Directions of Development of New Technologies for the Improvement of Agriculture and Agricultural Villages" lecture course text, Japanese Society of Irrigation, Drainage and Reclamation Engineering (JSIDRE), National Institute for Rural Engineering, pp. 69-81 (1999)