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Review

Two Decades of Integrated Flood Management: Status, Barriers, and Strategies

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Abstract: Losses from flood disasters are increasing globally due to climate-driven forces and human factors such as migration and land use changes. The risks of such floods involve multiple factors and stakeholders, and frameworks for integrated approaches have attracted a global community of experts. The paper reviews the knowledge base for integrated flood risk management frameworks, including more than twenty bibliometric reviews of their elements. The knowledge base illustrates how integrated strategies for the reduction of flood risk are required at different scales and involve responses ranging from climate and weather studies to the construction of infrastructure, as well as collective action for community resilience. The Integrated Flood Management framework of the Associated Programme on Flood Management of the World Meteorological Organization was developed more than twenty years ago and is explained in some detail, including how it fits within the Integrated Water Resources Management concept that is managed by the Global Water Partnership. The paper reviews the alignment of the two approaches and how they can be used in tandem to reduce flood losses. Success of both integrated management approaches depends on governance and institutional capacity as well as technological advances. The knowledge base for flood risk management indicates how technologies are advancing, while more attention must be paid to social and environmental concerns, as well as government measures to increase participation, awareness, and preparedness. Ultimately, integrated flood management will involve solutions tailored for individual situations, and implementation may be slow, such that perseverance and political commitment will be needed.

Keywords: flooding; risk; governance; integration; social effects; capacity; IWRM

Citation: Grigg, N.S. Two Decades of Integrated Flood Management: Status, Barriers, and Strategies. *Climate* **2024**, *12*, 67. https://doi.org/10.3390/cli12050067

Academic Editor: Alessandro Pezzoli

Received: 7 April 2024
Revised: 4 May 2024
Accepted: 6 May 2024
Published: 8 May 2024

1. Introduction

Among the natural hazards, floods and thunderstorms cause the most damage globally, running up to billions of dollars of losses every year, in addition to their social and environmental damages. No single metric tracks the total impact of floods annually, but studies indicate they are becoming worse due to climate change [1]. With growing populations, the rising sea levelsC, and increasing vulnerabilities, the magnitude of losses seems to be on the rise. Only a small portion of private losses are insured, and many losses involve uninsured public infrastructures [2]. The environmental and social impacts are difficult to measure, and when they are counted, overall flood losses and impacts are much more severe than economic statistics show.

Many international reports demonstrate the severity of flood risks, the difficulties in anticipating and mitigating their effects, and the multiple factors they involve. To confront these challenges, the Associated Programme on Flood Management (APFM) was organized two decades ago by the World Meteorological Organization (WMO) and the Global Water Partnership (GWP). The APFM developed a framework named Integrated Flood Management (IFM) to support countries to implement integrated approaches that maximize benefits from floodplains and minimize loss of life and impact. Reflecting the participation of the GWP, the IFM is considered to operate within the broader framework of Integrated Water Resources Management (IWRM) [3].

Flood risk management has also been studied by many investigators and groups. A substantial effort was launched in the early 2000s by the FLOODsite consortium with participation among 37 European institutes and universities and other participants from government, business, and research organizations [4]. In the United States, multiple agencies work to develop flood solutions, and intergovernmental coordination among 14 federal agencies is provided through the Federal Emergency Management Agency (FEMA). State governments have key roles as well, and local governments administer most program elements like floodplain management and mapping. The US Army Corps of Engineers has a lead role due to its management of major rivers and flood control reservoirs. As such, a Federal Flood Risk Management Standard has been developed [5].

While intergovernmental collaboration is beneficial, interdisciplinary coordination is also required. Recognizing the need for greater cooperation among climate scientists and water resources managers, flood risk and its relationships to climate were assessed in a meeting of experts organized by the writer and colleagues in 2016 at Colorado State University to probe into the necessary actions. The conclusions of that meeting have been used to inform parts of the paper [6]. In addition, the discussion is shaped by the writer's experiences in flood risk management that extend back to the 1960s, prior to the US National Flood Insurance Program (NFIP). The experiences of other writers as reported in the international literature and in case studies have also been used to develop the paper.

The intended contribution of the paper is to provide a comprehensive and contemporary review of IFM and to derive conclusions about the needs to advance the concept, given more than two decades of experience with it. As support for the APFM's IFM program has continued, its elements will be used to organize the discussion. The paper reviews the governance needed to foster IFM and its elements and compares them with those for IWRM, which is considered by the APFM to include IFM. The discussion addresses risk assessment, flood hazard analysis, hydrologic predictions and forecasts, floodplain analysis, flood infrastructure and management programs, damage assessment and flood economics, social and environmental impacts, and legal frameworks. Each of these comprises a substantial subfield, so only the main points are included. The literature reviewed spans the globe, and several examples from the US experience are included, given that its policies predate the work of the APFM. Much of the literature reviewed involves European perspectives, and the examples from the US will add to the knowledge base of IFM, which is broad and deep.

A Situation Review report by the APFM in 2005 provides a comprehensive overview [7], and this paper contributes further by reviewing subsequent work and developments. The background study for this paper identified many reports about flood risk management, including more than twenty bibliometric reviews of the subject matter. Some 25 of these relating to elements of IFM were reviewed and classified. They cover general concepts including the following: resilience, governance, and climate change; classification of types of floods like urban, coastal, and flash floods; vulnerability and health issues; technical topics like machine learning, use of indicators, sensors, and drones; and risk analysis and assessment. Like with IWRM, some papers claiming to take an integrated viewpoint only relate to parts of IFM. Themes that emerged in bibliometric studies included a continuing shift toward resilience strategies and away from flood control [8] and a large increase in publications during the last two decades with a shift in activity from US dominance to other nations in Asia and Europe. A broad range of topics is addressed, including methodological and scale issues, uncertainty, mapping, economic damages, and need for social impact analysis, as well as science and technology issues like global warming, big data, machine learning, and remote sensing [9].

The paper begins with an explanation of IFM, which is followed by a short section to illustrate how it relates to IWRM. These introductory sections are followed by reviews of flood hazard analysis methods, flood infrastructure and management programs, methods to assess the impact of floods, legal issues, and governance approaches for flood risk management. A comprehensive analysis and discussion section is then followed by overall conclusions.

2. Integrated Flood Management

As mentioned, the APFM has conceptualized that IFM fits within the broader concept of IWRM. By comparing the definitions of the two frameworks, the influence of the GWP as a major partner in the APFM stands out due to similar phrases (Table 1).

Table 1. Definitions of IFM and IWRM.

Integrated Flood Management	Integrated Water Resources Management
a framework that promotes sustainable, long-term flood resilience by combining social, economic, financial, environmental, and institutional solutions, as well as those involving engineering, disaster preparedness, insurance, and emergency response [7].	a process which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems [10].

Another definition, by the FLOODsite consortium and seeking to align with the EU Flood Directive, is that flood risk management is the "holistic and continuous societal analysis, assessment and reduction of flood risk", and a "process which comprises pre-flood prevention, risk mitigation measures, and preparedness, backed up by flood management actions during and after an event". Investigators have argued that the challenges of integrated approaches call for a process approach [11], as outlined in [12]. These different definitions confirm that integrated approaches, whether IWRM or IFM can be called processes or frameworks, depending on perspectives. The boundaries of the issues they address are so broad that no concise definition will ever satisfy everyone.

The APFM definition envisions that IFM combines flood risk analysis to determine risk, flood risk assessment to weigh costs and benefits and support decisions, and the application of physical measures and policy instruments for flood risk management. It connects these diverse strands and is offered as a cascade diagram to illustrate the five categories of risk reduction [13]. A simplified version of the IFM measures is shown in Figure 1. The input to the left shows risk and at the end, the diagram shows flood resilience, which is improved as a result of the steps shown.

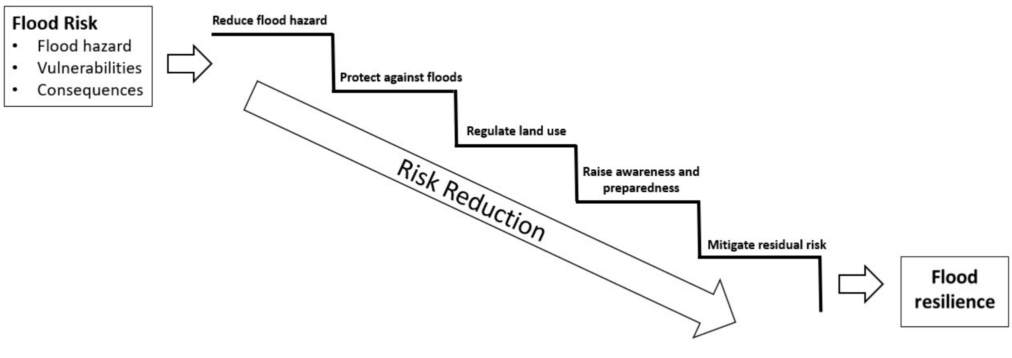

Figure 1. Cascade diagram of IFM measures.

A flood hazard is generally defined as the likelihood of a damaging event, which involves hydrologic and hydraulic factors. Vulnerabilities can be those of the flood protection infrastructure, which affect the likelihood of a hazard impacting people, property, or nature. The vulnerabilities of people, property, and nature make a second category of vulnerability, which leads directly to the categories of the consequences as economic, social, and environmental impacts. The phases of disaster management, preparedness, mitigation, response, and recovery can be considered as implicitly embedded in the definition of IFM and in Figure 1 [14,15].

The cascade diagram is useful to illustrate the multiple means of flood risk reduction, which is a term used by a pioneer of the field, Gilbert White, who was an early advocate of cooperative multiple-purpose and multiple-means river basin development [16].

The solutions include structural and non-structural measures, land use planning and controls to reduce exposure, flood forecasting and warning systems, and emergency response, relief, and recovery. All would be connected through flood risk reduction institutions, methods for coordination and communication, and safety nets like risk financing and insurance.

Flood risk has been studied from diverse perspectives during recent decades, and a large community of scholars has emerged with several journals focused on it [17]. The large increase in papers during recent decades indicates an expanding number of institutions and authors [18]. Studies of integrated approaches normally focus on partial integration where situations involve at least two aspects of flooding, but a broader perspective will involve more aspects [19]. This is like IWRM, where some studies are reported with situations claimed as integrated, but the degree of such integration may be limited [20]. Integrated perspectives usually deal with collective action and shared governance with different technical approaches that depend on the situations.

There is evidence of emerging comparisons of integrated frameworks and the use of systems analysis methods to examine complex phenomena like flooding. Researchers think that systems thinking could help in formulating better approaches, but it is being applied slowly [8,21]. In some cases, a systems method may claim credit for a solution, whereas another writer may attribute success to an integrated framework, like IWRM. This has been the case, for example, in examining the Singapore water story [22].

As mentioned, the Situation Overview prepared by the APFM explained issues that remain current [7]. It described how IFM involves a mix of strategies, different points, and types of interventions, and short- and long-term actions. It requires a participatory approach with the appropriate stakeholders and must deal with competing interests through trade-offs and compromises. Furthermore, it has grouped the issues into five categories or key elements as follows: addressing the land phases of the water cycle in totality, integration of land and water management, use of the best mix of strategies, a participatory approach, and integrated mitigation of hazards. The impediments identified included a lack of policies and strategies, inappropriate legal frameworks or institutional arrangements, ineffective flood forecasting and warning, limited community participation, and the absence of mechanisms for data management. Not surprisingly, these issues apply to IWRM as well.

Ample guidance is available to advise flood risk managers on integrated approaches and the use of flood risk tools. Examples are a guide for the Asian Development Bank [23] and a Flood and Drought Portal [24], which is part of a project funded by the Global Environment Facility with participation by UN Environment and the International Water Association. This Flood and Drought Management Tools project provides a management framework and online tools.

3. IFM and IWRM

The APFM defines IFM as part of IWRM, but both frameworks can be confusing because they are so broad. The two frameworks were compared side-by-side in Table 1 above, and interpreting IFM to be a part of IWRM requires clarification. The key is that both frameworks involve interactions between the water and land. This poses a difficulty with IWRM in that it requires the interpretation of the framework to be more general than managing only the water resources. This problem does not loom as large for IFM because flood risk resilience means protecting targets from water damage that are mostly land-based. There are always exceptions, of course, such as protecting riverine ecosystems from flood damage, but the major focus is on issues involving land.

The companion difficulty is to how to include flood risk management in IWRM in the first place. Most expressions of the purposes of water resources management focus on supplying needs for water. For example, the World Bank explained that "water resources management seeks to harness the benefits of water by ensuring there is sufficient water of adequate quality for drinking water and sanitation services, food production, energy generation, inland water transport, and water-based recreational, as well as sustaining healthy water-dependent ecosystems and protecting the aesthetic and spiritual values of lakes, rivers, and estuaries". That definition shows the multiple purposes that water resources management should address. Then, the Bank explained that it also "...entails managing water-related risks, including floods, drought, and contamination" [25]. While flood risk management can be grouped like this under water resources management, the combination is awkward and requires repetitive explanations.

Another problem with linking IFM and IWRM is that neither concept has its own Sustainable Development Goal (SDG). IWRM is assigned to SDG 6, which focuses on water and sanitation, aiming mostly at health issues. SDG 6 has been expanded to embrace a broader view of water resources management, which is evident in the targets and some eleven indicators. IWRM has been assigned indicator 6.5.1, "degree of integrated water resources management" [26]. No mention of flood risk appears in the indicators for SDG 6, but flood risk has been included within natural disasters as a target under SDG 11, Sustainable Cities and Communities. It has three indicators, namely deaths and injuries from natural disasters, economic losses from natural disasters, and damage to critical infrastructure and disruptions to basic services [27]. As almost half the world's population still live outside of cities, this might seem to only address part of the problem, but the real issue is the difficulty in classifying and defining complex interaction phenomena.

Like IWRM, published examples of IFM may claim to show integration, but they mainly illustrate different ways of addressing flooding issues. The main determinant in claiming an integrated approach for reducing flood risk will normally be when it involves more than a single structural method. Among the posted IWRM cases [28], the examples shown included the following: in Brazil, the merger of flood risk with water resources management; in Central Europe, natural small water retention; in China, smart systems and a national strategy for living with floods; in Greece, resolution of water and human conflicts; in Malaysia, managing floodplains; in Pakistan, flood management in the Indus Basin; and in Tanzania, youth flood mappers. In the development phase of the AFPM, case studies were collected to help formulate the Integrated Flood Management concept. Some 27 cases were listed, and 19 were used in the situation paper, which is now 20 years old [7]. The cases were like those posted by the IWRM Action Hub, and they were used to study the range of flood issues, including the areas, populations, numbers of flood events, severest events and years of occurrence, impacts, and damage losses.

To summarize the comparison between IFM and IWRM, both frameworks experience difficulty with classifying complex interaction phenomena. With so many situations, both illustrate the idea expressed by Ben Braga, former President of the World Water Council, at the XVI World Water Congress of the International Water Resources Association in 2017. He stated that IWRM really means, simply, "good water resources management", and the same can be said about IFM, while recognizing that multiple means are required in management in both instances.

4. Flood Hazard Analysis

According to an economic perspective, much more attention has been given to the hazard component of flood risk than to vulnerabilities and consequences [29]. The literature confirms this with many papers addressing climate, hydrology, and floodplain issues. In the definition of flood risk, the hazard is a threat that can have a negative impact and is a function of the probability and magnitude of the threat occurring [30]. The other elements in flood risk are exposure, or the economic value of assets subjected to flood hazard, vulnerability, the relationship of properties to economic loss, and performance, or the effect of flood protection and damage mitigation measures to modify flood hazard, exposure, or vulnerability. The focus on economic damage shows that work is needed to extend analysis to social and environmental losses and vulnerabilities.

The NFIP refines the definition of flood hazard to explain it as involving water surface elevation–exceedance probability functions [31,32]. Determining these requires knowledge of the likelihood of the forcing functions in the form of storms, which must be transformed to likelihood of water levels and, in some cases, water velocities which add to the flood threats. From this, we see that the determination of flood hazards involves hydrologic analysis, hydraulic analysis, and floodplain mapping and that they are independent of vulnerabilities and consequences in the pure definition of risk.

Hydrologic analysis involves atmospheric and land phenomenon for short- and long-term studies using hydrometeorology, or the study of the "atmospheric and terrestrial phases of the hydrological cycle with emphasis on the interrelationship between them" [33]. Long-term climate data are needed for planning and design studies and extreme precipitation values are used for different scales and time intervals to provide forcing functions for runoff models [34]. Statistical data continue to improve, but non-stationarity must be considered [35]. Numerical weather prediction based on remote sensing and computer models can provide short-term weather prediction for flood forecasting.

Statistical data and the analysis of long-term precipitation continue to evolve. In the US, the National Weather Service published Technical Paper 40 in 1961 as the first precipitation atlas for the country [36]. Now, the agency supports the U.S. Climate Atlas [37] and Atlas 14 of the National Oceanic and Atmospheric Administration as a resource for regional estimates of extreme precipitation [38,39]. Other countries and regions have similar approaches, such as the Climate Atlas for Europe [40,41]. Most continue to evolve and serve as data portals with statistical information and guidance about climate change. Of course, data availability around the world is variable, and some regions are data poor.

The availability of studies about the changes in extreme precipitation due to climate change continues to expand to include how extreme rainfall varies with event rareness [42], how extreme precipitation likelihood relates to atmospheric moisture, and how these vary with climate change [43]. Data on changes in extreme precipitation from high-quality stations have shown increases across most of the globe [44]. Ultimately, the availability of data on likelihood of extreme precipitation will depend on location, scale, and availability of monitoring stations, among other variables. Even when relatively long-term data are available, recent experiences show that unusually extreme events can happen [45,46].

Snowmelt must be considered, or flood underestimation is likely in some regions [47]. This can involve plains or mountain snow, and in large basins, both may be involved. Snowmelt models were reviewed in [48]. Most models did not consider blowing snow or frozen ground and these can improve accuracy of runoff models. Rain-on-snow events need more study and the integration of satellite data can help with this.

Issues of non-stationarity make the determination of flood hazards more complex because they call into question the use of historical data to make predictions and analyze risk. They must be studied based on the sites involved. The techniques proposed and their challenges for flood risks and low flows were reviewed in [49]. Other investigations have provided empirical and simulation-based frameworks for analysis, along with identification of future research needs [50].

The methods of runoff modeling have advanced rapidly since the 1960s, when comprehensive distributed models were enabled using the early computers [51]. Hydrologic models are used to transform forcing functions to streamflow, but spatial heterogeneities of watersheds and rainfall patterns create uncertainties and thus models have proved most useful for smaller catchments. For larger basins, gaging records are commonly used when they are available, with the threats due to non-stationarity considered. Modeling advances have been incorporated into advanced integrated software packages that are available through open sources and commercial outlets [52]. In the US, models are available from the US Geological Survey [53], Agricultural Research Service [54], US Army Corps of Engineers [55], and Natural Resources Conservation Service [56]. Other countries have different sets of models, like in the UK with the ReFH2 model [57] and the MIKE NAM model [58]. Commercial versions of some of the models are also available.

Flood frequency analysis requires the combination of precipitation analysis and runoff modeling to provide information to hydraulic models. The UK has a Flood Estimation

Handbook [59] that combines all factors. Results can be uncertain due to unknown factors, including limited data, non-stationarity, and other factors. A study by a committee of the National Research Council showed how to use combined methods to develop a reliable estimate of flood frequencies [60]. Flood frequency reporting also requires improvement to promote public understanding [61]. To improve communication, uniform and consistent methods can help in collaboration among stakeholders, and federal agencies have produced a set of Guidelines for Determining Flood Flow Frequency, to include non-stationarity [62,63].

The basis of floodplain analysis lies in open-channel hydraulics which, as a subdiscipline of hydraulic engineering, has a long and storied history dating back thousands of years in the analysis of major rivers like the Nile and the Yangtze [64]. In the analysis of flood plain flows, the predicted discharges are used to estimate water surface elevations in the floodway and floodplain. Analysis can now include two dimensions to study channel and overbank areas to include bridges, culverts, and other obstructions. Choices of models are available, and benchmark tests were developed by the United Kingdom (UK) Joint Defra (Department for Environmental Food and Rural Affairs) Environment Agency [65]. The USACE has benchmarked its flagship floodplain model [66] and FEMA has issued general guidance about modeling [67]. It is inevitable that models will give different results, which was predicted in studies of hydrologic and hydraulic sources of uncertainty and continues to be the case [52].

Once water surface elevations have been predicted, spatial analysis of floodplain geometry is used for floodplain mapping, and various methods are used [68] across different countries. Given the spatial analysis capabilities and 2D models, floodplains can be mapped much better than in the past, but long stream distances to map make it hard to perform well everywhere. Technologies have evolved from early manual methods through aerial photography and photogrammetry to the current use of digital data bases [69] and remote sensing methods. Early experiments with digital terrain models led to digital elevation models (DEMs), with the USGS establishing a standard in 1992, which is published openly and used around the world. In addition to the use of DEMs, remote sensing methods, light detection and ranging (lidar), and interferometric synthetic aperture radar (IFSAR) are useful aerial mapping technologies [70]. The public has become accustomed to access to visual spatial data like Google Earth. Such mapping is used for many purposes, such that there is a need for digital orthophotography covering the nation that is updated regularly [71].

Reforms in floodplain mapping continue to be needed. NRC's 2009 study had stated that "topographic data are the most important factor in determining water surface elevations, base flood elevations, and the extent of flooding and, thus, the accuracy of flood maps in riverine areas;" [72] and the first recommendation from NRC's 2007 study states that "elevation for the Nation should employ lidar as the primary technology for digital elevation data acquisition" [73]. Now, the USGS 3D Elevation Program or 3DEP, based on lidar with 2 foot contour accuracy or better, is becoming used to map floodplains and coastal areas. The program is managed by the USGS National Geospatial Program, which is a shared effort. It started at full effort in 2016, and by 2023, 94% of the US was mapped [74].

Anticipating floods requires forecasts for medium to large scales and short- to long-term time scales, and flood forecasting practices continue to improve. The US has the Advanced Hydrological Prediction Service (AHPS) managed by the National Weather Service [75]. Most water data in the AHPS are from the gages of the USGS [76], with additional information added. The National Weather Service also [77] has a program for 6 h Quantitative Precipitation Forecasting (QPF). Weather Forecast Offices and River Forecast Centers run hydrologic models to create displays on AHPS webpages. General circulation models and downscaling are being used more as technologies and data improve [78]. The method of "nowcasting" increases the usefulness of flash flood warnings, and a summary of its status is available at [79].

5. Flood Infrastructure and Management Programs

It has been common to refer to flood risk measures as structural and non-structural, and the structural part can be categorized as flood infrastructure and include green systems like wetlands as well as physical infrastructure like levees, channels, and flood control dams. In cities, green approaches can include an assortment of practices, including ponds and nature-based wetlands and retention sites, including China's Sponge City program [80]. The use of dams as flood control measures is controversial, but studies show that large economic damages can be avoided when they operate effectively [81,82]. The condition of levees is problematic and if they are not maintained well, they can fail the many people who rely on them [83].

As climate change occurs, with difficult effects like rising sea levels, potential failures of these infrastructure systems become more worrisome. An example of a response is New York City's Cloudburst infrastructure program, taken in cooperation with Copenhagen, Denmark [84]. To confront the threats, attention to maintenance and asset management is required for all flood infrastructure. Unfortunately, complacency sometimes leads to neglect and to problems when extreme events do occur [85].

Non-structural management programs require vigilance as well. They have evolved to include measures such as the regulation of land use, building restrictions, and flood proofing. Measures to raise awareness and preparedness include early warning systems, evacuation plans, and flood hazard maps. After these measures, residual risk can be mitigated by emergency response, insurance and relief funds, and recovery plans [86]. Managing these programs between extreme events can become difficult due to the same complacency that afflicts infrastructure neglect. In particular, flood insurance in the US has a mixed record. Once, when inspecting a flood disaster site, a resident asked the writer why the government did not give them an advance notice of 30 days about the extreme flood so that they could buy insurance. The NFIP is now viewed as problematic due to financial insolvency and affordability as concerns. Uncertainties due to flood risk mapping are an ongoing issue. Now, climate variability is causing more frequent and intense coastal zone and riverine flooding [87].

Flood Impact Assessment

In decisions about flood risk reduction, impact assessments are used to determine the best strategies [88]. Definitions of terms about impact assessment were discussed in [88] and differences can be seen among sources such as the Society for Risk Analysis [89], the ISO [90], and the UN [91]. Flood risk assessment addresses impacts in the economic, social, and environmental categories in the same way as IWRM, which considers the triple bottom line in its goal "to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

From the perspective of economists, studies of flood impacts have a long history, but further development is needed. Reported needs focus on estimation of damage, data, and model development. They see pitfalls like the choice between replacement costs or depreciated values, that model validation is not adequately performed, and that improvements would add uncertainty to analyses and scrutiny of model inputs. Economists think that much more attention has been given to the hazard part of risk, and much more is needed on impact assessment. They focus, as expected, on economic damages [29].

Social impacts involve outcomes like degraded public and individual health, losses of property that may not show up much in economic statistics but be essential to families, grief, long term suffering and loss of opportunities, and other issues. They are arguably the most important, most complex, and most difficult to assess. They involve many variables and fewer studies are available, as compared to economic impacts. Their categories include socioeconomic and demographic factors that influence community resilience and household resilience. A recurring theme is the extent to which residents can participate in decisions [92]. Flood risk mapping must be improved to assess them [93]. Vulnerable people are affected more than others, experience more difficulty in the recovery phase, and are more likely to die. Detailed social vulnerability indices were discussed in [94,95]. While indices are useful, they should express the welfare of societal groups in terms of resilience and recovery capacity, impacts of rare events, and distributional impacts [96]. As these involve many variables, studies of social impacts tend to focus on case studies in different countries [97–99].

Methods for the environmental impact assessment have been in active development for more than fifty years and have been adopted in many countries. A literature study by [100] provided an overview. As explained by the APFM [101], they can be positive or negative and affect environmental assets like streams, catchments, floodplains, ecological systems, and aquifers. On the negative side, stream erosion, pollution, and loss of habitat occur. On the positive side, floods fertilize agricultural lands, replenish wetlands, and recharge aquifers.

6. Legal Frameworks

Flood law does not appear much in discussions of IFM, but it can be a significant factor in policy development, flood risk projects and programs, and relief after disastrous flooding. The legal frameworks for it will differ from country to country, but they converge toward similar policies and measures. For example, the European Union's Flood Directive specifies flood risk assessments, flood maps, and flood risk management plans [102,103]. Japan [104,105] has more centralized rules about river management and flooding. England and Wales have parallel requirements to those in the EU, which include a national strategy, methods, framework, and tools to manage flooding, supporting roles of local authorities, assessing flood and coastal erosion risk, managing funding, enforcement, and flood warning [106]. Transboundary flood issues may be significant, as when an upstream state has large-scale deforestation or massive urbanization that will affect the downstream state. The International Law Association adopted Rules on Flood Control in 1972, but it has not gone beyond dealing with other measures. There are also treaty provisions, such as on the Rhine and Danube rivers at the basin level [107].

In the US, flood law is a composite of common law, liability, constitutional, and statutory laws [108]. Drainage law is addressed in different doctrines that vary among states, called the common enemy, including civil and modified civil doctrines [109]. The evolution of flood policy and law in the US dates to before 1900 with a policy about the federal role in flood risk improvements. The federal government recognized that some flood victims might merit relief, but little was carried out because this was considered as a responsibility for states and local districts [110]. A notable outcome of flood disasters was the recognition that the legal doctrine of liability created a loophole in flood losses, and the 1889 Johnstown PA disaster led to the defining of the doctrine of strict liability for flood losses, which increased the risk for owners of flood control facilities [111]. The next phase of the policy was on flood control where major events like the 1927 Mississippi River flood led to the 1928 and 1936 Flood Control Acts, which created immunity for government flood control efforts and led to BCA [110]. By the 1960s, federal support for flood hazard reduction projects had diminished and the Flood Insurance Act of 1968 shifted more responsibility to non-structural approaches.

Flood losses proved problematic in the US legal structure, and while the Supreme Court usually finds that the government is not obligated to help citizens with social goods like flood relief, it has found that the Constitution restrains government from depriving persons of basic rights. Some flood claims are now being filed under takings law per the Fifth Amendment of the U.S. Constitution [108].

7. Flood Risk Governance

Governance is the central organizing force to mobilize the actions needed in IFM and it attracts many studies. An extensive bibliometric review of flood risk management and governance identified 3059 articles from more than 100 countries. Most articles addressed issues of developed countries, with a focus on Europe. The frequency of publication increased rapidly over the last two decades, and the papers reflect a relatively small number of journals and show dominance by a few authors. The papers show a tendency toward shared governance among governments and individuals. The focus on urban flooding as opposed to riverine flooding has increased, there has been emphasis on protection of property, and attention to exposure has been less than on hazard and vulnerability [18].

Governance generally means the institutional arrangements for flood risk management, which involves the means and methods to take actions and operate projects and programs. There is relatively more emphasis in the literature on management, and governance can stand more attention on analysis of processes and solutions. The authors wrote that both fields should have more attention from the political science, public administration, and policy fields. The management literature tends to be more technical with emphasis on modeling, prediction, and probability, and the governance literature focuses on social science aspects such as actors, institutions, participation, and policy.

Given the complexities of IFM, it is not surprising that reports show shortcomings in governance, both in developing countries [112] and in developed countries, like England [113,114]. Studies of governance issues tend toward case studies, like one about large cities in Italy where the Institutional Analysis and Development (IAD) framework was used to study factors that might enable or hamper risk-based approaches. Problems identified included poor coordination across levels of government, actors, and policy domains. The author drew from successes in Europe to recommend reforms that include enhancing flood risk perception and awareness, improving collaborative governance and participatory processes, strengthening knowledge sharing and consensus building, diversifying strategies, clarifying task allocation and the division of responsibilities, and tackling unauthorized planning practices [115].

8. Analysis and Discussion

Explanations of IFM as developed by the APFM were worked out around 25 years ago and, like IWRM, the success of the concept as a framework depends on governance and institutional capacity as well as technological advances. The main elements of IFM that require collective action, a coordinated framework, and a mixture of measures had evolved for several decades prior to organization of the APFM, but the international exposure of the IFM framework offers promise for application in a broader set of countries. Solutions at all scales and levels require effective analysis and planning with institutional arrangements that are appropriate for contextual situations. Implementation may be slow, which is also the case with IWRM, but perseverance is needed for long-term implementation and short-term expectations may be too myopic.

An important institutional arrangement that is in control of governing authorities is organization of effective data and decision support systems as essential elements for IFM to provide shared information systems to bring stakeholders together. Databases must be managed with clear responsibilities and provided with the resources needed. Data may extend beyond climate and streamflow to include information on economics, cooperative networks among stakeholders, communication channels and protocols, and other information depending on the contextual situation.

While current analysis tools are effective, the continued advancement of climate science and hydrometeorology is needed to support improved models and forecasts. With artificial intelligence, these should be poised for more effective transfer to all locations. Streamflow models are already advanced, but improving usability and transferability is needed. Ultimately, how well these support flood warning systems and flood mapping provides a test for their adequacy. Flood mapping also depends on land use information and keeping it current poses an ongoing challenge.

While climate science, hydrometeorology, and stream hydraulics require more research, less is known about the consequences of floods. More work is needed, especially to improve analysis of economic, social, and environmental categories. Vulnerability assessments provide valuable information to help with decisions, but more focus on sensitive populations is needed. Social and environmental categories may be under-represented in studies of consequences and vulnerability.

With respect to the five-step cascade presented by the APFM, flood risk can be reduced by use of nature-based facilities like wetlands and green infrastructure as a few cases demonstrate. However, more is known about these at small scales like low-intensity development (LID) or the sponge city system in China than at large scales. Even at small scales, promising advances are possible by implementation of appropriate land use practices.

The knowledge base demonstrates a continuing trend to move from reliance on flood control toward an approach based on resilience. Whereas the shift toward non-structural solutions began more than fifty years ago, newer thinking moves from traditional measures toward risk management with adaptation approaches applied through planning, response, and recovery phases [116].

Although emphasis on structural solutions has diminished, the many levees, coastal flood barriers, and flood control reservoirs indicate that a great deal of attention to maintenance and management is needed. With rising threats from climate change, including sea level, reevaluations of past studies and assumptions are needed. Like other physical infrastructures, deterioration in condition can increase risk, and vigilance in asset management is required to ensure operational capacity.

Regulation of land use depends on effective governance at the local levels where most settlement on or near flood plains occurs. In addition to the location of vulnerable structures, flood proofing rules, together with enforcement, are needed. This can challenge local governments that lack effective governance structures and arrangements, but the inappropriate use of flood plains is a major cause of flood losses.

Raising awareness and preparedness levels goes together with other nonstructural measures and requires effective communication systems for flood warnings, evacuation notices, and other actions that must be taken by residents. Participation requires trust in government authorities, which can be a difficult issue in some settings [117]. Floodplain mapping is an essential tool to inform residents of hazards, and it requires continuing attention to overcome sources of change.

The elements of IFM devoted to mitigating residual risk have been the subject of many policy studies. Emergency management (EM) or other security-related frameworks like disaster management and crisis management generally have the same phases of preparedness, response, mitigation, and recovery. Planning is embodied in these, both in terms of preventing damage and preparing to respond and recover from disasters.

In the US, the NFIP was approved to remove the government from the relief responsibilities, but in its 50 years of operation, it has not proved possible to achieve such removal completely. Individual responsibility is required, and it leaves some residents in quandaries when they lack capacity to do so. The nation continues to seek ways to provide additional institutional support to address emerging issues, and professional groups continue to study policy needs and recommend administrative actions by the governing authorities [118].

Despite the measures in IFM, an increasing number of people continue to stand in nature's way. Floods do not always occur in flood plains, and this causes surprises, along with climate change increases in flood magnitude. As a result, risk and litigation exposure continue to increase.

Of the measures in IFM, governance stands out as the most important overarching tool to promote effective implementation. As IFM has different strands, specific needs must be outlined. As with any important program, political commitment is essential, or nothing will happen. Once there is commitment, policy analysis can be meaningful. It should involve the required legal and institutional frameworks to demarcate jurisdiction and responsibilities of agencies. A funded mechanism for inter-agency coordination and cooperation is required to oversee implementation of policies and plans. Like in IWRM, flood management objectives must be outlined in clear terms and related to other sector policies.

Shared governance requires a clear understanding of the organizational hierarchy and management functions at the different jurisdictional levels. It might involve the delineation of the spatial planning unit for IFM, such as the river basin. Institutional capacities must be supported for all governmental levels and related agencies, such as river basin commissions, land planning agencies, emergency management agencies, community groups, and any other stakeholders with major roles, such as energy, housing, or transport authorities.

Capacity development should be a core function of IFM, and it will depend on levels of economic development and investments in infrastructure and human resources. These depend on the same factors that affect the effectiveness of government, such as institutional arrangements, socio-economic conditions, and traditions and values. Without knowledge, expertise, experience, and competence, neither IWRM nor IFM can succeed, and ongoing training and practice programs will be essential. It is difficult to keep interest levels high between emergencies, and authorities must not let apathy creep in.

9. Conclusions

Flood disasters seem to be worsening due to climatic and demographic factors, and the IFM framework was developed two decades ago to provide a way to mobilize stakeholders and methods to confront them. The IFM framework fits into the broader IWRM framework, and both involve water and land issues in a nexus. These integrated approaches provide a way to conceptualize the merger of multiple objectives, means, and stakeholders so that their complex interrelationships can be understood. Considering the many global scenarios, success of IFM and IWRM as integrated management approaches depends on governance and institutional capacity as well as technological advances.

The review showed that technological progress continues to advance with methods and tools such as remote sensing, monitoring, modeling, and assessment, but more attention is needed to address social and environmental concerns to go along with economic risks. On the management side, integrative governance must focus on the need for shared responsibility among levels and sectors of government and with the private sector, community groups, and individuals. Such shared governance requires clear understanding of the organizational hierarchies and management functions at the different jurisdictional levels. In each of these stakeholder cohorts, capacity development must be a core function of IFM, as it is with IWRM.

While technological progress is evident, specific advances are still needed, such as improved data and decision support systems, which may lack political support and understanding. Continued advancement in climate science and hydrometeorology will lead to better assessments and forecasts, and improved analysis methods for all categories of impacts can lead to better decisions, even while environmental and social impacts are difficult to measure.

Flood risks can be reduced by the use of nature-based facilities like wetlands and green infrastructure, and these can go along with levees and measures to keep people and property out of harm's way. Floodplain mapping is needed for these strategies, and it requires continuing attention to overcome sources of hydrologic and land use changes. Physical flood infrastructure like flood barriers, levees, and flood control reservoirs require vigilant condition assessment and care to ensure their reliability and robustness. Nonstructural measures also require vigilance to ensure that they are ready and will succeed, in areas like regulation of land use, flood proofing, and flood warning. Raising awareness and preparedness levels is required if all stakeholders are to fill their roles and this will require governance authorities to increase participation.

Ultimately, the key to advancement of IFM will lie in effective governance, capacity building, and cooperative participatory approaches to reduce losses and hardships. Implementation of IFM may be slow, as it is with IWRM, but perseverance is needed for long-term implementation and to avoid myopia. As always, political commitment is essential, or nothing will happen. Effective explanations of the IFM and IWRM concepts can help. The many advances and reforms that have been identified have been demonstrated in some places, but extension to broader spheres of application and to more stakeholders requires vigilant approaches that must be based on sharing of knowledge and greater cooperation.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

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