ANALYSIS OF RISK INSTRUMENTS IN AN IRRIGATION SUB-SECTOR IN MEXICO

Submitted to the Inter-American Development Bank
Technical Cooperation Program
IDB-Netherlands Water Partnership Program (INWAP)

June 30, 2005

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Acronyms and Abbreviations

ARC	*Adolfo Ruiz Cortinez Reservoir*
CARA	*Constant relative risk aversion*
CCP	*Chanced-constrained programming*
CDF	
CE	*Certainty equivalent*
CME	
CNA	*Comision Nacional del Agua*
Mm^3	
MVP	*Marginal value product*
O&M	*Operation and management*
OTC	
PDF	
RRAC	*Relative risk aversion coefficient*
SDP	
SERF	
SRL	*Sociedad de Responsabilidad Limitada*
WTP	*Willingness to pay*

Executive Summary

The Rio Mayo Valley district in the state of Sonora is one of about 50 irrigation systems in Mexico. The size of its reservoir, the Adolfo Ruiz Cortinez, is in the mid-range of reservoirs in the Mexican system. Operations of the water released from the reservoirs of Mexico are being turned over to farmer-operated user associations called Sociedades de Responsabilidad Limitada or SRLs. An agency of the Mexican government, La Comision Nacional del Agua or CNA, is responsible for releasing water from the reservoir for use and distribution by the SRLs. The risk of not having enough water in the system to satisfy user needs is a major impediment to effective management of the Mexican system and for irrigation systems around the world.

This project focuses on understanding the details of the hydrology and management of the reservoir in the Rio Mayo Valley irrigation system to investigate the feasibility of introducing risk-shifting mechanisms in an irrigation district in Mexico. The Rio Mayo irrigation district was chosen to apply a detailed example for motivating new thinking about how to do this. Three objectives for the project are 1) assessing the potential demand for a risk transfer mechanisms for irrigation risk; 2) designing prototype risk transfer mechanisms and assessing the potential supply for such contracts; and 3) investigating the institutional environment to make specific recommendations for the improvement of the overall efficiency of water use in the complex and changing world of Mexican water rights with the use of risk transfer mechanisms.

The major risk facing water users in the Rio Mayo Valley district is the amount of water that flows into the system over a given timeframe. This study details the management of the water system and reservoir with recommendations to indemnify irrigators based on the annual inflows into the reservoir with specific prototype insurance contracts that would pay when inflows are below normal. Given the different levels of risk aversion, the research then focuses on developing fully loaded premium rates for these contracts and performing a sensitivity analysis to examine demand for the risk-shifting mechanism. The results of both the analytical and field work suggest that: 1) it would be possible to develop a useful insurance mechanism to transfer much of the risk out of the irrigation district; 2) there should be a willingness to pay for such an insurance mechanism even with a moderate level of risk aversion; 3) a number of institutional innovations could follow the introduction of a risk transfer mechanism given the level of sophistication among the managers of the water system; and 4) these innovations could enhance the efficiency of the water market via improved trading of water usage rights from year to year.

While the institutional environment and the physical management of water in an irrigation system like the Rio Mayo Valley is complex, even a very straightforward contract that would pay when the cumulative annual inflow of water is below normal levels could provide a beneficial financial mechanism for protecting against irrigation risk. The value of agriculture in the Rio Mayo Valley is estimated at US$ 65 million. When inflows are significantly below normal, these values can decline by 35 to 40 percent. A prototype contract was developed so that the income would be protected at levels of about $52 million. The model suggests that even with loaded premium rates, such levels can be protected at a premium rate of about 6 percent of the average value of crops in the valley.

Of considerable significance is the great diversity of crops, profitability, and efficient water delivery system that is present in the Rio Mayo Valley. While landowners have rights to water, these rights are conditioned by the availability of water. Given normal water use, the rights that are tied to the land can be thought of as a water quota. Informal water markets have emerged to "rent" these water rights up to a full year before the water is needed. As one might expect, the farmers growing high value crops are keen to secure water rights well into the future. In some limited farm visits, farmers with high value crops reported paying between 2000 and 3000 pesos per hectare for water rights even before anyone know how much water will be available. Clearly, those who wait until there is a water

shortage must pay much more if they can even lease water rights at that point. Those leasing well into the future exercise their right to the leased water only if there are shortages. If not, the original quota holder of the water is able to use the water. One can think of these practices as an option market. Such markets clearly demonstrate a willingness to pay for insurance. More fundamentally, if insurance markets were introduced, one might expect that there would be even a greater willingness of the less efficient water users to pre-lease their water rights in this fashion.

A number of alternatives for introducing insurance that pays for shortfalls in inflows are possible. During the presentation to farmers in the Rio Mayo Valley, a system whereby all water users would be assessed a fee for the premium was explained that would then provide a single indemnity payment to the SRL. The rules for distributing the benefits would still need to be agreed upon.Given past experience with rule setting by the members of the SRL, one would think they are fully capable of setting such rules. A mixture of market principles and social principles are possible. For example, those at the most risk in the current environment are the water users who currently stand to lose the most when there are cutbacks in the release plans. These individual may be assessed at higher rates. However, they may also be the users who would receive the largest indemnity payments. Still the current distribution rules appear to be more egalitarian than market based. Given cutbacks in release plans, water to all users are cutback on a roughly proportional basis. The detailed rules were not shared.

During meetings with the water users the idea of developing inflow contracts by module was also introduced. There are 16 modules within the Rio Mayo Valley. Only the users know which of these modules currently receive the best treatment when there are water shortages. Users within each module could vote on whether they would be willing to purchase a collective contract to insure the shortage of inflows in a fashion that matched both their risk and the total value of the expected loss given different levels of inflow shortfalls. The SRL would need to be very careful with such a system as it could not be used as the excuse for cutting back one module that was insured while releasing the normal water to a module that was uninsured.

The most effective insurance is more complex than simply paying when inflows over the previous year are short. A reservoir is insurance as long as there are inflows. One cannot insure against the amount of water that is released as this is a management decision and one of the first principles of insurance is to avoid insuring against management decisions. The amount of inflows from October through September influences how much water is available for release. The announced release influences how much can be planted in the fall-winter. Thus, the inflows from the previous year have a major influence on the plantings and the income for the current year. Effectively the insurance is prepaying for cutbacks and lost income. However, if there is above average inflows during the fall-winter season, the reservoir can be replenished and certain farmers will be allowed to plant in the spring-summer. Thus, the most effective insurance would have a dual trigger. An early and partial payment would be made at the beginning of the fall-winter campaign. The second payment would be conditioned on the amount of inflows occurring in the fall-winter. The higher the inflows; the more the income for the year and the less indemnity is needed. Such a system makes the insurance more affordable and provides more effective risk protection. Nonetheless this system begs the question of who the winner and losers are and what rules are needed to distribute indemnity payments in a fashion that is most equitable and efficient.

1. Introduction

Water, perhaps the most precious natural resource for humankind, is seldom at the exact place, time, quantity, and quality to serve the different needs of human life. In regions where rains are scarce, communities rely on hydraulic systems for supplying populations with water, irrigating large cropping areas, drainage, and sometimes, generating power. From year to year, high degrees of uncertainty are characteristic if the replenishment of reservoirs depends on streamflows from a river or system of rivers, leading to water shortages when their replenishment is at extremely low levels, and flooding when replenishment exceeds the storage capacity of their hydraulic systems.

For irrigated agriculture in particular, a large number of systems around the world are characterized by a highly variable supply of surface water and an abundance of land. The uncertainty of water supplies limits the streams of income for producers and irrigators, and the multiplier effects of this uncertainty for economies based on irrigation extend to issues of food security and rural employment. In addition, water supply uncertainty deters irrigators from making investments in water technology to improve water usage at the farm level, and creditors and investors from financing projects to maintain and develop irrigation infrastructures.

Mexico serves as a good example of this problem. According to the National Water Commission (CNA, 2004), there is a disparity between the natural availability of water and the locations where water is most needed. In particular, 64 percent of the resource availability occurs in the south of the country where only 11 percent of the land is suitable for agriculture, while in the north, 53 percent of land is arable, but only 7 percent of the water resources are available. Due to the relative scarcity of rainfall, cropping activities in the most productive lands of northwest Mexico depend almost entirely on irrigation. Furthermore, the disproportionate endowment of the water resources is accompanied by rapidly growing populations in water scarce areas; consequently, there are serious water conflicts among water users when the replenishment of reservoirs is low.

Although CNA employs elaborate hydrological models that provide some guidance in the allocation of reservoir water for irrigated agriculture, these plans do not include any type of formal financial assistance or water banking scheme to mitigate the opportunity costs imposed by the uncertain availability of water. The only type of financial assistance available to farmers is the occasional *ad hoc* disaster payment disbursed from the state governments. Thus, a typical irrigator in northwest Mexico operates in a risky environment characterized by the random availability of the most limiting factor of production and without access to formal risk-sharing markets to hedge against such a risk.

Considering these problems, the goal of this research is to investigate the feasibility of introducing risk-shifting mechanisms in an irrigation district in Mexico. Much of the conceptual thinking for attempting to introduce risk-shifting mechanisms comes from the growing literature on index-based insurance (Skees, Barnett, and Hartell, 2005; Hess, 2003; Hess and Stoppa, 2003; Parchure, 2003; Mahul 2001; Skees, 2000; Skees, 1999; Skees, Hazell, and Miranda, 1999).

Given that a considerable amount of this literature focuses on the use and evaluation of weather markets and weather insurance products, this work begins with the premise that a collection of weather stations in the watershed could be used to transfer the risk of water going into the reservoir. With some considerable work on this front, the focus turns to historic measures of

inflows to the reservoir. Informal interviews with three major reinsurers support the notion that these important risk transfer markets would be receptive to using such a measure to write either an insurance or a derivative product.[2]

Although a specific irrigation district in the Rio Mayo Valley was selected to carry out the analysis, this research is relevant to many irrigation systems in Mexico that depend on surface water for irrigation supplies. To achieve the goal of this research, a model is framed with the most relevant variables for the operation of an irrigation district. First, a model of the operation of the Adolfo Ruiz Cortinez (ARC) reservoir is developed, including its release rules and most relevant physical characteristics. This component is recursive in nature and aims at depicting the inter-temporal dimension of the problem. Second, based on historical data on reservoir releases and hectares planted, planting response functions are fit to represent the physical relationship between irrigation water, conveyance efficiency, and the size of the irrigated area. Finally, a contract that derives its value from the inflows to the ARC reservoir is designed as a put contract that pays indemnities when reservoir inflows are below a strike.

The findings indicate that the proposed insurance is feasible when payments are discounted by the occurrence of higher than average inflows in the fall/winter season. Since inflows during this period allow irrigators to carry out production activities at the end of the season, farmers can naturally use these inflows to mitigate the cost of water shortages. In other words, inflows that accumulate between October and March serve as a natural hedging mechanism for irrigators.

2. Literature Review

The random nature of water supply represents a major source of risk in irrigated agriculture and has been the subject of many research reports in the agricultural economics literature. However, this literature has been focused on release rules under risk and the size of the reservoir as the primary means for managing these risks. The risks of inflows of water into a reservoir represent a significantly large risk for any market maker. These risks impact a large number of individuals at the same time. Traditional insurance markets involve pooling of independent risk that allow an insurer to collect small amounts of premiums from a large number of individuals and make a small number of payments to individuals during any given year. By pooling the variance of individual losses, the variance of the insurance pool is lower than the variance of the individuals. Thus, real market efficiency is possible using insurance solutions.

Despite criticism of schemes used by many governments, access to an efficient risk-transfer mechanism is an important economic objective. When producers are able to transfer some portion of their risk exposure, through mechanisms like insurance and banking, they are more likely to specialize, adopt new technologies, and make product or management specific investments that can enhance long-term productivity. These activities may offer a higher level of mean earnings, but frequently at a cost of potentially greater volatility in earnings. Risk-averse decision makers are less likely to make such investments without the aid of risk transfer given their preference for more predictable, albeit lower, income. This conceptual development that demonstrates that effective risk-transfer markets lead to greater investment in productive activities, along with the subsequent economic benefits for producers and local communities dates to early works by noble laureate Kenneth Arrow (Arrow, 1996, 1971).

[2] See Appendix A for an explanation for how these markets have evolved and the basic mechanisms for how they work. Material in this excerpt is from a book chapter by Skees, Hartell, and Hao, 2005. The chapter can be requested by email jskees@globalagrisk.com

2.A. Technical and Institutional Views of Water Supply Risk Management

Proposals to deal with water supply risk fall under two different, but complementary viewpoints: the technical and the institutional. While the main focus of the technical viewpoint is the optimal management of the resource at the supply side through reservoir operation rules, the institutional viewpoint broadens the spectrum of policy action by seeking rules that link the supply and demand for water through markets, particularly for resolving water shortages. Despite their apparent differences, researchers have combined the methodological developments of the technical view with institutional arrangements to provide general frameworks in the study of water allocation when the availability of the resource is uncertain.

Researchers on the technical side have developed methodologies to manage the random component of streamflows in the design and operation of reservoirs. For instance, stochastic dynamic programming (SDP) is a powerful tool for decision makers when resolving the inter-temporal dimension and deriving operation rules. The optimal rules equalize the marginal benefit of current usage with the discounted expected marginal benefits of future resource usage, taking into account that current usage impacts the availability of water in the future.[3] Alternatively, planners can develop probabilistic models using chanced-constrained programming (CCP), taking into account the random availability of the resource constraint and developing risk premiums to represent the costs of adopting aggressive operation policies. The method is based on the notion that the irrigator is willing to accept a given level of risk, expressed as how frequent water demand is satisfied (or violated).[4] The major contribution of the technical view is providing planners with an array of techniques that help develop useful insights to the economic impact of random inflows and incorporate risk management components in the reservoir operation rules.

However, the application of such optimized operation rules only limits to a certain extent the consequences of water supply shortages. While it is true that a reservoir by itself is a risk management tool that allows planners to store water for future use, there are two types of costs associated with this alternative. When water is the limiting resource or binding constraint in the production process, high opportunity costs are associated with water left idle in the reservoir. Operators strive to achieve a delicate balance between conservative operation rules and high opportunity costs. High transaction costs result when storing water because water evaporates and leaks. Water storage also creates the risk of flooding in the event that higher than expected inflows are accumulated during the replenishment season. The operation policies derived from DSP and CCP do not insulate the system from the economic consequences of uncertain reservoir inflows. Therefore, there is a clear need for other mechanisms that supplement operating rules in the management of water supply risk.

The institutional view proposes the use of market-based arrangements to deal with the problem of uncertainty in the supply of water. In particular, economists propose the establishment of a system of well-defined water rights. Such a system is fundamental for the development of water markets. It has been well established that these markets can potentially achieve efficient outcomes

[3] Applications of DSP in the operation and planning of reservoir systems can be found in the works of Dudley and Hearn, 1993; Rao, Sarma, and Chander 1990; Dudley and Musgrave, 1988; Dudley, 1988b, 1988a, 1972; Sobel, 1975; Mawer and Thorn, 1974; Dudley and Burt, 1972; Dudley, Musgrave, and Howell, 1972; Dudley, Howell, and Musgrave, 1971b, 1971a.

[4] Application of CCP to the operation of reservoirs for irrigated agriculture can be seen in Maji and Heady, 1978; Askew, 1975, 1974; and Eisel, 1972.

in allocating scarce water resources, particularly in times of water shortages (Livingston, 1998; Young, 1986; and Randall, 1981). In order to deal with the uncertain availability of water, several water rights systems have been proposed. For instance, the prior appropriations doctrine assigns water rights with different security clauses that clearly establish which rights are to be fulfilled first in the event of water shortages. The classic example of this system is the water markets in the western United States, where agriculture shares a good proportion of the senior rights to water.[5] Alternatively, water rights systems could be designed so that the risk of water supply is equally shared among water users. Three approaches considered in previous studies, but never implemented in practice, are reservoir content, volume, and capacity sharing (Dudley 1988b; Dudley and Musgrave 1988).

Despite their potential, very few water markets have been established. Howitt (1998) and Young (1986) suggest that the major challenges for implementing such institutions include high transaction costs associated with water transactions, and third-party effects associated with the physical transfer of water. For example, the physical losses during the conveyance of water might exceed the potential benefits of the transaction. In addition, water markets achieve efficient allocation of water only when the proper compensation procedures exist to resolve third-party effects or externalities imposed by water transfers.

2.B. The Use of Risk-Sharing Institutions

When the risks being insured are highly correlated, it is critical to use markets that shift these risks out of the local area and into the global market. Local markets generally cannot finance highly correlated losses. Global markets, such as reinsurance markets, can pool these risks by adding them to a global portfolio of independent risk.

Alternative risk-sharing institutions have the potential of transferring water supply risk to agents outside of the irrigation districts and employing a synergistic approach in which the markets for risk and water blend with operation rules. This approach could potentially generate a more efficient allocation of the resource, not only through space, but also through time. The literature refers to either insurance or derivatives when dealing with a “contingent claims product.” In either case, payments are contingent on a certain event. Regulators of insurance products are most concerned with whether buyers have an insurable interest and whether payments will be made when a loss occurs. Derivative products can generally be purchased by anyone.

Traditionally, agricultural insurance schemes protect farmers, including those in irrigated agriculture, against yield losses caused by multiple perils. The experience with such schemes indicates they are expensive to run, often financed by government subsidies, and plagued with problems of asymmetric information. In the literature of agricultural insurance there is no evidence of insurance markets being used to protect against the economic impact imposed by water shortages in irrigated agriculture.

In lieu of expensive agricultural insurance schemes, weather derivatives/insurance could be used in the management of water supply risk in irrigated agriculture. In spite of the popularity they have encountered in the energy markets of the United States, very few applications can be found in the agricultural sector. To date, only two proposals are found in the literature regarding the use of derivative/insurance contracts in the hedging of water supply risk in irrigated agriculture. Skees and Zeuli (1999) study the feasibility of introducing a rainfall derivative/insurance contract

[5] Examples of market-based proposals to deal with water supply risk can be found in Turner and Perry, 1997; Taylor and Young, 1995; Michelsen and Young, 1993; Hamilton, Whittlesey, and Halverson, 1989.

to protect against the variability of reservoir storage levels. In their application to the Blowering Reservoir in Australia, the authors are able to explain 70 percent of the variation of the water levels in the reservoir using a rainfall index based on three rainfall stations surrounding the reservoir area. However, correlating rainfall to the storage level implies a caveat. Specifically, the storage variable is basically the outcome of reservoir management decisions, and as such it is subject to manipulation. Variables subject to manipulation are also subject to moral hazard problems in insurance schemes. In order to establish the correlation between rainfall and storage levels in the reservoir the participants need to understand the operation rule of the reservoir and the effect of rainfall on reservoir inflows. Such relationships might prove difficult to understand, especially in cases where snow melting is a factor that influences the inflows into the reservoir.

In a similar proposal, Agarwal (2002b, 2002a) favors the design of a derivative contract using the water table as the underlying index. While a water table index provides a very strong correlation with the soil water contents and the availability of underground water, the author fails to recognize that water tables are subject to man-made changes. Although part of the variation on the level of water in aquifers, similar to surface reservoirs, is directly explained by the variations in the replenishing rate from water that filters to the soil from rainfall and snowmelt, the underground water stock is also subject to management-induced variations. In the particular case of irrigated agriculture, there is evidence that the unregulated pumping of the underground water might lead to the over-exploitation of aquifers. Therefore, the use of the water table as the underlying index of the weather contract might be subject to moral hazard problems and diminish the feasibility of the contract.

Two features distinguish this paper from the works described in the literature. First, reservoir inflows are used as the variable underlying the insurance instrument. While it is true that rainfall is an “act of God,” indexing this variable to account for reservoir inflows is a difficult task. Moreover, when the irrigation area is located in a desert-like region, as is the case of northwest Mexico, establishing the correlation between rainfall and storage proves almost impossible. Thus, our choice of inflows as the underlying variable is justified by three factors: data availability, ease of understanding (for irrigators) and prohibitive manipulation (i.e., “act of God”). In most irrigation systems there are quality historical measurements of reservoir inflows. This piece of information is critical even before the reservoir is put in place. Furthermore, irrigators trust and clearly understand these measurements. Thus, the relationship between storage and inflows and their plantings is relatively easy for them to establish. Finally, reservoir inflows are an “act of God,” thus they are not subject to manipulation or tampering, and in addition, the water users in these irrigation districts usually monitor activities to make sure that no water usage goes unaccounted or unmeasured.

The second feature to differentiate this paper is the integration of certain aspects of the technical and institutional views, specifically, by valuing the inflow-based insurance simulating the operation of the ARC reservoir. Release rules and planting response functions are included to incorporate the inter-temporal dimension of operating a reservoir. This approach is suitable for embedding in the model structure the trade-off between aggressive release rules and increasing risks of system failure, as studied in the technical view of water risk management. Finally, it is suggested that the SRL (Sociedad de Responsabilidad Limitada, or limited responsibility farmer/water user association) administer this program. This collective group of irrigators can serve as the decision maker that collects the insurance premiums from its members and distributes the indemnities according to their rules.

2.C. Index Insurance for Agricultural Risk Management

Thus, the economic linkages to improvements in private firm-level, *ad hoc* decision making motivate a wide range of stakeholders to search for alternative ways to approach the issue of incomplete risk-transfer markets for agriculture with the entire effort directed toward the efficient blending of government and markets to find improved ways to insure against crop losses created by natural hazards.

Government is clearly motivated to do something to assist producers in coping with catastrophic production risk. Assessing the appropriate role of government involvement is difficult, since social and market aspects of the risk problem often get blended together and even confused. Government intervention in the first place is usually justified on the grounds of an insurance market failure — private firms simply have trouble obtaining insurance against multiple events that create crop failure. But this diagnosis and subsequent proliferation of government agricultural insurance programs has done little to help correct the source of the problems and facilitate true markets. Rather, markets have been largely replaced by government.

Insurance markets that compensate for crop or livestock losses from natural disasters have long been touted as being an important component for recovery of poor households. Nonetheless, traditional insurance markets are missing or incomplete in most developing economies where asymmetric information and poor data create classic problems for insurance. Index insurance offers some promise for circumventing the problems with traditional crop insurance. Furthermore, innovation in global financial markets and in technology provides even more hope that index insurance contracts can be offered at more affordable prices.

3. Irrigation in Mexico

Mexico is a large country with an area of about 2 million square kilometers, with nearly two thirds of its land being arid or semi-arid and a total population of 100 million people. Annual rainfall around the country varies greatly from 181 mm in the deserts and northwest regions to over 2,300 mm in the humid tropics in the south. Studies by the Mexican National Water Commission (CNA) suggest that water used for agricultural purposes represents more than 82 percent of total water extraction. Agriculture consumes 90 percent of total surface water and 66 percent of total groundwater. These figures provide a good idea of the relative importance of agriculture in the Mexican water market due to its size and socioeconomic relevance in terms of rural employment and income for this country (CNA, 2001).

The irrigation sector reform began in 1988 with the transfer of the infrastructural assets of the public irrigation system to the water user associations (WUAs) and limited liability corporations (SRLs). By the end of 2002, 3.39 million hectares, representing 98% of the area under large and medium irrigation schemes had been transferred to 454 WUAs and 10 SRLs. The Mexican Irrigation Management Transfer Program (IMT) has led to considerable improvements in cost recovery, operation and maintenance (O&M), administrative efficiency, and water resource management. At the same time, the passing of the National Water Law in 1992 and the Federal Law of Regulations in Water Matters in 1994 provided the basis for the combined use of command and control and economic incentives to tackle the problems of water scarcity faced in some regions of the country.

Mexico has between 20 and 25 million hectares of land suitable for agricultural production. Between 18 and 22 million hectares are cultivated on an annual basis, and the increase in production in most recent years has been closely related to the expansion of irrigated lands. The

irrigated area has increased from 800,000 ha in 1926 to 6.1 million ha today. The average expansion of irrigated land has been 78,000 ha per year and in certain periods the expansion reached levels of 150,000 ha per year. The irrigated area is segmented into 80 irrigation districts that account for 3.3 million hectares and 30,000 medium-sized and small irrigation units that account for 2.7 million hectares.

The irrigation sub-sector of Mexican agriculture has been experiencing profound transformations, moving towards decentralization and market-oriented approaches in the management of irrigation water. These reforms have lead to well-documented advancements of water users associations; O&M (operation and management) cost recovery through user-fee collection; and user perception of water as an economic good. Nonetheless, significant challenges remain in getting water users more directly involved in the management of the water. To the extent that this can be accomplished it is believed that: 1) water loss rates could be lowered (i.e., more efficient delivery infrastructure could be built); and 2) users could organize more efficient ways to manage the water allocation given the great volatility of rainfall in many regions of Mexico.

The Comision Nacional del Agua or National Water Commission (CNA) has very elaborate systems for managing water allocation. Estimates of water needs are based upon detailed cropping plans submitted by individual farmers in the SRL. The management of the SRL notifies the farmers of the water levels in the reservoir so the farmers can arrange detailed farm plans for every crop to be planted by hectare. The CNA aggregates the plantings by location and estimates the total water needs. The CNA then announces the planned release by early October. While these allocations are negotiated and changed based upon rainfall occurring after the allocation decision, they form the basis of cropping decisions for an entire cropping year from October 1 to the following September 30.

To determine how much water to allocate, CNA uses information regarding water in the reservoir as of October 1, water needs for the crop plans, and historic inflows of water. These decisions are highly controversial and require careful management. Rainfall in the watershed above the dam determines the amount of available water for next year's allocation, as does the base level of water that is retained in the reservoir. Rainfall directly impacts the inflows of water into the reservoir, which is the key random variable that impacts the profitability of the farmers who depend upon irrigation water.

Trading off the value of the present year's crop at the prospect for full cropping in the following year is at the core of the economic question. If too much water is allocated for the present year and the rainfall is well below normal, there will be major cutbacks in water allocation for the following year. Cutting back on water allocation has a large opportunity cost as both the total plantings and the type of crops in the portfolio of crops must change when less water is allocated. In other words, farmers will plant less overall and the mix of crops in the portfolio will generally require less water usage and be of less value.

4. Irrigation in the Rio Mayo Valley

Given the dynamics of considering rainfall that feeds an irrigation system, it was important to select a relatively straightforward irrigation system. For this project three irrigation districts from northwest Mexico were considered: Rio Yaqui (Sonora), Culiacán Humaya (Sinaloa), and the Rio Mayo Valley (Sonora). The following criteria were used to select the Rio Mayo: 1) the reservoir is fed almost exclusively from upstream rivers and inflows have been monitored and estimated for well over 50 years; 2) the water system is largely self-contained and unencumbered by complex linkages to other reservoirs; 3) the primary use of water from the Rio Mayo Valley is

agriculture; and 4) there is only one water user association of farmers in the system. The water user association makes allocation decisions after CNA determines how much water to release. Some limited trading of water also occurs in this valley.

One complicating variable is present in this system. Information from the 2003-04 season suggests that supplemental water is provided from ground wells at a level of about 20 percent. Despite ground water supplies, the release plans are clearly driven by levels in the reservoir. Low releases can result in major cutbacks in the plantings — 60,000 hectares as opposed to the norm of about 85,000 hectares from some recent years. Some emerging evidence suggests that the ground water may be retained for some high value cropping areas and not used in a uniform fashion for all plantings.

The Adolfo Ruiz Cortinez (ARC) Reservoir and Son-42-Valle del Mayo aquifer satisfies the water demand of the Rio Mayo Valley irrigation district. In 2003-04, water from the reservoir made up approximately 80 percent of the irrigation needs for the valley; the other 20 percent came from underground wells in the aquifer. Total water usage in the area is almost exclusively for agriculture (about 97 percent for the 2003-04 plans).

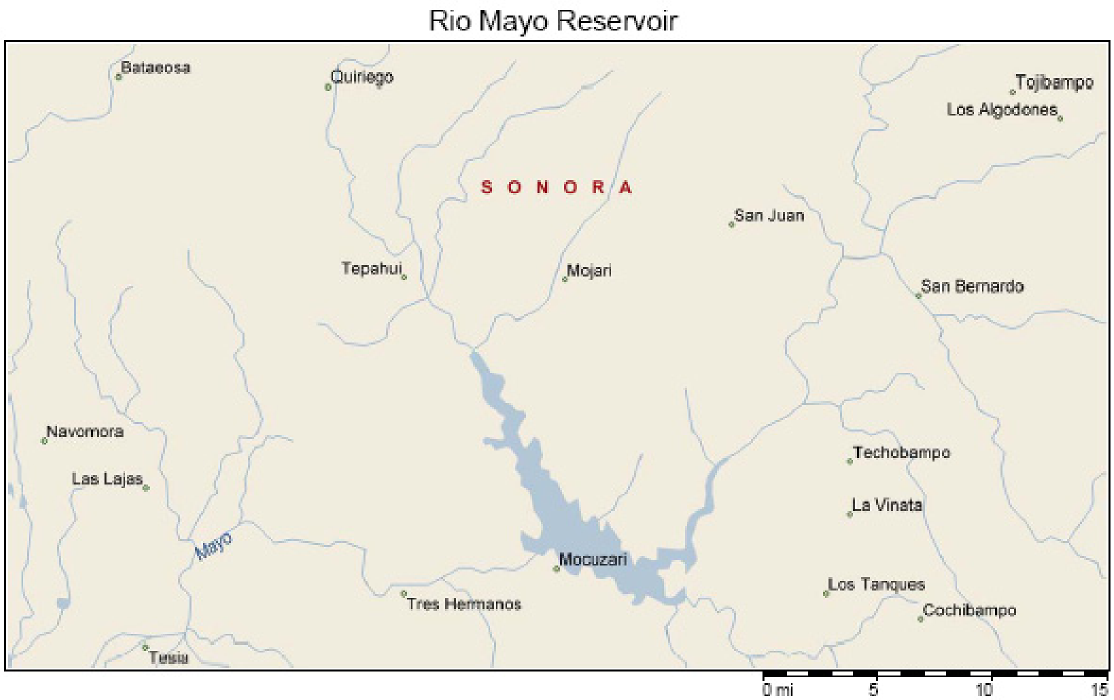
The Rio Mayo Valley irrigation district, also known as No. 038 in the CNA inventory of irrigation districts, is located in the southern part of the state of Sonora, 27°54’’ north and 109°36’’ west of the Greenwich meridian (Figure 4.1). The district is divided in 16 irrigation modules and includes an area of 98,598 ha suitable for irrigated agriculture. The area is bordered in the north by mountains that comprise part of the Sierra Madre mountain range, and in the southwest by the Gulf of California. The closest cities to the district are Navojoa, Huatabampo, and Etchojoa. The regional climate is desert-like, characterized by deficient humidity during all seasons. Mean temperature and rainfall in the area are 23°C (F) and 260mm, respectively. Most of the precipitation occurs between July and October, although occasionally cold fronts bring some rain between December and January. For water users in the Rio Mayo Valley the July-October period is critical because it determines the level of replenishment of the reservoir. [6]

The main source of water for the irrigation district is the watershed of the Mayo River (Rio Mayo), which covers an approximate area of 11,000 km^2. The river extends for approximately 350 km and averages 1000 million m^3 in streamflows. The hydraulic system used to secure the flows from the river is the ARC reservoir, also known as Mocuzari. The ARC reservoir was built in 1955 and its infrastructure consists of an earth-filled structure 81 m high above the riverbed. After an expansion project in 1968, the storage capacity increased from 1,100 million m^3 to 1,300 million m^3. However, the accumulation of silt has reduced the capacity. According to the inventory of reservoirs of CNA, the ARC reservoir is classified as a mid-sized reservoir in Mexico.[7]

[6] This information was obtained from the CNA report (2004) and personal communications with Rio Mayo Valley SRL.

[7] Of the 51 reservoirs in Mexico, the largest system is over 10,000 million m^3 and the smallest is around 270 million m^3. The Adolfo Ruiz Cortinez (or Mocuzari) Reservoir ranks 25th in size (CNA, 2004).

Figure 4.1: The Rio Mayo Valley Irrigation District

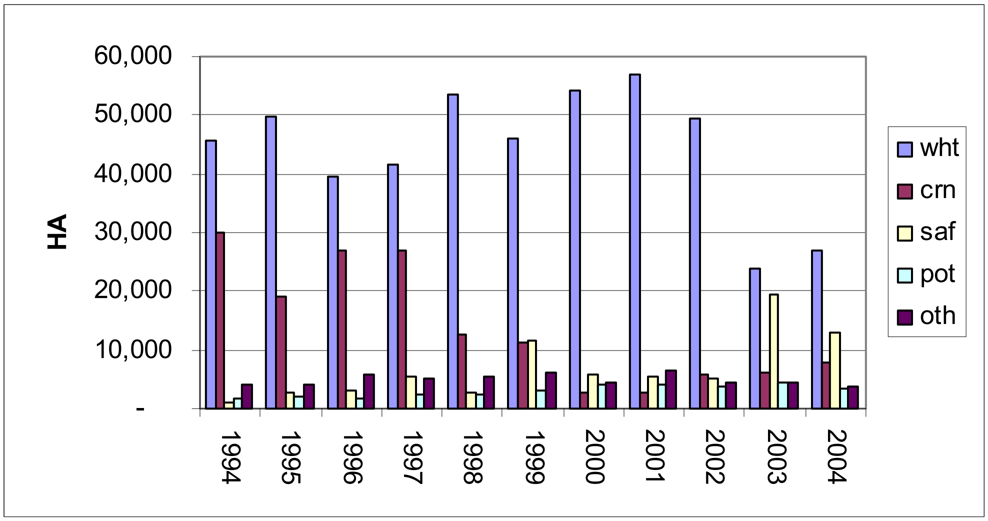


Source: Microsoft MapPoint Software: Note the dam is at the Southeastern point of the reservoir

5. Agriculture in the Rio Mayo Valley

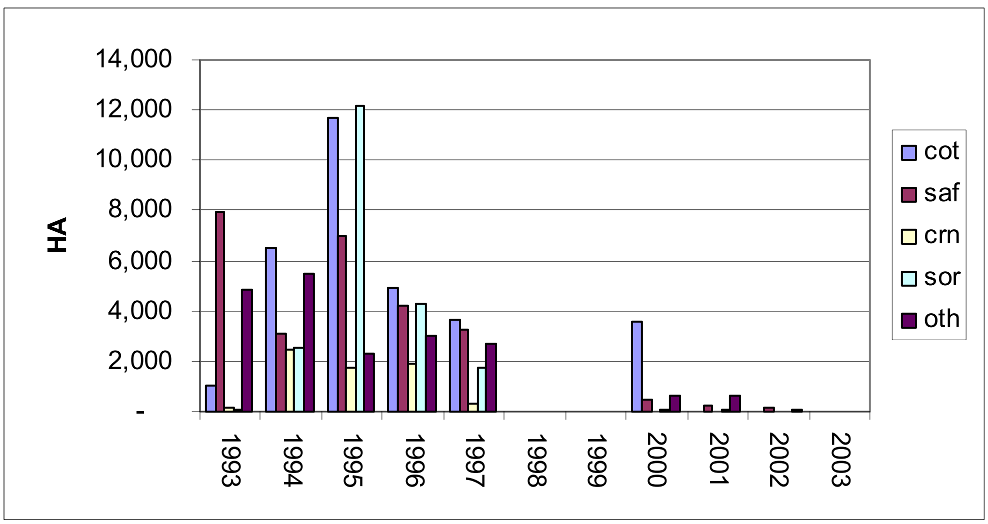
The production activities in the Rio Mayo Valley during the agricultural year are divided into two cropping seasons, and with an appropriate water supply, cropping activities can run throughout the year. During the first season, from October to April (fall/winter, FW; Season 1), farmers grow wheat (the main crop), maize, safflower, potato, and other minor crops. In the second season, from February to October (spring/summer, SS; Season 2), the main crops are cotton, sorghum, and maize. In addition, a small fraction of the irrigated land is dedicated to perennial crops. Figures 5.1 and 5.2 show the hectares cultivated in both seasons in the last decade.

Figure 5.1: Rio Mayo Valley Fall/Winter Cropping Patterns, 1994-2004



Source: Authors organization of data supplied by CNA

Figure 5.2: Rio Mayo Valley Spring/Summer Cropping Patterns, 1994-2004



Source: Authors organization of data supplied by CNA

5.A. Farmer Organization

Farmers in the Rio Mayo Valley are organized in a water user association, an SRL. The Rio Mayo Valley SRL is an association of 11,717 irrigators of two categories: private property owners and *ejidatarios* (collective ownership of small parcels of land). Private property owners typically operate larger farms and grow crops for the market. There are 3,867 private property irrigators that own approximately 47 percent of the land, with an average landholding of 11.9 ha. In contrast, ejidatarios own smaller parcels of land (on average 6.5 ha) and produce mainly for household consumption. There are 7,850 ejidatarios who own 53 percent of the land in the Rio Mayo Valley SRL.

The landholdings of irrigators are divided into 16 irrigation modules of various sizes and with significant differences in the efficiency of their water distribution (Table 5.1). For example, module 16 is furthest from the initial node where water is released. Well over 40 percent of the

water that is released is lost before it reaches this module. This is more than two times the water lost in modules 11, 12, and 13. In some cases, improvements such as the linings in irrigation ditches account for differences in irrigation efficiency among the modules. Such large differences highlight why farmers in different modules trade in informal water markets, leasing rights from year to year.

Table 5.1: Organizational Characteristics of the Rio Mayo Valley Irrigation District

Module	Efficiency *	Area	Ejidatarios		Private	
			Users	Area (HA)	Users	Area (HA)
1	75	7,898	653	4,073	430	3,825
2	75	8,637	819	6,098	225	2,538
3	75	5,214	430	4,164	81	1,049
4	70	5,468	513	2,762	337	2,706
5	68	5,289	321	1,390	600	3,898
6	75	7,875	472	2,303	374	5,572
7	73	8,130	1,132	6,220	63	1,911
8	79	3,766	246	2,372	92	1,395
9	77	6,063	286	2,755	91	3,318
10	77	5,154	355	2,874	93	2,280
11	81	5,168	364	3,408	38	1,760
12	85	7,032	95	488	183	6,544
13	81	6,545	240	2,775	97	3,769
14	77	4,797	508	2,460	249	2,337
15	71	6,086	1,055	5,158	144	928
16	59	3,925	361	1,757	770	2,167
Total		97,047	7,850	51,050	3,867	45,997

* Efficiency refers to the percentage of water released from the reservoir that actually reaches distribution point of the module.

Source: SRL of Rio Mayo Valley Irrigation District

5.B. Water Allocation Decisions

Although the operation of irrigation districts has been decentralized in Mexico, CNA still plays a dominant role in the allocation of irrigation water. Many parties participate in the highly complex decision-making process: the SRL, CNA, and the Watershed Council, which includes civil authorities such local governments. However, the ultimate decision-maker in this negotiation process is the CNA, headquartered in Mexico City. The most important steps of the process are outlined below.

At the beginning of the year, SRL representatives from the 16 irrigation modules develop an annual irrigation plan in a general assembly. Since the SRL closely monitors the main operation variables of the reservoir on a daily basis and has up-to-date information about water availability

for the upcoming year, the SRL representatives can develop a cropping plan likely to be approved by the CNA.

In the next round of decision-making, the CNA studies the irrigation plan and its feasibility. In particular, the CNA employs OPTIMA, a simulation-optimization program, to produce a release rule for a given volume in reservoir storage as of October 1. The release prescribed by OPTIMA is a minimum level of release taking into account additional supplies that are released throughout the year, the probabilities of the recorded worst year, and the inflows that accumulate within the FW season.

When the plan is approved, irrigation supplies are released from the reservoir according to a schedule that is jointly determined by the CNA, SRL, and irrigation modules. First, the CNA delivers water to the SRL in the main canals of the irrigation district. In turn, the SRL delivers water to each irrigation module. Finally, from the irrigation module delivery point, water is supplied to the individual irrigator. Throughout this delivery system, water losses occur due to evaporation and seepage. The greatest losses occur between the SRL level and module level due to the unlined canals used to convey water. Table 5.2 shows the efficiency ratios at different delivery points in the system.

Table 5.2: Average Water Conveyance Efficiency Ratios, Rio Mayo Valley Irrigation District

	Fall/Winter %	Spring/Summer %
From Reservoir to SRL	90	77
From SRL to Module	83	75
From Module to Farm	73	67
Overall (Reservoir to Farm)	55	39

Source: CNA, SRL

6. Understanding the Decision-Making Environment

To proceed with the development of an insurance model, it is important to understand the relationships that form the basis for decision making in the Rio Mayo Valley. First, the relationship between reservoir inflows and releases to the agricultural sector is very important because the released volume is the most important resource endowment for irrigators.[8] In this part of the world, land without water has a very low value. Also, it is important to understand the process that drives release decisions.[9] Second, it is important to understand the effect of release

[8] Reservoir releases account for 80 percent of the total water supply for the irrigation district. The rest is extracted from aquifers. Although aquifers could be used as buffer stock to mitigate the water shortages, the data on underground pumping are not readily available. According to water users, farmers prefer to use the surface supplies because of the lower cost (i.e., no pumping required), but data on these well extractions are not readily available.

[9] Although CNA implements statistical and hydrological models to control the reservoir, the implementation of the operation policy is quite questionable. The political economy usually leads to releases that exceed the prescription of the models.

on the annual plantings of the irrigation district in order to establish response functions that characterize the impact of releases on the hectares planted in the district.

6.A. Release Decisions

To answer the first question, a simple regression is used to explain releases. The first explanatory variable is the level of the reservoir as of October 1 of each year. This variable is a stock variable that provides information about the certain availability of water at the beginning of the agricultural year. The second variable is the inflows into the reservoir in the period that falls between October and April. This variable has a twofold importance: it allows irrigators to carry out supplementary irrigation for the crops already established in the FW season, and, it replenishes the reservoir for future irrigation in the SS season. The regression equation is reproduced below and the regression results are presented in Table 6.1.

$$\text{Release} = 245.9 + .55 * \text{Storage}_{Oct} + 1.07 * \text{Inflows}_{FW} - 0.007 * \text{Inflows}_{FW}^{\ 2}$$

Table 6.1: OLS Regression Results to Explain Release of Water

Variable	Coefficient	t-ratio	Mean
Constant	245.89	4.45	
October Storage	0.55	8.22	741
Fall/winter Inflows	1.07	7.12	375
(Fall/winter Inflows)^2	(0.007)	(5.021)	
Adjusted R^2	0.85		
F-statistic	62.63		
Durbin-Watson statistic	2.15		
Observations	33		

Source: Authors' calculations

The regression explains about 85 percent of the variation in releases. More importantly it confirms that the storage level of the reservoir as of October 1 of each year is not only statistically significant, but also significant in magnitude. Holding all other things constant, for an additional million m^3 in storage in the reservoir, more than half (55 percent) of that number will be released for irrigation purpose throughout the year. Second, although the inflows that occur in the October-April period lead to higher levels of releases, the relationship of this variable is not linear, but decreasing. In other words, there is a certain level of inflows (around 800 million m^3) after which annual releases will become negative (i.e., water will be stored). Basically, it takes close to 800 million m^3 for farmers to irrigate most of their land. Any additional supply of water has more value as storage for the beginning of the next agricultural year. Therefore, any release rule in place at the ARC reservoir must be based on two variables: beginning-of-year storage and October-April inflows.

6.B. Planting Decisions

Establishing the relationship between release volume and number of hectares cultivated is a challenging task for several reasons[10]. First, the crop data reveal that the portfolio of crops grown in the region has not remained constant over time. The reason for those changes might be due to economic factors (i.e., prices, subsidies, technical change) as well as institutional factors (i.e., water law, land reform, etc.). Unfortunately, not having a fixed crop portfolio does not allow us to estimate precisely the water needs of the crops. Second, the small data sample does not provide a robust estimation. Despite these challenges, the data were carefully selected to fit a response function. Furthermore, the results of the fitted functional forms were corroborated with SRL technical engineers in the Navojoa office.

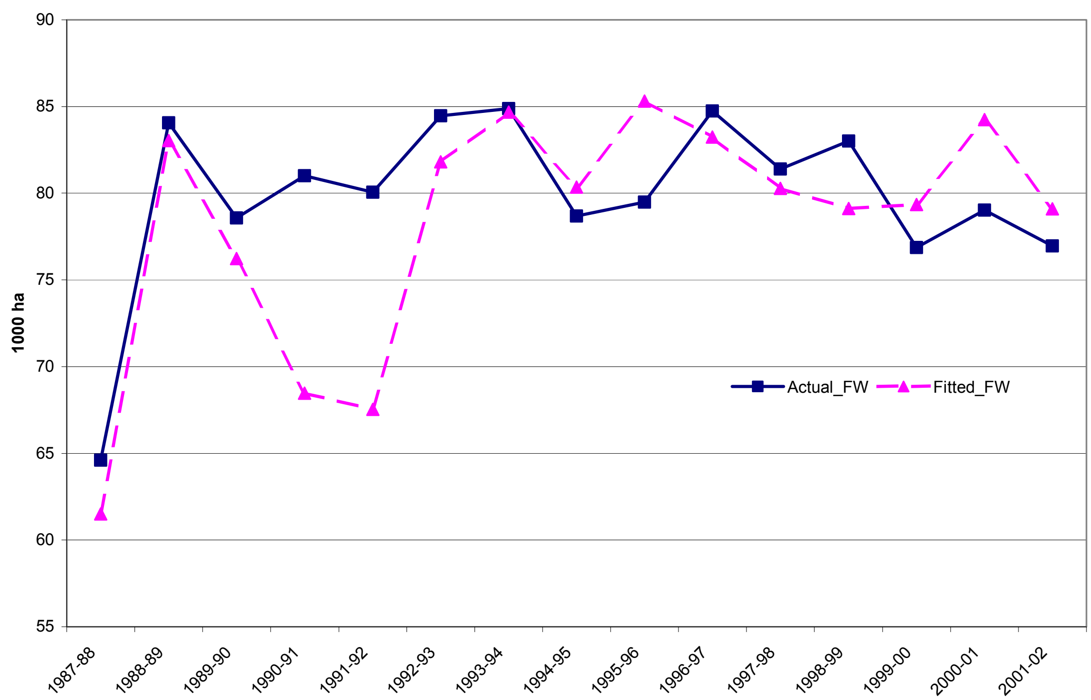
The specific functional form of the response functions is presented below:

$$\text{FW Plantings} = -19{,}000 + 380 \times \text{FW Release} - 8.8 \times \text{FW Release}^{1.5}$$

$$\text{SS Plantings} = -12{,}000 + 245 \times \text{SS Release} - 5.6 \times \text{SS Release}^{1.5}$$

There is a strong and statistically significant correlation between the predicted plantings and the actual plantings for the 1987-2002 period. Figure 6.1 gives a visual representation of this correlation. Figure 6.2 provides a representation of the seasonal response functions.

Figure 6.1: Actual vs. Fitted FW Plantings, 1987-2002

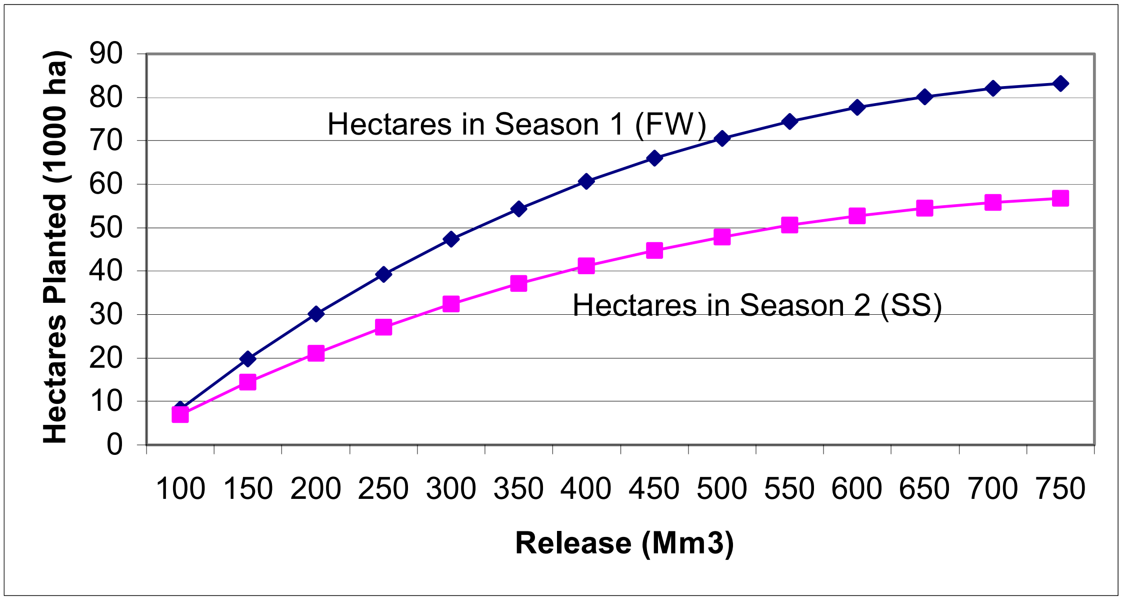


There are two important features in the fitted response functions that play an important role in the inter-seasonal allocation of water. First, the curvature of both response functions in Figure 6.2 reflect the fact that there are diminishing marginal returns to the application of water to land

[10] Release values do not include release for spillover when the dam is full.

parcels located at a greater distance from the main irrigation canals. Since the water conveyance structure is highly inefficient, growing crops in the more marginal areas of the district requires very large releases of water from the reservoir. In fact, for an additional million m^3 released from the reservoir, on average only 55 percent of this volume is actually received at the farm level[11]. The second feature relates to the inter-seasonal conveyance efficiencies. Since the average temperature during the SS season is higher, the conveyance inefficiencies in this season are relatively higher. Therefore, for each unit of water released from the reservoir, more land can be used in FW than in SS season.

Figure 6.2. Planting Response Functions



The production history of the district indicates that wheat is the main crop grown in the FW season (Table 6.2). The second two most important crops are maize and safflower. In terms of the profitability of these crops, it is important to notice that besides the market price, they receive government supports in the form of a per-hectare subsidy. This makes the relative profitability of the crops in the FW season higher. In terms of the SS season, the crop portfolio is highly variable. The evidence suggests that in the SS season, oilseeds are the recommended crops, particularly cotton and safflower. According to farmers in Rio Mayo Valley district, the production of SS crops has decreased dramatically due to the depressed prices and the lack of water for this season. Unfortunately, data for production prices and costs for the SS season are not available since production activities have been suspended during the last three years. To overcome the limited information, revenues of the district are expressed in a per-hectare equivalent. Large differences in profitability occur within the Valley; data suggest that profits in the SS season are about 70 percent of those in FW season.

[11] This information comes from engineers at the SRL for the Rio Mayo Valley.

Table 6.2: Crop Plan for the Rio Mayo Valley 2003-04

	Hectares	Cost per HA	Total Cost	Gross Returns	ProCampa	Net Returns	Net Return Per Hectare
		Pesos					
Wheat	27000	9035	243945000	240641000	25245000	21941000	813
Safflower	13101	7093	92925393	129051000		36125607	2757
Vegetables	3746	23217	86970882	144643000		57672118	15396
Corn	7867	9251	72777617	94369000		21591383	2745
Red Beans	2181	10322	22512282	23764000		1251718	574
Potatoes	3481	38273	133228313	417877000		284648687	81772
Sempoal	115	6500	747500	789000		41500	361
Garbanzo	2499	8524	21301476	18920000		-2381476	-953
Others	130	6634	862420	1604000		741580	5704
Perennials	2545	10175	25895375	28708000		2812625	1105
Totals	62665					424,444,742	6773

Source: Authors' calculation from data supplied by CNA and others in Mexico.

Since approximately 1988, it appears that rules have been imposed to allow for relatively constant planting in the fall/winter season without regard for the value of cropping in spring/summer. This could be simply because the value of fall/winter crops is significantly greater than spring/summer. Or it could be motivated by more egalitarian goals as assuring that every hectare is planted and every farmer has some crop in the fall/winter. One can envision that the last planting beyond some threshold (say 70,000 hectares) does not have the same value as the first plantings in a limited geographic area. Planting the first 10,000 hectares in spring/summer could easily have more value than the last 10,000 hectares in fall/winter. This is especially true given how the response curve flattens as the water release increases. For example, the last 100 Mm^3 of water allows for only an additional planting of about 2,700 hectares in Season 1. If this water is moved to Season 2, the plantings would be roughly 8,000 to 10,000 hectares. Thus, even if the portfolio of crops planted in Season 2 is less than two times as valuable as the portfolio is Season 1, it would be more efficient to hold the water until Season 2.

Based on data in Table 6.2 and data on the portfolio of crops grown in the valley, the average net returns per hectare in the valley for the 2003-2004 plan is around 6770 pesos per hectare. Similar calculations also suggest that the average net returns from the portfolio of crops grown in the valley in Season 2 are about 30 percent less than the fall/winter portfolio.

A preliminary look at the production history over the last 10 years and information of the water release decision process suggest that irrigators incur serious opportunity costs when the reservoir holds low volumes of water. More specifically, volumes of water in the reservoir as of October 1 are utilized in the fall/winter cropping season (wheat, safflower, corn, potato). The number of

hectares planted in the fall/winter season has been relatively steady since the early 1990s at around 80,000 hectares. Of course, these numbers are significantly lower in the past two years as the water levels in the reservoir have declined significantly. Perhaps the stabilization of the fall/winter hectares is a result of the institutional change brought about by the Water Law of 1992 that transferred the irrigation infrastructure to the water users. The spring/summer season is quite different, showing more volatile behavior and decline in hectares planted since the early 1990s. Clearly, the spring/summer season exists only when the reservoir volume is significantly high enough to satisfy the demand of two cropping seasons. The substantial reduction in reservoir volume experienced in the last five years has resulted in very few hectares planted in spring/summer as well as a reduction of plantings in the fall/winter season.

A further comparison of the number of hectares planted in spring/summer and the level of water in the reservoir at the beginning of the agricultural year suggests that farmers give up a substantial opportunity to generate revenue in the spring/summer season as a result of inadequate reservoir levels. The choice of planting more hectares in fall/winter could be viewed as the way in which farmers attempt to reduce the opportunity costs, including the reduction in water transfer losses due to higher evaporation rates in the spring/summer season.

7. Risk Analysis

Given the monthly observations of inflows, the data are grouped in three sets. The first set is the annual data and includes the accumulation of inflows for the October-September period. The other data sets were organized in semesters. The first semester corresponds to the accumulation of inflows between October and March. This accumulation is important because it determines whether agricultural production occurs in the SS season. According to the data, 30 percent of the annual accumulations occur in this semester. The second semester corresponds to the period April-October and is the most critical to replenish the reservoir. The data show that 70 percent of the inflows occur in this period.

Upon inspection, a normal distribution is not suitable to the data and is confirmed by normality tests. Thus, PDF and CDF distributions for reservoir inflows of the three data sets were generated, using the nonparametric kernel smoother in Simetar. Figures 7.1 and 7.2 represent the PDFs and CDFs. Taking into account that inflow during the October-March period is correlated at 0.23 with inflow for the April-September period, a bi-variate empirical marginal distribution was generated. From this distribution, 10,000 random draws were generated with the Latin Hypercube procedure in Simetar. These simulated distributions provide an analysis of the water supply risk that provides the foundation for the model design.

Figure 7.1: Empirical PDF for FW and SS Inflows

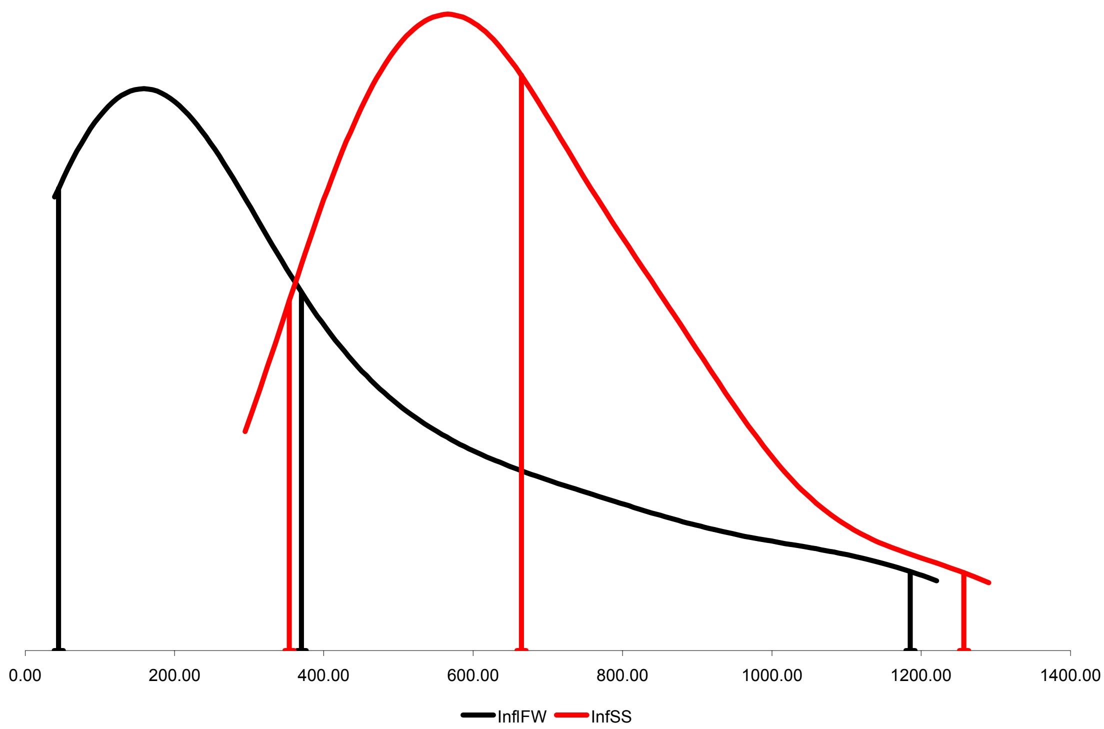
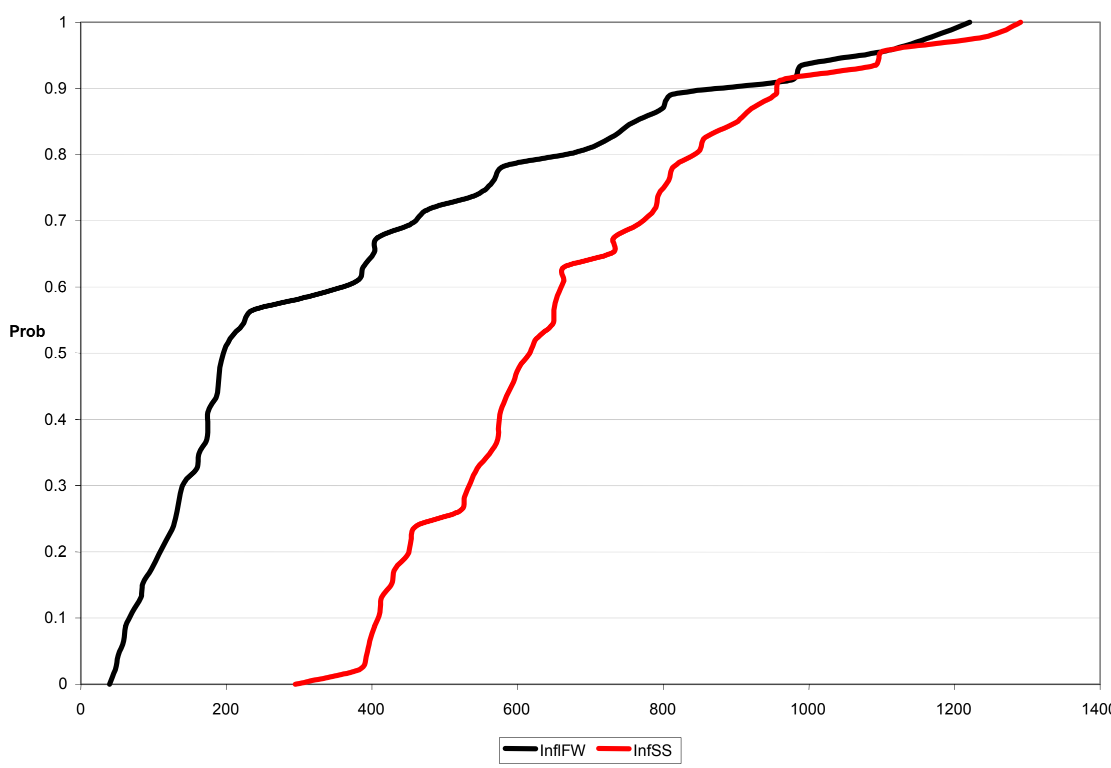


Figure 7.2: Empirical CDF for FW and SS Inflows



7.A. Testing for Autocorrelation

From the perspective of an insurance provider, it is desirable that the time series data on annual inflows do not show signs of strong autocorrelation as pricing the instrument becomes more challenging. The purpose of this exercise is to determine if the insurance provider needs to adjust the premium for the possibility of back-to-back drought periods. The presence of autocorrelation might prove difficult for the insurer because of indemnities would have to be paid in consecutive years. A box-Ljung statistic indicates the autocorrelation coefficient (first lag) is an issue. Although, the tests indicate statistical significance, the magnitude of the coefficient is small. The remaining coefficients are not significant at any level, indicating that the autocorrelation does not prevail after one lagged period. Therefore, insurers would not have any considerable problems with an insurance contract based on the inflows to the reservoir.

While no formal test for ENSO effects was performed for this study, ENSO has strong effects in this region. The most important issue for ENSO is that it provides an early signal for when rainfall is likely to be below normal. These signals can provide advanced information about when to purchase insurance or not. Generally, ENSO provides information that may change the conditional probability of rainfall as early as six months in advance. This is an important consideration for sitting appropriate sales closing dates for an insurance product. If such a deadline is not established for when someone can purchase insurance, the buyer will pick the bad years to purchase and the insurance will be unsustainable. This is referred to as adverse selection.

8. Modeling Irrigation Decisions in the Rio Mayo Valley

CNA and the SRL provided the hydrologic and economic data relevant to this study. The hydrological data include monthly records of reservoir inflows, storage, and releases. The quality of the hydrological data seems highly acceptable since they are based on observations posted daily in the SRL offices. Irrigators use this information for planning purposes. The descriptive statistics of these series are given in Table 8.1. The mean inflows accumulation to the reservoir over one agricultural year is approximately 1000 million m^3. The mean annual agricultural releases are 825 million m^3. This number does not account for releases for municipal use (around 20 million m^3), reservoir spills, and evaporation losses.

CNA provided historic monthly data on the storage, release, and inflow for the dam. The inflow data begin in 1943. Information on the dam releases begins in 1955. Release data do not include spillover data for water that must be released when there is excess inflow beyond the capacity of the dam. The release data refer to releases that are almost exclusively used for agricultural purposes. Since release data do not include spillover data, an adjustment was needed to estimate spillover data. This was done in a relatively few cases by examining the level of water in the reservoir and the inflow. If inflow was greater than capacity of the dam (roughly 1,100 Mm^3), estimates of spillover were made and added to the release number. It was also necessary to make some limited adjustments in storage numbers when it could be surmised easily that mistakes had been made and an adjustment was needed to smooth the storage values over a few months. Given these modest adjustments, an input-output model was tested to examine the integrity of the data.

(1) $$Storage_t = C + b_1 Storage_{t-1} + b_2 Inflow_{t-1} - b_3 Release_{t-1}$$

Table 8.1: Descriptive Statistics of Hydrological and Economic Characteristics of the Irrigation District

	Inflows [a]	Release	FW Storage [b]	SS Storage [c]	Plantings [d]
Mean	1,013	825	743	489	101,055
Standard Error	65	29	32	45	3,642
Median	914.50	824.70	685.00	415.39	99,243.00
Standard Deviation	453.52	202.30	226.74	315.92	215,48.41
Skewness	1.06	-0.01	0.20	0.38	-0.03
Minimum	454.73	440.88	314.80	25.11	51,809.00
Maximum	2,511.51	1,240.41	1,206.32	1,124.56	142,465.00
Count	49	49	49	49	35

a: inflows, releases and storage is measured in million m^3 (1 cubic meter = 0.0008107 acre foot = 35.315 cubic foot).

b: FW storage as of October 1 (beginning of agricultural cycle).

c: SS storage as of April 1

d: production measured in hectares (1 hectare = 2.47 acre).

Source: CNA, SRL

No time-series data for evaporation were supplied. Some limited evaporation data suggest that evaporation is relatively constant by month and year. Given that evaporation is not present in Equation 1 above, the intercept term will pick up this influence. All coefficients (b_1, b_2, b_3) should equal 1.

Equation 1 was fit with data from 1956-2002 and for 1970-2002. In both cases the R^2 exceeds .99. More fundamentally, the coefficients are very close to 1.

(2) $\text{Storage} = -6.5 + .99\ \text{Storage}_{t-1} - .89\ \text{Release}_{t-1} + .98\ \text{Inflow}_{t-1}$ (1956-2002)

(3) $\text{Storage} = -1.8 + .99\ \text{Storage}_{t-1} - .98\ \text{Release}_{t-1} + 1.0\ \text{Inflow}_{t-1}$ (1970-2002)

These data can prove quite valuable in developing a further understanding of how water is released from the reservoir. There are two very distinct growing seasons for this region: 1) a fall/winter season in the first 6 months of the irrigation year which begins in October; and 2) everything that is planted and growing in the second 6-month period (April to September). CNA makes an initial decision via negotiation with farmers in the region regarding the minimum level of water that will be released over the following 12 months. The equation used for this release is:

(4) $\text{Release} = \text{Storage}_{Oct} \times 1.05 - 77.7$

The records from recent years clearly demonstrate that this equation is used primarily to determine the minimum amount of water that will be released. As trends in the next section will demonstrate, a greater share of water is being used in the first season than in the past. The amount of water released even in the first season is exceeding the release rule presented in Equation 4. Planting patterns also strongly suggest that planting in Season 2 is quite volatile and largely a function of both storage and how much inflow arrives during the first 6 months (Season 1). It is

also likely that excess rain during the second time period also influences total release values. A regression to capture these features was fit for data from 1970-2002.

(5) $\text{Release} = C + b_1\text{Storage}_{Oct} + b_1\text{Inflow}_{Oct\text{-}Mar} + b_1\text{Inflow}_{Apr\text{-}Sep}$

Two regressions are needed as there is an estimate of total release (which includes excess release that is not used) and release that is used for agriculture (since agriculture is 97 percent of use there will be no attempt to separate other uses). Table 8.2 presents results from these two regressions.

Table 8.2: Regression Results Explaining Annual Release

	All Release	Agri Release	Means
R Square	94%	68%	
Release			993
Agri Release			878
Intercept	-61	591	
Storage	**0.77**	**0.26**	738
RunEarly	**0.89**	**0.43**	375
RunLate	0.23	-0.10	655

Source: Authors

Storage as of the beginning of October and the October to March inflow values are both highly significant in the two models. The inflow coming into the reservoir in the last six months of the year also explain excess release as there are occasions when the water in the dam must be lowered to make way for new inflow and prevent flooding. As expected, late inflow does not have a statistical relationship with water released for agricultural purposes.

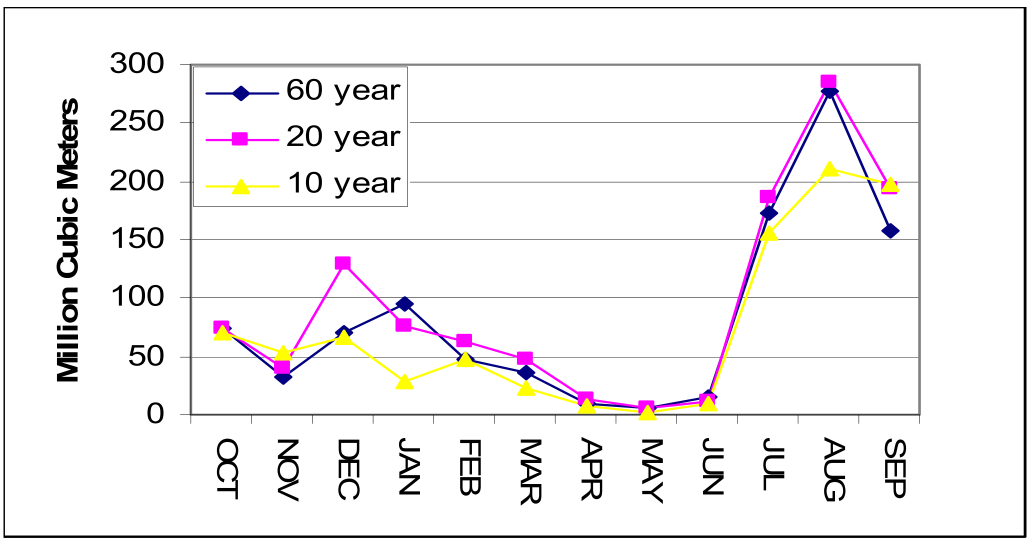
Given the mean values, the response associated with a 10 percent change in storage is 5.8 percent for total release and 2.2 percent for agricultural release. Response related to early inflow is 3.5 percent for total release and 1.8 percent for agricultural release. These relationships reveal a good deal about recent management of the release. While the official decision rule is a linear relationship associated with storage as of October 1, this is not the system that is being used. Given that the intercept term on the agricultural release is nearly 600 Mm^3, it is clear that management in recent years has been generous. From the 1997-98 season to the 2002-03 season, the average release for agriculture was nearly 50 percent greater than the decision rule allowed.

Models were also fit to examine the release of water in time period 1 and time period 2. Neither storage nor early inflow explained variation of water released in time period 1. Again, it seems that a certain amount of water is released for that time period regardless of storage and inflow. However, with time period 2, the regression explained 76 percent of the variation in release for agricultural purposes. The response from storage in October and early rainfall is equal: a 10 percent change in either of these important variables leads to a corresponding 5.4 percent change in the late release for agricultural use.

Inflow to the reservoir is quite volatile. Data for inflow are from the 1943-2002 period. While the average inflow approaches 1,000 Mm^3 per year (Oct 1 to Sept 30), there are two extreme years when there is approximately 2,500 Mm^3 of water, while over 8 percent of the observations from 1943-2002 have values that are less than 500 Mm^3. This pattern of volatility is of concern given that average release for agricultural use exceeds 850 Mm^3. Such usage and volatility in inflow is precisely the reason why management of the dam becomes critical. However, even more telling is the mismatch between the period of the largest levels of inflow and rain and the actual cropping season for the region. During the first six months when most of the cropping occurs, just over 1/3 of inflow comes into the dam. Over 60 percent of the inflow arrives in just three months (July, August, and September), when there is very little cropping.

Figure 8.1provides the average monthly inflow values for 1943-2002 (60 years), 1983-2002 (20 years), and 1993-2002 (10 years). Of course, average values mask some important dimensions of these data. For example, large values of inflow occur in January – March. These are likely from rainfall brought on by tropical storms (hurricanes in some cases). Of great interest is that such storms replenish the water in the reservoir in a significant fashion. Thus, a bad event for some (damage from hurricanes) is a good event for those wanting ample water in the reservoir. Such an event could offer some opportunity for trading risk between farmers in the Rio Mayo Valley and others exposed to losses from hurricanes. However, if the dam is full before excess rainfall events occur, extra water released from the reservoir creates flooding damage to farmers below the dam.

Figure 8.1: Average Monthly Inflow Values for 60, 20, and 10 years



The CNA provided a history of seasonal plantings. The series suggests that mean plantings are approximately 101,000 hectares per year. However, in the last 5 years plantings have experienced a downward trend due to water scarcity. Figure 8.2 gives the time series of inflows and plantings. Figures 8.3, 8.4, and 8.5 provide information on the operation of the ARC reservoir. There are striking declines in the reservoir contents in both October and April, along with dramatic declines in releases. In order to carry out plantings in the last 5 years, irrigators have pushed the system by releasing volumes of water that almost equal or surpass the inflows, thereby deleting the stock of water in the reservoir to very low levels. These figures confirm conclusions encountered in the literature of water resources that optimal release rules do not insulate irrigators from the random nature of inflows. The problem is compounded when in addition to the random inflows, irrigators exercise political power that push for more aggressive operation policies in the reservoir.

Figure 8.2: Annual Inflows and Plantings 1955-2004

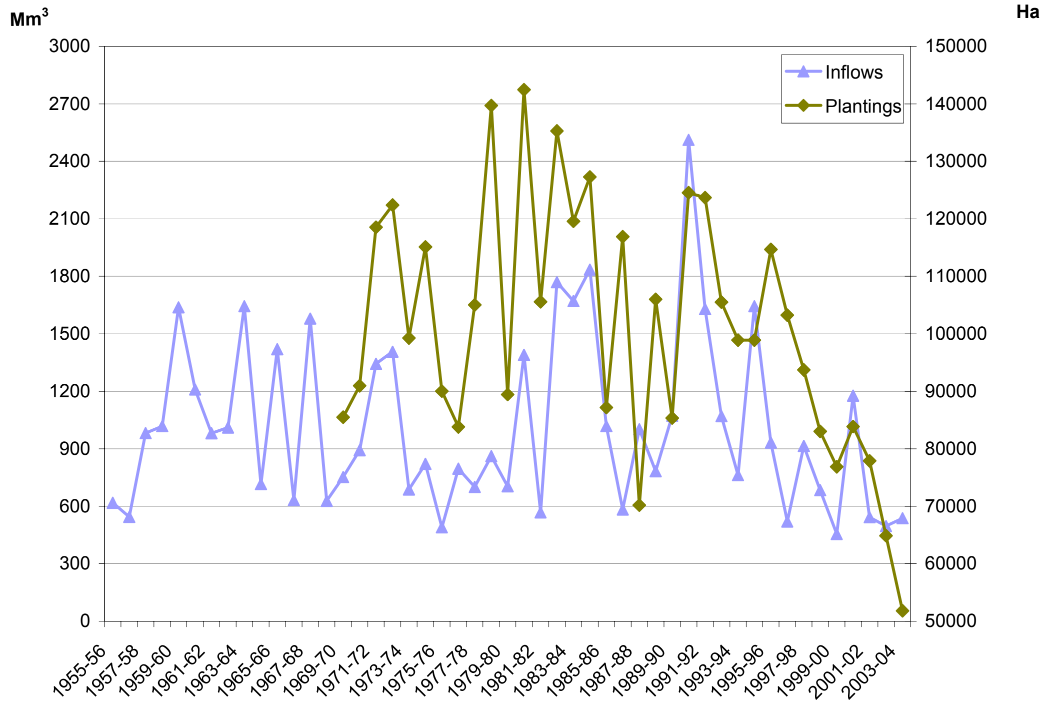


Figure 8.3: Releases for Agriculture from the ARC reservoir, 1955-2004

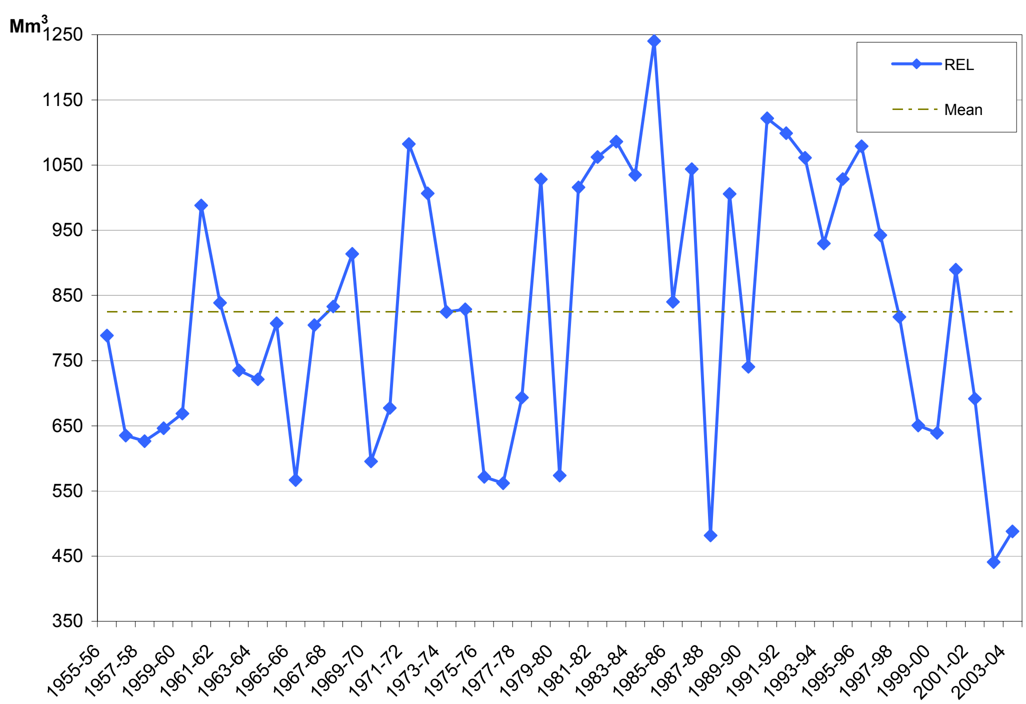


Figure 8.4: Storage Volumes as of October 1 in the ARC Reservoir 1955-2004

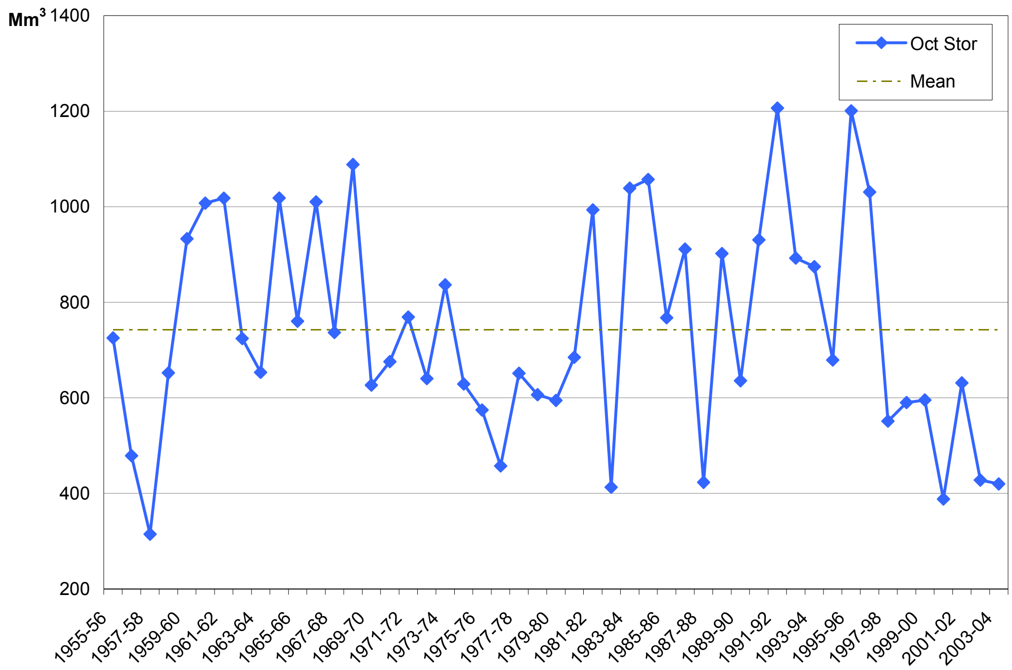
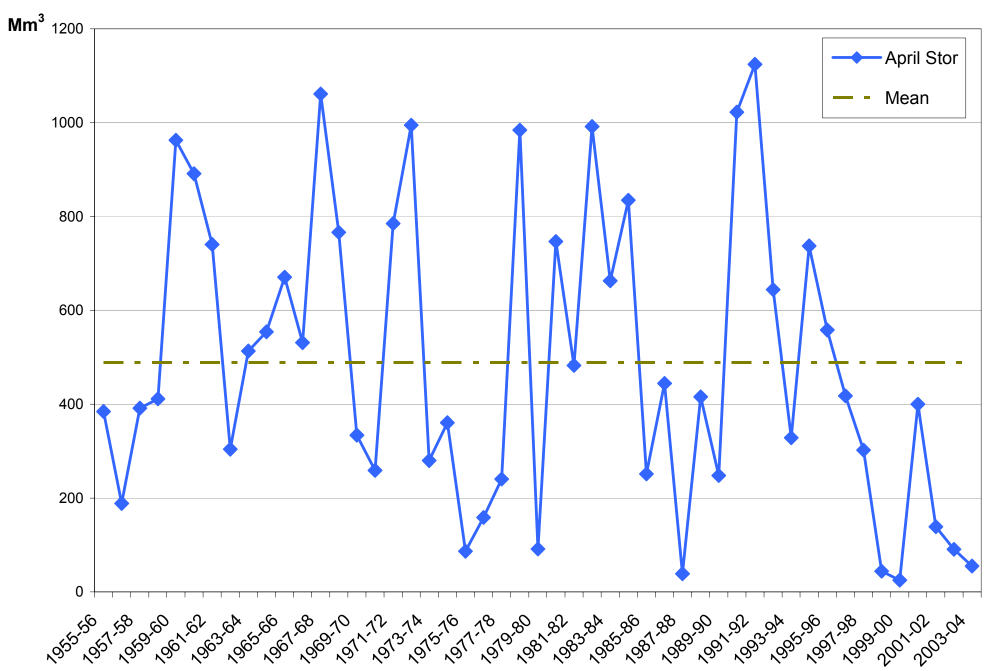


Figure 8.5: Storage Volumes as of April 1 in the Arc Reservoir 1955-2004



8.A. The Reservoir Operation Model

The reservoir operation model is driven by the objective of maximizing plantings. Since the price for water and the payment of O&M is not taken into account, maximizing plantings is equivalent to maximizing net returns. The model features release functions and physical characteristics of the dam. Since cropping activities in the Rio Mayo Valley are divided in two seasons, one operational rule will be applied to each season. In particular, the release rule for the FW season is a more aggressive rule due to lower water transmission losses in this season and to the higher value of the corresponding crop portfolio. Table 6.1 shows the specific form of the release functions.

Thus, given a beginning-of-the-year stock of water (October 1), the operator releases water according to the release rule for the FW season. This allocation of water is used to grow crops between October and March and the number of hectares planted is computed using the planting response function for the FW season. In the month of April, the operator computes the amount of water available for the SS season, taking into account the FW releases, the accumulated inflows, and the evaporation losses. In turn, the stock of water in storage as of April 1 and its corresponding release rules determine if the SS season will be carried out. If carried out, the SS plantings response function is used to compute the number of hectares planted. At the end of the year, two computations are carried out. First, the annual plantings are computed by adding the FW and SS plantings. Second, the end-of-the-year stock of water is computed, by adding inflows received and deducting releases and evaporation losses during the SS season. Consequently, the end-of-the-year stock is the starting stock for the planning period.

The conceptual framework of the operation of the Rio Mayo Valley irrigation district is designed to capture the fundamental decision of how to design reservoir release rules that maximize plantings in an environment characterized by stochastic reservoir inflows. The basic framework integrates three sub-components: a reservoir operation model, simulated inflows, and planting response.

Subcomponent 1: A Reservoir Operation Model

A reservoir operation dynamic algorithm is used to trace the state of the system at any point in time during a given planning horizon. The reservoir operation model is built upon the physical characteristics (e.g., maximum and minimum storage capacity, evaporation losses, transmission losses, etc.) of the Adolfo Ruiz Cortinez (Mocuzari) dam, which serves the irrigation needs of the Rio Mayo Valley irrigation district.

Subcomponent 2: Simulated Inflows

Monte Carlo simulation methods are used to generate simulated reservoir inflows for the two time periods; 1) October – March and 2) April – September. The simulated inflows are drawn from the empirical marginal cumulative distributions derived from the record of historical inflows in the 1944-2002 period. Bi-variant random inflows are developed to represent 1000 years of inflows. The correlation between time period 1 and 2 is .23.

Subcomponent 3: Planting Response

Planting response functions are used based upon the released of water from the reservoir for fall/winter (Season 1) and spring/summer (Season 2). These response functions account for the transmission losses in two dimensions: 1) diminishing transmission efficiency in the irrigation district as water is released to points far-off the reservoir, and 2) the relatively higher transmission losses that characterize Season 2.

The objective of the reservoir operation model is to trace the evolution of the system as dictated by release rules that manage hectares planted for each season given the uncertainty of replenishing the levels of storage. However, the evolution of the system must comply with the physical characteristics of the reservoir and the technical aspects of the response of plantings to irrigation applications. Among the physical characteristics, the levels of maximum and minimum storage capacity of the reservoir are taken into consideration. Additionally, evaporation losses in both seasons are tracked to account for water availability.

During each year on the planning horizon, the algorithm consists of 8 steps as presented in Figure 8.6. In the first year of the model, the first step is to decide how much water to release as dictated by the release rule for Season 1. When the program is initialized an initial storage volume is assumed, but in the subsequent years the model automatically computes the initial storage level in Season 1. In the second step the model computes the total plantings of a given crop portfolio using the planting response function for Season 1 and the results obtained in step 1. In step 3 the program updates the equation by taking into account reservoir inflows, evaporation losses, and releases during Season 1. Based on the initial storage level in Season 2, step 4 applies the release rule for Season 2. In step 5 the land response function is used to compute the plantings of the crop portfolio in Season 2. In step 6 the storage evolution equation is updated to compute the total availability of water for next year. In step 7 the total annual indemnity payments for the current year are computed and the premium for subsequent year(s) is paid. In step 8 the total net returns are computed by summing the payoffs from plantings and insurance applicable to the current year and deducting insurance premium for next year's contract. Finally, in step 9 the program is reinitialized to decide the water allocations for the subsequent year.

Figure 8.6: Model Notation

ha_{it} = total plantings of the crop portfolio in the i^{th} season of year t (hectares).

S_{it} = reservoir storage level at the beginning of i^{th} season in year t (m^3).

$S\max$ = Maximum capacity of the reservoir (m^3).

$S\min$ = Minimum (dead) capacity of the reservoir (m^3).

$S\max_2$ = Maximum storage level at the beginning of Season 2 for flood control (m^3).

I_{it} = reservoir inflows during year t in (m^3).

R_{it} = reservoir releases during year t in (m^3).

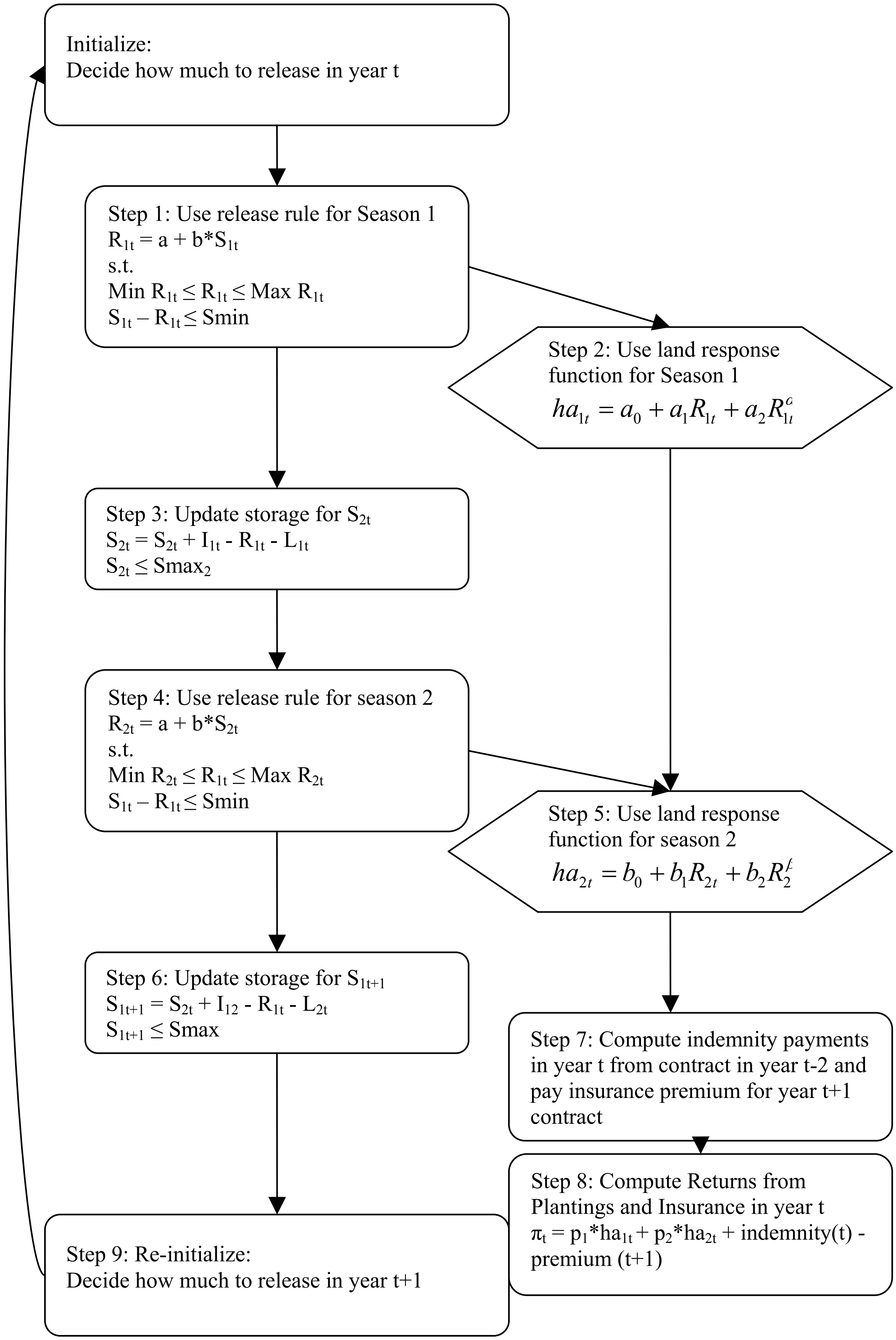
L_{it} = evaporation and other losses in year t in (m^3).

p_i = average (weighted) net return per hectare from portfolio ($).

π_t = total per-hectare net return in year t ($).

Note: the i^{th} season refers to either the fall-winter or the spring-summer season

Figure 8.6: Reservoir Operation Model



8.B. Planting Response Functions

Due to the physical characteristics of the district, the efficiency of water transmission is not the same across land parcels and between seasons. Land parcels located nearer the main canals benefit from greater transmission efficiency than the land parcels at more distant locations. Therefore, one expects that if all parcels in the district were to receive the prescribed water volume for maximum yield, some version of diminishing marginal returns to applied irrigation will take effect. The curvature of the response function of plantings to irrigation will capture such "diminishing returns" as they are triggered by the heterogeneous transmission efficiency across land parcels in the district. In the second dimension, the transmission efficiency is different for Season 1 and Season 2. During the higher temperature of the summer months the transmission losses due to evaporation are greater; therefore, other things equal, one cubic meter of water delivered to the same parcel irrigates more land in Season 1 than in Season 2. To reflect these relationships, response functions for plantings have been estimated for both cropping seasons.

9. Optimal Water Allocation and Insurance

Given the opportunity costs caused by inadequate water supply, farmers might be willing to pay a proportion of the opportunity cost in the form of an insurance premium for a weather derivative/insurance contract that will smooth their income over time. However, before estimating insurance premiums, it is necessary to estimate the opportunity cost and optimal allocation of water between the fall/winter and spring/summer seasons.

A conceptual model of the decision environment is presented as follows:

NTR = Net Total Revenue.

$y_{i,t}$ = yield of i[th] crop planted in season t. In this model t = 1,2.

$p_{i,t}$ = price of the i[th] crop in season t.

$c_{i,t}$ = per hectare production costs of the i[th] crop in season t.

$N_{i,t}$ = total hectares of land under the i[th] crop in season t.

$w_{i,t}$ = water application to i[th] crop in season t.

$\alpha_{i,t}$ = water response coefficient of the i[th] crop in season t.

$\beta_{i,t}$ = water response coefficient of the i[th] crop in season t.

$\overline{w}$ = water available as of October 1.

$\overline{N}$ = land constraint.

$$\underset{N_{i,1},N_{i,2},w_{i,1},w_{i,2}}{MAX} \sum_i y_{i,1}(p_{i,1}-c_{i,1})N_{i,1} + \sum_i y_{i,2}(p_{i,2}-c_{i,2})N_{i,2} \qquad (1)$$

s.t.

$$y_{i,1} = \phi + \alpha_{i,1}w_{i,1} - \beta_{i,1}w_{i,1}^2 \qquad (2)$$

$$y_{i,2} = \phi + \alpha_{i,2} w_{i,2} - \beta_{i,2} w_{i,2}^2 \quad (3)$$

$$\sum_i w_{i,1} N_{i,1} + \sum_i w_{i,2} N_{i,2} \leq \overline{w} \quad (4)$$

$$\sum_i N_{i,1} \leq \overline{N} \quad (5)$$

$$\sum_i N_{i,2} \leq \overline{N} \quad (6)$$

This model estimates the MVP (marginal value product) of water in fall/winter and spring/summer seasons, so that water will be allocated using equi-marginal principles. In this model, farmers would not have to plant all the available hectares in the fall/winter season, saving some water to be used for high value crops in the spring/summer seasons, discounting for transfer and evaporation losses. The modeling of this behavior will allow a more accurate computation of the revenue-generating opportunities forgone under any inadequate volume of water in the reservoir. Subsequently, the opportunity cost will give an estimate of the expected losses due to inadequate water supply and the premiums to be paid to hedge that risk. The input for the model appears in Table 9.1.

Table 9.1: The Current Model Input and Output Variables

Dam Management Parameters		Net Returns per Hectare		
			Without Insurance	With Insurance
Max Capacity of Dam	1386			
Min Capacity of Dam	28	Historic Income 1943 to 2002	91687	88371
Flood Control Level Stor2	1000	Monte Carlo Income	92523	89117
Min Release Season 1	200	Standard Deviation	15798	12811
Max Release Season 1	700	Coefficient of Variation	17.1%	14.4%
Min Release Season 2	50	VAR Threshold	15.2%	14.0%
Max Release Season 2	500	Conditional VAR	10054	9799
Relative Price Season 2	70%			
Evaporation Rate Season 1	7%			
Evaporation Rate Season 2	10%			

	Function Coefficients			
Rules for Release	C	B1	B2	Power
Release in Season 1	187	-0.0005	0.02	1.5

See Function: C + B1 * Stor1 + B2 * Stor1^Power				
Release in Season 2				
See Function: C + B1 * Stor2	0	0.6		
Response of Hectares Planted for Release in Season 1 vs. Season 2				
Response Function for HA1				
See Function: C + B1 *Rel1 +B2 * Rel1^Power	-21000	380	-8.8	1.5
Response Function for HA2				
See Function: C + B1 *Rel1 +B2 * Rel1^Power	-12000	245	-5.6	1.5

Table 9.1: The Current Model Input and Output Variables (cont'd)

Insurance Hedging Parameters*	
Strike to begin payments Mm^3 of runoff going into the dam	700
Response Function to reduce payments Min and Max levels	100 / 500
Payment rate for every one unit of water below strike approx. 1 unit = 100 HA	100
Set a minimum threshold for developing a VAR and Conditional VAR analysis	75,000
*Payments begin based on the total runoff in the year prior to the current crop year: They are reduced as the amount of runoff occurring in seasons one of the current crop year increases.	
Insurance Performance Variables	
Pure Premium in Units of Water	23 / 2.5
Premium in Hectare Equivalences	5677 / 2271
Loaded Premium Rates using Hectare Income	8.1%

Source: Authors – Modification from the Excel Spreadsheet Rio Mayo Valley Monte Carlo Model

10. Water Supply Risk

In this section a sensitivity analysis is performed with respect to the set of release rules. In the absence of insurance or other risk-transfer mechanism, the literature states that the only source of risk management for the reservoir operator is the release rule. However, the risk reduction achieved with this mechanism is marginal. This principle will be demonstrated comparing the simulation results obtained from two sets of release rules. In Table 10.1 the results from two release rules are compared. The first set favors a relatively aggressive policy in Season 2. In contrast, the second set is more aggressive in Season 1 and more conservative in Season 2.

Table 10.1: Simulation Output from Two Sets of Release Rules

Release Rule	Mean	Std Dev	Coef Var	Skewness	Minimum
Rule 1	92516	15791	17.0	-0.317	52074
Rule 2	92339	14718	15.9	-0.220	54178

Release rule equations:

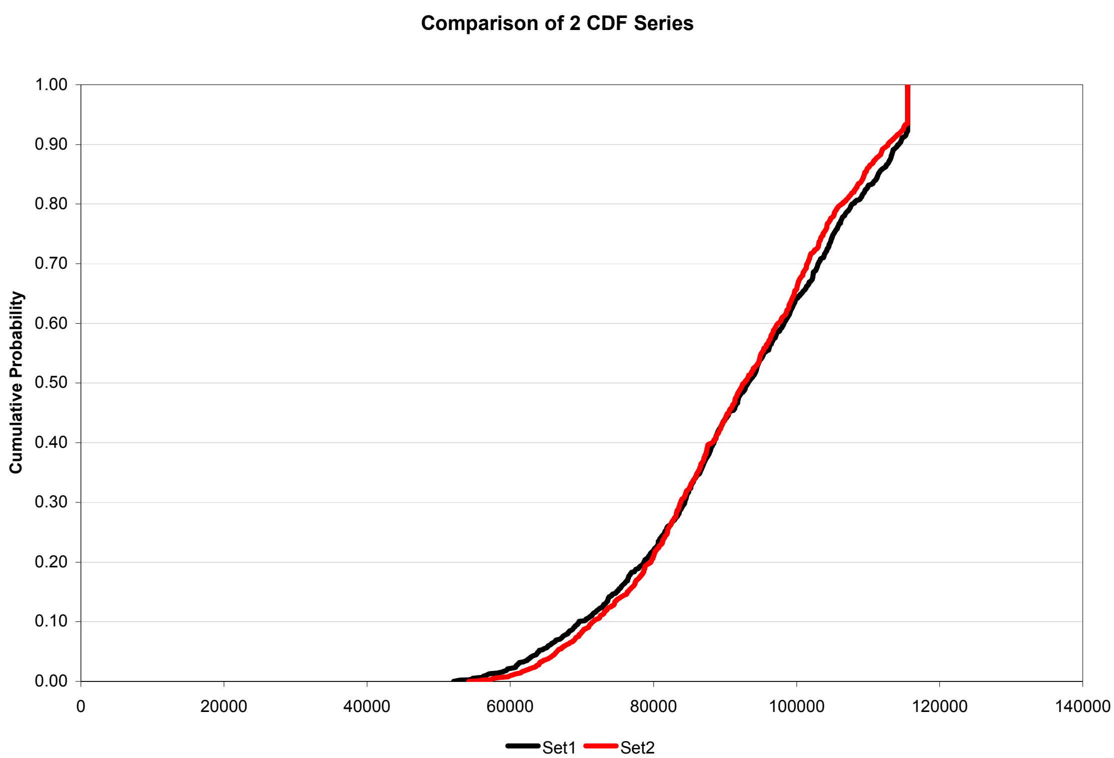
Release rule 1= 387 -0.0005 x StorOct1 + 0.020 x $StorOct1^{1.5}$

Release rule 2= 200 -0.0005 x StorOct1 + 0.021 x $StorOct1^{1.5}$

Source: Authors

Based on these functions, a Stochastic Efficiency analysis was carried out in Simetar. Figure 10.1 shows the CDF under both scenarios.

Figure 10.1: Empirical CDF Functions under Alternative Release Rules



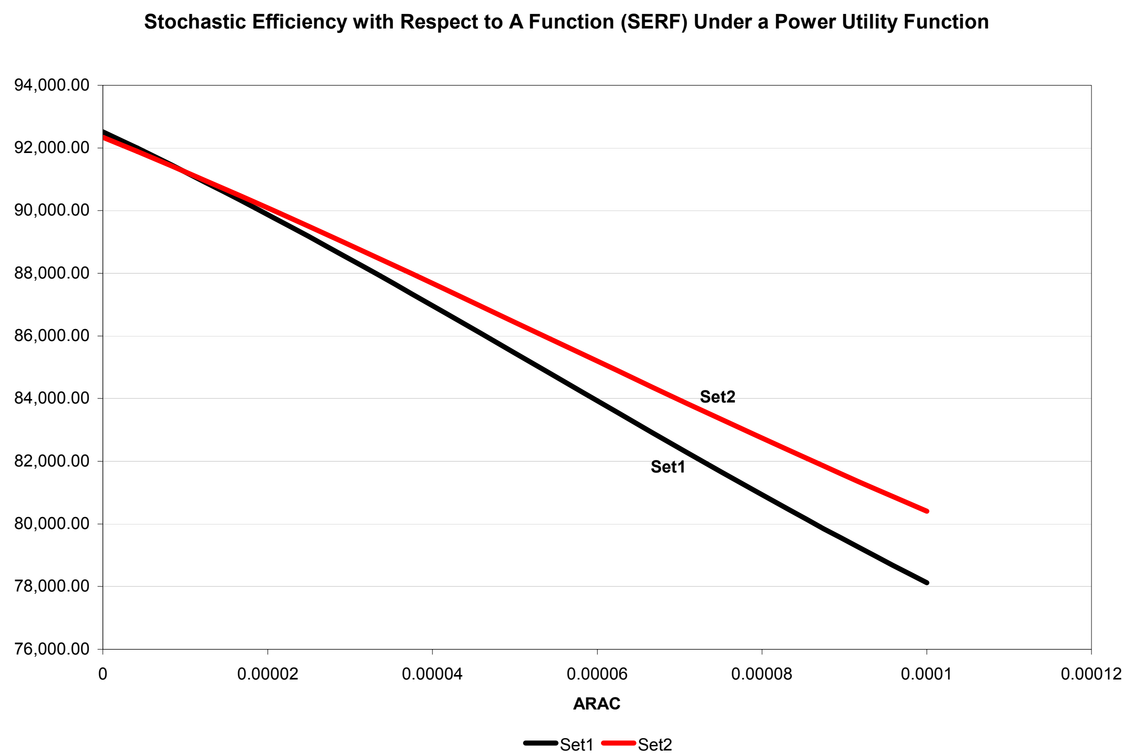
Source:

Figure 10.2 demonstrates that release rules are by themselves a source of risk management for operators of the ARC reservoir and Rio Mayo Valley irrigators. According to the stochastic efficiency analysis, irrigators would have to be slightly risk averse in order to be indifferent between “set 1” and “set 2” release rule scenarios. In terms of the certainty equivalent (CE)

measure[12] (amount of money that irrigators would have to be paid to be indifferent between the "set 2" scenario and the "set 1" scenario, for a given risk aversion coefficient), the "set 2" release rules is superior or preferred to "set 1." The higher the risk aversion the more preferred is "set 2."

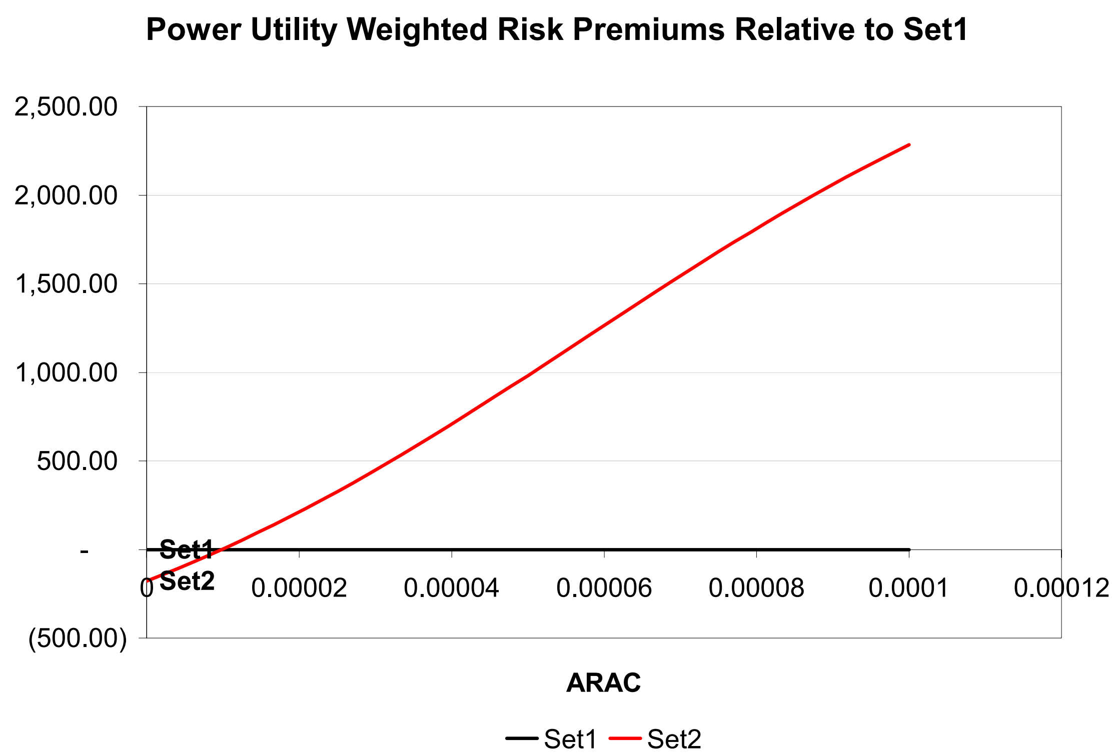
The risk premium is the amount of money irrigators would have to be paid to switch from the preferred strategy to the inferior strategy. The premium increases from -177 ha, for risk neutrality, to 2,284, for a higher level of risk aversion (Figure 10.3).

Figure 10.2. Certainty Equivalents for Scenarios under Alternative Release Rules



[12] The analysis is based on a power utility function that exhibits constant relative risk aversion (CARA) such that preferences are unchanged when all the payoffs are converted to a monetary unit by multiplying by the appropriate per hectare returns.

Figure 10.3. Risk Premiums for Scenarios under Alternative Release Rules



10.A. Combining Release Rules with Inflows Insurance

When insurance is imposed using the release rules described above, there are some insights into the level of risk aversion required for the SRL to engage in an insurance contract. For example, for the set 1 of release rules, the SRL would need to have relative risk aversion coefficient slightly below 0.0006 (or be "rather" risk averse) in order to find the contract-generated distribution "insurance1" more attractive. Figure 10.4 shows a relative risk aversion coefficient (RRAC) of slightly below 0.0006 the premium is zero. This means that the SRL would be indifferent between the buying the insurance and operating without insurance. In Figure 10.5, also at a RRAC slightly below 0.0066, the CE lines cross each other meaning that the SRL is indifferent between both scenarios; the insurance premium has been loaded for a factor of 2.5.

Figure 10.4. Risk Premiums for Set 1 and Insurance

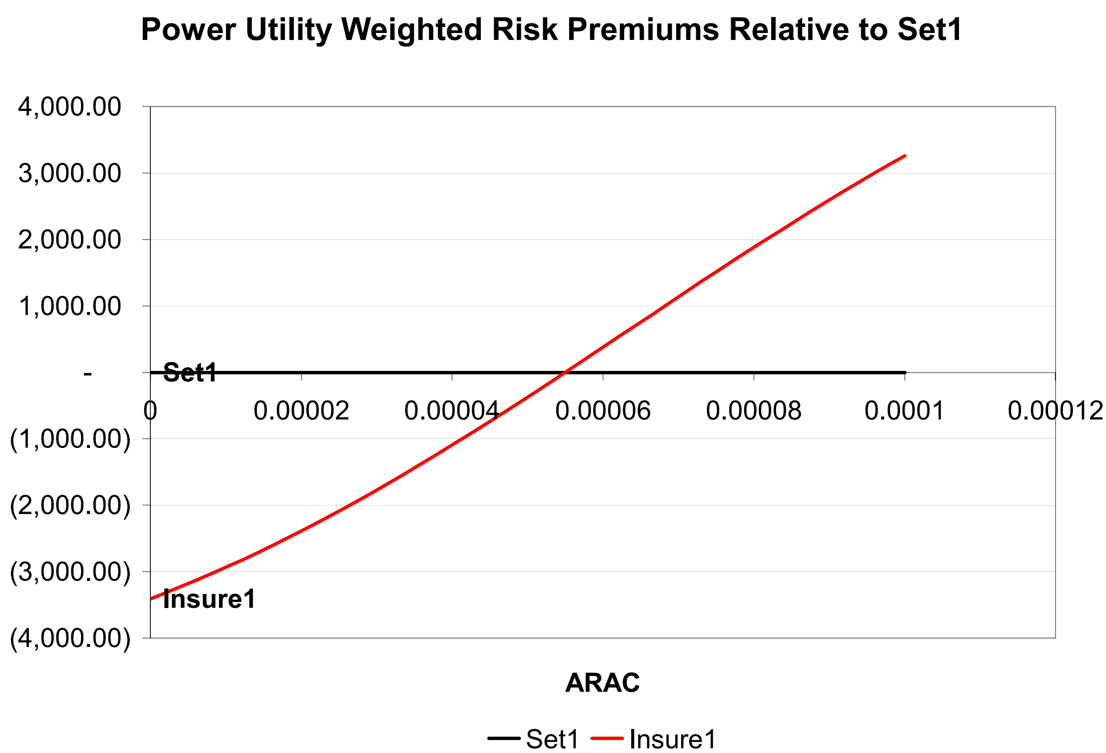
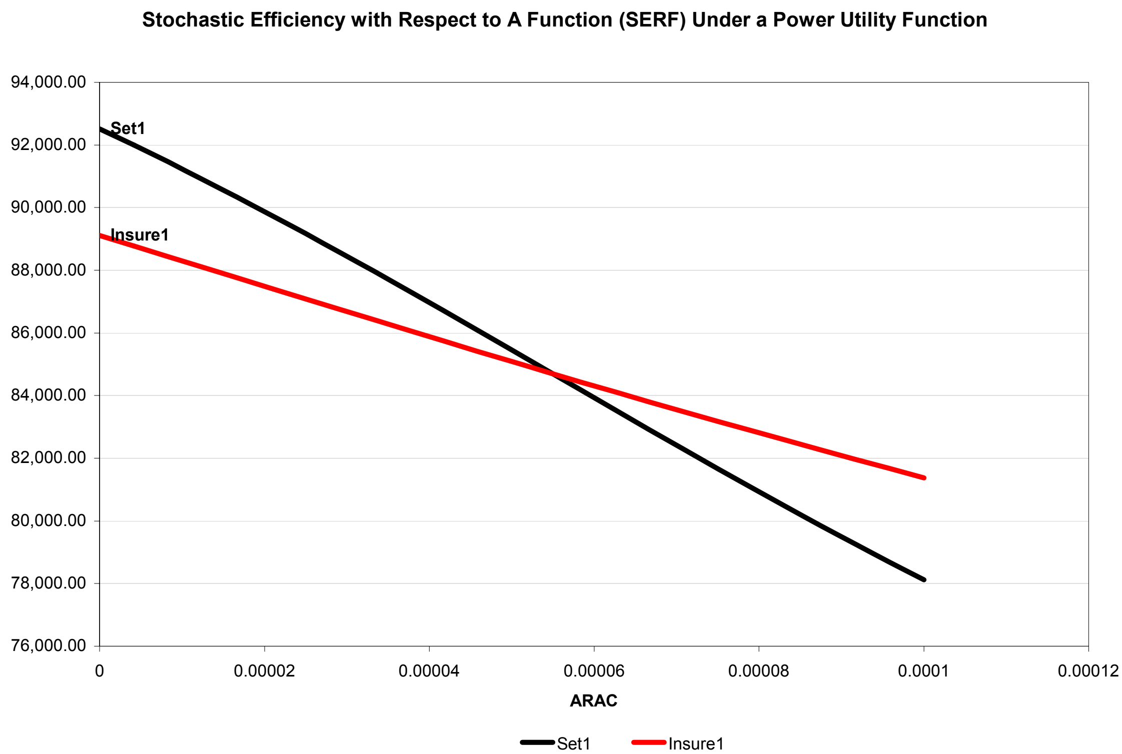


Figure 10.5. Certainty Equivalents for Set 1 and Insurance



However, in the case of the second set of release rules, the risk aversion required for the SRL to enter into the contract is higher (Figures 10.6 and 10.7). Specifically, the RRAC needs to be slightly above 0.0006 in order for the SRL to be indifferent between strategies with insurance and without insurance. The higher risk aversion required is a factor of the greater effectiveness of the second set of release rules to protect the tail of the distribution.

The analysis shows that more aggressive release rules will require a lower degree of risk aversion for the SRL to engage in the contract. More aggressive rules result in higher mean plantings, but at the expense of more risk. Several measures of risk can confirm these: Coefficient of Variation (CV), Standard Deviation (SD), Value at Risk (VaR), and Conditional Value at Risk (CVaR). The summary statistics for the four scenarios is given in the Table 10.2.

Table 10.2: Simulation Results under Alternative Release Rules and Insurance Mechanisms

Release Rule	Mean	Std Dev	Coef Var	Skewness	Minimum
Set 1	92517	15791	17.1	-0.317	52074
Release1	89108	12808	14.4	0.087	56334
Set 2	92339	14718	15.9	-0.220	54178
Release2	88930	11920	13.4	0.193	61465

Source:

Figure 10.6. Risk Premiums for Set 2 and Insurance

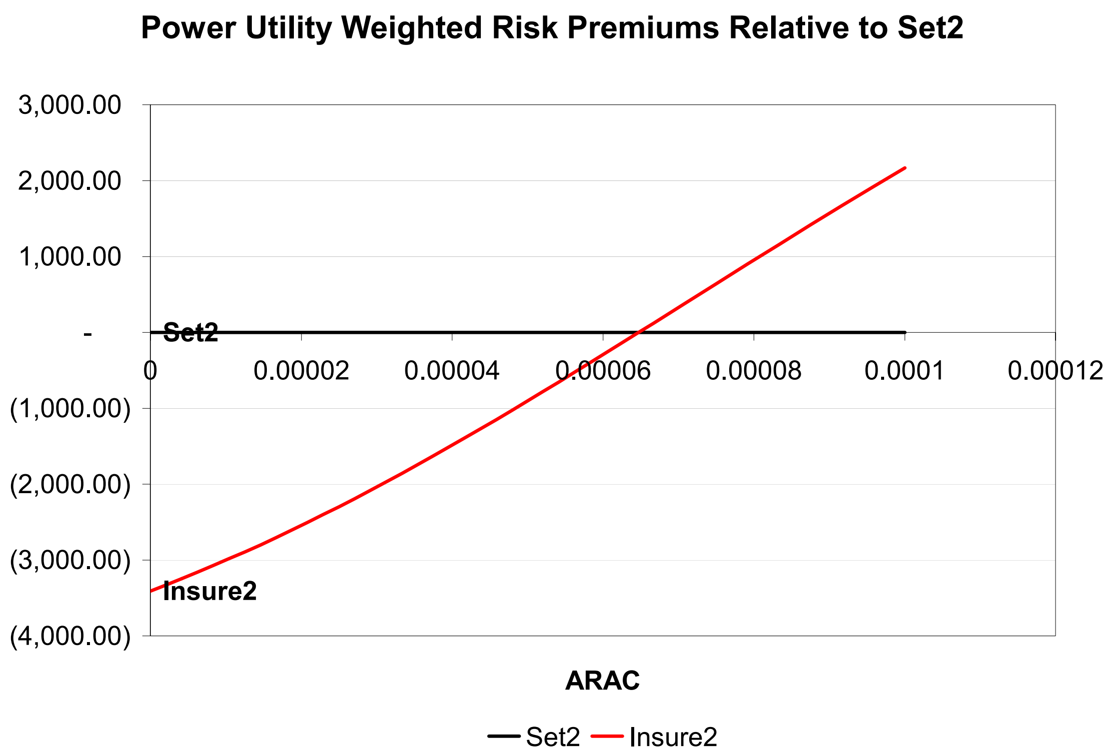
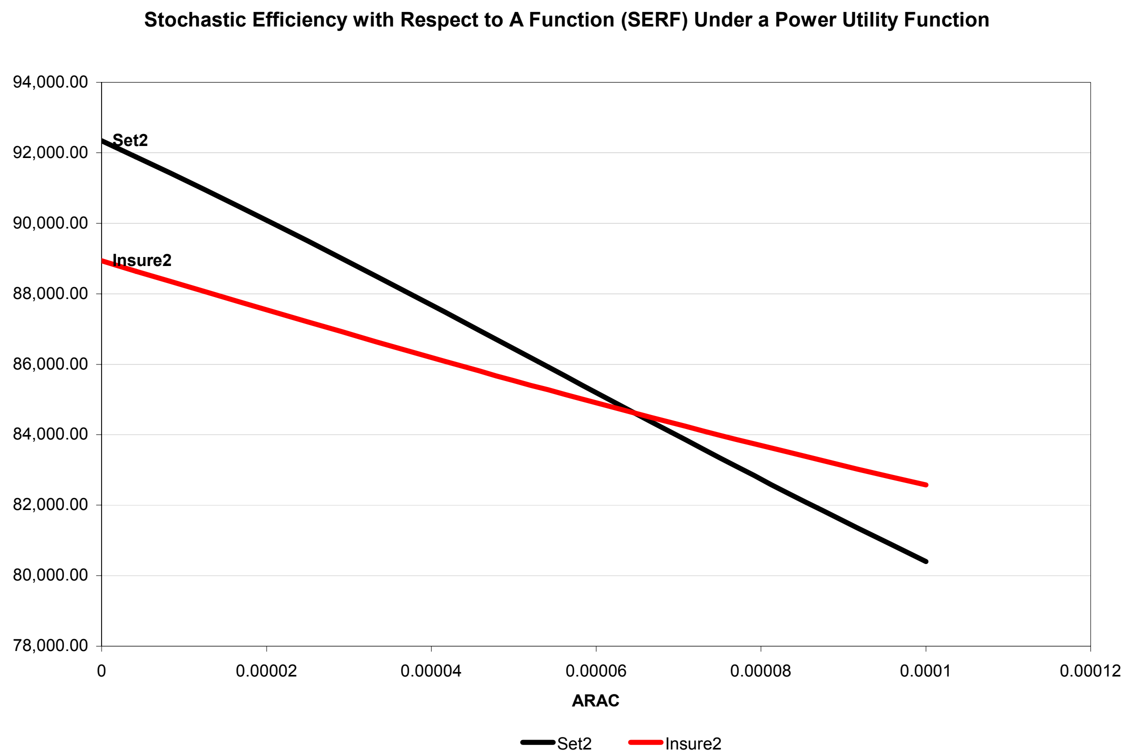


Figure 10.7. Certainty Equivalents for Set 2 and Insurance



11. Tailoring the Inflow-Based Insurance

There are six elements in the design of a weather insurance contract: the underlying variable, the accumulation period, the location of measurement, the trigger, the limit, the tick size, the liability, and the indemnity rules. Each element requires careful choices that ultimately determine the effectiveness of this hedging mechanism. To provide an example of how this language is used, consider writing a rainfall insurance contract that would pay anytime the rain in a specified period is below 600 mm of rain. The 600 mm of rain is the 'trigger'. Payments may stop at 100 mm of rain. The 100 mm of rain is the 'limit'. A tick size could involve a payment for each 1 mm of rain. The liability is the maximum payment that would be made if the rain dropped to the limit of 100 mm. Thus, if an insured purchased $100,000 of liability, it is easy to calculate the payment level for each 'tick' of rain below 600 mm – (600-100)/ 100,000 or payouts of $200 for every 1 mm of rain below 600 (see Appendix A for more detail on more complex insurance structures).

The underlying variable used in this research is reservoir inflows. Alternatively, one could have used reservoir storage. The problem with reservoir storage is that it is the result of a combination of management and random events. One of the most basic principles of insurance is not insuring management. In contrast, reservoir inflows are a purely random variable and no manipulation can

be exercised over it. In addition, just like reservoir storage and with the help of well-understood reservoir operation policies, inflows convey all the information about the scarcity of water to the irrigator and the consequences of major shortfalls.

In terms of the accumulation period, a contract is designed that takes into account two periods. The first period runs through the entire agricultural year, thus it takes into account the inflows accumulated throughout the 12-month period corresponding from October 1 to September 30. From the point of view of the irrigator, this 12-month period determines the availability of water for the FW season. The second period is more related to the particular characteristics of inflows in the Rio Mayo Valley. In the period corresponding to October 1 to March 30, there are events that bring more than expected inflows, here termed a “bonus” event. This event is beneficial for irrigators because it replenishes the reservoir previous to the beginning of the SS season. Thus, when the “bonus” occurs, irrigators are more likely to grow crops in the SS season. The importance of this event is that it partially decreases the need for insurance. Therefore, any contract that aims to protect the income of irrigators has to take this event into account both to make premiums more feasible and to correctly price the contract.

The location where the inflows are measured is the reservoir itself. Fortunately, before the reservoir was built, CNA measured the potential inflows generated by the Mayo River. Therefore, monthly observations were obtained of the inflows dating back to 1943. More importantly, irrigators and CNA trust in the quality of these measurements, which is essential for the decision-making process.

Since a per-hectare equivalent is being used to measure the net returns to irrigators, the tick size will also be in hectares. Specifically, the contract pays 100 ha for each million m^3 below the strike level. The choice of the strike level is based on the notion that operators follow a safety-first approach. Based on the observation that plantings in the most recent years have been around 80,000 hectares, it is assumed that the objective of the reservoir operator is to guarantee irrigation for at least 75,000 hectares (77 percent of the land in the irrigation district). Therefore, a put contract that has two strikes and two indemnity rules is proposed. The first strike relates to the first measurement period (the annual inflows). It states that if the accumulation of inflows is inferior to a strike inflow level, I_c, an indemnity payment, P, will occur in April 1 of the next year (18 months after purchasing the contract). However, this payment will be reduced if the “bonus” occurs. Thus a second component of the contract is the reduction rule. In particular, the contract states that the payment will not be discounted if the “bonus” falls short of a minimum level, denoted by I_{min}. But, if the “bonus” is greater than this strike, the payment will be reduced according to a linear rule. The maximum discount occurs when inflows surpass the upper level or I_{max}. The use of some equations might further clarify the design of the rules. The maximum payment that the irrigator can get at any given time is calculated according to Equation 1.

(1) $$\overline{P}_t = TIC \times \begin{cases} 0 & if\ I_{t-1} > I_C \\ \left(I_C - I_{t-1}\right) & if\ I_{t-1} < I_C \end{cases}$$

Where I_{t-1} is the accumulation of inflows from October to September in the previous cycle; TIC is the hectare-equivalent income paid for each unit below the strike; P is the maximum expected payment if no discount is applied. However, this payment might be reduced according to the following rule:

(2) $$P = \overline{P}_t * D$$

Where D is a discount factor calculated according to the following rule:

$$(3) \qquad D = 1 - \begin{cases} 1 & if\ I_{1,t} \geq I_{\max} \\ \left(\frac{1}{I_{\min} - I_{\max}}\right) \times \left(I_{\min} - I_{1,t}\right) & if\ I_{\min} < I_{1,t} < I_{\max} \\ 0 & if\ I_{1,t} \leq I_{\min} \end{cases}$$

and $I_{1,t}$ represents the inflows accumulated from October to March in the cycle.

For example, assume the following parameters: $I_c = 725$, TIC = 100 ha. Then, if the inflows corresponding to the agricultural year 2005-2006 period were 550 million m^3, then maximum payment would be 17, 500 ha.[13] However, if inflows of 300 million m^3 were registered in the October 2006 – March 2007 period, then the payment would have to be discounted[14] to 50 percent of the maximum payment, which is 8,750 ha.

12. Model Results

The results of the insurance contract design will be assessed for the following: affordability, value for the irrigator, and risk reduction effectiveness. The affordability will be assessed according to the risk premium. The risk premium rate carries two components: the pure premium and a load. The pure premium rate is equal to the average indemnities paid by the irrigator divided by the average income of the producer. In a world with no transaction costs and more uncertainty about the distribution function of inflows, the irrigator would expect that in the long run the premium payments would be offset by the mean indemnities. However, due to administration costs and uncertainty, the insurer usually charges a "loaded" premium. For this application, it is assumed the load is 250 percent over the pure premium[15]. The best design should afford enough protection with a relatively small premium.

The risk reduction of the instrument is examined using the value-at-risk (VaR) and coefficient of variation (CV) measures of risk. According to the financial literature, VaR is a measure of the maximum financial loss for a given confidence level in a specific time horizon. For example, for a specified probability level β, VaR is simply the loss that is exceeded over the time period with probability $1-\beta$. In this empirical application, VaR in terms of reduction in hectare equivalent income is considered. However, in a slight diversion from the financial literature, this approach consists of finding the probability that the lowest level of hectare-equivalent income exceeds a desired threshold. The level of threshold chosen is 75,000 hectares. It is assumed that the reservoir operator follows an operation policy that aims at guaranteeing this level of plantings. Shortfalls below this level impose severe hardship for the irrigators. This is the ultimate risk irrigators will try to hedge against by using the inflow-based insurance.

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13 $\overline{P} = (725 - 550) \times 100\,ha = 17{,}500$

14 $D = (1 - (-0.0025) \times (-200)) = 0.5$, supposing $I_{\min} = 100$ and $I_{\max} = 500$.

15 A load of 250 percent means that the price of insurance will be 2.5 times the pure premium. Such loads for this type of insurance could range from about 200 to 300 percent. The loading is sit high to build reserves for catastrophic risk and for other factors such as administrative cost and profits for risk-taking.

While VaR provides information about the probability of experiencing reductions beyond 70,000 ha, it does not provide information about the magnitude of those extreme reductions. Therefore, the notion of conditional value at risk (CVaR) is used to measure these expected reductions. In the financial literature CVaR is a currency-denominated measure of the significant unfavorable changes in the value of a portfolio. For example, for the confidence level β, there is a VaR that can be computed. CVaR is the expected loss that occurs in excess to the VaR threshold with $1-\beta$ probability. In this application, CVaR measures the average potential reduction in hectare equivalents that occur beyond the 70,000 threshold with a given level of probability.

A valuation of this instrument from the irrigator's point of view is developed further by using the CVaR measures. The value of this insurance can be inferred by comparing the mean expected reduction in plantings beyond the critical threshold of 75,000 ha — in other words, comparing the CVaR with and without risk sharing. The difference between both measures provides a good indication of what the expected plantings reductions would be in the worst-case scenario, what irrigators would like to avoid. A proxy for the willingness to pay for this instrument likely exists when the CVaR without the insurance is greater than the CVaR with the insurance.

First, the necessity of introducing a double-trigger contract to hedge the inflows risk, as opposed to a single trigger, is discussed. In order to make this necessity clear, a comparison is made between the effectiveness of the contract with and without the discounting rule. A single-trigger contract would be simpler to implement as it could be sold at the beginning of the agricultural year (October) and the indemnity payment would be received at the end of the year (September). The put contract would pay only if inflows fall short of the strike level. However, with this design the irrigator would not take advantage of the natural hedging mechanism offered by the reservoir and the inflows during the FW season. If the "bonus" inflows are sufficiently large, irrigators have the ability to carry out productive activities during the SS season, which increases their annual income. The results from the base-case scenario (no insurance) are presented in Table 12.1.

Table 12.1: Base-Case Scenario Simulation Results (No Hedging)

VaR[a] (percent)	15.2
CV (percent)	17.1
CVaR[a,b]	10,054
Expected Annual Income[b]	92,518
Minimum Income	52,075
Maximum Income	115,545

a: Evaluated at the 75,000 ha threshold.
b: Measured in hectare equivalent income.

Source: authors' calculation

Using the response function specifications described in Table 6.1, the simulation produces a mean hectare-equivalent income of 92,523. According to the VaR measure, there is a 15 percent chance that the annual income is lower than 75,000 ha. In addition, the CVaR measure indicates that the mean loss beyond the same75,000 ha threshold is 10,524 ha.

Table 12.2 presents the different criteria that demonstrate the superiority of a double-trigger contract. Three strike levels are compared: 500, 600, and 700. The results demonstrate that while the single trigger designs (columns 2, 3, and 4) yield lower levels of relative risk, they do not protect the tail of the distribution. In essence, all the contracts yield higher VaR and CVaR measures in the income stream compared to the base case. Furthermore, since the CVaR measures under the single-trigger contracts are higher than the base case, the insurance is not a beneficial strategy under these designs.

The contract with the double trigger yields better risk reduction results. For illustration only, consider a contract that pays whenever inflows fall short of the 700 units strike in October 1, but that linearly discounts the payment for inflows above 100 units in the FW season. The discount increases linearly to the point that no payment is made whenever these seasonal inflows accumulate to more than 500 units. In this case, the premium to be paid by the irrigator is higher, namely 8.1 percent. In addition, the contract reduces the probability of falling below the VaR threshold from 15.2 percent in the base scenario to 14 percent in the case of the double trigger. Moreover, the value of protection for this particular design is 255 units, as reflected by the difference between the CVaR measures.

Table 12.2: Comparison of Simulation Results: Single versus Double Trigger Design

	Base	Single Trigger Contract			Double Trigger Contract[a]		
	1	2	3	4	5	6	7
Strike Levels	-	700	600	500	700	600	500
Premium (percent)	0	0.2	0.7	0.2	8.1	4	1.2
VaR[b] (percent)	15.2	24	17.5	15.9	14.0	15.9	15.8
CV (percent)	17.1	15.1	15.8	16.6	14.4	15.7	16.7
CVaR[b, c]	10,054	16,535	11,917	10,663	9,799	10,987	10,631
Expected Annual Income[b]	92,523	86,333	89,928	91,862	89,108	91,088	92,150

a: Double trigger applies in the FW season inflows according to the following discount rule:
$I_{max} = 500$; $I_{min} = 100$.
b: Evaluated at the 75,000 ha threshold.
c: Measured in hectare equivalent income.

Source: authors' calculation

If irrigators are interested in protecting the tail of the distribution, the double-trigger contract yields better coverage. Although the premium associated with the double-trigger contact seems a bit higher, it actually is not too high in terms of affordability.[16] Actually, the higher premium is an indication of the increased protection that can be gained by a slightly higher premium. In summary, if the inflow-based insurance is designed with a double trigger, it can better serve the objective of protecting against the downside risk associated with reduced income due to water shortages.

[16] Premium rates below 10 percent are considered affordable.

Once established that the double-trigger is superior to the single trigger contract, the next question to be addressed is: which among the double trigger designs yields the best contract? Fixing the tick size at 100 ha, there are two choice variables to arrive at the "optimal" design. The first choice concerns the trigger to be used to compute the maximum possible payment as of October 1. The second choice variable is the parameter mix in the rule that discounts the maximum payment when "bonus" inflows occur during the FW season. Table 12.3 compares different hedging strategies (i.e., selection of strikes and discounting rules) available to irrigators in the the Rio Mayo Valley district. Equipped with this information, irrigators possess an array of information that characterizes different hedging strategies and return distributions associated with each strategy.

Table 12.3: Comparison of Simulation Results: Three Double Trigger Designs

	Base	*Discounting Design*		
		Strategy A $I_{max} = 500$; $I_{min} = 100$		
Strike Levels	-	700	600	500
Premium (percent)	0	8.1	4	1.2
VaR[b] (percent)	15.2	14.0	15.9	15.8
CV (percent)	17.1	14.4	15.7	16.7
CVaR[b,c]	10,054	9,799	10,987	10,631
Expected Annual Income[b]	92,523	89,108	91,088	92,150
Value	-	255	(933)	(576)
		Strategy B $I_{max} = 400$; $I_{min} = 100$		
Strike Levels	-	700	600	500
Premium (percent)	0	7.3	3.6	1.1
VaR[a] (percent)	15.2	14	16.6	15.8
CV (percent)	17.1	14.5	15.8	16.7
CVaR[a,b]	10,054	9,814	11,510	10,624
Expected Annual Income[b]	92,523	89,445	91,218	92,187
Value[b]	-	240	(1,456)	(570)
		Strategy C $I_{max} = 300$; $I_{min} = 100$		
Strike Levels	-	800	600	500
Premium (percent)	0	10.2	3.2	1
VaR[b] (percent)	15.2	14	17.3	15.8
CV (percent)	17.1	13.6	15.9	16.7
CVaR[a,b]	10,054	9,754	12,013	10,615
Expected Annual Income[b]	92,523	87,596	91,359	92,219
Value[b]	-	300	(1,958)	(561)

a: Evaluated at the 75,000 ha threshold.
b: Measured in hectare equivalent income.

Source: authors' calculation

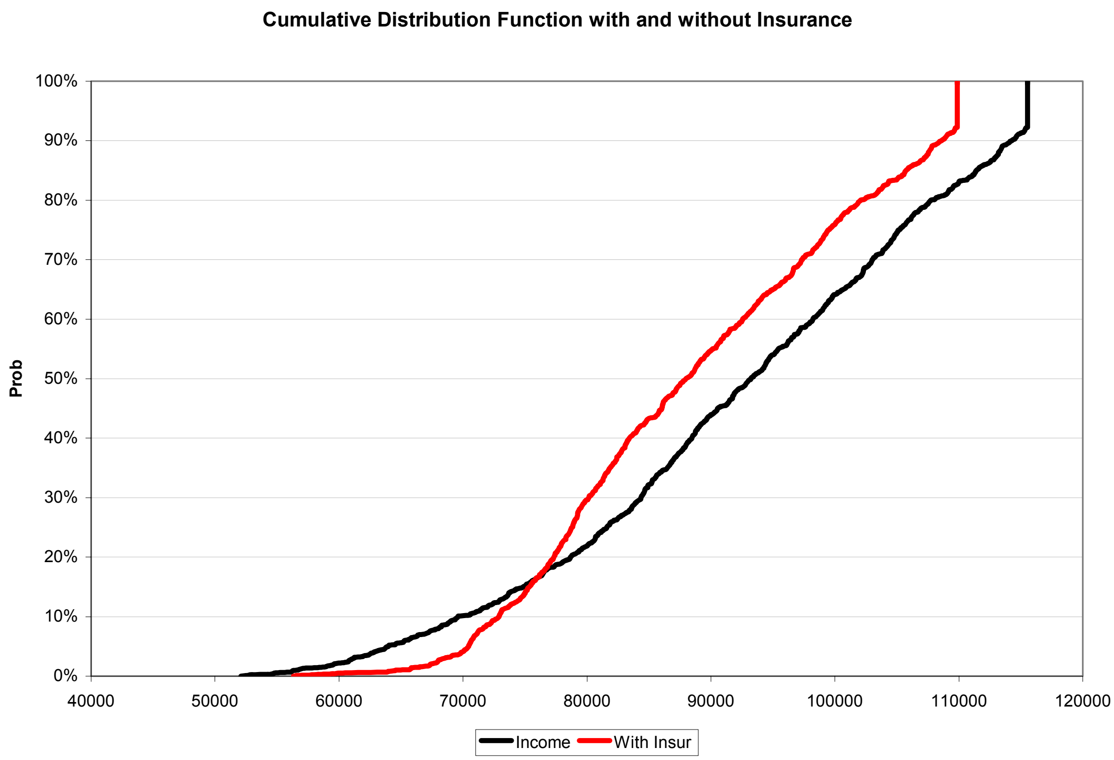
The superiority of the different designs changes across different strike levels. For example, at the strike level of 700, strategy A is superior in terms of risk reduction and valuation. The CV is strategy A is 14.0 versus 14.5 for strategy B. However, at the strike level of 800, strategy B is superior. Notice that strategy C at the 800 trigger level provides the greatest value of protection by reducing the CVaR measure by 300.

In Table 12.3 irrigators can compare the benefits and costs between strategies. For instance, consider the choice between strategy A (payments are completely discounted if FW inflows exceed 500 million m^3) and strategy B (payments are completely discounted if FW inflows exceed 400 million m^3) for a particular strike level, say 700. While under strategy A the irrigator receives a lower expected profit and pays a higher premium, the level of protection afforded with strategy A is superior as reflected in a lower probability of exceeding the VaR threshold, and a lower expected loss beyond VaR.

Upon comparison of three most feasible combinations of choice variables, it seems that the most effective contract in reducing risk is that which sets the first strike at 800 units and stops paying after 300 units in the FW season. However, this contract becomes relatively expensive as the premium rate is above 10 percent. Thus, there is a trade-off between an insurance contract that enhances risk protection and the loaded premium that needs to be paid to afford that protection.

Given these criteria, strategy A is recommended with a strike level of 700 for October 1 of each year. This strategy is affordable with a premium rate below 10 percent and yields highly satisfactory risk reduction measures. The CV measure is reduced from 17.1 percent to 14.4 percent. Moreover, the probability of producing hectare equivalent income below the 75,000 ha threshold is reduced from 15.2 percent to 14 percent. Taking into account the CVaR measures, the expected loss beyond the 75,000 ha threshold is 9,799 ha, which is 255 ha lower than the base scenario (i.e., no insurance). Figure 12.1 shows the CDF of the hectare-equivalent income under this design.

Figure 12.1. Hectare-Equivalent Income with Hedging and without Hedging



12.A. Insurance Loading and Willingness to Pay

In this section a sensitivity analysis performed to estimate the policyholder's potential willingness to pay for insurance. In this exercise, the sensitivity of the SRL to the loaded insurance premium is evaluated. In principle, if the SRL is offered an actuarially fair insurance premium, they would expect to pay a premium equal to the expected insurance indemnities made by the insurance provider. One way to gauge the willingness to pay (WTP) for any instrument is to load to premium until the SRL becomes indifferent to operating with insurance or without insurance. The maximum load can be interpreted as an upper bound of the maximum premium that can be charged to the SRL. At this loaded premium, the value of risk reduction must be positive in order for the insurance to be attractive for the group of irrigators. Table 12.4 provides the results of the sensitivity analysis with respect to the loading factor.

Table 12.4: Loading Factor Sensitivity

	Base	Alternative Designs			
Loading Factor	-	1	1.5	2	2.5
Premium (percent)		3.2	4.9	6.5	8.1
VaR[b] (percent)	15.2	8	9.7	12.1	14
CV (percent)	17.1	13.8	14	14.2	14.4
CVaR[b,]	10,054	5,672	6,846	8,520	9,799

Expected Annual Income[b]	92,523	92,515	91,379	90,244	89,108
Value		4,382	3,208	1,534	255

a: Evaluated at the 75,000 ha threshold.
b: Measured in hectare equivalent income.

Source: authors' calculation

The sensitivity analysis indicates that at the pure premium of 3.2 percent, the risk reduction measures and expected income are at their maximum. As the premium is loaded these measures start to decrease. The highest load at the 75,000 ha threshold is 2.5 to give a premium rate of 8.1 percent. This load should make the insurance contract viable for the insurer while still making it affordable for the group of irrigators. Loads beyond 2.5 will most certainly mean that the SRL must be strongly risk averse. This could very well be true as mitigating serious conflicts when there are water shortages is a strong priority for the SRL. Indemnity payments give them some opportunity to mitigate conflicts.

13. Summary and Conclusions

This report provides an assessment of the risk environment of the Rio Mayo Valley irrigation district in Sonora and developed a stochastic dynamic simulation model of the ARC reservoir. In order to accomplish this objective, empirical distributions were fitted to inflows and to plantings response functions. With this framework we designed an inflow-based insurance that mitigates the adverse impact of uncertain availability of irrigation supplies. The results indicate that for this particular reservoir the best design is a double trigger contract that discounts payments for occurrence of "bonus" inflows in each FW season. Results demonstrate that this design is feasible because it takes advantage of the natural hedging provided by the FW inflows. Furthermore, the contract is feasible as loaded premiums remain below the 10 percent benchmark.

13.A. Demand Assessment

Although we have modeled the irrigation district under the assumption that it is a single production unit, we know that in reality the district is a collection of decision units. However, the institutional characteristics of the SRL as a collective group indicate that the implementation of a contract of this type could be feasible. The SRL could be used as an intermediary between the irrigators and the insurance company that sells the contract. In this sense, the role of the SRL would be to collect the premium from the individual contribution of its members and distribute the indemnities accordingly. Since the SRL is a group of the same farmers, it already possesses informational advantages in terms of the impact of water shortages on each individual. For instance, we know that farms that are located closer see their supply see water curtailed at a lower proportion than marginal farms located in the most distant areas from the canal. The SRL could implement rules that differentiate the relative size of the premium to be paid or the indemnities to be received.

13.B. Market Assessment (supply-side considerations)

13.C. Institutional Impact and Opportunities

In the same line of thought, one could conceive that indemnity payments during water scarcity periods would provide additional liquidity to the system that would spur water market transactions. Those farmers willing to buy water will now have more cash to

confront the incremented marginal price of water due to its relative scarcity. Thus, in some fashion we can see that this contract would not only mitigate the losses to the irrigation district as a whole, but also would encourage the development of water markets that lead to an efficient use of the resource. Further research on this aspect is suggested.

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APPENDIX A: Excerpts from Skees, Hartell and Hao Paper: Weather and Index-Based Insurance for Developing Countries: Experience and Possibilities

The Emergence of Contingent Claims Markets for Weather

The advantages of weather or other index insurance products over the traditional crop insurance programs are numerous: the indemnity depends on an independent variable rather than actual losses such as crop failure, thus, moral hazard and adverse selection are significantly lower and the transaction costs are reduced significantly relative to other methods of underwriting the weather risks (Skees, Hazell, and Miranda, 1999). The underwriting of index insurance is also less costly since it does not require individual contracts and onsite inspection and loss evaluation. In a true weather market, any agent whose revenue depends on weather events would have a chance to purchase a weather index contract, such as input suppliers, microfinance organizations, banks with an agricultural book of business, and agribusinesses. The writers of indexed contracts could be anybody having counterparty risk or where their financial position moves opposite to that of agriculture for the same weather events.

New financial instruments, such as rainfall insurance, catastrophe options, and catastrophe bonds have emerged in recent years to hedge against natural disaster-related risks (Doherty, 1997; Skees, 2001). These contracts depend on indices to measure the insured losses from the catastrophe and determine the payments in a specific geographic region. Two most commonly designed weather index contracts are keyed to temperature or precipitation, measured at one or more sites.

Weather markets originated from the deregulation of the energy industry in U.S. and have expanded to Europe, Japan, and even some developing countries. The application of these markets has spread from the energy sector into agriculture, though actual trading of weather has slowed in recent years from energy markets to agricultural markets.

The history of hedging weather risk using contingent financial instruments is relatively brief although it was described as a `market' from the time of the first over-the-counter (OTC) trade made in 1997. As OTC activity grew, there became to a need for standardization and the credit assurances provided through exchange markets which was filled when the Chicago Mercantile Exchange (CME) initiated futures and options contracts on indices of temperature in 1999. Contracts were initially offered for only a few select locations but have since grown to ten seasonal and fifteen monthly contract locations in the U.S. In addition, the CME began listing a variety of derivative products on five European cities for temperature risk in October, 2003 (CME, 2003).

Over the past few years, the Weather Risk Management Association has retained PricewaterhouseCoopers to survey the size and growth the weather derivative market (PWC, 2002, 2003). They report that OTC trading has continued to grow from 695 to 4517 between 1998/9—2002/3, reflecting an ongoing need for highly tailored weather products. Most products continue to trade in temperature, but contracts written for other weather events such as rainfall, wind speed, and snow reached nearly 15 percent of volume in 2002/3. Weather derivative trading on the CME started slowly, reflecting limited initial product offerings and a lack of exposure to the new products. A record level 7,239 contracts were reported for 2002/3, up significantly from 303 in 2001/2. However, the notional value of CME trades is still relatively small compared to OTC contracts. Total weather derivative notional value of both CME and OTC contracts is estimated to be 4.2 billion USD, a slight decline from the previous year.

Furthermore, the World Bank has also been involved in providing significant technical assistance to introduce index contracts for rainfall in several developing countries (e.g., Morocco, Mexico, Tunisia, Ethiopia, Argentina, Turkey, Romania, Ukraine, and Mongolia [Skees, Varangis, Larson, and Siegel, 2002]).

The range of weather phenomena that can potentially be hedged appears to be limited only by imagination and the ability to parameterize the event. A few examples include excess or deficient precipitation either in the form of rain or snow during different times of the year, insufficient or damaging wind, frost, tropical weather events such as typhoons, various measures of temperature, and even celestial weather in the form of disruptive geomagnetic radiation from solar flare activity (Hyman, 2002). Contracts may also be designed for a combination of weather events, such as snow and temperature (Dischel, 2001; Ruck, 1999).

Despite recent growth, the industry still lacks depth in product offerings and participants—most contracts trade only in temperature and the majority of activity takes place in the energy sector. There are many other sectors that could benefit from contract innovation and risk transfer for a variety of perils (Richter Quinn, 1999; Ruck, 1999). Agriculture, whose greatest risk exposure is to that of adverse systemic weather events, is but one example of a potentially heavy user of weather-based contracts for precipitation and temperature (Harwood et al., 1999; Martin et al., 2001; Skees, 2002).

A weather derivative is a type of parametric contingent claim contract or financial security where the value of the payoff schedule is dependent on a measure of meteorological outcomes at a certain location during the contract period (CME, 2002; Hull, 2002). The instrument is parametric because the mechanism used to trigger payments is the realization of a predetermined weather index value, such as inches of rainfall or snow, rather than the direct measurement of financial loss. Unlike derivative products that are used to cushion a firm's revenue stream against output or input price fluctuation, a weather derivative allows a firm to hedge volumetric risk that results from adverse weather events (CME, 2002; Müller and Grandi, 2000). Volume compensation can be viewed as payment for real business losses that are a result of lower or higher demand (as in the case of energy) or lower production output (as in the case for agriculture) but which is not tied to the measurement of demand or output but rather to specific weather patterns having a known relationship to demand or output (Richards et al., 2002). The weather derivative "derives" its value precisely because of the relationship of measurable weather events to changes in a firm's revenue stream.

Contract form here refers to the payoff or indemnity function of a hedged position and is composed of the loss cost function and the liability. Most weather derivative contracts are of the European type where, if exercised, settlement is made at the expiration date. In general, contracts can be distinguished as being of a general form derived from standard puts and calls in a formal exchange setting or of non-standard forms developed in an OTC environment where the payoff structure is specially tailored to specific individual needs without relying on an underlying futures contract. Those belonging to the second type may be viewed loosely as insurance derivatives. All weather derivatives are considered exotic even if they are exchange traded because they are non-standard when compared to commodity derivatives. They are non-standard for the following reasons: 1) the underlying asset (weather) is not tradable but rather, is an index used for cash settlement; 2) because the payout usually depends on the accumulated value of the index over the contract period rather than on the terminal value; 3) because the strike is not a price but rather an index value; and 4) because the contract period may span many years and involve multiple opportunities to strike (Hull, 2002; Villinski, 2003).

The payout structures for weather put and call options are presented below. A long put option pays out the amount the strike (*X*) exceeds the weather index value (*W*) at maturity multiplied by the tick value (*k*), given by:

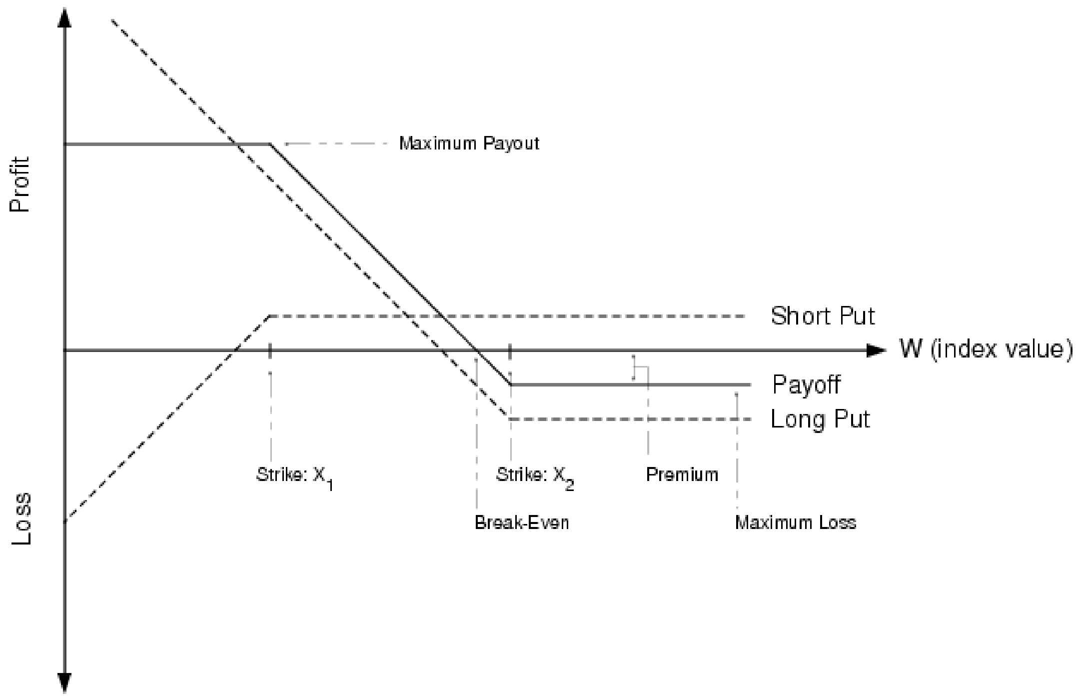
(1) $P_{put} = k \times Max(X - W, 0)$

A call option on a weather event is given by:

(2) $P_{call} = k \times Max(W - X, 0)$

To illustrate the potential flexibility of weather derivatives, consider a hedge against deficient rainfall (i.e., drought) using a combination of short and long put options. In an agricultural setting, farm production losses build as cumulative rainfall declines during some critical period. At some point, production losses are 100 percent for very low levels of precipitation (low index value) but before a zero value of the index. For hedging purposes, it may be sufficient to limit the payout in the area of the index where maximum losses are expected (in other words, only a layer of risk is important for the crop being considered). To form such a hedge in an exchange environment, a producer could create a vertical spread by taking a short put position at a low strike level (X_1) representing maximum loss (not zero precipitation) while also taking a long put position at a higher index value (X_2) corresponding to the first realization of loss. The payout structure for this combination is shown in Figure 1. By taking two put option positions with different strike prices, a bear spread is defined that protects a producer from downside risk (Hull, 2002). Such a spread may also be described as a capped put option. The advantage of capping the payout is a slight reduction in the overall hedge premium from writing the put and may serve to preserve liquidity in the market by limiting the potential financial exposure of market makers (Geman, 1999). The ambiguity associated with the very lowest levels of risk is most likely to be priced quite at much higher levels than for risk that are more common.

Figure A1: Illustrative payoff of a bear spread



Analogously, to protect against revenue losses associated with excessive precipitation, a producer could take two call option positions against the weather index to create a bull spread or a capped call option. Suppose a producer is interested in limiting exposure against both deficient and excessive precipitation. Such a strategy could be accomplished using ordinary puts and calls by constructing a reverse butterfly spread or a bottom vertical combination (strangle).

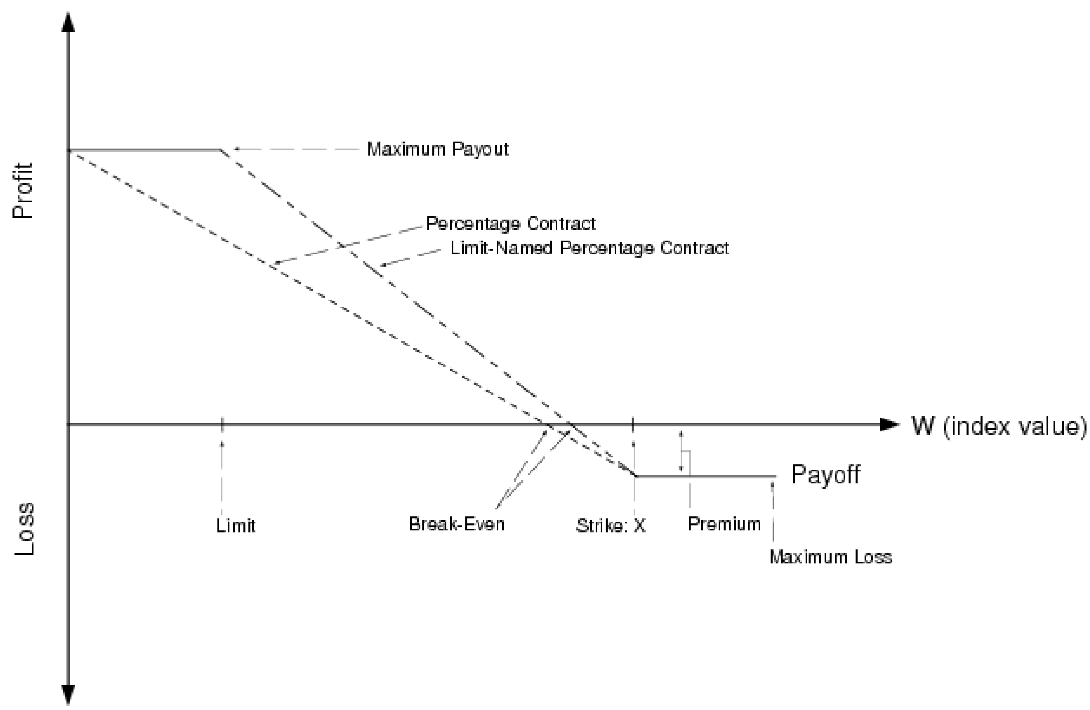
In the agricultural economics literature, a European precipitation option is proposed by Skees and Zeuli (1999) and later developed by Martin et al. (2001). In the first, a percentage contract is a variation on the linear form given in Equation 1 above. The payout is expressed as the desired level of liability (*l*), or coverage, multiplied by the percentage of the strike value realized at expiration (Skees, 2000). Notice that in defining a total liability level a ceiling on payments is imposed when the index is equal to zero. Martin et al. modified the percentage contract by the naming of a limit variable which specifies the index value below the strike value at which the full level of liability, or coverage, is paid, rather than when the index value stands at zero:

$$(3)\ P_{put} = l \times \begin{Bmatrix} 1 & if\ \ W \leq \lim it \\ \left[\dfrac{(X-w)}{(X-\lim it)} \right] & if\ \ X \geq W > \lim it \\ 0 & if\ \ W > x \end{Bmatrix}$$

In effect, the lower bound of the index is shifted to the right, resulting in a payoff schedule that more rapidly achieves the maximum payment level, as shown in Figure 2 (Martin et al., 2001). This structure closely mimics the bear spread and has the same advantages in that the index limit value can be set at the level of highest revenue loss associated with a weather event, which may

be less severe than implied by the range of the index. Similarly, the maximum payout is capped at the level of liability.

Figure A2 Illustrative payoff for a low precipitation derivative



As a financial instrument, weather derivatives may offer important additional leverage not available with other traditional risk coping strategies, potentially providing the same or better protection but at lower overall opportunity cost. A weather derivative essentially provides a cross hedge of production or demand volume with revenue. Furthermore, the most extreme weather events are likely to adversely impact more than one farming enterprise. Combining weather derivatives to manage volumetric risk with existing financial derivatives for hedging price risk, can result in a powerful set of tools to manage revenue risk.

Derivative Hedge versus Insurance

As demonstrated, the put option is designed to hedge against the downside risk on revenue associated with a particular weather event such as deficient rainfall. This characteristic of limiting or compensating for losses is analogous to insurance (Hull, 2002). A natural question to ask, therefore, is in what ways are weather derivative instruments and insurance different and, perhaps more importantly, what are the binding constraints against using traditional insurance contracts for weather related risks.

Weather derivatives do not fall completely in either category of these two frameworks. Weather risks are not independent but rather have large spatial correlations though these correlations are still less than 100 percent. The covariate risk of many weather events poses special problems for insurance. Weather events violate one of the preconditions for an insurable risk, namely the absence of catastrophic loss or the possibility that most individuals are negatively impacted by the same event over some geographic area. When risk is not independent, gains from pooling across

insured units is greatly reduced. Furthermore, the insurance premium associated with catastrophic loss coverage is unlikely to be affordable in the absence of a subsidy (Rejda, 2001). Not all weather events are geographically correlated. For example, crop losses due to hail are sufficiently independent such that private crop insurance against this peril is routinely available at affordable premiums.

Since insurance contracts are designed to indemnify only for actual loss, they are not meant to be instruments of speculators or gamblers (Rejda, 2001). While the purpose of hedging is risk reduction, derivative contracts may also be used by speculators wishing to take a (profitable) position in the market based on their expectations of future market or index movements. This is a legitimate activity and is one source of liquidity, at least in exchange markets.

Unlike an insurance product, weather derivatives may be used strategically to hedge the position of rivals or even suppliers whose volumetric risk might translate into price level risk for the enterprise (Müller and Grandi, 2000).

Pricing Weather Derivatives and Other Index Insurance Contracts

While options on stocks, commodities, and the weather all share the term "derivative'", the usual derivative pricing methods, such as the Black-Scholes option pricing model, fail in the case of the latter. Two principle reasons include: (1) A weather index does not have a traded underlying asset unlike a stock option---there is no spot market or price for weather events. Applying principles of risk-neutral valuation or a replicating portfolio to the valuation of weather options is inappropriate (Davis, 2001; Hull, 2002; Martin et al., 2001; Villinski, 2003); (2) There is considerable doubt that the data generating process of most weather events, or specifically the weather index, results from geometric Brownian motion (Dischel, 1999a; Martin et al., 2001; Richards et al., 2002). In practice, weather options are frequently valued using actuarial methods but sometimes in combination with modified (or naively used) option-type techniques. These different methods can deliver widely divergent results depending on the assumptions made and the position of the strike price (Turvey, 2002).

The burn rate, or historical burn, method refers to actuarial or insurance-type techniques of weather derivative pricing using historical data to compute probabilities of future events (Hull, 2002; Müller and Grandi, 2000; Turvey et al., 1999). The method involves obtaining a time series of historical data for the weather event of interest, removing the effect of trend in weather variability, and finally constructing the probability distribution function of the weather variable. The probability distribution may be used to develop a suitably specified derivative contract given an assessment of the value at risk and probability of loss. Applying the contract to the historical data then gives a distribution of payoffs, or expected loss, of which the mean or break-even value represents the actuarially fair, pure risk premium (Dischel, 2002; Ramamurtie, 1999,). This premium amount is normally discounted from maturity of the contract to present value at the risk free rate (Hull, 2002).

A primary advantage of the burn rate method is its relative ease of application; however there are a number of assumptions and shortcomings. The method is static in the sense that the future weather probability distribution and variability is assumed to be well represented by the past as analyzed today, which implies there is no ready means to incorporate new information and update the probabilities. This feature is seen to reduce the possibility of risk arbitrage and therefore limit trading activity (Richards et al, 2002; Turvey, 2002). One assumption underlying insurance pricing is that the insured portfolio is composed of a large number of similar but independent

risks which, by the Central Limit Theorem, reduces the coefficient of variation and per unit risk to the insurer (Rejda, 2001). In general however, there is no application of large numbers (few contracts) or necessarily independence of risk in the case of weather derivatives. Therefore, the pure premium is most certainly loaded to accommodate the ambiguity risk (Ramamurtie, 1999; Zeng, 2000). Of course, the premium may be loaded for other factors as well, such as administrative costs, profit, and on the basis of long-term forecasts (Dischel, 1999b).

There have been efforts to work through some methodological issues so that a pricing model in the spirit of Black-Scholes could be applied to weather. To do so, one basic need is to understand the form of the data generating process that describes the risk and outcomes associated with weather patterns (Turvey, 2002). While many weather events can be described as evolving from a continuous-time stochastic process not unlike stock prices (Dixit and Pindyck, 1994), the uncritical application of geometric Brownian motion to describe the process may not be accurate. For example, Richards et al. (2002) find that a model of mean reverting, geometric Brownian motion with log-normal jumps and first-order autoregressive conditional heteroscedastic errors better represents the evolution of historical Cooling Degree-Day data than simpler models. Further, it is likely that different weather events (temperature vs. precipitation, for example) evolve differently.

Historical weather data are sometimes used to estimate the shape parameters of specific distributions. The gamma distribution is often used for events such as rainfall where there is a natural lower bound at zero but no upper bound (Martin et al., 2001). One shortcoming with this type of curve fitting is that it may fail to capture the real probability of severe events in the far left tail of the distribution, a feature not uncommon to certain weather events such as flood, excess rain, or wind speed.

Dischel (1999a) pursued work in simulation techniques using a mean reverting model of temperature and temperature change to form the probability distribution for temperature. He suggests that this approach may represent a more realistic approximation of the temperature "population" from which the observed historical sequence was drawn. While computationally burdensome, several other advantages include no imposed form of the probability distribution, the simulation incorporates temperature trend that may occur in the data, and the model may be adjusted for seasonal forecasts.

The assumption of a log-normal distribution for heating and cooling-degree days is frequently used nonetheless, backed by analysis of the historical data for certain locations (Müller and Grandi, 2000), or used within the context of dynamic programming to value options (Villinski, 2003). Other aspects of traditional derivative pricing, such as the use of the risk-free rate for discounting, are also questioned with the suggestion that the market price of risk is the appropriate discount rate to use (Turvey, 2002; Davis, 2001).

New Players and the Challenges Ahead

Several challenges face the weather market industry and its prospects for maturity. One is to continue to innovate and provide new contract offerings to meet the needs of potential participants outside the energy sector. A second is to continue development and refinement of weather option pricing methodologies (Richards et al., 2002; Turvey, 2002). Yet another challenge is to cultivate the emergence of a critical mass of market makers to provide for a competitive and liquid market (Dischel, 2002). Since the bankruptcy of Enron and the destabilization of several important industry participants, many of the professionals involved in weather trading have been hired by international reinsures. Some reinsurers that will write weather index insurance include – SwissRE, PartnerRE, SCOR, ElementRE, ACE, etc.

The advent of weather desk and weather insurance product development within reinsurance companies can be viewed as a positive sign. While one may not expect the efficiency in pricing that comes from a traded market, many of the weather products that are needed for agriculture are far too specific to emerge in a traded market. In most cases, these products require special tailoring (Hess, 2003). Furthermore, for many of the special cases in agriculture a logical counterparty risk may be lacking. In short, having a reliable party with good financial backing write weather insurance contracts will likely be far superior to the elusive promise of a weather market. Thinly traded generic contracts for agriculture may simply not fit, especially for a developing country. Nonetheless, there are significant challenges to reinsures writing weather insurance in developing countries: 1) the propensity to add heavy loads for extreme risk events and the ambiguity risk that accompany catastrophe level risk; and 2) the high transaction cost associated with building a weather market in a developing country. These challenges require special considerations that involve institution building. The World Bank has been involved with these efforts by providing technical assistance to a number of countries (Morocco, Mexico, Argentina, Ukraine, Romania, India, Nicaragua, Mongolia, etc.). Still, the discovery of appropriate roles for government, non-government organizations, and markets in natural hazard risk in general and agricultural production risk in particular requires further conceptual development and discussion. Furthermore there are limited examples of weather insurance experiments in developing countries at this stage.

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APPENDIX B: Memorandum Written After the Trip to the Rio Mayo Valley: Skees and Leiva: Impressions from the Rio Mayo Valley — April 7-10, 2005.

To begin, the trip to the Rio Mayo Valley was quite good. It was great to finally get to the site after working on the problem for a year. We were treated very well and the management of the SRL opened their records to us. One of the key people (Bisher) spent a great deal of time with us patiently explaining many details. He also organized the meeting for us to present on Friday. The PowerPoint that Akssel presented is attached. It was great to have Katia along and she did a wonderful job representing IDB. The presentation was well attended. The three of us (Katia, myself, and Akssel) presented in turn for about 40 minutes. At the head table with us were the local leadership from the SRL, CNA, and SAGAPA. Each made brief comments to endorse the concepts when we completed our comments. Watching the crowd, it was clear that they were keen to learn our ideas and they were very attentive. We also had two representatives from AGROASEMEX (Jesus and Roberto). We asked Jesus to comment as well. He endorsed our project and explained a good deal about other projects that are ongoing on index-based insurance. We should discuss this in the context of the Antigua meetings soon.

The questions from the audience were quite good. As you can see in the PowerPoint, we followed the advice of Bisher (SRL) and made the concept very straightforward. The audience was comprised of representatives of the 16 modules and other leadership in the community. There were about 35 in attendance. My impression is that they understood the concept quite well for an initial presentation. There was also a good article in the Obregon newspaper the next day. Key ideas to come from the audience can be summarized as follows:

- Modules may be a better point of sale for the index insurance
- They wanted to insure release or storage; we insisted this is not insurable
- They wanted a subsidy; SAGAPA endorsed this as did CNA and SRL
- They understood the need to obtain financing for capital improvement
- Some understood the need for cash to facilitate water trading (leasing)
- One individual came to me privately and endorsed the idea with a view that this would help mitigate corruption in the system. What he described as corruption may be more akin to how water prices reflect the relative value during severe shortages.
- They were hunger for more detail on the contract design and prices
- They wanted some individual coverage (of course!)
- Conflicts among operators of modules surfaced even during the Q&A
- Discussions after the meeting closed revealed to me that we motivated a great deal of discussion about different ways that this mechanism could be used in the Rio Mayo Valley context.

Several other ideas were developed based on other information we collected:

- One important finding was the structure of the water fee charged to irrigators in Rio Mayo. *Water does become more costly to individual users during times of shortages*. The collection of water fees is used to pay for the O&M of the irrigation infrastructure of the district. The contributions seem to account for more than 90 percent of O&M. The fee is estimated using budgets developed to maintain infrastructure at the different points of water control: CNA-to-SRL, SRL-to-module and module-to-user. These budgets are only adjusted year-to-year for inflation, therefore, they are relatively constant. However, the user fee is not constant. In fact, the user fee is determined aggregating the three budgets and dividing it by the volume of water measured at the user level. Hence, in dry years when the delivery of water is relatively low, the water fee becomes relatively higher. According to SRL and CNA, during dry years the contribution of water user fees to pay O&M decreases, which compounds the cost of O&M in subsequent years. While the water fee is meant to cover only the O&M, it might also reflect the relative scarcity of the resource and be used as a price signaling mechanism. The methodology used to collect the fee might be used to collect premiums and distribute payments of a potential contract.

- Last fall, only 60,000 hectares were planted due to water shortages. The water trading activities in the Rio Mayo Valley are more developed than we expected. Water is traded on a per hectare basis. In this market, the seller gives up his right to irrigate his farm (ha) and sells the water (or even leases the land) to a potential buyer. The transactions can within users of the same module and across modules. Perhaps infrastructure is the main constraint for the trading activities to develop. Last FW season, the water price ranged between $1,500 and $2,500 per hectare.

- The water allocation system is akin to a quota. We have some experience with quota and leasing of quotas with the government program for tobacco in Kentucky (which was recently liberalized and farmers no longer own quotas). Users in the Rio Mayo Valley lease quota from year to year. While it appears that quotas and individual releases are established using pro-rata principles, we remain uncertain about how this actually is operationalized. It is possible that via the farm plans some modules are allowed to grow more water intensive crops than others during a water shortage. If that is true, then politics also plays a role in how water actually gets distributed.

- On our field trip we learned that some irrigators purchase water rights one year in advance, to hedge against the higher price that sets in when the releases are constrained. This is extremely interesting as it demonstrates very clearly that these users are buying insurance already! The reason this is clear is that during years when the inflows are abundant, the volume released from the reservoir is sufficient for everyone and the water rights purchased the year before become useless. In effect, these users are buying an option on the right to obtain the water a year before. In theory, they would be in position to purchase a call option on excess inflows to protect the lost income from leasing the water a full year in advance. Such a system is beyond the scope of our efforts, but it clearly demonstrates that a market maker would have users in the system who have offsetting risk.

- One of the goals was to learn more about the groundwater usage. We do not believe this issue will create any major concerns for how we have modeled the system up to now. We do have a time series on ground water releases in the system and there is some evidence that it serves as insurance. However, the preliminary examination of the data suggests

that this is only marginal. Still they are using the underground water as buffer supply when the reservoir inflows are low. Since the water fee for O&M increases and the price of water in the market also increases, the relative price of pumping water from the reservoir decreases. Thus, farmers will tend to pump water more aggressively during the years of deficient reservoir inflows. Almost 80 percent of the water extracted from wells is dumped into the canals. The rest is directly applied in the individual parcels. It is important to notice that there is a new program being implemented in which the government subsidizes the first portion of the expenses from pumping water.

- We were also told that by lining the canal, they could improve the efficiency by 30 to 35 percent. Given that the current efficiency of the system is 55 percent, this could be a significant step forward. Still, such investments are very expensive and we have no information regarding the potential benefit/cost ratio of such investments. Our impressions are, however, that risk is one impediment to such investments.

- Upon arrival we were told that despite good levels of storage, the spring summer plans only had about 3000 hectares; excellent rains early this year have replenished the dam to 800. At first the low plantings were explained by saying that relative prices were driving that decision. Later we learned that repair to the canals would shut the system down and that was the motivation. We can speculate that the low levels of water last fall (about 460) made everyone believe they could repair the canals with little lost opportunity to plant spring/summer. In the end, we still believe that spring/summer planting opportunities represent a bonus when rains come from Jan-Mar. Nonetheless, the timing of rains and plantings is very tricky in this system.

- While on the surface, it appears that the SRL is quite organized and has well-developed rules for mitigating conflicts, one can never be certain what actually transpires in terms of the political influence of different users. Impressions would continue to support the notion that those users who are most advanced have better access than those who are comprised of small and limited resource farmers. Unfortunately, our field trip was focused on the most advanced users. About 7000 hectares have advanced technologies (center pivot or similar systems). This is less than 10 percent of the system in terms of hectares. However, these users are planting the high-value crops as you might expect. They will also be the ones who are more likely to continue to grow even during times of shortage by leasing water rights.

In summary, the trip was invaluable for the efforts. We need to continue to think about the institutional setting to deliver the contract; in particular the SRL vs. module.

APPENDIX C: Excerpts from Memorandum by Katia Covarrubias — Case Study: Indexed Insurance on Dam Inflows in the Rio Mayo Valley District – April 7-10, 2005.

AGROASEMEX has expressed interest in taking the above-described concept and applying it to dam inflows in the Rio Mayo Valley district in the state of Sonora in Mexico. The Rio Mayo Valley is a district with one dam, one SRL, and 16 modules that are the primary users of the dam's water supply; 97 percent of the water is used for agricultural purposes, which means that among the 11,600 users in the district water is used in the irrigation system for crop production.[17] In this district, indemnity payments would be paid out when the inflows to the dam are below a given trigger level, 700 million cubic meters (Mm^3), for example.

The Rio Mayo Valley district is an ideal scenario for the design of this kind of insurance given the simple organization of the district, but also because the trend over time has demonstrated an interesting transition in crop production patterns. In 1991, an SRL was formed in the Rio Mayo Valley to represent the users in the sixteen modules and to assume water allocation responsibility to the modules from the CNA; the CNA only retained responsibility over the dam water release decision.[18] Water release from the dam is based on historical inflows, expected inflow, current storage and the module's proposed seasonal crop portfolio. The onset of drought in the late 1990s led the CNA annual water release decision to be very conservative, producing varying degrees of water, production, and income uncertainty among the Rio Mayo Valley water users. These uncertainties are magnified by the poor efficiency of the system. Of the water authorized for release from the dam, only 55.34 percent actually reaches the producers due to efficiency losses through the course of the irrigation system.[19] The limited efficiency of the system is further complicated by the fact that the irrigation system was designed to serve 70,000 ha yet the titled land within the irrigated sector is 96,000 ha.

The uncertainty of the CNA water release decision set off a trend in crop portfolios in which production in the Summer-Spring (SS) season nearly ceased since the crops available for production in that season require more water yet yield fewer earnings. Therefore, production is concentrated in the Fall/winter (FW) season, which is then reflected in the production plan the modules prepare for CNA annually in order to receive water. This, in turn, has placed downward pressure on the CNA water release decision since producers do not replace forgone SS production with an equivalent increase in FW production. Though this has a positive influence on dam storage, it is limiting the improvement of farmer's livelihoods since only enough water is released for FW production; allocations beyond that volume must be petitioned by April 1st of the year.

Rio Mayo Valley producers, however, recognize that though they do not plan production for SS, certain crops that are considered FW, such as sweet maize, chilies, beans, and certain kinds of potato, must be planted before the FW cycle begins on October 1st. These crops must be planted

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[17] The producers are of all sizes and include ejido producers and three FONDOS.

[18] The Comité Hidraúlico, a committee with representatives from CNA, SRL, the AURs, and SAGARPA, the Ministry of Agriculture, reviews the CNA's decision; however, the final decision is made by CNA.

[19] 10 percent is lost from the dam to Tésia, where distribution authority is passed from CNA to SRL. From Tésia to the modules, 16.7 percent is lost, and from each module entry point to individual users, 27 percent of the water is lost.

as early as August, but if water is scarce, the possibility that farmers may produce those crops diminishes. However, this production decision also is contingent on the profitability of the crops given variable prices; if prices are lower than average, selling the water rights is more profitable.

Rio Mayo: Opportunities for Indexed Insurance. The implementation of an insurance product to indemnify against low water inflows to the Rio May dam would reduce the water availability, production, and livelihood uncertainty of producers. An indexed insurance product based on inflows to the dam would best insure the water users if implemented at an aggregate level, such as by module or through the SRL, the two entities below the CNA that distribute water to the users but do not make the final water release decision. In the case of insuring at the SRL level, users would pay a premium to their module's AUR (Asociación de Usuarios de Riego), which would then pay the aggregate premium to the SRL, who, in turn, would then pay the insurer the total premium. Indemnity payments would be made in inverse order: from insurer to SRL to AUR to the individual users; indemnities being allocated according to a pre-specified risk level. Contracts could be for a growing season (FW or SS), or up to two years.[20] It would not be obligatory to produce in a given year, however, the intent would be to insure water users that intend to produce in a given year.

Potential Benefits. Indexed insurance presents multiple benefits to the irrigated sector in Rio Mayo. In terms of risk for the producers, the risk of lost income due to drought would be transferred away to the insurance company since the insurer has the commitment to indemnify in drought situations. The fact that the insurance would be purchased collectively would pool the risks (at the module or district level) such that there would be less variability in the risk profile of the insured, preventing the premium from being too expensive. The water rights market would likely become more competitive since producers would have an option to sell their water rights in drought years without losing income, also improving producer efficiency. Moral hazard would be reduced or eliminated since the only monitoring necessary would occur at the dam level in verifying the accuracy of inflows to the dam. Adverse selection would also be absent from these contracts since the risk of low inflows to the dam is uniform for the district, making all insured water users homogeneous in the eyes of the insurer.

An additional benefit would be greater access to credit for the producers. Currently, the Fideicomisos Instituidos en Relación con la Agricultura (FIRA) is reluctant to extend credit to producers in the SS cycle given the lack of production during that period, which translates into a lack of income and a reduced ability to repay debt. The extension of credit in the FW cycle does not suffer from this constraint and FIRA currently lends to producers for investments that improve FW production. The introduction of the indexed insurance is of interest to FIRA, and possibly other banks, since it would directly compensate for low inflows to the dam, which, given recent trends and discounting price effects,[21] is the main factor influencing the lack of production in the SS cycle and a major factor in the earnings variability of debtors, creating potential obstacles to the repayment of debt. Ultimately, the risk incurred by banks when lending to agricultural producers would be reduced.

[20] In a presentation of the insurance model to the Rio Mayo stakeholders, some producers expressed interest in longer contracts, such as for ten years, however, the management of contracts of such length is complicated such that shorter terms are preferable

[21] Producers also stated that prices are an additional factor that has limited their SS production.

Increased access to credit could create an opportunity for the efficiency of the irrigation system to be improved by new investments in infrastructure. Currently, the Rio Mayo Valley is undertaking an investment to improve the lining of one of the two principal canals extending from the dam. Although this investment will increase the land area the system is able to serve, according to the CNA and SRL, it falls short of what is necessary to make up for the losses incurred in the system. The water users, modules, and/or SRL could use the indexed insurance contracts as collateral for credit to undertake a range of investments at different levels of the irrigation system that could build capacity and improve service.

Rio Mayo: Challenges. Any insurance product that bases the contract on an index that does not have a linear correlation with losses is likely to introduce basis risk. In the Rio Mayo Valley district, index-based insurance undoubtedly would present some basis risk given that indemnities would not be paid out based on individual losses from a drought. However, since the water received by producers is a function of several factors, one of which is inflows (historical and expected) to the dam, the negative effect of low inflows on individual production can be offset by the CNA release decision, which can be adequate for seasonal production if, for example, the previous year received above-normal inflows. **In other words, management rules can serve as a form of insurance**. Furthermore, the water rights market can diffuse the negative effects of low inflows on production since water rights can be transferred between producers. Overall, basis risk would be present, but because of these factors, it may not present a high risk for the water users. Overall, for such an insurance product to be enacted successfully in Rio Mayo, the administrative and organizational capacity of the modules must be consolidated, as must the confidence in the potential insurance companies and the CNA to be consistent in its release rules. Without adequate organization within the module and a degree of trust, an indexed insurance system could be unsustainable. However, in Rio Mayo, the existence of FONDOS, collective ejidos, and the presence of a functioning water market demonstrates a level of organization that appears to have the structure to undertake a collective insurance scheme.

Rio Mayo: Future Paths. An interesting direction that indexed insurance for dam inflows could take the development of formalized futures markets for water rights. In the Rio Mayo, the cost of water rights when traded ranges from MXN1,500 to MXN3,000 per hectare, the range being defined by fluctuations in supply and demand and the date at which the rights are purchased. Therefore, individuals who choose to purchase additional water rights must pay more when water is scarcer. In order to plan for a full crop season in a drought period, producers generally will purchase water rights by October 1st of any given year; however, often the rights are bought much earlier in order to guarantee access to water. Purchasers of water rights incur a degree of risk when undertaking this transaction. If substantial rain falls following the purchase of the water rights (which is quite likely if a producer purchases the rights during the rainy SS cycle for the following year, anticipating a dry season), the producer will have paid more than the value of the water rights. And if it rains to the point where water rights are unnecessary to obtain water, the investment in water rights becomes a complete loss to the producer.[22]

This situation presents a scenario in which call options for the purchase of water rights would introduce greater efficiency to the system and reduce the risk and losses for those engaging in

[22] For example, the Rio Mayo entered the 2004-5 planting season with low dam storage levels. In November 2004 through February 2005, substantial rain fell out of season, pushing down the price of water rights. If the SS cycle receives normal quantities of rain, water restrictions would be deemed unnecessary and the purchase of water rights would be unnecessary.

water rights transactions.[23] A producer could pay a premium to an insurer for the option to purchase water rights at a given price by a certain date. If the cost of the water rights is greater than the willingness to pay of the producer, then producer can forgo the purchase of the water rights, incurring the loss of only a premium. However, if the water rights are priced at or below the amount specified in the insurance contract, the producer can purchase the water rights and forgo additional expenses. This concept has not yet been developed for the Rio Mayo Valley but the successful implementation of an indexed insurance system based on dam inflows could open this opportunity to the water users in the Rio Mayo.

[23] Discussions with Jerry Skees in the Navojoa, April, 10, 2005.