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The International Energy Agency Technology Collaboration Programme on Hydropower

Measures to Enhance the Climate Resilience of Hydropower

IEA Hydro Task 17

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December 2025
https://doi.org/10.5281/zenodo.17779682

THE INTERNATIONAL ENERGY AGENCY AND THE TECHNOLOGY COLLABORATION PROGRAMME

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The IEA Technology Collaboration Programme on Hydropower ("IEA Hydro")

The IEA Technology Collaboration Programme on Hydropower (IEA Hydro) is a working group of International Energy Agency member countries and others that have a common interest in advancing hydropower worldwide. Current members of IEA Hydro are Australia, China, EU, Finland, Japan, Norway, Switzerland, USA. Sarawak EB is a sponsor. Member governments either participate themselves, or designate an organization in their country to represent them on the Executive Committee (ExCo) and the working groups (Tasks), through which IEA Hydro's work is carried out. Some activities are collaborative ventures between the TCP and other hydropower organizations.

Vision

Through the facilitation of worldwide recognition of hydropower as a well-established and socially desirable energy technology, advance the development of new hydropower and the modernization of existing hydropower.

Mission

To encourage through awareness, knowledge, and support the sustainable use of water resources for the development and management of hydropower.

To accomplish its Mission, the Executive Committee has identified the following programme-based strategy to:

- Apply an interdisciplinary approach to the research needed to encourage the public acceptance of hydropower as a feasible, socially desirable form of renewable energy.
- Increase the current wealth of knowledge on a wide array of issues currently associated with hydropower.
- Explore areas of common interest among international organizations in the continued use of hydropower as a socially desirable energy resource.
- Bring a balanced view of hydropower as an environmentally desirable energy technology to the worldwide debate.
- Encourage technology development.

IEA Hydro is keen to promote its work and to encourage increasing involvement of non-participating countries. All OECD and non-OECD countries are eligible to join. Information about membership and research activities can be found on the IEA Hydro website www.ieahydro.org.

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Cover picture: Yamasubaru Dam in the Mimikawa river system

DoI: https://doi.org/10.5281/zenodo.17779682

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ACKNOWLEDGMENTS

The IEA Technology Collaboration Programme on Hydropower (IEA Hydro) Task 17 has been implemented since its statement of objectives was approved at the 38th Executive Committee, March 2021. The Task 17 has been led by Japan with the cooperation of Switzerland for the lead of Subtask1 whereas Subtasks 2 and 3 were led by Japan.

Task 17 identifies risks caused by climate change and examines measures that hydroelectric power companies should take to address flood risks caused by climate change. The survey was conducted through questionnaire surveys and literature surveys targeting hydroelectric power companies and public utilities in Japan and other countries. The study organized examples of climate change disasters that could endanger power facilities and identified risk mitigation measures those hydroelectric power companies can take.

We hope that the results of Task 17 will be fed back to hydroelectric power companies and contribute to the reduction of flood risk due to climate change, which is expanding around the world.

Taking this opportunity, I would like to express my gratitude to members of the Task 17, Executive Committee Secretary, members of Japan Domestic Committee and Expert Committee, the Ministry of Economy, Trade and Industry.

Tatsuo Nishiuchi

IEA Hydro Task 17 Task Manager

December, 2025

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
EB	Enterprise Bureau, Japan
ENEL	Italian National Electricity Company
EPCO	Electric Power Company, Inc., Japan
GLOF	Glacier Lake Outburst Flood
GNSS	Global Navigation Satellite System
HS	Hydropower Sustainability
HSS	Hydropower Sustainability Standard
ICT	Information and Communication Technology
IEA	International Energy Agency
IGA	Integrated Geohazard Assessment
IHA	International Hydropower Association
IoT	Internet of Things
JWA	Japan Water Agency
J-Power	Electric Power Development Co., Ltd., Japan
KEPCO	Kansai Electric Power Company, Inc., Japan
MLIT	Ministry of Land, Infrastructure Transport and Tourism, Japan
NLMCO	Nippon Light Metal Company, Ltd., Japan
P.T. PLN	PT Perusahaan Listrik Negara (State-Owned Electric Power Co., Indonesia)
TCFD	Task Force on Climate-related Financial Disclosures
TEPCO	Tokyo Electric Power Company Holdings, Inc., Japan
TS	Total Station
UAV	Unmanned Aerial Vehicles

EXECUTIVE SUMMARY

In recent years, the risks associated with climate change have become a common global concern. Amidst growing concerns about the increasing risks of natural disasters, it is essential for power generation companies to fulfil their roles in ensuring the safety of power generation facilities and the stable supply of electricity.

Subtask 1: This chapter focused on potential natural disasters caused by climate change and examined design criteria and mitigation measures that hydropower companies should implement. Technical documents and case studies were collected and reviewed to assess the impacts of climate change on hydropower facilities and to identify proactive strategies to ensure their safety and reduce disaster risks.

Subtask 2: This survey focused on enhancing resilience in disaster recovery projects for hydropower facilities in the context of climate change. A questionnaire and literature review were conducted to gather information on climate change-induced disasters, and measures to strengthen resilience during the recovery process were identified and organized.

Subtask 3: This survey focused on reservoir sediment management in the context of climate change, with the aim of maintaining effective reservoir capacity and ensuring efficient operations for power generation. A questionnaire and literature review were conducted to examine sediment management methods and technologies, and good practices were collected through analysis and evaluation of sedimentation issues.

It was difficult to identify specific preventive measures or design criteria against disasters caused by climate change. However, through a literature survey of disaster recovery countermeasures, specific examples of measures to enhance resilience to climate change were provided. These examples are considered to be highly valuable references for enhancing the resilience of hydropower facilities.

Furthermore, by focusing on the power plants and reservoirs located along the same river in Subtasks 2 and 3, we can recognize the significance of 'River Improvement Plans' and 'Comprehensive Sediment Management Plans' aimed at disaster prevention, securing effective power generation capacity and promoting environmental conservation based on stakeholder consensus from a comprehensive management viewpoint.

It can be said that it is important to consider measures to enhance resilience to climate change in alignment with these plans.

In this context, the case studies presented in Section 4.6 and listed below are considered extremely meaningful and insightful:

- Collaborative Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River (MLIT, KEPCO)
- Case of Integrated Sediment Management Plan in Mimikawa river system (Kyushu EPCO)

1 INTRODUCTION

1.1 Background

In recent years, risks caused by climate change are common concerns across the world. This is true for hydropower plants and some are forced to have long-time operation stoppage with recovery works for flood damage with climate change as post-maintenance. In order to protect power facilities, hydropower producers need to analyse potential risks and implement precautionary measures to reduce the risk as far as possible, and to have flood damage mitigation measures such as pre-remodelling works against new hazards triggered by climate change.

There is also a concern of the increase of sediment inflow to reservoirs that might be caused by glacier retreat and intensive rainfall with climate change. So, hydropower producers are requested to maintain power generation function with further optimized reservoir sediment management to secure reservoir capacity.

1.2 Objectives of Task 17

The main objectives of Task 17 are as follows:

This Task identifies risks caused by climate change and investigates possible countermeasures that hydroelectric power companies could take against flood risks and other risks caused by climate change.

Surveys have been conducted among hydroelectric power producers in Japan and other countries. The study organized examples of climate change disasters that could endanger power facilities and identified risk mitigation measures those hydroelectric power producers can take. The survey includes case histories of flood-damaged hydropower facilities in each country and they are reviewed and systematized based on the analysis and evaluation of the risk mitigation effect of the countermeasures.

The outputs of the survey will be fed back to hydroelectric power producers and contribute to the mitigation of flood risks in the expanding climate change around the world.

1.3 Subtasks of Task 17

The Task 17 is composed of the following three Subtasks.

Subtask 1: Potential natural hazards and suitable countermeasures.

Subtask 2: Countermeasures to mitigate damage to hydropower plant facilities caused by extreme floods.

Subtask 3: Reservoir sediment management.

2 SUBTASK 1: POTENTIAL NATURAL HAZARDS AND SUITABLE COUNTERMEASURES

Within Task 17 “Measures to Enhance the Climate Resilience of Hydropower” Subtask 1 is an overview of potential natural hazards triggered by climate change impacts and an evaluation of design criteria and other countermeasures for safety check of power facilities. Individual aspects are:

- identify impacts caused by climate change affecting hydropower plants
- overview of potential climate change risks for hydropower plants
- predict possible impacts
- strengthen the resilience against climate change impacts
- pre-emptive countermeasures and innovative design criteria
- case studies of hydropower plants that have implemented preemptive measures

2.1 Introduction and Overview

In this subtask we try to provide an overview of possible impacts that may be caused by climate change and how hydropower owners and operators can protect their facilities in a preemptive strategy. The safety and integrity of all components as well as the safety of the operation and power generation despite climate change impacts will be investigated. This subtask is describing measures that can be taken or should be taken before any damage caused by climate change impact has occurred with the purpose of minimizing or avoiding such damage in the case of severe climate change impacts.

This report will not address the effect of climate change on power and energy generation in hydropower plants.

2.1.1 Objectives

The Subtask 1 Objectives are as follows:

Climate change can have various impacts on hydropower plants, both direct and indirect. Floods with growing intensity are one of the most evident and immediate impacts but many other types of impacts can be triggered by climate change. Hydropower owners and operators have to understand potential risks and must take suitable measures ensuring the safety of power generation facilities and the stable supply of electric power. Power facilities should be designed to withstand even extreme floods based on the proper design criteria.

Design bases are regularly reviewed and updated according to new hydrological analysis taking into account the effect of climate change. In order to evaluate the current design criteria, it is necessary to make an inventory of probable hazards due to climate change which may endanger flood safety of power facilities. Potential new hazards affecting flood safety may be linked to new potential landslides, glacier lake outbursts with mud flows in addition to significantly increased flood flows and it is necessary to forecast the potential natural hazards for the safety check of power facilities.

In this report we will attempt to summarize and list potential natural hazards triggered by climate change and provide an evaluation of design criteria and other mitigation measures for the safety check of hydropower facilities.

2.1.2 Scope

The scope of work includes the following:

- An overview of potential natural hazards caused by climate change will cover various aspects including the estimation of probable flood discharges triggered by climate change including potential risks such as a bores (impulse waves) caused by landslides or glacier lake outburst floods (GLOF).
- Technical measures and design criteria to increase the resilience of hydropower facilities against such impacts and natural hazards will be described and evaluated. In the review upgrade works and design criteria for important hydropower power structures and components such as dams and spillways could be covered.

2.1.3 Task Activities

Main activities of the task include the following:

- Collect and document technical information about potential impacts and natural hazards caused by climate change from literature published from universities and laboratories or river management authorities or power utilities and review them. The increase of probable flood discharges triggered by climate change will be evaluated and, where available, the increase of flood discharges in the context of climate change scenarios will be documented.
- We attempted to collect documentation on revised design criteria for hydropower facilities against climate change impacts, but only very little information could be identified. However, a literature survey and other sources revealed cases in which facility owners had assumed various risks based on past damage and had independently implemented risk mitigation measures and resilience strengthening measures. Please refer to section 3.5 "Analysis and Evaluation of the Individual Questionnaire Survey and the Literature Survey" of this report for details.

2.2 Literature Review

2.2.1 The “Climate Resilience Guide” of the International Hydropower Association

The International hydropower Association IHA has published in 2019 an excellent report for the hydropower sector titled “Climate Resilience Guide”. The development of this report was supported by international financing institutions that support large hydropower projects and with a strong involvement of IHA’s hydropower community and many other organizations and experts.

IHA and the IEA Hydropower TCP collaborate and support each other, trying to coordinate our efforts to avoid duplication. In this report we will therefore not attempt to duplicate the efforts that went into this excellent and comprehensive document but we recommend to download the report and use it as a reference.

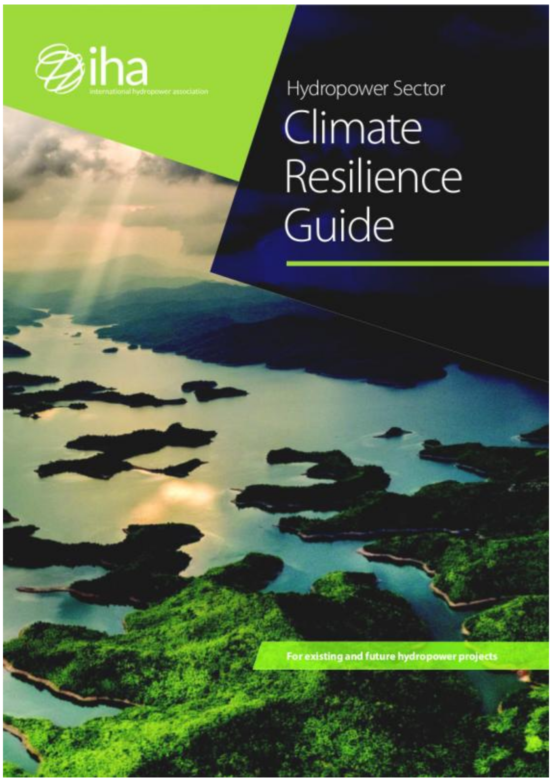


Figure 2-1 Cover Page of the Climate Resilience Guide, Download: https://www.hydropower.org/publications/hydropower-sector-climate-resilience-guide

Some of the information presented in this report here is taken from the IHA report and supplemented with additional information or aspects. First a short summary of the IHA report is provided here. The methodology presented in the IHA guide is applicable to any type of hydropower project, existing or new, any geographic region and to individual or cascade type projects. It describes a stepwise methodology.

The individual phases to be implemented are:

- phase 1: project climate risks screening
- phase 2: initial analysis
- phase 3: climate stress test
- phase 4: climate risk management
- phase 5: monitoring evaluation and reporting

Each of the phases are described in terms of the objective and the expected outcome. The methodology is then described for each of the phases.

Towards the end of the report a whole series of annexes is provided listing the most important relevant aspects to be considered. This information can be used as a checklist for a specific hydropower plant under investigation.

Annex A of the report is describing climate stressors on specific components of the HP scheme. These are:

- precipitation and streamflow

- temperature
- wind
- the specific components of hydropower schemes considered are:
- energy generation (is not further considered in this report)
- access roads and camps
- dams and appurtenance works (including intake, spillway, sediment handling structures)
- reservoir
- powerhouse, tailrace and switchyard
- waterways (e.g. delivery channels)
- electromechanical equipment
- transmission lines

For each of the combinations of stressors and hydropower component possible impacts are described, the indicators that can be used to assess the impacts and the respective timescales from extreme and sudden to gradual and long-term are described.

Annex C of the report is describing examples for structural and functional adaptation measures. The same systematic as in Annex A is used. For each of the combinations of climatic stressor and hydropower scheme component examples for the possible impact on the project component and potential measures to increase the resilience of the structural component are provided.

The guideline does possibly not cover all present and future aspects of climate change impacts, particularly indirect ones, but additional climate stressors can be easily added to the lists provided and included in the general methodology.

In Switzerland for example, there have been several studies over the past years looking at floating woody debris carried by large floods, intensified by climate change, that develop massive wood jams which reduce spillway efficiency and therefore can have serious impacts even on dam safety. This is an issue relevant for both run of river and storage hydropower plants with forested catchments.

2.2.2 The "How to Guide Hydropower Climate Change Resilience" of the Hydropower Sustainability Alliance (HSA)

The Hydropower Sustainability Alliance HSA has published in 2025 an excellent report for the hydropower sector titled "How to Guide Hydropower Climate Change Resilience" in collaboration with IHA member AFRY.

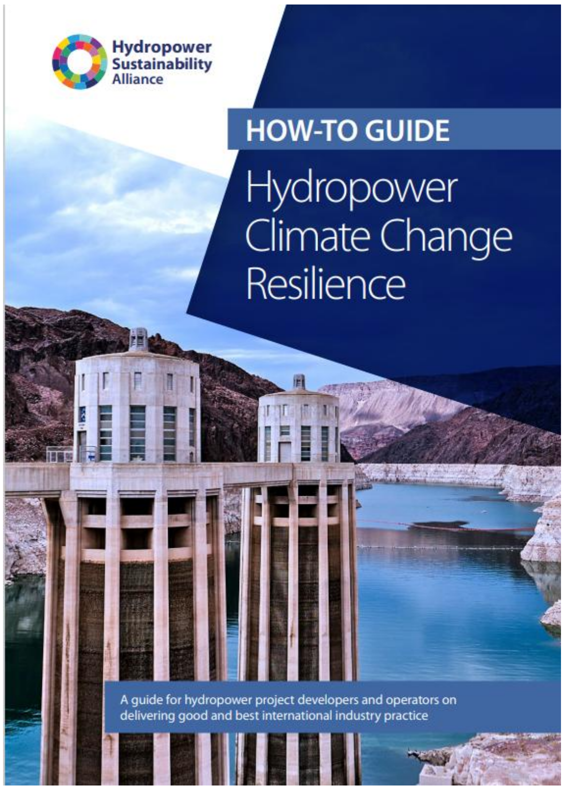


Figure 2-2 Cover page of the How to Guide Hydropower Climate Change Resilience, Download: https://www.hydropower.org/publications/how-to-guide-on-climate-resilience

This guide replaces the existing guide “Climate Resilience Guide” of IHA (2019).

This guide aims to provide guidance on how to meet industry good and best practices in climate change resilience, as defined in the performance requirements of the Hydropower Sustainability Standard (HSS-12).

The guide expands on the concepts described in the HS Standard providing a platform to:

- support developers, owners or operators to prepare for official HSS assessments;
- guide developers, owners or operators through internal or self-assessments;
- improve training materials provided by the HS Training Academy;
- strengthen institutional capacity of local regulators or regional bodies to adopt the HS Standard in national guidelines or internal policies.

The step-by-step guidance in Chapter 4 of this document can also be used to assess the climate change resilience of hydropower projects independently of HSS assessments.

Essential parts of the earlier guidance document have been integrated into this How-To guide, with updated references to relevant data sources and a general requirement for climate resilience assessment and climate risk management in all projects meeting the HSS.

A key component adopted from the earlier guide is a phased approach for climate resilience assessments, including a climate stress test with bottom-up and top-down elements. The approach aims at cost-efficient climate risk management and gradual building of resilience, achieved through implementation of non-structural and structural measures, including adaptive design solutions.

This guide also makes reference to other existing guidelines in the field of climate risk reporting and corporate sustainability reporting such as the TCFD (Task Force on Climate-related Financial Disclosures) recommendations and recent taxonomy regulations implemented in different economic regions.

This guide maps out the steps and processes that responsible parties should follow to meet good and best international industry practice in relation to the project life cycle, from early concept through to detailed design, construction and operation. Aspects of end-of-life decommissioning and circularity are also addressed.

The guide is presented in four chapters and eight annexes:

- Chapter 1: Introduction
- Chapter 2: Understanding climate change issues in hydropower
- Chapter 3: Achieving good/best international industry practice
- Chapter 4: Strategies and approaches
- Annex 1: Bibliography
- Annex 2: Specific Tables
- Annex 3: Guidance on required level of detail for climate resilience assessment
- Annex 4: Decision making under Uncertainty
- Annex 5: Example of stress test based on bottom-up approach
- Annex 6: Example of risk register and risk adaptation matrix
- Annex 7: Example of High-Level Integrated Geohazard Assessment
- Annex 8: National and Regional Policies on Climate Change - Examples

Furthermore, the How-to Guide reflects the general structure of the Hydropower Sustainability Standard with consideration of separate aspects (Assessment, Management, Conformance/Compliance) and three life-cycle stages (Preparation stage, Implementation stage, Operation stage).

2.3 Case Studies of Hydropower Plants with Implemented Preemptive Countermeasures Against Climate Change Impacts

Experienced hydropower experts from within the IEA Hydropower TCP as well as outside were asked personally if they had any knowledge or experience about hydropower plants that have taken preemptive countermeasures against climate change impacts. Among those experts were consultants, researchers, representatives of multilateral hydropower organizations and key experts of hydropower operating companies with the large number and variety of hydropower assets. The outcome was that there are basically no known cases where preemptive countermeasures specifically against climate change impacts have already been implemented. However, in some situations investigations into such measures are ongoing and it can be assumed that eventually measures will be implemented. A few such examples will be described in the following.

2.4 Measures Against Climate Change Impacts on Hydropower Components in General

No examples of specific preemptive measures implemented against climate change impacts at hydropower plants could be identified. Therefore we try to give an overview of examples for approaches that can be taken to investigate the need for adaptations to strengthen the climate change resilience of planned or existing hydropower projects. This is not a systematic analysis but a collection of examples identified during the work on this report.

2.4.1 Climate Change Impacts in the European Alps

In the European Alps there are three typical aspects of climate change impacts which are occurring and need investigation.

- Change of hydrological regimes with a tendency to more extreme floods and droughts
- extreme floods carrying large amounts of woody debris that can block spillways and reduce the conveyance capacity
- thawing of permafrost leading to destabilization of slopes and foundation rock. Landslides, rock falls, collapsing glaciers or avalanches impacting a reservoir or mountain lake can generate impulse waves that can potentially overtop the dam.
- glacier retreat with a tendency of increasing sediment supply

There are numerous studies to predict the impact of changes of the hydrological regimes on power generation, both in terms of quantity and seasonality. That aspect, however, is not part of the analysis presented here.

The other aspects which can cause threats to the integrity and the safety of certain components of a hydropower system have been studied since the early years of hydropower development in the European Alps and other regions. This was not done under the aspect of climate change impacts but under the aspects of mountain region hazards as traditional aspects of engineering considerations regarding safety and stability. Glacier melting in the European Alps has been going on since the 1850s but climate change has considerably accelerated the alterations and impacts. Therefore the climate change aspect has over the last two decades been attached to processes that have already been observed before the term climate change even existed. It is therefore not something completely new that floods and conveying capacities, slope stabilities or sediment flow into reservoirs are observed. Climate change is accelerating some or all of those aspects and has therefore given a new dimension to the problems. It is therefore not necessarily required to establish new investigation strategies or criteria but the standards applied must be adjusted and we cannot assume that the system we are working in is at a steady state (which was never the case in reality).

2.4.2 Switzerland and Austria

In Switzerland the regulator requires that dams must undergo a safety check every five years. Within this process it may be determined that, because of possible climate change impacts but also for other reasons, a reevaluation of the design flood is necessary and, depending on the outcome, it is necessary to increase the spilling capacity. In situations where this has been determined, such studies are already ongoing for several large dams.

Similarly, the retreat of permafrost as one of the typical climate change impacts in the European Alps, can cause slope destabilization which can lead to rockslides into the reservoirs, causing impulse waves, or slides that directly threaten critical hydropower infrastructure. Such studies are also ongoing for various sites.

Adaptation to strengthen the resilience against climate change impacts is therefore an ongoing and continuous process controlled by regulatory authorities in Switzerland.

The incident of Vajont (Italy) where more than 2000 people died in 1963 further increased the awareness about slope instabilities above the reservoirs. After the disaster at Vajont the impact of slope failures with large slides into the reservoir were further studied in more detail, including the modeling of dam overtopping at the Gepatsch Dam and reservoir (Austria) which was under construction back then. Since then such instabilities have been examined very carefully for reservoirs such as a new dam in Kühtai (Austria), an additional dam and reservoir for a pumped storage scheme in Austria. Dam overtopping as a consequence of a rock slide into the reservoir was studied in detail to prove the safety of the rockfill dam in such a situation.

In Switzerland there are a number of glaciers above reservoirs that are continuously monitored to detect if there is a risk of sudden collapse of parts of the glacier with the risk of large ice volumes rapidly sliding into the reservoirs below and causing impulse waves (bores). Examples are Mauvoisin (Axpo, Giétro-Glacier), Mattmark (Allalin-Glacier) and Lago Bianco (Repower, Cambrena-Glacier).

At the Massa River (Switzerland) the retreat of the Aletsch glacier is causing slope instabilities and slides could possibly dam the river bed, thus causing the development of a natural lake. Once filled such a natural dam could be overtopped which eventually can lead to a dam breach wave (similarly like in Darna, Lybia). The effect of such a wave has been studied for downstream Gebidem Dam and reservoir. In such a situation the reservoir water level would possibly have to be lowered to provide storage volume for the potential dam break wave.

The situation indicates that potential hazardous events are identified, studied and analyzed and possible emergency plans are developed or, where necessary and still possible (dams under construction), the design is adjusted. Examples for retrofitting existing Hydropower Plant structures specifically to increase the resilience against climate change impacts have not been identified.

The sedimentation rates of reservoirs have been gaining increasing attention over the last two decades. But of course reservoir sedimentation has always been occurring. Now that some reservoirs have reached an age of 50 or more years and the depositions are coming closer and closer to the dam it is also becoming increasingly relevant to observe, survey, quantify and manage reservoir sedimentation. This has obviously not been so relevant in the early years of the existence of a new reservoir. With increased retreat of the glaciers the input rates of suspended particles are increasing in most cases and that is at least partially attributed to climate change.

For the Chlus project (Repower in Switzerland) detailed studies were undertaken to assess sediment transport rates and volumes. This information was used to design intake desanders on small secondary intakes from tributaries.

2.4.3 Experience from High Mountain Areas

Hydropower plants in high mountain areas with partially glaciated catchments such as the Himalayas, Karakorum, Pamir, Andes etc. need special attention regarding hazards in general and climate change impacts in particular. Floods and flood events caused by landslides and different types of outburst-floods, particularly glacial lake outburst floods (GLOF), debris flows and mudslides can have very large scales and impact river beds far downstream of the site of the initial event. Traditionally hydro-meteorological and geological or geomechanical baseline data are investigated independently and the spatial extent of such studies is often limited. The risks of disaster triggers such as mudslides or GLOLF are increasing as a consequence of climate change. They can occur hundreds of kilometers upstream of the site under investigation and therefore for every hydropower project an integrated geohazard assessment (IGA) should be considered essential as part of the disaster risk management. Reynolds (2023) describes the necessity and the relevant components if such an IGA which can be applied to hydropower projects at any stage from earliest planning stages to the operational period. In less hazardous regions the approach can be adjusted to the specific situation. The outcome of such an analysis may lead to an improved design of a hydropower facility, the adaptation of an existing facility, better risk management plans or the better understanding of necessary insurance coverage. It is recommended to consider the recommendations made by Reynolds (2023).

2.4.4 Other Countries

47 cases of extreme flooding caused by meteorological changes and related events have been documented as part of this study (37 cases in Japan and 10 cases other countries). Please refer to section 3.5 " Analysis and Evaluation of the Individual Questionnaire Survey and the Literature Survey" of this report for details.

2.4.5 Other Effects from Climate Change

Climate change can have impacts that are not easily identified because they are indirect and somewhat hidden. A few examples are listed here:

Weather patterns with a strong impact such as triphones or hurricanes are changing their traditional or historic pathways because of changes in global circulation patterns. As a consequence, they can affect regions that have historically not been affected by such events and therefore natural and man-made systems are not prepared or designed to withstand such events. For example, trees and other vegetation in regions regularly affects by hurricanes can normally withstand such events, e.g. strong winds. If new regions are hit by such storms some of the vegetation is not able to withstand the event and gets uprooted. This is leading to enormous amounts of deadwood and floating debris that significantly exceeds the amounts occurring in areas that “are used” to such extreme events.

Dams and other infrastructure are often equipped with instrumentation that continuously monitors a large variety of parameters and thus monitors the behaviour of such structures. As one of the consequences of climate change temperatures of massive concrete structures or natural rock masses may rise slowly. A temperature increase of the concrete mass of as little as 1 degree will cause significant changes in stress, strain or deflections which are registered by the data collection system. In such a case it is not always clear what the cause of such a signal is, a consequence of the slowly progressing temperature increase or another cause which might indicate a problem with the structure.

2.5 Conclusions

This survey was collecting and evaluating technical documents and case studies on the climate change impact on hydropower plants and preemptive countermeasures. Specific examples where climate change impacts where specifically addressed in national or utility regulations or strategies have not been found. We hope that technical standards will be available to be considered in future tasks after more preemptive countermeasures are systematically implemented.

3 SUBTASK 2: COUNTERMEASURES TO MITIGATE DAMAGE TO HYDROPOWER PLANT FACILITIES CAUSED BY EXTREME FLOODS

Subtask 2 has a focus on hydropower plans where damage has occurred during events impacted or caused by climate change and what has been done following the event to repair the damage and mitigate the situation in the future.

3.1 Objectives of Subtask 2

Objectives of the Subtask 2 are as follows:

Amid concerns about an increase of flood damage risks caused by climate change, it is necessary for hydropower producers to take measures in order to ensure the safety of power generation facilities and the stable supply of electric power. In flood damage recovery work, it is required to formulate a recovery plan for power generation facilities and to repair the facilities at an early stage in consideration of the prevention works for similar disasters. In the recovery works against flood damage, the survey coordinates the recovery plan based on the damage factor analysis and the challenges in design and construction taking into account economy and construction technology.

Flood damage recovery is the post-maintenance work against facility damage caused by external factors such as torrential rainfall, but it is also required to take preventive maintenance to mitigate damage caused by climate change in the future. In renewing the power generation facility as preventive maintenance to reduce flood damage, structural examinations for functional enhancement and safety improvement in preparation for the expansion of future damage scale are coordinated. And the case histories on efficient and labor-saving efforts in operation and maintenance are reviewed as well.

Through collecting such case histories, we organize the countermeasures to enhance the resilience against flood damage caused by climate change.

Figure 3-1 Flood Damage Cases at Kyushu EPCO’s Kawabegawa No.1 Power Plant (Left: Damage to Intake, Right: Enlarged View of the Right Bank Slope)

3.2 Study Method

3.2.1 Scope of Works

The scope of work of case histories includes the following:

The facilities for renovation in flood disaster recovery works are for power facilities (dam, spillway, intake, waterway, head tank, penstock, powerhouse and outdoor switchyard) that belong to hydroelectric power producers and they are the targets for case histories covering their damages caused by floods and/or landslides.

In the renovation works at power facilities, not only the tangible measures (facility upgrade and/or remodel) to keep the soundness of facilities but also the intangible measures (remote and automatic control, upgrade of monitoring and patrol inspection) are targets of the survey.

Through these investigations, measures to maintain the functions of the facilities and enhance resilience against extreme floods caused by climate change will be organized.

3.2.2 Subtask 2 Activities

Main activities of the Subtask 2 include the following:

Collect and document flood damage recovery case histories of hydropower plants and review them. Analyse and evaluate the recovery works against the flood damage taking into account economy and construction technology based on the damage factor analysis from case histories of recovery works, and coordinate the challenges of investigation, planning, design and construction on flood damage recovery.

Collect and document renewal case histories of power facilities for flood damage mitigation and review the renewal details. Investigate how much of flood discharge did power producers estimate in the design of power facilities and how they are going to forecast the future scale of flood damage in facility renewal plan against climate change, and coordinate the issues in tangible measures (facility upgrade and/or remodel) for the soundness of facilities and intangible measures (upgrade of the facility operation and maintenance) from the renewal work case histories at power facilities.

Through collecting above case histories, we organize the countermeasures to enhance the resilience against flood damage caused by climate change.

The case histories were implemented through questionnaire surveys and literature surveys.

3.2.3 Method of the Questionnaire surveys and literature surveys

First through a general questionnaire survey, we grasp the current situation or tendency of disasters in Japan.

Through individual questionnaire surveys conducted with hydroelectric power producers and literature surveys focused on publications like the "Electric Power Civil Engineering" magazine in Japan, we collected case histories of disasters to existing hydroelectric power facilities caused by climate change and restoration works.

We analyse and evaluate restoration works from the view point of enhancing resilience to climate change.

We categorize restoration works aimed at enhancing resilience to climate change by case and type of structure.

3.3 Basic Policy of the Study

In a first step the definitions for the analysis and evaluation methods of external floods caused by climate change was established. While considering the theme of Subtask 2, the concept of what constitutes an extreme flood was developed.

3.3.1 Organizing the Fundamental Principles

The concept of what constitutes extreme floods, which are the main causes of disasters considered in Subtask 2, was established. In recent years, the earth has been experiencing global warming, identified as a major cause of abnormal weather patterns, leading to heavy rainfall and short-duration intense rainfalls, resulting in significant flooding and landslides. Actually, we recognize floods that cause such significant disasters as “extreme floods caused by climate change”.

These floods are events that could not have been anticipated based on conventional knowledge and experience. Conceptually organizing them, they would appear as shown in Figure 3-2.

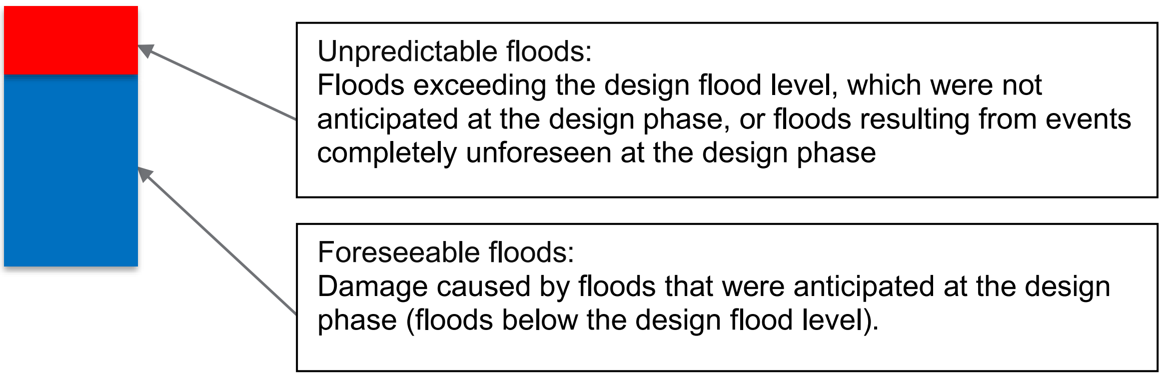


Figure 3-2 Concept of Extreme Flood

Therefore, in this report, we consider the red part in Figure 3-2 as extreme flood. Extreme floods caused by climate change are defined as follows:

- Floods exceeding the design flood discharge
- Floods resulting from events completely unpredictable at the design phase

3.3.2 Specific Disaster Cases Caused by Extreme Floods Due to Climate Change

The results of the literature survey are shown later, and Table 3-1 presents specific disaster cases caused by extreme floods due to climate change.

Table 3-1 Disasters Caused by Extreme Floods

Extreme floods caused by climate change	Concrete examples of disasters caused by extreme floods
Flood exceeding the design flood discharge	Flood exceeding the design flood discharge
● Floods from unexpected locations or Inflow of sediment	● Inflow of Sediment from upstream ● River blockage due to slope collapse in the river basin (increasing water level) ● Large-scale unexpected water inflow from unexpected locations around the power plant, inflow of sediment ● Others

3.3.3 Method of Analysis and Evaluation

3.3.3.1 Organizing Disasters

Based on the above considerations, we have decided to organize the evaluation and analysis using individual questionnaire survey and literature survey cases with the following method.

First, we organized whether the collected disasters were caused by climate change (extreme flood) or not. If the disaster was caused by climate change, it is a target in this study.

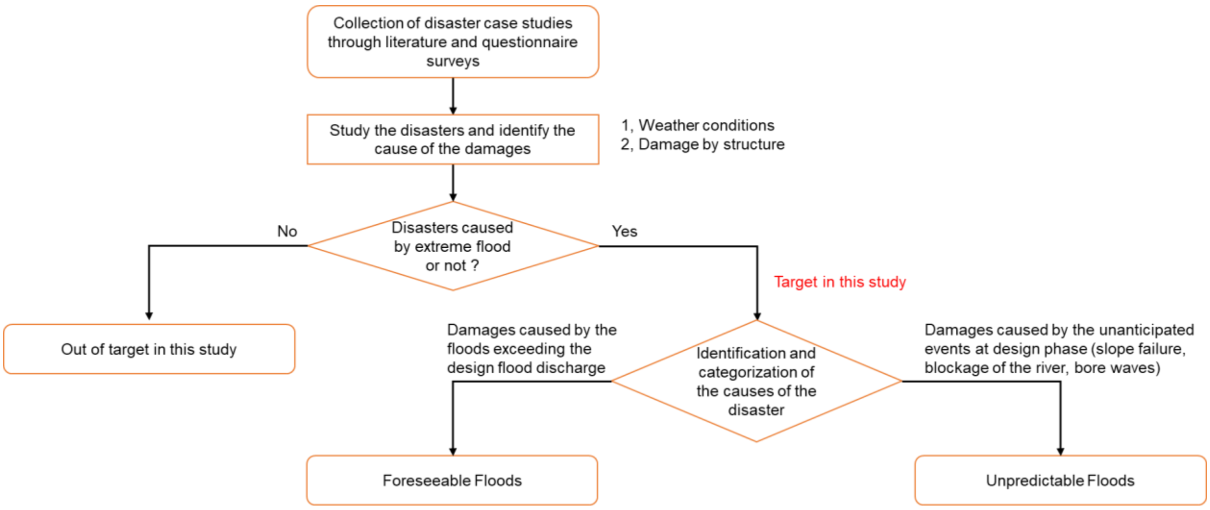


Figure 3-3 Organizing Disasters

3.3.3.2 Organizing Countermeasures

Next, we categorize the countermeasures against the damages organized in Figure 3-3 based on their aim to enhance resilience to climate change. The categorization is shown in Figure 3-4. If it includes measures to strengthen resilience to climate change, it can be considered a resilience enhancement measure to climate change.

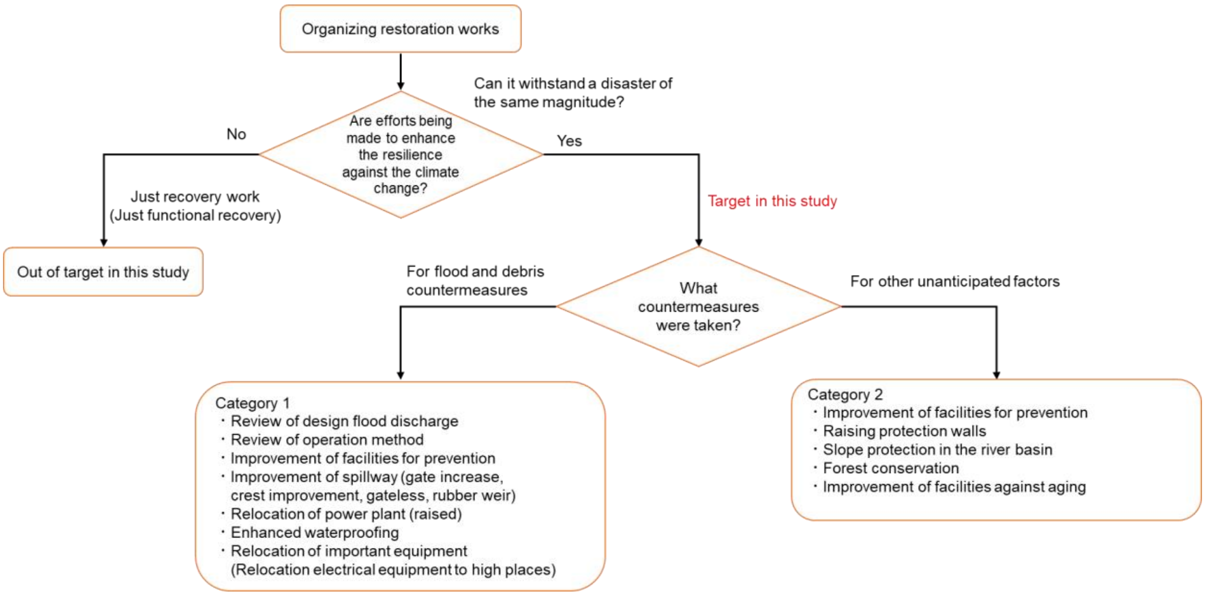


Figure 3-4 Organizing Countermeasures

3.4 Recent Disasters in Japan

3.4.1 The General Trend of Flood Disasters to Hydropower Facilities

To understand the general situation of hydroelectric power facilities and flood disasters in Japan, general questionnaire surveys were conducted targeting six electric power companies and publicly-owned electric power companies from October to December 2021.

3.4.2 Targets of General Questionnaire Survey

- Target period
  The past 20 years, from April 2000 to March 2019.
- The target of electric power companies
  Tohoku EPCO, TEPCO, Chubu EPCO, KEPCO, Kyushu EPCO, J-Power, Publicly-owned electric power companies.
- The target hydroelectric power facilities
  All 1,030 hydroelectric power facilities owned by the aforementioned electric power companies as of March 31, 2020.

The number of target hydroelectric power facilities is consistent with the “Potential Hydropower Table of the Agency for Natural Resources and Energy in Japan”.

The total number of power facilities is 1030 and the percentage of run-of-river type 65%, pondage type 29%. Reservoir type are 38 facilities and 40% are belonging to J-Power.

The differentiation between “pondage” and “storage” is that pondage refers to daily up to weekly storage whereas storage reservoirs are used for seasonal storage.

Table 3-2 The Number of Target Hydroelectric Power Facilities

Type	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Reservoir	1	3	6	3	5	15	5	38
Regulation pondage	37	62	37	68	29	25	40	298
Run-of-River	153	86	146	76	104	1	102	668
Pumped storage	2	8	6	4	3	2	1	26
Total	193	159	195	151	141	43	148	1030

3.4.3 The Result of General Questionnaire Survey

3.4.3.1 The Number of Power Plants Damaged by Flood

Only the disasters listed in the Electric Utility Safety Annual Report, based on Japan's electrical safety regulations, were counted as disasters.

The number of flood damage incidents from 2000 to 2019 (20 years) was 109 cases, with a concentration in 2011 with 46 cases and 23 cases in 2019. Excluding these, the annual average is 2.2 cases. In the period from 2000 to 2009, there were 23 cases, while from 2010 to 2019, there were 86 cases, indicating an increasing trend in flood damage in recent years.

Table 3-3 Number of Disasters by Flood Reported to Annual Report of Electrical Safety (Statistic Report of Electrical Safety by Public-Owned Electric Power Companies)

Year	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
2000	0	0	13	N/A	0	0	0	13
2001	0	1	0	N/A	1	0	0	2
2002	0	0	0	N/A	0	0	0	0
2003	0	0	0	N/A	0	0	0	0
2004	0	1	0	N/A	1	0	0	2
2005	0	0	0	N/A	0	0	0	0
2006	0	2	0	N/A	0	0	0	2
2007	1	1	0	N/A	1	0	0	3
2008	0	0	0	N/A	1	0	0	1
2009	0	0	0	N/A	0	0	0	0
2010	0	0	0	0	0	0	0	0
2011	30	2	3	8	1	1	1	46
2012	0	0	1	0	0	0	0	1
2013	1	4	0	1	0	0	0	6
2014	0	0	0	1	1	0	0	2
2015	1	1	0	0	0	0	0	2
2016	3	0	0	0	0	0	0	3
2017	1	0	0	0	0	0	0	1
2018	0	1	0	1	0	0	0	2
2019	4	18	0	0	0	0	1	23
Total	41	31	17	11	6	1	2	109

3.4.3.2 Damage Points and Types at Power Plants Affected by Flood Disasters

Damage points include dams/intake weirs, spillways/sediment flushing gates, water intakes, settling basins, waterways, surge tanks/head tanks, steel penstock, powerhouses, tailraces/outlets, other civil structures and outdoor switchyards. The power plant names have been anonymized for organization purposes.

The damage points are mainly dams/intake weirs, powerhouses and outlets.

Table 3-4 Damage Points at Facilities

Damage points	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Dam / Intake weir	22	8	9	0	0	0	0	39
Spillway /Sediment flushing gate	0	3	0	2	0	1	0	6
Water intake	28	10	3	0	2	0	0	43
Settling basin	2	1	2	0	0	0	0	5
Waterway	3	5	6	3	3	0	0	20
Surge tank / Head tank	1	2	1	0	1	0	0	5
Steel penstock	0	1	0	0	0	0	0	1
Powerhouse	6	7	8	5	0	0	2	28
Tailrace	1	1	2	1	0	0	0	5
Outlet	23	0	0	0	0	0	0	23
Outdoor switchyard	0	1	0	0	0	0	0	1
Total	86	39	31	11	6	0	2	176

Next, the disasters were categorized based on the damage points. There are many cases of "Partial damage due to flooding". This specification was used in cases where the cause was known but the specific components that were damaged were not clear.

Table 3-5 Damage at Dam or Intake weir

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Partial damage due to flooding	22	0	0	0	0	0	0	22
Partial damage to dam	0	0	3	0	0	0	0	3
Damage to dam	0	8	0	0	0	0	0	8
Wash away of upstream revetment	0	0	1	0	0	0	0	1
Sediment accumulation in reservoir	0	0	1	0	0	0	0	1
Damage to dam equipment	0	0	4	0	0	0	0	4
Total	22	8	9	0	0	0	0	39

Table 3-6 Damage at Spillway or Sediment Flushing Gate

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Damage to gate caused by driftwood	0	0	0	2	0	0	0	2
Damage to gate caused by overflow	0	0	0	0	0	1	0	1
Damage to apron and basement	0	3	0	0	0	0	0	3
Total	0	3	0	2	0	1	0	6

The table on Damage at Water Intake shows that many cases involve “Blockage caused by sediment inflow”.

Table 3-7 Damage at Water Intake

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Partial damage due to flooding	11	0	0	0	0	0	0	11
Damage caused by rainfall and flooding	0	0	0	0	2	0	0	2
Damage to retaining walls and gates	0	8	0	0	0	0	0	8
Blockage caused by sediment inflow	17	2	0	0	0	0	0	19
Sediment accumulation	0	0	1	0	0	0	0	1
Equipment damage	0	0	2	0	0	0	0	2
Total	28	10	3	0	2	0	0	43

Table 3-8 Damage at Settling Basin

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Partial damage due to flooding	2	0	0	0	0	0	0	2
Damage to retaining wall	0	1	0	0	0	0	0	1
Wall damage	0	0	1	0	0	0	0	1
Equipment damage	0	0	1	0	0	0	0	1
Total	2	1	2	0	0	0	0	5

Table 3-9 Damage at Waterway

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Partial damage due to ground collapse	2	0	0	0	0	0	0	2
Damage caused by inflow of sediment/ damage caused by falling rocks	0	0	0	0	2	0	0	2
Damage caused by driftwood and sediment	0	0	0	3	0	0	0	3
Damage due to flooding	0	0	0	0	1	0	0	1
Damage to retaining walls	0	5	0	0	0	0	0	5
Blockage caused by sediment inflow	1	0	0	0	0	0	0	1
Equipment damage	0	0	6	0	0	0	0	6
Total	3	5	6	3	3	0	0	20

Table 3-10 Damage at Surge Tank/ Head Tank

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Partial damage due to flooding	1	0	0	0	0	0	0	1
sediment inflow and damage caused by landslides	0	0	0	0	1	0	0	1
Equipment damage	0	0	1	0	0	0	0	1
Damage to spillway retaining walls	0	2	0	0	0	0	0	2
Total	1	2	1	0	1	0	0	5

Table 3-11 Damage at Steel Penstock

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Damage to steel penstock and anchor block	0	1	0	0	0	0	0	1
Total	0	1	0	0	0	0	0	1

The table on Damage at Powerhouse shows that many cases involve “Electrical equipment failure due to flooding”.

Table 3-12 Damage at Powerhouse

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Electrical equipment failure due to flooding	6	7	7	4	0	0	2	26
Power plant damage due to flooding caused by landslides	0	0	0	1	0	0	0	1
Sediment accumulation in draft tube	0	0	1	0	0	0	0	1
Total	6	7	8	5	0	0	2	28

Table 3-13 Damage at Tailrace

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Blockage caused by sediment inflow	1	0	0	0	0	0	0	1
Damage caused by driftwood and sediment	0	0	0	1	0	0	0	1
Damage to revetment	0	1	0	0	0	0	0	1
Damage to spillway energy dissipater	0	0	1	0	0	0	0	1
Sediment accumulation at spillway outlet	0	0	1	0	0	0	0	1
Total	1	1	2	1	0	0	0	5

Table 3-14 Damage at Outlet

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Blockage caused by sediment inflow	17	0	0	0	0	0	0	17
Damage to gate	6	0	0	0	0	0	0	6
Total	23	0	0	0	0	0	0	23

Table 3-15 Damage at Outdoor Switchyard

Damage category	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Damage caused by foundation washout	0	1	0	0	0	0	0	1
Total	0	1	0	0	0	0	0	1

3.4.4 The General Trend of Flood Disasters to Hydroelectric Power Facilities

The general trends regarding disasters related to hydroelectric power facilities were investigated by the general questionnaire survey.

In the period from 2000 to 2009, there were 23 cases, while from 2010 to 2019, there were 86 cases, indicating an increasing trend in flood damage after the year 2010. It is considered that the significant damage caused by heavy rain, storms, and typhoons, such as Typhoon No.15 in September 2019 and the heavy rain in Niigata and Fukushima in July 2011, has contributed to the increase in the number of disasters.

The locations of damage occurrence are most frequent at water intake (43 cases), followed by dams/intake weirs (39 cases), powerhouse (28 cases), and outlets (23 cases), with waterway (20 cases). From the above, damage from floods and sediment inflow tends to concentrate in the order from upstream to downstream.

Each facility is predominantly affected by the following types of damage:

- Water intake: Blockage due to sediment inflow, Partial damage due to flooding
- Dams and intake weirs: Partial damage due to flooding
- Powerhouse: Electrical equipment failure due to flooding
- Outlet: Blockage due to sediment inflow

From the above, damage from floods and sediment inflow tends to concentrate in the order from upstream to downstream.

To investigate the detailed situation of the above-mentioned damages, a literature study was conducted. The results are shown in the following sections.

3.5 Analysis and Evaluation of the Individual Questionnaire Survey and the Literature Survey

Based on the basic policy mentioned in Section 3.3, a literature survey, analysis and evaluation were conducted.

3.5.1 Organizing Disasters

We compiled information from a total of 47 cases, including 27 cases from Japan and 10 cases from other countries obtained through a literature survey, as well as 10 cases from Japan collected via individual questionnaire survey. The data was organized regarding meteorological conditions during the disaster, the situation of the disaster, the causes of the disaster and the damaged areas.

The causes are categorized for all 47 cases which are disasters due to climate change and those results are shown in Table 3-16.

Table 3-16 Causes of Disasters Attributed to Climate Change

1 Flood exceeding the design flood discharge	2 Floods from unexpected locations or Inflow of sediment	3 Complex Disasters (1 and 2)	Total
26	3	18	47

The overview of the meteorological conditions at the time of the disaster, the situation and causes of the disaster, as well as the affected areas in all 47 cases (excluding the 3 cases not attributed to climate change) are shown in Appendix A.

Out of all 47 cases examined in the Japan and other countries literature survey, as well as the individual survey in Japan, 8 cases were identified where elements of enhancing resilience to climate change could not be observed. Therefore, these cases were excluded from the target of this study.

Therefore, by analysing the remaining 39 cases, we can gain insights into resilience enhancement measures against climate change.

Appendix B shows an overview of the restoration works and the elements of resilience enhancement to climate change for all 39 cases.

Next, the major cases of disaster situations are organized according to the power generation types in Table 3-17 to Table 3-19 Reservoir Type Power Generation.

Table 3-17 Run-of-River Type Power Generation

Structure	Summary of damages	Name of power plant
Dam / Intake weir	Partial damage of weir, intake weir and dam	Nagamatsu, Shimodai, Saigawa, Kumakawa No.1, Shima
	Device failure by flooding	Shoumyougawa No.2
	Sedimentation	Shoumyougawa No.2
Water intake	Failure of Intake facilities	Kawabe No.1, Yunotani, Haneo, Tamano, Samigawa, Kakkonda No.2
	Sedimentation	Shoumyougawa No.2
	Scouring of spillway facilities	Sendatsu
Headrace	Blockage and failure by sediment flow	Shimodai, Otagawa, Kumakawa No.1
Penstock	Landslide near Penstock	Sendatsu
	Subsidence of supporting pier of penstock	Nagamatsu
Powerhouse	Flooding of power plant	Sendatsu, Yunotani, Hayatogawa, Doushi No.4
	Sediment inflow to turbine	Otagawa
	Destroyed by landslide	Nagatono
	Failure of protection wall of power plant	Haneo
Tailrace	Partially damage of protection wall	Nagamatsu

Table 3-18 Pondage Type Power Generation

Structure	Summary of damages	Name of power plant
Dam / Intake weir	Failure of spillway gate	Taki
	Flooding of dam control facilities	Shin-Sugawara
Water intake	Blockage by sediment flow	Taki, Miyashita
	Failure of Intake facilities	Yuyama
	Scouring of foundation of intake weir and protection wall on the left bank	Sukawa
Powerhouse	Flooding of power plant	Shin-Inotani, Yamasubaru, Otsu, Taki, Shin-Kurobegawa No.2
	Failure of protection wall	Otsu
Tailrace	Flooding of debris flow and sedimentation	Otsu, Taki
	Flooding of control equipment of tailrace gate	Shin-Inotani

Table 3-19 Reservoir Type Power Generation

Structure	Summary of damages	Name of power plant
Powerhouse	Flooding of Power plant	Kamishiiba, Tsukabaru
	Flooding of Switch yard	Kamishiiba

3.5.2 Elements of Enhancing Resilience against Climate Change

In this section, following the methods outlined in Section 3.3, we organized an overview of the restoration works for each case. Furthermore, to identify resilience enhancement measures for climate change, we screened approaches based on the following three criteria, as described below. Through this screening process, we identified countermeasures to enhance resilience to climate change.

- Is the owner conducting renovation works taking future flood risks into consideration?
- Is the owner conducting renovation and modification works considering future risks for power generation facilities?
- Is the owner reassessing operation and maintenance management with consideration of future risks?

The results of this screening are shown in Table 3-20.

Table 3-20 Number of the Cases of Enhancing Resilience to Climate Change

Country	Designing against future flood risks	Renovation work considering future risks	Reassessing operation and maintenance considering future risks	No elements of enhancing resilience to climate change
Japan	21	29	5	4
Other countries	4	3	1	4
Total	25	32	6	8

Note: "The elements of resilience allows for multiple answers.

3.5.3 Resilience Enhancement Measures

Focusing on the 39 cases screened in the previous subsection, resilience enhancement measures for climate change were organized by their causes of disasters (floods exceeding the design flood discharge, unexpected flooding by unanticipated events). The results are shown in Appendix C.

And the results of reorganizing the resilience enhancement measures for climate change by structures are shown in Table 3-21.

Table 3-21 Resilience Enhancement Measures for Climate Change by Structures

Structure	Flood exceeding the design flood discharge	Flood caused by unpredictable events
General	• Revising design flood discharge (Alignment with river improvement Plans managed by the administrative authorities) • Setting the design gradient of riverbed (Based on these data elevations of structures is calculated) • Introduction of more accurate inflow forecasting system	• Ensuring the alignment with river improvement plans managed by the administrative authorities
Pondage, Reservoir	N/A	• Implementation of continuous sediment management, including dredging, in accordance with river improvement plans managed by the administrative authorities • Construction of protection wall in the reservoir aligned with river improvement plans managed by the administrative authorities
Intake facilities	• Widening of the water intake weir (Enhancement of flow capacity) • Abolition of bridge piers (Expansion of flowing area) • Abolition of intake gate and weirs ⇒ Change to Steel Flap Gate with Rubber Bladders (Enhancement of flow capacity, preventing driftwood, Simplifying operations) • Reinforcing the spillway crest of intake dam with steel plates (Prevention of erosion) • Reinforcement and wear prevention of spillway invert (Prevention of erosion) • Raising the crest elevation of the protection wall of intake weir • Relocating control panels to a higher elevation (for gate control, water measurement) • Reinforcement of Riverbed protection (structures) of intake facilities (Adopting large concrete blocks)	• Relocation of control board for desander to high places • Replacement of the Tyrolean-style water intake (Preventing water intake failure due to frontal sedimentation) • Relocation of control board to high places • Review of operation and maintenance • Simplification of water intake control functions
Spillway	• Lowering the spillway crest (Enhancement of Flow Capacity) • Abolition of spillway gates, raising the spillway crest and expansion of spillway crest length (Enhancement of Flow Capacity, Preventing driftwood) • Abolishing piers (Enhancement of Flow Capacity) • Improvement of spillway gates • Removing central two spillway gates, lowering the spillway crest and installing one crest roller gate • Relocating the gate hoist room to a higher elevation (Prevention of submersion for control panel equipment) • Relocating control panels of gates to a higher elevation	• Improvement of spillway gates • Simplification of water intake control functions • Removing central spillway gates, lowering the spillway crest and installing crest roller gate
Waterways	• Reinforcement of spillway (change to the concrete gravity wall) • Relocation of the penstock	• Strengthening the drainage capacity around the penstock • Strengthening the drainage system around the waterway • Installing covers to prevent sediment entry into the head tank and spillway • Installation of concrete retaining walls to prevent landslide
Powerhouse	• Relocation of powerhouse to the higher elevation • Improvement of the power plant access road • Installing check valves on the basement floor third of the power plant building (Flood prevention) • Enhancement of drainage pit capability • Relocation of power-related equipment to upper floors (Flood prevention) • Installation of flood protection walls (Flood prevention) • Waterproofing reinforcement (Injection of urethane resin material, Installation of waterproof doors) • Closure of cable duct • Raising the elevation of the substation • Installation of flood protection walls around the switchyard	• Raising the height of the power plant's waterproof wall • Installation of anchoring concrete blocks upstream of the power plant • Reinforcement of the power plant's walls (Installation of reinforcement anchors) • Reinforcement of the slope behind the power plant access road (ground anchor work) • Waterproofing reinforcement (filled the wall gaps around the drainage pump outlet) • Sealing the ventilation fan opening (waterproofing) • Change in ventilation route (waterproofing) • Enhancement of drainage pit capability
Tailrace	• Installation of tailrace gates (Flood prevention for the powerhouse)	• Raising the height of the protection wall of tailrace
Tailrace channel	• Revision of the tailrace water level • Raising elevation of tailrace facilities • Raising the tailrace protection wall • Raising the elevation of the floor of controlling panel for tailrace gates (Flood protection for the control panel) • Direct connection of tailrace outlet and intake of downstream power plant (Measures to mitigate flood damage at cascaded hydroelectric plants) • Relocation of tailrace channel • Reinforcement of tailrace channel (Laying reinforced concrete on top of compacted concrete) • Reinforcement of the diversion wall (Enhancing the attenuation effect to reduce downstream flood damage)	• Change the tailrace open channel to culvert (prevention of sediment inflow) • Relocation of tailrace outlet to a downstream regulating pond unaffected by sediment discharge and construction of tailrace tunnel

3.5.4 Challenges in Implementing Resilience Enhancement Measures

In this subsection, the challenges of implementing resilience enhancement measures, based on literature and individual questionnaire surveys, were organized into planning and implementation stages.

(1) Challenges in the planning stage

When planning resilience enhancement measures, if it is necessary to review the design flood discharge or design flood level, it is essential to ensure consistency with higher-level plans, such as river improvement plans managed by the administrative authorities. Additionally, in order to safely discharge the revised design flood, it is necessary to formulate appropriate renovation plans for hydroelectric power facilities (including spillways, intake facilities, waterway, penstocks, powerhouse, and tailrace).

Some hydroelectric power facilities are located within national parks or tourist areas. In such cases, it is necessary to obtain prior consensus from local stakeholders regarding the timing and methods of construction, as well as considerations for landscape and environmental impact.

In many cases in the literature survey and individual questionnaire survey, it was observed that many electric power companies have expended considerable effort to overcome the aforementioned challenges.

(2) Challenges in the implementation stage

Many hydroelectric facilities are located in the mountains, making access and equipment transportation difficult due to underdeveloped infrastructure. Furthermore, since these are recovery projects following a disaster, access roads may have been washed away or interrupted by landslides. In some cases, access was difficult until slope stabilization measures were implemented.

Furthermore, during construction, it was challenging to secure sufficient construction sites, leading to cases where big machinery or heavy equipment could not be used. Additionally, there were cases where long pipes were required for concrete pouring.

On the other hand, ideally, the design flood discharge should be reviewed, and based on the results, the power facility itself should be improved. However, in reality, there are various constraints, and many cases have been observed where it is difficult to demolish or improve existing structures. In such cases, if an extreme flood exceeding the design flood discharge occurs again, flooding is inevitable.

To prevent reoccurrence of disasters of the same scale, disaster mitigation measures were implemented. These measures included raising surrounding water protection walls, improving the water tightness of the structures themselves, and enhancing the waterproofing performance of electrical systems such as control panels. Furthermore, in many cases, construction aimed at improving the river environment (e.g., installation of fish ways) was also carried out simultaneously with renovation work.

The challenges in implementing resilience enhancement measures are summarized in Table 3-22. The case-specific challenges in implementing resilience enhancement measures for climate change are shown in Appendix D.

Table 3-22 Challenges in Implementing Resilience Enhancement Measures

Phase	Challenges
Planning Phase	
(1) Coordination with the administrative authorities.	Consistency with river improvement plan • Compliance with applicable laws (River Law, Environmental Impact Assessment Law, others)
(2) Consensus with the Local Community	Securing consensus from local stakeholders and property owners
Construction Phase	
(1) Challenges Arising from Location Conditions (Inside national park, tourist spot, etc.)	Measures are needed for various environments • Consideration for wildlife, plants, and fishes, etc. • Prevention of turbid water generation • Prevention of noise and air pollution • Prevention of traffic troubles (safety, traffic jam, accidents)
	Construction period • Landscape consideration. (Not available during the tourism season)
	Construction methods, etc. • Restrictions on the use of large machinery, heavy equipment, etc.
(2) Constraints due to Weather	Construction period • Avoid flood season (choose dry season) • Avoid snow season
(3) Constraints due to topography and infrastructure development	Lack of infrastructure and difficulty in access
	No construction site, limited space, • Regulation of construction methods, Restrictions on the use of big machinery, heavy equipment, etc.
(4) Constraints due to disaster situation	Loss of access road
	Risk of landslide • Recovery works after implementing slope stabilization measures
(5) Difficulty in structural Improvement	Difficult to make changes to the structures • Disaster reduction measures, such as improving water resistance and enhancing flood barriers, to minimize the impact as much as possible.
(6) Others	Utilization of waste materials • Utilization of crushed stone and surplus soil generated during construction

3.6 Lessons Learned from Individual Questionnaire Surveys and Literature Surveys

The measures to enhance the resilience to climate change are shown in Table 3-21. While various measures have been studied, in short, it becomes the issue how to deal with the flood volume or flood level caused by extreme floods due to climate change, or how to safely discharge such extreme floods.

Two approaches can be considered to deal with this issue.

(1) When it is possible to respond to new extreme floods by improving structures
In this case, appropriate measures to extreme floods can be made by improving structures.

(2) When it is impossible to improve structures due to various constraints
In many power facilities, it is difficult to improve structures due to topographical constraints, difficulty in demolishing structures, cost constraints, and other factors. In such cases, it is difficult to safely discharge extreme floods.
If faced with another flood of the same magnitude, damage from flooding will occur again. However, it is extremely important to implement disaster mitigation measures to minimize the impact of such flooding as much as possible.

The study in Subtask 2 has shown that preventing damage (loss of control) caused by the flooding of electrical equipment is effective as a disaster mitigation measure. From these, we have learned the following points to consider:

- To relocate control panels of gates and other electrical equipment within the power plant to higher elevations to avoid submersion during floods.
- To prevent water from entering power plant facilities as much as possible (improve water tightness).
- To enhance the drainage capacity around power generation equipment.

3.7 Introduction of Other New Technologies and Initiatives Contributing to Enhancing Resilience to Climate Change

In response to risks to hydroelectric power generation facilities caused by climate change, measures to strengthen resilience were identified and organized through literature surveys. In this section, we introduce research cases that are not covered in the literature survey, but are thought to contribute to strengthening resilience through various research presentations.

- A study on operation determination method for flood dam operation using ensemble predicted rainfall [5].

  During flood times, the predicted rainfall used for dam operation has traditionally been a forecast based on a single initial and boundary condition. The accuracy of rainfall predictions has improved with advancements in forecasting technology.

  However, it is considered difficult to completely eliminate prediction errors, and uncertainty is unavoidable. Therefore, in the use of predicted rainfall for dam operations during floods, it is necessary to make decisions not based on conventional predicted rainfall but by taking into account the uncertainty of the predicted rainfall.

  This paper presents the method taking into account the uncertainty information obtained from ensemble forecasts, which have become increasingly available in recent years to determine operations during flood times, specifically pre-release operations from the water level requiring predicted rainfall for implementation judgment, pre-release operations from the flood storage reserve water level, and special disaster prevention operations. As a result of conducting dam operation simulations for past floods using this method, the applicability of the method was generally confirmed.

- Adaptation of ensemble rainfall prediction information to advanced operation of power generation dam reservoirs [6]

  As a method to increase power generation at existing hydropower plants, an evaluation was conducted on the use of long-term ensemble rainfall forecasts for the coordinated operation of dam reservoirs across the entire water system, not only during flood times but also during normal times. As a result of conducting a simulation of the operation of the reservoirs in the Oigawa river system, it was confirmed that the amount of hydroelectric power generation may increase compared to the operation based on the conventional forecast.

- Efforts to improve the accuracy of dam inflow prediction and to enhance power generation operation optimization technology [7]

  In order to increase the power generation by effective use of existing hydropower plants, we worked on advancing inflow prediction technology for dams and optimizing power generation operations by combining the following technologies.

Weather observation, Forecasting technology, Snow accumulation and snowmelt models, Runoff prediction models, IoT technology, and Optimization calculation methods.

- A case study on the advancement of downstream river bed monitoring survey [8]

  The riverbed downstream of the dam which is made of gravel varies greatly by the following factors. Discharge rate, water level downstream of the dam, order of gate operation, occurrence of swirling flow and, finally, the status of sediment supply from upstream.
  Highly accurate monitoring of the downstream riverbed level after high discharge is the most important data for grasping the scouring situation. The monitoring was conducted using a combination of methods, including multibeam surveying, single beam surveying, Global Navigation Satellite System (GNSS) surveying, Total Station (TS) surveying, and aerial photogrammetry with Unmanned Aerial Vehicles (UAV), observing the river conditions. The monitoring is carried out in the presence of fluctuations of the downstream water level.

- Efforts to improve internal inspections of waterway tunnel using cameras and AI technology [9]

  Inspections of the water way tunnels of hydropower plants are carried out by regularly draining the water inside the tunnel and conducting visual inspections. In recent years, Hokuriku EPCO, Ltd. has been aiming to improve the sophistication and efficiency of maintenance and management operations such as patrols and inspections by utilizing the latest ICT and IoT technologies as an initiative for smart safety.

- Disaster prevention and mitigation initiatives considered by River Administrator (10 Major measures) [10]

  - Implementation under consideration of the entire river basin by all parties involved (conversion to "river basin flood control")
  - Review of flood control plans reflecting the impact of climate change
  - Promotion of housing and land use for disaster prevention and mitigation
  - Control of the flow of people and logistics in the event of a disaster
  - Proactive measures to ensure the functioning of transportation and logistics
  - Preparing in advance for safe and secure evacuation
  - Measures to address aging infrastructure and strengthen regional disaster prevention capabilities
  - Advancement and acceleration of disaster prevention and mitigation through the use of new technologies
  - Promotion of easy-to-understand information dissemination
  - Establishing a disaster prevention and mitigation perspective among the activities and initiatives of governments, businesses and citizens

4 SUBTASK 3: RESERVOIR SEDIMENT MANAGEMENT

Climate change is generally increasing the amount of sediments being transported into reservoirs. Subtask 3 has a focus on reservoir sediment removal methods, taking into account environmental impact, cost effectiveness and technology, covering the range of upstream and downstream area.

4.1 Objectives of Subtask 3

The Subtask 3 objectives are as follows:

Reservoir sediment management has been important from the perspective of securing effective reservoir capacity for power generation and efficient reservoir operation. So, it is required to remove sediment from the reservoir in addition to the decrease of sediment inflow from upstream.

Amid the forecast of the increase of flood discharge, it is required to have further optimization of reservoir sediment management on removing sediment concerning the increase of sediment inflow to reservoirs.

Regarding the way of sand removal, in addition to the conventional ways such as reservoir dredging, in-lake transport, flushing through flushing gate embedded in the dam body, sediment bypass tunnel systems are starting to be newly applied. But there are some problems in the flushing efficiency and downstream environmental impact to be considered. To solve those problems, integrated sand removal by dams located on the cascade in the same basin is proposed as the effective way and a survey presents case studies of challenges and solutions, showing how each dam takes initiative in complex operations based on integrated management and monitoring.

Figure 4-1 Dredging at Sakuma Dam, J-Power

4.2 Study Method

4.2.1 Scope of Works

The scope of work of the literature survey includes the following perspectives:

A survey on reservoir sediment management covering the range from upstream area of sediment supply source to downstream area where the environmental impact must be checked.

Several reservoir sediment removal options (reservoir dredging, in-lake transport, flushing gate, bypass tunnel and others) are analysed and evaluated taking into account environmental impacts, cost effectiveness and technology.

After analyzing the different methods of reservoir management, the challenges of implementation and considerations of environmental conservation were considered.

At the end of this report, good practices in sediment management are presented.

4.2.2 Task Activities

Main activities of the task include the following:

- Examples of reservoir sediment management have been collected and described.
- Analyse and evaluate reservoir sediment management from the aspects of upstream sediment supply affected by climate change, measures to decrease sediment inflow and reservoir sediment flushing measures in consideration of necessity, technology and downstream environmental impact.

Through these considerations the way of sediment management is systematized and good practices are shown. The survey was implemented through questionnaire surveys and literature surveys.

4.2.3 Method of questionnaire surveys and literature surveys

First through a general questionnaire survey, we grasped the general methods or tendencies of sediment management in Japan.

In order to study methods of sediment management of the hydro power facilities in detail, we collected case studies through individual questionnaire surveys to power companies and conducted a literature survey focusing on publications like the "Electric Power Civil Engineering" magazine in Japan. Examples from abroad were also collected by the same magazine.

The necessity and methods of sediment management of the hydro power facilities were analysed. Finally, we organized the evaluation of the sediment management options implemented by the hydropower producers and show good practices.

4.3 Recent Sediment Management in Japan

4.3.1 Targets of the general questionnaire survey

- Target period
  The past 20 years, from April 2000 to March 2019.

- Targeted electric power companies
  Tohoku EPCO, TEPCO, Chubu EPCO, KEPCO, Kyushu EPCO, J-Power, Publicly-owned electric power companies
- Targeted hydroelectric power facilities
  All 1,030 hydroelectric power facilities owned by the aforementioned electric power companies as of March 31, 2020.

The number of target hydroelectric power facilities is consistent with the “Potential Hydropower Table of the Agency for Natural Resources and Energy in Japan”.

The total number of power facilities is 1030 and with 65% run-of-river type, and 29 % pondage type. 38 facilities are reservoir type and 40% of those are belonging to J-Power.

Table 4-1 Number of Target Hydroelectric Power Facilities

Generation Type	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Reservoir	1	3	6	3	5	15	5	38
Pondage	37	62	37	68	29	25	40	298
Run-of-River	153	86	146	76	104	1	102	668
Pumped storage	2	8	6	4	3	2	1	26
Total	193	159	195	151	141	43	148	1030

4.3.2 Results of the general questionnaire survey

4.3.2.1 Power facilities where sediment management was implemented

Sediment management was implemented in 223 out of 1030 power facilities (21.6%). When classified by power generation type, the number and proportion of each generation type is as follows: reservoir type 8 cases (21.0%), pondage type 87 cases (29.1%), run-of-river type 125 cases (18.7%), and pumped storage type 3 cases (11.5%). The pondage type accounts for the largest proportion at 29.1%.

Table 4-2 Number of Power Facilities Where Sediment Management was Implemented

Type	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Reservoir	1	0	2	1	0	2	2	8
Pondage	17	16	18	10	3	7	16	87
Run-of-River	0	4	109	0	0	0	12	125
Pumped storage	1	1	0	1	0	0	0	3
Total	19	21	129	12	3	9	30	223

4.3.2.2 Method of sediment management

We organized the sediment management methods by power generation type. Sediment management through dredging is widely conducted as shown in Table 4-3. The dredged sediment is transported either within the lake or outside the lake.

The results from Table 4-3 to Table 4-6, power generation type and sediment management methods are summarized in Table 4-7.

Table 4-3 Sediment Management Method of Reservoir Type

Sediment removal measures	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Flushing through sediment flushing gate	0	0	0	1	0	0	0	1
Dredging + transport within the site	0	0	0	0	0	0	2	2
Dredging + transport within the lake	1	0	0	0	0	0	0	1
Dredging + density current discharge	0	0	2	0	0	0	0	2
Excavation/dredging transportation outside the lake + transport within the lake	0	0	0	0	0	1	0	1
Excavation/dredging transportation outside the lake + transport within the lake	0	0	0	0	0	1	0	1
Total	1	0	2	1	0	2	2	8

Table 4-4 Sediment Management Method of Pondage Type

Sediment removal measures	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Flushing with sediment flushing gate	1	1	18	1	0	0	1	22
Dredging	15	7	0	0	0	0	0	22
Dredging + flushing with spillway gate	0	0	0	0	0	0	3	3
Dredging + transport within the lake	0	0	0	9	0	0	0	9
Dredging + transport within the lake + flushing with sediment flushing gate	1	0	0	0	0	0	0	1
Dredging, dredging + transport within the site	0	0	0	0	0	0	12	12
Excavation	0	6	0	0	0	0	0	6
Excavation + flushing	0	1	0	0	0	0	0	1
Excavation + dredging + sand pump	0	1	0	0	0	0	0	1
Transportation outside the lake	0	0	0	0	0	6	0	6
Water level reduction + transport outside the lake	0	0	0	0	0	1	0	1
Sediment passage through gate	0	0	0	0	2	0	0	2
Sediment discharge when water level reduction during flood	0	0	0	0	1	0	0	1
Total	17	16	18	10	3	7	16	87

Table 4-5 Sediment Management Method of Run-of-River Type

Sediment removal measures	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Excavation	0	4	0	0	0	0	0	4
Dredging + flushing with sediment flushing gate	0	0	0	0	0	0	5	5
Dredging, dredging + transport within the site	0	0	0	0	0	0	7	7
Flushing with sediment flushing gate	0	0	109	0	0	0	0	109
Total	0	4	109	0	0	0	12	125

Flushing through sediment gate is widely implemented in run-of-river type.

Table 4-6 Sediment Management Method of Pumped Storage Type

Sediment removal measures	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO	Kyushu EPCO	J-Power	Publicly owned	Total
Bypass	0	0	0	1	0	0	0	1
Dredging	1	0	0	0	0	0	0	1
Excavation + transport within the lake	0	1	0	0	0	0	0	1
Total	1	1	0	1	0	0	0	3

Note: Flushing and sluicing were treated as a single method. Dredging, excavation, removal outside the reservoir, and in-lake transport were also treated as a single method.

Table 4-7 Power Generation Type and Sediment Management Methods

Type	Flushing	Dredging (Evacuation)	Bypass	Total
Reservoir	1	7	0	8
Pondage	30	61	0	91
Run-of-River	114	16	0	130
Pumped Storage	0	2	1	3
Total	145	86	1	232

Note: Multiple sediment management methods were allowed for power facilities.

4.3.3 General Trend in Sediment Management

Based on the results of the general questionnaire survey, the following can be assumed.

- Regarding run-of-river type generation, 543 power facilities out of 668 power facilities (81.3%) didn't carry out any sediment management at all. In other words, four hydro-electric power companies (Tohoku EPCO. KEPCO, Kyushu EPCO, J-power) out of seven companies did not implement any sediment management at all. As for the remaining four companies, TEPCO and two Publicity-owned power companies carried out sediment management by excavation, dredging and flushing at 16 power facilities (8.5%) out of 188 power facilities. And Chubu EPCO carried out sediment management by flushing at 109 power facilities (74.7%) out of 146 power facilities.
- In the case of pondage type generation, dredging and excavation are commonly carried out, followed by flushing through sediment flushing gates.
- In the case of reservoir type generation, dredging and excavation are also commonly performed, followed by flushing through sediment flushing gates.

In general, for hydro-electric power facilities equipped with sediment flushing gates, it is commonly observed that flushing through sediment flushing gates is conducted first, and if sediment cannot be removed through sediment flushing gates, next excavation or dredging would be carried out.

Taking into account the general trends acquired from the general questionnaire survey, we tried to get more detailed information on the necessity of sediment management, specific implementation methods, and challenges in implementation through the analysis of individual questionnaire surveys and literature surveys.

4.4 Analysis and Evaluation of the Individual Questionnaire Surveys and Literature Surveys

We conducted individual questionnaire surveys on sediment management objectives, methods, effectiveness etc. and sent individual questionnaires to six electric power companies and two publicly-owned electric power companies targeting the same power companies as the ones mentioned in section 4.3 and obtained 8 responses. We received 15 responses, but 7 of them were duplicated with the literature survey mentioned below, so we counted them as 8 responses.

In addition, we conducted a literature survey covering 20 cases from Japan and 10 from other countries.

Furthermore, adding 2 additional responses from questionnaires conducted in other countries, we consequently analysed 40 cases in total, comprising 28 from Japan and 12 from other countries.

4.4.1 Necessity of Sediment Management

We analysed the reasoning behind sediment management based on individual questionnaire and literature survey.

Regarding the reasons for sediment management, we organized this aspect according to the items from "Compliance with Regulations" to "Others" as shown in Table 4-8. We organized it in a way that allows for duplication.

Table 4-8 Main Reason for Sediment Management

Country	Ensuring Effective Generation Capacity	Environmental Conservation	Disaster Prevention	Compliance with Regulations	Others	Total
Japan	18	17	12	0	8	55
Other countries	12	8	1	2	4	27
Total	30	25	13	2	12	82

There were no significant differences in trends between cases in Japan and other countries, except for "Disaster Prevention".

We obtained the following results that "Ensuring Effective Generation Capacity" (Maintenance of power generation capacity) was given as reason in 30 cases (18 cases in Japan), followed by "Environmental Conservation" in 25 cases (12 cases in Japan).

Regarding the result that "Ensuring Effective Generation Capacity" was found to be the highest predominant reason. Since hydro-electric power companies were targeted in this survey this does not come as a surprise.

As for environmental conservation, the most common consideration is given to the conservation of the downstream area of reservoirs (conservation of ecosystems), indicating that hydroelectric power companies are paying the most attention to the environment in the downstream areas of reservoirs. Furthermore, it was mentioned that in dams located on rivers that transport large amounts of sediment, it is necessary for sediment management to maintain continuous sediment transportation.

Following these priority aspects "Disaster Prevention" was often mentioned in Japan with the purpose of preventing upstream flooding due to backwater effects caused by sedimentation (riverbed rising). Furthermore, in dams with flood control functions, the necessity of maintaining flood control capacity by avoiding a reduction of the active storage volume was also mentioned. On the other hand, concerning power facilities in other countries, disaster prevention was not mentioned because their function is only for power generation. In the case of the Three Gorges Dam in China, the consideration for flood prevention in the reservoir area and disaster reduction in the downstream area of the dam were mentioned.

Regarding "Others", it was mentioned that in multipurpose dams for purposes other than power generation, such as water supply and flood control, the maintenance of capacity for water supply purposes was emphasized. Additionally, the effective utilization of sediment, such as its use as aggregate or fill material, was also mentioned. Regarding the Three Gorges Dam in China, ensuring smooth navigation in the reservoir was mentioned.

From these points, it can generally be said that the need for sediment management is of high concern for two reasons: (1) to maintain the capacity intended by the facility, and (2) environmental conservation.

Examples of the main concerns about ensuring effective generation capacity are:

- Decrease the reservoir function (Decrease in reservoir capacity) (Shichikashuku Dam)
- In addition to the sediment accumulation confirmed within the effective storage capacity of the reservoir, the sediment surface near the water intake and discharge facilities is also rising. (Shimokubo Dam)
- The maintenance of functions necessary for the appropriate implementation of water supply and flood control is required. (The Coordinated Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River)
- In a few years, the planned sediment capacity will be reached, causing trouble in water storage functionality. (Koshibu Dam)
- It is necessary to implement permanent sediment control measures and maintain flood control and water supply functions. (Yahagi Dam)
- Preventing damage to the power generation facilities due to the progression of sediment deposition in front of the intake. (Nagoro Dam)
- A large amount of sediment flowed in, advancing near the intake facilities and leading to wear on the hydraulic machinery. (Jirau Dam in Brazil)
- The advancement of sediment in the reservoir due to landslides caused by typhoons and other factors has become a problem, leading to issues with water supply, reduction in power generation capacity, and flood control capability. (Zengwen Dam in Chinese Taipei)

- Concerns were raised about sediment accumulation caused by erosion in the Himalayan Mountains, wearing down equipment at the power facility and reducing the capacity of the reservoir. (Nathpa Jhakri Dam in India)
- Decrease in reservoir functionality due to sediment impact. (Yakuwa Dam)

Examples of the main concerns about environment conservation:

- Improvement of the deepening and coarsening of pools occurring in downstream rivers due to reduced sediment supply. (Tsugaru Dam)
- Degradation of downstream river (Miyagase Dam)
- Degradation of river environments (Managawa Dam)
- Preventing pollution in downstream rivers (Nagoro Dam)
- As the sediment flowing downstream in rivers is being interrupted by dams, it leads to riverbed and coastal erosion. (Akiba Dam)
- Prevention of prolonged turbidity in reservoirs and improvement of water quality within reservoirs (Okuyoshino Power Plant)

Examples of typical explanations of disaster prevention:

- The deposition of sediment carried by Typhoon No.19 in 2019 caused the riverbed in the upstream area of the reservoir to rise, resulting in flooding. (Amahata Dam)
- Frequent flooding in the upstream areas of the reservoir by heavy rainfall in typhoon season (Sakuma Dam)
- Removal of sediment to prevent flooding in the upstream area of the dam since 1988 (Securement of Long-term Disposal Area by Cooperation between Public and Private)
- Damage during floods caused by the rise of the riverbed in the upstream area of the reservoir due to sediment (Setoishi Dam)
- Expansion of damage due to the accumulation of sediment in the dam reservoir (Case of Mimikawa river system)

Name of the project, current issues, objectives of sediment management, and necessity, are organized and shown in Appendix F.

4.4.2 Sediment Management Methods

We conducted surveys through individual questionnaires and literature surveys to investigate and organize examples of sediment management. In the case of run-of-river type power plants, we can find many cases aiming to recover functionality by flushing and sluicing through sediment flushing gates, thus enabling sediment discharge downstream similar to a natural river. However, in reality, a complete restoration of the functionality is often not achieved. Therefore, in order to remove sediments at obstruction sites due to sediment accumulation (in front of intake facilities, at the outlet of the tailrace, etc.), excavation and dredging are conducted as needed.

On the other hand, in pondage type and reservoir type generation, sediment reduces effective storage capacity and directly decreases the power generation capacity. Therefore, sediment management is implemented through various methods. In many power facilities or reservoirs, multiple sediment management methods are adopted for sediment removal.

The specific sediment management methods were organized based on individual questionnaire surveys and literature surveys (a total of 40 cases). Results are shown as follows.

Table 4-9 Sediment Management Methods

Country	Excavation /Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others	Total
Japan	22	8	3	8	6	4	51
Other countries	7	1	4	5	3	7	27
Total	29	9	7	13	9	11	78

(1) Excavation and dredging

Sediment management by excavation is a method of directly excavating and removing sediment that has accumulated at the upstream end of a reservoir during periods of low water levels.

There is a method to install the sediment storage dams at the upstream end of reservoirs to prevent sediment inflow from upstream and then excavating and removing the accumulated sediment. Dredging is a method of removing sediment that has entered a reservoir by directly sucking it up.

Removed sediment by excavation and dredging is classified into two categories: out-of-lake transportation to disposal areas where they can be secured, and in-lake transportation to the dead water zone when disposal areas are not available. Excavation and dredging is the most common method for sediment management in both Japan and other countries according to the individual questionnaire and literature surveys.

Examples for implementing this method are shown as follows:

- Shichikashuku Dam (MLIT)
- Shimokubo Dam (JWA. Gunma Prefecture)
- Amahata Dam (NLMCO)
- Takase Dam (TEPCO)
- Miwa Dam (MLIT, Nagano Prefecture)
- Koshibu Dam (MLIT, Nagano Prefecture)
- Ikawa Dam (Chubu EPCO)
- Sakuma Dam (J-Power)
- Jirau Dam in Brazil
- Zengwen Dam in Chinese Taipei
- Cameron Highlands Hydroelectric Scheme in Malaysia

(2) Sediment replenishment to downstream river

Sediment replenishment to downstream rivers is a sediment management method that involves placing excavated and dredged sediments downstream of a dam, allowing it to be transported during floods in a manner that closely resembles natural processes. This method is widely implemented in Japan. On the other hand, as for the case in other countries, we can find only one case of Three Gorges dam in China.

Examples implementing this method are shown as follows:

- The Cooperating Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River (MLIT, KEPCO)
- Tsugaru Dam (MLIT, Tohoku EPCO)
- Shimokubo Dam (JWA, Gunma Prefecture)
- Miyagase Dam (MLIT, Kanagawa Prefecture)
- Managawa Dam (MLIT, Hokuriku EPCO)
- Others

(3) Sediment Bypass Tunnel System

Sediment bypass tunnel system is a sediment management method that involves diverting floodwater and sediments introduced from the upstream side of a dam through a bypass tunnel to discharge it into the river downstream of the dam.

Examples implementing this method are shown as follows:

- Miwa Dam (MLIT, Nagano Prefecture)
- Koshibu Dam (MLIT, Nagano Prefecture)
- Zengwen Dam in Chinese Taipei
- Nathpa Jhakri Dam in India
- Patrind Dam in Pakistan
- Several dams and reservoirs in Switzerland (Solis, Pfaffensprung, Runcahez)

(4) Flushing

Flushing is a sediment management method to discharge flood and sediment at the same time through flushing gates with pressure during flood events. Flushing is a method that is implemented most frequently after excavation and dredging. Furthermore, flushing is also conducted as a discharge lasting several hours to preserve the downstream river environment.

Examples implementing this method are shown as follows:

- The Coordinated Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River (MLIT, KEPCO)
- Case of Mimikawa river system (Kyushu EPCO)
- Miyagase Dam (MLIT, Kanagawa Prefecture)
- Managawa Dam (MLIT, Hokuriku EPCO)
- Hitokura Dam (JWA)
- Zengwen Dam in Chinese Taipei
- Angostura Dam in Costa Rica

- Bakaru Dam in Indonesia
- Three Gorges Dam in China

(5) Sluicing

Sluicing is a method to freely release floodwater and sediment entering the reservoir downstream, resembling the conditions of a natural river by opening all sediment flushing gates. Examples implementing this method are shown as follows:

- The Coordinated Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River, (MLIT, KEPCO)
- Case of Mimikawa river system (Kyushu EPCO)
- Ikawa Dam (Chubu EPCO)
- Zengwen Dam in Chinese Taipei
- Nathpa Jhakri Dam in India
- Patrind Dam in Pakistan

(6) Other Methods

Here, some specific aspects classified as “others” are listed:

a) Utilization of sediment generated from excavation and dredging as aggregate or embankment material.

b) Operational rules that involve pre-emptively lowering water levels during floods and facilitating sediment passage by sluicing.

c) Operation by directly utilizing turbid water containing fine sediment for power generation

In particular, methods b) and c) are commonly observed in cases except Japan.

Examples of such methods are listed as follows:

- Shichikashuku Dam (MLIT), example of a)
- Sakuma Dam (J-Power), example of b)
- Jirau Dam in Brazi, example of b) and c)
- Angostura Dam in Costa Rica, example of b)
- Binga Dam in Philippines, example of b)
- Bolgenach Dam, Austria

Examples of sediment management based on individual questionnaire surveys and literature surveys are shown in Appendix G. Furthermore, a systematic overview of methods for sediment management is shown in Figure 4-2.

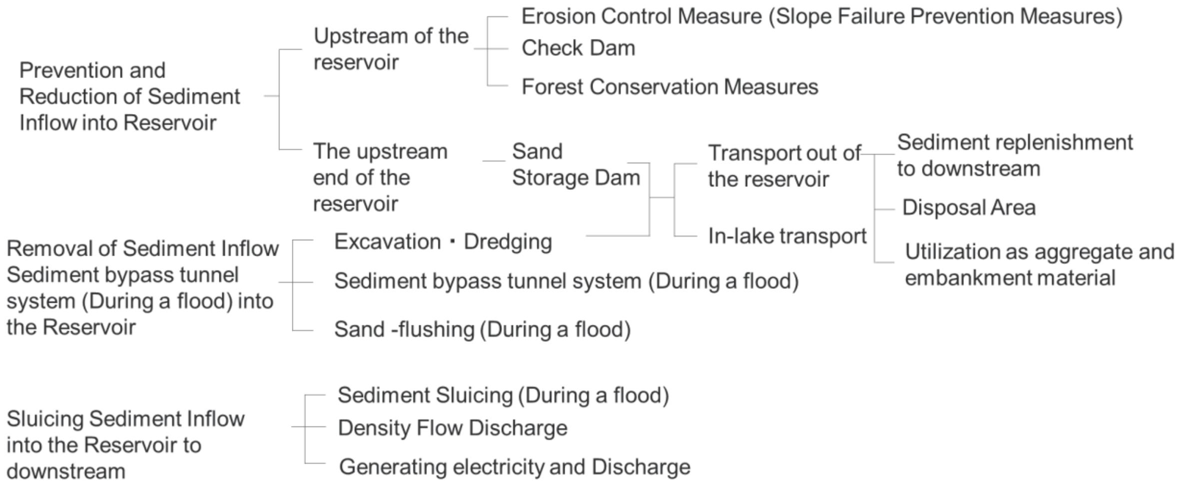


Figure 4-2 Systematic Organization of Sediment Management

4.4.3 Evaluation of Sediment Management

Evaluation of sediment management was conducted based on individual questionnaire surveys and literature surveys. The target comprises 40 cases in total, including 28 cases from Japan and 12 from other countries.

The evaluation of sediment management is closely related to its necessity (for the purpose of sediment management), so it was organized in a manner corresponding to the necessity (as shown in Table 4-8) and presented in Table 4-10. Additionally, we tried to compare cases from Japan and other counties.

The differentiation between effective and non-effective is based on the results of continuous and regular monitoring to evaluate the effectiveness of sediment management measures.

Table 4-10 Evaluation of Sediment Management (Overall)

Result	Ensuring Effective Generation Capacity	Environmental Conservation	Disaster Prevention	Compliance with Regulations	Others	Total
Effective	15	13	9	1	8	46 (56%)
Non-Effective	2	0	0	0	0	2 (2%)
Unknown (under monitoring)	13	12	4	1	4	34 (42%)
Total	30	25	13	2	12	82
Percentage of effective	50%	52%	69%	50%	67%	56%

Table 4-11 Evaluation of Sediment Management (Japan)

Result	Ensuring Effective Generation Capacity	Environmental Conservation	Disaster Prevention	Compliance with Regulations	Others	Total
Effective	10	10	9	0	7	36 (66%)
Non-Effective	2	0	0	0	0	2 (4%)
Unknown (under monitoring)	6	7	3	0	1	17 (31%)
Total	18	17	12	0	8	55
Percentage of effective	56%	59%	75%	–	88%	65%

Table 4-12 Evaluation of Sediment Management (Other countries)

Result	Ensuring Effective Generation Capacity	Environmental Conservation	Disaster Prevention	Compliance with Regulations	Others	Total
Effective	5	3	0	1	1	10 (37%)
Non-Effective	0	0	0	0	0	0 (0%)
Unknown (under monitoring)	7	5	1	1	3	17 (63%)
Total	12	8	1	2	4	27
Percentage of effective	42%	38%	0%	50%	25%	37%

Based on this literature survey, the overall evaluation of sediment management indicates that approximately 56% of objectives, as shown in Table 4-10, have been achieved with the implementation of sediment management for various purposes. For the remaining approximately 42%, it is considered necessary to continue further monitoring in order to evaluate their effectiveness.

When comparing cases in Japan and other countries, the percentage of cases deemed effective was higher in Japan at 66% as shown in Table 4-11, compared to 37% in other countries as shown in Table 4-12. In case studies from Japan, monitoring for assessing the effectiveness of sediment management is being conducted continuously and regularly, which is considered to contribute to a more reliable evaluation of effectiveness.

On the other hand, in cases from other countries, the description of monitoring implementation was unclear in many instances, and the effectiveness was not clearly described. Therefore, in the literature survey, it was unavoidable to categorize them as "Unknown".

Next, we tried to evaluate the effectiveness for the different purposes of sediment management. For "Ensuring Effective Generation Capacity", it can be said that the share of facilities where effectiveness was observed and facilities where effectiveness was unclear is approximately half each. Regarding facilities categorized as "unknown", it is difficult to grasp the inflow and outflow of sediment, thus further monitoring is necessary to evaluate effectiveness.

On the other hand, facilities categorized as "effective" include cases where sediment inflow and outflow (removal) are relatively easy to grasp, such as when a sediment storage dam is installed upstream of the reservoir and sediment are transported to the river downstream of the dam. These are cases where reliable results have been achieved through excavation and dredging at locations aimed at maintaining the function of power facilities (such as preventing burial due to sedimentation at the intake and outlet).

When comparing cases in Japan and other countries, the percentage of cases deemed effective is higher in Japan at 56% compared to 42% in other countries.

"Ensuring Effective Generation Capacity" is the most significant issue requiring sediment management, and it was observed that hydro-electric power companies in Japan and other countries are conducting it with considerable interest.

Regarding "Environmental Conservation", more than half, 13 cases (10 from Japan and 3 from other countries), out of a total of 25 cases, were evaluated as "effective". Monitoring surveys to regularly assess the improvement of environmental conditions are publicly available at most sites, mainly in Japan. Therefore, the evaluation is reflecting these monitoring results, particularly environmental improvement in the downstream areas of reservoirs. On the other hand, many facilities categorized as "unknown" aim to ensure the continuity of sediment transport from the upstream to the downstream reaches of rivers. To assess the achievement of this goal, monitoring is deemed necessary from a long-term perspective.

As for cases in other countries, in many instances, it was unclear whether monitoring is conducted or not. Therefore, only cases that clearly mentioned "effective" were counted as "effective", while cases without clear indication were categorized as "effectiveness unclear."

Regarding "Disaster Prevention" out of a total of 13 cases, 12 cases are examples from Japan. In many cases of "Disaster Prevention", flood prevention in the upstream area of reservoirs is recognized as a challenge. In this sense, the excavation and dredging of sediment at sediment storage dams upstream of reservoirs, as well as riverbed excavation, are evaluated to be effective in preventing flooding upstream of the reservoir. For facilities categorized as " unknown", monitoring is ongoing and they are considered as impossible to be evaluated at present.

Finally, for "Others" cases, “utilization as aggregate material" is recognized as effective because it was actually being implemented by contractors.

Furthermore, there were two cases, mainly from facilities in other countries, that cited "the changes of power plant operation rules". These cases were categorized as " unknown" because the effectiveness of the changes in operation rules is currently under monitoring.

Example of detailed explanations of the evaluation of sediment management according to its purposes are:

(1) Ensuring effective generation capacity,

- Efforts are continuing for effective methods of coordinating sediment flushing.
- In terms of water utilization and maintaining of flood control functions, it has shown some effectiveness. (The cooperating sediment flushing in the case of Unazuki dam and Dashidaira dam in Kurobe River)
- For the intake of sediment and outlet pipes, their functionality has been maintained through dredging. (Ikawa Dam)
- Through sediment management, the sediment volume has been maintained balanced. (Yahagi Dam)
- The removal of sediment at the intake front is being carried out appropriately, and the sediment at the front has been removed, achieving the initial objective. (Nagoro Dam)

- Upstream sediment storage dams prevent the inflow of 90% of sedimentation. The remaining sediment is also being removed through dredging. (Hvammur Dam in Iceland)
- The sediment bypass tunnel is effective for both moderate and large-scale floods. It has also brought about good results in terms of environmental conservation. (Solis Dam in Switzerland)
- The inflow and accumulation of sediment into the reservoir have been significantly suppressed and reduced by sediment management. (Sediment storage dam and dredging) (Cameron Highlands Hydroelectric Scheme in Malaysia)

(2) Environmental conservation

- The environmental improvement effects in the downstream river of the dam have been confirmed through flushing and sediment replenishment tests. (Miyagase Dam)
- Flushing was conducted in addition to sediment replenishment to the downstream river. As a result, contributions to the growth of algae and improvement of fish habitat have been observed. (Managawa Dam)
- The forest area has increased significantly. (Angostura Dam in Costa Rica)
- The inflow of sediment into the dam was suppressed and the annual sediment accumulation has decreased significantly. It is estimated that nearly 90% of the inflowing sediment passes through the bypass tunnel. (Okuyoshino Power Plant, KEPCO)
- The sediment balance in the reservoir has been properly maintained, ensuring the effective storage capacity for power generation. There are no concerns about flooding in nearby areas due to the rise in the riverbed upstream end of the reservoir. (Tamagawa No.3 Power Plant, Tokyo Metropolitan)

(3) Disaster prevention measures

- The sediment from upstream has been discharged downstream safely and almost as planned. (Miwa Dam)
- Excavation to mitigate the risk of flooding by backwater effects. As a result, there is no concern of flooding at current flood level. (Akiba No.1, No.2, No.3 Power Plant, J-Power)

(4) Other cases

- From 2013 to 2016 in four years, total approximately 30,000 cubic meters of excavation was conducted and supplied approximately 20,000 cubic meters of aggregate (sand). (Shichikashuku Dam)
- By installing a belt conveyor, the utilization of aggregate resources, conventionally averaging 400,000 cubic meters, has been expanded to 600,000 cubic meters. (Amahata Dam)

We organized information on effects, evaluation and challenges of sediment management in Appendix H for the 40 targeted cases in the literature survey.

4.4.4 Challenges in Implementing Sediment Management

The importance of sediment management becomes more significant as meteorological risks, such as extreme floods caused by climate change, are increasing. In this subsection, we analyze the challenges faced in implementing sediment management, such as the need for coordination with river administrators and local stakeholders, as well as infrastructure development and environmental aspects of specific cases based on individual questionnaire surveys and literature surveys.

(1) The necessity for coordination with river administrators and local stakeholders

In order to develop and implement sediment management plans, it is necessary to ensure the consistency with top-level plans such as river improvement plans established by river administrators. Similarly, it is necessary to implement sediment management plans only after achieving consensus among local stakeholders and residents through public meetings.

Implementing sediment management plans especially has impacts on the river environment downstream of dams and reservoirs, it is therefore necessary to conduct systematic monitoring continuously and regularly to grasp the environmental impacts. These activities should be based on an agreement among river administrators and all the local stakeholders.

(2) Challenges in infrastructure development for sediment management

The locations of pondage or reservoirs of hydro-electric power facilities are often located in mountainous areas where infrastructure is underdeveloped, leading to challenges shown in Table 4-13. In this table, examples of countermeasures to mitigate such challenges are also described.

Table 4-13 Challenges in Infrastructure Development for Sediment Management

Challenges	Examples of countermeasures
An overwhelming inflow of sediment beyond handling capacity	Prevention works against sediment production events upstream area (Forest conservation, Land slide prevention works in mountainous area, Erosion control works)
Difficulty to secure disposal sites with sufficient capacity to handle the removed sediment	To secure a disposal site with sufficient capacity through negotiations with landowners (In case not to keep the disposal site) Sediment replenishment to downstream of the dam, In-lake transport to the dead zone, Utilization for aggregate or materials for roadbed
Undeveloped road for transporting the removed sediment	Construction and maintenance of new transport road (In cases of large amounts of sediment to be transported) Introduction of belt conveyor
Noise and vibrations affecting public roads	Maintenance of public road, Traffic control, Sediment transportation by belt conveyor
Due to the limited discharge through the spillway gate for sediment management, the sediment volume dose not reduce below the planned amount	Review of the sediment discharge operation (Sluicing with low water operation)

As for examples of countermeasures, based on measures being considered locally, examples were described. Many of the challenges and countermeasures cannot be identified and decided solely by the power generation companies. Therefore, coordination and agreement among river administrators, regional landowners and other stakeholders is essential to make good decisions.

(3) Environmental challenges (Environmental considerations and mitigation measures downstream of dams associated with sediment discharge.)

It has become evident that in some cases there is concern about environmental impacts and mitigation measures should be considered. Environmental impacts and possible mitigation measures are shown in Table 4-14.

Table 4-14 Environmental Considerations and Mitigation Measures Downstream of Dams Associated with Sediment Discharge

Environmental impacts	Mitigation measures
Impacts on downstream areas due to turbid water	Sediment discharge is conducted only during flooding as a measure against unnaturally turbid water
Decrease in sediment supply downstream	Businesses extracting gravel downstream (for commercial use) have changed to directly extracting gravel from the reservoir
Impact on tourism areas	Dredging to prevent generating turbid water
Impact on fish due to the discharge of sediment slurry	Reduction of sediment deposition in the reservoir Suppression of suspended solids (SS) concentration during sediment discharge Increase in natural flow duration and frequency Management of sediment from rivers to coastlines
Noise and vibration during the transportation of sediment by vehicles	Road improvements, construction of long-distance conveyors, etc.
Impact on ecosystems	Monitoring of ecosystem impacts upstream and downstream of reservoirs

The environmental concerns and mitigation measures listed in in Table 4-14 are found in many cases and can therefore be considered relatively widely implemented mitigation measures.

4.5 Lessons Learned from Individual Questionnaire surveys and literature surveys

Dams and their reservoirs play an extremely important role in our society for flood control, power generation, domestic and industrial water supply and agricultural water supply. At the same time, society demands that their functions and safety be maintained over the long term as a common property of the people.

On the other hand, due to the occurrence of extreme floods caused by recent climate changes, sedimentation in reservoirs is accelerating, raising concerns about the deterioration of reservoir functions. In response to these circumstances, hydroelectric power producers are implementing sediment management practices to maintain the long-term functionality and safety of dams and reservoirs.

However, sediment management must be carried out over the long term and continuously, which has been confirmed to have a significant impact on the overall environment of the river basin.

Through the investigation in Subtask 3, we were able to learn about the difficulties in implementing sediment management. We summarize these difficulties and considerations for implementing sediment management as follows:

(1) Sediment management cannot be carried out by hydroelectric power producers alone.

(2) The following points need to be considered for the smooth implementation of sediment management:

- The sediment management plan must be consistent with the "river improvement" plan managed by river administrators.
- When implementing the sediment management plan, it is necessary to obtain consensus from stakeholders, landowners, and residents in the river basin.
- During implementation, attention must be paid to the conservation of the overall environment of the river basin, from upstream to downstream and to the coastal areas (consideration for flora, fauna, fish, etc., and sediment movement).
- It is also necessary to conduct regular and continuous monitoring to always understand the impact of sediment management on the environment.

4.6 Introduction of Good Practices

In this section, two good practices of sediment management in Japan, which have been implemented with careful consideration of the lessons learned from the previous section, are introduced. These examples are taken from publicly available information.

4.6.1 Coordinated Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River (MLIT, KEPCO)

4.6.1.1 Geographical and Topographical Features

The Kurobe River flows in an arch-like shape through a narrow basin surrounded by the Tateyama Mountain Range and the Ushiro-Tateyama Range, featuring steep mountainous terrain. In the eastern part of the basin, the Ushiro-Tateyama Range rises to altitudes of around 3,000 meters. Due to the abundant rainfall in the region, hydroelectric power generation has been utilized since ancient times. Currently, Kansai Electric Power Company operates 12 hydropower plant, supplying approximately 900 MW of electricity.

On the other hand, the abundant rainfall frequently causes floods in the Kurobe River. Known as one of Japan's steepest rivers, it carries a large amount of sediment during floods, resulting in significant sediment runoff per unit area of the basin. At the Dashidaira Dam, completed in 1985, securing sediment storage capacity was difficult, and a sediment flushing plan was implemented from the outset.

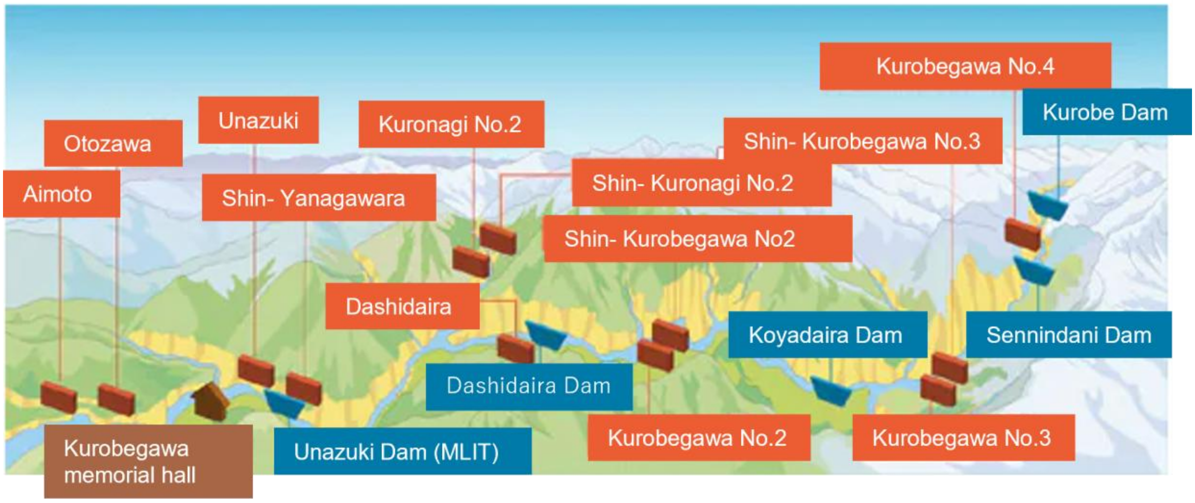


Figure 4-3 Power Generation Facilities in the Kurobe River System

4.6.1.2 Framework and System for Building Consensus among Stakeholders

At the Dashidaira Dam, the first sediment flushing was carried out in 1991, six years after its completion. However, the resulting turbid water spread to a marine area 3 km downstream, creating a significant social issue. In response, the Kurobe River Dashidaira Dam Sediment Flushing Impact Study Committee was established, comprising academic experts, government agencies, and related organizations. This committee aimed to foster a shared understanding with the local community and to review the approach to sediment flushing.

In 1998, the Kurobe River Dam Sediment Flushing Evaluation Committee and the Kurobe River Sediment Management Council were established. These organizations facilitated the implementation of sediment flushing annually, timed with periods of increased water flow.

Table 4-15 Composition of the Kurobe River Dam Sediment Flushing Evaluation Committee & Kurobe River Sediment Management Council

Committee Name	Purpose	Members
Kurobe River Dam Sediment Flushing Evaluation Committee	To deliberate and evaluate sediment flushing plans and environmental survey results.	University-affiliated individuals, members of national research institutes
Kurobe River Sediment Management Council	To discuss and coordinate sediment flushing plans and environmental survey plans. Additionally, to deliberate and evaluate progress and environmental survey results after implementation.	Mayors, Forestry Agency, Prefectural Government, Kansai Electric Power, Ministry of Land, Infrastructure, Transport, and Tourism (MLIT)

4.6.1.3 Examples of Coordinated Sediment Flushing

In 2006, the Basic Policy for River Development in the Kurobe river system was established, followed by the Kurobe river system River Development Plan in 2009. Under these plans, the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) initiated efforts to coordinate sediment flushing with the Unazuki Dam. The Dashidaira Dam and the Unazuki Dam work together to carry out sediment flushing, utilizing the river's natural flow force to efficiently discharge accumulated sediment downstream.

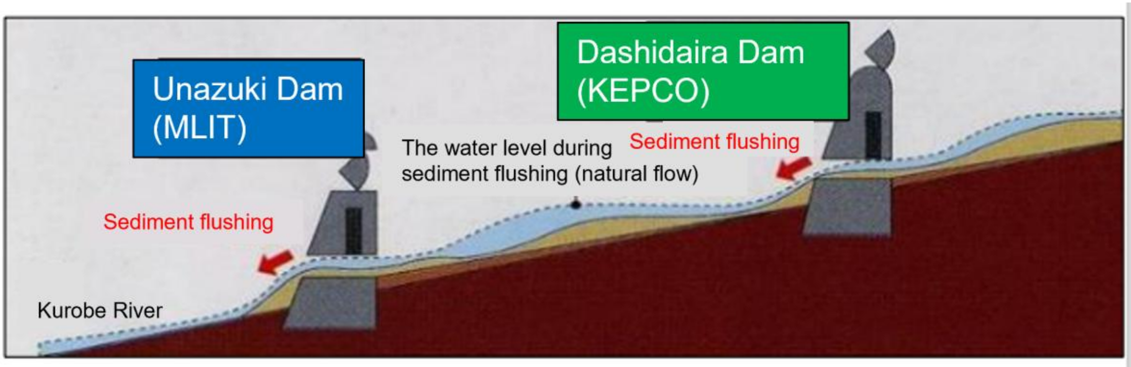


Figure 4-4 Coordinated Sediment Flushing in the Kurobe River

In 2010, sediment flushing was carried out, exceeding the target of 140,000 m³, with a total of 160,000 m³ flushed. A river survey conducted during the coordinated sediment flushing in June of the same year revealed that immediately after the Dashidaira Dam and the reservoir directly below the Unazuki Dam transitioned to a natural flow state, suspended solids (SS) temporarily reached high levels (peaking at 52,000 mg/l and 14,000 mg/l, respectively).

However, these levels decreased within a few hours. Dissolved oxygen (DO) levels showed no significant changes.

The sediment analysis of marine areas revealed that while some data exceeded the water quality standards for fisheries at certain regularly monitored locations, these instances were not persistent, and overall variations were not significant. Regarding the environmental survey results of the coordinated sediment flushing in 2010, the Kurobe River Dam Sediment Flushing Council stated that "based on the environmental surveys of water quality, sediment, and ecosystems, coordinated sediment flushing and sediment passage caused temporary environmental changes but had no significant impact compared to natural flood conditions."

This demonstrates that planned coordinated sediment flushing is an effective measure for discharging accumulated sediment while minimizing environmental impacts.

Based on this history, coordinated sediment flushing between the Dashidaira Dam and the Unazuki Dam has been conducted annually during periods of increased water flow. The coordinated sediment flushing and monitoring plans for 2023 are outlined below.

Table 4-16 2023 Sediment Flushing Plan at Kurobe River

Item	Sediment Flushing		Sediment Passage	
	Dashidaira Dam	Unazuki Dam	Dashidaira Dam	Unazuki Dam
(1) Timing	- Conducted during June to August when the dam inflow exceeds 300 m^3/s at Dashidaira Dam or 400 m^3/s at Unazuki Dam during the first flood event. (*Note 2*) - Additionally, during periods of high flow caused by snowmelt or the rainy season, it is also conducted if the Dashidaira Dam inflow reaches 250 m^3/s. - The operation is stopped if inflow during natural flow falls below 130 m^3/s.		Conducted during June to August whenever the dam inflow after sediment flushing exceeds 480 m^3/s at Dashidaira Dam or 650 m^3/s at Unazuki Dam during each flood event. (*Note 2*)	
(2) Volume	- Target sediment flushing volume: ~350,000 m^3 (*Based on May 2023 sediment flushing simulation*) (*Note 3*) - Expected fluctuation range: ~270,000 m^3 to ~430,000 m^3 (*Note 4*)	No specific target sediment flushing volume is set.	The natural flood flow is discharged each time using the sediment flushing gates.	
(3) Method	Natural flow method			
(4) Time	- Operation is completed once the target flushing volume is confirmed through calculation (within 12 hours of natural flow). (*Note 7*)	Within 12 hours of natural flow. (*Note 9*)	To be completed by the end of the natural flow operation at Unazuki Dam. (*Note 7*)	Within 12 hours of natural flow. (*Note 9*)
(5) Pre-Flushing / Passage Measures	Sediment flushing gates are operated from the early stage of the flood (high dam water levels).	Water level lowering operations are conducted during the later stage of flood regulation (high dam water levels).	Same as left. (*Note 8*)	
(6) Post-Flushing / Passage Measures	- After sediment flushing, hydropower intake is stopped, and dam inflow is discharged as is until the water volume required for Unazuki Dam's post-flushing measures is secured. (*Note 5, 6*)	After sediment flushing, approximately 400 m^3/s is discharged for a certain period (2–3 hours). (*Note 5*)	After sediment passage, dam inflow is discharged through the dam and downstream power plants until the water volume required for Unazuki Dam's post-sediment passage measures is secured. (*Note 5, 6*)	After sediment passage, approximately 400 m^3/s is discharged for a certain period (2–3 hours). (*Note 5*)
(7) Sediment Quality Degradation Prevention Measures	If no flood events meeting the above sediment flushing conditions occur, sediment quality degradation prevention measures are implemented between September 1 and September 2. (*Note 10*)			

Special Notes:

1. *In the event of unexpected large sediment inflows or unforeseen circumstances, appropriate measures will be discussed and implemented as necessary.*
2. *Sediment flushing and passage may continue beyond August 31 if required to complete operations.*

3. *The target sediment flushing volume for Dashidaira Dam is determined based on May surveys prior to flushing operations. If significant flood events occur post-survey, resurveying will be conducted, and the May survey results will be treated as provisional targets.*
4. *Fluctuation range is estimated based on past SS variation. Unusual floods (e.g., 1,000 m³/s class or higher) are not included.*
5. *Flushing/passage measures are conducted experimentally as described in this document.*
6. *Flushing/passage measures for Dashidaira Dam are conducted for a minimum of 3 hours. Operations affecting downstream facilities (e.g., hydropower plants) will be coordinated to avoid impacts.*
7. *Natural flow overlap between dams is the standard; however, Dashidaira Dam's flushing may complete before Unazuki Dam starts natural flow, depending on conditions.*
8. *Fine sediment passage is conducted if inflow exceeds 300 m³/s for Dashidaira Dam or 400 m³/s for Unazuki Dam. In this case, both dams will maintain high water levels in their reservoirs. Dashidaira Dam will primarily use its sediment flushing gates, while Unazuki Dam will open its water level lowering gates after completing flood regulation. If the flow during fine sediment passage does not reach the operational flow criteria for sediment passage, the termination of the operation will be appropriately determined by the implementing agency, considering factors such as dam inflow and downstream turbidity. Additionally, if the flow during fine sediment passage exceeds the operational flow criteria, the operation will transition to conventional sediment passage.*
9. *Experimental operations for sediment dynamics closer to natural conditions are conducted, including pre-emptive operations at Unazuki Dam. Natural flow adjustments between dams may be implemented if required.*
10. *Sediment quality control involves discharging ~80 m³/s of oxygenated water for ~8 hours to prevent sediment degradation.*
    https://www.hrr.mlit.go.jp/kurobe/haisa56/pdf/s1-1.pdf

Table 4-17 Coordinated Sediment Flushing and Monitoring Implementation Plan

Month		4	5	6	7	8	9	10	11	12	1	2	3
Overall Schedule Typical end of the rainy season: around July 20				Coordinated sediment flushing and passage period Flood season									
Implementation Items			Regular surveys	During sediment flushing or passage			Regular surveys		Regular surveys				
Water quality	Dam		●	●One Day After Sediment Flushing or Passage			●						
	River		●	●During sediment flushing or passage and one day after			●						
	Marine Area		●	●During sediment flushing or passage and one day after			●						
Sediment Quality	Dam		●				●						
	River		●				●						
	Irrigation Channel		●				●						
	Marine Area		●				●						
Aquatic Organisms	River		●				●		●				
	Marine Area		●				●						
surveying	River								●				
	Dam		●	●Conducted immediately after sediment flushing or passage			●			●			

Surveys are generally conducted one day after the completion of sediment flushing or passage. However, if safety cannot be ensured, such as when water is overflowing from the dam, the survey may be postponed until a safe date.

4.6.1.4 Evaluation of Coordinated Sediment Flushing

Coordinated sediment flushing is carried out annually, comparing the actual sediment flushed with target volumes. At the Dashidaira Dam, it has been confirmed that sediment flushing is achieved as planned, remaining within the anticipated range of variation. Similarly, at the Unazuki Dam, surveys have verified that sediment flushing is conducted as planned.

On the other hand, environmental monitoring during coordinated sediment flushing has focused on its effects on water quality, sediment, and aquatic organisms in both river and marine environments. As mentioned earlier, the 2010 survey results indicated temporary environmental changes due to coordinated sediment flushing. However, these changes gradually returned to normal levels, and the impact was deemed insignificant compared to natural flooding. This has confirmed that the environmental impacts of coordinated sediment flushing are extremely limited.

Since 2010, continuous and regular monitoring of water quality, sediment, and aquatic organisms has been conducted annually. The following diagram illustrates the process from implementing coordinated sediment flushing to evaluation monitoring.

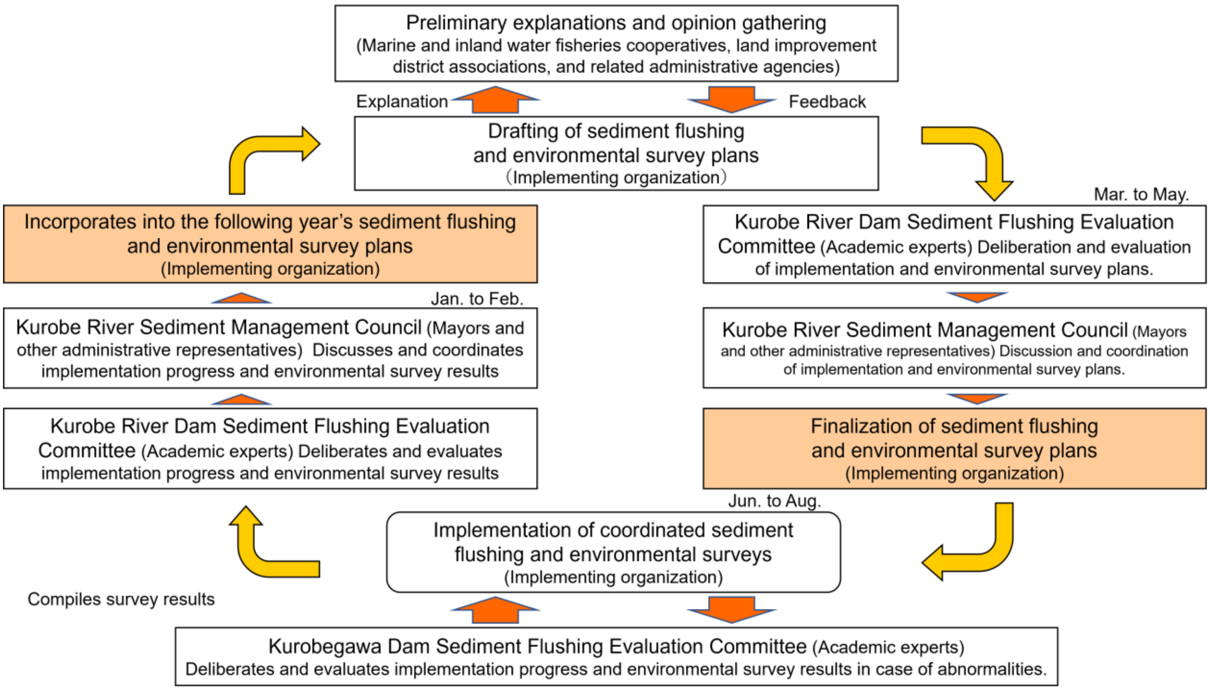


Figure 4-5 Flow of Coordinated Sediment Flushing Implementation Plan and Evaluation Monitoring

4.6.1.5 Challenges in Implementing Coordinated Sediment Flushing

- Continued Environmental Protection:

  Ongoing monitoring is essential to minimize the impact of coordinated sediment flushing on river and marine ecosystems.

- Collaboration with Local Communities:

  Providing information and building consensus with local communities are critical. Efforts to deepen understanding include operating a "Coordinated Sediment Flushing Projection" on the official website and sharing information with the community.

- Technical Challenges:

  To achieve efficient sediment flushing, innovations are needed to develop methods that closely mimic natural processes.

- Other Requests and Opinions:

  Discussions in forums such as the Kurobe River Sediment Management Council explore solutions to various additional issues raised.

4.6.2 Case of Integrated Sediment Management Plan in Mimikawa River System (Kyushu EPCO)

4.6.2.1 Overview of Mimikawa River System

The Mimikawa river system is located in the northern part of Miyazaki Prefecture. It is a power supply river system with seven (7) hydropower plants, accounting for more than 20% of Kyushu Electric Power's general hydroelectric capacity and generation. The basin is blessed with steep mountains and abundant water flow, and power generation has been ongoing for approximately 90 years. Kyushu Electric Power's dam reservoirs occupy about 40% of the total length of the river system, highlighting the company's responsibility for the impact of its facilities on the river basin.

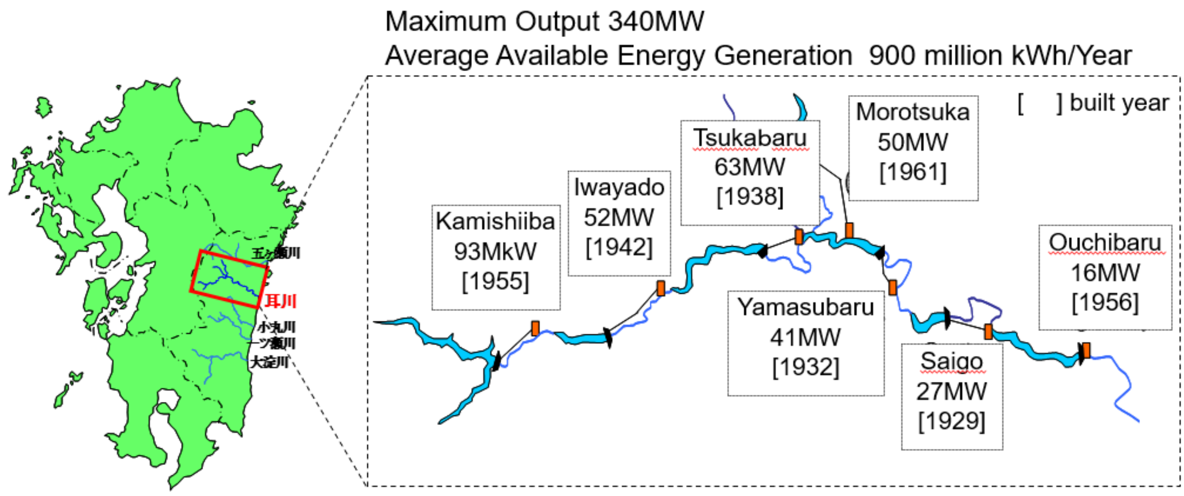


Figure 4-6 Overview of Mimikawa River System

4.6.2.2 Overview of the 2005 Typhoon No.14 Disaster

In 2005, Typhoon No.14 brought record-breaking heavy rainfall, causing widespread slope collapses (491 locations) and flooding (424 flooded houses) across the basin.

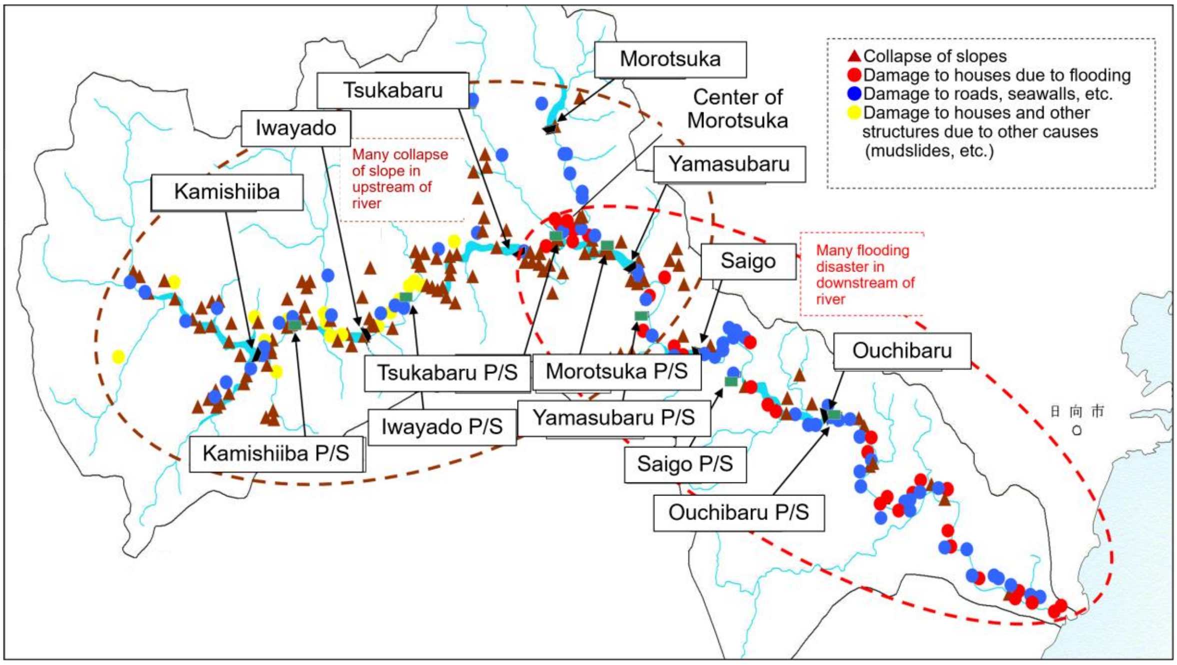
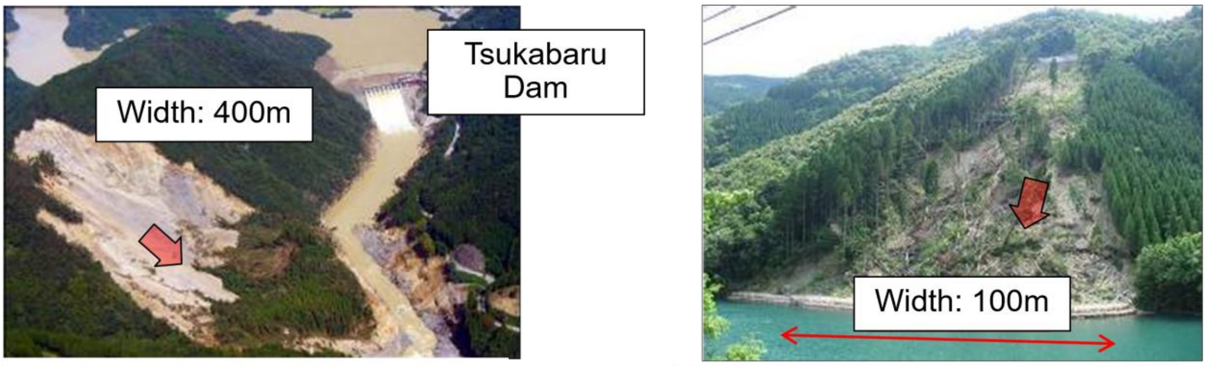


Figure 4-7 Disaster Status Caused by Typhoon No.14

(1) Slope collapse:
Numerous slope collapses occurred, resulting in a massive inflow of sediment into the rivers. A total of 10.6 million m³ of sediment flowed in, with half of that (5.2 million m³) accumulating in the reservoirs.



Collapse situation downstream of Tsukabaru Dam

Collapse in the regulating reservoir of the Yamasubaru Dam

Figure 4-8 Status of Slope Collapses

(2) Flooding Disasters
In the central area of Morotsuka, upstream of the Yamasubaru Dam regulating reservoir, a record seventy (70) houses were flooded. Four (4) power plants (Kamishiiba, Tsukabaru, Yamasubaru, and Saigo) became inoperable due to flooding. Overflow occurred at three (3) dams, and the dam management offices (Tsukabaru, Yamasubaru, and Saigo) were inundated.

Flooding situation in Morotsuka shopping area

Flooding at Tsukabaru Power Plant

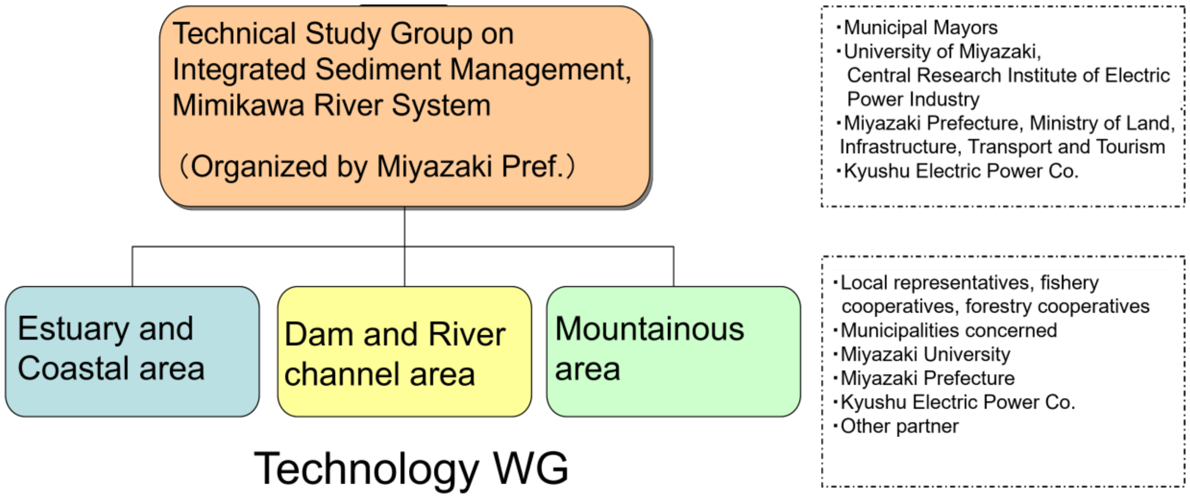
Figure 4-9 Status of Flooding Damage

4.6.2.3 Sediment Management of the Mimikawa River System

4.6.2.3.1 Establishment of the "Technical Review Committee on Sediment Management of the Mimikawa River System"

The Miyazaki Prefectural Government, as the river administrator, established the "Technical Review Committee on Sediment Management of the Mimikawa River System" to address various sediment-related issues in an integrated manner across the entire river basin, rather than tackling individual problems in isolation. The aim was to involve all stakeholders within the basin. Representatives of local residents and fisheries cooperatives also participated in discussions as part of the technical working group (WG).

As a result of this committee's efforts, the "Sediment Management Plan for the Mimikawa River System" was finalized in October 2011.



※Quoted from prefectural data

Figure 4-10 Composition Diagram of the Review Committee

4.6.2.3.2 Action Plan (Role Allocation for Achieving Objectives)

To implement comprehensive sediment management, it is crucial not only to strengthen collaboration among stakeholders but also for each organization to actively address and resolve challenges. To this end, "target directions" for issues and challenges in each area, as well as "action plans" that each organization should undertake, were established, clearly defining the roles and responsibilities of all parties involved.

Table 4-18 Target Directions and Action Plans

Area	Target Directions	Examples of Action Plans	Responsible Parties
Mountainous Areas	Aim to suppress sediment and driftwood discharge through forest conservation, erosion control, and disaster prevention efforts	- Forest maintenance projects - Promotion of thinning, etc. - Others (35 projects in total)	Miyazaki Prefecture Local municipalities
Dam	Restore sediment movement continuity and revitalize river functions through appropriate dam operation and management.	- Dam sediment flushing operations - Sediment movement within pondage - Bank reinforcement within pondage reservoirs	Kyushu EPCO
River Channels	Aim to restore river functions that ensure safety, security, and biodiversity, while fostering human-river interaction through proper river management.	- Comprehensive river restoration and repair projects - Sediment utilization for large-scale flood control projects - Monitoring local water environments - Others (18 projects)	Miyazaki Prefecture Local municipalities
Estuaries and Coasts	Strive to preserve sustainable estuarine and coastal areas through integrated sediment management across the water system.	- Regional measures for coastal debris management - Prefecture-led port projects	Miyazaki Prefecture

4.6.2.3.3 About the Sediment Management of the Mimikawa River System

Establishment of the "Evaluation and Improvement Committee"

Comprehensive sediment management involves an iterative process of adaptive management, which includes the following steps:

(1) Plan improvement (Formulating plans)
(2) Measure implementation
(3) Monitoring (of the physical environment and ecosystems)
(4) Evaluating

Based on these evaluations, the action plans in the next step are continuously improved. To facilitate this adaptive management approach, the "Evaluation and Improvement Committee" was established in July 2012, replacing the original "Technical Review Committee." This committee includes the participation of experts, private entities, government officials, and local residents.

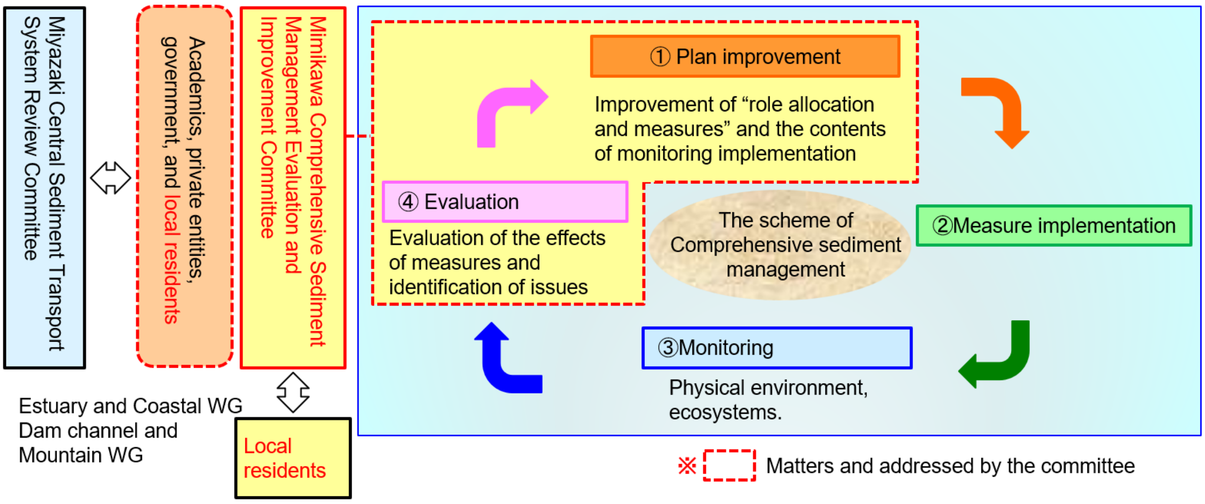


Figure 4-11 Sediment Management of the Mimikawa River System

4.6.2.4 Overview of the Kyushu Electric Power Action Plan for Comprehensive Sediment

4.6.2.4.1 Management of the Mimikawa River System

The overall outline of the project is as shown in the next figure.

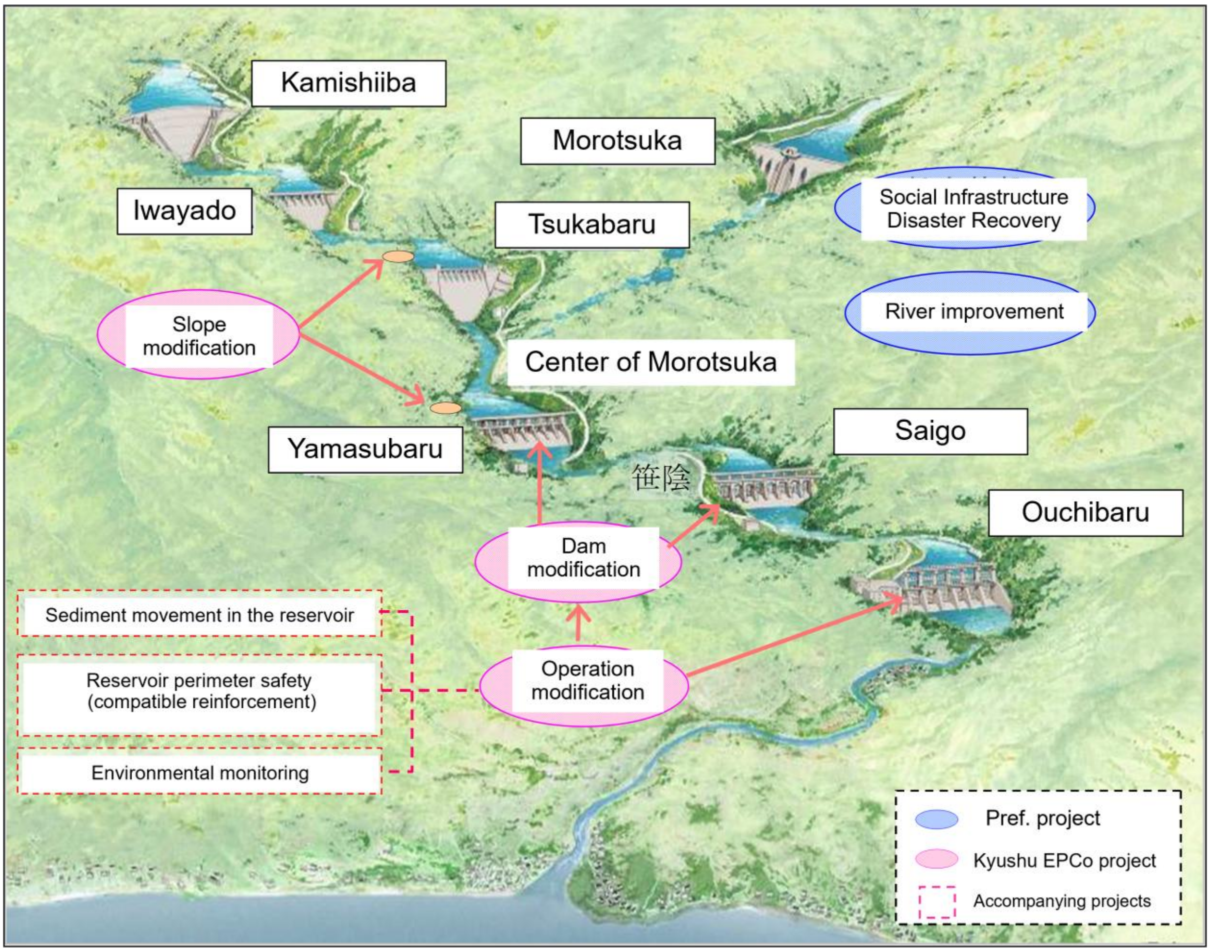


Figure 4-12 Detailed Map of the Mimikawa River System

4.6.2.4.2 Dam Sediment Flushing Operation

The dam sediment flushing operation involves utilizing the flood's scouring force to pass sediment inflowing into the reservoir through dam gates. Its purpose is to restore the natural sediment flow of the river, which has been blocked by the dam.

(1) Conventional Dam Operation:
During floods, sediment flowing in from upstream accumulates in the reservoir, raising the sediment level. This increases the risk of flooding in surrounding areas.

(2) Targeted Dam Operation (Sediment Flushing Operation):
By lowering the reservoir water level during large-scale flood events, such as typhoons, sediment inflowing from upstream can more easily flow downstream, replicating the natural behavior of the river.

The dam sediment flushing operation was implemented at three (3) downstream dams (Yamasubaru, Saigo, and Ouchibaru) with relatively high flood risk.

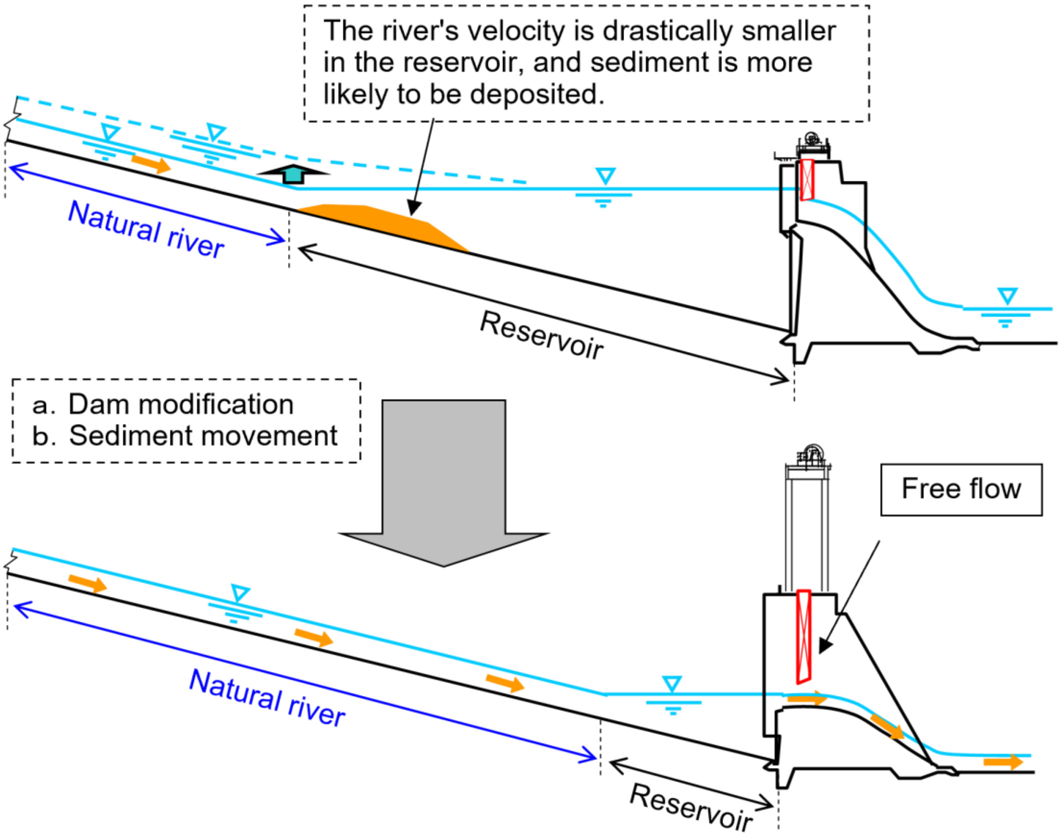


Figure 4-13 Overview of the Dam Operation Methods

4.6.2.4.3 Expected Benefits of Dam Sediment Flushing

The dam sediment flushing operation is expected to bring benefits in terms of flood control, water utilization, and environmental improvements.

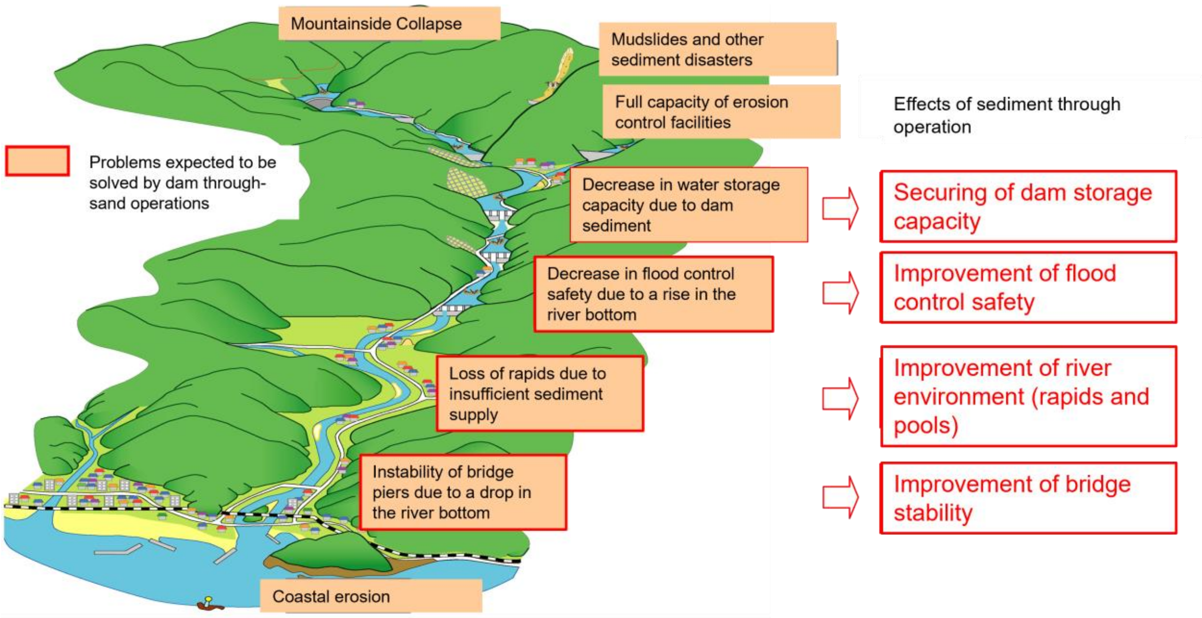


Figure 4-14 Effects of Dam Operation on Sediment-Related Problems in the Mimikawa River System

4.6.2.4.4 Expected Environmental Benefits of Dam Sediment Flushing

Previously, sediment trapped by the dam caused riverbed materials to coarsen. Through sediment flushing, a variety of particle sizes, such as stones, gravel, and sand, are supplied downstream. This process also leads to the expansion of sandbars and the formation of distinct riffles and pools, helping the river return to its natural state.

During floods, not only water but also sediment flows downstream, promoting the removal of algae attached to riverbed stones. This results in an increase in fresh algae, which serves as food for fish, thereby restoring a diverse biological environment.

In this way, dam sediment flushing is expected to improve the river environment downstream of the dam.

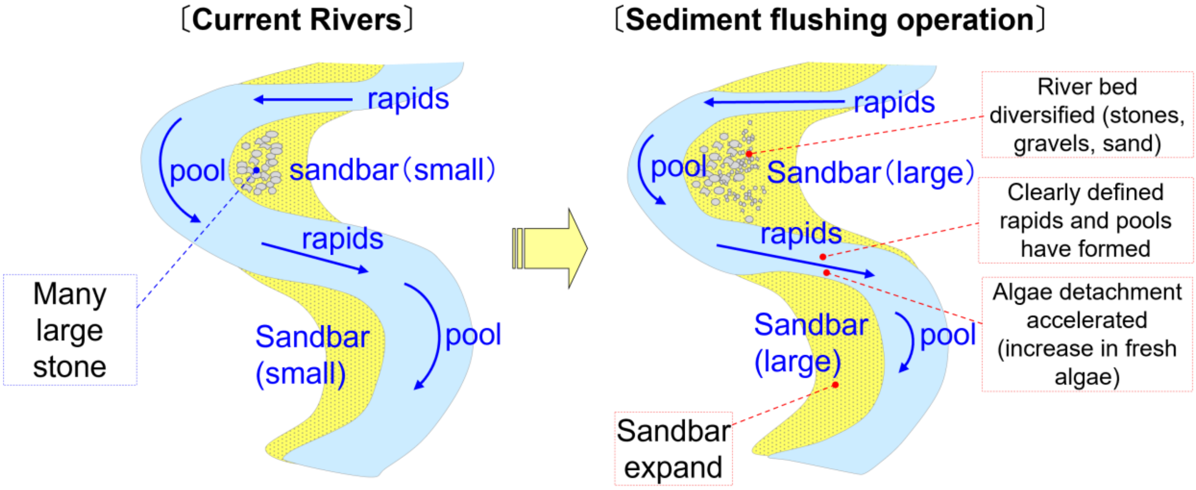


Figure 4-15 Expected Environmental Changes in Rivers Due to Dam Operation

4.6.2.4.5 Dam Modification

The previous structures of the Yamasubaru Dam and Saigo Dam were unable to efficiently flush sediment during floods. Therefore, modification work was carried out to partially lower the height of the existing dams within structurally feasible limits.

At Yamasubaru Dam, two (2) of the eight (8) existing radial gates were removed from the center, and the overflow crest was lowered by approximately 9 meters. A single radial gate was then installed to facilitate sediment flushing.

Figure 4-16 State of Yamasubaru Dam Before and After Modifications

At Saigo Dam, four (4) of the eight (8) existing roller gates in the center were removed, and the overflow crest was lowered by approximately 4 meters. Two (2) new roller gates were installed to improve sediment flushing capabilities.

Figure 4-17 State of Saigo Dam Before and After Modifications

On the other hand, at Ouchibaru Dam, lowering the reservoir water level can be managed with the existing facilities, allowing for sediment flushing operations without any dam modifications.

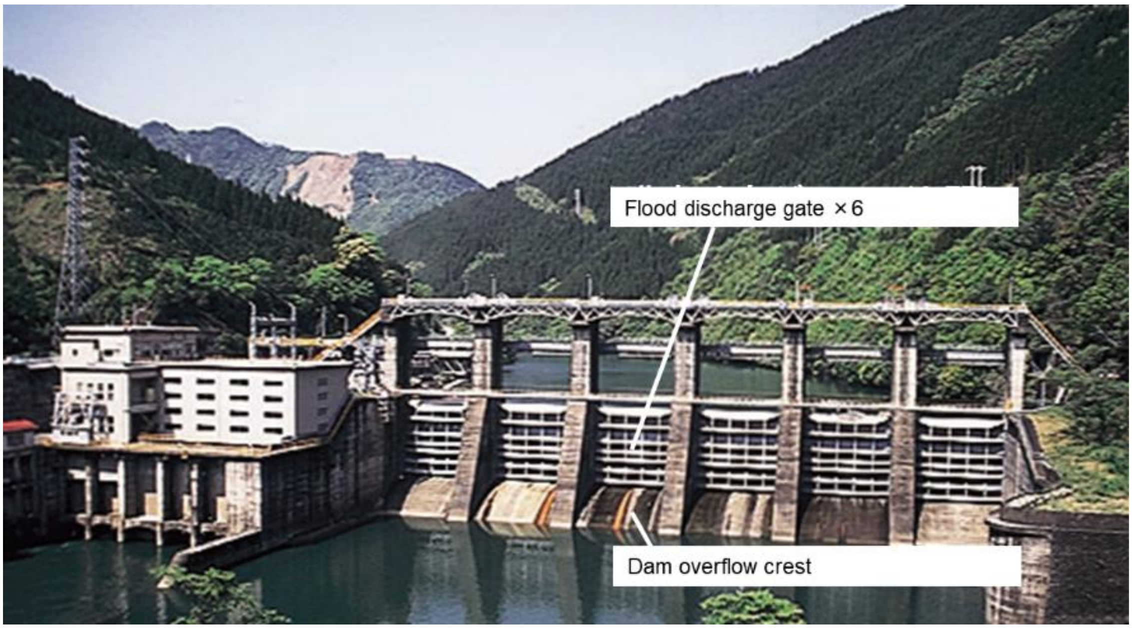


Figure 4-18 Ouchibaru Dam

4.6.2.4.6 Sediment Movement within Reservoirs

In the central area of Morotsuka, which experienced significant flood damage, sediment was dredged to enhance flood control effect.

In areas directly upstream of Yamasubaru Dam and Saigo Dam, sediment flushing operations would cause previously accumulated sediment to flow out rapidly, posing risks to downstream river safety and the environment. To mitigate this, sediment was pre-dredged and relocated to safe locations inside and outside the regulating reservoirs.

Further downstream at Ouchibaru Dam, fine silt-sized sediment had accumulated. Flushing operations would have caused this sediment to flow out, resulting in turbid water. To prevent this, the dredged sediment was used to cover the area with larger-grained materials, such as gravel.

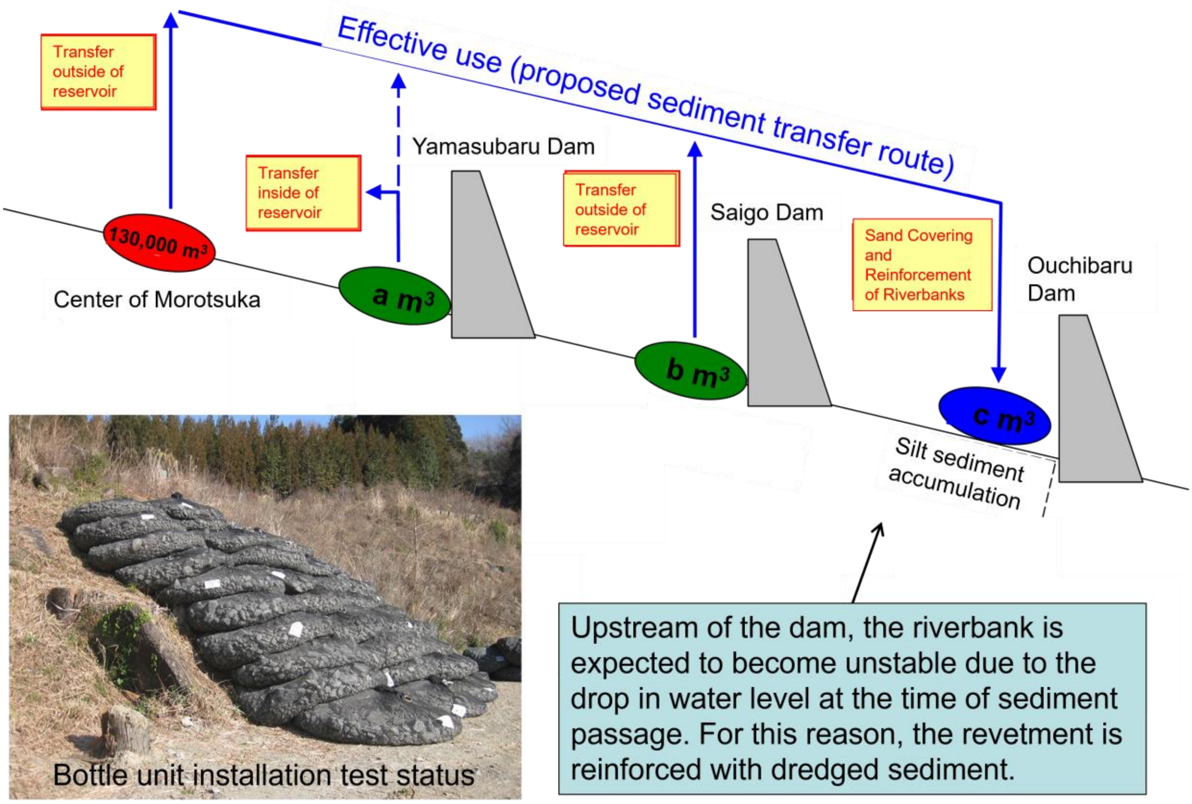


Figure 4-19 Sediment Movement within Reservoirs

4.6.2.4.7 Environmental Monitoring

To assess the impact of dam sediment flushing, environmental monitoring surveys have been continuously conducted since before the start of sediment flushing operations (in dam and river channel areas since 2007, and in estuaries and coastal areas since 2009)

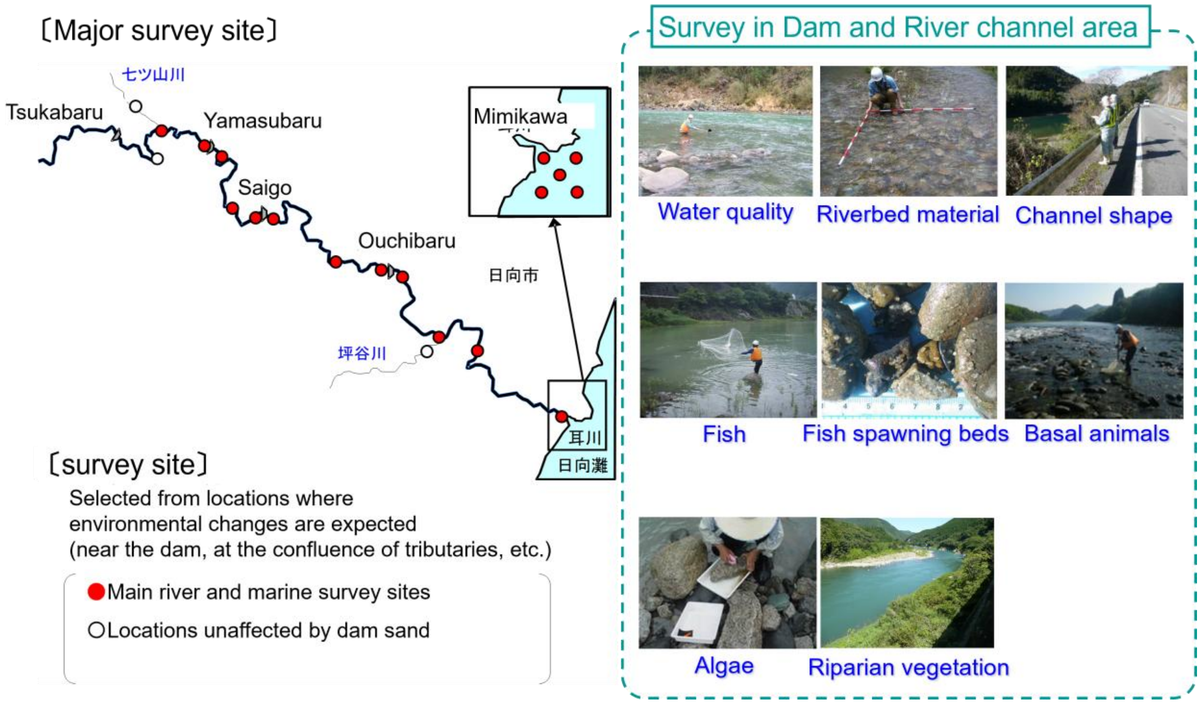


Figure 4-20 Environmental Survey Locations and Their Survey Items

4.6.2.5 Dam Sediment Flushing Operation Plan and Achievements

4.6.2.5.1 Technical Review for Developing the Sediment Flushing Operation Plan

To conduct technical reviews related to dam sediment flushing, the "Mimikawa River System Dam Sediment Flushing Technical Review Committee" (an internal committee) was established, consisting of academics and experts specializing in sediment flushing operations.

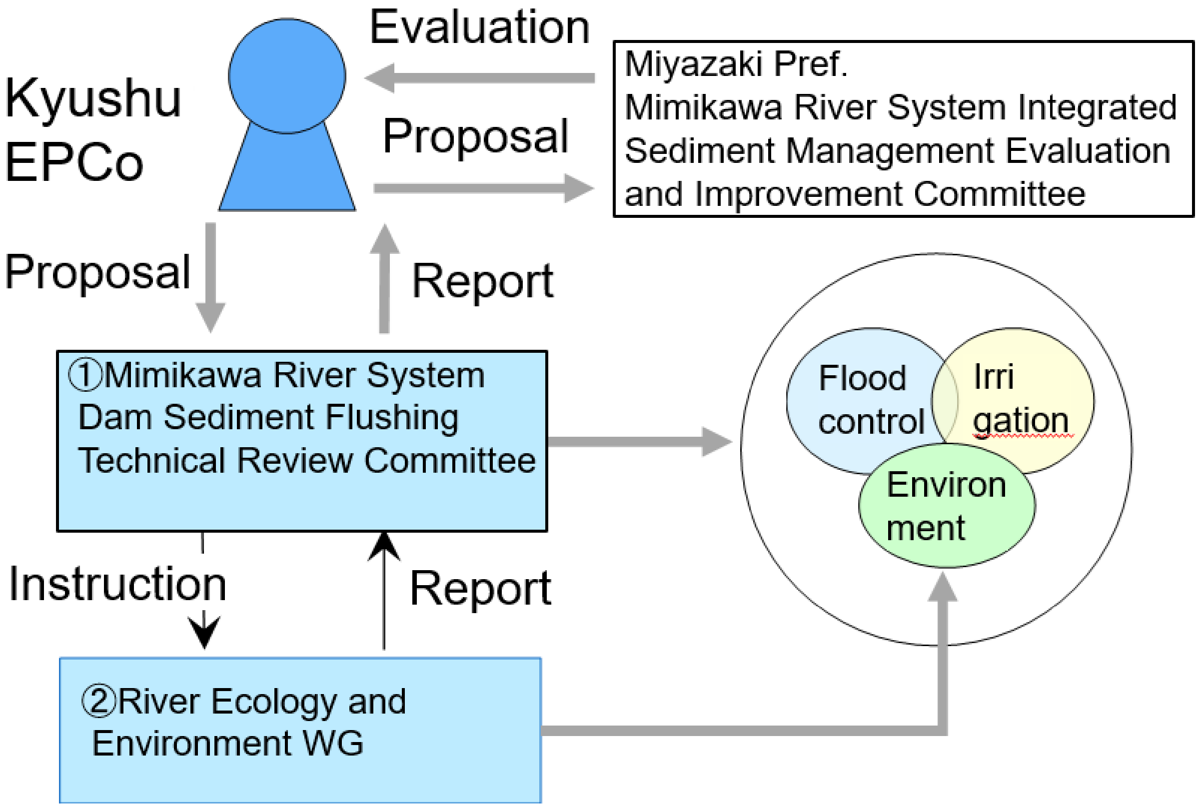


Figure 4-21 The Technical Review Committee and Its Roles

Table 4-19 Mimikawa River System Dam Sediment Flushing Technical Review Committee

Role	Member
Technical Guidance	Kyoto University, Kyushu University, Public Works Research Institute
Technical Cooperation	Hydraulic Engineering Center, Central Research Institute of Electric Power Industry
Guidance and Advice	Kyushu Regional Development Bureau, Miyazaki Prefecture

Table 4-20 River Ecology and Environment Working Group

Role	Member
Technical Guidance	Kyoto University, Kyushu University, Kumamoto University
Technical Cooperation	Central Research Institute of Electric Power Industry
Observer	Miyazaki Prefecture

4.6.2.5.2 Dam Sediment Flushing Operations

Partial sediment flushing began at Saigo Dam and Ouchibaru Dam in 2017 after the completion of modification work at Saigo Dam. Additionally, from 2021 onward, following the completion of modification work at Yamasubaru Dam, coordinated sediment flushing operations involving all three dams were implemented.

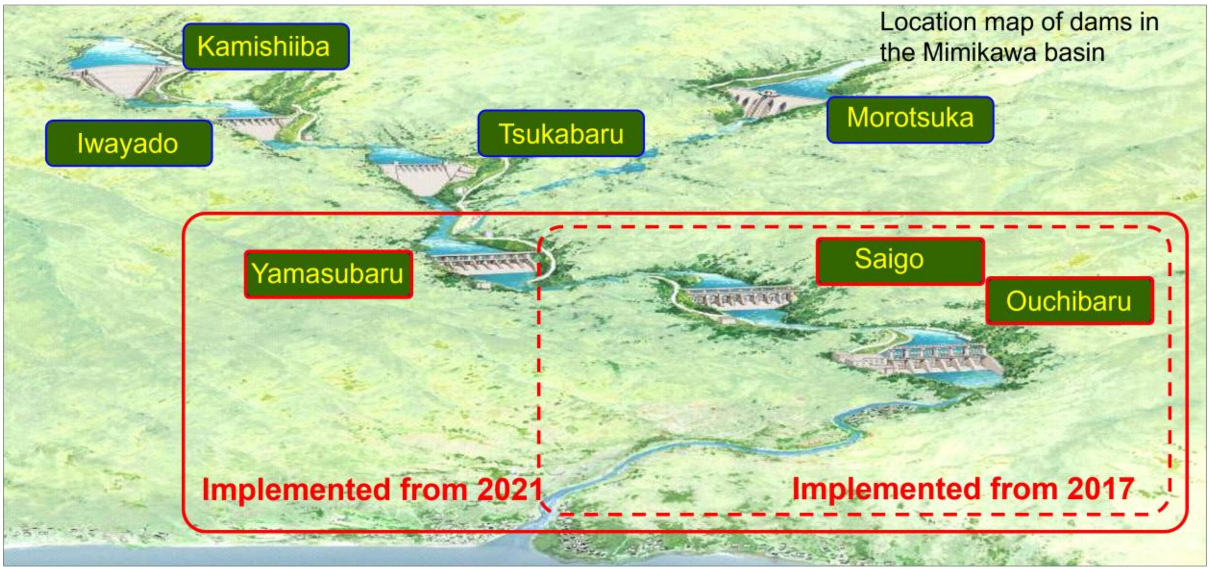


Figure 4-22 Map Showing the Locations of the Coordinated Sediment Flushing Dams

4.6.2.5.3 Achievements of Dam Sediment Flushing Operations

Since the initiation of sediment flushing operations in 2017, 5 sediment flushing events have been conducted. This includes 3 partial sediment flushing events involving 2 dams and 2 coordinated sediment flushing events involving all 3 dams.

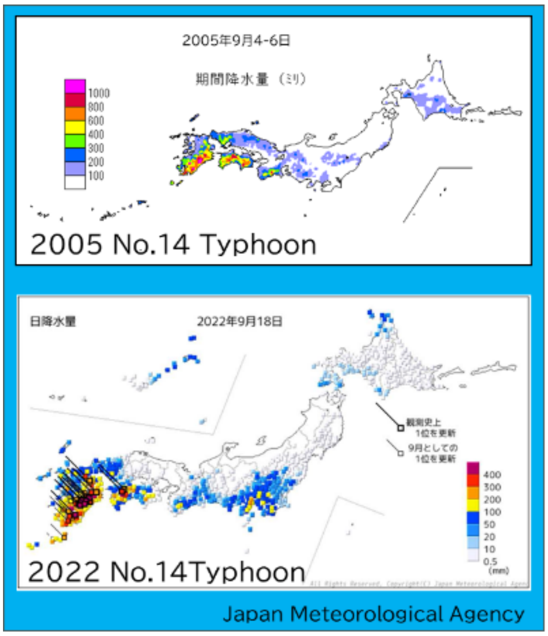
In 2022, the year following the completion of modification work at Yamasubaru Dam, the first coordinated sediment flushing operation involving all 3 dams was carried out. The scale of the flood during this operation was comparable to that of the 2005 Typhoon No.14, which had prompted the comprehensive sediment management efforts for the Mimikawa river system.

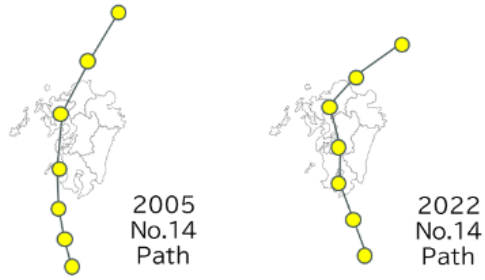
Table 4-21 Achievements of Dam Sediment Flushing Operations

Type	Start day of flushing	Day of Maximum inflow	End day of flushing	Maximum inflow			Time of flushing (Hour)		
				Yamasubaru	Saigo	Ouchibaru	Yamasubaru	Saigo	Ouchibaru
Partial flushing	2017/9/14	2017/9/17	2017/9/19	1,558	1,517	1,670	N/A	20	75
	2018/9/27	2018/9/30	2018/10/2	1,440	1,482	2,102	N/A	41	75
	2020/9/5	2020/9/7	2020/9/9	1,975	2,757	2,534	N/A	50	81
Coordinated sediment flushing	2022/9/16	2022/9/18	2022/9/22	3,613	4,907	5,847	65	64	135
	2023/8/5	2023/8/10	2023/8/12	2,069	2,159	2,675	65	67	153

4.6.2.5.4 Achievements of the 3-Dams Coordinated Sediment Flushing Operation (Typhoon No.14 in September 2022)

Rainfall and river flow comparable to the devastating flood of 2005 (Typhoon No.14) were observed during the 2022 typhoon. Both events were caused by Typhoon No.14, with similar paths passing along the western side of the Kyushu Mountains. This caused counter clockwise storm clouds to collide with the mountains, leading to high rainfall levels on the eastern side, affecting Miyazaki and Oita Prefectures significantly.





Mikado Observatory	2005	2022
1 day max	628 mm	695 mm
7days	1,348 mm	1,195 mm
Oouchibaru	**2005**	**2022**
Max inflow	5,454 m³/s	5,847 m³/s

Figure 4-23 Trajectory of 2022 Typhoon No.14 and Related Data Such as Rainfall

Yamasubaru Dam	Saigo Dam	Ouchibaru Dam
Sep. 19th, 2022 at 16:40	Sep. 19th,2022 at 16:00	Sep. 19th, 2022 at 11:00
Discharge rate : 1,140㎥/s	Discharge rate : 1,510㎥/s	Discharge rate : 2,156㎥/s

Figure 4-24 Picture of the 3-Dams Coordinated Sediment Flushing Operation

Table 4-22 Sediment flushing Volume of the Three Dams

	Yamasubaru Dam	Saigo Dam	Ouchibaru Dam
Sediment slouching amount	587,000 m^3	731,000 m^3	1,117,000m^3

4.6.2.5.5 Effects of Sediment Flushing Operations (Improved Flood Safety)

The central area of Morotsuka, which experienced flooding during Typhoon No.14 in 2005, avoided significant flood damage due to sediment flushing operations, embankment raising, and sediment relocation efforts.

Figure 4-25 Effects of Dam Sediment Flushing Operations

4.6.2.5.6 Effects of Sediment Flushing Operations (River Environment Improvement)

Downstream of the dam, increased diversity in riverbed materials and clearer distinctions between riffles and pools have been observed. In the area circled by the red dot on the right figure, we can observe a sandbar formed by sediment supplied from upstream through the dam.

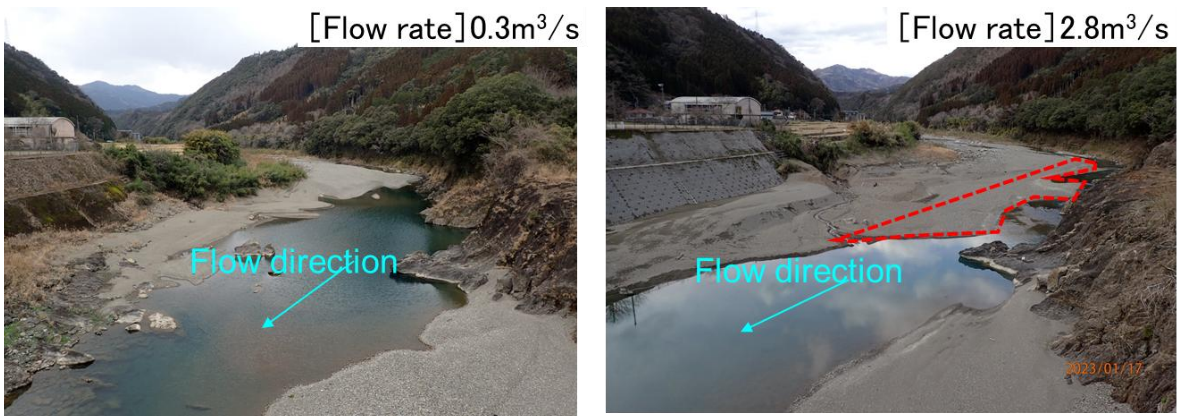


Figure 4-26 Comparison of the Situation 1 km Downstream of Saigo Dam (Left: Before Slouching, Jan.12th, 2022. Right: After Slouching, Jan. 17th, 2023)

4.6.2.6 Summary

The collaborative efforts in the Mimikawa river involving industry (Kyushu Electric Power), government (national, prefectural, and municipal), academia (experts), and local communities (residents and fisheries cooperatives) have proven to be highly effective in addressing issues correctly and fostering consensus among all stakeholders.

The effects expected from the 3-dams coordinated sediment flushing operations have been confirmed from both flood control and environmental perspectives.

Flood Control: Improved flood safety was observed in some upstream reservoir areas, with sediment movement leading to a reduction in riverbed elevation.

Environmental Improvement: Downstream of Yamasubaru Dam, Saigo Dam, and Ouchibaru Dam, sediment of various sizes was observed to move, and changes in riffles and pools were noted compared to conditions before sediment flushing.

Going forward, sediment flushing operations will continue, with monitoring maintained and plans revised as needed.

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APPENDIX A：ORGANIZATION OF DISASTERS (WEATHER CONDITIONS, OVERVIEW OF THE DISASTER, CAUSES OF THE DISASTER) (SUBTASK 2)

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-1 Damage and Restoration of Sekigawa River System	The disaster known as the 7.11 Flood occurred in the Joetsu region, where a power plant is located. Due to the influence of the seasonal rain front, a torrential downpour exceeding a total rainfall of 300 mm within 24 hours occurred starting from the night of the same day. In the basins of the Himekawa and Sekigawa rivers, floods and landslides occurred.	The so-called "7-11 Flood" that struck the Joetsu region of Niigata Prefecture from July 11 to 12, 1995, caused significant damage to Tohoku Electric Power's facilities. A total of 15 power plants were submerged, flooded, or otherwise damaged, resulting in the loss of approximately 60% of the total hydroelectric power output within the Niigata Branch's jurisdiction (46 locations, 251,961 kW). This represented the largest scale of hydroelectric power facility damage in history.	○	○			○		Loss of intake weir, Damage to the intake, Flooding of the power plant, Collapse of protection wall.	Flood
2-2 Restoration of Nagamatsu Power Plant	According to an investigation by the Meteorological Research Institute of the Japan Meteorological Agency, the recent 'Niigata-Fukushima Heavy Rainfall' met the conditions for torrential rain for an extended period. This was due to a drop in temperature to around -6°C at an altitude of approximately 5,800 meters and an increase in the amount of water vapor in the lower layers. It was found that within nine hours from the start of the rainfall, the total rainfall exceeded 500 mm. From the rainfall graph, it was observed that there were three consecutive days with daily rainfall exceeding 100 mm.	The torrential rain in Niigata and Fukushima in July 2011 caused damage to the facilities of the Nagamtsu Power Plant. This included partial damage to the embankment, partial destruction of the tailrace outlet protection wall, subsidence of the pier foundations of the penstock management bridge, and submersion of the power plant.	○			○	○	○	Partial damage to the dam, Partial damage to the tailrace protection wall, Settlement of the penstock management bridge's pier, Submersion of the power plant.	Flood
2-3 (Example of Flood Damage) Miyashita Power Plant	From July 28 to 30, 2011, heavy rainfall occurred mainly on Niigata Prefecture and the Aizu region in Fukushima Prefecture. The 24-hour rainfall locally exceeded 400 mm, and the prolonged heavy rain resulted in a total of 700 mm over three days. This torrential rain caused river flooding and landslides. The cumulative rainfall (711.5 mm), Japan Meteorological Agency observation station.	The torrential rain in Niigata and Fukushima in July 2011 caused various damages to the hydropower plants in the Agano river system. These included the submersion of power plants, the loss of equipment, and the blockage of intake and discharge outlets by large amounts of sediment and debris. The resulting shutdown of hydropower plants impacted the power supply capacity by approximately 1 million KW.		○	○		○	○	Intake (blockage due to sediment inflow), Waterway (blockage due to sediment inflow), Tailrace outlet (blockage due to sediment inflow), Flooding of the power plant.	Flood＋Sediment inflow

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-4 Overview of Recovery Works from Heavy Rain Disaster at Sendatsu Power Plant	On August 9, 2013, the inflow of moist air from the Japan Sea caused extremely unstable atmospheric conditions. This led to localized torrential rain in central-eastern and northern Akita Prefecture. Near the Sendatsh Power Plant, the Yoroi-hata site recorded the highest hourly rainfall of 88 mm and the highest daily rainfall of 278 mm, both the highest on record.	On August 9, 2013, Akita Prefecture experienced extremely heavy localized rain from early morning until early afternoon in the central-eastern and northern parts of the prefecture. A "large-scale debris flow disaster" occurred near the Sendatsu Power Plant, causing extensive damage.		○	○	○	○		Landslide of the western slope of the penstock (landslide area: 120 meters long, 30-40 meters wide) Landslide of the eastern slope of the penstock (landslide area: 20 meters long, 5-10 meters wide), Erosion of the surface of the spillway channel (192 meters long), Submersion of the turbine and generator (water depth: 2.5 meters), Sediment flowed into the waterway and caused overflow water that led to flow into the power plant.	Flood + Sediment inflow
2-5 (Example of Flood Damage) Shimodai Power Plant	In Aug. 2013, warm, moist air flowed into the Tohoku region, causing atmospheric instability. In Akita Prefecture, there were places that had unprecedented torrential rain from early morning until before noon. *Maximum hourly rainfall (68 mm): Japan Meteorological Agency observation station.	In August 2013, a low-pressure system caused flooding, resulting in a three-hour rainfall of 126 mm in Odate City. Consequently, the increased river flow caused washing away a part of the intake weir and the waterway was damaged due to a landslide.	○		○		○		Intake Dam (Erosion at the overflow section), Waterway channel (Inflow and damage due to sediment from surrounding landslides), Waterway culvert (Loss and damage due to soil cover washout), Flooding of power plant	Flood + Sediment inflow
2-6 Saigawa Power Plant	This is a case that is not caused by a specific flood event. Before renovation, the embankment of the Saigawa Power Plant had a fixed weir with a gabion structure and an old sand flushing gate. Due to the insufficient discharge capacity of the sand flushing gate, water overflowed the top of the gabion dam during floods, leading to frequent dam washouts.	Before renovation, the embankment of the Saigawa Power Plant had a fixed weir with a gabion structure and an old sand flushing gate. The sand flushing gate had low discharge capacity, leading to frequent washouts of the gabion embankment during floods due to overflow from the fixed weir. Therefore, part of the embankment and the steel gate were removed, and a large-scale SR composite undulating weir (SR weir) was introduced.	○						Washouts of the embankment.	Flood
2-7 Renovation Work of Tenjin Weir (SR Weir) Tenjin Power Plant	The Miyagawa river basin suffered damage such as flooding due to Typhoon No.23 on October 20, 2004.	Due to Typhoon No.23 on October 20, 2004, flooding occurred in the basin of the Kanzawa river system where the Tenjin Power Plant is located. As part of the restoration work, riverbed excavation and other river improvement measures were planned because the flow capacity near the Tenjin embankment was insufficient compared to the design flow. Along with these improvements, the Tenjin embankment was changed from a fixed weir to a movable weir (SR composite undulating weir) to allow for constant water level control, and the fishway was improved to enhance fish passage capabilities.							Although there was no damage to the facilities, measures were taken to reduce future flood risks (Renovations works aimed at enhancing resilience to climate change).	Flood

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-8 Construction of Bypass Channel of Oigawa Dam	The specific disaster is not a reason for implementing this construction project.	At the site of the Chubu Electric Power Company's Oigawa Dam, turbid water produced from landslides upstream of the Oi River during floods flowed into the Oigawa Dam reservoir through the waterway and was discharged into the river as maintenance flow (Maximum 3.49 m^3/s). This turbid water often affected the downstream river water. In response to local requests from Kawane Honcho town for river environment improvement, the company constructed a new turbidity control facility. This facility includes an intake weir and a bypass channel to divert clear river water before the turbidity occurs and discharge it downstream of the Oigawa Dam.							Responding to the river environmental improvement request from the local Kawane Honcho town, this renovation work was implemented as a new turbid water countermeasure.	Flood + Sediment inflow
2-9 Waterway Renovation Work of Shima Power Plant	The damage was caused by concentrated heavy rainfall in the Tokai region from September 11 to 12, 2000, and subsequent river flooding. From the early morning of September 11 to the early morning of the 12th, heavy rainfall poured down, with some areas along the Yahagi River observing rainfall exceeding 60 mm per hour. The total precipitation for the day exceeded 400 mm. Using records from the Ministry of Construction's Kami-Yahagi Rainfall Observation Station, the two-day rainfall was evaluated to be of a 500-year probability event. At this river basin, the maximum inflow reached 3,218 m3/s, which was approximately 1.4 times the planned high flow rate of 2,300 m3/s and exceeded the dam's design flood capacity of 2,900 m^3/s.	From September 11 to 12, 2000, concentrated heavy rainfall and resulting river overflow caused damage in the Tokai region. The renovation work involved directly connecting the upstream Kamimura Power Plant tailrace channel with the Shima Power Plant intake through a connecting channel, and removing the existing Shima Riverbed protection (structures) of intake facilities.	O						The existing Shima intake protection wall was washed out and led to the accumulation of sediment, debris, and driftwood.	Flood
2-10 Renovation works for apron works of Zakkokudani Intake Dam, Shoumyougawa No.2 Power Plant	On July 18, 2004, heavy rainfall at the Shomyo River main water intake point recorded 63 mm/hr and 161 mm over 24 hours and on June 30, 2005, during heavy rainfall, the conditions were 42 mm/hr and 214 mm over 24 hours. (The 24-hour rainfall was equivalent to a rainfall event exceeding a 200-year probability.) Due to sediment accumulation in front of and around the Zakkokudani intake dam, as well as flooding in the gate hoist room, those leaded to breakdown of automatic control devices and made impossible to intake water. It has been confirmed that while the Design flood water level at Zakkokudani intake dam is 1.5 meters, the water level during the disasters was 6.0 meters in 2004 and 5.5 meters in 2005. This indicates that a very large debris flow occurred. The 24-hour rainfall on June 30, 2005, was 214 mm, which corresponds to a rainfall event exceeding a 200-year probability.	The Hokuriku Electric Power Company's Shoumyougawa No. 2 Power Plant's Zakkokudani Intake Dam is located in a steep river with an average riverbed gradient of 1/5, where upstream landslides frequently occur. In 2004 and 2005, the dam suffered sediment accumulation and flooding damage from heavy rainfall and leading to an inability to intake water. In recent years, the upstream area of the intake facility has experienced significant landslides. Anticipating that similar damage may occur in the future, improvement works for the intake facility were carried out for the purpose of ensuring stable water intake.	O	O					Sediment and debris accumulated in front of the Zakkokudani intake dam and intake area. Failure of automatic control equipment due to flooding in the gate hoist room.	Flood + Sediment inflow

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-11 Improvement Works of Tailrace Shin-Inotani Power Plant	Typhoon No.23, which occurred in October 2004, combined with the autumn rain front and cross the Chubu area. It recorded 6,400 m³/s of river flow biggest ever recorded at the Jinzu Bridge location and caused extensive damage, including flooding and washing out, to many power plants in the Jinzugawa river system.	At the Shin-Inotani Power Plant tailrace channel in the Jinzugawa river system, an abnormal flood caused by Typhoon No.23 on October 21, 2004, resulted in the submersion of the tailrace gate opening device and control panel. Additionally, a large amount of sediment and debris flowed into the tailrace channel, leading to a disaster where the tailrace channel became unusable.					○	○	(1) Flooding of the tailrace gate control devices. (2) Flooding of power plant (flooding caused by water from the tailrace outlet).	Flood
2-12 (Example of Flood Damage) Nagatono Power Plant	Due to Typhoon No.12, which brought heavy rain and flooding to the Kii Peninsula from August 31 to September 4, 2011, the total rainfall over a wide area of the Kii Peninsula, located to the east of the typhoon's center, exceeded 1,000 mm. Several hydropower plants within Kansai Electric Power Co., Inc.'s Nara Power Division also suffered significant damage. (*Accumulated rainfall 1652mm, 72hours)	The record rain caused landslides in various areas of the prefecture, with the number reportedly reaching around 1,800 locations. It was assumed that the large-scale landslide in Totsukawa Village in Uguhara area flowed into the river, and the resulting surge is estimated to attack the power plant, causing its complete destruction.					○		A landslide downstream of the power plant entered the river, and the resulting surge went upstream and directly struck the power plant and destroyed completely.	Flood
2-13 Renovation Works of Kitagosho Weir, Nakagosho Power Plant	The Kitagosho weir, one of the intake weirs of the Nakagosho Power Plant, was damaged by debris flow caused by the torrential rain in April 2003.	Chubu Electric Power Co., Inc.'s Nakagosho Power Plant is a run-of-river type hydroelectric plant that intakes a total of 4 m³/s from the Shin-Nakagosho, Kitagosho, and Shin-Kurokawa embankments, generating electricity with a maximum output of 10,200 kW. One of the intake facilities, the Kita-Nakagosho embankment, suffered damage and became unusable due to a debris flow caused by concentrated heavy rainfall in April 2003.		○					The Kitagosho intake, one of the intake facilities of the Nakagosho Power Plant, was damaged.	Flood＋ Sediment inflow
2-14 (Example of Flood Damage) Kawabegawa No.1 Power Plant	Accumulated rainfall until disaster 345mm, 75hours, Maximum rainfall 46mm/hr. June689mm/month exceeding average monthly rainfall in recent 10 years 465mm, Accumulated rainfall in 30 days is 933mm which is maximum record in rainy season.	After reaching the peak flow, discharge operations continued with decreasing in inflow. However, shortly after sparks were observed in the direction of the intake, gate operation became impossible, and it was confirmed that the intake facility was damaged. And following the damage event, the damages were expanded to the collapse of the gate and management bridge. The maximum inflow was about 40% of the design flood flow (2,124 m³/s) and about 50% of the historical maximum flow (1,539 m³/s), so it was not a particularly large discharge.		○					Damage to the intake facilities (Including the main body of the intake, the screen, the intake gate, and the hoist). Damage to the right bank of fishway (downstream of intake).	Flood

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-15 Recovery works of Kamishiiba Power Plant	At each dam site (7 sites), the flood conditions were as follows: all seven dams exceeded the previous maximum inflow before Typhoon No.14, and five dams (except for kamishiiba and Morotuka Dam) exceeded their design flood discharge. The scale of flooding is larger in dams, such as yamasubaru, Saigo, Ouchibaru Dam, located in the middle to lower area of the river basin, due to the relatively large total rainfall in those areas. Regarding the typhoon's strength, it was a large typhoon with developed rain clouds covering wide area. As the typhoon moved, extremely intense rain of around 50mm/hr. began to fall from the beginning. Furthermore, it approached and landed in Kyushu while still accompanied by dense rain clouds. The heavy rain accompanying Typhoon No.14 did not involve extremely intense rainfall like 80-100 mm per hour, which is typically referred to as 'concentrated heavy rain'.Instead, it consistently rained heavily around 40 mm per hour for continuous period, resulting in a very large rainfall totally.	The Kamishibiba Power Plant (maximum output of 93,200 KW) is located at the upstream end of the Earikawa river system and plays a crucial hydropower plant in the system. Since its operation began in 1955, the power plant had experienced 50 years of operation, leading to significant aging of the turbines and generators. Power plant and switchyard were flooded.					○		(1) No.1 and No.2 turbine and generator (45,000kW) …Flooding (2) Switchyard …Flooding (3) No.1 Main transformer (220kV/110kV/11kV) damaged (4) Access Road to power plant… washed out (5) Tailrace outlet … Sediment accumulation	Flood + Sediment inflow
2-16 (Example of Flood Damage) Taki Power Plant	In the early hours of July 26, 2011, warm and moist air from the Pacific High to the south and cold and moist air from the Okhotsk High to the north flowed into the stationary front over Niigata Prefecture, intensifying its activity. This caused heavy rainfall primarily in the Chuetsu region of Niigata Prefecture and the Shizu region of Fukushima Prefecture from July 27 to July 30, 2011. 72-hour total rainfall: 700 mm, maximum hourly rainfall: 69.5 mm at Tadami AMeDAS Observation Station.	Due to the frontal heavy rain that occurred from July 28 to 30, 2011, in the Chuetsu region of Niigata Prefecture and the Aizu region of Fukushima Prefecture, the Agano river system's Tadami River basin suffered serious damage to public facilities, private houses, and agricultural land. J-Power also experienced damage to six hydropower plants located in the same river basin. Among them, at the Taki Power Plant, the damage included the destruction of the spillway gate, sediment inflow into the waterway from the intake to the tailrace, and damage to the downstream riverbank of the power plant. And the power plant was flooded, resulting in the loss of all power sources, including backup power. The flow discharge at the time of the disaster, 6,052 m^3/s, exceeded the design flood discharge of 5,100 m^3/s. River water exceeding the elevation of the power plant site flowed into the facility through the cable duct in the switchyard and flooded the power plant via the cable tunnels, resulting in a loss of all power resources.	○	○			○	○	Spillway gate (Damage to the gate leaf and the gate stop). Power plant (Flooding, Loss of main and backup power supplies).	Flood + Sediment inflow
2-17 (Example of Flood Damage) Countermeasure Works against aggradation of riverbed.	The 1995 rainy season brought heavy rainfall over a wide area from Tohoku to Kyushu region, recording 150% to 200% of the average July rainfall. From July 8 to 12, an active front stationed from the Sea of Japan to the Hokuriku region, bringing nearly 500 mm of rainfall to the Kurobe River basin (from July 10 to July 12) and recording hourly rainfall exceeding 50 mm, resulting in the largest flood in the Kurobe River since August 1969.	In the Nekomata area of the midstream section of the Kurobe River, which suffered damage including flooding of the power plant during the July 1995 floods, the riverbed rose by about 10m due to sediment accumulation even after restoration. This led to the burial of the tailrace outlet and resulted in issues that began to affect power generation.					○		Flooding of the power plant and the accommodation for workers, Buried of the Kurobe Railway's steel bridge due to sediment.	Flood + Sediment inflow Task3

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2-18 Recovery works of Otagawa Power Plant from heavy rainfall in Aug. 2014.	In Hiroshima City, on the night of August 19, 2014, to the early hours of August 20, unstable atmospheric conditions led to back building, forming a linear precipitation band extending from southwest to northeast of the city. This caused the intense heavy rainfall. This torrential rain set record-breaking values for hourly, 3-hourly, and 24-hour precipitation at each rain gauge station, leading to significant disasters in Hiroshima City's Asaminami and Asakita areas. It triggered numerous landslides, resulting in a major disaster that claimed the lives of 76 people. The current disaster is attributed to extremely heavy rainfall falling in a very short period and in localized areas, compounded by the significant impact of preceding rainfall. In Saniri Higashi, Asakita Ward, Hiroshima City, where a significant debris flow occurred, a cumulative rainfall of 493mm was recorded as antecedent rainfall from two months prior to one week before the disaster struck.	Due to unprecedented concentrated heavy rainfall and large-scale debris flows that occurred from the night of August 19, 2014, to the early morning of August 20, the Otagawa Power Plant of Chugoku Electric Power Company suffered serious damage. The head tank, spillway and tailrace channel were obstructed by debris flows and forced shutdown of power generation. Additionally, the area around the head tank suffered serious erosion due to the debris flows.			○		○		・Head Tank (1) Approximately two-thirds of the head tank is blocked by sediment and debris. (2) Downstream of the right bank upstream of the head tank, part of the right-side embankment has collapsed. (3) Extensive erosion of the left bank hillside of the head tank. (approximately 20,000 m3) (4) Part of the access road to the reservoir was washed out. ・Spillway (1) Half of the spillway channel (overflow section) was blocked by sediment and debris. (2) Almost of spillway culvert section was blocked by sediment and debris. (3) Overflow from the air duct from the spillway culvert. ・Power Plant (1) No damage to the foundation of the power plant. (2) Small volume of sediment flowed into the turbine. (3) Sediment accumulation of approximately 1.0 to 1.5 meters in the power plant area. (4)The outdoor substation area experienced temporary flooding but suffered no significant damage. ・The building of the power plant (1) Damage to walls (including glass) due to sediment and debris which flowed out from the air duct of the spillway culvert ・Tailrace channel (1) Sediment and sand accumulated along the entire length of the tailrace channel. (Downstream of the junction of the spillway channel for a distance of 100 meters, sediment accumulation depth is approximately 2.9 meters, while elsewhere it ranges from 0.2 to 0.4 meters along the entire length.) ・Other surrounding facilities.	Sediment inflow

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas: Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace	Details of the disaster	Causes of the disaster
2-19 (Example of Flood Damage) Shin-Sugawara Power Plant	Typhoon No.5 landed Miyazaki Prefecture on August 2, 2007, and then proceeded northward towards Oita Prefecture. The central atmospheric pressure at landfall was 965 hPa, and highly developed rain clouds extended northward of the typhoon, staying near the border between Miyazaki and Oita Prefectures, resulting in localized intense heavy rainfall. There was continuous rainfall exceeding 50 mm per hour for 4 hours, with the maximum hourly rainfall during this period recorded at 126 mm.	At the dam, the actual flow discharge exceeded the design flood discharge of 700 m³/s. Although the three spillway gates were fully open, the increasing water level caused to an orifice situation. (Assumed flow discharge; 1310m³/s) And overflow occurred from both the non-overflow section of the embankment (right bank) and the cutoff wall (left bank), leading to flooding of the dam management office and damage to the dam management equipment (Power Receiving Equipment, Backup Generator, Dust Collector, Water Level Gauge and others).	○						Damage and flooding of intake-related facilities	Flood
2-20 Recovery works of Uenogawa Intake Weir, Sukawa Power Plant	Due to the impact of Typhoon No.9 in September 2010, Shizuoka Prefecture's Sunto District, where the Uenogawa intake weir is located, recorded a daily rainfall of 490 mm, setting a record for the highest daily rainfall in its recorded history. After the disaster, estimates of the flow rate based on flood traces at the Uenogawa intake weir site revealed a flood discharge of 129 m³/s, significantly exceeding the design flood discharge of 37 m³/s.	Due to the impact of Typhoon No.9, which made landfall on September 8, 2010, the hydroelectric power facilities within the Kanagawa Branch Office of Tokyo Electric Power Company (now TEPCO Renewable Power, Inc. Matsuda Office), located in the eastern part of Shizuoka Prefecture and the western part of Kanagawa Prefecture, suffered serious damage. Among them, the Uenogawa intake weir of the Sukawa Power Plant experienced a flow discharge more than three times the design flood discharge. This resulted in the erosion of the downstream riverbed protection works, as well as the scouring of the intake weir's foundation and the left bank protection wall.As the severe damage affecting the stability of the intake weir, urgent restoration work was carried out to ensure the stability of the intake weir.	○						Due to the impact of this rainfall, the riverbed protection works and left bank revetment of the Uenogawa intake weir were washed out. Additionally, when the river returned to the normal condition, new scour around the foundation of the intake weir was observed. The damaged areas include the embankment, apron works, riverbank protection, intake facilities, sediment removal equipment, and ancillary facilities.	Flood

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-21 (Example of Flood Damage) Yuyama Power Plant	Typhoon No.15, which formed over the southern seas of Japan on September 13, 2011 at 21:00, moved slowly in a counterclockwise circle over the western seas near Nishidaito Island. It then accelerated while approaching from the southern seas of Shikoku to the Ki Peninsula, making landfall near Hamamatsu City, Shizuoka Prefecture around 14:00 on the 21st, maintaining its strength as it moved northeastward through the Tokai region, Kanto region, and then into the Tohoku region. The typhoon then moved offshore to the east of Fukushima Prefecture late on the night of the 21st, and by 15:00 on the 22nd, it had transformed into an extratropical low-pressure system near the Chishima Islands. Typhoon No.15 stayed over the western seas near Minamidaito Island for a while, allowing moist air to flow into Honshu for a long period. After making landfall, it continued to maintain its strength while moving northeastward, resulting in severe winds and record-breaking heavy rainfall across a wide area from western to northern Japan. From midnight on September 15 to 9:00 am on September 22, total rainfall exceeded 1000 millimeters in parts of Kyushu and Shikoku and in many areas total rainfall recorded more than twice the average September rainfall. 24-hour rainfall total of 320 mm, maximum hourly rainfall of 44 mm: Recorded at our company's observation station.	On September 20, 2011, due to the impact of Typhoon No.15, heavy rain fell in the Tokai region. At the company's rainfall observation station near the Omakawa embankment, the cumulative rainfall reached 483 mm. The Omakawa Dam, located downstream from the Yuyama Power Plant, recorded a peak flow rate of 1,548.5 m³/s, which was the highest ever recorded. As a result, flooding and large-scale landslides occurred in the Omakawa River. The intake weir and intake facilities (Hoisting Device, Automatic Control System and Others), dust removal equipment, and discharge warning systems at the Yuyama Power Plant were damaged. The sediment removal gates and intake gates became inoperable, leading to a shutdown of generation.	○						Most of the main facilities at the Oma embankment received nearly complete destruction, except for the embankment itself. Observation building: Flooding of automatic control panels and others. Damage to the intake facilities: Intake facilities damaged by drift wood and flooding (intake gate, sand flush gate, dust collector, various water level gauges, conduit sluice gates, and conduit sediment removal gates).	Flood
2-22 Renovation works of Kubusu No.2 Dam, Kubusugawa No.2 Power Plant	Due to deforestation and subsequent sedimentation in the upstream mountainous areas and flooding caused by Typhoon No.16 on September 15, 1999, a large amount of sediment flowed into the reservoir, causing it to reach full capacity. As a result, not only was water intake affected, but also sediment accumulation made sediment flushing impossible.	The Kubusu No.2 Dam at the Kubusugawa No.2 Power Plant experienced a massive inflow of sediment into its reservoir due to the typhoon-induced flooding in September 1999. This caused the reservoir to reach its full sediment capacity and the accumulation of submerged driftwood made both water intake and sediment discharge impossible. The upstream area of the dam has experienced significant mountainous degradation, making it difficult to restore power generation capacity with the current facilities. Therefore, a fundamental dam improvement project was undertaken for the smooth operation and management.							Although there was no equipment damage, the sedimentation reached full capacity due to the flood, and it caused to prevent not only water intake but also sediment removal due to the accumulation of submerged wood. Rather than damage to the facility from flooding, progress of sedimentation became the obstacle to the power generation. Therefore, dam improvement works were carried out to streamline operations and management.	Flood＋Sediment inflow

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			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-23 Renovation works of decelerating work of downstream Honna Dam, Honna Power Plant	According to a survey by the Japan Meteorological Agency's Meteorological Research Institute, the "Niigata-Fukushima Heavy Rain in July 2011," event saw conditions conducive to heavy rainfall persisting for an extended period, characterized by a significant decrease in temperature to around 6 degrees Celsius at an altitude of approximately 5,800 meters, along with increased moisture content in the lower atmosphere. It has been determined that these conditions contributed to the occurrence of torrential rainfall exceeding 500 mm within the first 9 hours of the onset of rain. (A flood exceeding the designed flood capacity occurred.)	In July 2011, heavy rainfall in Niigata and Fukushima caused flooding that exceeded the design flood capacity of the Honna Dam, resulting in extensive damage to farmland and other areas downstream of the dam. To mitigate the impact on areas downstream of the dam in the event of a similar-scale flood in the future, construction of a diversion wall using steel sheet piles was carried out. The work primarily involved the installation of steel pipe sheet piles using a down-the-hole hammer and the assembly of temporary support structures using the LIBRA method.						○	There was no damage to the power plant itself	Flood
2-24 Recovery works of Yamasubaru Dam from No.14 Typhoon in 2005	Due to the relatively large total rainfall in the midstream, the discharge volumes increased significantly at the Yamasubaru Dam, Saigo Dam, and Ouchibaru Dam located in the middle to downstream areas. Regarding the intensity of the typhoon, it was large and had developed rain clouds distributed over a wide area. Consequently, very intense rainfall of approximately 50 mm per hour began even when the typhoon was at a distance. Furthermore, it approached Kyushu while still accompanied by dense rain clouds, and made landfall. The heavy rainfall associated with Typhoon No.14 did not typically feature extremely intense rainfall rates like 80-100 mm per hour, which are often referred to as "concentrated heavy rainfall". Instead, it sustained intense rainfall of around 40 mm per hour continuously for a long period. As a result, the total rainfall accumulation was exceptionally high.	The flood caused by the intense rainfall by Typhoon No.14 exceeded previous maximum flow discharge and surpassed the design flood discharge of five out of seven dams in the Mimikawa river system. (Except for Kamisiiba Dam and Morotuka Dam.) At Yamasubaru Dam, the flood reached 4,110 m³/s, exceeding the design flood discharge of 3,387 m³/s. The flood caused the power plant to be submerged, making it inoperable. Large-scale landslides also occurred within the dam reservoir. Between 2003 and 2005, the area of landslides expanded 3 to 10 times, and the annual sedimentation volume increased sharply by 2 to 20 times. Additionally, these landslides generated a massive amount of driftwood, reaching 1.5 times the annual average in just one typhoon.					○		(1) Flooding from No.1 to No.3 turbine and generator. (2) 110kV distribution and switchyard …Flooding (3) Sediment accumulation of waterway. (4) Sediment accumulation of tailrace outlet. (5) A large-scale landslide occurred within the regulating reservoir.	Flood＋Sediment inflow Task3
2-25 Recovery works of Saigo Dam from No.14 Typhoon in 2005 Saigo Power Plant	Due to the relatively large total rainfall in the midstream, the discharge volumes increased significantly at the Yamasubaru Dam, Saigo Dam, and Ouchibaru Dam located in the middle to downstream areas. Regarding the intensity of the typhoon, it was large and had developed rain clouds distributed over a wide area. Consequently, very intense rainfall of approximately 50 mm per hour began even when the typhoon was at a distance. Furthermore, it approached Kyushu while still accompanied by dense rain clouds, and made landfall. The heavy rainfall associated with Typhoon No.14 did not typically feature extremely intense rainfall rates like 80-100 mm per hour, which are often referred to as "concentrated heavy rainfall". Instead, it sustained intense rainfall of around 40 mm per hour continuously for a long period. As a result, the total rainfall accumulation was exceptionally high.	The flood caused by the intense rainfall by Typhoon No.14 exceeded previous maximum flow discharge and surpassed the design flood discharge of five out of seven dams in the Mimikawa river system. (except for Kamisiiba Dam and Morotuka Dam.) At Yamasubaru Dam, the flood reached 4,110 m³/s, exceeding the design flood discharge of 3,387 m³/s. The flood caused the power plant to be submerged, making it inoperable. Large-scale landslides also occurred within the dam reservoir. Between 2003 and 2005, the area of landslides expanded 3 to 10 times, and the annual sedimentation volume increased sharply by 2 to 20 times. Additionally, these landslides generated a massive amount of driftwood, reaching 1.5 times the annual average in just one typhoon.					○		(1) Flooding of No.1 generator. (2) 66kV distribution and switchyard …Flooding (3) Shutdown of the No.2 generator (Sediment accumulation of waterway).	Flood＋Sediment inflow Task3

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2-26 Renovation works of Taisho Pond intake weir of Kasumisawa Power Plant	Regarding the scale of the flood discharge, there is no clear documentation. When the river flow exceeded the drainage capacity of approximately 61 m³/s, the water would regularly overflow the crest of embankment weir and cause natural collapse.Moreover, collapse occurred approximately twice a year on average over the past ten years. (It can be assumed that the flood discharge exceeded the design flood discharge.)	The Kasumisawa Power Plant intake weir is an intake facility constructed by embankments and intake weir at Taisho Pond, located at the uppermost reaches of the Katsura River in the Shinano river system. The current drainage capacity of Taisho Pond is approximately 61 m³/s through the intake gate, sand flush gate, and drainage gate. If the river flow exceeds this capacity, the flow will overflow the weir crest and result in natural collapse. It should be noted that collapse have occurred approximately twice per year on average over the past ten years.	○						Washout of the embankment as the intake for the Kasumisawa Power Plant. (This embankment maintains the water level of the tourist site Taisho Pond.)	Flood
2-27 Renovation works of Kakkonda No.2 Power Plant, Power Plant by flood damage in Aug.2017	From August 24 to 25, 2017, a stationary front passing through the northern Tohoku region caused intense rainfall, with total precipitation exceeding 200 mm over the two days.	The Kakkonda No.2 Power Plant suffered serious damage to its intake facilities and sedimentation tanks due to heavy rainfall from a stagnant front in the northern Tohoku region between August 24 and 25, 2017, rendering it inoperable.	○		○				(1) Damage to the upstream protection wall of the intake. (2) Washout the observation building. (3) Partial damage to the intake structure. (4) Damage to the automatic control device of the intake. (5) Washout of the screen. (6) Damage to the spillway channel of the settling basin and sediment inflow into the waterwayl.	Flood
2-28 (Example of Flood Damage) Nagayama Power Plant	With the passage of Typhoon No.6 in July 2011, the cumulative rainfall in the surrounding regions at that time exceeded 1,000 mm. The river inflow exceeded the Hiranabe Dam's design flood discharge of 1,000 m³/s, reaching a recorded 1,700 m³/s.	A large-scale slope collapse occurred on a tributary on the right bank, approximately 500 meters upstream of the Hiranabe Dam. The resulting debris flow entered the pondage, creating a surge that overflowed the dam. The overflow situation at that time was confirmed through visual observation by the gate operators and TV monitors of the Hiranabe Dam. The surge that overflowed the dam reached a height of about 2 meters above the dam crest, and the overflow lasted for several tens of seconds. As a result of this overflow, the control equipment for the spillway gate was submerged and became non-functional.		○					Inoperable of the spillway gate due to submersion of the spillway gate control device.	Flood＋Sediment inflow
2-29 (Example of Flood Damage) Yunotani Power Plant	According to a survey by the Japan Meteorological Agency's Meteorological Research Institute, the "Niigata-Fukushima Heavy Rain" event saw conditions conducive to heavy rainfall persisting for an extended period, characterized by a significant decrease in temperature to around 6 degrees Celsius at an altitude of approximately 5,800 meters, along with increased moisture content in the lower atmosphere. It has been determined that these conditions contributed to the occurrence of torrential rainfall exceeding 500 mm within the first 9 hours of the onset of rain. The rainfall graph showed that daily rainfall exceeded 100 mm for three consecutive days. Cumulative rainfall (453 mm): Recorded at our company's observation station.	The heavy rainfall in Niigata and Fukushima in July 2011 caused damage to the intake weir and the protective embankments of the power plant, leading to flooding of the power plant and damage to the electrical equipment.	○				○		Intake embankment (partial damaged by flooding). Power plant (Electrical equipment failure due to flooding). Partial damage to the protection wall of the power plant.	Flood

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2-30 (Example of Flood Damage) Haneo Power Plant	Typhoon No.19 brought heavy rainfall to the upper stream of the Agatsuma River from October 11 to 12 in 2019. At the Tashiro Observation station in the upper stream of the Agatsuma River, heavy rainfall was observed with a maximum hourly rainfall of 44 mm and a cumulative rainfall of 442 mm. This resulted in a significant inflow water and sediment into the Haneo Intake Dam. * 24-hour rainfall total (442 mm), maximum hourly rainfall (44 mm): at Tashiro observation station.	In October 2019, Typhoon No.19 brought heavy rain to the Kanto and Koshin regions, causing flooding and landslides in the upper reaches of the Agatsuma River. At the Haneo Power Plant, the dam embankment, intake side walls, and protection embankments of the powerhouse (substation) suffered serious damage.	○				○		Damage to the intake dam structure Damage to the intake structure sidewall Damage to the power plant (substation) embankment.	Flood
2-31 (Example of Flood Damage) Kumakawa Power Plant	Typhoon No.19 brought heavy rainfall to the upper reaches of the Kumakawa River from October 11 to 12 in 2019. At the Hairon Observation station in the upper stream of the Kumakawa River, heavy rainfall was observed with a maximum hourly rainfall of 47 mm and a cumulative rainfall of 517 mm. This resulted in a significant inflow water and sediment into the Kumakawa Intake Dam. At the spillway and head tank, heavy rain also occurred. * 24-hour rainfall total (511 mm), maximum hourly rainfall (47 mm): at Dokohara observation station.	In October 2019, heavy rain from Typhoon No.19 affected the Kanto and Koshin regions, causing flooding in the upper reaches of the Kumakawa River. At the Kumakawa No.1 Power Plant, the intake dam embankment was damaged, and the streams around the head tank increased. This led to runoff from the backyard and collisions with debris flows, causing damage to the side walls of the spillway channel.	○		○				Damaged to the dam damaged to the side wall of the spillway channel	Flood＋Sediment inflow
2-32 (Example of Flood Damage) Otsu Power Plant	Due to Typhoon No.19 in October 2019, a large amount of rain fell on the upper reaches of the Agatsuma River and the Kuma River from October 11 to October 12. At the Tashiro (JMA) observation station located in the upper reaches of the Agatsuma River, a maximum hourly rainfall of 44 mm and a total of 442 mm were recorded. At the Hiron (MLIT) observation station in the upper reaches of the Kuma River, a maximum hourly rainfall of 47 mm and a total of 517 mm were observed, resulting in a peak inflow to the Otsu Dam of 1,198 m³/s. (It can be assumed that the peak inflow exceeded the design flood discharge.)	In October 2019, heavy rain from Typhoon No.19 affected the Kanto and Koshin regions, causing flooding in the upper reaches of the Agatsuma River and the Kumakawa River basin. At the Otsu Power Plant, the downstream area of the dam and the protection wall of the power plant were washed away, and the power plant itself was flooded with turbid water and debris, resulting in extensive damage.					○	○	Damaged to the downstream protection wall of the dam and power plant, Flooding of the power plant (structure, electrical equipment). Sediment accumulation at the tailrace outlet.	Flood
2-33 (Example of Flood Damage) Tamano Power Plant	Typhoon No.15, which formed over the southern seas of Japan on September 13, 2011 at 21:00, moved slowly in a counterclockwise circle over the western seas near Minami-Daito Island. It then accelerated while approaching from the southern seas of Shikoku to the Ki Peninsula, making landfall near Hamamatsu City, Shizuoka Prefecture around 14:00 on the 21st, maintaining its strength as it moved northeastward through the Tokai region, Kanto region, and then into the Tohoku region. The typhoon then moved offshore to the east of Fukushima Prefecture late on the night of the 21st and transformed into an extratropical cyclone near the Chishima Islands around 15:00 on the 22nd. Typhoon No.15 lingered over the western seas near Minamidaito Island for a while, allowing moist air to flow into Honshu for an extended period. It maintained its strength while moving northeastward, resulting in widespread severe winds and record-breaking heavy rainfall across western to northern Japan. From midnight on September 15 to 9:00 am on September 22, the total rainfall exceeded 1000 millimeters in parts of Kyushu and Shikoku, with many locations recording total rainfall more than twice the average September rainfall.24-hour rainfall total: 383.5 mm, Maximum hourly rainfall: 68 mm, at Tajimi observation station.	On September 20, 2011, heavy rain from Typhoon No.15 affected the Tokai region. The nearby Japan Meteorological Agency observation station (Tajimi Station) recorded a total rainfall of 496.0 mm from September 19 to 21. As a result, flooding occurred in the Shonai River, causing damage to the intake weir, intake facilities (including the hoisting equipment, machine control panel, and automatic control devices) of the Tamano Power Plant located downstream, as well as to the settling basin and waterway. The sand flush gates and intake gates became inoperable, leading to the shutdown of the generation. Due to the restoration work for these damages, the power plant was forced to stop operation, resulting in 89-day shutdown of commercial operations.	○		○				Embankment, inlet of the intake facilities, settling basin, waterway (damaged to the intake facilities by drift wood and flooding).	Flood

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2-34 (Example of Flood Damage) Samigawa Power Plant	Typhoon No.15, which formed over the southern seas of Japan on September 13, 2011 at 21:00, moved slowly in a counterclockwise circle over the western seas near Nishidaito Island. It then accelerated while approaching from the southern seas of Shikoku to the Kii Peninsula, making landfall near Hamamatsu City, Shizuoka Prefecture around 14:00 on the 21st, maintaining its strength as it moved northeastward through the Tokai region, Kanto region, and then into the Tohoku region. The typhoon then moved offshore to the east of Fukushima Prefecture late on the night of the 21st and transformed into an extratropical cyclone near the Chishima Islands around 15:00 on the 22nd. Typhoon No. 15 lingered over the western seas near Minamidaito Island for a while, allowing moist air to flow into Honshu for an extended period. It maintained its strength while moving northeastward, resulting in widespread severe winds and record-breaking heavy rainfall across western to northern Japan. From midnight on September 15 to 9:00 am on September 22, the total rainfall exceeded 1000 millimeters in parts of Kyushu and Shikoku, with many locations recording total rainfall more than twice the average September rainfall.24-hour rainfall total: 283.5 mm Maximum hourly rainfall: 30.5 mm: at Kanayama observation station.	On September 20, 2011, heavy rain from Typhoon No.15 affected the Tokai region. The nearby Japan Meteorological Agency observation station (Kanayama Station) recorded a total rainfall of 307.5 mm from September 19 to 21. As a result, flooding occurred in the Sami River, causing damage to the intake weir and intake facilities (including the hoisting equipment, automatic control devices, etc.) of the Sami River Power Plant located downstream. The sand flush gates and intake gates became inoperable, leading to the shutdown of the generation. Due to the restoration work for these damages, the power plant was forced to stop operation, resulting in a 132-day shutdown of commercial operations.	○						Embankment and inlet of the intake facilities (damaged by drift wood and flooding)	Flood
2-35 (Example of Flood Damage) Tsukabaru Power Plant	Due to the relatively large total rainfall in the midstream, the discharge volumes increased significantly at the Yamasubaru Dam, Saigo Dam, and Ouchibaru Dam located in the middle to downstream areas. Regarding the intensity of the typhoon, it was large and had developed rain clouds distributed over a wide area. Consequently, very intense rainfall of approximately 50 mm per hour began even when the typhoon was at a distance. Furthermore, it approached Kyushu while still accompanied by dense rain clouds, and made landfall. The heavy rainfall associated with Typhoon No.14 did not typically feature extremely intense rainfall rates like 80-100 mm per hour, which are often referred to as "concentrated heavy rainfall". Instead, it sustained intense rainfall of around 40 mm per hour continuously for a long period. As a result, the total rainfall accumulation was exceptionally high.	The heavy rain from Typhoon No.14 in September 2005 caused numerous landslides around the river (approximately 470 locations). Medium to large-scale landslides have occurred on the right bank of the upstream river from the Yamasubaru Power Plant. Specifically, large-scale landslides occurred on the right bank 5,000 meters upstream of Tsukabaru Dam and 500 meters downstream of Tsukabaru Dam, leading to river blockage (natural dam) phenomena.					○		(1) Flooding from No.1 to No.4 turbine and generator (15650KW). (2) Flooding or No.5 turbine and generator (490KW). (3) Sediment accumulation of tailrace outlet.	Flood＋ Sediment inflow

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-36 (Example of Flood Damage) Hayatogawa Power Plant	Typhoon No.19 in 2019 brought heavy rainfall. Due to sediment accumulation near the tailrace, the riverbed water level rose, causing river water to backflow through the drainage outlet in the powerhouse.	In October 2019, heavy rain from the approach of Typhoon No.19 affected the Kanto region, with the total rainfall on the 12th reaching 766 mm at the Hayato observation station within the basin. As a result, flooding occurred in the Hayato River, causing the Hayatogawa Power Plant to lose power and suffer other damages due to the flooding of the power plant. Since the outlet of the drainage pump installed in the turbine generator room is positioned above the design flood level, the gaps in the wall openings were deliberately left unsealed to allow natural drainage in the event of a power loss. A large amount of sediment has accumulated downstream of the weir, enough to block the tailrace outlet, and the riverbed elevation downstream has also risen. Therefore, it is estimated that the water level rise is due to sediment accumulation. As a result, the generator became inoperable, and the restoration work for these damages led to a 16-month shutdown of commercial operations.					○		Electrical equipment failure due to flooding of the power plant.	Flood + Sediment inflow
2-37 (Example of Flood Damage) Doushi No.4 Power Plant	Typhoon No.19 in 2019 brought heavy rainfall. 24-hour rainfall total: 269.2 mm, Maximum hourly rainfall: 39.8 mm: at Doushi observation station.	In September 2011, heavy rain from the approach of Typhoon No.15 affected the Kanto region, with the total rainfall in the Doshi River basin reaching 269.2 mm. As a result, rainwater flowed down along the backyard of the Doshi No.4 Power Plant and the penstock of the No. 2 Power Plant, exceeding the capacity of the drainage facilities. The water entered through openings such as the ventilation fans of the Doshi No.4 Power Plant, causing flooding, power loss, and other damages at the power plant. As a result, the power plant was shut down for 18 months for restoration work.					○		Electrical equipment failure due to flooding of the power plant.	Flood
2-38 Flood Damage of Oroville Dam (US)	The rainy seasons of 2016–2017 recorded the highest rainfall in California's history. Due to heavy rainfall, there was a record inflow from the Feather River, resulting in the release of water through the spillway. The release from the spillway in February reached 1,400 m³/s.	The rainy season of 2016–2017 recorded the highest rainfall on record in California. Due to the heavy rain, there was a record inflow from the Feather River, and water was released through the spillway. In February, the discharge from the spillway reached 1,400 m³/s. This unusual condition made the discovery of a subsidence hole more than 12 meters deep in the concrete foundation. However, with the continued rainfall, it was necessary to keep using the spillway, and the damage worsened. There was also an emergency spillway, but its use was avoided as much as possible due to concerns that it might affect the transmission lines. This was another reason for continuing to use the damaged spillway. In the first year of repairs, temporary reinforcement was carried out. Starting in 2018, full-scale reinforcement began, including work such as laying reinforced concrete over the compacted concrete.			○				Scour of the concrete foundation of the spillway channel.	Flood

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-39 Upper Bhote Koshi Power Plant (Nepal)	Since August 2014, this powerhouse has sustained damage from three consecutive disasters. (1) Landslides caused by heavy rainfall. (2) Influence of upstream dams (Collapse due to flooding caused by rainfall above June averages).	Since August 2014, this power plant has been damaged by disasters three times in succession. (1) Due to a landslide caused by heavy rain, a natural dam was formed, damaging the transmission towers. Construction of new transmission towers resulted in a 6-month suspension of operations. (2) The landslides triggered by the 2015 earthquake (with magnitudes of 6.7 and 7.3) caused sediment to flow into the power plant and damaged the penstock. (3) The upstream dam broken down due to the effects of heavy rain (with inflow volumes higher than average for June). The dam, intake, spillway, gates, and power plant were all extensively damaged, resulting in widespread damage to all equipment.	○	○	○		○		(1) Damage to the transmission tower. (2) Damage to the dam, flooding of intake, overflow channel, gates, and the power plant.	Flood + Sediment inflow
2-40 Renovation works of Callahuanca Power Plant (Peru)	The 2017 Coastal Niñon brought heavy rain to northern South America, including Peru. The cumulative rainfall from January to March 2017 was approximately 550 mm, making it the third highest rainfall amount between 1997 and 2017. In the town of Barba Blanca near the powerhouse, 120 houses have been lost.	The Callahuanca Power Plant is a hydropower plant located on the Santa Eulalia River, which is part of the Rímac River basin in Peru. The power plant was forced to shut down due to the damage to the water conduit and turbine generator equipment caused by the torrential rains brought by the El Niño phenomenon. The report indicated that instead of renovating the facility, it was restored. The equipment, including the generator, turbine, transformer, and control devices, were all completely replaced.			○		○		The power plant was affected by landslides. (1) Damage to the turbine, generator, control equipment, and transformer. (2) The waterway was affected by landslides.	Sediment inflow
2-41 Back online of the Thomson Power Plant (US)	On June 19, 2012, approximately 10 inches of rain fell over the St. Louis River basin within a 24-hour period. This led to the flooding of the turbines at six Thomson hydroelectric powerhouses, overflow of the Thomson Reservoir and part of embankment. Consequently, power generation was halted for about two years.	The 120MW Thomson project - the largest hydroelectric facility in the US state of Minnesota - sustained major damage following severe flooding almost two years. About 10 inches of rain fell in the St. Louis watershed during a 24-hour period beginning June 19, 2012, swamping the six Thomson turbines, overtopping Thomson Reservoir and breaching a portion of an earthen dike at the fore bay. Working in consultation with the Federal Energy Regulatory Commission (FERC), Minnesota Power and its contractors have undertaken a 22-month repair project, planning and rebuilding the fore bay, cleaning, repairing and refurbishing the powerhouse and its six turbines.					○		(1) Submersion of the turbine and generator. (2) Overtopping of embankment. (3) Damage to the intake weir.	Flood
2-42 Flood-damaged Lower Modi No.1 hydro project (Nepal)	The heavy rainfall and flooding in early July 2021 resulted in a nationwide disaster, causing fatalities across the country. Pokhara city in central Nepal recorded 203.3 mm of rainfall, while Lumle near the Kaski district recorded 147.5 mm.	The Lower Modi No.1 hydro power project suffered 300 meters of canal damage due to flooding, but early restoration work allowed for a prompt resumption of operations.			○				Damage to the waterway.	Flood + Sediment inflow

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-43 Halton Lune Hydro Power Project (UK)	In December 2015, northern England experienced two major flooding events with extreme, even in some locations unprecedented, rainfalls and flooding. New 24-, 36-, and 48-hour UK rainfall records were created of 341.4, 401.4, and 405.2 mm, respectively.	Although the power plant began operation in 2014, on Saturday, December 5, 2015, catastrophic flooding occurred in North Lancashire. The River Lune rapidly rose to a level approximately 1.5 meters higher than previously recorded water levels. The power plant was submerged, and a large number of debris and sediment accumulated in the power facilities and fish way.					○		(1) Inflow of sediment into the fish way and the power plant. (2) Flooding of the power plant.	Flood＋ Sediment inflow
2-44 Flood damage of Kulekhani Power Plant (Nepal)	In July 1993, a heavy rain event with an hourly rainfall of 80 mm and a daily precipitation of 540 mm caused a major flood, resulting in damage from flooding and debris flows.	In July 1993, a heavy rain event with an hourly rainfall of 80 mm and a daily precipitation of 540 mm caused a major flood, resulting in extensive damage to the penstock and intake facilities, rendering the power plant inoperable. As a permanent measure, the penstock, which was washed away by debris flows, was placed underground. Temporary restoration work was carried out on the intake facilities of the Mandu River, and power generation was resumed in December 1993.		○		○			Serious damage to the steel penstock and intake structures.	Flood＋ Sediment inflow
2-45 Rehabilitation of the Tenom Pangi Hydropower Project (Malaysia)	During the concentrated heavy rainfall in September 1988 (Monthly rainfall:250.1 mm), flooding occurred in the Padas River.	The Tenom Pangi Power Plant, which began operation in 1984, is the only large-scale hydroelectric power plant in Sabah, Malaysia. It serves as a key power plant supplying electricity to the western coast of the state, including Kota Kinabalu, which consumes about 40% of the state's total electricity generation. The station is located along the Padas River, 120 km south of Kota Kinabalu. The power generation capacity is 66 MW (22 MW × 3 units), and at the time of its commissioning, it supplied 50% of the peak electricity demand of 123.1 MW in the western coast region. However, during the heavy rainfall in September 1988 (monthly rainfall of 250.1 mm), flooding in the Padas River caused damage to facilities around the intake for power generation (such as debris screens and vertical gates), causing trouble of hydro power operation. As a result, an unplanned shutdown of operations led to a halt in power supply, making it impossible to ensure a stable electricity supply. To overcome this situation, urgent implementation and appropriate rehabilitation measures became an urgent priority.	○						Damage to the trash rack and vertical gate.	Flood

Name of the project	Weather conditions at the time of the disaster	Overview of the disaster of Power facilities	Destroyed areas						Details of the disaster	Causes of the disaster
			Intake	Spillway	Waterway	Penstock	Powerhouse	Tailrace		
2-46 Rainbow Falls Power Plant Restoration (US)	This damage was caused by Hurricane Irene in 2021.Irene caused widespread destruction and at least 49 deaths. Damage estimates throughout the United States are estimated near $13.5 billion, making Irene one of the costliest hurricanes on record in the country. In addition, monetary losses in the Caribbean and Canada were $830 million and $130 million respectively for a total of nearly $14.2 billion in damage.	In late August 2011, Hurricane Irene battered eastern New York State with torrential rains and high winds, which flooded the Rainbow Falls hydroelectric powerhouse. The facility is located on the Ausable River, 5.5 miles upstream of Lake Champlain and in the northeast corner of Adirondack Park. It is operated by a local utility company. The powerhouse, dam and other surrounding infrastructure was heavily damaged, and this set off a multi-year recovery and reconstruction effort that began shortly after the hurricane. Multi-disciplinary teams worked across technical boundaries and company lines to complete rehabilitation efforts in 2020, resulting in new, modernized equipment that will perform for decades to come. Today, the power plant has a generating capacity of 2.6 MW, which produces enough clean, local, renewable energy to power about 1,775 average homes.					○		(1) Flooding of the power plant. (2) Scour of the surface of the spillway channel. (3) Isolation between the dam's pier structures.	Flood
2-47 Restoration of Moco-Moco Power Plant (Guyana)	The cause of this case was a landslide triggered by heavy rainfall in 2003.	The Moco-Moco Power Plant, which began operation in May 1997, was developed as a run-of-river type hydroelectric power plant. It is located on the Moco-Moco Creek in Region 9 of Guyana. The Moco-Moco Creek begins in the northern part of the Kanuku Mountains and is a tributary of the Amazon river system, joining the Rio Catuaba, which forms the boundary river between Guyana and Brazil, 1 km south of Resehm. The Moco-Moco Creek has a total length of 26 km and a difference of height of approximately 400 meters. The section of the creek developed as part of the hydroelectric power project is approximately 1.5 km long, with a height difference of about 225 meters. The purpose of this project was to supply electricity to Resehm and the surrounding villages. On July 5, 2003, a sudden heavy rain occurred, and on July 6, 2003, a landslide happened, causing damage to the penstock. Due to the damage to the penstock, water leaked out, causing damage to the supports and other structures, which led to a halt in power generation. Since there was no clear prospect of resuming operation, it remained as it was. In recent years, a renovation plan has been decided. The plan involves utilizing existing facilities and constructing new facilities in areas with a lower risk of sediment disasters.				○			Damage to the steel penstock (Water leakage due to damage to the steel penstock).	Sediment inflow

APPENDIX B：OVERVIEW OF RENOVATION WORKS AND ELEMENTS OF ENHANCING RESILIENCE FOR CLIMATE CHANGE (SUBTASK 2)

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-1 Damage and Restoration of Sekigawa River System	Designated as the 'Sekigawa Disaster Recovery Subsidy Project' by the government and received financial assistance. To comply with the River Management Facilities Structural Standards, the following measures were implemented: ・Due to the review of planned high-water level, Stability of the embankment was restored by adding a buttress to the dam's rear and increasing the elevation of protection wall. ・ Due to the route change of the river, functions of the structure were restored by widening the intake bank, connection and installation of the sand discharge channel and spillway. ・As part of restoring the functionality of existing structures due to planned riverbed lowering, the following measures were implemented: installation of root extensions for existing embankments and relocation of connecting channels. ・ As part of environmental conservation measures for river flora and fauna, renovations to existing fish ways were carried out. No changes to maintenance management.	The anticipated future flood risk：The design flood discharge was revised and changed to the planned maximum flood discharge determined in the River Improvement Plan by Niigata Prefecture. Renovation and modification plans for power generation facilities：Implementation of river improvement and renovation of facilities (Expansion of flow capacity). Review of operation and maintenance management：none.	There was no access road near the site, and it was located within the Joshinetsu National Park. Due to the difficulty of concrete placement, a Putzmeister high-pressure pump was used. (Piping length of 1,620 meters.)	Flood
2-2 Restoration of Nagamatsu Power Plant	Partial damage to the embankment, Partial damage to the tailrace protection wall, Settlement of the pier foundation of the steel penstock management bridge, Restoration work for the submerged power plant.	The anticipated future flood risk：Revision of the design flood discharge. Renovation and modification plans for power generation facilities：Abolition of the supporting pier of the penstock management bridge (Enhanced flow capacity by expanding flow accumulation).	Regarding the construction of the steel penstock management bridge, the pull-in rail method was adopted considering safety and cost factors.	Flood
2-3 (Example of Flood Damage) Miyashita Power Plant	Since the construction site is near to the main river, temporary cofferdams were installed, and ground improvement was conducted to ensure safety. For sediment removal, a combination of air-jet pumps (MPJ construction method) and air-lift methods was adopted.	The anticipated future flood risk：Increase in sediment supply. Continuous dredging in the pondage as a sediment management. Renovation and modification plans for power generation facilities：Raising the height of the power plant's flood protection wall Renovation works of bank protection walls within the pondage coordinated with the River Improvement. Improvement of flow diversion walls, Increased volume of dredging within the pondage, Hourly updates of dam information on the website Review of operation and maintenance management.	Widespread damage from the intake to the tailrace channel by debris and driftwood.	Flood＋Sediment inflow
2-4 Overview of Recovery Works from Heavy Rain Disaster at Sendatsu Power Plant	Landslide on the western slope of the penstock (Slope of penstock): Selection of the ground reinforcement soil method. A combination of shotcrete and rebar insertion methods was used. Renovation work on the western slope of the penstock (Upper slope of the landslide): Selection of the ground reinforcement soil method. A combination of shotcrete and rebar insertion methods was used. Spraying vegetation materials were adopted at the lower part of shotcrete slope. Measures for stream water management on the eastern side of the penstock: Existing spillway waterway were utilized to construct new stream water management facilities.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Strengthening storm water treatment capacity around the penstock and the power plant, Enhanced slope protection along the waterway channel, Enhanced measures for stream water management. Review of operation and maintenance management：none.	N/A	Flood＋Sediment inflow

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-5 (Example of Flood Damage) Shimodai Power Plant	(1) For the intake dam, concrete repair method was adopted for repairing scour damage. (2) The dust collector was installed by removing trees around the sedimentation basin and the dust collector control panel was placed 2 meters higher inside the intake station. (3) Removal of sediment from the waterway channel. (4) Removal of sediment and driftwood from the No.1 waterway bridge. (5) For the restoration of the No.3 culvert, loose rocks at the landslide area on the mountainside were removed to stabilize the slope. In addition, a floor slab was placed to prepare for debris flows in the water conduit and retaining walls were constructed to protect the conduit embankments. (6) For the No.4 culverts, to stabilize the collapsed slope, the existing water conduit culvert was removed and replaced to a pipe of the same cross-section.	The anticipated future flood risk：none Renovation and modification plans for power generation facilities：Strengthening slope protection around the facility, Strengthening the flow capacity of the spillway channel (Flood prevention for the power plant), Relocating the dust collector control panel to a higher position. Review of operation and maintenance management：none	N/A	Flood＋ Sediment inflow
2-6 Saigawa Power Plant	A part of the embankment and the steel gate were removed, and an SR weir was installed. Contents of the construction are as follows: Removal of the sand flush gates (width 3mx 2 gates), Removal of part of embankment (57m), Installation of upstream bed protection works (5m), Installation of downstream bed protection works (19m), Installation of an SR composite adjustable weir (1gate-7units), Clear span 35mx effective height 2.95m.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Removing steel gates from the dam and replacing to SR weirs. Review of operation and maintenance management：none.	N/A	Flood
2-7 Renovation Work of Tenjin Weir (SR Weir) Tenjin Power Plant	The Tenjin Weir is a fixed concrete weir, and because it causes to the rise in river water levels near the intake facilities, there has been a demand to convert it to a movable weir. Therefore, when comparing weir types, an SR composite adjustable weir and a rubber weir were considered. The SR composite adjustable weir was chosen due to its ability to maintain a constant water level and its resistance to sediment and metallic debris. And the fishway was renovated with consideration for environmental factors.	The anticipated future flood risk：Changing the design discharge from 1800m3 to 2200m3 considering future flood risk. Renovation and modification plans for power generation facilities：Changing from a fixed weir to an SR weir, Simultaneously reconstructing the fish way and considering environmental impacts. Review of operation and maintenance management：none.	N/A	Flood
2-8 Construction of Bypass Channel of Oigawa Dam	At the uppermost reach of Lake Oi River Dam, an intake weir and intake were installed close to the downstream of Nagashima Dam. From this intake, a bypass tunnel was constructed extending to just downstream of the Oi River Dam, including the intake weir, intake, and waterway (comprising open channels, culverts, and tunnel sections).	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：A bypass waterway tunnel was constructed from the intake to directly downstream of the dam (This contributed to sediment control measures). Review of operation and maintenance management：none.	Based on the request from Kawane Honcho town for river environment improvement, a bypass tunnel was constructed as a new measure for turbidity control.	Flood＋ Sediment inflow
2-9 Waterway Renovation Work of Shima Power Plant	This renovation project involved directly connecting the upstream Kamimura Power Plant tailrace channel with the Shima Intake weir via a new waterway, and to remove the existing Shima Intake embankment.	The anticipated future flood risk：Improvement of the power plant's waterway system. Renovation and modification plans for power generation facilities：Connected the tailrace of upstream Kamimura Power Plant directly to the intake of the Shima Power Plant through connecting waterway, in order not to affected by flood risks. Review of operation and maintenance management：none.	N/A	Flood

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-10 Renovation works for apron works of Zakkokudani Intake Dam, Shomyou-gawa No.2 Power Plant	In the restoration works, to prevent debris flows into the intake and ensure stable water intake from the central part of the river, a new Tyrolean-style intake (horizontal screen) was installed at upstream of the existing intake dam. The intake area was covered with a concrete slab, and directly connect to the existing intake inlet. To prevent flooding of power and monitoring control equipment, the gate hoist room was relocated to a place 7 meters higher than the crest of the intake dam (4 meters higher than the existing hoist room). This relocation was based on the consideration of water level rises during the damage events in 2004 and 2005. For wear and scour issues at the overflow section and water impact areas of the intake dam, wear-resistant cast steel plates were adopted considering constructability and economic efficiency.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Renovated to a Tyrolean-type intake (Preventing intake blockage due to sediment accumulation in the front), Raising the elevation of the gate hoist room (Protection against flooding for power and control monitoring devices), Installed abrasion-resistant cast steel plates to prevent wear and scouring at the overflow and water impact areas of the intake dam Review of operation and maintenance management：none.	N/A	Flood＋ Sediment inflow
2-11 Improvement Works of Tailrace Shin-Inotani Power Plant	As the restoration work, disassembly and inspection were carried out to restore the turbine and generator at the power plant to their original condition. At the tailrace tank, the elevation of the waterproof walls was increased, and the slab of the tailrace gate operation device was also elevated. At the tailrace facilities, water-tightness improvements were implemented to the tailrace gates, the operation device for the gates was relocated, and a cover was placed to prevent sediment inflow from the opening of the discharge outlet.	The anticipated future flood risk：To prevent flood damage, starting from the 2005 fiscal year, 115 hydropower plants were categorized into three levels of importance based on their individual characteristics, and high water levels were reviewed. Renovation and modification plans for power generation facilities：Implementation of raising the height of the power plant's flood protection wall, Raising the elevation of control devices of tailrace gates, Improvement of tailrace outlet (Waterproofing of the control gate, Replacement of control devices, Change from open channel to culvert). Review of operation and maintenance management：none.	N/A	Flood
2-12 (Example of Flood Damage) Nagatono Power Plant	In the restoration plan, the following considerations were taken into account: (1) Design flood water levels and tailrace water levels for power generation. (2) Foundation type of the power plant (Ground improvement). (3) Design of the main power plant based on (1). (4) Design of the tailrace gates. (5) Design of access roads etc.	The anticipated future flood risk：Predicting and examining the impacts of climate change are studied in collaboration with the Central Research Institute of Electric Power Industry. Review of the design flood level, Raising the power plant site elevation by approximately 4 meters, Structural improvement of the tailrace outlet (Tailrace facilities with protection wall), Set the tail water level 2.5 meters higher. Renovation and modification plans for power generation facilities：Enhancement of the power plant's waterproofing measures (Installation of waterproof doors, Installation of motorized valves to prevent flooding), Ground improvement of the power plant foundation, Installation of anchoring blocks upstream of the power plant. Review of operation and maintenance management：none.	This renovation work was so big, it was like a new construction.	Flood
2-13 Renovation Works of Kitagosho Weir Nakagosho Power Plant	Since there are still many landslide areas in the upstream area, even relatively small-scale runoff can trigger debris flows, and the risk of further damage would be very high. Therefore, by evaluating the potential for recurrence of damage, the cost of restoration work, and profitability, an economical restoration plan with streamlined water intake control functions was developed. The outline of the restoration work is as follows: (1) Replacement of automatic waterway control devices (Streamlining of control functions). (2) Installation of patrol bridges. (3) Installation of a waterproof wall on the left bank upstream of the weir. (4) Repairs to buildings.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Relocation of control devices to a higher elevation. Review of operation and maintenance management： Review of intake control (Simplification of control function).	N/A	Flood＋ Sediment inflow

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-15 Recovery works of Kamishiiba Power Plant	According to the damage assessment, it was determined that the No.2 main transformer and No.2 generator can continue to be used for the time being. After comparing multiple restoration plans, it was decided to temporarily restore the No.2 unit by cleaning, drying, and replacing some damaged parts to resume operation quickly and reduce overflow power. Following the provisional restart of No.2, the plan is to sequentially replace the No.1 and No.2 turbines and generators (final restoration). Regarding the flooding of the power plant, debris flows from the upstream stream blocked the main flow of the Mimikawa River, causing a rise in river water levels. This led to overflow of the waterproof wall on the downstream side of the power plant, which then flowed into the plant building. Consequently, the elevation of the waterproof wall was increased.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities： Reinforcement of the power plant's exterior walls (Installation of reinforcement anchors) Raising the height of the power plant's flood protection wall, Implemented measures for the unstable slope behind the power plant access road (Ground anchor works). Review of operation and maintenance management：Triggered by the intense rainfall and widespread landslides caused by Typhoon No.14 in 2005, the river administrator developed the 'Mimikawa Watershed Comprehensive Sediment Management Plan' and subsequently established a dam sediment passage operation plan aimed at smooth sediment passage in the reservoir.	Related to Subtask 3	Flood
2-16 (Example of Flood Damage) Taki Power Plant	(1) Removal and replacement of damaged spillway gates. (2) Removal of sediment from the intake and casing. (3) Removal of sediment from the draft and tailrace tank. (4) Improvement of the water tightness of the power plant (Insertion of polyurethane-based resin material into cable duct penetration holes, Convert the partition doors between the cable tunnel and the power plant into waterproof doors, Relocate system power-related equipment to upper floors). (5) Flood prevention measures (Installation of flood protection walls around the switching station). (6) Maintenance of the access roads to the power plant.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities： Strengthen the capability of water proofing of the power plant Implementation of flood prevention measures. Review of operation and maintenance management：none.	N/A	Flood
2-17 (Example of Flood Damage) Countermeasure Works against aggradation of riverbed, Shin-Kurobegawa No.2 Power Plant	The sediment accumulated in the Nekonata area was transported to the Dashidaira Dam reservoir. Additionally, emergency sediment discharge from the Dashidaira Dam was carried out three times, as decided by the 'Kurobe River Disaster Recovery Coordination Committee' (established in 1995 to make recovery works efficiently), which includes representatives from the national government, prefectural government, local municipalities, and KEPCO company. Additionally, the embankments of the tailrace area at the Kurobegawa No.2 Power Plant were raised to the flood level of the 1995 disaster. New discharge outlets were added above the existing ones to allow for discharge even with sediment accumulation. This setup was designed to be operable depending on the riverbed conditions.	The anticipated future flood risk：Raising the height of the protection wall of tailrace at the Kurobegawa No.2 Power Plant, Relocation of the tailrace outlet to a higher elevation. The tailrace outlet of the new Kurobegawa No.2 Power Plant was relocated to the downstream Dashidaira Dam reservoir, which is unaffected by sediment, and the tailrace tunnel was replaced. Renovation and modification plans for power generation facilities： Replacement of the water turbine and generator. Review of operation and maintenance management：none.	N/A	Flood＋ Sediment inflow
2-18 Recovery works of Otagawa Power Plant from heavy rainfall in Aug.2014.	(1) Disaster Recovery Measures: The least conditions to restart the generation, restoration work of head tank, spillway and tailrace channel were implemented and to prevent the sediment inflow to the head tank and spillway, cover was installed on them. (2) Reinforcement of Surrounding Ground: To ensure the safety of the facilities after the restarting of power generation, concrete retaining walls were installed as reinforcement for the surrounding ground of the head tank.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities： Improvement of head tank and spillway Reinforcement of the surrounding slopes. Review of operation and maintenance management：none.	N/A	Flood＋ Sediment inflow

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-19 (Example of Flood Damage) Shin-Sugawara Power Plant	To achieve safe and reliable dam management, an overflow-type design was adopted, creating a gateless dam considering labor-saving operations and economic advantages. The dam was converted into a gateless dam to secure its flood discharge capacity because the dam operation facilities was damaged seriously. As a result of this modification, the dam's design flood discharge increased from 700 m³/s to 1,310 m³/s."	The anticipated future flood risk：Reviewed the dam's design flood discharge in line with the renovation works (historical maximum), Removed the previous spillway gates and raised the overflow crest, Extended the overflow length and converted to a gate-less design. Renovation and modification plans for power generation facilities：After confirming the flood discharge that caused the damage, the renovation works have been decided. Since it is anticipated that sediment accumulation will increase due to the raising of the overflow crest, sand flush gates were installed. Review of operation and maintenance management：none	N/A	Flood
2-20 Recovery works of Uenogawa Intake Weir Sukawa Power Plant	The basic policy was to restore the damaged intake weir to the original condition by the next flood season (June 2010) to ensure safety. Furthermore, starting from the next dry season (November 2011), permanent measures were implemented based on the current standards (River and Sabo Engineering Standards). The permanent measures took two years to complete due to the several flooding and snowfall. Concrete was poured primarily into the scoured areas of the intake weir foundation. To ensure the stability of the intake weir and surroundings in case of the revised design flood flow, protection walls were constructed upstream and downstream of the intake weir. Additionally, anti-scouring measures were implemented downstream using a combination of concrete and wire mat works. As a permanent measure, a concrete gravity intake weir was constructed downstream of the existing intake weir, and new protection walls and apron works were also installed.	The anticipated future flood risk：The design flood discharge has been reviewed, and the historical maximum discharge (129 m³/s) has been adopted. Renovation and modification plans for power generation facilities：As a permanent measure, a new gravity-type intake weir was constructed downstream of the existing intake weir and new protection wall and apron works were also newly installed. Review of operation and maintenance management：none.	N/A	Flood
2-21 (Example of Flood Damage) Yuyama Power Plant	The floor elevation of the observation station, which supplies oil for waterway control equipment and maintenance, was raised. And the wiring for cable ducts and similar installations was relocated to a higher elevation. Replacements were made for the automatic control panel and discharge alarm system of the intake equipment, as well as the internal control panel. Additionally, maintenance was performed on the intake gate hoist, and parts of the dust collector were replaced.	The anticipated future flood risk：Review of the design flood discharge. Renovation and modification plans for power generation facilities：Raising the elevation of the observation building, Relocation of control equipment, including cable ducts, to a higher position and enhancement of waterproofing capabilities. Review of operation and maintenance management：none	N/A	Flood
2-22 Renovation works of No.2 Kubusu Dam, Kubusugawa No.2 Power Plant	Existing management bridge: Removal of piers (for expanding width of overflow). Work was carried out to enlarge the sand flush gate and install settling basin.	The anticipated future flood risk：Removal of the piers supporting the spillway management bridge, Prevention of driftwood accumulation. Renovation and modification plans for power generation facilities：Enlargement of the sand flush gate. Review of operation and maintenance management：none.	Election of the pier cutting method (methods that avoid damaging the structure). Utilization of the cut piers as blocks (as retaining blocks). Utilization of concrete waste as roadbed material.	Flood＋Sediment inflow
2-23 Renovation works of decelerating work of downstream Honna Dam, Honna Power Plant	To significantly reduce the impact on the downstream areas of the dam, construction of a flow diversion wall using steel pipe sheet piling was carried out. The work primarily involved the installation of steel pipe sheet piling using a down-the-hole hammer and the assembly of a temporary construction platform using the LIBRA method.	The anticipated future flood risk：The objectives of improvement works are is to enhance the energy reduction effect against flood and disaster mitigation effect in the downstream area by improving the diversion wall downstream of the dam. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management： none.	Since the construction work within the river was limited to the dry season, significant reduction in the construction period was required.	Flood

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-24 Recovery works of Yamasubaru dam from No.14 Typhoon in 2005, Yamasubaru Power Plant	Considering various factors that could affect the slope (such as changes in dam water levels, groundwater fluctuations, and self-impact), slope protection measures were implemented. Restoration of the turbines and generators was also carried out following the flooding. The purpose of the dam modification is to add sand bypass function to the existing spillway gates.	Following the concentrated heavy rainfall and widespread slope landslides caused by Typhoon No.14 in 2005, Comprehensive Sediment Management Plan in Mimikawa river system was formulated under the leadership of River Administrator. Additionally, a dam sedimentation operation plan was developed with the aim of promoting sediment passage through the reservoirs. Regarding the Yamasubaru Dam and Niigo Dam, the current structure could not achieve the necessary water level reduction for sediment passage operations, so improvement to the dams were being implemented. And in order to prevent forest degradation, the forest management plan was also implementing. The anticipated future flood risk：Review of the sediment management plan. Renovation and modification plans for power generation facilities：Change of gates. Review of operation and maintenance management：Modification of the operational plan due to a review of the sediment management plan.	Related to Subtask 3	Flood＋ Sediment inflow
2-25 Recovery works of Saigo Dam from No.14 Typhoon in 2005, Saigo Power Plant	The purpose of the dam modification is to add sand bypass function to the existing spillway gates. As for the Yanbaru Dam, after removing the four central spillway gates of the existing structure, the spillway crest was lowered by 9.3 meters, and new two crest radial gates were installed. Additionally, the existing operation device was raised by 2 meters.	Following the concentrated heavy rainfall and widespread landslides caused by Typhoon No.14 in 2005, the 'Mimikawa River System Comprehensive Sediment Management Plan' was formulated under the leadership of river management authorities. Additionally, a dam sedimentation operation plan was developed with the aim of promoting sediment passage through the reservoir. The anticipated future flood risk：Review of the sediment management plan, modification of dams. Renovation and modification plans for power generation facilities：Modification of gates, elevation increase. Review of operation and maintenance management：Changes to the operational plan due to the review of the sediment management plan.	Related to Subtask 3	Flood
2-26 Renovation works of Taisho Pond intake weir of Kasumisawa Power Plant	Based on the premise of reusing the existing concrete dam foundation, various countermeasures were economically compared, and a rubber tube weir was constructed. Additionally, since it is a tourist area, efforts were made to minimize the impact on the landscape.	The anticipated future flood risk：Installation of a rubber tube weir. Renovation and modification plans for power generation facilities：A stair-step fish way was adopted as the flow release facility for the river maintenance flow. (Environmental consideration.) Review of operation and maintenance management：none.	Comparing the options economically. Construction was carried out during the winter season to avoid the tourist peak season. (From Nov. to Jun.) Construction work in the national park (measures to prevent noise etc.)	Flood
2-27 Renovation works of Kakkonda No.2 Power Plant by flood damage in Aug.2017	In the restoration process, priority was given to the early resumption of operations and prevention of further damage considering the characteristics of coordinated power generation with the upstream Kakkonda No.1 Power Plant, in this restoration work, large block revetment work was carried out for the intake protection, and gravity concrete retaining walls were constructed for the settling basin and spillway.	The anticipated future flood risk：Reinforcement of the intake protection wall, spillway, and other structures. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	N/A	Flood

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-28 (Example of Flood Damage) Nagayama Power Plant	Due to the dam overflow causing the spillway gates to become inoperable, measures were taken to ensure that the gates would remain functional even if overflow occurred for several seconds at a height approximately 2 meters above the dam crest. However, since the dam water level during the disaster was approximately 1 meter below the full water level, the design water level elevation was set at 3 meters above the full water level to account for the possibility of recurrence at full water level. Investigations after the disaster indicated that the failure of gate operation was due to flooding of the control panels and motors, which reduced insulation resistance. Consequently, measures were taken with a focus on ensuring water tightness.	The anticipated future flood risk：Improved to withstand water levels exceeding the full reservoir level by 3 meters, Enhanced the water tightness of the spillway gate control devices. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management： none.	N/A	Flood
2-29 (Example of Flood Damage) Yunotani Power Plant	The spillway gates and wooden stop logs were removed, the crest of the overflow section was raised to the full water level, and the dam was converted to over-flow gateless type.	The anticipated future flood risk：Review of the design flood discharge 350m3/s-->530m3/s (River Improvement Plan of Niigata Prefecture), Removal of the spillway gate (gate-less) and modification of dam (Elevation increase of the overflow section). Renovation and modification plans for power generation facilities：Setting the planned sedimentation slope (Based on the backwater calculations according to the planned sedimentation slope, measures were taken for the road, embankments, and hot spring facilities upstream of the dam). Review of operation and maintenance management：none.	N/A	Flood
2-30 (Example of Flood Damage) Haneo Power Plant	In the restoration of the intake dam embankment and the power plant wall, temporary cofferdams were constructed within the river, and restored by using concrete. For the restoration of the intake side walls, concrete precast products were used to shorten the construction period.	Basically, the goal was to aim for early recovery. Judging from the meteorological conditions at that time, it can be assumed that the area was hit by a flood exceeding the historical maximum flow discharge. The anticipated future flood risk：Flood prevention measures through the installation of tailrace gates. Renovation and modification plans for power generation facilities：Installed backflow prevention valves on the basement level 3 floor (Flood prevention measures) Improvement of drainage pit functionality. Review of operation and maintenance management：none.	N/A	Flood＋ Sediment inflow
2-32 (Example of Flood Damage) Otsu Power Plant	In the restoration work of the downstream dam and the power plant protection wall, it was difficult to establish temporary cofferdams and access roads within the river because of the large amount of river flow. Therefore, restoration work was carried out using embedded formwork that allowed construction without temporary cofferdams and scaffolding ・The restoration of the power plant (buildings and electrical equipment) is currently planned to be carried out through replacement. (It is also planning to remove the sediment accumulated at the tailrace.)	The anticipated future flood risk： Review of the design flood discharge730ｍ3/s --> 1200m3/s (historical maximum). Renovation and modification plans for power generation facilities：Elevation increase of the power plant, Installation of waterproof walls for buildings. Review of operation and maintenance management：none.	N/A	Flood
2-35 (Example of Flood Damage) Tsukabaru Power Plant	・Considering the aging of the facilities, a comprehensive upgrade was carried out. ・Review of design flood discharge and replacement of aging gates. ・Taking into account the flooding damage in 2005, the power plant building was relocated to a different site as part of the comprehensive renovation work. (Relocation of power plant and tailrace downstream of steel penstock.)	The anticipated future flood risk：Review of design flood discharge, Replacement of aging gates. Renovation and modification plans for power generation facilities：Relocation of the power plant to a higher elevation, Relocation of the steel penstock, Relocation of the tailrace channel (Sedimentation prevention measures). Review of operation and maintenance management：none.	Since the project involved mostly new construction, an environmental assessment was required.	Flood

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-36 (Example of Flood Damage) Hayatogawa Power Plant	Sealing the wall gaps at the drainage pump outlet.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Seal the wall gaps at the drainage pump outlet (Improvement of water tightness). Review of operation and maintenance management：none.	N/A	Flood
2-37 (Example of Flood Damage) Doushi No.4 Power Plant	・The drainage path for rainwater was reviewed and modifications were made to ensure the required water flow cross-section. ・The location of the ventilation fan openings and the ventilation route were modified. ・As a preventive maintenance measure, The elevation of the power plant was raised by 1.7 meters.	The anticipated future flood risk：Conducting flood level survey, Review of the drainage system, Sealing of the openings of the ventilation system (water proofing), Modification of ventilation routes. Renovation and modification plans for power generation facilities：Conducted flood level survey, modified the structure to withstand the new design flood level, and increased the structural elevation by 1.7 meters. Review of operation and maintenance management：none.	N/A	Flood
2-38 Flood Damage of Oroville Dam (US)	In the first year of repairs, temporary reinforcement was carried out, and from 2018, full-scale reinforcement began. More than 730 feet of the upstream section of the main spillway channel was demolished and reconstructed with reinforced concrete. And reinforced roller-compacted concrete buttresses were constructed at the base of the emergency spillway channel.	The anticipated future flood risk：Reinforcement of the tailrace channel (Place the reinforced concrete on top of the roller-compacted concrete). Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	N/A	Flood
2-39 Upper Bhote Koshi Power Plant (Nepal)	Restoration to the original condition is the fundamental policy.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：Installing concrete shielding and rock fall protection fences to protect the steel penstock from falling rocks. Review of operation and maintenance management：none.	N/A	Flood
2-41 Back online of the Thomson Power Plant (US)	As part of the restoration work for the spillway and power plant, equipment in the power plant was replaced, turbines were cleaned, and the steel penstock and substation were also renovated during this period.	The anticipated future flood risk： Review of the design flood discharge. Renovation and modification plans for power generation facilities：Elevation increase of the substation to protect flooding. Review of operation and maintenance management：none.	N/A	Flood＋Sediment inflow
2-44 Flood damage of Kulekhani Power Plant (Nepal)	Three years after the emergency restoration work, the following renovation work was carried out: (1) Improvement of intake. (Construction of a sloping intake.) (2) Installation of protection wall for Mando head works. (3) Construction of check dams in the upstream of the Kulekhani River and at the entrance of the reservoir. (4) Installation of a telemetry system for monitoring water levels at the power plant and alarm systems for dam discharge. (5) Procurement of operational and management vehicles. (6) Construction of operation and management road between the first power plant and the dam, and implementation of comprehensive flood control measures. And modification the steel penstock to an underground.	The anticipated future flood risk：In the renovation work, risks such as sediment inflow were anticipated. Renovation and modification plans for power generation facilities：Modified the steel penstock to an underground type, Introduction of check dams, etc. Review of operation and maintenance management：none.	N/A	Flood
2-45 Rehabilitation of The Tenom Pangi Hydropower Project (Malaysia)	Restoration of damaged areas and repair work for equipment that had sustained damage or breakdown unrelated to flooding were carried out.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：Introduction of an inflow forecasting system for flood prediction.	N/A	Flood

Name of the project	Overview of renovation works	Elements of enhancing resilience to climate change	Key points and challenges of the countermeasure works	Causes of the disaster
2-46 Rainbow Falls Power Plant Restoration (US)	Repair of spillway and restoration from flooding were carried out. The electrical panels were relocated at a higher position where they would not be submerged. In addition, the apron surface was repaired because it had become rough, which was thought to negatively impact the flow.	The anticipated future flood risk：Considering future floods, the following systems have been introduced: Installed an underground drainage system at the weir, The control systems, opening and closing devices, measurement panels, and transformers were move to be installed in a newly constructed middle second floor from the turbine generator floor. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	N/A	Flood
2-14 (Example of Flood Damage) Kawabegawa No.1 Power Plant	It was restored by converting to a rubber tube weir (rubber weir), considering cost-effective, reliability of operation, and simplify of management. Regarding the cutoff wall, in addition to ensuring the length of the seepage path, steel sheet piles were driven down to the bedrock on both the upstream and downstream sides to prevent erosion and piping caused by the movement and scouring of the structure's foundation.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：The cause of the disaster was related to structural issues.	Out of the target of this study as shown in Figure 3-3	Flood
2-31 (Example of Flood Damage) Kumakawa Power Plant	In the restoration of the intake dam embankment, temporary cofferdams were constructed within the river, and the original shape was restored by using concrete. For the side walls of the spillway overflow channel, embedded formwork was used to eliminate the need for temporary scaffolding to facilitate early recovery and the original shape was restored by using concrete.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Flood
2-33 (Example of Flood Damage) Tamano Power Plant	Disassembly maintenance of the sand flush gates of intake, settling basin, and waterway channel were carried out, along with replacement of parts (such as relays) in the control panels and distribution panels.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Flood
2-34 (Example of Flood Damage) Samigawa Power Plant	Disassembly maintenance of the sand flush gates of intake, settling basin, and waterway channel were carried out, along with replacement of parts (such as electromagnetic switch) in the control panels and driftwood collector. Additionally, parts replacement (such as transformers) for the automatic control system of the equipment was carried out.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Flood
2-40 Renovation works of Callahuanca Power Plant (Peru)	The collected information is related to the restoration work of power plant facilities and the renewal work of the aforementioned devices.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Sediment
2-42 Flood-damaged Lower Modi No.1 hydro project (Nepal)	As the restoration work for the spillway and power plant, equipment in the power plant was replaced, turbines were cleaned, and the steel penstock and substation were also renovated during this period.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Flood＋ Sediment inflow
2-43 Halton Luna Hydro Power Project (UK)	Removal of sediment and repair (replacement) of generators were carried out.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	Flood＋ Sediment inflow
2-47 Restoration of Moco-Moco Power Plant (Guyana)	Since there were no prospects for restarting operations at this power plant, it remained in a state of prolonged shutdown. As a result, the power plant was scheduled for renovation. Particularly regarding the steel penstock, relocation to low-risk areas for sediment disasters would be considered after conducting a geological survey.	The anticipated future flood risk：none. Renovation and modification plans for power generation facilities：none. Review of operation and maintenance management：none.	Out of the target of this study as shown in Figure 3-3	N/A

APPENDIX C：RESILIENCE ENHANCEMENT MEASURES FOR CLIMATE CHANGE (SUBTASK 2)

Name of the project	Resilience enhancement measures	
	Flood exceeding the design flood discharge	floods by unanticipated events
2-1 Damage and Restoration of Sekigawa River System Power Generation Facilities in the case of Joetsu Flood, Sekigawa River System Power Plant (15 Power facilities)	・Review of Design Flood Discharge (Alignment with the River Improvement Plan) ・Raising the Height of the Embankment ・Expansion of Intake Weir ・Connection of Sediment Discharge Channel and Spillway Channel	N/A
2-2 Restoration of Nagamatsu Power Plant	・Review of Design Flood Discharge ・Removal of pier of inspection bridge for steel penstock (Enlargement of water flow area)	N/A
2-3 (Example of Flood Damage) Miyashita Power Plant	N/A	・Raising the Height of protection wall for the powerhouse ・Renovation works of protection wall in the pondage and guide wall for the river flow harmonizing with the River Improvement Plan ・Continual dredging in the pondage
2-4 "Overview of Recovery Works from Heavy Rain Disaster at Sendatsu Power Plant ", Sendatsu Power Plant	N/A	・Strengthen the capacity of rainwater drainage around the steel penstock and powerhouse ・Strengthen the stream water management along the waterway
2-5 (Example of Flood Damage) Shimodai Power Plant	N/A	・Strengthen the protection wall around the powerhouse ・Relocation of control board for the dust collector to higher place
2-6 Saigawa Power Plant	・Removal of steel gate at the weir and change to SR weir	N/A
2-7 Renovation Work of Tenjin Weir (SR Weir) Tenjin Power Plant	・Review of Design Flood Discharge ・Change from the fixed concrete weir to SR weir	N/A
2-8 Construction of Bypass Channel of Oigawa Dam, Oigawa Power Plant	N/A	・A bypass waterway was constructed from the intake to directly downstream of the dam.
2-9 Waterway Renovation Work of Shima Power Plant, Shima Power Plant	・Removal of existing embankment ・Connection of the outlet of Kamimura Power Plant in the upstream and the intake of Shima Power Plant by connection channel directly (decreasing the flood risk)	N/A
2-10 Renovation works for apron works of Zakkokudani Intake Dam, Shomyougawa No.2 Power Plant	・Relocation the Gate Hoisting Device room to the higher place (for flood prevention) ・Installation of wear-resistant steel plates at the apron of the overflow section of the intake dam to prevent erosion and scouring by the flood. ・Connection of the outlet of Kamimura Power Plant in the upstream and the intake of Shima Power Plant by connection channel directly (decreasing the flood risk)	Improvement works to Tirolean type intake facilities (Prevention of blockage by the sediment in front of intake facilities)

Name of the project	Resilience enhancement measures	
	Flood exceeding the design flood discharge	floods by unanticipated events
2-11 Improvement Works of Tailrace Shin-Inotani Power Plant	・ Review of Design Flood Discharge ・ Raising the Height of the protection wall of the tailrace outlet ・Relocation roll device of the tailrace gates to the higher position	Structural change from open channel of the tailrace to culvert (for the protection of sediment inflow)
2-12 (Example of Flood Damage) Nagatono Power Plant	・Review of Design Flood Discharge・ Raising the level of the powerhouse ・Review of the tailrace water level ・Razing the level of the tailrace and change the structural design (Almost completely destroyed, requiring mostly new construction)	・Strengthen waterproofing measures of the powerhouse(Install the waterproofing doors) ・Install the motor-operated valve for the ventilation system for waterproofing ・Installation of concrete blocks to protect foundation of upstream of powerhouse
2-13 Renovation Works of Kitagosho Weir Nakagosho Power Plant	N/A	・Relocation the control device to the higher place ・Review of the operation and maintenance method ・Simplification of the intake control function
2-15 Recovery works of Kamishiiba Power Plant	N/A	・Reinforcement of the powerhouse exterior walls (Installation of reinforcement anchors) ・Raising the height of waterproofing wall of the powerhouse ・Reinforcement of the slope of the powerhouse access road (Provision of ground anchor works)
2-16 (Example of Flood Damage) Taki Power Plant	・Strengthen the water tightness of the powerhouse (Insertion of urethane resin material to the holes of cable duct, Installation of the waterproofing doors) ・Relocation of the power control devices to upstairs ・Installation of the waterproofing wall around switchyard. ・Maintenance of the access road to the powerhouse	N/A
2-17 (Example of Flood Damage) Countermeasure Works against aggradation of riverbed, Shin-Kurobegawa No.2 Power Plant	N/A	・Raising the height of the tailrace protection walls of the No.2 Kurobegawa powerhouse ・Relocation of the outlet of No.2 Shin-Kurobegawa powerhouse into the downstream reservoir of Dashidaira Dam which is not influenced by the flood sediment and change to the new tailrace tunnel
2-18 Recovery works of Otagawa Power Plant from heavy rainfall in Aug. 2014.	N/A	・Install the roof on the head tank and spillway to prevent sediment inflow ・Installation of the concrete retaining wall to prevent landslide
2-19 (Example of Flood Damage) Shin-Sugawara Power Plant	・Review of Design Flood Discharge ・Removal of spillway gates and raising the crest level of the overflow weir, the spillway length was extended and make gateless.	N/A
Construction of Bypass Channel of Kurobuchi Dam, No.2. Nishiyosino Power Plant	Out of the target of this study as shown in Figure 3-4	N/A

Name of the project	Resilience enhancement measures	
	Flood exceeding the design flood discharge	floods by unanticipated events
2-20 Recovery works of Uenogawa Intake Weir Sukawa Power Plant	・ Review of Design Flood Discharge ・Installation of new gravity type intake weir at downstream of existing intake weir and maintenance of attaching apron works and protection walls	N/A
2-21 (Example of Flood Damage) Yuyama Power Plant	・Review of Design Flood Discharge・Raising the level of the inspection house (control device of waterway, storage of the tools for the maintenance) ・Relocation of the control devices including cable duct to the higher place. ・Strength of waterproofing capability	N/A
Protection sheet against Tubid water in Sakuma reservoir, Sakuma Power Plant	Out of the target of this study as shown in Figure 3-4	N/A
Construction of surface intake facilities of Sakamoto Dam, Owase No.1 Power Plant	Out of the target of this study as shown in Figure 3-4	N/A
2-22 Renovation works of No.2 Kubusu Dam,Kubusugawa No.2 Power Plant	N/A	・Removal of the weir supporting maintenance bridge of the spillway (Protection of blockage of drifting woods) ・Enlargement of the flushing gate
2-23 Renovation works of decelerating work of downstream Honna Dam, Honna Power Plant	・ Improvement of the downstream guide wall of the dam to enhance the energy reduction effect (Aiming to reduce downstream flood damage) ・Consideration for the local community	N/A
2-24 Recovery works of Yamasubaru Dam from No.14 Typhoon in 2005, Yamasubaru Power Plant	In response to widespread landslides caused by concentrated heavy rainfall from Typhoon No.14 in 2005, a comprehensive sediment management plan for the Mimikawa River basin was developed with river management authorities mainly by the river administrator. Furthermore, a dam sediment transportation plan aimed at promoting sediment passage through reservoirs was formulated. Due to the current structure, it is not possible to lower the water level as required for sediment transportation operations at the Yamasuhara Dam. Therefore, it has been decided to undertake dam modifications. Additionally, concerning the countermeasures against driftwoods, to address driftwood concerns, forest management plans are implemented for aiming to prevent forest degradation. The two central gates of the existing flood spillway were removed, and the overflow crest was lowered by 9.3 meters, with the installation of a new crest roller gates.	N/A
2-25 Recovery works of Saigo Dam from No.14 Typhoon in 2005, Saigo Power Plant	In response to widespread landslides caused by concentrated heavy rainfall from Typhoon No.14 in 2005, a comprehensive sediment management plan for the Mimikawa River basin was developed with river management authorities mainly by the river administrator. Furthermore, a dam sediment transportation plan aimed at promoting sediment passage through reservoirs was formulated. Due to the current structure, it is not possible to lower the water level as required for sediment transportation operations at the Saigo Dam. Therefore, it has been decided to undertake dam modifications. Additionally, concerning the countermeasures against driftwoods, to address driftwood concerns, forest management plans are implemented for aiming to prevent forest degradation. The four central gates of the existing flood spillway were removed, and the overflow crest was lowered by 4.3 meters, with the installation of two new crest roller gates. And level of gate control devices was raised by 2m.	N/A

Name of the project	Resilience enhancement measures	
	Flood exceeding the design flood discharge	floods by unanticipated events
2-26 Renovation works of Taisho Pond intake weir of Kasumisawa Power Plant	Installation of Rubber Dam	N/A
2-27 Renovation works of Kakkonda No.2 Power Plant by flood damage in Aug.2017	・Reinforcement of intake protection walls (Adaption of big concrete block) ・Reinforcement of spillway (change to the gravity type concrete walls)	N/A
2-28 (Example of Flood Damage) Nagayama Power Plant	・Review of Design Flood Discharge ・Strengthen of capability of water tightness of the control device of gates	N/A
2-29 (Example of Flood Damage) Yunotani Power Plant	・Review of Design Flood Discharge ・Removal of spillway gates (Gateless Conversion) ・Raising of the level of overflow weir ・Review of operation and maintenance ・Setting the planned sedimentation gradient (Based on this condition, backwater of the river, road and retaining walls alignment are designed.)	N/A
2-30 (Example of Flood Damage) Haneo Power Plant	・Protection from flood by installation of tailrace gates ・Installation of backflow prevention valve on underground 3 floor of powerhouse (flood prevention measures) ・Improvement of drainage pit	N/A
2-32 (Example of Flood Damage) Otsu Power Plant	・Review of Design Flood Discharge ・Raising level of powerhouse ・Installation of waterproofing walls of the powerhouse	N/A
2-35 (Example of Flood Damage) Tsukabaru Power Plant	・Review of Design Flood Discharge ・Replace of existing gates ・Raising the level of powerhouse ・Relocation of penstock ・Relocation of tailrace channel (prevention of sediment)	N/A
2-36 (Example of Flood Damage) Hayatogawa Power Plant	N/A	Improvement of water tightness of powerhouse (Filled the gaps in the wall around the drainage pump outlet)
2-37 (Example of Flood Damage) Doushi No.4 Power Plant	・Review of Design Flood Discharge ・Raising the level of facilities	・Review the drainage system around the facilities ・Filling the gap of outlet of ventilation fan ・Change of ventilation route
2-38 Flood Damage of Oroville Dam (US)	・Reinforcement of tailrace channel (Place the reinforced concrete on the existing concrete invert)	N/A
2-39 Upper Bhote Koshi Power Plant (Nepal)	N/A	・Installation of concrete protection wall for steel penstock from rock fall ・Installation of rock fall protection barrier

Name of the project	Resilience enhancement measures	
	Flood exceeding the design flood discharge	floods by unanticipated events
2-41 Back online of the Thomson Power Plant (US)	・Review of Design Flood Discharge ・Raising the level of substation for the prevention of flooding	N/A
2-44 Flood damage of Kulekhani Power Plant (Nepal)	N/A	・Renovation works to prevent the risk of sediment inflow ・Conversion of the steel penstock to underground buried type ・Installation of check dam
2-45 Rehabilitation of The Tenom Pangi Hydropower Project (Malaysia)	Introduction of an inflow forecasting system for flood prediction	N/A
2-46 Rainbow Falls Power Plant Restoration (US)	N/A	・Introduction of underground drainage system ・The control system, switching devices, metering panel, and transformers are installed on the intermediate floor, situated above the floor of the water turbine generator.

APPENDIX D：THE CHALLENGES OF IMPLEMENTATION OF ENHANCEMENT MEASURES FOR CLIMATE CHANGE (SUBTASK 2)

Name of the project	Challenges (Issues)	Detailed explanation
2-1 Damage and Restoration of Sekigawa River System Power Generation Facilities in the case of Joetsu Flood, Sekigawa River System Power Plant (15 Power facilities)	Restrictions on construction methods within National Parks (Restrictions on Construction Methods Due to Site Conditions) and Difficulty of Access (no access road).	Regarding the Takazawa Power Plant, it is located in a steep mountainous area at an elevation of approximately 900 meters. There was no access road to the site, and it was situated within a national park. The urgent need for the plant's restarting, combined with the difficulty of constructing a new access road due to the construction schedule, made the method for placing the required concrete (a total volume of approximately 6,500 cubic meters) a critical pass for this recovery works. In conclusion, long-distance concrete pumping was carried out over an extended pipeline of 1,620 meters.
2-2 Restoration of Nagamatsu Power Plant	Construction in heavy snowfall areas (Security management).	Regarding the construction of the steel penstock management bridge, the pull-in rail method was adopted considering safety and cost factors.
2-3 (Example of Flood Damage) Miyashita Power Plant	Widespread damage from the intake to the tailrace channel by debris and driftwood.	Appropriate methods for soil disposal were considered based on the location.
2-4 Overview of Recovery Works from Heavy Rain Disaster at Sendatsu Power Plant	Prevention of Slope Failure (Dangerous areas).	For the slope failure on the west side of the penstock (penstock slope), talus accumulation was observed on top of the tuff layer. Although the rock classification is CL class, it exhibits signs of weathering, raising concerns about further progression of weathering.
2-5 (Example of Flood Damage) Shimodai Power Plant	Restoration work carried out after preventing ground collapse.	N/A
2-6 Saigawa Power Plant	Tourist Attraction site (Swan Migratory Site).	N/A
2-7 Renovation Work of Tenjin Weir (SR Weir) Tenjin Power Plant	Environmental Considerations (Fish Migration). Improvement of Flow Capacity (Replacing to SR weirs).	N/A
2-8 Construction of Bypass Channel of Oigawa Dam	Based on the request from Kawane Honcho town for river environment improvement, a bypass tunnel was constructed as a new measure for turbidity control.	Since the bypass channel has two sections that are in close proximity to existing tunnels (Ikawasen Tunnel of Ohigawa Railway and Old Ikawasen Tunnel (currently a walking path)), measures were taken to avoid damaging the existing tunnels during construction.
2-9 Waterway Renovation Work of Shima Power Plant	Debris had become obstacles at the weir's sand flush gate pier, disturbing ting flood flow and exacerbating flood damage in the surrounding area. As a result, a comprehensive improvement of the weir was required.	N/A
2-10 Renovation works for apron works of Zakkokudani Intake Dam, Shomyougawa No.2 Power Plant	No access road to the construction site, transportation of the construction materials by helicopter. Structural change from reinforced concrete to steel frame, (for reducing transportation and temporary facilities cost) Restriction of construction period due to snow melting and flood season (July ~ Nov.) Construction in the national park.	N/A
2-11 Improvement Works of Tailrace Shin-Inotani Power Plant	N/A	N/A
2-12 (Example of Flood Damage) Nagatono Power Plant	A large-scale renovation works that involved nearly complete reconstruction.	N/A
2-13 Renovation Works of Kitagosho Weir, Nakagosho Power Plant	Due to the high costs associated with restoring automatic water control devices, the plan was revised to focus on restoring only the essential water intake functions, and efforts were made to reduce the costs of the equipment.	N/A
2-15 Recovery works of Kamishiiba Power Plant	The access road to the power plant was washed away. Because the turbine and generator could not be transported from the power plant, a monorail was installed during the construction period.	N/A

Name of the project	Challenges (Issues)	Detailed explanation
2-16 (Example of Flood Damage) Taki Power Plant	The access road to the power plant was washed away. (Restriction in progressing of restoration works.)	Regarding the removal of draft and discharge yard sediment, methods such as the hanging jet pump (MJP method) and underwater suction pumps operated by divers were adopted, based on the experience of the sediment removal works by Tohoku Electric Power Company's hydroelectric plants and construction works were implemented. However, due to the discovery of obstacles near the tailrace outlet, the method was changed to install a temporary cutoff using steel sheet piles just downstream of the outlet and to drain the inside of the draft, and remove the sediment using small heavy machinery.
2-17 (Example of Flood Damage) Countermeasure Works against aggradation of riverbed, Shin-Kurobegawa No.2 Power Plant	Construction in the national park, Handling of Excavated Soil. (Since disposal sites were far away, temporary facilities were needed.)	N/A
2-18 Recovery works of Otagawa Power Plant from heavy rainfall in Aug. 2014.	The access road to the head tank was washed away.	N/A
2-19 (Example of Flood Damage) Shin-Sugawara Power Plant	The structure's design has to be changed.	Due to changes in the shape of the spillway and the design flood discharge, as well as the complex topography of the downstream from the dam, hydraulic model experiments were conducted.
2-20 Recovery works of Uenogawa Intake Weir Sukawa Power Plant	N/A	N/A
2-21 (Example of Flood Damage) Yuyama Power Plant	N/A	N/A
2-22 Renovation works of No.2 Kubusu Dam, Kubusugawa No.2 Power Plant	Method to cut the pier. (Adopted the wire sawing method to avoid damaging the structure.) Utilization of the cut pier blocks. (Utilized as retaining wall blocks.)	N/A
2-23 Renovation works of decelerating work of downstream Honna Dam, Honna Power Plant	Since the river work was limited to the dry season, a significant reduction in construction period was required.	N/A
2-24 Recovery works of Yamasubaru Dam from No.14 Typhoon in 2005	The change of structural design was required.	N/A
2-25 Recovery works of Saigo Dam from No.14 Typhoon in 2005 Saigo Power Plant	The change of structural design was required.	The SR weir was adopted as a temporary gate for temporary coffering, and the weir height was reviewed. The review of the weir height considered the following factors: (1) The water depth corresponding to the safety capacity (storage capacity) required to ensure a 2-hour period for dam discharge in case of issues such as generator troubles that prevent water intake. (2) The water depth required for power generation the SR weir with a height of 4.0 meters will be the tallest in Japan, exceeding the current design guideline limit of 3.0 meters. It will also be the first in Japan to adopt a double-tube design. Therefore, the "SR Weir Technical Review Committee," consisting of experts on dams and SR weirs, as well as representatives from the national government, Miyazaki Prefecture, and our company, was established. The committee discussed the design review based on existing SR weirs (single-tube design) and studied on the technical challenges of the double-tube design. Specifically, tests were conducted to verify the bag shape, expansion rate of the upper and lower bags, stress distribution in the bags, and the structural suitability of the connection between the upper and lower bags. Since the tests could not confirm conditions in the water-filled state, it was decided to verify and confirm the operational state through on-site testing, and then report the findings to the committee.
2-26 Renovation works of Taisho Pond intake weir of Kasumisawa Power Plant	Tourist Attractions (Tourist Spots) within the national park.	The countermeasures were decided based on an economic comparison. Construction was carried out during the winter (Nov. to Jun.) to avoid the tourist season. As the construction in the national park. The landscape was considered through the use of locally generated stones, including apron, surface stone lining (Rip Rap), protection wall, etc.
2-27 Renovation works of Kakkonda No.2 Power Plant by flood damage in Aug.2017	N/A	N/A

Name of the project	Challenges (Issues)	Detailed explanation
2-28 (Example of Flood Damage) Nagayama Power Plant	N/A	N/A
2-29 (Example of Flood Damage) Yunotani Power Plant	Construction in Heavy Snow Areas. (Safety Management and Other Considerations.)	N/A
2-30 (Example of Flood Damage) Haneo Power Plant	N/A	N/A
2-32 (Example of Flood Damage) Otsu Power Plant	N/A	N/A
2-35 (Example of Flood Damage) Tsukabaru Power Plant	N/A	N/A
2-36 (Example of Flood Damage) Hayatogawa Power Plant	N/A	N/A
2-37 (Example of Flood Damage) Doushi No.4 Power Plant	N/A	N/A
2-38 Flood Damage of Oroville Dam (US)	N/A	N/A
2-39 Upper Bhote Koshi Power Plant (Nepal)	N/A	N/A
2-41 Back online of the Thomson Power Plant (US)	N/A	N/A
2-44 Flood damage of Kulekhani Power Plant (Nepal)	N/A	N/A
2-45 Rehabilitation of The Tenom Pangi Hydropower Project (Malaysia)	N/A	N/A
2-46 Rainbow Falls Power Plant Restoration (US)	In North America, it was uncommon to renovate a dam and a power plant simultaneously, so it became difficult to coordinate among contractors.	N/A

APPENDIX E：GENERAL INFORMATION OF THE PROJECT (SUBTASK 2)

Name of the project	Name of power plant	Detail data											
		Implementing body	Location / Country of site	Generating Method	Type of Plant	Catchment Area (km2)	Type of Dam	Dam height (m)	Name of Dam	Name of River	Name of river system	Maximum Output (MW)	Year of commission
2-1 Damage and Restoration of Sekigawa River System	Sekigawa River System Power Plant (15 Power facilities)	Tohoku EPCO	Niigata Pref.	Dam and waterway	Run-of-River	Total 1140	N/A	N/A	N/A	Seki	Seki River System	Total 154.96	1906 ~1939
2-2 Restoration of Nagamatsu Power Plant	Nagamatsu Power Plant	Tohoku EPCO	Niigata Pref.	Dam and waterway	Pondage	19.9	N/A	N/A	N/A	Isazawa	Shinano River System	3.3	1946
2-3 (Example of Flood Damage) Miyashita Power Plant	Miyashita Power Plant	Tohoku EPCO	Fukushima Pref.	Dam and waterway	Pondage	2467	Concrete Gravity	53	Miyashita	Tadami	Agano River System	94	1946
2-4 Overview of Recovery Works from Heavy Rain Disaster at Sendatsu Power Plant	Sendatsu Power Plant	Tohoku EPCO	Akita Pref.	Dam and waterway	Run-of-River	60.4	N/A	N/A	N/A	Sendatsu	Omono River System	5.3	1948
2-5 (Example of Flood Damage) Shimodai Power Plant	Shimodai Power Plant	Tohoku EPCO	Akita Pref.	Dam and waterway	Run-of-River	104.9	N/A	N/A	N/A	iwase	Yoneshiro River System	0.34	1922
2-6 Saigawa Power Plant	Saigawa Power Plant	Chubu EPCO	Nagano Pref.	Dam and waterway	Run-of-River	1330	Concrete Gravity	5.8	Sikawa Enbankment	Sai	Shinano River System	1.7	1923
2-7 Renovation Work of Tenjin Weir (SR Weir) Tenjin Power Plant	Tenjin Power Plant	Chubu EPCO	Gifu Pref.	Dam and waterway	Run-of-River	457.7	N/A	N/A	N/A	Miya	Jintsu River System	0.6	1924
2-8 Construction of Bypass Channel of Oigawa Dam	Oigawa Power Plant	Chubu EPCO	Shizuoka Pref.	Dam and waterway	Pondage	537	Concrete Gravity	33.5	Oi	Oi	Oi River System	68.2	1936
2-9 Waterway Renovation Work of Shima Power Plant	Shima Power Plant	Chubu EPCO	Gifu Pref.	Dam and waterway	Run-of-River	78.7	N/A	N/A	N/A	N/A	Tahagi River System	1.8	1927
2-10 Renovation works for apron works of Zakkokudani Intake Dam Shomyougawa No.2 Power Plant	Shomyougawa No.2 Power Plant	Hokuriku EPCO	Toyama Pref.	Dam and waterway	Run-of-River	30.8	N/A	N/A	N/A	Shomyou	Jogannji River System	8.1	1960

Name of the project	Name of power plant	Detail data											
		Implementing body	Location / Country of site	Generating Method	Type of Plant	Catchment Area (km2)	Type of Dam	Dam height (m)	Name of Dam	Name of River	Name of river system	Maximum Output (MW)	Year of commission
2-11 Improvement Works of Tailrace Shin-Inotani Power Plant	Shin-Inotani Power Plant	Hokuriku EPCO	Toyama Pref.	Dam and waterway	Pondage	762	Concrete Gravity	56	Shin-Inotani	Takahara	Jintsu River System	33.5	1964
2-12 (Example of Flood Damage) Nagatono Power Plant	Nagatono Power Plant	KEPCO	Nara Pref.	Dam and waterway	Run-of-River	157.4	N/A	N/A	N/A	Totsu	Shingu River System	15.3	1937
2-13 Renovation Works of Kitagosho Weir Nakagosho Power Plant	Nakagosho Power Plant	Chubu EPCO	Nagano Pref.	Dam and waterway	Run-of-River	23	N/A	N/A	N/A	Nakagosho	Tennryu River System	10.2	1980
2-14 (Example of Flood Damage) Kawabegawa No.1 Power Plant	Kawabegawa No.1 Power Plant	Kyushu EPCO	Kumamoto Pref	Dam and waterway	Run-of-River	360.3	Rubber Weir	5.8	Kawabegawa No.1 intake weir	Kawabe	Kuma River System	2.6	1937
2-15 Recovery works of Kamishiiba Power Plant	Kamishiiba Power Plant	Kyushu EPCO	Miyazaki Pref	Dam and waterway	Reservoir	279.6	Arch	110	Kamisiiba	Mimi	Mimikawa River System	93.2	1955
2-16 (Example of Flood Damage) Taki Power Plant	Taki Power Plant	J-Power	Fukushima Pref	Dam	Pondage	1978.8	Concrete Gravity	46	Taki	Tadami	Agano River System	92	1961
2-17 (Example of Flood Damage) Countermeasure Works against aggradation of river bed Shin-Kurobegawa No.2 Power Plant	Shin-Kurobegawa No.2 Power Plant	KEPCO	Toyama Pref.	Dam and waterway	Pondage	404.8	Concrete Gravity	51.5	Koyadaira	Kurobe	Kurobe River System	74.2	1936
2-18 Recovery works of Otagawa Power Plant from heavy rainfall in Aug. 2014.	Otagawa Power Plant	Chugoku EPCO	Hirosima Pref.	Dam and waterway	Run-of-River	894	Concrete Gravity	2	Yoshiyamagawa	Ota, Yoshiyama	Ota River System	16.4	N/A
2-19 (Example of Flood Damage) Shin-Sugawara Power Plant	Shin-Sugawara Power Plant	Kyushu EPCO	Miyazaki Pref	Dam and waterway	Pondage	51	Concrete Gravity	17.8	Nishihata	Tsunanose	Gokase River System	7.5	1958
2-20 Recovery works of Uenogawa Intake Weir Sukawa Power Plant	Sukawa Power Plant	TEPCO	Shizuoka Pref	Dam and waterway	Pondage	29.2	N/A	N/A	N/A	Su	Sakawa River System	6	1912

Name of the project	Name of power plant	Detail data											
		Implementing body	Location / Country of site	Generating Method	Type of Plant	Catchment Area (km2)	Type of Dam	Dam height (m)	Name of Dam	Name of River	Name of river system	Maximum Output (MW)	Year of commission
2-21 (Example of Flood Damage) Yuyama Power Plant	Yuyama Power Plant	Chubu EPCO	Shizuoka Pref	Dam and waterway	Pondage	178	Concrete Gravity	64	Senzu	N/A	Oi River System	24.1	1935
2-22 Renovation works of Kubusu No.2 Dam, Kubusugawa No.2 Power Plant	Kubusugawa No.2 Power Plant	Hokuriku EPCO	Toyama Pref.	Dam and Waterway	Pondage	41	Concrete Gravity	18.5	Kubusugawa No.2	Kubusu	Jintsu River System	3.8	1941
2-23 Renovation works of decelerating work of downstream Honna Dam, Honna Power Plant	Honna Power Plant	Tohoku EPCO	Fukushima Pref.	Dam	Pondage	2142	Concrete Gravity	51.5	Honna	Tadami	Agano River System	78	1954
2-24 Recovery works of Yamasubaru Dam from No.14 Typhoon in 2005 Yamasubaru Power Plant	Yamasubaru Power Plant	Kyushu EPCO	Miyazaki Pref	Dam and Waterway	Pondage	1197.2	Concrete Gravity	29.4	Yamasubaru	Mimi	Mimikawa River System	41	N/A
2-25 Recovery works of Saigo Dam from No.14 Typhoon in 2005, Saigo Power Plant	Saigo Power Plant	Kyushu EPCO	Miyazaki Pref	Dam and Waterway	Pondage	1295.6	Concrete Gravity	19.9	Saigo	Mimi	Mimikawa River System	27.1	1929
2-26 Renovation works of Taisho Pond intake weir of Kasumisawa Power Plant	Kasumisawa Power Plant	TEPCO	Nagano Pref	Dam and Waterway	Run-of-River	115.4	N/A	N/A	N/A	Azusa	Shinano River System	3.3	1928
2-27 Renovation works of Kakkonda No.2 Power Plant by flood damage in Aug.2017	Kakkonda No.2 Power Plant	Tohoku EPCO	Iwate Pref.	Dam and Waterway	Run-of-River	101	Zoned Earth-rockfill	N/A	N/A	Kakkonda	Kitakami River System	5.1	1953
2-28 (Example of Flood Damage) Nagayama Power Plant	Nagayama Power Plant	J-Power	Kochi Pref.	Dam and Waterway	Pondage	233.4	Concrete Gravity	38	Hiranabe	Nahari	Nahari River System	37	1960
2-29 (Example of Flood Damage) Yunotani Power Plant	Yunotani Power Plant	Tohoku EPCO	Niigata Pref.	Dam and Waterway	Run-of-River	80	N/A	N/A	N/A	Sanashi	Shinano River System	0.72	1925
2-30 (Example of Flood Damage) Haneo Power Plant	Haneo Power Plant	TEPCO	Gunma Pref.	Dam and Waterway	Run-of-River	353.6	N/A	N/A	N/A	Agatuma	Tone River System	1.3	1925
2-31 (Example of Flood Damage) Kumakawa No.1 Power Plant	Kumakawa No.1 Power Plant	TEPCO	Gunma Pref.	Dam and Waterway	Run-of-River	63.7	N/A	N/A	N/A	Kuma	Tone River System	2.7	1922

Name of the project	Name of power plant	Detail data											
		Implementing body	Location / Country of site	Generating Method	Type of Plant	Catchment Area (km2)	Type of Dam	Dam height (m)	Name of Dam	Name of River	Name of river system	Maximum Output (MW)	Year of commission
2-32 (Example of Flood Damage) Otsu Power Plant	Otsu Power Plant	TEPCO	Gunma Pref.	Dam and Waterway	Pondage	451	Concrete Gravity	19.55	Outsu	Agatuma	Tone River System	2.2	1931
2-33 (Example of Flood Damage) Tamano Power Plant	Tamano Power Plant	Chubu EPCO	Aichi Pref.	Dam and Waterway	Run-of-River	440.2	Concrete Gravity	8.79	Tamano	Shounai	Shounai River System	0.55	1921
2-34 (Example of Flood Damage) Samigawa Power Plant	Samigawa Power Plant	Chubu EPCO	Gifu Pref.	Dam and Waterway	Run-of-River	56.7	N/A	N/A	N/A	Sami	Kiso River System	0.33	1928
2-35 (Example of Flood Damage) Tsukabaru Power Plant	Tsukabaru Power Plant	Kyushu EPCO	Miyazaki Pref.	Dam and Waterway	Reservoir	545.4	Concrete Gravity	87	Tsukabaru	Mimi	Mimikawa River System	67.05	1938
2-36 (Example of Flood Damage) Hayatogawa Power Plant	Hayatogawa Power Plant	Kanagawa Prefecture EB	Kanagawa Pref.	Dam and Waterway	Run-of-River	18.3	Concrete Gravity	7.27	Hayatogawa	Hayato	Sagami River System	0.072	2018
2-37 (Example of Flood Damage) Doushi No.4 Power Plant	Doushi No.4 Power Plant	Kanagawa Prefecture EB	Kanagawa Pref.	Dam and Waterway	Run-of-River	112.5	Concrete Gravity	32.8	Doushi	Doushi	Sagami River System	0.059	2010
2-38 Flood Damage of Oroville Dam (US)	Hyatt Power Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant	California State Dept of Water Resources	California, USA	Dam and Waterway, pump-storage	Reservoir	9340	Earth fill	230	Oroville Dam	Feather	Sacramento River System	819	1968
2-39 Upper Bhote Koshi (Nepal)	Koshi Hydroelectric Plant	Bhote Koshi Power Company	Nepal	Dam and Waterway	Run-of-River	2132	N/A	N/A	N/A	Bhote koshi River	Koshi River System	45	2001
2-40 Callahuanca Power Plant (Peru)	Callahuanca Power Plant	ENEL. Peru	Huarochirí Province, Peru	N/A	Run-of-River	N/A	N/A	N/A	N/A	N/A	Rímac River System	84.17	1938
2-41 Back online of the Thomson Power Plant (US)	Thomson Power Plant	N/A	Minnesota, USA	Dam	Run-of-River	23,710	Concrete Gravity, Arch	N/A	Thomson Dam	Sant Louis	Sant Louis River System	N/A	1907
2-42 Flood-damaged Lower Modi No.1 hydel project begins power production (Nepal)	Lower Modi No.1 Power Plant	United Modi Hydropower Pvt. Limited	N/A	Dam and Waterway	Reservoir	575	N/A	N/A	N/A	Modi Khola	Gandaki River System	10	2012
2-43 Update after the Halton Floods (UK)	Halton Lune Power Plant	Halton Lune Power Plant	Northern Lancashire, UK	Dam and Waterway	Run-of-River	N/A	N/A	N/A	N/A	Lune	Lune River System	0.16	2015

Name of the project	Name of power plant	Detail data											
		Implementing body	Location / Country of site	Generating Method	Type of Plant	Catchment Area (km2)	Type of Dam	Dam height (m)	Name of Dam	Name of River	Name of river system	Maximum Output (MW)	Year of commission
2-44 Flood damage of Kulekhani Power Plant (Nepal)	Kulekhani No.1 Power Plant	Nepal Electricity Authority	Kulekhani, Makwanpur	Dam and Waterway	Reservoir	126	Rock fill	114	Kulekhani	Kulekhani	Ganges River System	60	1982
2-45 Rehabilitation of The Tenom Pangi Hydropower Project (Malaysia)	N/A	Sabah Electricity Sdn. Bhd.	Sabah, Malaysia.	Dam and Waterway	Run-of-River	7815	N/A	N/A	N/A	Padas	Crocker Range River System	66	1982
2-46 Rainbow Falls Power Plant Restoration (US)	Rainbow Falls Power Plant	New York State Elec & Gas Corp	Clinton County, NY, USA	Dam and Waterway	Run-of-River	N/A	N/A	N/A	N/A	Ausable	N/A	2.6	1926
2-47 Restoration of Moco-Moco Power Plant (Guyana)	Moco-Moco Power Plant	Guyana Energy Agency	Region 9, Guyama	Dam and Waterway	Run-of-River	N/A	N/A	3	N/A	Moco-Moco	Amazon River System	0.5	1997

APPENDIX F：ORGANIZING THE NECESSITY OF SEDIMENT MANAGEMENT (SUBTASK 3)

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-1 Sediment Management at the Tsugaru Dam	Tsugaru Power Plant Reservoir	Dam: MLIT Plant: Tohoku EPCO	Scouring and decreased sediment deposition occurred in the downstream area of the Tsugaru Dam due to reduced sediment supply, impacting zoobenthos and fishes.	To restore the degraded riverbed (improvement of scouring and sediment deposition).				○	
3-2 Sediment Management at the Shichikashuku Dam	Shichikashuku Power Plant Reservoir	MLIT	Deterioration in the reservoir function (decrease in the reservoir capacity).	To secure the reservoir functions (maintenance of capacity). Effective utilization of aggregates (sand) for ready-mix concrete that are in shortage due to recovery and reconstruction works for the Great East Japan Earthquake.			○		○
3-3 Sediment Management at the Shimokubo Dam	Shimokubo Power Plant, Shimokubo No.2 Power Plant, Reservoir (Shimokubo), Run-of-River (No.2)	Dam: JWA Plant: Gunma Prefecture EB	Deterioration of the reservoir function (decrease in reservoir capacity) In addition to the confirmation of sediments in the valid reservoir capacity, an increase in sediments near the irrigation and discharge equipment has also been confirmed.	To secure the reservoir functions (maintenance of capacity).		○		○	○
3-4 Sediment Management at the Amahata Dam	Sumise Power Plant Reservoir	NLMCO	The riverbed at the upper end of the reservoir rose due to the accumulation of inflow sediments from Typhoon 19 in 2019, which caused flooding damage.	To prevent flooding damage at the upper end of the reservoir.		○	○		○
3-5 Sediment Management at the Miyagase Dam	Aikawa No.1 Power Plant Reservoir	Dam: MLIT Plant: Kanagawa Prefecture EB	Degradation of downstream river environment.	To protect the environment of the downstream rivers and maintain the reservoir functions.			○	○	

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-6 Cooperating Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam on Kurobe River	Shin-Yanagawara Power Plant, Otozawa Power Plant, Dashidaira Power Plant, Unazuki Power Plant, Pondage (Shin-Yanagawara, Otozawa, Unazuki), Run-of-River (Dashidaira)	Dashidaira Dam: KEPCO Unazuki Dam: MLIT Plant: KEPCO	The maintenance of functions to appropriately implement irrigation and flood control is required. Since the volume of water in the Kurobe River is large and its slope is steep, flood damage frequently occurs. At the same time, since this river has a large volume of sediment yield, discharging these sediments downstream is required.	To maintain the functions of a water supply reservoir and a flood-prevention dam.			○	○	○
3-7 Sediment Management at the Managawa Dam	Managawa Power Plant Reservoir	Dam: MLIT Plant: Hokuriku EPCO	Degradation of river environment.	To preserve the river environment. To enhance the effectiveness of flush discharge by combining sediment replenishment (gathering sediments in the reservoir of the dam, and transporting and adding soils to the downstream rivers) with flush discharge (50 m3/s).				○	
3-8 Sediment Management at the Takase Dam	Shin-Takasegawa Power Plant Pumped Storage	TEPCO	About 0.75 million cubic meters of sediments flow into the Takase dam reservoir every year, and about 20% of these sediments are excavated and transported to the temporary storage yard by dump trucks. However, If this situation will continue, the function of dam and reservoir such as flood control and power generation capacity may not be maintained in the future.	To recover and maintain functions, including flood and power generation of the dam.			○		
3-9 Sediment Management at the Miwa Dam	Miwa Power Plant Pondage	Dam: MLIT Plant: Nagano Prefecture EB	Flooding in the upstream area of the Tenryu River.	Strengthen the flood control function.		○			
3-10 Sediment Management at the Koshibu Dam	Koshibu No.1, No.2, No.3 Power Plant, Pondage (No.1, No.2), Run-of-River (No.3)	Dam: MLIT Plant: Nagano Prefecture EB	As of 2015, the sediment rate reached 89%. There was a concern about obstacles to the reservoir function, as sediments would reach the planned sediment capacity in a few years.	To reduce sediments flowing into the reservoir of the dam.		○		○	

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-11 Sediment Management at the Ikawa Dam	Ikawa Power Plant Reservoir	Chubu EPCO	The occurrence of a huge volume of sediments produced by floods and landslides will cause not only landslide disasters and devastation of forest land but also considerable progress in the accumulation of sediments in the dam downstream. As a result, further disasters could occur.	1. Maintain and secure the ‘disaster protection functions’ that protect the region from landslide disasters, flood disasters, and high flood tide damage. 2. Maintain and preserve the ‘water/material cycle’ and the ‘habitation/rearing environment of creatures’ that form forests, rivers, and seas. 3. Maintain and secure the ‘irrigation function’ that uses running water (based on the basic notion of ‘the General Sediment Management Plan for the Quicksand-system of the Oi River’).		○	○	○	
3-12 Sediment Management at the Sakuma Dam	Sakuma Power Plant Reservoir	J-POWER	Steep landform, fragile geological features, and rainy conditions. Because of these three factors, sediment damage and floods frequently occur in the areas along the coast of the Tenryu River. Under these situations, damage from submergence due to torrential rain during typhoons frequently occurred in the upstream area of the reservoir. To prevent such damage, sediment management was started (dredging began).	Avoid creating impacts on backwater upstream of the dam.		○	○	○	○
3-13 Sediment Management at the Yokoyama Dam	Yokoyama Power Plant Reservoir	Dam: MLIT Plant: Chubu EPCO	The Ibi River basin has the largest rainfall volume among the Kiso Three Rivers, and there are many faults, including the Neodani fault, and fragile geological features. As a result, large-scale collapses caused by heavy rain often occur along the upper reaches of the Yokoyama Dam. Regarding the state of sediments after 57 years since the completion of the dam, the total sediment volume is 7.87 million cubic meters, and the sediment rate is 78.7%, which indicate that sedimentation has progressed faster than initially planned. However, in recent years, no sediment within the valid capacity is seen due to sediment management measures and the commencement of service of the Tokuyama Dam, thus securing the capacity.	To secure the flood control function of the reservoir, sediments are continuously removed by excavation.		○			

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-14 Sediment Management at the Yahagi Dam	Yahagi No.1 Power Plant Reservoir	Dam: MLIT Plant: Chubu EPCO	The geological features of the basin include the spread of granites formed from the Cretaceous period of the Mesozoic era to the Cenozoic era and the fragility of granites on the surface as they turn into decomposed granites. Therefore, the volume of sediment yield is large, presenting a typical sand bar river. At the reservoir of the Yahagi Dam, a check dam was installed in 1988 to manage sediments, such as excavating accumulated sediments. However, sediment accumulation has progressed faster than planned, and as of FY2012, the sediment volume reached about 103% of the planned sediment volume, exceeding the valid reservoir capacity. Therefore, continuous measures against sediments need to be taken to maintain the flood and irrigation functions of the Yahagi Dam.	As measures against sediments, the 'Yahagi Dam Weir Improvement Project' was adopted in FY2005 to improve and maintain the physical and biological environment in the lower reaches, including the dam functions and the mouth of the river. A sediment dam is installed upstream to maintain flood control functions and facilitate excavation. From an environmental perspective, it is necessary to maintain the riverbed environment that is appropriate for sweet fish and other species to grow and spawn by restoring the quicksand environment and providing reasonable disturbance. For the region of the river mouth coast, preservation and creation of a dry beach and shallow area are considered important.			○		
3-15 Securement of Long-term Disposal Area by Cooperation between Public and Private	Wada Power Plant, Kawai Power Plant Pondage	KEPCO	After about 80 years since the start of operation, sediment accumulated in the reservoir increased due to the degraded mountain region along the upper reaches of the dam. Although the removal of sediment has been performed to prevent inundation damage to the upper reaches since 1988, the disposal area for sediment became full, necessitating the creation of a new disposal area.	To prevent inundation damage along the upper reaches of the dam. To secure the dam's service water capacity.		○	○		
3-16 Sediment Management at the Hitokura Dam	Hitokura Power Plant Reservoir	JWA	Issues of water quality occurred in the reservoir (such as a freshwater red tide and water bloom). Measure: Installation of lower-layer aeration equipment.	To maintain the flood control function and the irrigation function of the dam.				○	
3-17 Sediment Management at the Nagoro Dam	Nagoro Power Plant Pondage	Shikoku EPCO	Following the progress of sediment accumulation in front of the intake of the Nagoro Power Plant, the prevention of damage to power generation equipment and the prevention of contamination of downstream rivers are required.	To prevent damage to power generation equipment and pollution in the downstream of the river.			○	○	

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-18 Sediment Management at the Nagayasuguchi Dam	Hinotani Power Plant, Kagedaira Power Plant, Pondage (Hinotani), Pumped Storage (Kagedaira)	Dam: MLIT Plant: Tokushima Prefecture EB (Hinotani) Shikoku EPCO (Kagedaira)	Deterioration of reservoir functions due to advanced sedimentation caused by sediment supply from a fracture zone in the northern area of the dam basin.	At the Nagayasuguchi Dam, sediment management (land excavation and sediment replenishment) is performed. The objectives of the management are to secure the valid reservoir capacity in 30 years, considering the development period of the river development plan, and to restore the river environment by recovering the continuity of sediment transportation.			○	○	○
3-19 Sediment Management at the Setoishi Dam	Setoishi Power Plant, Pondage	J-POWER	Damage during a flood along the upper reaches caused by a rise in the riverbed upstream of the reservoir due to sediments (controlled by reserved discharge).	To prevent flood damage upstream by operating sluicing and discharging. To improve the environment of the downstream river and the sea area by transporting sediments.		○		○	
3-20 Mimikawa River Basin Integrated Sediment Flow Management Plan	Yamasubaru Power Plant, Saigo Power Plant, Ouchibaru Power Plant, Pondage (Yamasubaru, Saigo), Reservoir (Ouchibaru)	Kyushu EPCO	Sediments in the reservoir of the dam are one of the causes of the spread of flood damage occurring along the Mimikawa river system.	To solve various problems and issues originating from sediments in the entire basin: In the mountain region, control the outflow of sediments and driftwood by performing flood control and erosion control together. In the dam region, achieve to restore river functions by recovering the continuity of sediment relocation and by operating and managing the dam appropriately. In the river region, achieve a safe and diverse habitat for creatures to restore river functions.		○	○	○	
3-21 Sediment Management at the Jirau Dam in Brazil	Jirau Power Plant Run-of-River	Eletronorte	The area was hit by a historic flood in 2014. A large volume of sediments flowed in, changing the landform of the river and causing sediments to progress near the intake works. It also caused wear on the hydraulic works.	To perform smooth power generation by removing accumulated sediments that prevent water intake. To reduce wear on equipment. To prevent flooding.			○	○	○

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-22 Sediment Management at the Shihmen Dam in Chinese Taipei	Shihmen Power Plant Reservoir	Taiwan Power Company	The reliability of water supply to the area has declined since sediments progressed due to a flood triggered by a typhoon.	To secure the reservoir functions (maintenance of capacity).			○	○	
3-23 Sediment Management at the Zengwen Dam in Chinese Taipei	Zengwen Power Plant Reservoir	Taiwan Power Company	Since sediments in the reservoir made progress by slope failure triggered by typhoons, decline of drinking water supply, power generation capacity, and flood control capacity becomes a problem.	To secure the reservoir functions (maintenance of water supply capacity).			○		
3-24 Sediment Management at the Angostura Dam in Costa Rica	Angostura Power Plant Run-of-River	Costa Rican Electricity Institute	Without performing sediment removal in cooperation with the Cachi Power Plant located upstream, the reservoir will be lost to sedimentation in 20 years.	To secure the reservoir functions (maintenance of capacity).	○		○	○	○
3-25 Sediment Management at the Hvammur Dam in Iceland	Hvammur Power Plant Run-of-River	Landsvirkjun	An enormous volume of sediment is produced by the erosion of natural glacier ground, and inflow into the reservoir needs to be prevented.	To secure the reservoir functions (maintenance of capacity).			○	○	○
3-26 Sediment Management at the Nathpa Jhakri Dam in India	Nathpa Jhakri Power Plant Run-of-River	Satluj Jal Vidyut Nigam Ltd	There were concerns that sediments from the erosion of the Himalayas would cause wear on the power plant equipment and reduce the reservoir capacity.	To prevent wear on various hydraulic machines caused by sediments and to secure the reservoir capacity.			○	○	
3-27 Sediment Management at the Bakaru Dam in Indonesia	Bakaru Power Plant Run-of-River	P.T.PLN (PERSERO)	The catchment area of the Bakaru Dam suffers from severe landslides, and the annual sediment volume is estimated at 0.76 million cubic meters. Securing the reservoir capacity and damage from wearing of turbines cause problems.	To maintain and secure the reservoir capacity.			○		
3-28 Sediment Management at the Patrind Dam in Pakistan	Patrind Power Plant Run-of-River	Star Hydro Power Pvt. Limited	Due to the large volume of sediment supplied from the Kunhar River, which flows from the Himalayas, sedimentation is the most important issue for the Patrind Dam.	To maintain the reservoir functions and to reduce damage on water turbine, etc.			○		
3-29 Sediment Management at the Binga Dam in Philippines	Binga Power Plant Run-of-River	SN Aboitiz (SNAP)	Due to insufficient consideration given to sediment management, the reservoir capacity was lost to sediments in a short period. Aboitiz Power purchased the concerned power plant in 2008, and sediment management has become the biggest issue.	To realize a stable power generation project by recovering the reservoir functions.			○		

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-30 Sediment Management at the Solis Dam in Switzerland	Sils Power Plant, Rothenbrunnen Power Plant, Pondage	Elektrizitätswerk of Zurich (EWZ)	The Solis Dam was built in 1986 as a part of a series power generation scheme in the Swiss Alps. The total reservoir capacity was reduced by about 50% due to accumulated sediments by 2012.	To maintain the reservoir functions, the operation of a sediment bypass tunnel was started in May 2013. In addition, environmental protection in the downstream river is set as an objective.			○	○	
3-31 Cameron Highlands Hydroelectric Scheme in Malaysia	Total of five power plants, including the Kampung Raja Power Plant and the Kuala Terla Power Plant Run-of-River	Tenaga Nasional Berhad (TNB)	The impact of the failure of natural vegetation on the environment and the power generation /operation of equipment has become a serious concern because the degree of soil erosion along the basin is increasing.	To maintain the reservoir functions, To prevent damage to machine parts of the power plant, To protect the environment of the reservoir.			○	○	
3-32 Sediment Management at Three Gorges Power Plant in China	Three Gorges Power Plant Reservoir	China Yangtze Power Co., Ltd.	It is recognized that sediment management and monitoring are important for the safe, stable, and effective operation of the project.	Sediment management is performed to prolong the service life of the reservoir, prevent inundation of the reservoir area, facilitate shipping in the dam area, operate a generator, and reduce disasters along the downstream.	○	○	○	○	○
3-33 Akiba No.1, No.2, No.3 Power Plant, Example of sediment management	Akiba No.1, No.2, No.3 Power Plant Pondage	Electric Power Development Co., Ltd.	Since many faults, including the Median Tectonic Line, go through the Tenryu River basin and the landform is steep, sediment production is active, which has caused many landslide disasters in the past. The decrease in the riverbed and coastal erosion are in progress, as the continuity of sediments flowing in the river is intercepted by the dam reservoir.	To maintain the functions of the reservoir, and to prevent flood damage (solving the problem of flooded land).		○		○	○
3-34 Yakuwa Power Plant, Example of sediment management	Yakuwa Power Plant Reservoir	Tohoku EPCO	The sluice gate of the Yakuwa Power Plant, located 3.6 kilometers upstream from the dam, is situated in the upstream area of the reservoir and is easily affected by sediments. To ensure stable water intake, dredging work has been carried out since 1973. Due to the impact of sediments, the effective water depth has been reduced to about 10 meters in recent years, indicating significant degradation in reservoir functions.	Implement to secure the service capacity of power generation.			○		

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-35 Honna Power Plant, Example of sediment management	Honna Power Plant Pondage	Tohoku EPCO	Following the 2011 Niigata-Fukushima heavy rain and flood, a large volume of sediments flowed in. As a result, the sediment rate of the Honna Dam reached 37.7%. Dredging of an average of about 50,000 cubic meters was performed in the most recent five years, and the average increase in the volume of sediments is about 0.34 million cubic meters per year.	Implement to secure the service capacity of power generation.			O		
3-36 Kasumisawa Power Plant, Example of sediment management	Kasumisawa Power Plant Pondage	TEPCO	The initial capacity of the reservoir of Taisho Pond in 1928 was 0.71 million cubic meters. However, it decreased to one-ninth, about 0.08 million cubic meters, by 1976 due to the annual inflow of sediments from the upper reaches and Mt. Yakedake. Since then, full-scale dredging work has been carried out since 1977 to secure the reservoir (pontage) capacity, based on an environmental impact investigation conducted by experts. Although dredging of about 20,000 cubic meters of sediment is carried out annually to secure the necessary reservoir (pontage) capacity, the capacity shows a decreasing trend due to the large inflow of sediments from heavy rains in recent years. The rise in the riverbed due to sediments from the upper reaches is seen as a problem throughout the Kamikochi region, including Taisho Pond. Measures against riverbed rise will be carried out as part of the "Kamikochi Vision" operation, run by relevant ministries and agencies, prefectures, cities, and companies, with the Ministry of the Environment leading the initiative.	Implement a dredging work to secure the service capacity of power generation.			O		
3-37 Hatanagi No.1 Power Plant, Example of sediment management	Hatanagi No.1 Power Plant Multiple-use pumped storage type	Chubu EPCO	The annual volume of inflow sediments in Hatanagi Dam #1 is about 0.9 million cubic meters (49% of the sediment rate as of FY2020), which is quite large. It is difficult to drastically transport sediments during excavation and dredging due to the geographical conditions of the mountainous region. Similar to the reservoir of Ikawa Dam, the reservoir of Hatanagi Dam #1 undertakes water supply to the lower reaches and possesses a bottom outlet to prepare for power supply failure. To maintain the functions of the outlet structure at the base of the dam, dredging (relocation within the lake) is performed in front of the intakes of the drainpipe, and the drainpipe is discharged during a flood.	Measures against sediments for maintaining the functions of the bottom outlet of the dam.					O

Name of project	Name of power plant (Type of generation)	Implementing body	Current problems	Necessity of sediment management	Objectives of sediment management				
					Compliance	Disaster Measures	Securing effective power generation capacity	Environmental Protection	Other
3-38 Okuyoshino Power Plant, Example of sediment management	Okuyoshino Power Plant Pure pumped storage type	KEPCO	The sediment bypass of Asahi Dam detours sediments flowing into the dam during a flood to a tunnel that directly discharges sediments to the downstream river. Significant effectiveness in reducing prolonged muddy water in the reservoir and in reducing sediments has been confirmed. Additionally, the water quality of the reservoir and the environment of the downstream rivers have improved.	Implement to solve prolonged muddy water and to reduce sediments.			○	○	
3-39 Nishiyama Power Plant, Example of sediment management	Nishiyama Power Plant Pondage	Yamanashi Prefecture EB	The volume of sediment discharge in the Hayakawa River water system is extremely large and has been exceeding the planned volume since FY1959. To manage the sediment rate of 127%, regular dredging in the non-flood season and flushing discharge in the flood season are implemented to maintain the balance of sediments in the reservoir. It has been confirmed that there is no concern about a rise in the upstream water level during the flood season, as the sediment state in the reservoir is surveyed every year.	Implement measures to meet objectives, such as securing the service capacity of power generation and preserving the landscape.			○	○	
3-40 Tamagawa No.3 Power Plant, Example of sediment management	Tamagawa No.3 Power Plant Pondage	Bureau of Transportation, Tokyo Metropolitan Government	The total sediment rate against the total capacity of Shiromaru is 32.0%, showing no fluctuation in recent years. Although there were some seasons with large volumes of inflow sediments due to the collapse of the volcanic edifice upstream, the volume of inflow has stabilized in recent years. Regarding scouring, dredging work is carried out around the inflow area of the dam and the floodgate of the Hikawa Power Plant located upstream if it is judged that there is a risk of disaster due to accumulated sediments. Additionally, although not considered sediment management, natural scouring is carried out by opening gates during large-scale floods, such as during typhoons, to serve like a natural river.	Implement to secure the floodgate of the Hikawa Power Plant, such as securing the service capacity of power generation, preventing disasters, and preserving landscape.		○	○	○	○

APPENDIX G：ORGANIZING METHODS OF SEDIMENT MANAGEMENT (SUBTASK 3)

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-1 Sediment Management at the Tsugaru Dam	To improve riverbed degradation and coarse granulation in the downstream area.	Supply of sediment to downstream river (by embankment).	Reservoir preservation facilities at two locations (sediment control (check) dam).		○				
3-2 Sediment Management at the Shichikashuku Dam	・To sustain storage capacity in the existing reservoir. ・To supply aggregate as shortage materials for reconstruction in relation with the Great East Japan Earthquake.	Procurement of aggregate in trapping pond in the upstream area of the reservoir.	Check dam (sedimentation dam) is installed in the upper end of the reservoir.	○					○
3-3 Sediment Management at the Shimokubo Dam	・To use sediment for aggregate. ・To improve environment and ecology in the downstream area.	・Mechanical excavation. ・Dredging. ・Supply of sediment to downstream river (by embankment).	A site previously used as a quarry site is used as a disposal area.	○	○				
3-4 Sediment Management at the Amahata Dam	・To eliminate the damages due to inundation in the upstream area and debris flow. ・To ensure the reservoir function in the future.	・Mechanical excavation (carry involving dump trucks and belt conveyors).	The upstream area was damaged by torrential rain during Typhoon No.10 in August 2019 and Typhoon No.19 in October 2019.	○					
3-5 Sediment Management at the Miyagase Dam	To sustain storage capacity in the existing reservoir.	・Flushing. ・Supply of sediment to downstream river (by embankment).	N/A		○		○		
3-6 Cooperating Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam on Kurobe River	・To sustain functions of both water utilization and flood control. ・To preserve riverbed level in the downstream river. ・To protect shoreline against erosion.	・Flushing ・Sluicing	Operation by cooperative scouring				○	○	

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-7 Sediment Management at the Managawa Dam	To improve the river environment.	・Flushing. ・Supply of sediment to downstream river (by embankment).	N/A		○		○		
3-8 Sediment Management at the Takase Dam	To mitigate the risk of reservoir storage being divided into a few areas due to sedimentation.	Mechanical excavation (carry involving dump trucks).	At the Takase Dam, sedimentation is much higher than planned. A new sediment transport tunnel and belt conveyor are being considered for removing the sediment to a temporary storage yard downstream. Three dams such as Takase Dam, Nanakura Dam, and Omachi Dam are located at upper reach of that river system and these capacities will be used for flood control.	○					
3-9 Sediment Management at the Miwa Dam	To sustain the dam's function.	・Mechanical excavation in the sand trapping pond. ・Bypass tunnel.	Implement scouring by the check dam, the branch weir, and the sediment bypass.	○		○			
3-10 Sediment Management at the Koshibu Dam	・To mitigate sediment load in the reservoir. ・To ensure consecutive sediment flow.	・To mitigate sediment load in the reservoir. ・To ensure consecutive sediment flow.	The check dam and branch weir are installed at the upper end of the reservoir; gravel is collected by the check dam for effective use. Other coarse-grained and fine-grained gravel is discharged downstream through the bypass tunnel. The inlet frame is complex, with two orifice gates and two crest gates, designed to naturally adjust the branching volume and prevent complicated gate operations. To combat abrasion, rubber steel and steel linings are used around the inlet, and high-strength concrete is used for the inverted arch of the entire tunnel.	○		○			○
3-11 Sediment Management at the Ikawa Dam	To prevent the intakes of both the discharge conduit and the flushing conduit from becoming embedded.	・Dredging. ・Riverbed shaping by mechanical excavation.	As the volume of inflow sediments is extremely large, "the Study Committee of General Sediment Management Plan for Quicksand-system of Oi River" was established to study it at the river basin.	○				○	
3-12 Sediment Management at the Sakuma Dam	・To sustain functions of both dam and reservoir. ・To prevent floods from overflowing in the upstream area of the dam.	・Dredging. ・Excavation (Gravel excavation). ・Sediment relocation.	Planning to implement the following sediment management measures in collaboration with the MLIT. ・Transport the dredged sediment to the pumped-up sediment are within the reservoir. ・Transport by a belt conveyor from the pumped-up sediment area to the stockyard directly under the dam.	○					

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-13 Sediment Management at the Yokoyama Dam	To recover the dam function especially in order to ensure reservoir storage capacity for disaster prevention operations.	Excavation in trapping pond in the upstream area of the reservoir.	The check dam is installed at the end of the reservoir to excavate sediments.	○					
3-14 Sediment Management at the Yahagi Dam	To sustain the dam function.	・Dredging. ・Mechanical excavation.	Examination on permanent measures against sediments (installation of a sediment bypass tunnel) is being carried out.	○					
3-15 Securement of Long-term Disposal Area by Cooperation between Public and Private	・To prevent floods from overflowing in the upstream area of the dam. ・To sustain service storage capacity in the existing reservoir.	Mechanical excavation.	N/A	○					
3-16 Sediment Management at the Hitokura Dam	To improve the river environment.	・Flushing. ・Mechanical excavation. ・Supply of sediment to the downstream river (placing directly into the river using a backhoe).	N/A	○	○		○		
3-17 Sediment Management at the Nagoro Dam	Dredging to prevent the intake of water mixed with gravel and sand.	Dredging.	N/A	○					
3-18 Sediment Management at the Nagayasuguchi Dam	・To sustain the effective reservoir capacity.	・Excavation (removal of sediment from the sediment storage dam upstream of the reservoir, placing the sediment downstream of the dam, installation of a belt conveyor for future sediment transportation). ・Sediment replenishment (by embankment downstream).	Installation of selective water withdrawal equipment (measures against muddy water and warm water intake). Install two more spillways (improve the discharge capacity).	○	○				
3-19 Sediment Management at the Setoishi Dam	・To prevent flood disaster in the upstream area with sediment countermeasure operation. ・To improve the river and seashore environment with sediment flow.	・Mechanical excavation (Gathering aggregate). ・Flushing. ・Sluicing.	N/A	○			○	○	

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-20 Mimikawa River Basin Integrated Sediment Flow Management Plan	・Prevention of sediment and driftwood runoff through forest conservation and mountain erosion control. ・Restoration of continuity of the sediment movement.	・Sluicing. ・Yamasubaru Dam: After removing two of the existing eight radial gates in the center, the overflow crest will be lowered by about 9 meters, and one new radial gate will be installed. Saigo Dam: After removing four of the existing eight roller gates in the center, the overflow crest will be lowered by about 4 meters, and two new roller gates will be installed. Ouchibaru Dam: Managed with the current structure (no modifications).	Lessons from the damages caused by Typhoon No.14 in 2005 led to the formulation of the “Mimikawa River Basin Integrated Sediment Flow Management Plan” in October 2011, positioning the securing of the continuity of sediment relocation in the river (sluicing) as an important factor for problem solving.					○	
3-21 Sediment Management at the Jirau Dam in Brazil	・To maintain natural sediment transportation in the Madeira River without causing negative impacts on the socioeconomic and biophysical environment due to power generation operations.	・Suction Dredging ・Implementation of wear-resistant coating for turbines. ・Modify operating rule (focus on reduction of sediment upstream of the dam).	Use slightly muddy water for power generation.	○					○
3-22 Sediment Management at the Shihmen Dam in Chinese Taipei	・To sustain storage capacity in the existing reservoir.	・Reduce sediment production (installation of sediment storage dam) ・Sluicing (muddy water) ・Excavation, dredging (proposing sediment bypass tunnel)	Multi-purpose dam (water use restrictions occur based on turbidity) As water demand increases during the dry season, water restrictions are implemented.	○		○		○	○
3-23 Sediment Management at the Zengwen Dam in Chinese Taipei	Ensuring reservoir capacity, as a multi-purpose dam, securing water for agriculture, industry, and domestic use. (During the dry season, water shortages occur and water restrictions are implemented.)	・Flushing (discharge of muddy water). ・Excavation at the upstream end of the reservoir and the sediment storage dam. ・Dredging near the intake. ・Flushing through tunnels near the intake (under consideration).	N/A	○			○		
3-24 Sediment Management at the Angostura Dam in Costa Rica	・Implementation of sediment management measures in the upstream reservoir. ・Ensuring stable power supply by securing the minimum necessary capacity.	・Reduce sediment production (Sediment management). ・Flushing. ・Modify operating rule (Innovations in flushing methods).	N/A				○		○

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-25 Sediment Management at the Hvammur Dam in Iceland	・Extending the lifespan of reservoirs. ・Pond operations to easily form ice cover. ・Watershed management for vegetation restoration.	・Reduce sediment production (prevent sediment inflow at the sediment storage dam). ・Upstream sediment trapping t the sediment storage dam). ・Excavation.	・Reduction of sediment production in the upstream of the reservoir. ・Prevention of glacial melting and wind erosion.	○					○
3-26 Sediment Management at the Nathpa Jhakri Dam in India	・To preserve the reservoir storage in the future (Generating stable and safe electricity under conditions of high sediment load).	・Upstream sediment trapping. ・Bypass tunnel. ・Sluicing. ・Flushing. ・Modify operating rule (Modification of silt load restrictions passing through turbines). ・Installation of silt removal facilities within the power plant. ・Due to the high sediment load passing through the turbines, plasma coating is applied to the runners, guide vanes, etc.	・The high soil erosion during the melting of Himalayan glaciers brings a significant sediment load, particularly quartz particles, which can cause severe damage to the generation equipment of the plant. ・Installation of silt removal facilities within the power plant.	○		○	○	○	○
3-27 Sediment Management at the Bakaru Dam in Indonesia	To keep the reservoir volume stable at the present level.	・Excavation and dredging. ・Pressure flushing.	Ideally, the water level should be lowered and the gates fully opened to sluice out the sediment, but due to the importance of the power supply in Bacal, it is difficult to operate with a lowered water level. The deficit will be managed by dredging.				○		
3-28 Sediment Management at the Patrind Dam in Pakistan	To maintain the reservoir storage.	・Bypass channel/tunnel ・Sluicing ・Excavation ・Optimization of sediment management	CDM project by the Korean Government	○		○		○	
3-29 Sediment Management at the Binga Dam in Philippines	To ensure long-term power generation operations, balance the sediment inflow and outflow to stabilize the impact of sediment accumulation.	Modify operating rule (Optimization of sediment management).	Insufficient consideration on sediments during the design stage.						○
3-30 Sediment Management at the Solis Dam in Switzerland	・To maintain of effective reservoir capacity. ・To supply of sediment trapped in the downstream reservoir (consideration for the downstream river environment).	Bypass channel/tunnel.				○			

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-31 Cameron Highlands Hydroelectric Scheme in Malaysia	・To secure and maintain the valid reservoir capacity. ・To prevent damage to machine parts of the power plant. ・To protect the environment of the reservoir.	Sediment replenishment (Embankment at the downstream river of the dam)	・Installation of a settling basin in front of intake ・Installation of a weir ・Excavation/dredging	○					
3-32 Sediment Management at Three Gorges Power Plant in China	・To secure the valid reservoir capacity. ・To preserve the environment. ・Compliance.	During flood periods and discharge periods, perform (1) sediment replenishment, and (2) flushing as necessary.	N/A		○		○		
3-33 Akiba No.1, No.2, No.3 Power Plant, Example of sediment management	Solve a problem of submerged land.	・Excavation (Transport to outside the lake) Treatment at the disposal area (by 1998). ・Dredging (Relocation within the lake) (by 1998) Currently dredging, effective use (collecting gravel) and additional layer of soil on the downstream.	From 1978, the measures against sediments at the Akiba Reservoir included transportation to a disposal area outside the lake, relocation within the lake, and collection of gravel. Utilization as aggregates by dredging and excavating sediments by traders was implemented. However, as disposal areas nearby outside the lake are used up and the disposal areas in the regulating reservoir for relocation within the lake have decreased, we started dredging accumulated sediments with a dredger from FY1998. Sediments are pulled up to the sucked sediment area equipped on the lakefront of the regulating reservoir. It has been decided that, basically, all the sucked sediments are effectively utilized.	○	○				○
3-34 Yakuwa Power Plant, Example of sediment management	Implement to secure the service capacity of power generation.	The sluice gate of the Yakuwa Power Plant, located 3.6 kilometers upstream from the dam, is situated in the upstream area of the reservoir and is easily affected by sediments. To ensure stable water intake, dredging work has been conducted since 1973. Due to the impact of sediments, the depth of water that can be effectively used has been about 10 meters in recent years, indicating a significant degradation in reservoir functions.	Although sediments are relocated to the dead region within the lake by pressure feeding after grab dredging, the current dredging efforts cannot halt the progress of sedimentation.	○					
3-35 Honna Power Plant, Example of sediment management	Implement to secure the service capacity of power generation.	Following the 2011 Niigata-Fukushima heavy rain and flood, a large volume of sediments flowed in. As a result, the sedimentation rate of the Honna Dam reached 37.7%. Over the most recent five years, an average of about 50,000 cubic meters of dredging has been performed annually, and the average increase in the volume of sediments has been about 0.34 million cubic meters per year in the same period.	N/A	○					

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-36 Kasumisawa Power Plant, Example of sediment management	Implement a dredging work to secure the service capacity of power generation.	The initial capacity of the reservoir of the Taisho Pond in 1928 was 0.71 million cubic meters. However, it decreased to about one-ninth to approximately 0.08 million cubic meters by 1976 due to the annual sediment inflow from the upper reaches and Mt. Yakedake. Since then, full-scale dredging work has been carried out since 1977 to secure the reservoir capacity based on expert investigations on environmental impact. Although about 20,000 cubic meters of dredging is carried out annually to manage the same volume of incoming sediment, the reservoir capacity has shown a decreasing trend due to large inflows of sediment from recent heavy rains. The rise in the riverbed caused by sediment inflow from the upper reaches is a problem throughout the Kamikochi region, including Taisho Pond. Measures against riverbed rise are part of the "Kamikochi Vision" operation run by relevant ministries and agencies, prefectures, cities, and companies, with the Ministry of the Environment taking the lead.	Together with the flowing of sediments by dropping a rubber weir during floods, the dredging of accumulated sediments has been ongoing.	○				○	
3-37 Hatanagi No.1 Power Plant, Example of sediment management	Measures against sediments for maintaining the functions of the bottom outlet of the dam.	The annual volume of the inflow sediments in Hatanagi Dam #1 is about 0.9 million cubic meters (49% of the sediment rate as of FY2020), which is quite large. It is hard to drastically transport sediments during excavation and dredging, due to the geographical conditions of the mountainous region. Similarly, to the reservoir of the Ikawa Dam, the reservoir of Hatanagi Dam #1 undertakes water supply to the lower reaches and possesses a dam bottom outlet to prepare for power supply failure. To maintain the functions of the outlet structure at the base of the dam, dredging (relocation within the lake) is performed in front of the intakes of the drainpipe, and the drainpipe is discharged during a flood.	N/A	○			○		
3-38 Okuyoshino Power Plant, Example of sediment management	Implement to solve prolonged muddy water and to reduce sediments.	The sediment bypass of the Asahi Dam detours sediments flowing in the dam during a flood to the tunnel to directly discharge sediments to the downstream river. Significant effectiveness against prolonged muddy water in the reservoir and in reducing sediments is confirmed. In addition, the water quality of the reservoir and the environment of the downstream rivers are improved.	Started the operation from 1998 as bypass scouring equipment that discharges muddy water to the downstream of the Asahi Dam through a bypass tunnel of 2,350 meters. The equipment takes water from the dam whose height is 13.5 meters and length is 45.0 meters installed in the upper end of the reservoir.			○			

Name of project	Sediment management			Method of sediment management					
	Details of Basic Policy	Outline	Features	Excavation/Dredging	Sediment replenishment	Sediment bypass	Flushing	Sluicing	Others
3-39 Nishiyama Power Plant, Example of sediment management	Implement to meet objectives, such as securing the service capacity of power generation, and landscape preservation.	The volume of sediment discharge of the Hayakawa River water system is extremely large, and has been exceeding the planned volume of sediments since FY1959. (For measures against the sediment rate 127, regular dredging in a non-flood season and discharge as a measure against sediments (flushing discharge) in a flood season are implemented to keep the balance of sediments in the reservoir.) It is confirmed that there is no concern about rise in the water level of the upstream by draining in a flood season, since the state of sediments in the reservoir is confirmed by surveying every year.	Dredging and discharge as measures against sediments are performed annually to maintain the balance of incoming and outgoing sediments. Sediment discharge (flushing) is carried out through the spillway gate.	○			○		
3-40 Tamagawa No.3 Power Plant, Example of sediment management	Implement to secure the floodgate of the Hikawa Power Plant, such as securing the service capacity of power generation, preventing disasters, and preserving landscape.	The total sediment rate against the total capacity of the Shiromaru is 32.0%, showing no fluctuation in recent years. Although there were some seasons where a volume of inflow sediments was large due to the collapse of the volcanic edifice in the upstream, the volume of inflow in recent years is stabilized. As for scouring, dredging work is carried out to secure around the inflow area of the dam and the floodgate of the Hikawa Power Plant located in the upstream if it is judged that there is a risk of disaster due to accumulated sediments. In addition, although it is not considered sediment management, natural scouring is carried out by opening gates during a large-scale flood, such as during a typhoon, to serve as a river to discharge. The balance of sediments accumulated in the reservoir is appropriate and the valid reservoir capacity for power generation is secured. In addition, there is no concern about flood damage to the neighboring areas due to rise in the riverbed of the upper end of the reservoir.	As for measures against sediments, if it is judged that there is a risk of disaster as the volume of sediments near the flowing area of the upstream increases, the basic response is to perform dredging work in the upstream area of a flooding region.	○				○	

APPENDIX H：EFFECTS AND EVALUATIONS OF SEDIMENT MANAGEMENT (SUBTASK 3)

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-1 Sediment Management at the Tsugaru Dam	•Sediment replenishment (additional layer of soil on the downstream river of the dam).	N/A	N/A	The sediment volume of 220 cubic meters was managed by placing it per replenishment.	As a result of the improvement of the bat box, the number of bats that use the box favorably increased. The fine growth of transplanted and observed plants is promoted. Buildings across the reservoirs are beginning to function as travel paths for the mammals. As a result of a fishway investigation, it is understood that the fishway function is maintained and upstream swimming of Tribolodon ezoe is confirmed. Thus, the Okawa River is expected to be used as a new habitat and spawning ground. An almost satisfactory result is obtained."	River where many endangered fishes across the country inhabit.
3-2 Sediment Management at the Shichikashuku Dam	•Excavation (Install a check dam to excavate gravel. Make effective use of excavated gravel as aggregates.)	N/A	The average supply of sediments is below the planned volume of sediments, so a continuous excavation has been implemented in the sediment storage dam.	About 30,000 cubic meters of sediments were collected in the four years from 2013 to 2016, and about 20,000 cubic meters of aggregates (sand) were supplied.	A sediment storage dam is installed as a measure against sediments. The volume of sediments is below the planned values. Maintaining an appropriate reservoir level secures the flood control capacity and provides a good effect.	Although the average supply of sediments is below the planned volume, continuous implementation of excavation in the check dam is needed.
3-3 Sediment Management at the Shimokubo Dam	• Excavation. • Dredging. • Sediment replenishment (additional layer of soil on the downstream river of the dam).	Upper reaches with geological features with many fragile sections and a steep landform.	Exceeds the planned value (2.2 times the speed of excavating sediments). Geological features with many fragile sections.	N/A	Although excavation, dredging, and sediment replenishment are performed as measures against sediments, sedimentation is advancing at a speed exceeding the planned value (2.2 times the speed of excavating sediments). The reason for this is that the upper reaches, whose geological features include many fragile sections and steep landforms, are the source of sediment supply.	Geological features include many fragile sections, steep landforms, and a large supply of sediments.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-4 Sediment Management at the Amahata Dam	Excavation (Transport sediments using a dump truck and a belt conveyor.)	N/A	The volume of sand produced is incredibly large nationwide, resulting in an enormous volume of sediments. A total of 3.7 million cubic meters of sediments flowed in due to floods that occurred in two consecutive years, 1982 and 1983."	The capacity of the belt conveyor that transports accumulated sediments to the downstream of the dam was increased from 0.5 million to 1.5 million cubic meters. The utilization as a source of aggregates was enhanced from 0.4 million, as in the past, to 0.6 million cubic meters.	Towards the end of 2020, management improved equipment such as reinforcing the capacity of the conveyor tunnel that transports accumulated sediments from the reservoir to the downstream of the dam, increasing it from 0.5 million m^3/year to about 1.5 million m^3/year. Currently, the performance results are being monitored.	Impact on fishing as a result of discharging thickened sediments (sludge).
3-5 Sediment Management at the Miyagase Dam	• Flush discharge. • Sediment replenishment (additional layer of soil on the downstream river of the dam).	N/A	The volume of sediments has exceeded the planned volume. Until 2012, the volume of sediments reached 2.86 million cubic meters, which is 26.8% of the planned volume. Sediments are mainly seen in the inflow area of the river, at the upstream end of the reservoir.	Observation continues while securing the reservoir capacity by excavation.	The flush discharge and sediment replenishment test confirm the improvement of the environment in the downstream river of the dam. A significant increase in the volume of sediments is not observed due to the effect of the sediment storage dam, which was constructed with simple blocks.	Improvement of downstream environment.
3-6 Cooperative Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River	• Flush discharge. • Sluicing.	Large-scale collapsed land, which was weathered into decomposed granite soil, in the upper reaches.	The Kurobe River is a leading river nationwide that deposits a large volume of sediment yield.	Perform scouring and sluicing when a flood that exceeds the designated flow rate occurs. The target volume of scour for the Dashidaira Dam is about 0.28 million cubic meters. No particular target value is set for the Unazuki Dam.	Since 2001, cooperative scouring during floods has been performed by the Dashidaira Dam of Kansai Electric Power, located in the lowermost part of the Kurobe River, and the Unazuki Dam of the Ministry of Land, Infrastructure, Transport and Tourism to discharge accumulated sediments downstream. Certain results have been achieved in terms of maintaining irrigation and flood control functions. The search for effective methods to perform cooperative scouring continues. At the Dashidaira Dam, sediments are resolved, and almost all sediments are discharged downstream. At the Unazuki Dam, the speed of sediment accumulation has decreased.	Impact on fishes as a result of discharging thickened sediments (sludge). Decrease in sediments accumulated in the dam Control the concentration of suspended solids (SS) during scouring. Increase in the time and number of gravity flow Sediment management which covers from the river to the coast.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-7 Sediment Management at the Managawa Dam	• Flush discharge. • Sediment replenishment (additional layer of soil on the downstream river of the dam).	N/A	Thirty-eight years passed from the start of the management in 1979 to 2017. The total volume of sediments is 2.237 million cubic meters (as of 2016), and the sediment rate against the planned volume of sediments (20 million cubic meters) is about 11.1%. The volume of sediments contained in the valid reservoir capacity is 0.476 million cubic meters, which is about 0.5% of the valid reservoir capacity (95 million cubic meters).	Perform flush discharge (30 to 50 m^3/s). No planned sediment scouring is performed.	・The volume of sediments stably changes within the range of the plan. Monitoring still continues. On the other hand, in addition to flush discharge, sediment replenishment is performed to preserve the environment of the direct downstream area of the dam. As a result, a result that contributes to the growth algae and habitat improvement of fishes is obtained. In addition, the cleaning effect on river gravels is confirmed. • Confirmed effectiveness in removing algae.	N/A
3-8 Sediment Management at the Takase Dam	• Excavation. • Selected a proposal concerning "Trap and excavate sediments at the check dam to transport them outside the reservoir using a belt conveyor," which is superior in terms of economy and environmental aspects. (Install a check dam at the upper end of the Takase Dam reservoir to excavate sediments and transport them using a belt conveyor to the downstream of the Omachi Dam (due to be completed by 2029).)	Large-scale collapsed land in the upper reaches of the dam.	Large-scale collapsed land exists in the upper reaches of the dam and reservoir. Annual volume of 0.75 million cubic meters of sediments flows in. Among the annual volume, 70% of it consists of transportable sand and gravel.	Currently, the annual transportation of 0.15 million cubic meters of sediments is performed by excavation at the swamp flowing into the reservoir of the Takase Dam. In the future, 0.23 million cubic meters of inflow sediments will be transported by a belt conveyor instead of excavation. The remaining 0.52 million cubic meters of sediments will be allowed to accumulate in the reservoir.	As for flood control, the Takase Dam, the Nanakura Dam, and the Omachi Dam perform it in cooperation with each other. They aim to prolong the service life of the reservoir functions to 60 years by treating 0.23 million cubic meters out of 0.75 million cubic meters of sediments that flow into the Takase Dam using a tunnel for transporting sediments (a belt conveyor).	Large-scale collapsed land exists in the upper reaches of the dam.
3-9 Sediment Management at the Miwa Dam	• Excavation (in the check dam). • Sediment bypass (Transporting sediments flowed into the dammed lake through a sediment bypass at the branch weir to the outside of the dammed lake).	Upper reaches with fragile geological features, characterized by a complex geological structure in which the median tectonic line runs north and south.	685,000 cubic meters of sediments flow in a year.	Trap 0.16 million cubic meters of sediments at the check dam at the upper end of the reservoir. The trapped sediments are transported and used as gravel. Among the fine-grained sediments passing through the check dam, 0.399 million cubic meters are flowed through the bypass. Another 0.126 million cubic meters of fine-grained sediments are flowed through the scour gate in the dam. The remaining fine-grained sediments are returned to the stock yard in front of the branch weir by dredging and are flowed through the bypass during flooding.	Sediments from the upstream are safely flowed almost as planned. The impact on the environment, such as impact on creatures by discharging from the bypass, is continuously being investigated.	Impact on creatures in the downstream rivers.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-10 Sediment Management at the Koshibu Dam	• Excavation (in the check dam). • Sediment bypass.	Upper reaches with fragile geological features, characterized by a complex geological structure in which the median tectonic line runs north and south.	It is assumed that 151,000 cubic meters of sediments flow in a year.	The branch dam in the upper end of the reservoir traps most of coarse-gained sediments and transports them as gravel. The remaining are discharged through the bypass tunnel. Sediments in the reservoir can be controlled by 20% of annual flowing sediments.	Through sediment discharge via the bypass tunnel, the annual volume of inflow sediments can be reduced by up to 20%.	Impact on the downstream environment.
3-11 Sediment Management at the Ikawa Dam	・Dredging (Dredge up sediments in front of the sand discharge pipe and the discharge pipe, pack the dredged sediments into bags, and sink them in a dead zone). ・Riverbed shaping (Bring sediments to a dead zone to prevent the riverbed from rising at the upper end of the reservoir, thereby preventing flood damage upstream).	Upper reaches with a large amount of rainfall, in addition to fragile geological features affected by diastrophism and weathering.	In February 2017, the Study Committee of General Sediment Management Plan for Quicksand-system of Oi River started, and in June 2020, the General Sediment Management Plan for Quicksand-system of Oi River (the First Version) was established. As the "Quicksand-system of the Oi River," measures that enhance the continuity of the relocation of sediments, including artificial transportation of sediments, from the region of sediment production/transported sediment to the seashore region while utilizing the natural agency are examined.	A remarkable rise in the riverbed is seen in the Ikawa Dam and Hatanagi Dam #1 due to sediments in the reservoir. The annual volume of inflow sediments in the Ikawa Dam is about 0.8 million cubic meters (32% of the sediment rate as of FY2020), which is quite large. It is hard to transport sediments during excavation and dredging due to the geographical conditions of the mountainous area. To maintain the functions of the outlet structure at the base of the dam, dredging is performed in front of the intakes of the sand discharge pipe and the drainpipe in the reservoir of the Ikawa Dam (Relocation within the lake). Also, discharging from the sand discharge pipe is performed during a flood. If flooding is a concern due to the rise in the riverbed in the upper end of the reservoir, the excavation of the riverbed and the relocation of sediments are performed using heavy machinery."	The management is performed in accordance with "the General Sediment Management Plan for Quicksand-system of the Oi River," and the Committee monitors the management in detail. The functions of the intakes of the sand discharge pipe and the drainpipe are maintained by dredging. In addition, the excavation of the riverbed prevents flooding in the upper reaches of the dam.	When discharging the sand discharge pipe, management is performed while monitoring the environment to consider the impact on the ecosystem in the lower reaches of the dam. To transport an extremely large volume of inflow sediments, drastic improvements to ordinary roads in the mountainous region are required.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-12 Sediment Management at the Sakuma Dam	• Dredging (Relocate sediments within the reservoir by a dredger.) Relocate dredged sediments to the region that is below the service capacity (dead zone) in the downstream of the reservoir. • Excavation (Gravel excavation) Excavate gravel using a backhoe in the upstream riverbed and treat it at the disposal area. Relocate excavated gravel to the outside of the reservoir by a dredger. Relocated gravel is picked by gravel traders. • Sediment relocation Lower the water level of the dam in a dry season to make the middle- and upper-reaches of the reservoir like a natural river channel to relocate accumulated sediments to the downstream area of the reservoir using running water of a flood having occurred during said season.	Upper reaches whose landform is steep, in addition to fragile geological features that are affected by crushing and metamorphism.	Inflow of sediments 1.8 million m^3/year. (Average from 2020 to 2024)	• Relocated within the reservoir: 0.79 million m^3/year. • Transported from the reservoir: 0.17 million m^3/year including transported by gravel traders. (Average from 2020 to 2024).	Preventing flood damage in the upstream area.	Reduction of dead water volume by relocating sediments within the reservoir.
3-13 Sediment Management at the Yokoyama Dam	Excavation for maintenance is in progress (Excavation at the check dam was carried out until 2010).	Upper reaches with a large amount of rainfall, in addition to fragile geological features.	Relatively stable due to excavation.	Continuously remove a total of about 14,300 cubic meters of sediments per year.	The increase in the volume of sediments has been controlled by excavating 10,000 cubic meters of sediments every year since the start of the service of the Tokuyama Dam in 2008, securing the valid reservoir capacity.	Need to perform monitoring of regular water quality test.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-14 Sediment Management at the Yahagi Dam	• Dredging. • Excavation.	Collapsed land in the upstream of the dam.	The Yahagi River originates from Mount Okawairi (1,908 meters above sea level) located at the southern tip of the Central Alps in Shimoina District, Nagano Prefecture. It flows through the mountainous area along the border of Aichi and Gifu Prefectures and flows into Mikawa Bay. The Yahagi River is a first-class river with a basin area of approximately 1,830 km². The river basin's surface is composed of granite that has weathered into crumbly sand, making it prone to erosion and resulting in large amounts of sediment discharge during rainfall.	Excavate about 83,000 m3/year of sediments between FY2011 and FY2017.	Almost no fluctuation in the volume of sediments (balanced state) by the sediment management continues. Measures against sediments need to be continuously taken to maintain the functions of the dam. Permanent measures against sediments are examined in the early stage, such as a sediment bypass proposal at the Yahagi Dam.	Improve downstream river environment. Soundness of quicksand in a river system. (As measures against cold muddy water, selective water withdrawal is installed to the dam body and a fence for preventing muddy water is installed at two locations in the reservoir.)
3-15 Securement of Long-term Disposal Area by Cooperation between Public and Private	Excavation.	Deep collapse in the upstream of the dam.	About 295,000 million cubic meters of sediments were accumulated in the pondage of the Tsuzurao Dam by Typhoon No.12 in September 2011.	After removing sediments flowed in the reservoir, sediments were delivered to the new disposal area.	The project succeeded because the objectives aligned with securing a permanent disposal site for sediment for Kousei and Tsudurao Dams of KEPCO and the removal of disaster-related sediment in Tenkawa Village for recovery and reconstruction.	Implementation of traffic regulations to reduce noise/vibration on public roads and ensure safe transportation of sediments, as well as to alleviate traffic jams.
3-16 Sediment Management at the Hitokura Dam	• Flush discharge. • Excavation. • Sediment replenishment (by heavy equipment).	N/A	Inflow of sediments 29,000 m^3/year.	14,000 m^3/year Continuously replenish sediments to the downstream of the dam.	Improvement of the armoring of the riverbed is observed. Monitoring is being performed for other environmental conditions. The volume of sediments is at the same level as the planned volume of sediments.	I Improvement of downstream river environment (armoring in the riverbed, decrease in the habitat of fishes and zoobenthos, flourishing algae that can be food for river creatures, decrease in the number of fishes, such as sweet fish).

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-17 Sediment Management at the Nagoro Dam	Dredging (Dredge sediments in front of the intake by a pump, prevent muddy water): Nagoro Dam frequently releases water, and the soil properties targeted for removal are silty cohesive soil and sandy soil. Additionally, there are very few obstacles (such as driftwood) at the bottom of the lake, making suction suitable. Therefore, a pump Shin-Sugawara dredging method was adopted. The sucked-up water containing sediments is transported through pipes, dehydrated (aerated), and solidified by mixing with cement at a disposal site before being filled in the disposal area.	N/A	Inflow of sediments 10,000 m^3/year.	During the construction, 800 m^3/day of muddy water (40 m^3/day of sediments) was treated.	Sediments accumulated in the front are removed, as the removal of sediments in front of the sluice gate is appropriately performed. The original purpose was achieved. In the future, the timing of removing sediments will be fixed to appropriately perform the removal.	Impact on the landscape (selection of a forced scouring method).
3-18 Sediment Management at the Nagayasuguchi Dam	• Excavation (Remove sediments in the check dam at the upper end of the reservoir, place the additional layer of soil directly downstream of the dam, transport/replenish sediments by a belt conveyor in the long run.) (Planned). • Sediment replenishment (additional layer of soil on the downstream river of the dam).	Crushed zone in the north of the dam site.	Inflow of sediments 267,000 m^3/year.	0.141 millionm3/year Trap sediments in the upstream, and place an additional layer of soil on the downstream of the dam (sediment replenishment). The amount of sediments removed from 2007 to 2014 was 1.27 million cubic meters; of them, 0.14 million cubic meters were effectively used, and the remaining 1.13 million cubic meters were replenished.	The incoming and outgoing sediments are nearly balanced.	・The current method for transporting sediments for sediment management measures is by dump truck. Due to considerations for local residents and the environment, the volume of transportation has its limit. ・Improve the downstream river environment.
3-19 Sediment Management at the Setoishi Dam	• Excavation (Gravel excavation). • Flush discharge. • Sluicing.	N/A	Inflow of sediments 31,000 m^3/year.	Because of continuous excavation for preservation of sedimentary soils in a planned manner, the volume of sediments in FY2020 was lower than the planned volume of sediments.	It is reported that the volume of sediments is reduced by managing with sluicing and flush discharge.	Concerns about flood damage to the upper and lower reaches due to the rise in water levels caused by sediments.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-20 Mimikawa River Basin Integrated Sediment Flow Management Plan	Sluicing. Yamasubaru Dam: After removing two gates in the center from the existing eight radial gates, a new radial gate was installed by cutting the crown of the overflow by about nine meters. Saigo Dam: After removing four gates in the center from the existing eight roller gates, two roller gates were installed by cutting the crown of the overflow about four meters. Ouchibaru Dam: Cope with the current structure (No conversion).	Faults and crushed zones distributed in the upper reaches. Unstable slope due to the road construction.	Due to a flood caused by Typhoon No.14 in September 2005, many medium- to large-scale collapses occurred (470 locations) around the river. Large-scale collapses occurred on the right bank 5,000 meters upstream and the right bank 500 meters downstream of the Tsukabaru Dam, resulting in the occurrence of river blockage phenomenon. It is estimated that the volume of sediments collapsed at that time was 22.7 million cubic meters, and the volume that flowed into the river was 10.5 million cubic meters.	By operating the management of sluicing of the dam, a recovering trend in the continuity of the transportation of sediments is observed.	(1) At the Yamasubaru Dam and the Saigo Dam, reconstruction that lowers the height of the dams is being performed. (2) At the Ouchibaru Dam, sluicing is achieved by improving the management. Environmental monitoring is being conducted for biodiversity.	Improve downstream river environment.
3-21 Sediment Management at the Jirau Dam in Brazil	Suction dredging. ・Apply abrasion-resistant coating over a turbine (muddy water passing the turbine). ・Change the dam operation rules (to prevent the formation of a delta (sediment) at the edge of the reservoir).	Historical flooding of 2014.	The Madeira River covers about half of the sediment load of the entire basin of the Amazon River.	N/A	N/A	About 70% of catchment area of Jirau Dam is located outside the territory of Brazil, making it difficult to monitor and collect sediment data.
3-22 Sediment Management at the Shihmen Dam in Chinese Taipei	・Establish two more spillway tunnels. ・Reduce the production of sediments by basin management (Build a check dam). ・Sluicing (muddy stream). ・Excavation. ・Dredging. ・Also proposing a bypass tunnel.	Upper reaches with geological features that are heavily weathered and easily eroded.	3.53 million m^3/year.	Scouring from turbine/spillway: 0.47 million m^3/year. Scoring by dredging/excavation: 0.32 million m^3/year.	A scouring-related project is being performed to complete the management by 2021. It is planned to remove 55% of the annual volume of sediments by the sand flush gate, a spillway, a tunnel spillway, and power generation, and to scour the remaining 45% by excavation, dredging, and a scour tunnel.	N/A

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-23 Sediment Management at the Zengwen Dam in Chinese Taipei	• Flushing (Discharge muddy stream.) • Excavate at the check dam in the upper end of the reservoir. • Dredge near the sluice gate. • Flushing by a tunnel near the sluice gate (under consideration).	Upper reaches with weathered geological features and steep landform.	5.61 million m^3/year.	Since it is hard to maintain the capacity of the reservoir with annual excavation of 0.15 million tons and dredging of 0.5 million tons near the sluice gate, a bypass tunnel is being planned.	It is hard to maintain the capacity of the reservoir with annual excavation of 0.15 million tons and dredging of 0.5 million tons near the sluice gate.	N/A
3-24 Sediment Management at the Angostura Dam in Costa Rica	• Reduce the production of gravel by basin management (forestry management). • Flushing. • Change the dam operation rules (Devise the flushing method).	Basin with steep slope and a large amount of annual rainfall of over 6,000 mm.	N/A	Although flushing to empty the reservoir is performed twice a year, it is insufficient to reduce the loss of the capacity of the reservoir.	It is insufficient in terms of reducing loss of the capacity of the reservoir. Additional measures, such as dredging, are needed. As for environmental protection, a forest area is greatly extended.	Due to the spread of water hyacinth, a boat cannot reach some areas. As a result, there are places where grasping (surveying) the capacity of the reservoir is difficult.
3-25 Sediment Management at the Hvammur Dam in Iceland	• Reduce the production of gravel by basin management (Prevent the inflow of gravel at the debris barrier in the upstream). • Sediment trap in the upstream of the reservoir (Remove sediments at the check dam). • Excavation.	Erosion caused by melting glaciers and wind.	50,000 m^3/year.	Most of the flowing sediments are removed.	Ninety percent of the inflow of sediments is prevented by the check dam in the upstream of the dam. The remaining sediments are removed by dredging.	Dredged sediments are used at cultivated land.
3-26 Sediment Management at the Nathpa Jhakri Dam in India	• Sediment trap in the upstream of the reservoir. • Sediment bypass. • Sluicing. • Flushing. • Change the dam operation rules (Change the restriction of slit load passing the turbine). • Install silt removal equipment in the power plant facility. • Apply tungsten coating over a runner, a guide vane, etc., as the gravel load passing through the turbine is high.	Basin with soil erosion caused by melting, fragile geological features, and steep landform.	430,000 tons/year.	N/A	The scouring management will be performed by sediment trap, sediment bypass, sluicing, flushing at the check dam in the upstream of the reservoir, and changing operation rules that centralize or redistribute sediments.	N/A

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-27 Sediment Management at the Bakaru Dam in Indonesia	• Flushing (pressure type). • Excavation. • Dredging.	N/A	988,000 tons/year.	Sufficient scouring is not performed. (If the flow rate exceeds 200 m^3/s, sluicing should be performed. However, it is hard to lower the water level, and pressure flushing is performed.)	The Bakaru Power Plant has greatly contributed to the region's power supply. Since management involves temporary interruption of the power plant, implementing drawdown and sluicing is difficult. As additional measures for removing sediments, pressure flushing, mechanical excavation, and dredging are performed.	N/A
3-28 Sediment Management at the Patrind Dam in Pakistan	• Sediment bypass. • Sluicing. • Excavation. • Optimize the measures against sediments.	Earth and sand equivalent to 40 million tons are transported through the Kunhar River flowing from the Himalayas yearly.	4.28 million tons/year.	N/A	Sediment bypass, which was not included in the original plan, is additionally installed.	N/A
3-29 Sediment Management at the Binga Dam in Philippines	Change the dam operation rules (Optimize the measures against sediments).	Landslide caused by the combined effect of large-scale flooding caused by a typhoon and an earthquake.	Landslide caused by the combined effect of large-scale flooding caused by a typhoon and itself.	N/A	N/A	Landslide caused by the combined effect of large-scale flooding caused by a typhoon and itself.
3-30 Sediment Management at the Solis Dam in Switzerland	Sediment bypass.	N/A	80,000 m^3/year.	About two-thirds of the annual volume of sediments are discharged through the bypass tunnel.	A sediment bypass tunnel is effective in both medium-scale flooding and large-scale flooding. Two-thirds of the annual inflow sediments pass through the bypass tunnel, bringing positive result in terms of environmental protection.	Since the operation needs to be carried out with limited data, it is hard for operators to operate.
3-31 Cameron Highlands Hydroelectric Scheme in Malaysia	Install a sand settling basin in front of the intake facilities, install a check dam, excavation/dredging.	Extensive deforestation in the Cameron Highlands area and indiscriminate land development.	Since the 1960s, the volume of sediments floating in Sg. Telom (Telom River) and Sg. Bertam (Bertam River) increased by 20 times and 17 times, respectively. The Ringlet Reservoir has lost about 53% of its total water reserves due to sedimentation since the start of management in 1963. The current estimated value comes to about 3.5 to 4 million cubic meters.	Sediment removal work performed from the mid-1970s to the early-1990s prevented the entry and accumulation of over 1.5 million cubic meters of sediments to the Ringlet Reservoir. The completion of new Telom Desander and Habu Silt Retention Weir and their sediment removal work after the completion prevented at least over 1.5 million cubic meters of sediments for the Ringlet Reservoir during the past few years.	Inflow and accumulation of sediments in the Ringlet Reservoir were notably controlled and reduced.	(1) Build another sediment storage dam on the Ringlet side of the Ringlet Reservoir, Ringlet River, to further decrease inflow sediments into the reservoir. (2) To recover the partially lost reservoir capacity, examine the feasibility of removing sediments from the reservoir. (3) For future development, implement the basin management plan and impose the duty of soil conservation.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-32 Sediment Management at Three Gorges Power Plant in China	N/A	The Jialing River is the main supply source of sediments.	Sediments in the reservoir of the Three Gorges Dam are mainly supplied from rivers, including the Jinsha River, the Jialing River, and the Wu River. Especially the Jialing River is the main supply source of sediments.	Actively make adjustments to reduce sediments during the flooding season and the drainage season.	Efficiency of scoring sediments during the flood season is improved, resulting in improved distribution of accumulated sediments in the reservoir area.	Sediments flowing into the reservoir are not equally distributed in the Three Gorges Dam. The adjustment to distribute sediments in the reservoir area is an important issue for project management. Environmental preservation in the lower area is required.
3-33 Akiba No.1, No.2, No.3 Power Plant, Example of sediment management	Excavation (Transport to outside the lake). Treatment at the disposal area (by 1998). ・Dredging (Relocation within the lake) (by 1998). ・Currently dredging, effective use (used as aggregates, used for river works, beach nourishment materials) and additional layer of soil on the downstream.	In addition to a steep landform upstream, sediment production is frequent due to a fragile geological structure with catacaustic metamorphism. The sedimentation rate exceeds 30% in more than half of the dams of the Tenryu river system.	Considering sediments from branch rivers, the volume of sediments discharged from the Sakuma Dam, and the volume of excavation from the reservoir, it is estimated that the annual volume of sediments flowed is about 0.53 million tons.	The annual volume of sediments discharged from the Akiba Dam is estimated to be 0.49 million tons.	Excavation to prevent flood damage along with the influence of backwater is implemented. As a result, with the current flood stage, a condition that has no problem of land being submerged is secured. Some sediments from excavation and dredging are utilized as aggregates, materials for works involving rivers, and materials for beach nourishment. However, according to a provisional calculation, nearly one million cubic meters of sediments a year reach the mouth of the river. It is therefore hard to fully grasp the impact based on the sediment management that covers several ten thousand cubic meters per year.	Lack of disposal areas in the neighborhood, and reduced disposal area in the regulating reservoir for transporting within the lake.
3-34 Yakuwa Power Plant, Example of sediment management	Dredging continuously since 1973 The sluice gate of the Yakuwa Power Plant is located upstream of the reservoir, 3.6 kilometers away from the dam. As a result, it easily comes under the influence of sediments, which threatens the security of the water depth that allows stable water intake.	Sediments from upstream.	Supply of sediments by measuring depth reservoir is grasped and the estimation of sediments is calculated.	As it is easily affected by sediments, dredging work has been continuously carried out since 1973 for stable water intake.	Although sediments are relocated to the dead zone within the lake by pressure feeding after performing grab dredging, the current dredging cannot stop the progress of sedimentation.	N/A
3-35 Honna Power Plant, Example of sediment management	Dredging	Sediments from upstream.	The increase in the volume of sediments is thought to be caused by the spread of collapsed land in the upstream due to the 2011 Niigata-Fukushima heavy rain and flood and by sediments from the dam located in the upstream.	About 50,000 cubic meters/year Dredging of an average of about 50,000 cubic meters was performed in the most recent five years, and the average increase in the volume of sediments was about 0.34 million cubic meters a year in the most recent five years.	Constant lack of dredging.	Constant lack of dredging This hydropower plant is located in a steep mountainous region, which raises the issue of securing stable disposal areas.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-36 Kasumisawa Power Plant, Example of sediment management	Dredging	Sediment inflow from the upstream area and Mt. Yakedake.	Although the annual average volume of sediments of the regulating reservoir is about 20,000 cubic meters, the volume of inflow sediments from the upstream was increased due to heavy rain in 2020 and 2021. It is known that a large volume of sediments flowing into the Taisho Pond exists, since a rise in the riverbed causes a problem at the upstream river of the Taisho Pond.	About 20,000m^3/year Although dredging of about 20,000 cubic meters is carried out every year to secure necessary capacity of the regulating reservoir (Pondage), the capacity of the regulating reservoir (Pondage) shows a decreasing trend due to inflow of a large volume of sediments by heavy rain in recent years.	As about 20,000 cubic meters of sediments accumulate every year at the Taisho Pond, dredging work of about 20,000 cubic meters is performed every year to secure the capacity of the regulating reservoir (Pondage). If the inflow of the rivers reaches 60 m^3/s, sediments from the upstream are flowed by making the reservoir like a river by falling down of a rubber weir. Although the evacuation and transportation of sediments accumulated on the riverbed are performed, it seems that no outstanding result is obtained. Together with flowing sediments by falling down of a rubber weir during a flood, the dredging of accumulated sediments is continued.	Dredged sediments are transported and treated at the company-owned disposal area. However, since buyers who can effectively utilize them cannot be found, the company has a hard time securing places to transport sediments after the disposal area becomes full.
3-37 Hatanagi No.1 Power Plant, Example of sediment management	N/A	Upstream collapsed area.	The annual volume of sediments of the reservoir is 0.9 million cubic meters. The volume of sediments in recent years is the same level as in the past. The main cause of inflow sediments is thought to be the collapsed land in the upstream of the Oigawa River. Most of sediments in the reservoir are bed loads and suspended sediments and are accumulated in the upstream and midstream of the reservoir. Wash loads are accumulated in the vicinity of the dam.	0.9 million cubic meters Sediments accumulated in front of the intake of the water drainage equipment are dredged and discharged to the downstream.	The function of water discharge equipment is maintained. The Hatanagi No.1 Power Plant undertakes water supply to the lower reaches and possesses a dam bottom outlet to prepare for power supply failure. To keep the function, as well as dredging in front of the intake, a discharge pipe is regularly discharged for a short time to release sediments accumulated in front of the discharge pipe. Discharge of the discharge pipe is performed by selecting a time when the downstream of the rivers become muddy.	・To transport an extremely large volume of inflow sediments, drastic improvement of ordinary roads in the mountainous region is required. ・ In addition, it is required to make a detour around the Ikawa Dam and the Nagashima Dam (operated by the MLIT) for transporting sediments to the downstream of the river. As a result, big issues arise, including one physical is nature (volume that can be transported) and one environmental in nature (noise caused by transportation). ・Environmental impact on ecosystem in the lower reaches of the dam.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-38 Okuyoshino Power Plant, Example of sediment management	Sediment bypass tunnel.		Although the annual volume of sediments in the reservoir between 1978 and 1988 was 24,000 cubic meters, it increased rapidly from 1989 onward. As of 1995, it came to 0.62 million cubic meters, reaching one-fourth of the planned volume of sediments. According to the sediment simulation, sediments will progress to the front of the intake and flood gate in about 10 years, which arouses concern over a difficulty in pumping operation.	It is estimated that nearly 90% of the volume of inflow sediments passed the bypass tunnel.	(Effect of the reduction of sediments) Little change in the form of sediments accumulated in the reservoir has been observed since 1998. Since the inflow of segments to the dam is controlled, the annual volume of sediments is greatly decreased. It is assumed that nearly 90% of sediments flowed passes through the bypass tunnel. (Effect of reduction of muddy water being prolonged) Before the operation of the bypass, the number of days that the turbidity of five ppm or over in the upstream and downstream of the dam was observed was 51 days on annual average. After the operation, it is reduced to 7 days, which allows us to confirm the effect against prolonged muddy water. The results of examinations of fishes, benthos, attached algae, etc., indicate that the river environment is changing favorably.	Continuing examination by monitoring is required. No big change in the riverbed of the downstream after operating the sediment bypass is observed. Some sections were lowering of the riverbed occurred are also changed stably. On the other hand, there are some eroded sections, and the regeneration of erosion, accumulation, and relocation of sediments take place like natural rivers. It is believed that the reconstruction of the form of the downstream of river has been progressing by operation of the bypass.
3-39 Nishiyama Power Plant, Example of sediment management	Dredging.	It is estimated to be due to the expansion of the upstream collapsed area caused by heavy rain.	Measurement of suspended sediment and calculation of the volume of sediments associated with the collapse of the slope in the upstream and flood transportation are not carried out. Although dredging and discharging for measures against sediments are carried out every year, the volume of sediments remains at the same level. It is therefore assumed that the cause is spread of collapsed land in the upstream following heavy rain.	N/A	Dredging is carried out during non-flood periods by lowering the reservoir water level and using regular heavy machinery. Although there are limitations on the work period and the daily amount of sediment removed, the effects are noticeable. As Hayakawa River experiences rapid increases in water volume due to rainfall, we have been trialing sediment flushing releases from the floodgate since 2015, taking advantage of the fact that water intake becomes impossible several times a year due to rising water levels. By conducting regular dredging of the reservoir and sediment flushing releases during flood periods, the sediment balance of the reservoir is maintained.	・The planned volume of sediments cannot be below due to discharge from the spillway gate. ・Impact by the occurrence of muddy water: ・To reduce the supply of sediments to the downstream, since a company that normally carries out the collection of gravel in the downstream of the river collects gravel directly from the dam, the impact is thought to be minimal. ・Since discharge for measures against sediments (flushing discharge) is performed only during a flood, the implementation of these measures will not cause the impact of muddy water. ・Dredging is performed by lowering the reservoir level during a non-flood period to avoid impacting the river water.

Name of the project	Outline of sediment management	Supply of sediment		Annual volume of scour by sediment management	Result of the implementation of the sediment management (evaluation)	Issues relating to the implementation of scouring (Points to note)
		Supply source	Assumed volume of present supply			
3-40 Tamagawa No.3 Power Plant, Example of sediment management	Dredging	Bed loads and suspended sediments that flow in during the flood season	Although the annual average volume of sediments flowing into the reservoir is about 8,100 cubic meters, it has fluctuated constantly in recent years due to sediments discharged from the dam during large-scale flooding. The upstream slope has stabilized, as no large-scale collapses have occurred in recent years. Most of the sediments in the reservoir are bed loads and suspended sediments that flow in during the flood season and accumulate throughout the reservoir.	In case of sediment deposition near intake facilities and the tailrace outlet of the upstream Hikawa Power Plant, which is judged a disaster risk, dredging work is carried out to secure these areas. Additionally, although it is not considered sediment management, natural scouring is performed by opening gates during large-scale floods, such as typhoons, to discharge water like a natural river.	The supply of sediments and the volume of scouring have been balanced in recent years due to dredging as required and natural flushing by discharge. Natural flushing during a large-scale flood is given priority to consider the impact on the environment for the ecosystem in the lower reaches of the dam. However, reduced electric power caused by lowering the water level of the reservoir affects the service; flooding the dam is performed by carefully calculating the timing. The balance of sediments accumulated in the reservoir is appropriate and the effective reservoir capacity for power generation is secured. Additionally, there is no concern about flood damage to the neighboring areas due to the rise in the riverbed at the upper end of the reservoir.	Sediment discharge is carried out with priority given to natural scouring during large-scale floods to consider the environmental impact on the ecosystem downstream of the dam.

APPENDIX I：GENERAL INFORMATION OF THE PROJECT (SUBTASK 3)

		3-1 Sediment Management at the Tsugaru Dam	3-2 Sediment Management at the Shichikashuku Dam	3-3 Sediment Management at the Shimokubo Dam	3-4 Sediment Management at the Amahata Dam	3-5 Sediment Management at the Miyagase Dam
Name of the project		3-1 Sediment Management at the Tsugaru Dam	3-2 Sediment Management at the Shichikashuku Dam	3-3 Sediment Management at the Shimokubo Dam	3-4 Sediment Management at the Amahata Dam	3-5 Sediment Management at the Miyagase Dam
Name of power plant		Tsugaru Power Plant	Shichikashuku Power Plant	Shimokubo Power Plant Shimokubo No.2 Power Plant	Sumise Power Plant	Aikawa No.1 Power Plant
Detail data	Implementing body	Dam: MLIT Plant: Tohoku EPCO	MLIT	Dam: JWA Plant: Gunma Prefecture EB	NLMCO	Dam: MLIT Plant: Kanagawa Prefecture EB
	Location/Country of site	Nishimeya Vil. in Aomori Pref.	Shichikashuku Town in Miyagi Pref.	Kanna Town in Gunma Pref.	Hayakawa Town in Yamanashi Pref.	Sagamihara City in Kanagawa Pref.
	Generating Method	Dam	Dam	Dam	Dam and Waterway	Dam
	Type of Plant	Reservoir	Reservoir	Reservoir (Shimokubo) Run-of-River (No.2)	Reservoir	Reservoir
	Catchment Area (km2)	172	236.6	322.9	99.7	213.9
	Type of Dam	Concrete Gravity	Rockfill Dam with Central Clay	Concrete Gravity	Arch	Concrete Gravity
	Dam height (m)	97.2	90	129	80.5	156
	Name of Dam	Tsugaru	Shichigasyuku	Shimokubo	Amahata	Miyagase
	Name of River	Iwaki	Shiraishi	Kanna	Amahata	Nakatsu
	Name of river system	Iwaki River System	Abukuma River System	Tone River System	Fuji River System	Sagami River System
	Maximum Output (MW)	8.5	3.6	15MW (Shimokubo) 0.27MW (No.2)	13	24
	Year of commission	2016	1992	1968 (Shimokubo) 2001 (No.2)	1967	1997

Name of the project		**3-6 The Cooperating Sediment Flushing in the Case of Unazuki Dam and Dashidaira Dam in Kurobe River**	**3-7 Sediment Management at the Managawa Dam**	**3-8 Sediment Management at the Takase Dam**	**3-9 Sediment Management at the Miwa Dam**
Name of power plant		Shin-Yanagawara Power Plant Otozawa Power Plant Dashidaira Power Plant Unazuki Power Plant	Managawa Power Plant	Shin-takasegawa Pumped Storage Power Plant	Miwa Power Plant
Detail data	Implementing body	Dashidaira Dam: KEPCO Unazuki Dam: MLIT Plant: KEPCO	Dam: MLIT Plant: Hokuriku EPCO	TEPCO	Dam: MLIT Plant: Nagano Prefecture EB
	Location/Country of site	Kurobe City in Toyama Pref.	Ono City in Fukui Pref.	Omachi City in Nagano Pref.	Ina City in Nagano Pref.
	Generating Method	Waterway (Shin-Yanagawara) Dam and Waterway (Otozawa) Dam (Dashidaira, Unazuki)	Dam and Waterway	Dam and Waterway	Dam
	Type of Plant	Pondage (Shin-Yanagawara, Otozawa, Unazuki) Run-of-River (Dashidaira)	Reservoir	Pumped Storage	Pondage
	Catchment Area (km2)	461.2 (Dashidaira) 617.5 (Unazuki)	223.7	131	311.1
	Type of Dam	Concrete Gravity	Arch	Central core type of Rockfill Dam	Concrete Gravity
	Dam height (m)	Unazuki:97 Dashidaira;76.7	127.5	176	69.1
	Name of Dam	Dashidaira Unazuki	Managawa	Takase	Miwa
	Name of River	Kurobe	Manar	Takase	Mibu
	Name of river system	Kurobe River System	Kuzuryu River System	Shinano River System	Tenryu River System
	Maximum Output (MW)	41.2 MW (Shin-Yanagawara) 124 MW (Otozawa) 0.54 MW (Dashidaira) 20 MW (Unazuki)	14	1280	12.2
	Year of commission	1993 (Shin-Yanagawara) 1985 (Otozawa) 2014 (Dashidaira) 2000 (Unazuki)	1977	1979	1958

Name of the project		3-10 Sediment Management at the Koshibu Dam	3-11 Sediment Management at the Ikawa Dam	3-12 Sediment Management at the Sakuma Dam	3-13 Sediment Management at the Yokoyama Dam	3-14 Sediment Management at the Yahagi Dam
Name of power plant		Koshibu No.1, No.2, No.3 Power Plant	Ikawa Power Plant	Sakuma Power Plant	Yokoyama Power Plant	Yahagi No1 Power Plant
Detail data	Implementing body	Dam: MLIT Plant: Nagano Prefecture EB	Chubu EPCO	J-POWER	Dam: MLIT Plant: Chubu EPCO	Dam: MLIT Plant: Chubu EPCO
	Location/Country of site	Matsukawa Town in Nagano Pref.	Shizuoka City in Shizuoka Pref.	Hamamatsu City in Shizuoka Pref.	Ibigawa Town in Gifu Pref.	Toyota City in Aichi Pref.
	Generating Method	Dam (No.1, No.3) Dam and Waterway (No.2)	Dam	Dam and Waterway	Dam	Dam
	Type of Plant	Pondage (No.1, No.2) Run-of-River (No.3)	Reservoir	Reservoir	Reservoir	Reservoir
	Catchment Area (km2)	288	459.3	4156.5	471	504.5
	Type of Dam	Arch	Hollow Concrete Gravity	Concrete Gravity	Hollow Concrete Gravity	Arch
	Dam height (m)	105	103.6	155.5	80.8	100
	Name of Dam	Koshibu	Ikawa	Sakuma	Yokoyama	Yahagi
	Name of River	Koshibu	Oi	Tenryu	Ibi	Yahagi
	Name of river system	Tenryu River System	Oi River System	Tenryu River System	Kiso River System	Yahagi River System
	Maximum Output (MW)	3 (No.1) 7 (No.2) 0.55 (No.3)	62	350	70	60
	Year of commission	1969 (No.1, No.2) 2000 (No.3)	1957	1956	1964	1970

Name of the project		3-15 Securement of Long-term Disposal Area by Cooperation between Public and Private	3-16 Sediment Management at the Hitokura Dam	3-17 Sediment Management at the Nagoro Dam	3-18 Sediment Management at the Nagayasuguchi Dam	3-19 Sediment Management at the Setoishi Dam
Name of power plant		Yokoyama Power Plant	Hitokura Power Plant	Nagoro Power Plant	Hinotani Power Plant Kagedaira Power Plant	Setoishi Power Plant
Detail data	Implementing body	KEPCO	JWA	Shikoku EPCO	Dam: MLIT Plant: Tokushima Prefecture EB (Hinotani), Shikoku EPCO (Kagedaira)	J-POWER
	Location/Country of site	Tenkawa Vill. in Nara Pref.	Kawanishi City in Hyogo Pref.	Miyoshi City in Tokushima Pref.	Naka Town in Tokushima Pref.	Ashikita Town in Kumamoto Pref.
	Generating Method	Dam and Waterway	Dam	Dam and Waterway	Dam and Waterway	Dam
	Type of Plant	Pondage	Reservoir	Pondage	Pondage (Hinotani) Pumped Storage (Kagedaira)	Pondage
	Catchment Area (km2)	120.4 (Wada) 30.6 (Kawai)	115.1	21.2	582.9	1629.3
	Type of Dam	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity
	Dam height (m)	Tsudurao: 26.5 Kouse: 36.5	75	37	85.5	26.5
	Name of Dam	Tsudurao (Wada) Kouse (Kawai)	Hitokura	Nagoro	Nagayasuguchi	Setoishi
	Name of River	Tenno	Hitokura Oroji	Iya	Naka	Kuma
	Name of river system	Shingu River System	Yodo River System	Yoshino River System	Naka River System	Kuma River System
	Maximum Output (MW)	2.1 (Wada) 7 (Kawai)	1.9	1.3	62 (Hinotani) 46.5 (Kagedaira)	20
	Year of commission	1937 (Wada) 1940 (Kawai)	1983	1961	1955 (Hinotani) 1968 (Kagedaira)	1958

Name of the project		3-20 Mimikawa River Basin Integrated Sediment Flow Management Plan	3-21 Sediment Management at the Jirau Dam in Brazil	3-22 Sediment Management at the Shihmen Dam in Chinese Taipei	3-23 Sediment Management at the Zengwen Dam in Chinese Taipei	3-24 Sediment Management at the Angostura Dam in Costa Rica
Name of power plant		Yamasubaru Power Plant Saigo Power Plant Ouchibaru Power Plant	Jirau Power Plant	Shihmen Power Plant	Zengwen Power Plant	Angostura Power Plant
Detail data	Implementing body	Kyushu EPCO	Eletronorte	Taiwan Power Company	Taiwan Power Company	Costa Rican Electricity Institute
	Location/Country of site	Misato Town in Miyazaki Pref.	Rondonia in Brazil	Taoyuan City in Chinese Taipei	Chiayi County in Chinese Taipei	Turrialba District in Costa Rica
	Generating Method	Dam and Waterway (Yamasubaru, Saigo) Dam (Ouchibaru)	Dam	Dam	Dam	Dam and Waterway
	Type of Plant	Pondage (Yamasubaru, Saigo) Reservoir (Ouchibaru)	Run-of-River	Reservoir	Reservoir	Run-of-River
	Catchment Area (km2)	598.6 (Yamasubaru) 647.8 (Saigo) 741 (Ouchibaru)	972710	763.4	481	1463
	Type of Dam	Concrete Gravity	Embankment and Concrete Gravity	Rockfill	Earth	Concrete Gravity
	Dam height (m)	Yamasubaru 29.4 Saigo 20 Ouchibaru 25.5	63	133.1	128	38
	Name of Dam	Yamasubaru Saigo Ouchibaru	Jirau	Shihmen	Zengwen	Angostura
	Name of River	Mimi	Madeira	Dahan	Zengwen	Reventazón
	Name of river system	Mimikawa River System	Amazon	Tamshui	Zengwen	Reventazón
	Maximum Output (MW)	41 (Yamasubaru) 27.1 (Saigo) 16 (Ouchibaru)	3750	90	50	177
	Year of commission	1932 (Yamasubaru) 1929 (Saigo) 1956 (Ouchibaru)	2013	1964	1973	1960

Name of the project		3-25 Sediment Management at the Hvammur Dam in Iceland	3-26 Sediment Management at the Nathpa Jhakri Dam in India	3-27 Sediment Management at the Bakaru Dam in Indonesia	3-28 Sediment Management at the Patrind Dam in Pakistan	3-29 Sediment Management at the Binga Dam in Philippines
Name of power plant		Hvammur Power Plant	Nathpa Jhakri Power Plant	Bakaru Power Plant	Patrind Power Plant	Binga Power Plant
Detail data	Implementing body	Landsvirkjun	Satluj Jal Vidyut Nigam Ltd	P.T.PLN (PERSERO)	Star Hydro Power Pvt. Limited	SN Aboitiz (SNAP)
	Location/Country of site	Selfoss Town in Iceland	Himachal Pradesh State in India	South Sulawesi Region in Indonesia	On the border of Abbottabad District of KPK and Muzaffarabad city, of AJK, Pakistan	Benguet Province in Philippines
	Generating Method	Dam and Waterway	Dam and Waterway	Dam and Waterway	Dam and Waterway	Dam and Waterway
	Type of Plant	Run-of-River	Run-of-River	Run-of-River	Run-of-River	Run-of-River
	Catchment Area (km2)	7300	49820	1080	2429	936
	Type of Dam	Zoned Earth-rockfill	Concrete Gravity	Concrete Gravity	Concrete Gravity	Zoned Earth-rockfill
	Dam height (m)	120	185	16.5	26	107.4
	Name of Dam	Hvammur	Nathpa Jhakri	Bakaru	Patrind	Binga
	Name of River	Þjórsá	Sutlej	Mamasa	Kunhar	Agno
	Name of river system	Þjórsá	Indus	Sadang	Jhelum	Agno
	Maximum Output (MW)	93	1500	126	150	140
	Year of commission	N/A	2003	1991	2017	1960

		3-30 Sediment Management at the Solis Dam in Switzerland	3-31 Cameron Highlands Hydroelectric Scheme in Malaysia	3-32 Sediment Management at Three Gorges Power Plant in China	3-33 Akiba No.1, No.2, No.3 Power Plant, Example of sediment management
Name of the project		3-30 Sediment Management at the Solis Dam in Switzerland	3-31 Cameron Highlands Hydroelectric Scheme in Malaysia	3-32 Sediment Management at Three Gorges Power Plant in China	3-33 Akiba No.1, No.2, No.3 Power Plant, Example of sediment management
Name of power plant		Sils Power Plant Rothenbrunnen Power Plant	Kampung Raja Power Plant, Kuala Terla Power Plant, Robinson Falls Power Plant, Habu Power Plant, Sultan Yussuf Power Plant	Three Gorges Power Plant	Akiba No.1, No.2, No.3 Power Plant
Detail data	Implementing body	Elektrizitätswerk of Zurich (EWZ)	Tenaga Nasional Berhad (TNB)	China Yangtze Power Co.,Ltd	J-Power
	Location/Country of site	Grisons State in Switzerland	The state of Pahang, Malaysia	Sandouping, Yiling District, Hubei,China	Shizuoka Prefecture
	Generating Method	Dam and Waterway	Kampung Raja, Kuala Terla, Robinson Falls, Habu: Dam Sultan Yussuf: Dam & waterway	Dam	Dam and Waterway
	Type of Plant	Pondage	Kampung Raja, Kuala Terla, Robinson Falls, Habu: Run-of-River, Sultan Yussuf: Pondage	Pondage	Pondage
	Catchment Area (km2)	900	Kampung Raja 30.8, Kuala Terla 43.3, Robinson Falls 21.4, Habu 132.7, Sultan Yussuf 183.4	1,000,000	4490
	Type of Dam	Arch	Concrete & Rockfill	Concrete Gravity	Concrete Gravity
	Dam height (m)	61	40	185	89
	Name of Dam	Solis	Sultan Abu Bakar Dam	Three Gorges Dam	Akiba
	Name of River	Albula	Sg. Bertam.	Yangtze	Tenryu
	Name of river system	Hinterrhein	Sg. Bertam.	Yangtze River Basin	Tenryu River System
	Maximum Output (MW)	26 (Sils) 38 (Rothenbrunnen)	Kampung Raja 0.8MW, Kuala Terla 0.5MW, Robinson Falls 0.9MW, Habu 5.5MW, Sultan Yussuf 100 MW	22500	Akiba No.1 47.2 MW, Akiba No.2 35.3 MW Akiba No.3 46.9 MW,
	Year of commission	1986	Kampung Raja Power Plant 1964, Kuala Terla Power Plant 1964, Robinson Falls Power Plant 1959, Habu Power Plant 1964, Sultan Yussuf Power Plant 1963	2003	Akiba No.1 1958 Akiba No.2 1958 Akiba No.3 1991

Name of the project		3-34 Yakuwa Power Plant, Example of sediment management	3-35 Honna Power Plant, Example of sediment management	3-36 Kasumisawa Power Plant, Example of sediment management	3-37 Hatanagi No.1 Power Plant Example of sediment management	3-38 Okuyoshino Power Plant, Example of sediment management
Name of power plant		Yakuwa Power Plant	Honna Power Plant	Kasumisawa Power Plant	Hatanagi No.1 Power Plant Multiple-use pumped storage type	Okuyoshino Power Plant, Pure pumped storage type
Detail data	Implementing body	Tohoku EPCO	Tohoku EPCO	TEPCO	Chubu EPCO	KEPCO
	Location/Country of site	Yamagata Prefecture	Yamagata Prefecture	Nagano Prefecture	Shizuoka Prefecture	Nara Prefecture
	Generating Method	Dam and Waterway	Dam	Dam and Waterway	Dam and Waterway	Dam and Waterway
	Type of Plant	Reservoir	Pondage	Run-of-River	Reservoir, Multiple-use pumped storage type	Pump-storage
	Catchment Area (km2)	148.4	2142	115.4	318	39.2
	Type of Dam	Concrete Gravity	Concrete Gravity	Rubber tube weir	Hollow Concrete Gravity	Arch
	Dam height (m)	97.5	51.5	4.45	125	86.1
	Name of Dam	Yakuwa	Honna	Taisho Pond	Hatanagi No.1	Asahi
	Name of River	Bonji	Tadami	Azusa	Oi	Upper: Setotani Lower: Asahi
	Name of river system	Aka River System	Agano River System	Shinano River System	Oi River System	Shingu River System
	Maximum Output (MW)	60.3 MW	78 MW	39 MW	86 MW	1,206 MW
	Year of commission	1958	1952	1927	1962	1978

Name of the project		3-39 Nishiyama Power Plant Example of sediment management	3-40 Tamagawa No.3 Power Plant, Example of sediment management
Name of power plant		Nishiyama Power Plant Pondage	Tamagawa No.3 Power Plant Pondage
Detail data	Implementing body	Yamanashi Prefecture EB	Bureau of Transportation, Tokyo Metropolitan Government
	Location/Country of site	Yamanashi Prefecture	Tokyo Metropolitan
	Generating Method	Dam and Waterway	Dam
	Type of Plant	Pondage	Pondage
	Catchment Area (km2)	192	134
	Type of Dam	Concrete Gravity	Concrete Gravity
	Dam height (m)	40.4	30.3
	Name of Dam	Nishiyama	Shiromaru
	Name of River	Haya	Tama
	Name of river system	Fuji River System	Tama River Sysem
	Maximum Output (MW)	18.8 MW	16.4 MW
	Year of commission	1957	1963