MODERNIZATION OF Japan's Hydromet SERVICES

A Report on Lessons Learned for Disaster Risk Management

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP
GFDRR
Global Facility for Disaster Reduction and Recovery
FRICS
JMBSC

CONTRIBUTORS

World Bank: Jack Campbell and Makoto Suwa (Co-leads); Toshihiro Sonoda (GFDRR Hydromet Team); Ray Canterford, Anne Himmelfarb and Sonia Luthra (Consultants); and James Newman, Keiko Kaneda, Naho Shibuya and Vibhu Jain (DRM Hub, Tokyo), under the guidance of Francis Ghesquiere, Luis Tineo and Vladimir Tsirkunov.

Japan Meteorological Business Support Center (JMBSC): Mitsuhiko Hatori (Head), Tokiyoshi Toya, Michihiko Tonouchi, Hiroshi Yokoyama, Masao Mikami, Tsutomu Jyoumura, and Yasutaka Makihara.

Foundation of River & Basin Integrated Communications, Japan (FRICS): Akihiko Nunomura (Head), Minoru Kuriki, Masaaki Nakayasu, Hideyuki Kamimera, and Atsuhiro Yorozuya.

ACKNOWLEDGMENTS

The Government of Japan provided substantial inputs and advice in the drafting of the reports and overall strategic guidance. Particular thanks go to the Ministry of Land, Infrastructure, Transport and Tourism (MLIT); the Japan Meteorological Agency (JMA); the Cabinet Office; the International Centre for Water Hazard (ICHARM); and the Japan International Cooperation Agency (JICA).

Special thanks are extended to the experts of JMA and MLIT who were very helpful in providing a great deal of comprehensive and precise information on the past and current meteorological and hydrological services in Japan, as well as valuable comments and suggestions, and to a number of former staff members of JMA and MLIT, and their predecessors, who devoted a substantial effort to the modernization of Japanese meteorological and hydrological services over 100 years, and which gives the valuable lessons and models of modernization for developing countries as reviewed in the this report and background papers.

ABBREVIATIONS

AMeDAS	Automated Meteorological Data Acquisition System
CCTV	closed-circuit television
CREWS	Climate Risk and Early Warning Systems
DRM	disaster risk management
FRICS	Foundation of River & Basin Integrated Communications, Japan
GFCS	Global Framework for Climate Services
GFDRR	Global Facility for Disaster Reduction and Recovery
ICAO	International Civil Aviation Organization
ICT	Information and Communications Technology
IMO	International Meteorological Organization
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
JMBSC	Japan Meteorological Business Support Center
LMOs	Local Meteorological Offices
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
NHK	Japan Broadcasting Corporation
NMHS	National Meteorological and Hydrological Service
NTT	Nippon Telegram and Telephone Corporation
NWP	Numerical Weather Prediction
QPE/QPF	Quantitative Precipitation Estimation/ Quantitative Precipitation Forecast
SDG	Sustainable Development Goal
TMO	Tokyo Meteorological Observatory
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO IHP	International Hydrological Programme
UNESCO IOC	Intergovernmental Oceanographic Commission
WMO	World Meteorological Organization
WDMB	Water and Disaster Management Bureau
WWC	World Water Council

Table of Contents

ACKNOWLEDGMENTS i
ABBREVIATIONS i

1. Helping Developing Countries Reduce Disaster Risk from Natural Hazards Through Modern Hydromet Services 3

1.1 Role of the World Bank 4
1.2 Role of International Frameworks and Agreements 5
1.3 Structure of this Summary Report 5

2. The Emergence of Modern Hydromet Services in Japan 6

2.1 Overview 6
2.2 Institutional Strengthening 7
2.2.1 Meteorological Services 7
2.2.2 Hydrological Services 8
2.2.3 Legal Framework and Warning Dissemination 10
2.3 Modernization of Systems 12
2.4 Enhanced Service Delivery 15
2.4.1 Seamless Early Warning Services and a Comprehensive Multi-hazard Approach 15
2.4.2 Institutional Cooperation for Improved Flood Forecasting Service Delivery 16
2.4.3 Landslide Alert Information 17
2.4.4 Private Meteorological Services 17
2.4.5 Cost-Recovered Aviation Weather Services 18

3. Lessons Learned, Conclusions, and the Way Forward 20

1. Helping Developing Countries Reduce Disaster Risk from Natural Hazards through Modern Hydromet Services

This summary report aims to provide a knowledge base for policy and decision makers that will allow governments and sponsor organizations to understand the fundamental operations of weather, climate, and hydrological services (together constituting "hydromet" services) and consequently target effective funding, in particular to developing countries. It summarizes two detailed and comprehensive supporting reports: a background paper by the Japan Meteorological Business Support Center (JMBSC) on meteorological services; and a background paper by the Foundation of River & Basin Integrated Communications, Japan (FRICS), on hydrology and water resources.[1] The background papers and this summary report were commissioned by the World Bank's Disaster Risk Management (DRM) Hub, Tokyo to document the modernization trajectory of Japanese meteorological and hydrological services.

It is clear that disasters from natural hazards are having extensive impacts on vulnerable communities and the economies of many nations. Well-prepared and resourced hydrological and meteorological services can warn governments and communities so that this disruption is minimized, and can also aid in rescue and recovery efforts and in reconstruction; daily weather information can help prevent secondary disasters in environments where vulnerability and risk are high, and flood hazard maps and other tools can guide rebuilding efforts. Japan's comprehensive multi-hazard approach covering weather, climate, ocean-related, and terrestrial services has been applied and developed through numerous experiences of disastrous events, such as the 2011 Great East Japan Earthquake, strong typhoon landfalls, and volcanic eruptions. Taking Japan's approach as a model, this summary report contributes to a growing knowledge base around how to avoid uncoordinated investments in the hydrological and meteorological sector, which in the past have sometimes led to fragmented and unsustainable outcomes for developing countries.

Against the above background, international cooperation for developing technological and human capacities in NMHSs is rapidly increasing. International financing for improved and responsive services, particularly in adaptation to climate change, has increased the availability of targeted funds, while international financial and technical institutions—for example, the World Bank and the Japan International Cooperation Agency (JICA)—have increased their technical capacity to deliver to developing country clients. Indeed, the number of countries looking to modernize their own observation, forecasting, and early warning systems is on an upward trend.

Sharing knowledge between countries and facilitating effective coordination between development partners can substantially increase the prospect that investments are sustainable and fit-for-purpose. As part of this effort, taking a historical perspective on the evolution of developed National Meteorological and Hydrological Services (NMHSs) can help countries embarking on their own modernization effort to set their pathways for investment and

1. Japan Meteorological Business Support Center (JMBSC), A Background Paper on Meteorological Services in Japan and Lessons for Developing Countries (2016). Foundation of River & Basin Integrated Communications, Japan (FRICS), A Background Paper on Hydrological Services in Japan and Lessons for Developing Countries" (2016). Each paper stands alone in its value to operational and policy clients.

benchmarks of progress. Clear steps for moving forward are particularly important given the long time frames for investment, and the necessary incremental improvements in service delivery.

In their book on weather and climate resilience for the World Bank, Rogers and Tsirkunov describe the importance of NMHSs and note their decline in some developing countries: "Over the past 15–20 years, the situation in many NMHSs in developing and least developed countries has worsened."[2]

The present study, which is a comprehensive analysis of Japan's hydrological and meteorological services, uses the three-component framework developed by Rogers and Tsirkunov for large-scale modernization:

- Institutional strengthening, capacity building, and implementation support (hereafter referred to as "institutional strengthening");
- Modernization of observation infrastructure and forecasting (hereafter referred to as "modernization of systems"); and
- Enhancement of the service delivery system (hereafter referred to as "enhanced service delivery").

In addition, drawing on Japan's experience in modernizing its NMHSs, it presents lessons learned over a century of changes in legal and institutional arrangements, advances in technology, and responses to major natural disasters. The eight lessons referenced in the report are collected and further elaborated in Section 3: Lessons Learned, Conclusions, and the Way Forward. Further recommendations on how developing countries can undertake a modernization project are detailed in the two background papers.

1.1 Role of the World Bank

This summary report is part of a series of knowledge projects led by the DRM Hub, which seeks to document and apply knowledge from Japan in developing countries. The DRM Hub has commissioned this work as a contribution to a broader initiative—led by the specialized Hydromet Team at the Global Facility for Disaster Reduction and Recovery (GFDRR)—to provide more guidance to project teams and clients on options and pathways for modernizing meteorological and hydrological services.

This report, along with the background papers, is expected to provide a knowledge base for the generation of more targeted guidance and reference materials for task team leaders and their clients, and to inform technical assistance to countries. The World Bank Hydromet Community of Practice will be a critical partner in this effort, particularly in light of growing scale of demand for technical and financial services in this sector. The report is also timed to coincide with the launch of major programs, such as the Regional Framework Program to Improve Hydrometerological Services in Sub-Saharan Africa and the Climate Risk and Early Warning Systems (CREWS) initiative.[3]

In addition, the Japan–World Bank Program for Mainstreaming DRM in Developing Countries, which the DRM Hub Tokyo implements, has a growing portfolio of technical assistance projects focused on the development of modern meteorological and hydrological services. Projects in Afghanistan, Cambodia, Ghana, Honduras, the Lao People's Democratic Republic, Myanmar, Nicaragua, and the Pacific have been launched, and projects are in the pipeline for countries in Africa. These all offer an opportunity to apply knowledge and expertise identified through this knowledge program, in coordination with JICA.

2 David P. Rogers and Vladimir V. Tsirkunov, *Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services* (Washington, DC: World Bank, 2013).

3 See GFDRR, "CREWS—Climate Risk and Early Warning Systems," http://www.gfdrr.org/crews-climate-risk-early-warning-systems. GFDRR, Program Profile: Strengthening Climate and Disaster Resilience in Sub-Saharan Africa https://www.gfdrr.org/sites/default/files/publication/Program_Profiles_Africa_Hydromet.pdf

1.2 Role of International Frameworks and Agreements

The Japanese model of hydromet services outlined in this summary report and the background papers is an excellent example of a modern service with strong government involvement and institutional governance built up over decades, comprehensive infrastructure, and sound and advanced service delivery. Japan's hydromet services are also effectively engaged in relevant global and regional structures and services, including those of the World Meteorological Organization (WMO) and the Global Framework for Climate Services (GFCS).

For hydromet services, operating within international agreements and frameworks is extremely important because it allows them to share data and provide consistent and standardized services to their own country and neighbors. Hydromet hazards know no boundaries, and global connections are essential. In the global and regional context, the Japanese model and its institutional arrangements all are harmonized with the agreed international operating frameworks of WMO, the World Water Council (WWC), the International Civil Aviation Organization (ICAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO) International Hydrological Programme (IHP), and the UNESCO Intergovernmental Oceanographic Commission (IOC). Especially for developing countries seeking modernization, the historical development of Japanese hydromet services can be seen as an exemplar for strengthening hydrological and meteorological services and enhancing early warning systems.

1.3 Structure of this Summary Report

Section 2 explains the key historical phases of modernization of each service (as described in the background papers), which led to the current integrated modern service provided for the public good. The analysis follows the World Bank's three-component framework (developed by Rogers and Tsirkunov) for large-scale modernization: Institutional strengthening (Section 2.2), modernization of systems (Section 2.3), and enhanced service delivery (Section 2.4).

In Section 3, the paper concludes with a synthesis of the key elements of the Japanese experience understood as a model for countries undertaking modernization, and discusses possible implications for developing countries.

4 See the GFCS website at http://www.gfcs-climate.org/.

2. The Emergence of Modern Hydromet Services in Japan

2.1 Overview

A major driver of modern meteorological and hydrological services in Japan has been the desire for effective disaster management. But DRM is not new in Japan. Pre-19th century, Japanese families sought to protect their homes and property from recurring flood and other hydrometeorological risks. Households would often monitor the sky and rivers, and predict the weather and water levels based on traditional knowledge and techniques.

The Japan Meteorological Agency (JMA), Japan's National Meteorological Service, began efforts to modernize its services in the early 1950s, when the modern Meteorological Service Act was enacted, and the first operational weather radar and Numerical Weather Prediction (NWP) model were introduced. Japan's National Hydrological Service, the Water and Disaster Management Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (WDMB/MLIT, previously the River Bureau of the Ministry of Construction), was modernized as an integral part of flood management and water resources management. Both WDMB/MLIT and JMA have evolved steadily since around 1950s through numerous steps in order to respond to challenges—including devastating disasters and growing requirements—while embracing advances in science and technologies, including the information and communications technology (ICT) available at the time.

Identifiable meteorological, hydrological, and geophysical services in Japan originated in the 19th century. They have had similar development paths, albeit different legal and institutional drivers and consequential governance frameworks.

It is important to recognize that the modern service that Japan now enjoys was established over several decades and with careful institutional and observational consideration on both the meteorological and hydrological sides. Certain extreme events, such as the devastating 1959 Typhoon Vera and the 2011 Great East Japan Earthquake and associated tsunami, also helped shape the service over time.

The resulting modern services were established in a series of long-term steps (see Lesson 1) and include four key features:

1. **Issuance of warnings and countermeasures for natural hazards.** The source of the single authoritative voice for early warning in meteorological services, JMA issues warnings for severe weather, strong ground motions by earthquakes, tsunami, ocean waves, and storm surges in collaboration with stakeholders (central, prefectural, and municipal governments), the media, first responders, and the private sector. It also notifies the authorities and the public of disaster countermeasures.

2. **Issuance of early flood warnings to assist in evacuation planning.** The river management authorities, in cooperation with JMA, provide early warnings of floods to the media, the public, and prefectural and municipal governments (heads of municipalities via a hotline in emergency events) in order to assist with evacuation plans.

3. **Support of regional and other NMHSs with data and capacity development activities.** JMA provides geostationary meteorological satellite imagery to the NMHSs in the Asia-Pacific region. It also carries out various capacity development activities for NMHSs in developing countries through the projects implemented by WMO and JICA.

4. **Institutional integration of hydrological services and river management.** Under the river management authorities, all components of river management, including disaster management, river water use, flood forecasting, and conservation of the river environment, are integrated for optimized and enhanced hydrological services.

Today, hydromet services in Japan range over various areas, driven by public service mandates for disaster risk reduction as well as market forces (see Figure 1 from the meteorological service perspective and Figure 2 from the hydrological service perspective). The roles and responsibilities of hydromet service providers, including the government, the media, and the private sector, are legally defined in the River Law and Meteorological Service Act.

Lesson 1

MODERNIZATION OF METEOROLOGICAL AND HYDROLOGICAL SERVICES REQUIRES LONG-TERM STEP-BY-STEP EFFORTS, WHICH SHOULD BE ANCHORED TO WELL-DEFINED MEDIUM- AND LONG-TERM STRATEGIES.

It is important to note in Figures 1 and 2 that both general public and user-specific services also form part of, and are codependent on, integrated services for nongovernment sectors and the private sector. In terms of modernization, this is an important contribution or partnership that needs to be recognized by sponsors or donor organizations in maximizing the impact of resource contributions.

2.2 Institutional Strengthening

Japan launched its first national meteorological service in 1875, and informal hydrological services are even older; levee building to prevent flood disasters started hundreds of years ago. The first-ever storm warning and weather map date to 1883, and the first national weather forecast was issued to the public in 1884. The first tsunami warning system was established in 1941. What steps did Japan take from these beginnings to develop the world-class systems that exist today?

2.2.1 Meteorological Services

In the 19th century, Japan's national meteorological service began as a nationwide network of meteorological observatories that relied on telegram for communication. It was rapidly expanded to establish the then-modern forecast/early warning services. In those early days, Japan faced almost the same challenges that developing countries are facing today. The newly established Japanese government was assisted by many foreign experts in its drive toward modernization. In 1885, two years after the first weather map and warning were issued, the Tokyo Meteorological Observatory (TMO) joined the International Meteorological Organization (IMO, the predecessor of WMO).

The legal framework of meteorological services in Japan was established in 1952 under the Meteorological Service Act. This act defined the statutory form of the roles and responsibilities of the JMA and its partners, as well as the mechanism for wider collaboration across public and private spheres. It assigned JMA, as the National Meteorological Service, a key role as the single authoritative voice for warning services. In 1953, Japan joined WMO, and the current organizational structure of JMA was established; this structure still exists in its fundamental form today. **Full legal and regulatory frameworks can be seen to be essential in establishing modern hydromet services**, as highlighted in Lesson 2 (see page 8).

In 1993, in response to a rapid expansion of private sector forecasting activities, and to the growing need for specific meteorological information issued by JMA (such as NWP data, products, analysis, and forecasts), Japan established the institutional frameworks of the private meteorological service support center[5] and the certified weather forecaster system. The center supports the weather business in the private sector by distributing various data and products from JMA, including consulting and research. In 2002, the center was officially granted responsibility for verifying meteorological instruments.

Figure 1 illustrates the institutional landscape of meteorological service institutions and user communities as they operate today.

2.2.2 Hydrological Services

Hydrological services in Japan have evolved to keep pace with demands for the management of flood and other hydrometeorological disaster risks. In Japan, levee building to prevent flood disasters started hundreds of years ago. Before the Edo era (1603–1868), circle levees – designed to protect only the builder's own community – were very common. Over time, however, communities located upstream and downstream, or on the right and left banks, began to have conflicts over safety issues. To solve such conflicts, flood management policy shifted instead to continuous levees on both sides of rivers to contain floodwaters within river courses and to discharge to the sea as fast as possible. These beginnings of integrated river basin management aimed to provide each riparian community with the same level of protection against floods. **The revised version of the River Law, enacted in 1964, required that integrated river basin management underpin the management of all rivers in Japan** (see Lesson 3, page 10).

As demands for water resources increased, dams were constructed in the upper reaches of rivers for water supply. In parallel, as flood safety increased through improved river management, towns and cities expanded to river banks and flood plains, and the acquisition of land to control floodwaters became more difficult. At that time, plans were developed by river management authorities (the Ministry of Construction or prefectural governments) to construct dams and retarding basins in the upper reaches to store floodwaters. In response, a "Specified Multipurpose Dam Act" was enacted in 1957 to reflect the multi-purpose use of dams to both control floods and provide safe drinking water.

Lesson 2

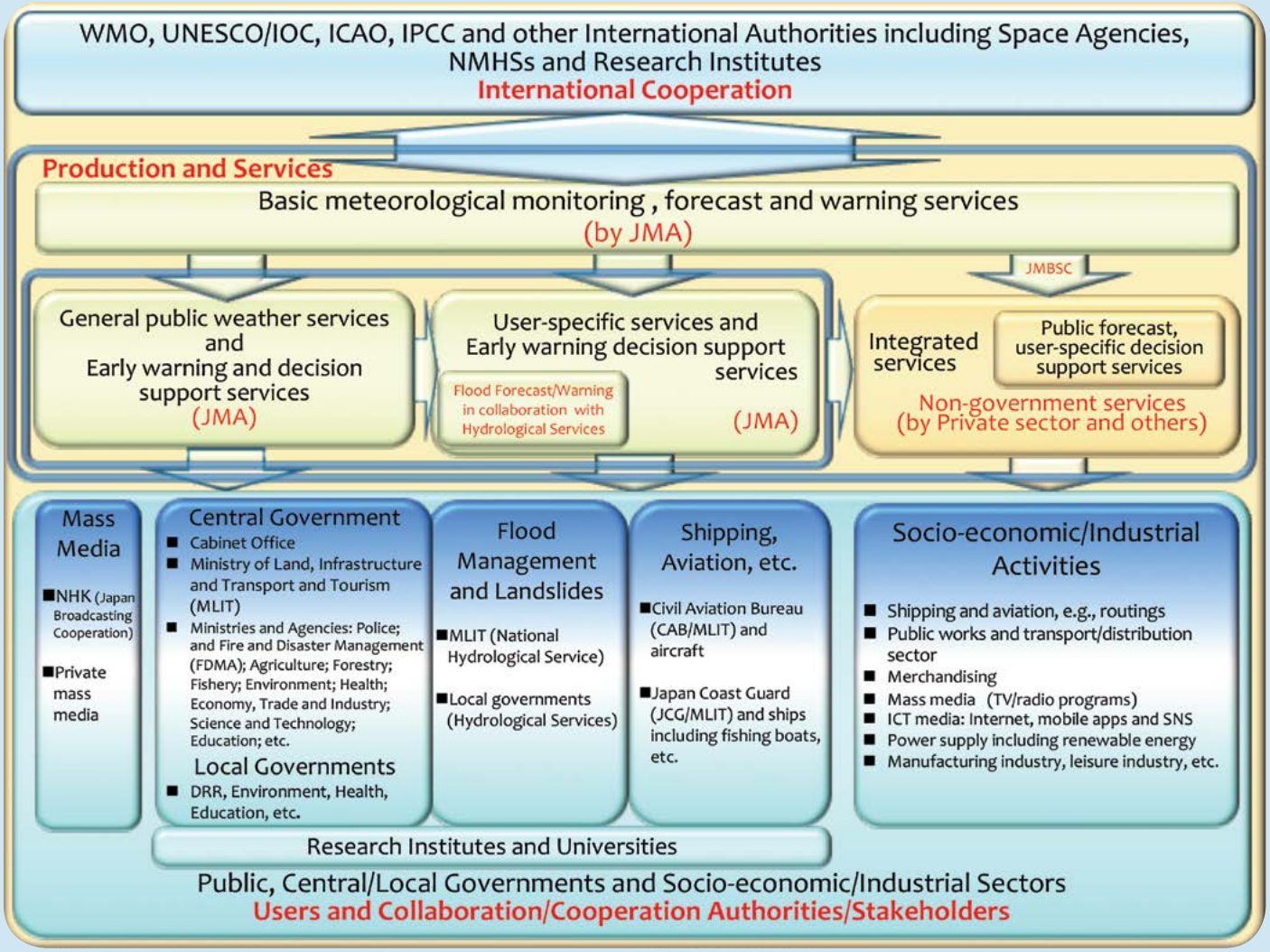
LEGAL AND REGULATORY FRAMEWORKS SHOULD CLEARLY DEFINE THE ROLES AND RESPONSIBILITIES OF THE NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICE, AS WELL AS THOSE OF THE PUBLIC AND PRIVATE SECTOR STAKEHOLDERS WHO PROVIDE METEOROLOGICAL, HYDROLOGICAL, AND EARLY WARNING SERVICES.

Consequently, to manage river basins in an integrated way, Japan needed to collect hydrological data from entire basins. Since 1938, national data on rainfall and discharge have been published annually to meet demand. Furthermore, design standards for levees have increasingly shifted to probabilistic methods (as the climate changes, construction based on historical records is no longer sufficient). This again requires statistical analysis of hydrological data collected from the entire river basin, which in turn requires the accumulation of hydrological data for a long period of time. This has further increased demand for hydrological services and data collection at the basin level.

Hydrological services have continued to expand despite resource pressures. Experts with practical knowledge of, and skill in, river management and

5 This is the legal designation of the Japan Meteorological Business Support Center (JMBSC).

Figure 1: **Institutional Relationships and User Communities in Meteorological Services in Japan**



DRM are essential for providing these critical services, and additional funding support beyond that of government was required to meet the growing need for them. A new agency, FRICS (Foundation of River & Basin Integrated Communications), was established in 1985 with funding from public and private organizations, in addition to a subsidy from government. With the establishment of FRICS, the institutional arrangement was in place to deliver high-quality hydrological information, mainly observations by the national government. These types of arrangements—in which the public and private sector collaborate—are not unique to Japan, because of the linkages of river forecasting to water resources management. FRICS offers an excellent example of such arrangements.

Figure 2 illustrates the institutional landscape for flood protection and other hydrological services for DRM (as well as broader water resource management).

2.2.3 Legal Framework and Warning Dissemination

In Japan, all the laws related to hydromet services—such as the River Law, Meteorological Service Act, Disaster Countermeasure Basic Act, and Flood Protection Act—consistently and clearly stipulate the roles and responsibilities of the National Hydrological Service and National Meteorological Service of Japan (WDMB/MLIT and JMA) and key stakeholders. The River Law outlines responsibilities for integrated river basin management. The Meteorological Service Act formulates the roles and responsibilities of JMA and its partners; these include providing basic national services with an open data policy, and establishing coordination and collaboration mechanisms with the private sector. The Disaster Countermeasure Basic Act and Flood Protection Act systematically and holistically address DRM issues, including issuance of evacuation advisories and orders in relation to early warning messages, as well as the development of disaster management plans, designation of disaster risk areas, and disaster response and recovery (see Table 1 on page 12).

Lesson 3

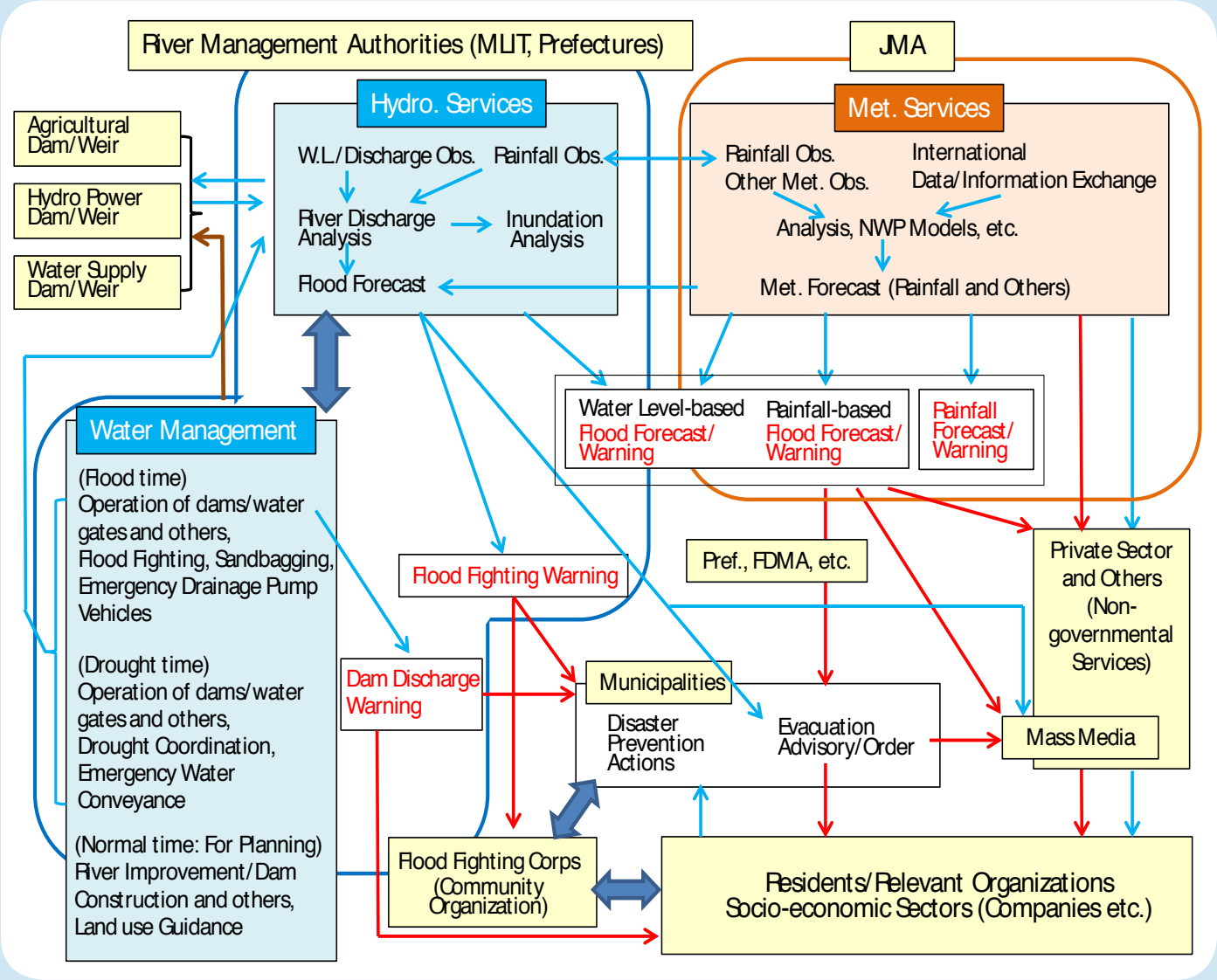
DESIGN AND DEVELOPMENT OF HYDROLOGICAL REGULATORY FRAMEWORKS IN DEVELOPING COUNTRIES SHOULD BE FULLY ALIGNED AND WHERE POSSIBLE, FULLY INCLUDED WITHIN INTEGRATED WATER RESOURCES MANAGEMENT (IWRM).

A key area of cooperation between providers of meteorological and hydrological data is on early warning services for flooding protection and management. This is a collaborative effort of the WDMB/MLIT, JMA, and prefectural governments. This is critical for understanding the core hydrological and meteorological inter-relationship in Japan and lessons learned (and being learned still). The basis for this cooperation is enshrined in the Flood Protection Act, as well as the Meteorological Service Act.

Early warning systems for severe weather, tsunami, ocean waves, and storm surges were institutionally established under the Meteorological Service Act in 1952. JMA provides warnings to relevant authorities, including the National Police Agency, the Fire and Disaster Management Agency, prefectural governments, and the Nippon Telegram and Telephone Corporation (NTT), and through them to mayors of cities, towns, and villages. JMA also provides warnings to the Japan Broadcasting Corporation (NHK) for immediate broadcast to the public. The private mass media and authorized forecast service companies also play significant roles in warning dissemination. **These multiple routes are critical for exceedingly reliable warning dissemination to end users.**

Early warning systems were strengthened in 2013 with the introduction of a system of emergency warnings for catastrophic events. Under this system, JMA issues emergency warnings when there is significant likelihood of catastrophes in association

Figure 2. Overview of Information Flow in Flood Protection and Water Resource Management in Cooperation between Hydrological and Meteorological Services in Japan



Note: Almost all information is delivered through the website of each organization. Colors of arrows show data/analytical information (blue), order/request (brown), and forecast/warning (red). W.L. = water level; Obs. = observation; Pref. = prefectural governments; FDMA = Fire and Disaster Management Agency.

Table 1: Key Moments in the Development of a Modern Institutional and Legal Framework for Early Warning for Flood Protection and Management in Japan

1955	The Flood Protection Act and the Meteorological Service Act required that MLIT (then the Ministry of Construction) and the Japan Meteorological Agency designate rivers and issue advisories and warnings in cooperation. Required data and information were consequently exchanged smoothly. Institutional cooperation was non-negotiable, particularly due to the very high public awareness and demand for effective flood warning. As telemetry expanded from the late 1960s, and online data exchange became widely available in 1990s, the number of rivers covered rapidly increased to include small and medium-sized rivers managed by the national government and rivers managed by the prefectural governments.
1959	In 1959, Typhoon Vera hit Japan and left 5,098 people dead or missing - the biggest disaster until that point to affect 20th century Japan. The disaster led to the enactment of the Disaster Countermeasure Basic Act, which systematically addressed issues regarding development of disaster management plans, DRM, designation of disaster risk areas, issuance of evacuation advisories and orders, disaster response, and disaster restoration. It defined the roles and authority of the national and local governments, and designated public organizations and the general public, as well as financial measures. This legislation facilitated further improvement of hydrometeorological services in a more systematic way.
2001	The Flood Protection Act was revised, additionally requiring the river management authorities to designate the expected inundation area, to notify the prefectural governments with the inundation area and depth, and to inform the general public as well.
2005	The Flood Protection Act was revised, additionally requiring the river management authorities to forecast the expansion of inundation area due to flooding, and to inform the general public with the inundation area and depth. In addition, the revision obligated local governments to distribute flood hazard maps indicating expected inundation area, inundation depth, media of flood forecast communication, and others. Currently, such maps are distributed in almost all municipalities in Japan.

with natural phenomena of extraordinary magnitude, such as the 2011 Great East Japan Earthquake or the heavy rains induced by Typhoon Talas in 2011; mayors are to immediately convey these warnings to the public in their respective municipalities.

Establishment of the Cabinet Office in Japan in 2001, which designs and coordinates disaster management policy, has helped to streamline disaster risk management activities, including early warning services.

2.3 Modernization of Systems

Both meteorology and hydrology systems in Japan have steadily modernized in a step-by-step process. Major system (infrastructure) improvements in meteorology occurred over four stages of modernization: (1) initial/primitive stage of modernization (1950–1965); (2) nationwide automation and networking development stage (1965–1985); (3) nationwide digitization, computerization, and networking stage (1985–2005); and (4) advanced networking stage with modern ICT to meet future challenges (2005–present).

The JMA Automated Meteorological Data Acquisition System (AMeDAS), a nationwide observation network of more than 1,300 automatic weather stations, was established in 1974. The concept of AMeDAS was quite innovative; with observation rates of 99.7–99.9%, it targeted the fourth modernization stage from the beginning. After several system upgrades/replacements, the latest system collects all the data from representative stations every minute, and delivers the information to users within 40 seconds. In the case of severe events, the data are disseminated through the mass media to the public. All the quality-controlled observation data are archived and used to establish effective early warning services, as well as to properly monitor and predict climate change and variability.

The first operational weather radar was established in 1954, and by 1971, radar service areas had been expanded to cover all of Japan. In 1982, the modernization of data processing was initiated by the digitization of radar data, and by the introduction of a quantitative precipitation estimation/quantitative precipitation forecast (QPE/QPF) technique using high-quality AMeDAS data and NWP models. Doppler weather radars were introduced in 2006–2013 with the aim of improving the ability of services to cope with strong gusts, including tornadoes, specifically through the issuance of the "alert information for tornadoes" (from 2008) and the "nowcast for tornadoes" (from 2010). Japan's advances in satellite technology are ongoing and are described in the box below.

Like meteorological observations, hydrological measurements have developed considerably over the last century—progressing from manual to fully automated observations of various elements such as rainfall, river water levels, and flow velocity. The advances have been driven in part by users' needs for better observation accuracy and more user-friendliness. Historically, MLIT's rainfall and water level measurements were carried out daily in the case of rainfall, or twice a day for water level, with the cooperation of volunteers who record the depth of precipitation stored in a container or the water surface on a staff gauge. When abolished in 2002, there were more than 600 rainfall observation stations and more than 1,000 water level observation stations recorded manually by volunteers.

Aside from these manual stations, technology has evolved over the last decades. A "tipping bucket" automated precipitation gauge was introduced in Japan around the mid-1950s, alongside a telemeter system to enable real-time observation. The float type water level gauge was developed in 1962. This type required a stilling well and is now largely replaced by pressure-type recording gauges.

In recent years, more advanced devices have been developed that use radio waves or ultrasound to observe flow velocity. Other advances in hydrology-related technology include use of CCTV (closed-circuit television) images to observe river surface flow velocity and use of satellite images for flood forecasting.

As these examples suggest, technologies developed in different areas have been successfully adopted for hydrological observation. One further example is radar technology, which has been found very useful for disaster management purposes because it is capable of observing the condition of raindrops over a widespread area. The rapid progress of information technology has also contributed to disaster management by hydrological services because it allows large volumes of data to be processed and transmitted at a faster rate. Advanced ICT has enabled in-depth analysis of voluminous data, production of more user-friendly interfaces, and provision of information with handheld devices. This sharing of information and techniques across disciplines can be highly effective as long as suitable data-sharing arrangements are established, as in Japan.

Quality-assured data are a critical part of modernized hydromet systems. They are essential for establishing the long-term meteorological, climatological, seismic, and hydrological databases

A major scientific and technological achievement for Japan has been the series of Japanese Geostationary Meteorological Satellites Himawari-1 to Himawari-7, which have made an enormous contribution to NMHSs in the Asia-Pacific region for about 40 years. Himawari-8, the first third-generation geostationary meteorological satellite, started its operation on July 7, 2015, and is expected to significantly enhance monitoring and forecasting capabilities of NMHSs in the region. The Himawari-series satellites contribute significantly to both hydrological and meteorological services.

that form the basis for effective DRM and climate change adaptation strategies. **An open data policy and user-friendly data dissemination systems, developed over time and at the request of stakeholders, are needed to ensure a broader use of data and thus greater socioeconomic benefits.** Lesson 4 emphasizes this important requirement for high-quality data to underpin **all** services. As part of this, the Japan case demonstrates the importance of establishing systems to observe, collect, and accumulate accurate and comprehensive hydromet data. Reliability and credibility of data are fundamental to meet the needs and expectations of end users. In Japan, the focus on accurate and complete data has been a steady effort since the early stages of modernization.

The Japan Meteorological Business Support Center (JMBSC) and FRICS have been established to facilitate and ensure the broader use of meteorological and hydrological data, respectively. JMA not only delivers comprehensible meteorological information to the general public, but through JMBSC, also disseminates all its data, products, and information—including the gridded data of NWP—on a real-time, 24/7 basis free of charge. (As one of the pioneers among NWP centers, JMA has continued active development and enhancement of a suite of NWP systems since operational numerical prediction began in 1959.)

MLIT, through FRICS, similarly disseminates hydrological data. FRICS combines hydrological data from MLIT and local governments, controls their quality, and translates them into comprehensible risk information for the general public and flood-related information used by municipalities in issuing evacuation information. FRICS, like JMBSC, also disseminates this information on a real-time, 24/7 basis free of charge.

The number of users of JMBSC's dissemination services has steadily been increasing; current users include not only the public sector, private weather companies, and mass media, but also the manufacturing, transport, power, and construction sectors, which access these data sets regularly to use in their daily decision making.

Lesson 4

SOUND METEOROLOGICAL, SEISMIC, AND HYDROLOGICAL OBSERVATION AND DATA MANAGEMENT SYSTEMS ARE A PREREQUISITE FOR ANY ASSOCIATED SERVICES. AN OPEN DATA POLICY SUPPORTS BROADER USE AND HIGHER VALUE OF THE DATA FOR THE COMMUNITY.

In modern hydromet services, it is important to have a level of redundancy in systems to ensure at a minimum the functioning of emergency services (such as typhoon warnings) and some aviation services. In meteorological services by JMA, the redundant center is located at the JMA's Osaka Regional Headquarters. It is an active (hot standby) center. The data collection and dissemination system, as well as the meteorological observation systems (including weather radar and AMeDAS) and seismic monitoring systems, are generally developed so as to ensure redundancy both in systems (hardware and communication) and in geographical location (Tokyo and Osaka). This dual form of redundancy is extremely effective in case of earthquake, fire, power loss, pandemic, or other disaster. Lesson 5 emphasizes **the requirement for developing countries to have at least a**

Lesson 5

A "HOT" BACKUP OF A HYDROLOGY AND METEOROLOGY SYSTEMS-AND-SERVICES HUB IS ESSENTIAL FOR BUSINESS CONTINUITY.

geographically separated second center that can operate the most basic emergency services.

The system improvements highlighted above make clear that the modernization of Japanese infrastructure and systems has come together across institutions, driven by the need for timely information on severe weather, flood, earthquake, and tsunami. Lesson 6 highlights this Japanese accomplishment and the need to continue the testing of institutional arrangements.

The service improvements arising from system improvements are discussed in the next section.

2.4 Enhanced Service Delivery

As modern Japan has developed, meteorological services have expanded to serve an ever-increasing numbers of users. Public services—weather forecast and water- and storm-related disaster countermeasures—rely on the availability of timely and accurate information. Sectors of industry—from shipping, aviation, and railways to agriculture and fisheries—also generate increasing demand.

Lesson 6

USER-ORIENTED, RISK-BASED, AND SEAMLESS EARLY WARNING SERVICES SHOULD BE ESTABLISHED AND ADVANCED IN CLOSE COOPERATION WITH THE RELEVANT AUTHORITIES AND THE PUBLIC. MAINTAINING AND TESTING INSTITUTIONAL ARRANGEMENTS ARE KEY TO AN EFFECTIVE SERVICE.

A systematic approach to improving services has been undertaken by Japan and can be emulated in other NMHSs. It involves a risk-based approach (see Lesson 6) to the identification of the major natural hazards affecting the country and engagement with stakeholders across all levels of government, the private sector, and disaster management. As discussed earlier, it also recognizes the growing risks of some hazards, such as those affected by climate change. Communities are also demanding more services in real time and for their particular location. New technologies such as smartphones and social media are putting additional pressure on NMHSs in generating demand for information, but this also is an opportunity to reach more people.

The importance of new technology is perhaps most evident in service improvements for typhoons, which are the most disastrous severe weather phenomenon in the northwestern Pacific region, including Japan. The accurate prediction of their locations and intensities has always been a vital challenge for JMA. It took around 60 years from the initiation of operational typhoon forecasts to meet this challenge; 24-hour through 48-hour track forecasts became possible in 1989; 72-hour track forecasts became possible in 1997; and by 2009, five-day track forecasts were in use.

The comprehensive framework of early warning services for multi-hazards, including the legal framework imposed by the Meteorological Service Act as discussed above, was enhanced greatly. For example, there were originally (until 1997) around 90 service areas at the prefecture level, corresponding to the responsibility for disaster countermeasures in local governments. Using risk-based quantitative criteria for issuing warnings (underpinned by QPE/QPF techniques), the warning service areas were subsequently subdivided into the municipality level to enhance the effectiveness of warnings. The number of service areas reached around 1,800 in 2010 (see Figure 3 on page 16).

2.4.1 Seamless Early Warning Services and a Comprehensive Multi-hazard Approach

Real-time information on evolving severe weather events is issued to authorities and the public by JMA in collaboration with disaster management authorities of central and local governments and other stakeholders. Alerts for typhoons, for example, start with a five-day track forecast; the public also receives bulletins, advisories, and warnings (including

emergency warnings) as alert levels increase. Bulletins are issued to complement advisories and warnings from local meteorological offices and headquarters; the number of bulletins issued may reach several dozen in cases of a typhoon making landfall. Japan's NMHSs classify events in terms of danger levels that correspond to recommended actions to be taken by municipalities and residents when an advisory, warning, or emergency warning is issued. They further encourage municipalities and the public to promptly respond to those advisories/warnings, which may change with the evolving stages of severe weather events, in cooperation with the relevant authorities. **An essential component of early warning services is strong links to disaster first responders**, as shown in Lesson 7.

2.4.2 Institutional Cooperation for Improved Flood Forecasting Service Delivery

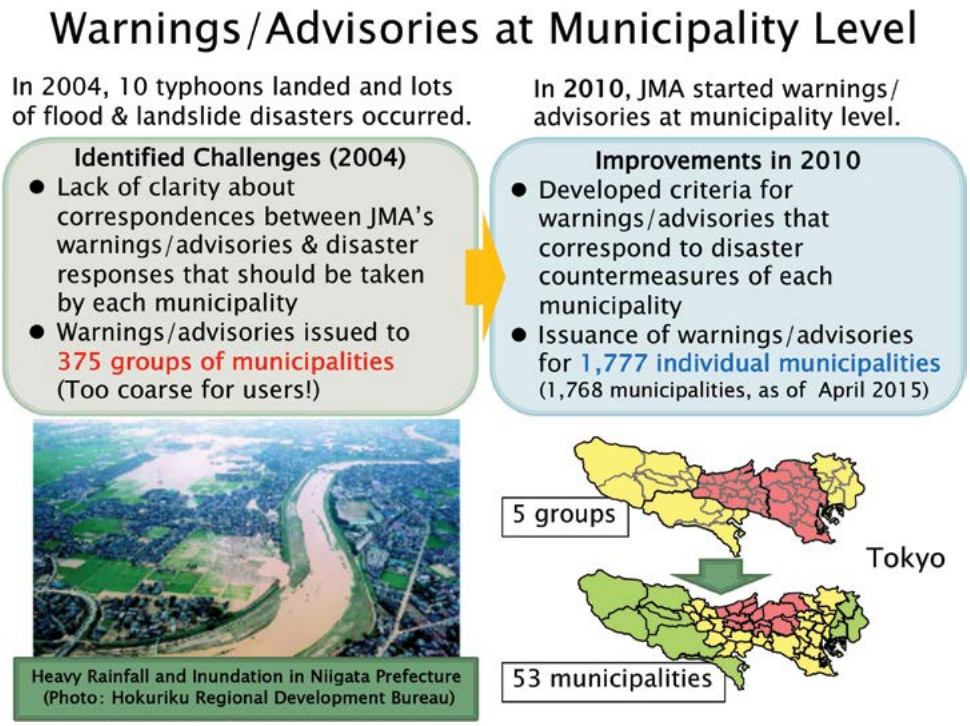
As noted above, cooperation between hydrological and meteorological services is particularly critical for flood forecasting. Data collected by JMA on rainfall, typhoons, and other meteorological factors, and data collected by MLIT on basin rainfall, river water level and discharge, and other hydrological factors are shared between the two organizations in real time.

To release flood forecasts, river management authorities forecast river water levels and floods, exchanging data with JMA in addition to their

Lesson 7

IT IS IMPERATIVE TO MAINTAIN A STRONG COLLABORATION WITH LOCAL EMERGENCY FIRST RESPONDERS, AS WELL AS WITH THE PUBLIC. THIS "LAST MILE" IS CRITICAL TO THE SUCCESS OF EARLY WARNING SYSTEMS.

Figure 3. Early Warnings at the Municipality Level has Improved in the Last Decade (provided by JMA)



self-collected data. River management authorities conduct simulations for water level forecasting using real-time data and a runoff analysis model furnished with basin rainfall and upstream water levels as the main input. Flood forecasting reports for individual rivers are created through mutual consultation between river management authorities and Local Meteorological Offices (LMOs) of JMA and jointly released. In the case of inundation forecasts, which are conducted by river management authorities, multiple flood scenarios are simulated ex ante. When a flood occurs, the simulation closest to reality is employed to forecast the development of the inundation. These simulations ahead of time are important because it is usually impossible to forecast the effect and extent of a flood in real time (unless the flood is very slow developing).

Mayors of local governments are responsible for issuing evacuation advisories and orders for proper evacuation of residents. The issuance, in the case of flood, is based on the information of river water level, flood forecast, and inundation forecast. To help contribute to their decision, mayors hold a hotline call with directors of MLIT offices and LMOs, who manage rivers on the ground and watch severe weather, respectively.

Lesson 8

USER NEEDS SHOULD DEFINE THE MODERNIZATION OF METEOROLOGICAL AND HYDROLOGICAL SERVICES.

For flood forecasts to be utilized in evacuation actions of every single resident, information should be received quickly without fail. An information delivery service for smartphone users, including information of flood hazard maps, started in April 2016 as an option for individuals. **The interface of JMA and river authorities with central/local governments and the mass media, and more recently with the Internet and mobile media, continues to grow. In developing these services, user needs across all stakeholders must be taken into account** (see Lesson 8). In particular, it is important to recognize the vital role of the Internet and mobile media in disseminating warnings and other hydrometeorological and related information. Recent surveys show that the data volumes and traffic for meteorological information have soared year by year for a wide range of industrial corporate activities in Japan.

2.4.3 Landslide Alert Information

MLIT, and in particular MLIT's Sabo (Erosion and Sediment Control) Department, and JMA Headquarters established an additional partnership with prefectural governments in 2005 to issue landslide alert information. In close collaboration with the Sabo Department, prefectural governments have established local networks of precipitation measurements and topographical and geological information, including hazard maps. Based on the combined information—that is, QPE/QPF and soil-water index data from JMA, along with landslide hazard maps from prefectural governments—landslide alert information is collaboratively issued by LMOs and sediment control authorities.

2.4.4 Private Meteorological Services

Commercial meteorological services have expanded in recent years under the national open data policy, and forecast service companies, authorized by JMA, provide specific user-oriented forecast services. As a result of collaborative efforts between JMA and the private sector, combined with recent rapid advances in ICT and improvements in the quality (i.e., accuracy and timeliness) of JMA data, the utilization and application of meteorological information by the public and industry have widely expanded in recent years.

The private sector provides a wide variety of integrated services; authorized forecast service companies, for example, offer value-added forecasting to the public and specific users. The background paper on meteorological services provides details on these important complementary services.

Any modernization project should recognize that the private meteorology sector, as well as the media, can play an important role for a developing country.

2.4.5 Cost-Recovered Aviation Weather Services

Cost-recovered aviation weather services are an important component of both modern and developing hydromet services. Delivered under the regulatory framework of the ICAO, these services are predominantly cost-recovered from the aviation industry, and many NMHSs rely on this funding to complement public weather and emergency management services. They should not be considered in isolation but rather incorporated within any modernization project. Indeed, aviation weather services rely heavily on the public weather training of meteorologists and (often) publically funded systems infrastructure. There is usually an interdependent relationship that benefits both the public and the aviation industry, which often funds additional observations and systems on an incremental basis. Quality management systems are mandatory internationally for aviation weather services as a means of quality assurance.

As one of the most advanced national aviation weather service authorities, JMA issues meteorological information for both airspace and aerodromes for air traffic services units of the Civil Aviation Bureau of MLIT and airlines under the international frameworks of ICAO and WMO. Among those aviation services, providing information to the air traffic management and on the volcanic ash from volcanic eruptions is a good practice of the cooperative dialogues with the aviation community, and of comprehensive multi-hazard approach due to volcanic eruptions.

3. Lessons Learned, Conclusions, and the Way Forward

Given that Japan is subject to a range of meteorological, hydrological, and geophysical hazard impacts, it is one of several countries that can offer lessons about the requirements for modern hazard services (see Table 2 for a summary of the lessons contained in this document). Following this in-depth study of Japan's hydromet services, similar studies of other countries with advanced, modernized systems could offer other extremely valuable parallels and additional lessons.

Table 2: Lessons Learned from Japan's Institutional Strengthening, Modernization of Systems, and Enhanced Service Delivery

	Lesson learned	Description
1.	**Modernization of meteorological and hydrological services requires long-term step-by-step efforts, which should be anchored to well-defined medium- and long-term strategies.**	This summary report on Japanese hydromet services demonstrates that hydrological and meteorological strategies need to take into consideration currently available science and technology, as well as financial and human resources. Thorough strategic planning is a continuous and iterative process; special attention should be paid to opportunities to reexamine and revise these strategies immediately **after major disasters**, as such events usually offer valuable lessons on gaps in systems or services. Well-defined strategies should also facilitate coordination among donors if support is provided by multiple donors.
2.	**Legal and regulatory frameworks should clearly define the roles and responsibilities of the NMHS, as well as those of the public and private sector stakeholders who provide meteorological, hydrological, and early warning services.**	Effective early warning systems require good coordination among stakeholders that have clearly defined roles and responsibilities, and streamlined operational procedures to ensure timely delivery of actionable messages to all residents at risk, and to avoid multiple and contradicting warnings. To promote these effective systems, national law(s) should clearly define the NMHS as the single authoritative voice for warning services, and effective regulatory framework and standard operational procedures should be in place.
3.	**Design and development of hydrological regulatory frameworks in developing countries should be fully aligned with and where possible, fully included within, Integrated Water Resources Management (IWRM).**	IWRM, designated a Sustainable Development Goal by the United Nations, is currently being enhanced through a river basin approach around the world. In Japan, hydrological services have evolved as an integral part of IWRM.

	Lesson learned	Description
4.	**Sound meteorological, seismic, and hydrological observation and data management systems are a prerequisite for any associated services. An open data policy supports broader use and higher value of the data for the community.**	Maintaining and operating robust, sustainable, quality-assured, and user-oriented observation systems is the key for successful meteorological and hydrological services. **They are essential for a climate change adaption and DRM strategy.** Observation systems should use instruments with a high degree of traceability within national, regional, and global meteorological and hydrological communities, and with adequate maintenance mechanisms for quality assurance/quality control and data archive.
5.	**A "hot" backup of a hydrology and meteorology systems-and-services hub is essential for business continuity.**	In developing countries, there should be at least, a geographically separated "second" services center that can operate the most basic emergency services. This should include redundant observations and ICT, and minimal services for "hot" rapid activation.
6.	**User-oriented, risk-based, and seamless early warning services should be established and advanced in close cooperation with the relevant authorities and the public. Maintaining and testing institutional arrangements are key to an effective service.**	Some disasters could result from a complex combination of multiple events. Thus, effective preparation and management of such events requires a comprehensive multi-hazard approach through collaboration with multiple stakeholders, including water authorities, disaster management agencies, and local governments.
7.	**It is imperative to maintain strong collaboration with local emergency first responders, as well as with the public. This "last mile" is critical to the success of early warning systems.**	At the local, public level—that is, the final operational level of actions for DRM ("first responders")—it is imperative to strengthen the interface with local governments and the public in a variety of ways. This is because early actions are generally not ensured just by issuing warnings and associated information, nor by the management of the government authorities. This is an important lesson for emerging hydromet services.
8.	**User needs should define the modernization of meteorological and hydrological services.**	Socioeconomic values of meteorological and hydrological information are generated only when users understand and utilize information to make decisions and take actions. Moreover, it is user needs that should define the scope and types of services to provide the necessary amount of information and minimum quality requirements. Modernization of hydromet services in Japan has been largely driven by evolving user needs, be it for flood management, water use planning, navigation, transport, agriculture, energy, or early warning for hydromet hazards.

The preceding sections describe the extensive modernization accomplished by the hydromet services of Japan over the last century. Included in this historical journey are essential lessons for the reader. The developments and associated lessons, it should be noted, fit remarkably well within the modernization framework outlined by Rogers and Tsirkunov.[6] The framework highlights Japan's expertise, skill, and forward-looking strategic thinking, melded with tactical responses to major disasters, including the 2011 Great East Japan Earthquake and tsunami. Many of the lessons emphasized in this study are ones that other modern NMHSs have learned and possibly

6 Rogers and Tsirkunov, *Weather and Climate Resilience*.

responded to in similar ways. Although this study follows Japan's progress toward becoming a world-leading NMHS, it offers lessons that should be of value to any other NMHSs, especially in developing countries.

In countries like Japan where the National Meteorological Service and the National Hydrological Service operate separately, it is important to strengthen collaborative efforts between the two Services, including the exchange (and archive) of observation data and to ensure effective early warning services and flood (and drought) management. A particular challenge faced by developing countries is that they often have little data to exchange. This lack of observed data will affect all aspects of meteorological and hydrological service delivery, and needs to be addressed as part of any modernization effort.

As modernization efforts proceed, coordination of donors must be paramount; mechanisms such as those of WMO and certain NMHSs are effective in modernizing NMHSs in developing countries. Support from international donors has historically been offered independently, based on donors' own interests and priorities, and has not necessarily been well coordinated with other support. Some bilateral coordination mechanisms have recently been developed, such as a recent first hydrometeorology development partners' roundtable, co-hosted by the World Bank and WMO in Geneva in April 2016.

In essence, NMHSs are expected to contribute to disaster risk reduction activities and the enhancement of a wide range of socioeconomic activities. Thus relevant policies, legal/institutional contexts, and design and implementation of NMHSs themselves require a common understanding among stakeholders on certain key issues: the broad societal benefits offered by NMHSs at various scales (global to local), the status of and challenges faced by NMHSs, and the roles the services are expected to play. Going forward, a high priority should be placed on meeting the specific needs of potential beneficiaries and improving their resilience against water-related and other disasters.

The regional and international contexts and collaboration referred to in the earlier sections include such asset sharing as data exchange, which is indispensable for all NMHSs given that meteorological and hydrological phenomena do not respect national boundaries. They also include use of regional and global resources and services provided by global and regional centers of excellence, which can promote the most efficient design and implementation of modernization programs.

The types of asset sharing now taking place are evident in JMA's role as both a WMO Global Information System Center and a Regional Specialized Meteorological Center; NMHSs in developing countries should enhance information and communication networks and computer resources to fully avail themselves of such products. Capacity building is also essential for successful and sustainable modernization. Education and training opportunities, such as those offered by JMA and MLIT to meteorological and hydrological services in many developing countries, should be taken advantage of, and a mechanism should be established to systematically transfer knowledge and expertise attained through such trainings to all other NMHS staff.

This study shows that donors, international organizations (such as Multilateral Development Banks, WMO, ICAO, United Nations Office for Disaster Risk Reduction, and WWC), and developed countries should support and coordinate development cooperation projects. To help developing countries achieve sustainability in the modernization of their NMHSs, partners' efforts should be based on the lessons highlighted above, such as the use of well-defined medium- and long-term strategic planning and management for sustainability; development and maintenance of observation, monitoring, and forecast systems; and improvement of service delivery to user communities.

Japan's efforts to modernize its hydromet services, the lessons described above, and Japan's extensive experience in assisting developing countries are

all described in the background papers focused specifically on meteorology and hydrology. These papers offer important recommendations on how to design and implement development projects on a collaborative international basis. WMO provides the foundation (regulations, coordination for networks, etc.) of global and regional meteorological services and the framework for such international cooperation under the Convention of the World Meteorological Organization. Both papers also make clear that well-planned and well-executed fact-finding studies or missions are essential prior to designing, or seeking additional financial support for, a project.

This study was conducted in the context of the Japan–World Bank Program for Mainstreaming DRM in Developing Countries. The Japanese knowledge, technology, and expertise assessed through this review have already contributed—and will continue to contribute—to the modernization of NMHSs in developing countries, in particular in terms of systems, operations, and human resources development, as well as to World Bank operations. Interested parties should draw on the experience of and/or closely collaborate with the WDMB and JMA, both under the MLIT, as they seek to modernize water-related disaster management, water use, and operational weather, climate, ocean-related, and terrestrial services, especially in the Asia-Pacific region, through long-term, sustainable efforts.

Contact:

World Bank Disaster Risk Management Hub, Tokyo
Phone: +81-3-3597-1320
Email: drmhubtokyo@worldbank.org
Website: http://www.worldbank.org/drmhubtokyo

The World Bank Disaster Risk Management Hub, Tokyo supports developing countries to mainstream DRM in national development planning and investment programs. As part of the Global Facility for Disaster Reduction and Recovery and in coordination with the World Bank Tokyo Office, the DRM Hub provides technical assistance grants and connects Japanese and global DRM expertise and solutions with World Bank teams and government officials. Over 37 countries have benefited from the Hub's technical assistance, knowledge, and capacity building activities. The DRM Hub was established in 2014 through the Japan-World Bank Program for Mainstreaming DRM in Developing Countries – a partnership between Japan's Ministry of Finance and the World Bank.