Risk Management of Water Resources in a Changing Climate

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Abstract

Fresh water is a critical resource for human survival. However, conflicting demands and threats on fresh water supplies constantly arise, jeopardizing the sustainability of these resources. Decisions made today regarding water resources have an impact not only on current water usage, but also on that of years to come. Thus, both surface and groundwater resources should be managed with sensitivity to present needs, as well as consideration for future threats. The risks concerning water resources are either natural risks that may be difficult or impossible to be controlled and prevented, or risks resulted from human actions.

The risk management method is most commonly used in the planning and developing phases of complex industrialized projects. The current paper demonstrates that this methodology is applicable with some modifications to help manage projects, organizations, and even monetary risks of water resources. Traditionally, risk events are measured by two main criteria: *impact* and *probability of occurrence*. However, some of the risks associated with water resource management may contain high expected costs and be beyond the control of human society. Therefore, an additional criterion is proposed for the assessment of risks – the *controllability*. The introduction of this criterion adds a third dimension to the risk evaluation process.

To explore the applicability of the risk management methodology and its modification, it is applied to the risk management of water resources in Israel. For this specific empirical setting, the addition of the controllability criterion alters the order of severity of some of the perceived risks.
Keywords: Risk management, Water resources, Risk controllability

1. Introduction

Fresh water resources are critical for human survival. Without them, human society would be unable to prosper or even exist. The ever-growing conflicting demands for fresh water supplies threaten the sustainability of this essential resource. Decreasing usable water supplies, coupled with rapid increases in demand and poor management, have led to the inefficient and unsustainable use of water resources with significant economic, social, and environmental ramifications. The failure to meet basic human and environmental needs for water has given rise to increasing tensions over access to water. Many believe that the competition over scarce water resources, which regularly occurs at local, regional, and international scales, will increase tensions and possibly cause armed conflicts between states and sectors (see for example Clarke 1991; Gleick 1993; 2000; Postel 1997; Duba and El-Ashry 2000).

In the current work, the use of risk management methodology is suggested to increase the flexibility and security of agreements over the management of water resources. This methodology has a long history of experience in the field of project management. It has its roots in the understanding that risk events without preplanned responses have the potential to cause irreversible damage to projects. The experience, gained through managing risks related to commercial projects, has greatly contributed to the applicability of risk management theory. Therefore, it is an adequate tool, which can help improve water resource management by mitigating risks involved in its maintenance and utilization.

In this paper, the risk management methodology is adopted to increase flexibility, which is necessary for the efficient management of water resources. Since the nature of this resource predetermines that many of the risks associated with it are not easily controlled, we suggest a modification of the standard risk management methodology by accounting for an inability to control a given risk at an early planning stage. Thus, the controllability of the risk is incorporated among the risk identification parameters, in order to avoid dealing with natural risks that are *a priori* impossible to control.

The paper is organized as follows: Chapter 2 discusses some aspects and considerations associated with managing a water resource, the natural and social constraints that may affect both the risks associated with the resource and the possible treatments for these risks. Chapter 3 presents some basics of the risk management methodology, and introduces the concept of risk controllability, which is important for addressing risks in an efficient manner. In Chapter 4, an empirical study of risk analysis is carried out regarding Israeli water resources, followed by Chapter 5's concluding remarks.

2. Water resource management

Water resource management can be broadly defined by two large and, at times, conflicting, systems: *the natural ecological system* and *the human societies that rely upon the water resources for their livelihood*. The literature related to water management has, thus, been greatly influenced by disciplinary addresses from the fields of hydrology, and engineering via scientific research and social science, all of which indicate the increasing recognition of the interdisciplinary nature involved in the management of any water resource. This leads to the recognition that the risks involved in the maintenance of water systems also involve not only the natural risks associated with these resources, but also risks associated with the ways in which societies utilize the water, as well as the values with which humans attribute to it. Therefore, before discussing the specific risks of any given water resource, stakeholders' consideration, the system's constraints, and environmental issues in the water arena should first be introduced. In this chapter, these issues are discussed in some detail.

2.1 Natural considerations

Water is perceived as the basis of all life. Civilizations, from ancient times up to the present, have maintained complex relationships with water. Balancing often contradicting needs to supply for soil cultivation, natural habitats, and industrial and human needs; the approach to water resource management alternates between the materialized approach of industrialized societies, which perceives water largely as another raw material input for commodity production in agriculture and industry, to the idyllic conceptualization of water as a sacred source of life, thus maintaining its nonuse value.

From the natural system perspective, water plays an ecological role, as it flows across land, from the land into the sea, from the sea into the atmosphere, and from the atmosphere back to the land. Management that focuses on water merely as a resource to be tapped and distributed has harmful effects on its conflicting uses in the hydrological cycle and the replenishment of watersheds. On the other hand, a water resource management perspective that views water as a resource to be consumed, rather than a natural flow in the water cycle, generates the misconception that water resources can be continually augmented through large man-made structures.

The ecological understanding of water involves two factors: firstly, an understanding of the relationship between water and other elements in the ecosystem; and secondly, an understanding of the limits of water use, which must be enforced by the preservation of the water cycle. A mare bias that favors water development fails to perceive the natural river flows as being critical for drainage purposes, recharging of groundwater, and maintaining the balance between fresh water and seawater.

The impounding of water in large dams leads to deforestation in the catchment areas, changes in the micro-climate, as well as soil erosion, thus decreasing the availability of water, and in some cases leading to floods. The transport of large volumes of water over long distances for agricultural and household use results in water wastage through seepage. The introduction of large volumes of water beyond the natural drainage capacity of the ecosystem disrupts the hydrological cycle and results in water logging and salinity.

2.2 Social constraints

The natural perspective is only one side of water resource management. The other side is the perspective of the human society that utilizes the resource for its livelihood. Considering the social values, beliefs and arrangements involved in the utilization of any fresh water resource significantly expands potential adaptation strategies with implications for meeting agreed-upon future goals. Many adaptation challenges are due to social constraints, and are restricted to the social ability to employ different means of adaptation over time, at different stages of conflicts, and in response to different perceptions of what constitutes the challenges that must be met.

Viewed from this perspective, the evolution of water management practices involves responding to social conflicts over perceived risks by identifying bottlenecks, and finding appropriate tools to meet the challenges posed. As policy makers seek different adaptation strategies, they often experience a perceived scarcity in the social means required to initiate policies for watershed management. Social tools are needed, so that the necessary policies required to control water crises are transformed into a driving force that can actively initiate changes in social perspective and power distribution. Managing this process involves learning how to deal with different types of conflicts - conflicts encountered as a result of the natural resource scarcity itself, as well as conflicts encountered as a result of inadequate strategies adopted to treat water demands and needs.

However, the social perspective is not only about the needs related to the water resource. It is also the perspective of social power related to the utilization of such a resource. Social frictions over resource scarcity impede the supply of social ingenuity, particularly as regards the formation of new and reformed institutions, and contribute to the formation of social coalitions that oppose change (Homer-Dixon, 1995 and Olson, 1982). These coalitions often operate across multiple scales and may disrupt cooperation solutions for the commonwealth, as they pursue their own self interests. Thus, there may be an increase in conflicting interests among those involved in the physical management of water. This type of involvement can prevent efficient problem-solving and increase the turmoil in local management bureaucracy; which in turn, could prevent effective management procedures at the local level.

A growing body of literature shows how narrow, interest-based coalitions obstruct sustainable economic development and effective social adaptation to resource scarcity (Olson, 1982; Reed, 1992; Ostrom, Schroeder, and Wynne 1993; Ruttan, 1989). As water contamination and scarcity increase, and acceptable social adaptations fail to materialize, competition over water usage begins to develop among interest groups. As these narrow, interest-based coalitions pursue their own private interests, they often hinder the creation and implementation of broad-scale welfare programs aimed at improving institutional solutions for water resource problems.

Mancur Olson's (1982) work on the ability of different types of social coalitions to provide collective goods for their members offers critical insight into the nature of these coalitions. First, small groups generally organize more quickly and exert their interests more vigorously than larger groups. This provides small groups with greater relative political power and allows them to be more efficient in their lobbying efforts (e.g. flexible, focused and effective). Second, the ability to yield disproportionate power, relative to size, is especially evident in "unstable" societies (a phenomena which characterizes most poor nations) because larger coalitions take time and social stability to grow and mature. As a result, Olson argues that governments of unstable nation-states are "systematically influenced by the interests, pleas and pressures" of small coalitions (Olson, 1982; Homer-Dixon, 1995). Third, and perhaps most importantly, small coalitions tend to pursue their own narrow self-interests, rather than the broader social interest; hence, their actions often hinder the establishment of institutions that might serve to benefit society at large. Because of this, narrow coalitions tend to be characterized as "distributional", in that they seek to redistribute wealth rather than create it.

Narrow interest-based coalitions clearly have the potential to intensify existing conflicts and complicate any risk management processes. The increasing participation of new actors in water policy and management decisions at all social scales (local, regional, national, transnational) will likely make it much easier for these narrow coalitions (at all social scales) to advance their interests in the risk management arena.

Historically, social adaptations to water scarcity were determined and implemented by centralized government agencies. Until recently, donors presumed sovereignty of national governments by working with national legislatures on water issues and by providing economic assistance at the national level. Nation-states were perceived as sole sovereign powers and the sole potential recipients of donor aid for water investments (Ostrom, 1992). This increased and consolidated the power of central authorities over local authorities and the population in general.

This view has changed significantly. In the past decade, there has been an increased participation of new actors in water policy and management decisions at all social scales (local, regional, national, transnational). This increased participation is the result of two factors. The first is an increased internal restlessness with the performance of central governments by local communities. This restlessness arises in response to the choice of the central government to ignore local needs of certain populations. This practice of the central government may be rooted in its inability to collect needed information that is accessible to local population, or in its insensitivity to the needs and interests of communities located away from influencing power.

Thus, an increase in public participation also plays the role of voicing interests that were previously unheard under central government management of a water resource. An increase in public participation also results from the central government's choice to ignore local interests. So, from both aspects, an increase in public participation strengthens management efficiency and enhances social welfare. This, in turn, augments social adaptive capacity with regard to the water resource. An awareness of the needs that were ignored enables a central government to suggest compensation and other means of livelihood. In addition, this awareness also helps to decrease the social restlessness of population segments that may have felt deprived of their fair share in public goods offered by the state.

2.3 Legal flexibility

Risks associated with water may be augmented by complex legal situations that tie water rights to other aspects of property rights. One reason that a government may want to keep water-augmented occupations concerns legal land water attachments. The most obvious example is that of the total rejection of any water use agreement between Israel and the Palestinian Authority. Narrowly considering the water dispute between Israel and the Palestinians suggests that, since the water conflict between these two entities is actually a moderate income dispute (e.g., Zeitouni et al. 1994; Becker and Zeitouni, 1998), one entity should be able to compensate the other for shifting part of its agricultural sector to other fields of employment, thus preserving the income generation interests of this sector by way of a simple money transfer. As true as the economic concept of compensation may be, failing to acknowledge the fact that the legal link between plowing the land and its ownership that is originated back in the Ottoman era, led to under-representation of the opportunity cost of water as agricultural input. Under different legal ties between water and land ownership, the opportunity cost of giving away water may have been smaller.

2.4 Economic constraints

Reducing possible damage from water - associated risks may first and for most come from reducing unnecessary excessive use of water. This ability depends at large on the ability of societies and individuals within societies to adopt more efficient usage patterns. However, the opportunity cost of giving up part of the water from the very same river basin may vary widely between countries of different technological and economic adaptability.

The reason for this is the different capability of nations regarding changes in employment opportunities. Nations with a social structure that allows for relatively easy mobility from water augmented occupations and livelihood into other occupations or employment opportunities incur smaller social costs for restructuring their use of water resources. Social stability is gained by using the water resource as a low-cost means to support employment in traditional ways, mainly through agriculture production. The cost of the water input may be lower to the user nation since, in the absence of agreed-upon international allocation, a bordering water body country can exploit the common pool's externality of this resource. This external benefit enables the bordering nation to ignore the actual real cost of the water.

In the short run, inefficient utilization of a water resource allows at least some of the involved parties to enjoy the external benefit, at the expense of other parties involved in this dispute. For these parties, these external benefits increase the cost of resolving the dispute.

Industrialization and economic development may ease the pressure on water use as a primary input by providing the necessary (but not sufficient) augmentation of employment opportunities. Thus, in the modern arena, any discussion of risk adaptation must first acknowledge the notion that a possible course of action is not necessarily about matters of life and death for individuals (i.e., thirst), but rather a matter of social inflexibility that needs to be addressed in order to reduce the social opportunity costs of resolving the water conflict.

2.5 International stakeholders

Surface water and groundwater that cross international boundaries present significant challenges to regional stability because hydrologic needs can often be overwhelmed by political considerations. There are 261 rivers (Hammer, 1998) around the world, which cross the boundaries of two or more nations, and a large number of international groundwater aquifers. The basin areas that contribute to these rivers comprise approximately 47% of the earth's land surface, and 40% of the world's population, contributing to almost 60% of the freshwater flow (Wolf et al. 1999). With the continuous growth of world population and the

diminishing water quality and quantity, water scarcity is increasing. As access to water is essential to the prosperity of communities, the threat of conflict over the use of transboundary water is also on the rise.
Disputes over water seldom accelerate into an armed conflict. However, there are quite a few examples where water disputes have evolved into a real threat to such an open conflict. While many believe that water may be a source or cause of conflicts (Samson and Charrier, 1997; Butts, 1997; Homer Dixon, 1994; Toset and Gleditsch, 2000), others are convinced there is strong evidence that nations are willing to find cooperative solutions for the use of transboundary water (Wolf, 1998; Salman and de Chazournes, 1998; Turton, 2000).

In most cases, there are usually certain understandings and statutes that are maintained over time, even in the absence of an official agreement. However, often as a result of an absence in flexibility regarding the implementation of the agreement, the involved parties try, from time to time, to change the statutes. Some examples of this phenomenon presented themselves in the case of the Jordan River basin, where several incidents occurred in which Syria and Lebanon tried to divert the sources of the Jordan River. These incidents finally culminated in an extended period of tension, which continued to mount, almost leading to an armed conflict. This example indicates that, whenever possible, a flexible agreement should be clearly defined, and the penalties for each deviation should be clearly spelled out to all sides.

Lowi (1995) discusses several agreements concerning the water allocation of the Jordan River and the Euphrates. In both cases, there is no official agreement for sharing the water and the resource is managed by some form of cooperation in order to meet the nations' needs. Lowi (1995) addresses ways in which to improve the development and management of water-related international disputes without pre-agreed upon guidelines or rules regarding the management of conflicts among the nations involved.

3. Risk management

Risk management methodology was described in detail by Wideman (1992) to address possible risks associated with a given project. The methodology was then improved by the PMI, (2004), adding details based on users' experience. As described by the PMI (2004), the main steps for any risk management plan are as follows: planning the risk assessment, identifying all risks, assessing the risks, writing a response plan and control plan and, throughout the duration of the project, continuously assessing the program's risks.

It is only a natural extension, then, to apply this methodology to the field of resource management, as was presented by Gonen and Zeitouni (2008) for the case of transboundary water resources. The difference between managing private projects and managing public resources lies in the nature of some of the risks, their evaluation, and the strategies that are available for mitigating them.

3.1 Risk Assessment

In general, threats are identified and then assessed according to their likelihood or probability to occur, and their realized conditional damage functions. Thus, expected damage is calculated as a reference measure in the decision about proper action. This approach enables the estimation of a risk budget when there is more than one risk. However, it is not very suitable for water resource management, since some of the damages are difficult to estimate, and the probability of their occurrence is even more complicated to estimate. In addition, the question of risk controllability is not readily answered. Most natural risks cannot be controlled; therefore, the possibility to propose a response plan is limited. In order to handle these types of risks, we suggest quantifying risks into **three dimensions,** instead of the two that are used today. The third dimension, which is introduced below for the measured risk, relates to its **controllability**. The *controllability* of a given risk reflects the ability to control it, mitigate it, or even prevent it. Assessing the controllability may reduce the efforts and the spending of managerial time and expenses on non-controllable risks and direct the attention of management only to controllable risks.

In order to formulate this idea mathematically, let Ω be the set of all possible relevant risk events, Ω={α/ α is a risk event}. Let the damage function, D, be a function from Ω to R^+, which satisfies the condition" that if a_1 and a_2 are two risks in Ω:

$$D(\alpha_1) \le D(\alpha_2) \qquad for \quad \alpha_1 \subseteq \alpha_2 \tag{1}$$

Then, for a given probability measure P that is defined on Ω, the expected damage *E(D,P)* can be calculated as the weighted sum of damages at all phases, $E(D,P) = \sum P(a)*D(a)$.

3.2 Evaluating the damage function

Methods to attach a monetary value to the damage function may vary. It is, however, important to note that research has shown that the results of the use of valuation techniques can depend not only on the probability of an event's occurrence, but also on the incorporation of the valued socio-economic effects into the decision making process. A Risk Assessment approach takes both dimensions into account.

The influence of the probability of occurrence on the use of valuation techniques

A very small probability of occurrence reduces the appropriateness of several valuation techniques. For example, land market traders appear unable to incorporate flood potential without some major flood to anchor their perceptions to. Hedonic estimates are sensitive to the market traders' recent experience with a natural hazard. Hedonic estimates are either very large or zero, depending on the timing of the study vis-à-vis the latest flood (Shabman and Stephenson [1996]). Bartosova et al. [1999] show that when using the Hedonic Price Method, the detrimental effect of flood risk is eliminated after the expected flood risk falls to once every 33.33 years. Daun et al. [2000] confirmed the hypothesis that a household's WTP for the maintenance of current levels of flood risk is positively related to flood risks as proxied by the household's distance from the river.

It can be concluded that the choice of valuation techniques determines, to some extent, the weight given to prescribed risks. The results of some techniques (such as Replacement/ Substitute costs) are unaffected by the probabilities itself. In contrast, other techniques (like the Hedonic Price Method) are highly affected by the probabilities.

The Risk Assessment Approach

The application of a valuation technique is only one issue that determines the way given threats are dealt with. Other characteristics of the decision making process may affect the assessment as well. Among them are: accounting for all possible damages, monetarizing them, selection and use of valuation methods, use of discount rate, accountability for non-monetary values, presence of limiting conditions, and the risk attitude of decision-makers.

When weighing up the costs and benefits of a decision regarding management of a given risk, the result will strongly depend on the effects that are taken into account. The choice between social or private costs and benefits will be largely determined by the social responsibility valuators take. The choice of effects to be monetarized will also be influenced by their risk attitude.

The outcome of the use of a valuation technique is often used to calculate present values in the context of the damage function. This implies that weights are attached to effects of the specific risk in the future. Defining the appropriate discount rate is not straightforward and no firm conclusions can be drawn about which rate should be used. Economic theory does not impose a certain rate on the decision-maker; it is, rather, the opinion of the decision-maker himself within his institutional context that determines the rate.

The extent to which non-monetary effects are taken into account in the calculation of the damage function will also have its implications on how society deals with the risk. Limiting conditions can have an effect on both probabilities and possible damage. The timing when the assessment is carried out may be crucial in determining whether a given condition is limiting or not. For example, the consideration of a flood risk may lead to different recommendations regarding the risk handling, if it relates to the question of whether or not to go on with a housing project that is being built on a river bank, than when it relates to possible flood control after houses are already standing on the same river bank. Moreover, the attitude towards handling uncertainties regarding the outcome of each step in the process of damage function valuation (starting with the identification and selection of effects up to the application of valuation methods) may strongly steer if and how the valuation takes place.

3.3 Response and controllability

The sole consideration of expected damage is insufficient in the management of water resources, since not only are the damages and their respected probabilities difficult to estimate, but most natural risks cannot be controlled; therefore, the possibility to propose a response plan may be very limited. In order to handle these types of risks, it is suggested to define any given *risk* by its three-dimensional definition, instead of the two-dimensional definition that is used today. The third dimension is *the controllability* of the risk.

For each risk event a, there is a set of possible responses R_α, such that $R_\alpha = \{\beta / \beta$ is a response plan to event $a\}$. A *response* is an operation that requires expenditure and changes the probability and/or the damage function. A response plan β for risk a can mathematically be defined as a *triple* $(C_\beta, P(a/\beta), D(a/\beta))$ where: C_β is the cost of response β. $P(a/\beta)$ is the probability of risk α , given that response β was applied. Note that a given response may be directed towards lowering the probability of the risk occurrence or reducing the damage function or both. Let *P(a/β)* be the conditional probability of the risk, given that response β was taken. *P(α/β)* equals *P(a)* when the response is aimed directly at the damage function itself and not at changing the probability of the risk.

D(a/β) is the damage that may occur if risk α is realized, given that response β was applied. Let us define the social utility from response *β* as:

$$U_\beta = P(a)^*D(a) - (C_\beta + P(a/\beta)^*D(a/\beta)) = E(D(\alpha)) - [E(D(\alpha/\beta)) + C_\beta] \quad (2)$$

U_β measures the difference between the expected cost without response β and the expected cost with it. If a response β is selected, its cost is C_β and the expected damage changes to: *P(a/β)*D(a/β)*. Therefore, if U_β is positive for a given response *β*, then the response lowers the expected damage sufficiently to offset the cost of the response. If U_β is negative, then the given response is too costly, relative to its effect on the expected damage. If for every possible response plan *β* - U_β is negative, then the risk α is said to be **uncontrollable.**

A positive U_β is necessary for a risk to be controllable, but it is often not sufficient. A risk *a* may have a profitable response plan, but the policy maker does not have an available budget that can be allocated for it. The set of all responses to risk *a* is: $R_\alpha = \{\beta / \beta \text{ is a response plan to event } a\}$. The **controllability measure** is:

$$B_\alpha = max\{U_\beta / \beta \in R_\alpha\} \quad (3)$$

Thus, a positive B_α indicates the **capability** of mitigating risk α.

The following numerical example illustrates the use of the controllability concept. Consider the possibility of terrorists poisoning water resources over the next 10 years. The probability of such an event would depend on the country in which the resource is located, its enemies, its political situation, and the like. Let us assume that this probability is 0.01 % or P_α=0.0001. The realized damage depends on the type of poisoning, the capability to detect this poisoning, and the size of the water resource. Let us assume that there are no detection sensors and that the poisoning level is highly severe. Thus, the damage is estimated to be \$10,000M. In this case, the expected value of the damage, *E(D(α))*, would be \$1,000,000.

There is a response plan β that includes installing a detection system for the cost of \$0.5 M (C_β=500,000), which has a 90% chance of detecting such an event. If this detection system is introduced, the expected damage would only be \$100 M. Thus, the detection system indicates a conditional probability of damage, $P(\alpha/\beta)=P_\alpha{}^*0.1=10^{-4}\bullet 10^{-1} = 10^{-5}$ and the value of the conditional damage function, $D(\alpha/\beta)=10^8$. Hence, the social utility from this particular response is equal to:

$U_\beta = 1{,}000{,}000 - (500{,}000 + 10^8 \bullet 10^{-5}) = 499{,}000$.

Since $U_\beta > 0$, we say that **the risk is controllable**.

4. Evaluating threats for Israel water resources

4.1 Background on the Israeli water system

Israel's water resources include the Sea of Galilee, some streams, three main underground aquifers, a few dams, and rain water that seeps into the underground aquifers or is pooled into above-ground reservoirs. In addition, the country exploits a considerable amount of effluents, sewage water that is cleaned and filtered by undergoing various types of treatments and water desalination. Table 1 presents the amount of water produced and consumed in Israel between 2000 and 2007.

Sequence of dry years: Over the past several years, Israel has suffered from a sequence of drought years; less than 80% of the average precipitation coupled with unresponsive consumption has served to quite substantially reduce the reservoir levels, mainly in the Sea of Galilee, the biggest reservoir from which water is transported throughout the country from north to south.

Distribution of Precipitation: Most of the precipitation is in the form of rain during the winter, with some rainy days in the spring and autumn. About six months of every year are dry and substantially hot.

Evaporation: Evaporation can cause a big loss of fresh water and influence the balance between production and consumption. Since the big reservoirs are out in the open, evaporation becomes a major risk to the Israeli water system management (Alpert, 2008).

Growing demand: The growth of demand for fresh water is due mainly to population growth. However, new technologies in industry and agriculture are being successfully developed in an attempt to conserve water.

WATER PRODUCTION AND CONSUMPTION (millions of cubic meters)

PRODUCTION	*2007	2006	2005	2000
BY PRODUCER(2)				
TOTAL	**2,199**	**1,996**	**2,063**	**1,996**
Mekorot Water Co.- total[1]	*1,394*	*1,330*	*1,379*	*1,341*
Wells (3)	747	670	564	725
Hamovil water carrier (Kinneret)	224	242	401	230
Upper water	194	201	211	216
Effluents (4)	229	217	203	170
Other producers - total	*682*	*666*	*684*	*655*
Wells	317	316	319	331
Upper water	207	208	233	225
Effluents	158	142	132	99

[1] *Mekorot* is the main water company in Israel. It is the main producer and supplier, as shown in the above table.

CONSUMPTION				
BY CONSUMER AND SUPPLIER(2)				
TOTAL	**2,072**	**1,959**	**1,961**	**1,924**
Mekorot Water Co.	1,418	1,333	1,303	1,269
Other suppliers (5)	654	626	658	655
Agricultural	*1,186*	*1,108*	*1,126*	*1,138*
Mekorot Water Co.	700	662	655	667
Other suppliers	486	446	471	471
Domestic and public	*767*	*737*	*715*	*662*
Mekorot Water Co.	639	596	571	519
Other suppliers	128	141	144	143
Industrial	*119*	*114*	*120*	*124*
Mekorot Water Co.	79	75	77	83
	40	39	43	41

Table 1. Main sources of water supplied and main water consumers in Israel 2000-2007 (Sources: Israel Central Bureau of Statistics, 2008; Water Authority).

Water Quality: Despite limits placed on water withdrawal, the regime of natural water flows has decreased as a result of drought. At the same time, the influx of pollutants from human activity and negligence on the land over the aquifers is increasing, resulting in the increase of minerals, non-degradable, and other pollutants in the groundwater. Due to unbalanced exploitation and return flow from irrigation, an increase in the salinity of the groundwater has occurred in many wells. The re-use of sewage water and the infiltration of unused sewage add over 200,000 tons of salt to the aquifers every year. Moreover, they have also added nitrates, soluble organic materials, heavy metals and other chemicals, including carcinogenic ones. The coastal aquifer is contaminated by sea water, garbage dumps, sewage flow, uncontrolled field fertilizers and pesticides application, toxic industrial waste discharge, and fuel leaks.

Part of the sewage that reaches the aquifer is not treated at all or only undergoes preliminary treatment before it enters the streams and sea. In addition, in many areas throughout the country, water lines are laid next to sewage pipes, thus causing leakages to the water system due to poor maintenance. A balance forecast of water in Israel, conducted by the World Bank in 1994, indicates an annual cumulative gap of 1 billion cubic meters by 2020.

***International agreements*:** Part of Israel's water sources are shared with Syria, Lebanon, Jordan and the Palestinian Authority. Numerous incidents occurred between Israel, Jordan, Syria and Lebanon until a clear status-quo was determined. These clashes began in 1951 - when the countries established unilateral plans for the distribution of the water - and continued until the last military confrontation among the riparian in 1969, when Israel attacked Jordan's East Ghor Canal. Israel attacked Jordan's East Ghor Canal believing Jordan was partly responsible to some Palestinians attacks and retaliated by leading two raids against Jordan in June and August of 1969, destroying the new East Ghor Canal. Following the attack, the U.S. mediated negotiations between Israel and Jordan, which led to an agreement in 1970. Israel was convinced that the reduced flow of the Jordan was a natural occurrence, and Jordan agreed to follow the Johnston Plan and cease Palestine Liberation Organization activity on its territory.

Another conflict for which there has been no solution as of yet concerns Israeli control of the West Bank aquifers since 1967. The 1967 nationalization of all the West Bank water resources by Israel increased the already existing tension over land issues between the Palestinians and Israelis. In the other part of the Palestinian Authority, Gaza, the quality of water in the groundwater aquifer is very low due to severe over-pumping. The coastal aquifer in this area has been almost completely destroyed; most of the damage is on the Palestinian side. Israelis and Palestinians will have to share water from the mountain aquifer, where there is a serious danger of salting, due to over-pumping and the use of untreated water for irrigation by the Palestinians. Israel controls and allows extraction of the Palestinian Authority over the mountain aquifer, according to the modification made in the Johnston Agreement to address water allocation to the Palestinian Authority.

Governance

The Israeli Water Authority is basically responsible for managing most of the water resources. Despite the existence of sufficient legislation regarding effective measures to prevent water pollution and encourage the purification and reuse of contaminated water, the water authority is not effective in enforcing this legislation. Beyond the problem of enforcement and deterrence against water polluting sources, there is no significant legislation regarding the utilization of water resources.

The last inclusive master plan for managing water resources was prepared in 1988. This plan included proposed sizes of desalination facilities, regardless of some contradicting economic considerations. The implementation of the plan was at most partial. Several rainy years and the high cost of implementation caused the government to postpone large parts of the plan; in particular, construction of several desalination facilities as the condition for establishing the desalination facilities was a government commitment to purchase large quantities of desalinated water, which is currently considered by the government to be too costly and inefficient.

Another responsibility of the water authority is the security of the water supply. Among the security issues, terrorism is ranked as one of the eminent risk factors. The Water Authority makes a fairly big and successful effort to secure water facilities and diminish the likelihood of damage from any possible terrorist attack. There is also a backup and repair plan, in the event of any possible damage to the water facility. An automatic monitoring system, which operates throughout the national water carrier and in most existing reservoirs, is designed to detect any possible damage. In addition, natural sensors, such as fish and bacteria, are placed at important intersections and are monitored constantly to detect any possible change in their reaction to the environment.

4.2 Identifying the risks

The first step in risk management is *the identification of possible risks*. This task requires information from experts in the field. For this study, interviews with experts in various fields related to water management in Israel were conducted, in order to identify the specific risks that are relevant to Israel. The major identified risks are presented in Table 2.

	Risk	Description	Category
1	Drought	Sequence of dry years with low precipitation	Natural causes
2	Earthquakes	Powerful earthquakes that severely damage the water and sewage systems	Natural causes
3	Local Terrorism - Sabotage	Damaging/destroying the pumping facilities or major pipe lines	Water Security
4	Local terrorism - Poisoning	Poisoning reservoirs	Water Security
5	Reservoir evaporation	Increase in temperature, causing a rapid evaporation of exposed water reservoirs	Natural causes
6	Agricultural pollution	Seepage of chemicals and fertilizers into groundwater	Management policy
7	Preventing water seepage	Construction and development prevent water seepage into the aquifers	Management policy
8	Diversion of transboundary water resources	Diverting transboundary water resources without an agreement can cause confrontations that might end in war	Geopolitics
9	Climate changes	Climate changes can raise the sea level and cause the transfer of seawater into the coastal aquifer. It can change the rain distribution and the rainy season.	Natural causes
10	Changes in the distribution of rain	Changes in the rain distribution that cause more rainy days and extreme floods	Natural causes
11	Over-pumping the mountain aquifer	Lack of coordination in water usage may cause over-pumping of mountain aquifer, which leads to increased salting of water resources	Geopolitics
12	Industrial pollution	Flow of industry waste, seepage of chemicals - without sufficient enforcement	Management policy

13	Commitment to supply Jordan	Shortages as a result of political commitments for water supply to neighboring countries, such as Jordan	Geopolitics
14	Political involvement in decision making	Too much political involvement, which disrupts the master plan development	Management policy
15	Disregard of facilities	Disregard of pumping facilities, pipelines and other components of the water system, due to budget constraints	Management policy
16	Inadequate legislation and enforcement	Inadequate legislation and enforcement allow excessive quotas, and uncontrolled pollution of water	Management policy
17	Increase in demand	Increase in demand, due to population and production technology	Management policy
18	Irrigation by effluents	Groundwater pollution, due to irrigation by low quality effluents	Environmental factors
19	Groundwater pollution by garbage, oil, etc.	Embolic garbage or oil that penetrates and pollutes the groundwater	Environmental factors
20	Environmental damage to "Sea Canal"	The "Sea Canal" is a project that aims to add sea water to the Dead Sea, either from the Mediterranean or the Red Sea. This is both an opportunity and an ecological risk to wells	Geopolitics + environmental factors
21	Incompatible utilization of Jordan or Yarmouk rivers	Keeping water agreements on both sides of the border is essential. Since the water agreements are sensitive to the geopolitical situation, one side may break the agreement, causing deterioration that could lead to a war in the area	Geopolitics
22	Development suspension resulting from geopolitical reasons	The possibility that one day Israel will transfer part of the lands in a peace agreement prevents a certain amount of system development	Geopolitics
23	Governance crisis	Management failures, due to political constraints, agreements and wrong decisions	Management Policy

Table 2. Identified risks in the water arena

4.3 Quantitative analysis of the risks

Rating the urgency and severity of risks is the second step in the risk-ranking process. To rate the risks that are presented in Table 2, questionnaires were distributed to professionals from government, academia and the industry, who are involved in the water arena in Israel. The questionnaires requested the rating of three measures for each risk: *probability of occurrence, impact level of the risk,* and *controllability*. The risk probability was measured by a Likert-type scale, ranging from 1 (Highly unlikely event) to 5 (very likely event): As for the damage function, although ideally it would have been optimal to estimate the damage function for each risk, making such estimations is a costly and time-consuming effort. Given the budget limitation for this project, only ranking was required. Impact level and Controllability were scaled between 1 and 5. The measures for controllability were ranked as follows:

5 - The risk is not controllable.
4 – The risk is difficult and expensive to control.
3 - The risk is partially controlled.
2 – The risk is controllable.
1 - The risk is easy to control.

Next, the Borda Rank (Engert, Lansdowne, 1999) was calculated. The results are summarized in Table 3.

	Risk	Probability	Impact	Controllability	P-Rank	I-Rank	C-Rank (Reversed)	Total P&I Ranks	Final P&I Rank	Total P&I&C Ranks	Final P&I&C Rank
1	Drought	5	3	4	5.5	11.5	15	17	6	32	14
2	Earthquakes	1	5	5	21.5	2.5	22	24	15	46	21
3	Local Terrorism - Sabotage	1	3	2	21.5	11.5	4.5	33	21	37.5	16
4	Local terrorism - Poisoning	2	5	2	17.5	2.5	4.5	20	9	24.5	7
5	Reservoir evaporation	5	1	5	5.5	22	22	27.5	17	49.5	23
6	Agricultural pollution	5	1	2	5.5	22	4.5	27.5	17	32	14
7	Preventing water seepage	4	4	2	12	6	4.5	18	7	22.5	6
8	Diversion of transboundary water resources	2	5	3	17.5	2.5	7.5	20	9	27.5	10
9	Climate changes	1	5	5	21.5	2.5	22	24	15	46	21
10	Changes in the distribution of rain	2	1	3	17.5	22	7.5	39.5	23	47	22
11	Over-pumping the mountain aquifer	5	4	1	5.5	6	2	11.5	1	13.5	1
12	Industrial pollution	5	2	3	5.5	18	7.5	23.5	13	31	12
13	Commitment to supply Jordan	3	2	3	14.5	18	7.5	32.5	20	40	17
14	Political involvement in decision making	5	3	2	5.5	11.5	4.5	17	6	21.5	5

	Risk	Probability	Impact	Controllability	P-Rank	I-Rank	C-Rank (Reversed)	Total P&I Ranks	Final P&I Rank	Total P&I&C Ranks	Final P&I&C Rank
15	Disregard of facilities	5	3	1	5.5	11.5	2	17	6	19	2
16	Inadequate legislation and enforcement	5	3	2	5.5	11.5	4.5	17	6	21.5	5
17	Increase in demand	5	2	1	5.5	18	2	23.5	13	25.5	9
18	Irrigation by effluents	3	4	2	14.5	6	4.5	20.5	10	25	8
19	Groundwater pollution by garbage , oil, etc.	5	3	2	5.5	11.5	4.5	17	6	21.5	5
20	Environmental damage to "Sea Canal"	1	2	2	21.5	18	4.5	39.5	23	44	19
21	Incompatible utilization of Jordan or Yarmouk rivers	2	3	4	17.5	11.5	15	29	18	44	19
22	Development suspension from geopolitical reasons	4	2	2	12	18	4.5	30	19	34.5	15
23	Governance crisis	4	3	2	12	11.5	4.5	23.5	13	28	11

Table 3. The Risks - Ranking

Notes: The pink cells indicate the top ten threatening risks.

In Table 3, the three aspects associated with any risk - the probability, the impact and the controllability - were derived from experts' assessments, after which rounded averages of these assessments were calculated. Then, the Borda Rank was calculated for each factor, (presented in columns P-rank for *probability*, I-rank for *impact* and C-rank for *controllability*). In order to explain the Borda Rank, a demonstration may be useful. Consider the P-rank column. There are 10 risks, whose probability is ranked 5 (very high). They are ordered from 1 to 10 with average of 5.5. Therefore, these 10 risks are assigned a P-rank of 5.5. There are 3 risks that are given a rank of 4 (high probability of occurrence). Therefore, they are ordered 11, 12, and 13 and their average order is 12. These 3 risks are assigned a P-rank of 12. The same procedure is iterated for the 2 risks whose probability was ranked as 3. They are given the order 14 and 15 and their assigned P-rank is 14.5. In the same manner, risks at probability group 2 are assigned a P-rank of 17.5. The last group, probability 1, is assigned a P-rank of 21.5. The same calculations are applied for the I-rank.
The C-rank is calculated in reverse order. Contrary to the impact and probability ranking, controllability's high rank implies a lower priority. Thus, low rank should increase its priority of response. Therefore, the 3 risks with a controllability rank of 1 are assigned as order 2 in the C-rank, while the most non-controllable risks, ranked at controllability 5, are assigned a C-rank of 22.

The sum of the P-rank and I-rank is displayed in the column named "Total P&I Ranks". This column is ranked into the column named "Final Rank of P&I". The meaning of this rank is that the lowest value should be handled with high priority, e.g. risk number 11 - "over-pumping the mountain aquifer" - which has a very high probability of occurring and high impact and damage rankings - should be handled first. The ranking is calculated using "Risk Matrix" software (Engert, Lansdowne, 1999). The column "Final Rank of P&I" provides the priorities of handling risks based on their probability and impact. It is presented such that the lowest ranks should be handled with high priority.
All three ranks - P-rank, I-rank and C-rank - are summed in the column named "Total P&I&C Ranks". This column is ranked into the column named "Final Rank of P&I&C", which is a measure that acknowledges all three risk criteria - probability, impact and controllability. The final rank is actually in reverse order (the lower the final rank, the higher its priority).

4.5 Results Analysis

Table 3 indicates that although in this case the addition of the C-rank did not alter the order of risks substantially, the result is that it eliminated uncontrollable risks that have high priority and enable the handling of other risks with higher potential benefit. Figure 1 shows the two final ranks, after sorting the list of risks. The risks were ordered (sorted) by their P&I&C ranks.

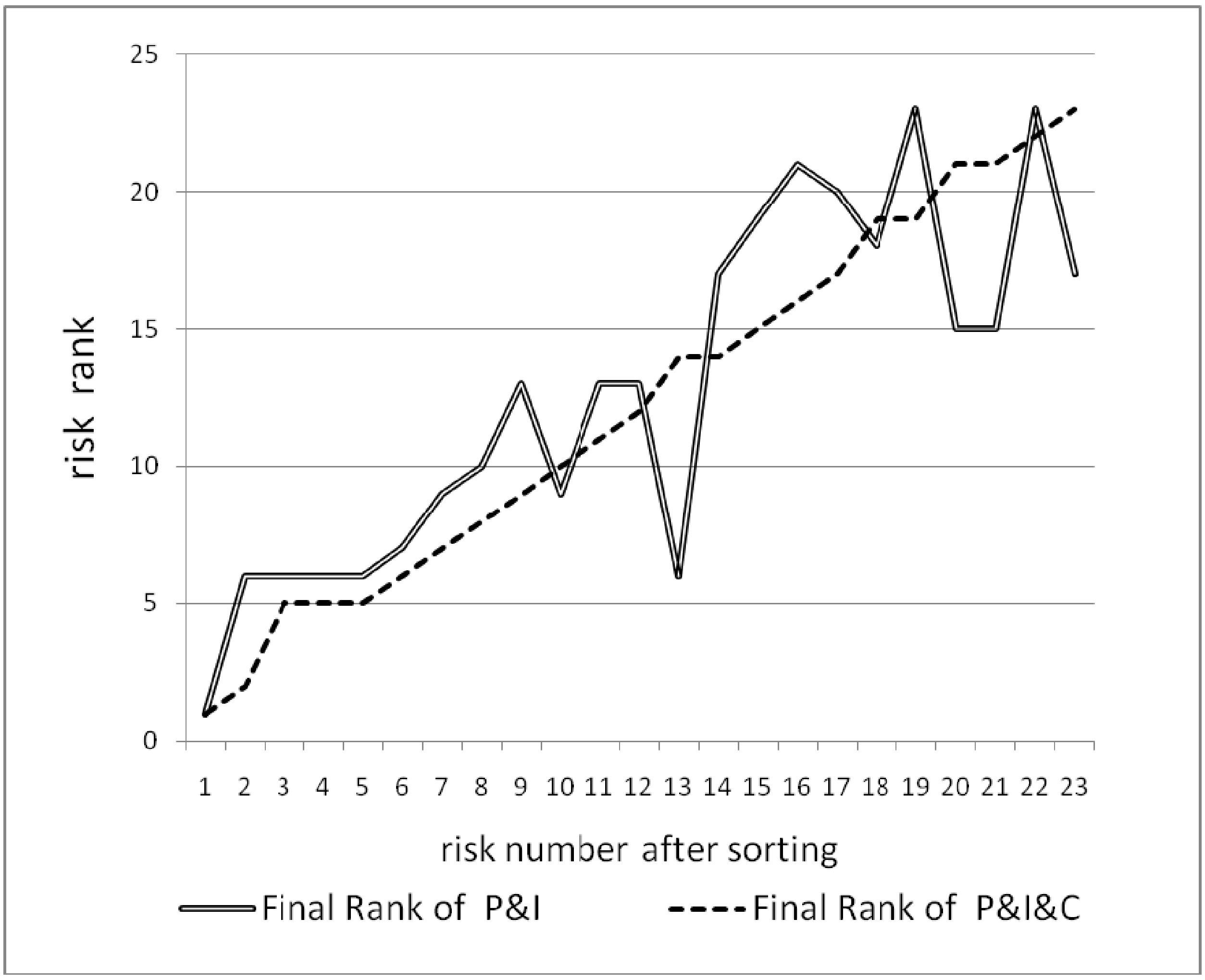

Fig. 1. Final Ranks of all the risks

The figure shows that most risks follow the same trend. Namely, risks with high priority, according to the final P&I rank, will have a high priority, according to the final P&I&C rank, and vice versa. The risk with the lowest rank is "over-pumping the mountain aquifer" (see Table 3). This risk has a high probability, since this aquifer is utilized by both the Israeli and the Palestinians; this risk also has a high impact and is controllable within the framework of the existing legal situation (even though the laws are not currently enforced). According to the P&I rank, the second risk to be handled is *drought*. Drought is not among the top 10 risks, according to the P&I&C rank, since it is hardly controllable. Hence, the only thing that the government does regarding this risk is to insure farmers for crop losses.

In Table 3, classifying the risks into categories (natural causes, geopolitics, management policy, water security, and environmental factors) is helpful in analyzing groups of risks, instead of individual risks. The difference between the P&I rank and the P&I&C rank, may be better understood by a comparison of the average of these ranks over each risk category. The difference between the two ranks is shown in Figure 2. For each category of risks, the average of the P&I rank and the P&I&C rank value is presented. In addition, the number of risks in each category is added to the category name.

It can be seen that the addition of controllability decreased the average rank of the "natural caused" category and increased all the other categories. This is because according to the expert opinion, risks derived from natural causes are mostly non-controllable; therefore, it is less effective to develop any response plan for them. In this case, although the average P&I rank is high, these risks' priority is reduced. On the other hand, the priorities among the other groups remain the same, where the groups of environmental factors and management policy risks have the lowest average ranks, and thus should be addressed first.

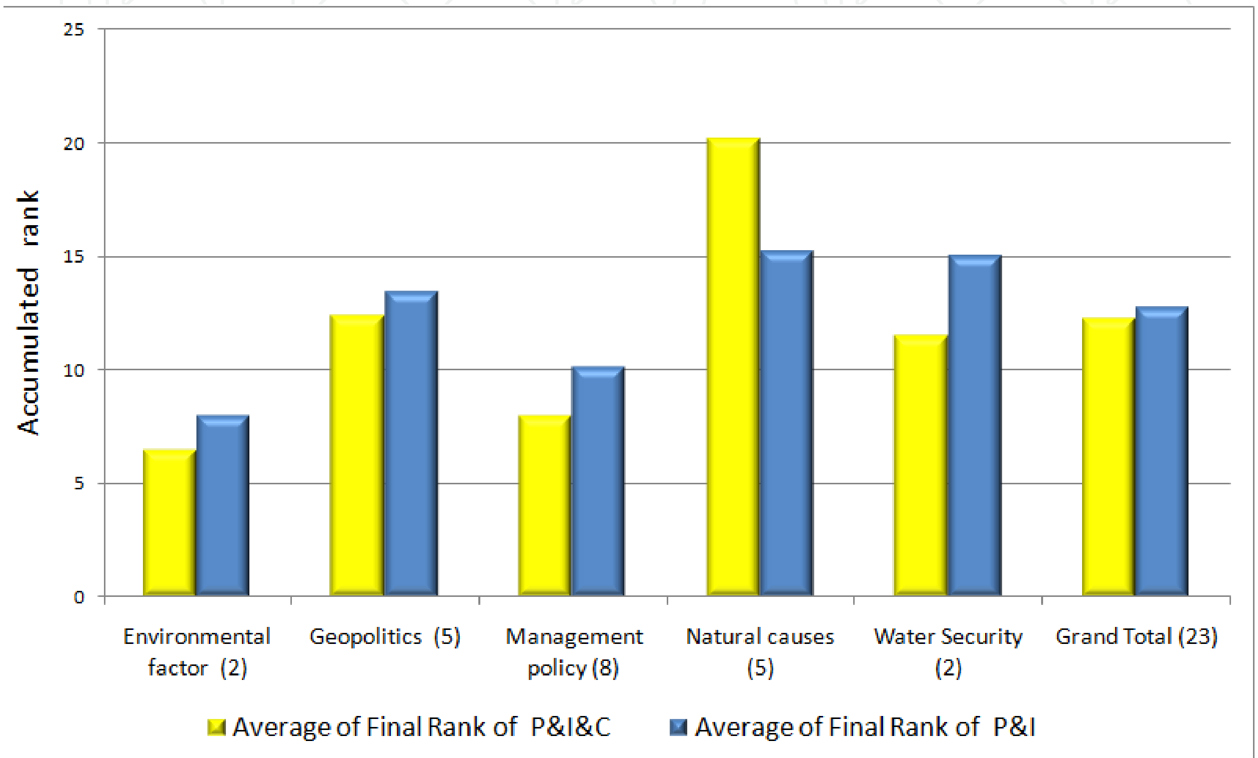

Fig. 2. Average ranks of all the categories risks

4.6 The most threatening risks

According the P&I&C rank of the risks, as presented in Table 3, the most threatening risks are: "Lack of coordination in water usage", "Disregard of facilities", "Political involvement in decision making", "Inadequate legislation and enforcement", and "Groundwater pollution by garbage, oil, etc." The first risk is a very common geopolitical problem, but its impact has not yet been fully understood. The other risks can be resolved by management policies and law enforcement. Risks like drought or earthquakes do not appear in the high priority part of the table, due to their lack of controllability and low probably of occurrence (earthquakes).

It is interesting to note that most of the natural risks, such as earthquakes, climate changes, changes in the distribution of rainfall, and reservoir evaporation are located in the low priority part of the table. This is mainly due to a lack of controllability and either low probability or low impact. The controllability criteria assigned them a more realistic priority. It should be mentioned that the experts contacted in this research claimed that these are very important risks that should be handled carefully. However, they could not provide a solution for addressing the issues concerning these risks. The incorporation of the controllability criterion captures this dichotomy.

5. Conclusions

Efficient and flexible management of fresh water resources are critical for the wellbeing of human society. Without it, human society would be unable to prosper or even exist. Conflicting demands coupled with decreasing usable water may lead to inefficient and unsustainable use of resources, which may result in significant economic, social, and environmental ramifications. In the current work, risk management methodology is utilized to increase flexibility and security over the management of water resources.

Since by their very nature many water resources are often associated with risks that are not readily controllable, a modification of the standard risk management methodology was adopted. This modification allows the accounting for the ability or inability to control the risk under consideration at an early stage of the planning. The controllability of the risk is incorporated among the risk identification parameters in order to avoid dealing with risks that are *a priori* non-controllable.

The risk management of any water resource must address two large systems: the natural ecological system and the human societies that utilize the resource. Thus, it follows that the risks involved in the maintenance of water systems also involve both natural risks, as well as risks associated with the ways in which societies utilize the water and the values which humans attribute to it. Furthermore, the social values, beliefs and arrangements involved in the utilization of any fresh water resource serve to expand potential adaptation strategies, on one hand, while presenting challenges and social constraints regarding possible risk mitigation strategies by the other hand. They are restricted to the society's ability to employ different means of adaptation over time, at different stages of risk management, and in response to different perceptions about what constitutes the challenges that must be met.

To better illustrate the approach, a study on the risks associated with the management of water resources in Israel is presented. In order to understand the possible risks and their magnitude, experts' opinions were solicited. It turned out that the risks can be classified into five main groups: natural causes, geopolitics, management policy, water security, and environmental factors. Incorporating the controllability criterion into the risk assessment decreases the importance of the environmental risks, since according to the experts' opinions these are difficult or impossible to control. These natural risks are the most common risks for water resource management. Usually, these risks do not appear in the classical projects' risk analyses. Having a sizable natural environmental aspect, water systems are more susceptible to natural risks than commercial projects. The introduction of controllability criterion enables the government to identify and focus on responding to the most threatening risks requiring attention and action. Some of the risks that were initially assumed to be high risks are those of sabotage and terror attacks. These risks, however, were actually found to have a low impact and may be controlled in a relatively easy manner. Unlike environmental risks, risks of pollution and geopolitical risks can be controlled; therefore, their rank was enhanced by the introduction of the controllability criterion.

This chapter demonstrates the incorporation of the controllability criterion at the assessment stage of risk management. Future studies conducted in other settings should further explore the effectiveness and usefulness of this modification - for risk management of water resources in particular - and for any other type of project management in general.

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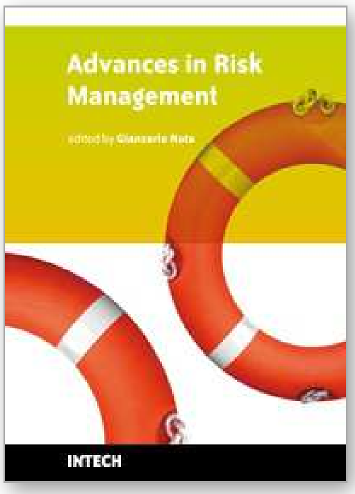

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