Chapter 1
Water, Governance, and Infrastructure for Enhancing Climate Resilience

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Abstract Water management, climate change, and climate variability—along with their numerous interlinkages and the extent of related hydrologic, economic, social, environmental, and political impacts over time and space—have become issues of increasing global concern. Despite their importance for freshwater systems and the fundamental services they provide, numerous factors and uncertainties prevent us from forecasting their likely future multidimensional and multisectoral impacts with any accuracy. These factors include, but are not necessarily limited to, a lack of scientific understanding of their complexity and interrelationships, as well as an absence of reliable data that would otherwise allow us to understand them more reliably. Therefore, policy alternatives, management and development decisions, and investment choices on any adaptation strategy are challenging tasks under the best of circumstances. Given the uncertainties related to climate change and variability, nonclimatic factors have thus become more relevant. Governance—or decision-making by multiple actors with dissimilar interests grouped under formal and informal institutions—is one of the most important. This chapter discusses several case studies that analyze the roles that infrastructure and governance play in the context of adaptation in increasing resilience to climate variability and change in different regions, basins, and projects. Water infrastructure is fundamental to build resilience and adapt to climate variability and change. However, to be effective, it needs to be part of a governance framework that considers multisector needs and multilevel actors in the longer term.

Keywords Resilience · Climate change · Infrastructure · Governance · Adaptation

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1.1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC 2007), resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure, ways of functioning, capacity for self-organization, and capacity to adapt to stress and change. The concept of resilience is often linked to climate change; however, the related issues are much broader. In fact, social and ecological systems have always had capacity to adapt to stress and change. They have been essential to the progress of societies throughout the history of humankind. The numerous local and global changes in human and natural environments, global use of and competition for scarce natural resources, growing populations, globalization, information and communication revolutions, increasing social expectations, and rapid progress in scientific and technological developments have affected—either positively or otherwise—the resilience of populations and their environments all over the world.

Adaptation, in the context of climate change, has been described as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC 2007). *Mitigation*, also in the context of climate change, has been described as "technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks" (IPCC 2007).

Freshwater systems and their future development depend on climate-related factors such as precipitation, temperature, and evaporative demand, as well as on nonclimatic factors. Given the uncertainties related to climate change and variability and the lack of data to predict them with certainty within given timeframes, nonclimatic factors have become more relevant. Examples include management, governance and policy issues, land use considerations, infrastructure development (reservoirs, groundwater storage, and recovery), technology and innovations, and diversification of water resources through water reuse and desalination.

Reservoirs have become an integral part of basic infrastructure by offering indispensable benefits, such as domestic, livestock, industrial, and irrigation water supplies, as well as hydropower, flood control, drought mitigation, navigation, fish farming, and recreation. The construction of new reservoirs has often been controversial during recent decades because social and environmental impacts have not always received due consideration (Scudder 2012). However, the limited and skewed distribution of water over time and space has created difficulty in meeting the increasing demands of uses and users at national, regional, and global levels—some of them new. Thus, the world has realized that more reservoirs, their improved operation, and broader policy, management, development, and governance alternatives are necessary to promote development and meet basic human needs. Global dynamics in terms of water, energy (including electricity trade), food, and climate securities have recast the importance of the roles of reservoirs in national development. In many cases, this has triggered massive investments in the construction and modernization of multiple projects in both developed and developing countries, such as Turkey, China, India, Laos PDR, Bhutan, and the United States (Tortajada 2014; Tortajada et al. 2014).

The World Water Council and the National Water Commission of Mexico (CONAGUA), in collaboration with the National Association of Water and Sanitation Utilities of Mexico, have supported a series of case studies on the roles that infrastructure and governance play in the context of adaptation to increasing resilience to climate variability and change in different parts of the world. These case studies aimed to improve understanding of the policy, management, governance, and development of water resources in changing environments.

These case studies focus on regions, river basins, and projects, including the arid Americas (with examples from the United States and Mexico), the Murray–Darling River basin in Australia, the Koshi River basin in Nepal, the Indus River basin in Pakistan, the Yellow River basin in China, and the Durance–Verdon River basin in France. In terms of reservoirs, the case studies examine Sobradinho in Brazil, high-risk dams in Mexico, Seyhan Dam in Turkey, High Aswan Dam in Egypt, and Sterkfontein Dam in South Africa. Some of the studies are transboundary, such as Arizona–Sonora and the Indus, Koshi, and Nile River basins. These cases have very different geographical and hydrological characteristics; they also differ in the related governance frameworks.

In all of the studies, the authors—who are from the government, private sector, and academia—analyze the numerous challenges faced by policymakers and society at large at the basin, national, and regional levels. These issues are related to governance (policies, institutions, and decision-making), infrastructure development, technical and knowledge constraints and limitations, and the economic, social, and environmental impacts of climate change and variability. Decision-making has changed but still needs to improve in the face of climatic uncertainty, knowledge and data gaps, aging infrastructure, increasing demands for water resources that tend to be scarcer and more polluted for an increasing number of uses and users, and numerous unresolved water management-related concerns. Many problems that need to be addressed more immediately seem to have lost urgency because of climate concerns; in reality, all concerns should be addressed concurrently.

The case studies demonstrate that decision-making has become quite complex. Traditional decisions on infrastructure development are based on historical trends that lack the understanding of long-term uncertainty in climate variability and change. There are concomitant issues concerning erosion and sedimentation, ecosystem degradation, social impacts, sharing benefits with local communities, and financial and institutional implementation modalities. However, as climate-related conditions change, knowledge and understanding of their social, economic, environmental, and political effects need to improve and become more comprehensive—a goal that is still in progress globally. More robust policy, institutional, development, and management frameworks need to be developed and implemented in collaboration with users and affected sectors of society.

The authors of the case studies argue that overall decision-making should become more efficient. In many cases evolve from monolithic and unidirectional structures to more responsive and inclusive ones, and concerned with the interests, contributions, and needs of several sectors, including society generally.

1.2 Infrastructure in a Changing Environment

Infrastructure is an indispensable component of economic growth, poverty reduction, and climate change adaptation. Infrastructure has distinct potential to help overcome growth constraints, respond to urbanization pressures, improve social and environmental conditions, encourage competitiveness and productivity, underpin improvements in quality of life and social inclusion, and enlarge and speed up communication and mobility. Thus, infrastructure should be an ongoing priority for all public and private sectors in society (Bhattacharya et al. 2012). Developing infrastructure in isolation of development policies, efficient management, and consideration of social needs and environmental concerns has only limited value.

In relation to water resources management, it is assumed that the stationarity on which water resources have been managed historically is no longer valid and that water systems have to be optimized in different ways. It is argued that the extent of alteration to the means and extremes of precipitation, evapotranspiration, and rates of river discharge due to anthropogenic effects make it necessary to identify new nonstationary probabilistic models of relevant environmental variables. In turn, these variables will provide the relevant information necessary when renewing and building water infrastructure (Milly et al. 2008. For a discussion on Milly et al. 2008 and nonstationarity, see WMO no date).

Most dams and reservoirs were constructed when climate change was not a consideration. Despite this, they have been able to respond to potential impacts of climate change and cope with extreme events by means of operation or modernization in some cases (Lima and Abreu 2016; Muller 2016) but not all cases (Alcocer-Yamanaka and Murillo-Fernandez 2016; Pittock 2016; Selek et al. 2016).

In the uncertain face of climate change, governments are undecided on the most appropriate water management practices and development-related decisions to help their countries adapt positively while continuing to grow economically and socially. Rather than focusing on models alone, the case studies in this book suggest that more attention should be given to adaptation mechanisms that consider water infrastructure as a means to build resilience by augmenting and regulating water resources and thus availability. More attention is also required for more efficient water management; poor practices may not only constrain development under normal conditions but also exacerbate extreme events.

Because extreme events are likely to increase in the future, it is essential that countries prepare for them. Although infrastructure is critical, it is not enough. Policies, institutions (both formal and informal), laws, regulations, management practices, pricing instruments, and participation models that encourage the efficient management of water resources and water-related services are fundamental to build resilience (Molden et al. 2014). Given the changing local, regional, and global economic situation, social expectations, and environmental considerations, it is essential to assess the extent to which infrastructure can actually help build resilience, how it can be improved, if its operation needs to be changed, or, in extreme cases, if it needs to be put out of operation or even decommissioned. This assessment will be achieved only within a broader framework of development, with governance as an essential component.

Policymakers are aware of the importance of strategies for adaptation to climate change, particularly with respect to water resources and ecosystem management. They are also aware that adaptation measures are needed to deal with more or less precipitation. Nevertheless, the devil is in the details. After all, it may be that societies will have to learn how to live with less water and more widespread landscape transformation in the non-too-distant future (Overpeck and Udall 2010). Adaptations are needed either to more or less precipitation. These adaptations include policy measures that are more comprehensive, the involvement of formal and informal institutions at different levels, demand management strategies that focus on the basins rather than the cities (even when the basins are transboundary), conservation practices, technological innovations, market-based solutions, infrastructure adaptation, and, most importantly, the engagement of users and the public in general (AghaKouchak et al. 2015).

The use of all means available and the development of new alternatives for the purposes of adaptation to climate change—but more immediately, to local, regional, and global changes—are in the political agendas of governments all over the world. Climate change challenges have joined the long list of challenges that governments and populations face on daily basis and have made them re-evaluate their water and development policies. These challenges include the provision of services to larger urban populations and to impoverished rural communities; a race to achieve economic growth and compete globally for the provision of products and services; increasing demand for natural resources that are more limited, polluted, scarce, and overexploited and for which competition has become global in scope; and very complex decision-making processes that frequently involve formal and informal institutions concurrently from more than one sector, basin, region, and (in many cases) country. As mentioned by Scott and Lutz-Ley (2016), extreme events seriously limit management responses to increase the supply of water resources. Therefore, it is important to improve the effectiveness of current management practices, which in many cases leave much to be desired.

1.3 Governance to Build Resilience

Governance usually refers to decision-making that is more inclusive and considers multiple partners, including formal and informal institutions at different levels and in several sectors. It provides several actors with the opportunity and responsibility to contribute local experiences and traditional knowledge, which have the potential to render great benefits. Governance is expected to result in better management of water resources under normal conditions and especially during extreme events, which will result in greater resilience (Pittock 2016).

The comparative assessment of Arizona and Sonora in this book focuses on factors affecting water security in the two states of two different countries, United States and Mexico. These factors include hydroclimatic and water-demand uncertainties, the capacity for institutional learning, the level of flexibility of policies for infrastructure that also address water governance, and the existence of science–policy linkages to underscore reservoir infrastructure and governance mechanisms to improve resilience. One of the most important arguments that Scott and Lutz-Ley (2016) make is that the provision of water requires the implementation of policy instruments (such as pricing and water rights for water allocation or reallocation), institutional arrangements or rearrangements, new rules or rules as necessary, financing mechanisms, social learning, and, of course, built infrastructure for it to be effective.

Governance can be an important element when the development of infrastructure and reallocation of water resources are necessary, as any change in flow allocation that will benefit any use and users will affect all of them—more so in the so-called closed basins or vulnerable basins (Falkenmark and Molden 2008; Pittock 2016). Among these basins, the Murray–Darling is an example where institutional and policy reforms as well as governance practices have evolved by responding to the extreme climatic variability faced through the years. The numerous reforms have focused, for example, on groundwater extraction and water accounting to purchase and manage water entitlements for environmental flows (Pittock 2016). Even though opinions vary on the effectiveness of reform implementation, environmental flows have been an essential component of the development and policy agendas in the basin.

A basin where infrastructure is a priority but where institutional and policy reforms for them still have to become more effective is the Koshi (also known as Kosi) River basin in Nepal. Although water infrastructure is urgently needed for water supply, energy generation, and flood control (even when this has been debated), it will render more positive results if the infrastructure is developed within a framework of responsive governance, both nationally and at the transboundary level (Wahid et al. 2016). As the authors discuss, it is not only the need to develop infrastructure under conditions of climate uncertainty but also development challenges that should encourage more comprehensive decision-making. To be more effective, institutional arrangements, policy options, and the costs and benefits of irrigation and hydropower development projects should be based on cumulative effects economically, socially, and environmentally, as well as at multiple levels rather than individually (as is done at present). Planning and implementation should also benefit from governance practices that consider more successful models of stakeholder engagement that include responsibility, accountability, and transparency aspects. For infrastructure development to benefit the country in the long term, planning and implementation should consider the potential impacts of climate change and, more broadly, the economy of the country, the benefits to society, and the impacts to the natural environment on which development of the country depends.

The study of the Indus River in Pakistan shows how extensively flood disasters can hinder not only the development of the basin but of the country. Mendoza and Khero (2016) argue that the management of water resources and infrastructure development, as well as its proper operation prior and during floods, should enable the river system to absorb adverse impacts. They also argue that this has proven to be a real challenge because of the multiplicity of actors involved in individual planning, decision-making, and management of the river, both nationally and at the transboundary level.

The case study explains that the 2010 floods were the worst in the country's history, causing damages of approximately USD 10 billion. They affected all provinces, inundated 38,600 km^2, and resulted in the deaths of some 1600 people. The reasons for the flood included not only the intensity of rainfall but also an inadequate early warning system and reduced capacity of the available waterways. Despite the large number of reservoirs in the basin, the floods in 2010 (and also 2014) indicate not only that storage is needed—its operation needs to be more efficient. In the specific case of the Indus River basin, provinces have to coordinate water management options rather than deciding on them individually. Systems are interdependent and management practices taken in different places in the basin have impacts in other places. Water infrastructure is a requirement to build resilience in the Indus River basin. However, also necessary are comprehensive policies, institutions that are able to set systems that are cost effective, multisector and multilevel governance structures, data collection and sharing of information, monitoring of multihazards, risk assessment evaluations, technology for flood early warning systems, communication of risk information to the vulnerable population, and the building of response capabilities at community and national levels (Mendoza and Khero 2016).

A very large river basin in China—the Yellow River basin—has seen the benefits of infrastructural development as well as improvements in the institutional structure and policy—and decision-making. A total of 30 large dams and hydropower facilities have been built on the main stream of the river for water supply for domestic, agricultural, and industrial uses, as well as power generation, drought management, and flood control. This extensive infrastructure development has had both positive and negative impacts and has resulted in significant changes of flow regime and water allocation. For example, in the 1990s and until 2003, the river would run dry before it reached the sea. A more comprehensive development framework was implemented by the Yellow River Conservancy Commission.

The infrastructure was reoperated with a focus on water scarcity, water quality, environment flow and ecological restoration, flood discharge, and optimization of flow and sediment transportation (Sun and Fu 2016). The end result has been the river flowing into the sea.

Sun and Fu (2016) argue that, despite the enormous benefits of the infrastructure, there are still numerous challenges related to the management of water resources at the river basin level, for which both structural and nonstructural measures are under implementation. Governance is one of the most important nonstructural measures. It includes changes in institutional arrangements as well as consideration of laws, regulations, policies, and economic approaches; management at the river basin level; and a policy framework that considers declining water availability, water quality degradation, riverine wetlands, geomorphology, sedimentation, and water conservation.

The last study on a basin focuses on the Durance–Verdon River basin in the south of France (Branche 2016). In this basin, water resources are under increasing pressure from considerable abstractions for domestic, irrigation, industrial, hydropower, and recreational uses. Given the importance of climate variability and change, population growth, and socioeconomic development, Électricité de France (EDF) developed three strategies for climate change adaptation: the R2D2 2050 program, value creation methodology, and water-savings agreements. The R2D2 2050 program tries to evaluate possible impacts of climate change on the quantity and quality of water resources, biodiversity, and changing demands and uses in the river basin in 2050. Model-based scenarios for future water demand were developed in collaboration with different stakeholders. The value creation methodology has the objective to identify the socioeconomic benefits of hydropower. The water-saving agreements are voluntary economic instruments that require EDF to pay back to users a part of the savings if specific targets are reached.

The three initiatives have been positive but have proven to be complex. For example, the scenarios developed under R2D2 2050 were very useful for collecting physical, biological, and socioeconomic data; understanding the impacts of hydropower development in the basin; and further realizing the complexity of the potential economic, social, and environmental impacts of climate change. Even when they were not able to consider water management in its totality, potential research topics were identified for further study. Through the value creation methodology, it was possible to establish a relationship between the financial and economic contributions of hydropower-related services, tax payments to the region, governance models, and thus the involvement of a broad base of stakeholders. Finally, the water-savings methodology is useful for understanding how complex decision-making can be when there are conflicting interests. A main finding of the study has been that more infrastructure does not necessarily contribute to adaptation or resilience to climate change impacts. What contributes more effectively is appropriate governance frameworks of the water storage available. This reinforces the arguments of other case studies in this book in the sense that infrastructure is necessary but so are governance practices.

Moving from river basins into projects, the first case study in the book is that of Sobradinho Reservoir in the Sao Francisco drainage basin. The basin covers 7.5 % of Brazil, with 60 % of it located in the semi-arid region of the country, which is subject to long periods of drought due to low precipitation and high evapotranspiration. Sobradinho—a multipurpose reservoir for human, livestock, irrigation, hydropower, fish farming, navigation, recreation, tourism, and environmental purposes—also plays an important role in flood control. Opinions vary on the effectiveness of the traditional reservoir's operation as allocation had favored one sector over the others. According to Lima and Abreu (2016), the main user of water of the reservoir was originally the hydropower sector; however, this has changed with time in order to meet multipurpose uses.

The case study discusses that the years 2014, 2015, and part of 2016 experienced the lowest average annual unregulated flows historically. This reduced the volume of water stored in the reservoir, affecting the related productive and nonproductive activities and thus the thousands of jobs and quality of life of the population. A series of mitigation measures were implemented to prevent further reduction of the water stored and minimum outflows were discussed, agreed upon, and implemented. The users in the Sao Francisco River basin are aware of the situations and of the possible restrictions. Lima and Abreu (2016) highlight the importance of good governance practices in the Sobradinho Reservoir during drought conditions, when the demands of many sectors have to be addressed concurrently. This is important because effective decision-making strategies need to be established; extreme events will likely be more frequent and more severe in the future.

Considering the possible impacts of more frequent and more severe extreme events, the Mexico study analyzes high-security dams (Alcocer-Yamanaka and Murillo-Fernandez 2016). The study assesses the mitigation measures that are needed to operate the dams under conditions of change in climate, the resulting and probable floods, and possible impacts on populations living nearby and downstream, including property and the environment. Measures are both corrective and preventive, including management and structural considerations, operating policies, dam safety laws, regulations and standards that define conservation, and monitoring and supervision procedures.

The study concludes that changes in meteorological, hydrological, and structural conditions, in addition to negligence, have resulted in approximately 115 dams becoming unsafe in the country. As in many other cases, land use changes (in this specific case, from agriculture and forested areas to mainly agricultural and urban areas) have resulted in increasing runoff and thus floodwater. Dams in urban areas require limiting storage during the rainy season to avoid any flooding downstream. The fact that some of them are for recreational purposes also creates a problem because they are kept full most of the year, resulting in lower flow capacity.

According to the study, the owners of the dams are aware of their conditions and possible alternatives (which may include taking the dams permanently out of service) and the final decisions on how to proceed depends on them. As Alcocer-Yamanaka and Murillo-Fernandez (2016) discuss, knowledge and understanding of hydroclimatological variables, evolution and forecasting, the current conditions of storage infrastructure, and flood control are essential for safe operation of the dams. Effective participation and collaboration of the water users and those in charge of the operation of infrastructure are necessary because they have practical implications in terms of safety.

The Turkish case study focuses on the Seyhan Dam in the Seyhan River basin. Seyhan Dam provides water for domestic, irrigation (mainly cotton), and industrial uses, as well as energy generation and flood control. It also has environmental benefits for the Adana Plain. Predictions for the Seyhan River basin in the future vary, but they estimate that precipitation will decrease (in one case up to 25–35 %), with changes in seasonality resulting in earlier snowmelt over the mountains. Less available water is expected to put additional stress on local populations, wildlife, and groundwater resources for irrigation, as well as increase the risk of pollution and salt water intrusion along the coastal regions, sometimes up to 10 m inland (Selek et al. 2016).

Given the importance of the Seyhan River basin for agricultural production locally and nationally and the expected lower precipitation in the future, Selek et al. (2016) argue that new water projects may have to be constructed: more efficient irrigation will be necessary but not be enough. Therefore, various adaptation measures for resilience building will have to be implemented in all sectors. These will include policy, legal, regulatory, institutional, governance, and coordination aspects, in addition to water conservation initiatives, the building of capacities at the basin-scale for water users and rural communities, and managerial and technological development and transfer. Resilience has to become more robust in all sectors in order to adapt to changing conditions—be they climatologic, economic, social, or environmental.

According to Selek et al. (2016), reservoirs that store and regulate river flow are essential to manage the impacts of climate variability on water resources. However, efficient institutions, management, land use planning, and conservation measures (not only storage) will determine the equitable allocation of available water resources to all users under stress conditions.

High Aswan Dam and Lake Nasser in Egypt are the focus of the case study by Biswas (2016). The author explains that Egypt depends entirely on a single source of water and that the needs and expectations of the population have been sustained for millennia by the waters of the Nile River. Water is a cross-cutting issue. In the case of Egypt, it is even more essential for water, food, energy, environment, and climate security, not to mention national security. Even so, poor management of water resources is still the rule rather than the exception, which has the potential to constrain development and exacerbate the impacts of extreme events. Water storage is as essential in Egypt as it is in the upstream countries in the Nile River basin. In the case of Egypt, Lake Nasser is critical because it stores and regulates the only source of water the country has. Therefore, additional storage options, more efficient water management that considers institutional rearrangements, and collaboration with upstream countries should be pursued. Otherwise, the task of delivering water derived from only one source for a growing population and for the increasing uses of water by the water, food, and energy sectors will become increasingly complex.

The final study presented in the book focuses on South Africa. Muller (2016) analyzes how the Sterkfontein Dam has contributed to the economic and social development as well as the water security of a large region in the country. The author explains how, in a variable river system, the operation of the dam has helped to manage the impacts of extreme events, such as droughts. As explained in the case study, as important as the dam and its operation have been, so have been the institutional arrangements that have enabled the most appropriate decisions to be made and implemented. During the 2016 drought, for example, the operation of the dam was so efficient that the users and sectors supplied from this system have not yet experienced water restrictions at the time of writing.

1.4 Water Infrastructure Within a Governance Framework: An Evolving Paradigm

The construction of dams, reservoirs, and other water infrastructure has traditionally been proposed as the most effective way to address water scarcity, meet increased water demand for several uses, and protect the infrastructure itself in the case of breaching of levees, such as barrages and bridges. Taking into consideration the potential impacts of climate variability and change, water infrastructure now has the objective of building resilience to more frequent and more severe events within a framework of uncertainty.

As discussed in all case studies in this book, water scarcity may not only be the result of climate change, but also of policy, management, development, and governance-related long-term decisions. Resilience (economic, social, environmental, and often also political) depends on multiple variables. For example, impoverished and vulnerable populations either in urban or rural areas are less able to face any type of pressure—be it economic, social, or environmental—because they lack basic services and infrastructure. Therefore, they are often simply unable to cope with extreme events (Scott and Lutz-Ley 2016).

In many places, planning for extreme events is still limited to reactive measures rather than preventive ones, to protect populations prior to the events and, in fewer cases, to support them after the events have occurred. Infrastructure is thus essential to provide the whole array of services that a population needs and demands. Comprehensive, well-thought-out plans are needed to make society resilient or resistant to extreme events in the long term. Poor management of resources and poor decision-making can limit very seriously any type of support public or social organizations can provide.

As suggested in all studies, one way or another, the benefits and costs of reservoirs must be considered at the river basin level rather than at the project level to be able to provide a broader view of the situation. This together with planning, management, financial, and governance strategies, as well as scientific advances and information systems, are likely to result in more comprehensive planning, efficient management, wider social and ecological processes, and more effective contributions and commitments from the different parties involved. An assessment of benefits and costs is fundamental not only in monetary terms (Scott and Lutz-Ley 2016) but also from an overall resilience viewpoint. This may be a challenging situation, but it will have to become a reality given the serious development and climate-related challenges that the world is currently facing. Resilience needs to be built at all levels.

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