Effective Utilization of Existing Dams in Japan

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Abstract

To satisfy future demand for flood control and water supply, effective utilization of existing dams as important social capital stocks is sought for in Japan as the nation's investment capability has reduced with the advent of the aging society and the social demand for the preservation of natural environment has been escalating. The Japan Commission on Large Dams (JCOLD) established the Committee on Effective Utilization of Existing Dams and carried out various activities between 2003 and 2004. With the aim of contributing to the forward planning and implementing effective dam utilization, the committee summarized the subjects to the achievement of its goals by investigating the effective operation and improvement measures for dams and putting together precedents for existing facilities to enhance their functions. This paper outlines the committee's research results.
Keywords: *Existing dams, Effective utilization, Questionnaire survey*

1. INTRODUCTION

In order to satisfy future demand for flood control and water supply in Japan,, there has been an escalation in demand for the effective utilization of existing dams as vital social capital stocks as the nation's investment capability has reduced with the advent of the aging society and the social demand for the preservation of natural environment has been escalating. Thus, in addition to the improvement of dam management and the cooperative operation of multiple reservoirs, the purposes and methods of utilization of storage capacity have changed and, in more and more cases, dams are reorganized into a new system.

From the perspectives of physical technology, the technical subjects necessary for raising the height of dams, building additional structures and making modifications to intake and outlet facilities have risen in importance. And the same time, there have been advances in the field of research, design and construction that have greatly enhanced the techniques of dam heightening, remodeling and enlarging of outlet structures. To satisfy the future demand for flood control and water supply, requirements for non-physical innovations concerning the modification of operating methods and the reorganization of dam groups seem to be imposed more and more.

In this light, the Japan Commission on Large Dams (JCOLD) established the Committee on Effective Utilization of Existing Dams and carried out its activities for two years. With the aim of achieving its goals and thereby contributing to the forward planning and implementation of effective dam utilization, the committee summarized subjects by investigating effective operation and improvement measures for dams and putting together precedents for existing facilities to enhance their functions.

This paper introduces the ways in which existing dams have been utilized effectively in Japan, demonstrating 227 cases collected and analyzed by the committee and their trends according to time period and purpose. This paper represents only a part of total research results obtained by the committee and its final report will be issued later this year[1].

2. TRENDS OF RESEARCH CASES

2.1. Measure used in the case study

Besides such general procedures as the enlargement of capacity by means of dam heightening and the reallocation of capacity, an attempt was made in this research to gather a number of informative cases by broadly defining effective dam use, including those projects for increasing downstream maintenance flow, building fish ladders and adding sediment management functions as environmental protection measures. The dams investigated in this research include the following: those under the jurisdiction of the Ministry of Land, Infrastructure and Transport and the Ministry of Agriculture, Forestry and Fisheries; those administered by private electric power companies; and those managed by public power districts.

A questionnaire was sent out to each organization to elicit the following information:

1) Examples of the effective utilization of existing dams through operational improvement and rehabilitation including redevelopment
2) Technical descriptions regarding the remodeling and reinforcement of relevant dam facilities
3) Adjustments of cost sharing and property rights among the owners of existing dams and the organizations undertaking their improvement and redevelopment

As a result, information on a total number of 227 cases was collected.

2.2. Case Types

The cases of the effective utilization of existing dams were classified with two codes: a case code (project category for effective utilization) and a technical code (technical method to realize effective utilization).

Both the case code and technical code are summarized below.

2.2.1. Case code

The case code is a classification that focuses on the category of projects for the effective utilization of existing dams. Table 1 presents a list of the case codes used. Because, in some examples, one case may correspond to several case codes, the total number of cases given in the summary table for case codes (Table 3) is not necessarily equal to the total number of the cases examined.

2.2.2. Technical code

The technical code is a classification that focuses on the type of engineering methods for the effective utilization of existing dams. Table 2 is a list of the technical codes used. Because there are some cases in which physical techniques are not employed, the total

Table 1 Case codes

Case code	Description of effective dam utilization
1-(1)	A case in which a dam operation scheme is modified in response to a change in a water supply plan to meet social demand (single dam)
1-(1)-1	A case in which storage capacity is expanded by means of raising the height of an existing dam, constructing a new dam in a downstream site which submerges an upstream existing facility, or dredging/excavating the sediment in a reservoir.
1-(1)-2	A case in which a dam operation scheme is changed by cutting back generation hours while at the same time increasing the maximum output for a hydropower plant to produce on-peak energy.
1-(2)	A case in which a new dam is constructed and the efficiency of both the old and new dams in the same river system is enhanced by modifying the operating plan of the existing dam.
1-(3)	A case in which integral operation is practiced on a group of dams to improve the efficiency of individual dam operation (a group of dams in the same river system).
1-(3)-1	A case in which upstream dam groups are orderly supplemented so that dead outflow can be reduced and storage efficiency can be enhanced in the total dam system.
1-(3)-2	A case in which hydropower generation is efficiently operated or a power plant is newly constructed in a river system after reviewing a generation plan on the occasion of the construction of a new dam-type power plant.
1-(4)	A case in which water service to benefited areas is reallocated among several dams.
1-(5)	A case in which an integrated dam operation is carried out with another river basin beyond a given river system.
1-(6)	A case in which existing dam facilities are effectively utilized as in an increase in the capability of outlet structures, eliminating gates, modifying flood control rules and implementing sedimentation measures.
1-(6)-1	A case in which water supply operation is efficiently and simply conducted in upstream dams through the effective use of mid-to-downstream regulating reservoirs.
1-(6)-2	A case in which an efficient dam operation is realized by adding a new control channel (integrated operation in a dam group)
1-(6)-3	A case in which flood control and water supply functions are reallocated and made efficient within a river system or conjoined with another river system (reorganization in a dam group)
1-(6)-4	A case in which an existing dam is utilized effectively by adding a power plant that includes low power generation using maintenance flow or by increasing output.
1-(6)-5	A case in which an existing dam is effectively utilized by enhancing the maintenance flow to improve the river environment, by building a surface/selective intake facility or by taking various sediment control measures such as transporting sediment down a river.
1-(6)-6	A case in which an outlet structure and a bulb are constructed and/or added to supply water.
1-(6)-7	A case in which an outlet structure to control flooding is added, in which gates are eliminated or in which an emergency flood spillway is remodeled so that the dam management situation is improved.
1-(6)-8	A case in which flood control rules are modified to respond to the improvement status of downstream river channels or in which water service operations are revamped and the purposes of the water supply is converted to align with the changes in social situations.
1-(6)-9	A case in which the construction of a check dam and a bypass as well as dredging works are carried out to prevent sedimentation in a reservoir.
1-(6)-10	Other than above.

Table 2 Technical codes

Technical code	Description of effective dam utilization
2-(1)	A method in which dam capacity is increased by raising the height of a dam or constructing a new dam which submerges an existing dam and its reservoir.
2-(2)	A method in which both the intake and outlet capacities are increased to comply with changes in an operating plan.
2-(3)	A method in which outlet capability (reliability and minute adjustability) is increased for compliance with changes in an operating plan.
2-(4)	A method in which selective intake capability is increased, including such measures for cold or turbid water.
2-(5)	A method in which a reservoir is equipped with a sediment removal function (which includes a downstream sediment supply as an environmental strategy).
2-(6)	A method in which a fish ladder is added.
2-(7)	Drilling and cutting of a dam body
2-(8)	Construction of connecting tunnels between river channels or dam reservoirs
2-(9)	Addition of power generators and the like
2-(10)	Other than above.

Table 3 Breakdown of effective dam utilization (case code)

Dam type / Case code	Multipurpose dam	Agricultural dam	Hydroelectric dam	Total
1-(1)-1	38	8	3	49
1-(1)-2	0	0	4	4
1-(2)	13	2	7	22
1-(3)-1	1	5	0	6
1-(3)-2	0	0	3	3
1-(4)	3	0	0	3
1-(5)	5	0	0	5
1-(6)-1	1	0	0	1
1-(6)-2	3	1	0	4
1-(6)-3	2	0	0	2
1-(6)-4	4	3	20	27
1-(6)-5	26	3	29	58
1-(6)-6	6	1	0	7
1-(6)-7	9	4	7	20
1-(6)-8	3	5	0	8
1-(6)-9	11	2	6	19
1-(6)-10	0	2	0	2
Total	125	36	79	240

Table 4 Breakdown of effective dam utilization (technical code)

Dam type / Technical code	Multipurpose dam	Agricultural dam	Hydroelectric dam	Total
2-(1)	28	8	2	38
2-(2)	24	2	18	44
2-(3)	4	2	7	13
2-(4)	15	2	6	23
2-(5)	15	1	1	17
2-(6)	0	0	3	3
2-(7)	10	0	5	15
2-(8)	7	0	1	8
2-(9)	5	3	22	30
2-(10)	2	1	0	3
Total	110	19	65	194

number of cases given in the summary table (Table 4) does not necessarily correspond to the number of cases examined or to the summary table for case codes.

2.3. Result of Case Classification

All cases of effective dam utilization classified by case code and technical code are illustrated in Tables 3 and 4 as well as Figures 1 and 2, in which dam functions are further divided into three purposes: multipurpose (flood control), agricultural and hydroelectric.

Regarding the case code, of all 240 cases, as many as 49 cases were classified into the 1-(1)-1 category and 58 cases into the 1-(6)-5 category, for which further information is provided in Figure 3. Among the 49 cases in the 1-(1)-1 category, capacity was enhanced by raising the dam height on the same dam axis in 23 cases while dam heightening was executed on the downstream dam axis in 14 cases. In six cases, the existing capacity was reallocated and dead storage

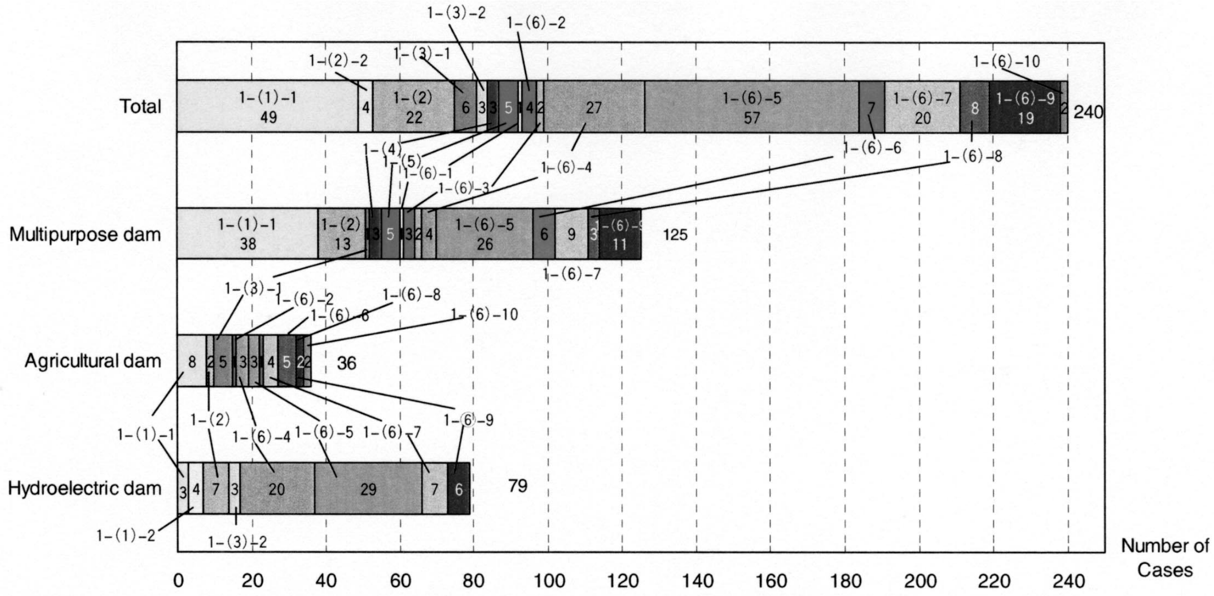


Figure 1 Breakdown of effective dam utilization (case code)

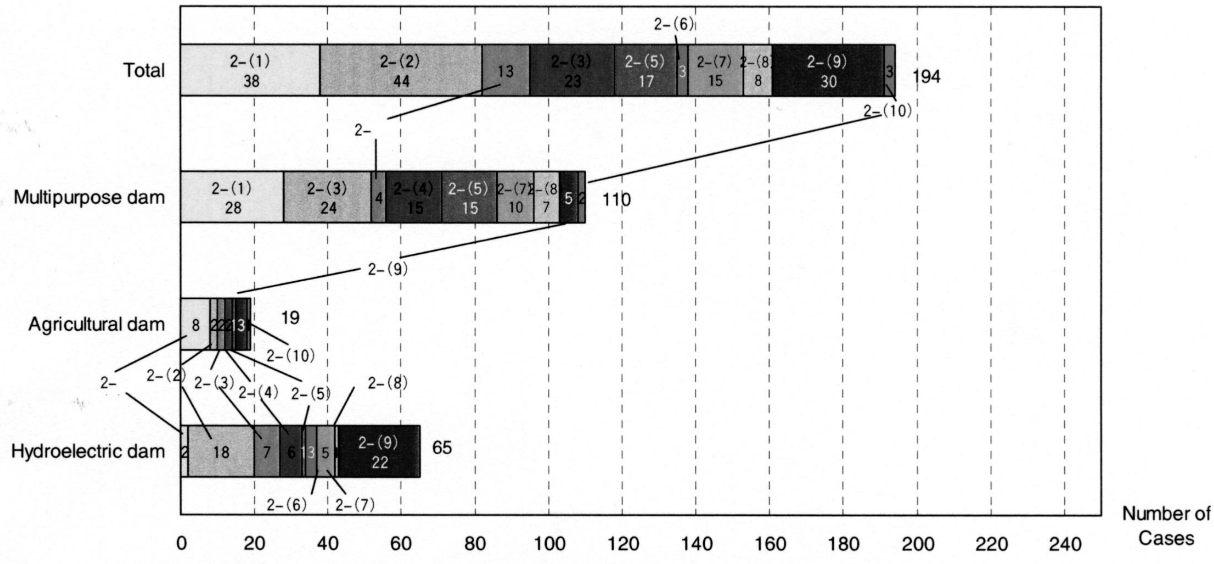


Figure 2 Breakdown of effective dam utilization (technical code)

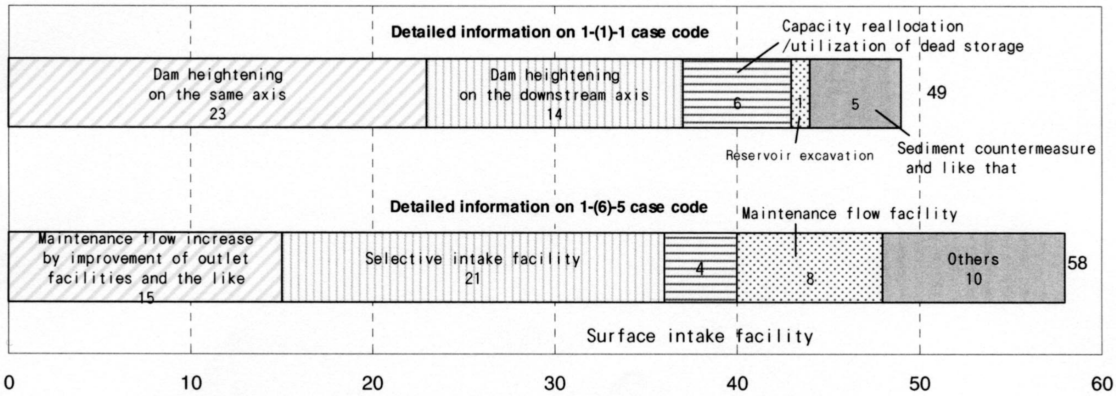


Figure 3 Detailed information on 1-(1)-1 and 1-(6)-5 case codes

was effectively utilized. Excavation within a reservoir was carried out in one case and new capacity was secured by controlling sedimentation etc. in five cases. Among the 58 cases in the 1-(6)-5 category, river maintenance flow was increased by improvement of outlet facilities and the like in 15 cases: a selective intake facility was constructed in 21 cases: a surface intake facility was installed in four cases: a maintenance flow facility was built in eight cases: and other effective measures were employed in ten cases. Multipurpose dams show a similar tendency to the whole. Within the total of 125 cases, 38 cases and 26 cases were grouped into the 1-(1)-1 and 1-(6)-5 categories, respectively. Within a total of 36 agricultural dams, eight cases in the 1-(1)-1 category and five cases in the 1-(3)-1 and 1-(6)-8 categories each outnumber the others. For hydroelectric dams, as many as 29 cases and 20 cases were grouped into the 1-(6)-5 and 1-(6)-4 categories, respectively.

Regarding technical code, of the total number of 194 cases, 38 cases in the 2-(1) category and 44 cases in 2-(2) category suggest their dominance. A similar tendency to the rest is shown in the cases of 111 multipurpose dams, with 28 cases in the 2-(1) category and 24 cases in the 2-(2) category. In 19 agricultural dams, category 2-(1) is often seen. As for hydroelectric dams, the categories of 2-(3) and 2-(4) in addition to 2-(2) and 2-(9) are characteristically often seen. This includes the expansion of intake/outlet facilities and the installation of selective intake structures, reflecting the movement to protect water quality and the river environment.

2.4. Transition in Effective Utilization of Existing Dams

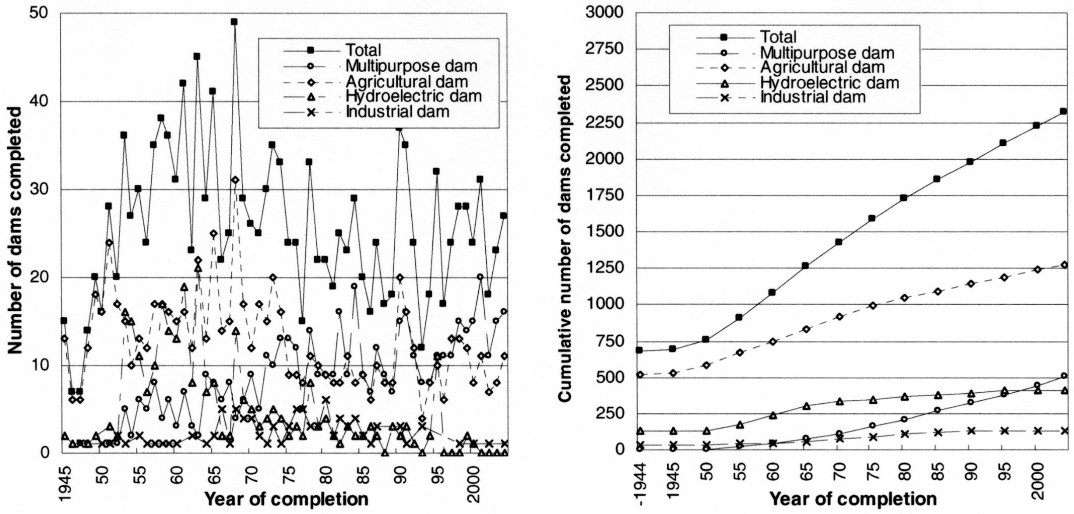
2.4.1. Changes in the number of completed dams

To examine the trends in effective dam utilization, changes in the number of completed dams are reviewed. Based on the database[2] provided by the Japan Dam Foundation, the changes in the total number of completed dams from 1945 to 2004 are itemized under several categories: all dams, multipurpose dams including flood control dams, agricultural dams, hydroelectric dams and industrial dams. Figures 4 (1) and (2) depict their yearly and accumulative data, respectively.

A dozen to a score of hydroelectric dams were built annually between 1953 and 1963. The number of dams constructed remained almost as stable at about five dams per year until 1996 with the exception of three years, 1968, 1978 and 1995 when 13 dams, 8 dams and 11 dams were constructed, respectively. After 1996, no additional new dams were constructed although three dams were built in 1999 and one in 2000. On the whole, there was a decline in the number of hydroelectric dams constructed after 1965. Agricultural dams, on the other hand, have been completed relatively constantly. From 1945 to 1974, more than ten dams were completed every year. Particularly, in 1963, 1965 and 1968, as many as 22 dams, 25 dams and 31 dams were increasingly added. Although there is a slight decline in the tendency since 1975, nearly ten dams have been completed annually. Regarding multipurpose dams including flood control dams, one dam a year was built from 1945 to 1952 and several dams were built yearly between 1953 and 1971. After 1972, the numbers fluctuated but approximately ten to twenty dams were completed in a year, showing no conspicuous tendency of increase or decrease. The number of industrial dams completed was five a year at most. When the overall trend from 1945 to 1975 is examined, the number reached a peak in early 1960s and started decreasing slightly from 1970.

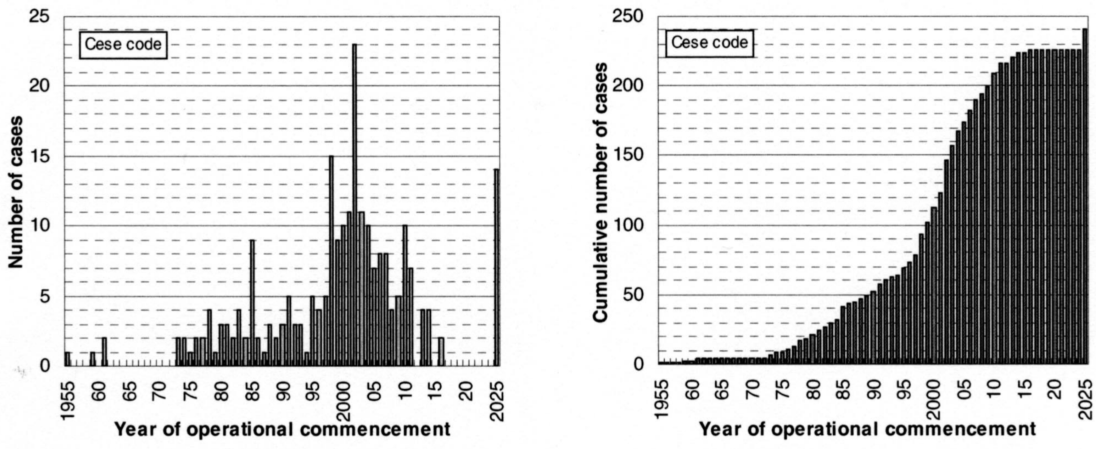
2.4.2. Comprehensive tendency of effective dam utilization

Figures 5 (1) and (2) show yearly and cumulative information on operational commencement of effective dam utilization. As for data for the years following 2004, projected years are used in the questionnaire,



(1)Yearly data (2)Cumulative data

Figure 4 Change in the number of completed dams



(1)Yearly data (2)Cumulative data

Figure 5 Change in the number of effective dam utilization cases

while those projects that do not have a clear completion date are arbitrarily fixed at 2005.

In this research, 1955 was the year when the effective utilization of an existing dam first began. Several cases of effective dam utilization are identified during the time period between 1973 and 1995 with a peak in 1985. However, the number has increased sharply since then, jumping up to 22 cases in 2003. As far as the cumulative data are concerned, the trend started to progress gradually from the mid-1970s and accelerated greatly after the second half of the 1990s. To date, 74 projects (including those which do not have a clear completion date) are under examination or construction.

2.4.3. Tendencies of effective dam utilization by case code and technical code

Figures 6 (1) through (14) and Figures 7 (1) through (12) depict information on operational commencement for codes 1-(1)-1, 1-(2), 1-(6)-4, 1-(6)-5, 1-(6)-7, 1-(6)-8, 1-(6)-9, 2-(1), 2-(2), 2-(5), 2-(7) and 2-(9), into which a relatively large number of cases were grouped.

From 1959 until 2016, one to five cases a year started or will start operations under the 1-(1)-1 category and this number has constantly increased since the second half of the 1990s. The total number of such cases including those still in the planning process is 49. The increase in the number of capacity reallocation cases, a typical method of effective dam utilization, is a manifestation of the movement developed in the late 1990s in which flood control capability can be increased at a lower cost by making using an existing dam with greater efficiency. Accordingly, the concentration of many cases is higher after the 1990s, reflecting the social demand for a more effective use of existing facilities.

As for the 1-(6)-4 case prior to 1990, the completion of large-sized uppermost reservoirs in river systems introduced the possibility of year-round plant operation, which, as a result, expanded available discharge and realized large peak-discharge operation, enabling the addition of downstream power plants. After 1990, electric power shortage due to economic development came to the surface. To support the peak-load, many measures were taken, in which the operation hours of existing pumped storage power plants were shortened while discharge was increased to boost output.

For the 1-(6)-5 case, the operations began in the early 1970s. The number of cases started to increase after the early 1990s and this tendency became much conspicuous in the late 1990s. The total number of such cases including those still in the planning process is 58. The enhanced social awareness of environmental preservation seems to be reflected behind the scene.

The 1-(6)-7 case appeared in 1979, and its number increased noticeably from the late 1990s. The total number of such cases including those still in the planning process is 20. Through the rationalization of future maintenance and management, it is expected that there will be an increase in the number of elimination of gates.

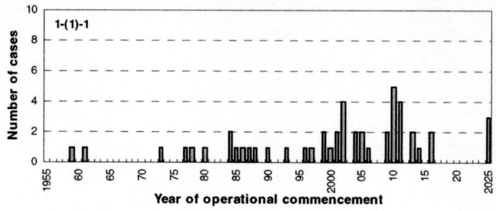
For the 1-(6)-8 case, one example appeared in 1982 and one or two examples after 1995. It is assumed that a review of flood control rules and the modifications in water use will appear more often in future for reasons stated below.

The 1-(6)-9 case appeared as early as in 1959, revived after the first half of the 1970s and rapidly increased from the 1990s.

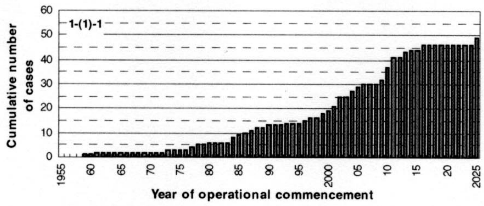
The tendency in the technical code is discussed in this section.

One example of the 2-(1) method was found in 1959. From the late 1970s until 2000, the number remained as constant at approximately one case per year, and this figure has increased in recent years. The total number of such cases including those still in the planning process is 38.

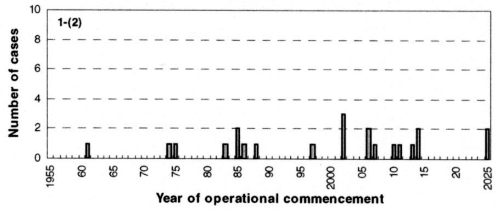
The 2-(2) method appeared in the mid-1970s, and the figure tended to increase from around 1991, suggesting a growing demand for flood control and water



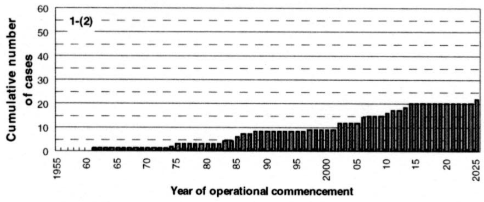
(1) Yearly data for 1-(1)-1



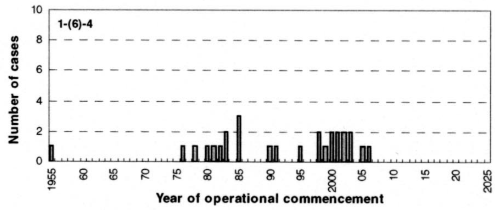
(2) Cumulative data for 1-(1)-1



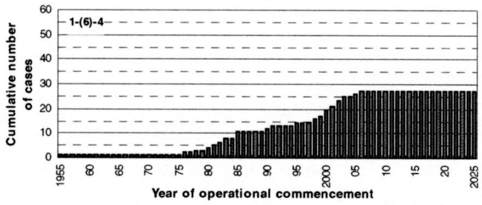
(3) Yearly data for 1-(2)



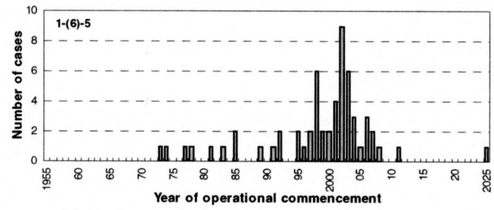
(4) Cumulative data for 1-(2)



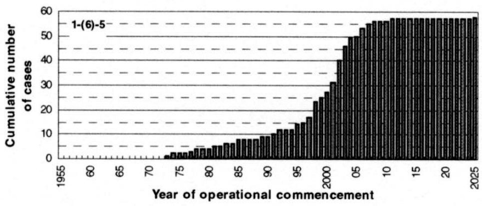
(5) Yearly data for 1-(6)-4



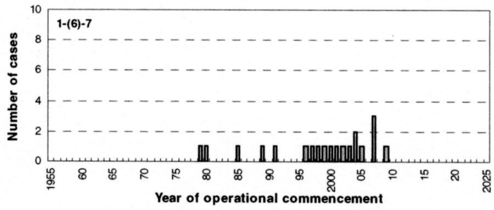
(6) Cumulative data for 1-(6)-4



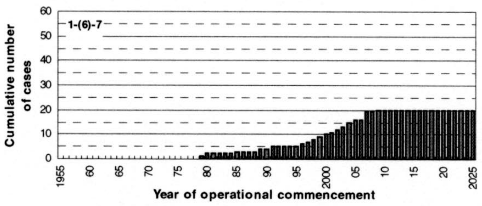
(7) Yearly data for 1-(6)-5



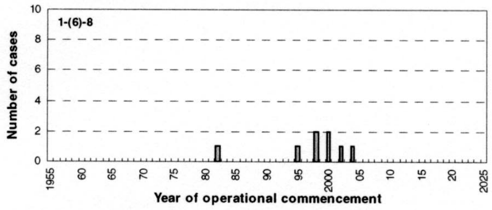
(8) Cumulative data for 1-(6)-5



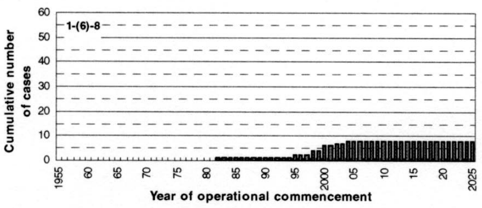
(9) Yearly data for 1-(6)-7



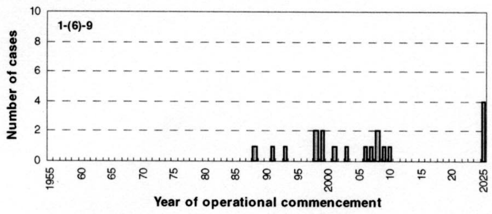
(10) Cumulative data for 1-(6)-7



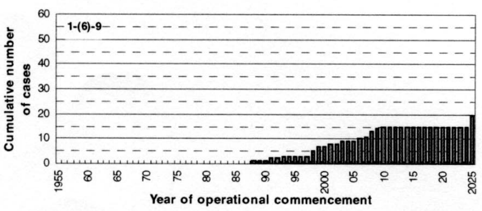
(11) Yearly data for 1-(6)-8



(12) Cumulative data for 1-(6)-8



(13) Yearly data for 1-(6)-9



(14) Cumulative data for 1-(6)-9

Figure 6 Change in the number of effective dam utilization cases (case code)

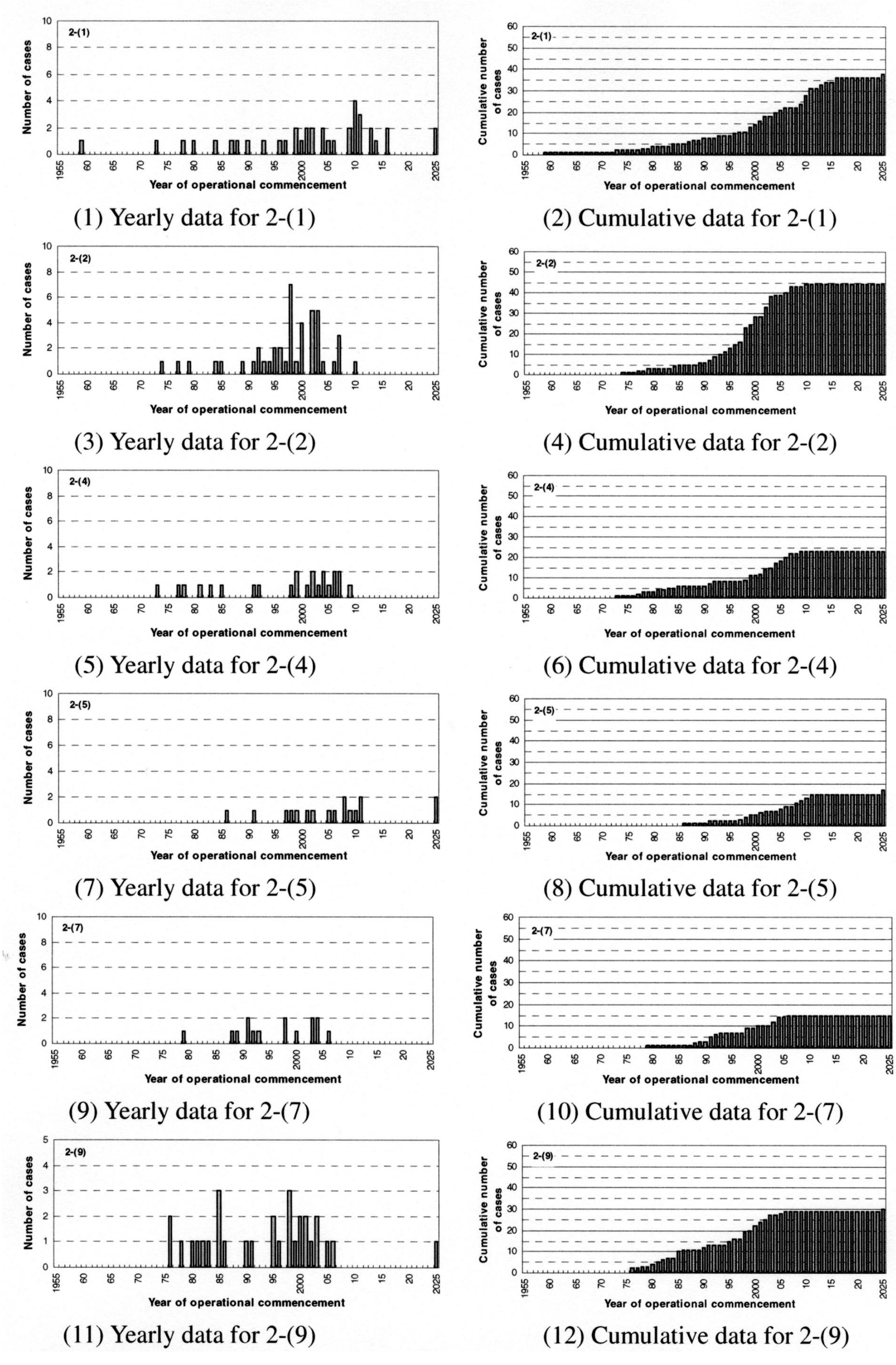


Figure 7 Change in the number of effective dam utilization cases (technical code)

supply. The total number of such cases including those still in the planning process is 44.

The 2-(4) method is a technical measure for the 1-(6)-5 case, and therefore these data show a similar tendency. This method started to appear in the mid-1970s as a water preservation measure against cold/turbid water in reservoirs and increased slightly in the late 1990s. Although it is suspected that the social background of a deterioration in forest management has led to the increase in the number of sources of turbid water, the promoted social awareness of environmental preservation and the advancement of relevant engineering techniques encouraged implementation of the measure in the late 1990s and after. The total number of such cases including those still in the planning process is 23.

Effective dam utilization employing the 2-(5) method was first conducted in 1986. One or two projects have been carried out annually since 1991. The total number of such cases including those still in the planning process is 17.

The figure of the 2-(7) methods tended to increase from around the late 1980s, and the current total number is 15.

The figure of the 2-(9) methods tended to increase from around the late 1970s, and the current total number is 30.

2.5. Background of Overall Tendency

In Japan, the Comprehensive National Development Plan has been revised every ten years, and a part of which the Water Resources Plan has been compiled. In the 1989 Water Resources Plan, for example, a new concept of water environment was characteristically introduced in addition to the goal of quantitatively securing enough water. The plan also mentions an environmental effect brought about by the construction of water resource development facilities such as dams, and discusses the importance of maintenance works to prevent their superannuated malfunction. On that point, however, a prospect to positively promote effective utilization of existing stocks has yet not been drawn up. Nevertheless, the plan underlines the necessity to actively preserve and improve the quality of stored water in accordance with local situations and the importance of an integrated management system to bring about greater efficiency in the function of existing facilities.

However, in the 1999 Water Resources Plan includes a perspective of securing water quality depending on water supply purposes to establish a sustainable water supply system. Its concrete measure, "effective utilization of existing water resource development facilities" was proposed to take into consideration the yearly cost increase in water use, and the report stresses the necessity of positively promoting effective measures which were already in existence by that time. In relation to the Environmental Impact Assessment Law enacted in 1997, there is a greater emphasis on the concern for environmental preservation while executing any project.

As stated above, the emphasis of Japan's water resource planning has shifted over time from the construction of new water resource development facilities to the effective utilization of existing facilities. Effective dam utilization measures are called for because of the "cost increase in water use," and "environmental awareness, including the preservation of water quality." It goes without saying that the increase in the cost of water use is an important element affecting the feasibility of a water development project in the light of stringent finance of both national and local governments. From the standpoint of cost-benefit efficiency, methods which are capable of securing new water resources by improving existing facilities such as dam heightening are attractive options. Underlying this is the complexity of water resource development and the shortage of appropriate dam construction sites. Another important viewpoint is the fact that there is the impact on the society by caused by engineering activities such as site transference is very small. Awareness of the dam-related river environment has greatly triggered an increase in the promotion of improving the functionality of existing facilities. Also noteworthy in the tendency of effective utilization is the addition of selective intake facilities since the 1990s so that proper water quality can be secured according to the purpose of water use.

Changes in the pattern of water demand over time are also a powerful driving force in promoting the effective utilization of existing facilities. There are a number of cases in which effective utilization measures have been taken with the aim of converting from one water supply purpose to another or for changing water supply capacity into flood control capacity. In these cases, remodeling or construction of an outlet structure may be required but the cost is much more reasonable than executing a large-scale project, including dam heightening. To utilize the existing stocks with as great efficiency as possible, it may be necessary to rethink the original purposes of a dam and to apply effective utilization measures to several dams together. Some examples of implementing and planning the cooperative operation of multiple dams can be seen in recent years. In addition to the transference of capacity mentioned above, it is expected that the focus of effective dam utilization will shift from on physical technology to on non-physical factors.

Characteristic tendencies of the effective utilization of existing dams can be summarized as follows.

1) A full-scale movement of effective dam utilization started in the mid-1970s and the number of cases rapidly increased from the late 1990s.
2) An increase of maintenance flow came into practice from the early 1970s, and the number of cases grew from the early 1990s, showing a noticeable increase since the late 1990s.
3) An improved selective intake function as a water quality preservation measure was introduced in the mid-1970s, and the number of cases increased slightly during the late 1990s. Works to improve selective intake functions have been applied only to those dams that were completed by the early 1980s.
4) The implementation of a sediment-related function has been mostly came into practice after 2000.

Among all the dam operators, the tendency of those conducting effective utilization of "irrigation-oriented dams" can be described as follows.

1) Measures for the effective utilization of existing dams began to be applied in relatively recent years.
2) The proportion of effective dam utilization cases for

river environment improvement is lower while that for increasing capacity for single agricultural use is higher.
3) Capacity transference came into practice while at the same time reinforcing dam functions (restoration and improvement of downstream disaster prevention efficiency, functional longevity and smooth management) and changing the purposes of water supply, as a result of the reduction in the area to be served by irrigation.
4) The introduction of small-scale hydroelectric power generation has come into practice to reduce maintenance and management costs.

"Dams for development of electric power resources" has been effectively utilized in the following manners.
1) As some dams were constructed prior to World War II, their equipments have become aged, and for these, some gates have been renewed or a gateless system has been introduced.
2) To respond to the demand for qualified water, selective intake facilities have been installed and the maintenance flow has been secured.
3) To more effectively utilize pumped-storage power plants, generators have been added in some power stations.

"Flood control oriented multipurpose dams" are effectively utilized in the following manners.
1) In addition to the integrated operations of multiple existing dams, collaborative operations between new dams and existing dams have been conducted.
2) Flexible management of dam storage has being promoted.
3) Preliminary discharge has come into practice for the purpose of flood control by making effective use of the capacity saved for other purposes.

3. CHALLENGES IN THE SMOOTH IMPLEMENTATION OF EFFECTIVE DAM UTILIZATION PROJECTS

Under restricted topographical and geological conditions, the achievement of an effective development of water resources has become more difficult. While financial conditions for improving infrastructure are stringent, the social awareness of the natural environments has grown. Under these circumstances, a tendency to make effective use of existing dams will developed and promoted with the aim of satisfying water demands (including requirements in the environmental and sediment management) in the current and future society at a low cost although the priorities and execution periods differ among the various project fields.

In order to more smoothly perform the effective utilization of existing dams, there are various challenges to be overcome. JCOLD intends to continue to carry out close examinations to make effective use of existing dams. On the basis of the investigations carried up to this time, it is proposed that the following need to be dealt with:

* Establishment of diagnostic procedures to verify the functionality and soundness of existing structures
* And examination of the countermeasures for sediment accumulation according to dam conditions
* Data-based safety execution using Information-Technology (e.g. dam drilling)
* Development of a low vibration method for dam drilling
* Invention of the optimum cofferdam to carry out redevelopment works while maintaining reservoir operations
* A rational design for a diversion work at the time of dam heightening
* Adoption of a large-scale cavity excavation technique to construct a large connecting water channel
* Provision to meet opportunities for stakeholders to build a consensus regarding the integrated operation of dams

To facilitate effective dam utilization, dam-related legal and institutional aspects (e.g. property rights and water rights) would also have to be examined. Supportive measures including fund-raising aids also need to be investigated.

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