Application Portfolio 6

Design Strategy Final

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Executive Summary

This project investigates the impact of uncertainty in an irrigation project and it aims to examine the value gained from small scale projects that enable the project manager to capture the high demands but limit loss if faced with low demands. Three systems are modeled in this case by making very general and simplifying assumptions to transform irrigation to cash flows by using the price of the crop (in this case corn) the demand for the crop, the crop yield, the water level and fixed and variable costs.

The variability in crop price and crop yieldconstitutes the main uncertainty factors. A Monte-Carlo simulation is conducted and the ENPV under the three design schemes is considered. The inflexible design is a larger irrigation project of 80,000 ha while the flexible option allows smaller projects of 20,000 ha with the option to expand by 20,000 ha up to 3 more times at any time using certain decision rules. Although one scheme is not stochastically dominant over the other, the results show that flexible design can limit the lower NPV's, however; the flexible scheme also has a more narrow range. Depending on the evaluation metric, the flexible or the inflexible design can be preferable. On an ENPV basis, the Inflexible design has the highest at $20.12 million compared with $16.76 million for the flexible. In terms of potential for loss however, the inflexible has an 11% probability of losing money whereas the flexible limits this to only 1%. The inflexible design has a higher range of ENPV but the flexible design is stochastically dominant in the range of benefit to cost ratio. Consequently the best decision depends on risk-tolerances.

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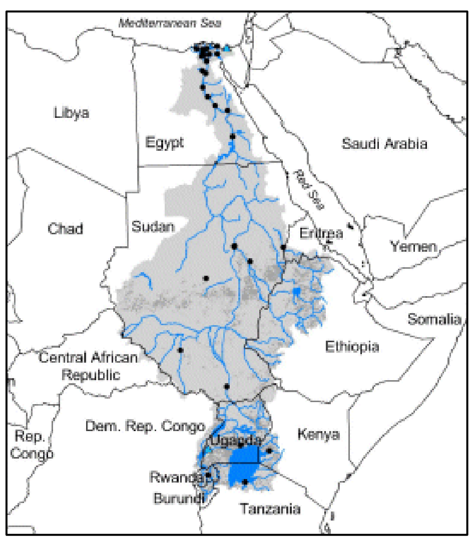
1.0 Introduction

1.1 The Big Picture

One major conflict in the NileBasin has been between Egypt and Ethiopia. The population in both countries is increasing rapidly. Egypt is the downstream country on the NileRiver and is extremely dependent on the waters of the Nile, particularly to meet the irrigation needs for agricultural production. Ethiopia is farther upstream; it is a more mountainous region that has not exploited its agricultural potential. Currently Ethiopia would like to use the water of the Nile for hydroelectric energy production and irrigation. This is a big source of controversy as it would create a reservoir and give Ethiopia control of the downstream flow rate. From a security standpoint, Egypt would like to ensure that the flow rate in the river is maintained for its purposes and would like to have the power to veto any development projects on the Nile River. These kinds of conflicts are not uncommon across the globe. Modeling an acceptable solution to such conflicts will be inherently complex.

Figure 1: Nile Basin

http://www.ess.co.at/WATERWARE/NILE/background.html



In this portfolio project, a verysimplified analysis of a potential upstream irrigation scheme in the Nile Basin is attempted. Recently the 10 countries in the Nile Basin Initiative met to try to establish an agreement on how to distribute water in the Nile; although they were unable to reach an accord, they have made progress in establishing an integrated plan for optimum use and development of the water resources. The Eastern Nile Subsidiary Action Program (ENSAP) for example, fast-tracked several projects in an effort to promote cooperation in the region and develop sustainable practices of watershed management. ENSAP approved the following projects: Watershed Management, Ethiopian Power Export, Irrigation and Drainage and Flood Preparedness Project. Here we will focus on the Ethiopian Irrigation and Drainage project. Currently, the Ethiopian Irrigation Drainage Project consists primarily of a feasibility study for an 80,000ha irrigation plan in Ethiopia's Nile Basin region. This drainage project is intended to promote food security, protection against droughts, alleviate poverty and boost agricultural productivity.

1.2 Scope of Application Portfolio

In this portfolio project, I will compare three models: 1) a standard large irrigation project with deterministic inputs, 2) an inflexible standard large irrigation project that accounts for uncertaintyand 3) a flexible smaller irrigation project with the option to expand that also accounts for uncertainty. The comparison will be evaluated on the following metrics:

- Expected net present Value (ENPV)
- Probability of losing money (P<0)
- Range of ENPV,
- 5^{th} and 95^{th} percentiles and
- Benefit-Cost (B/C) ratio.

The flexible approach may be mutually beneficial to Egypt and Ethiopia since a standard large scale irrigation may not be easily acceptable to Egypt, however a smaller project with the option to expand in future may be more tolerable.

The conventional thought with irrigation projects is that "big projects just do better than small projects." This tends to occur because of economies of scale, particularly when laying pipes, excavating and building the reservoirs. (IWMI, 2007) The analysis in this portfolio project will use tools from flexibility analysis to determine whether a large irrigation project (80,000hectares) orthe small irrigation schemes (20,000 Hectares) with option to increase capacity by the same amount over time is preferable.

2.0 Defining the System

The problem is complex but in this report we will make simplifying assumptions. Although this may come at a loss of accuracy, it is still possible to glean some insight about the preferred project. The system will focus on the irrigation project for single crop cultivation. The principle design levers or variables are the aspects of the project that can be controlled to improve performance. In a potential irrigation system, some of the principle design levers that would affect the design are identified as follows:

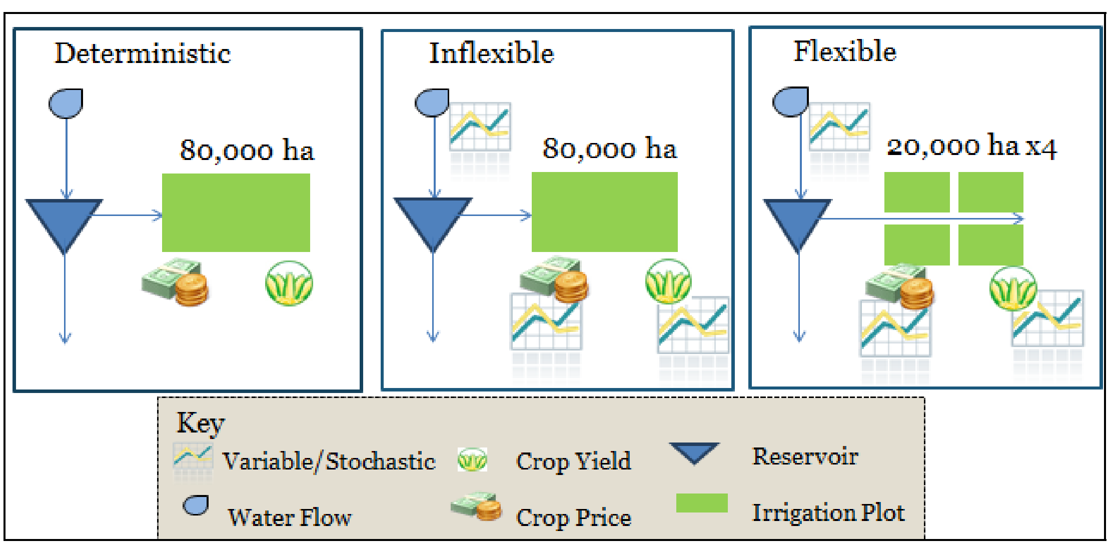
- Project Size (land area to be irrigated)
- Type of crop irrigated
- Demand and price of crop
- Availability of water and forecasted shortages
- Crop yield

The last three of these are stochastic (andexogenously determined) in nature. In order to incorporate uncertainty, and for the purposes of this analysis, the historical data is fitted to a distribution and it is assumed that this is the sampling distribution for future forecasts. Using tools from ESD.71 these uncertainties can be incorporate into the fixed and the flexible designs. This will result in a stochastic model that uses distributions instead of having a deterministic model that relies on historical averages. The design levers described above will be assumed to vary on a yearly basis.

2.1 Deterministic vs. Inflexible vs. Flexible

The large irrigation project for the deterministic and inflexible designs consists of 80,000 hectares of land as depicted in Figure2. It does not have the option to expand and builds for full capacity at the onset of the project. The flexible design consists of starting an irrigation scheme for 20,000 hectares of land, with the option to expand irrigation capacity in a block suitable for 20,000 hectares in any given year up to a maximum of 3 times, giving a total of four 20,000 ha such schemes as shown in Figure 2.

Figure 2: Layout of Irrigation Plans



2.2 Assumptions

Without necessarily sacrificing the goal of the report and to limit the scope of the project, the following simplifying assumptions are made:

- The project life for evaluating the irrigation schemes will be 20 years.

- Ethiopia's biggest crops are cereals. Prices of cereal crops historically have shown wide fluctuation. Corn offers an interesting case for studying uncertainty since it has high volatility.For this report corn will be assumed to be the only crop grown in the irrigated land plots.

- Cropping cycles are ignored and the yield is taken as an annual amount. The focus will be on price fluctuation and production yield. Based on the historical data supplied by USDA, the average corn yield in Ethiopia is 1.4 metric tonsper hectare. This is estimated as the historic corn productions divided by the historic area harvested with corn in Ethiopia.

- The cost estimates are taken from various sources. The average operating and maintenance cost for corn crop in the United States is estimated to be $12.5/acre and fixed cost is $88/acre. (Hogan) To account for the idiosyncrasy of Ethiopian conditions we need toscale these costs. Ichose to multiply the fixed cost by 2 to represent the more expensive implementation of irrigation projects in Africa. For our purpose these costs are converted to dollars per ha (1 ha =2.47 acres) resulting in costs of $30.88/ha for operations and maintenance and $419.9/ha for fixed initial cost. The cost of land is taken as 135 birr per hectare per year (Rice, 2010) and this is converted (1 Ethiopian Birr =0.06 $US) to US$ 8.15/ha. The lowest cost of corn production in the US is $1.2/bushel (1 bushel = 40MT) (Foreman, 2001). In Africa this cost which incorporates seeds, fertilizer and labor would be lower since labor is less expensive and fertilizers are not as widely used. We assume the cost of crop production to be $0.7/bushel, and using the average corn yield of 1.4 MT/ha convert this to $40/ha.

Table 1: Assumed Costs

Irrigation Project Costs	
Land Lease	$8.15/ha
Fixed Irrigation System Cost	$419.90/ha
O&M Irrigation System	$30.88/ha
Cost of Corn Production	$40/ha

- Assumed a discount rate of 12%. This representsthe cost of capital.
- Irrigation projects are standalone; they do not include hydropower or building reservoirs.
- If the average change in water level in the past 2 years is negative then thecorn yield will decrease at a rate of 0.9% for every 1% decrease in water level. This yield penalty assumption is made in order to incorporate water levels and the possibility of water shortages into the decision.
- Historical data is fitted to a distribution and the forecasts are taken as samples from this distribution.

3.0 Methodology

The simulation approach allows the combination of several uncertainties that are represented as stochastic distribution, and whose parameters are determined from the historical data. It's a very powerful tool when combined with @Risk software as it allows the use of excel as well as additional functionalities. It is better suited for this project than a lattice model because the lattice model would become too big very quickly as it is recombinant. With a lifetime of 20 years, a lattice model would have been difficult to handle. A decision tree could be used, however, that would require discrete probabilities. The Simulation allows us to make use of the continuous probability distributions.

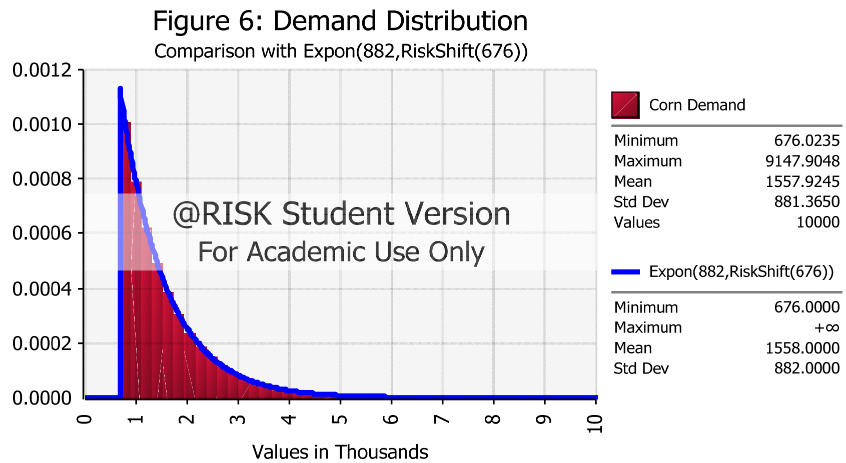
3.1 Uncertainty Distributions

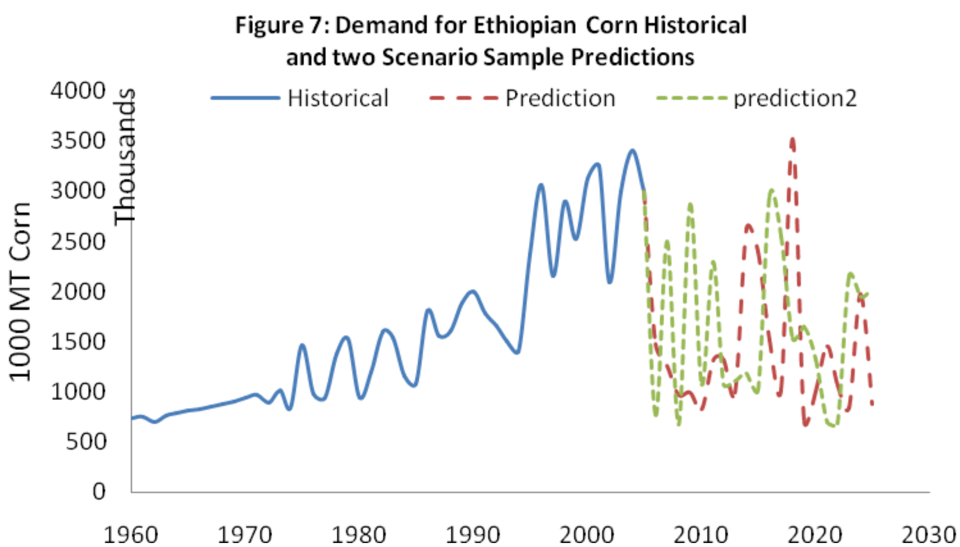
The demand for Ethiopian corn, the world price of corn, the yield production and Nile water flow were found as historical data series. Using the @Risk Software, these data series were fitted to distributions that describe the samples as shown in the following figures:

<u>Demand for Corn</u>

The Historical Demand for Ethiopian Corn was fitted to an exponential distribution with mean value of 1,558, 000 MT of corn and standard deviation of 882,000 MT. This distribution is expected since demands tend to follow population growths which are exponentially distributed. Figure 6 is the exponential sampling distribution for historical demand from @Risk and Figure 7 shows the historical data, and two prediction scenarios using the exponential distribution. Since the demand was based on the whole country, this uncertainty played a minimal role in the results. The capacity is always less than the demand, since capacity is, at most, for one 80, 0000 hectare farm and the demand is for all of Ethiopia.

Local demand was difficult to find, however, assuming perfect markets the corn price can serve as a good proxy for the demand.





Price of Corn

The average yearly price of corn was fitted to a lognormal distribution with mean of $116/MT and standard deviation of $27.8/MT and shown in Figure 8. This parameter shows a lot of volatility and fluctuations, consequently, the cash flows are sensitive to this parameter. Figure 9 shows the historical data and two sample predictions.

Figure 8: Average Yearly Corn Price

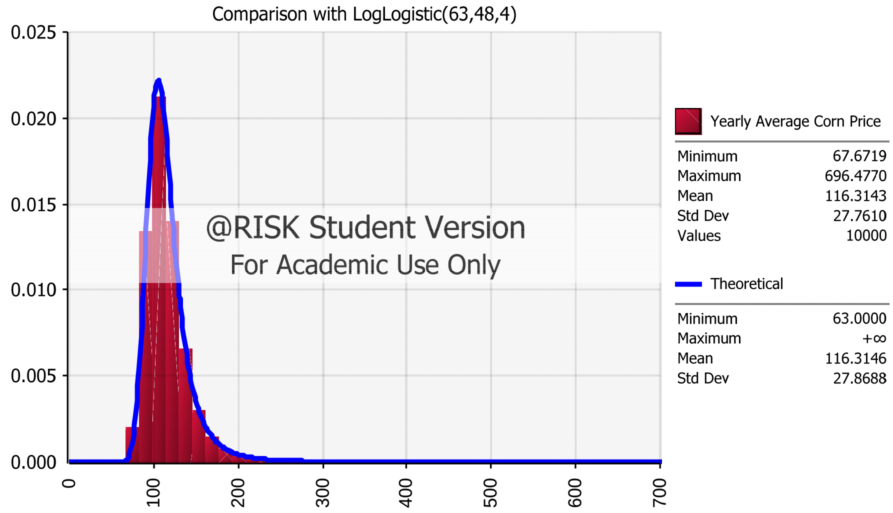
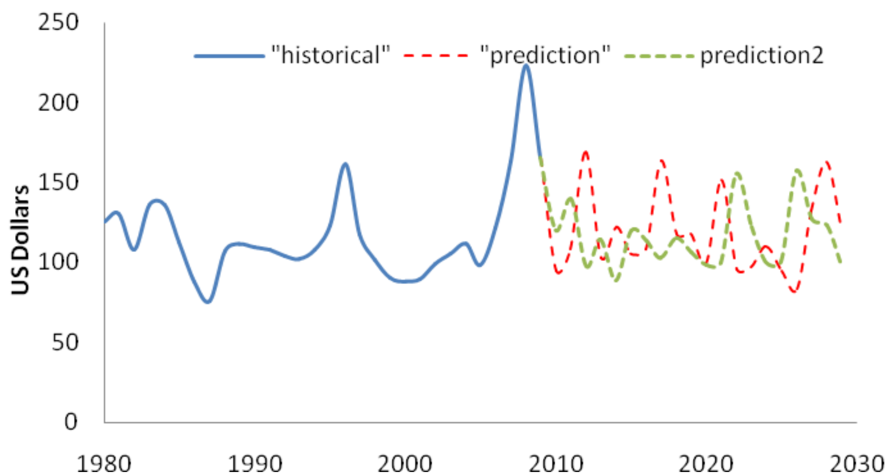
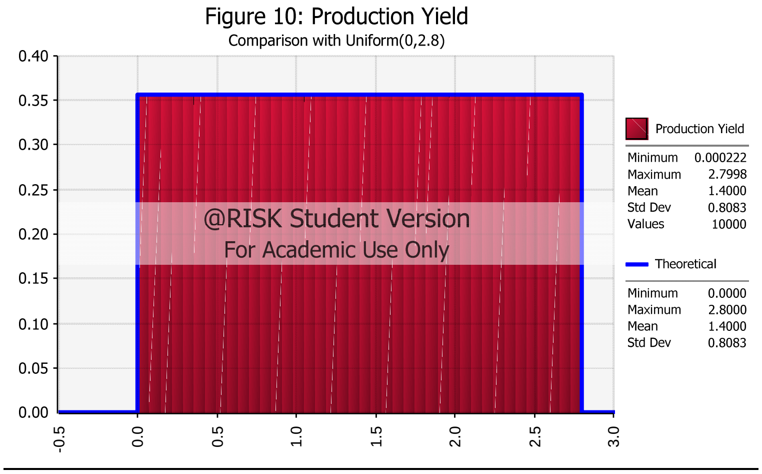


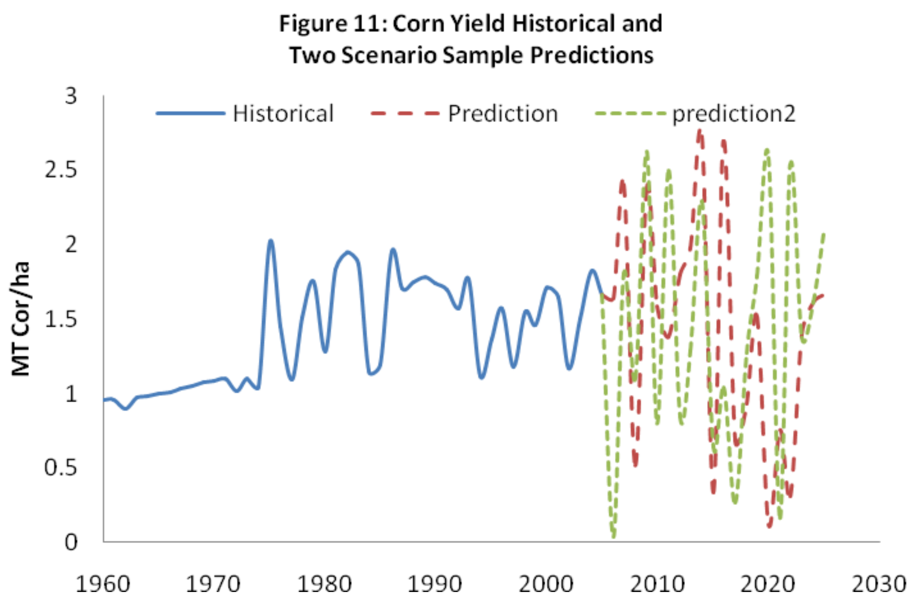
Figure 9: Average Yearly Historical Corn Price and two scenario predictions using distribution



Corn Yield

The corn yield was calculated based on historical data supplied by the USDA. The historic corn production in Ethiopia divided by the historic area harvested with corn in that year in Ethiopia was taken as the corn yield. This was then fitted to a distribution that resulted in a uniform distribution between 0.88 and 2.04 and mean of 1.4 metric tons per hectare. This represented the distribution for the whole country and therefore was somewhat unrealistic for one farm. A country has a very low possibility of losing its entire harvested crop, whereas this is more common for one farm. Consequently, I took the distribution to be uniform between 0 and 2.8 MT/ha, this maintained the historical average and shape of the distribution, but made it more realistic for a single farm by allowing the farm to lose its entire harvest. This modification also explains the big variation in the predictions when compared with the smaller variations in the historical data.





Nile Water Level

Given the political nature of the problem in the Nile Basin, it seemed important to establish a decision rule that took into account the change in water level. If the water level is low, this would affect the yield and would also affect the downstream countries. Using the limited water to irrigate instead of releasing it for downstream countries could cause conflict in the area. I incorporated this with the yield penalty due to low water levels described in the assumptions and also used it as a limiting criterion for expansion. The average flow was taken by fitting the historical data. The monthly flow data was converted to seasonal data by averaging the Ethiopian "Meher" crop season, which spans February to June, for each year. This was fitted to a log logistic distribution with mean 4806 million cubic meters (MCM) and standard deviation of 142 MCM of water.

Figure 12: Mehr Average Seasonal Flow of Nile

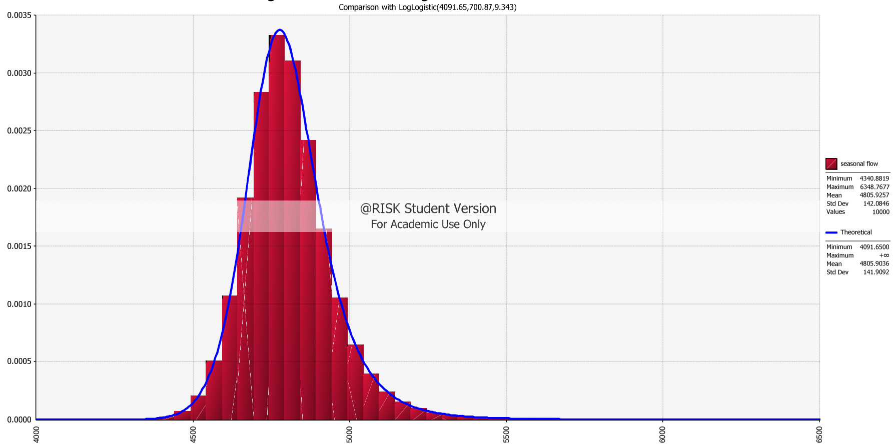
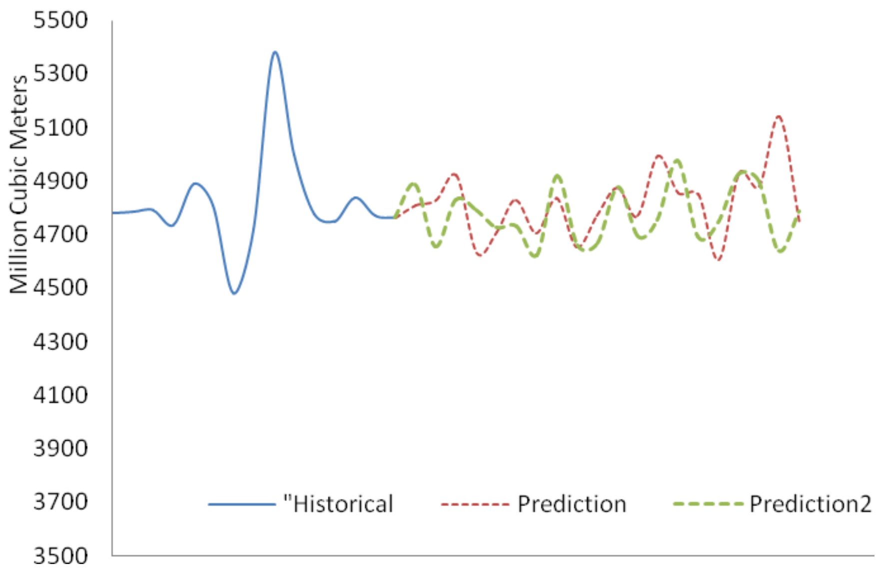


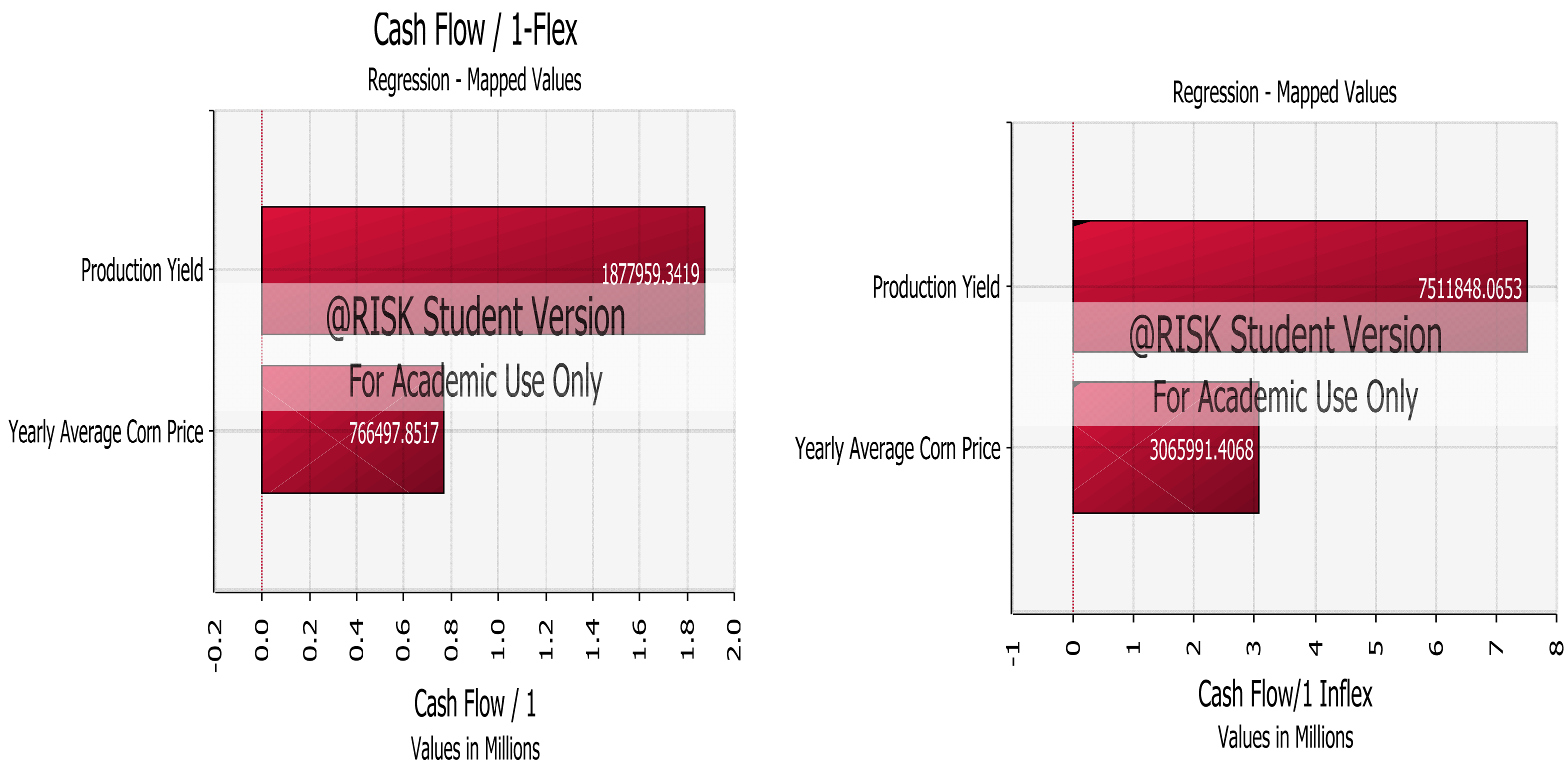
Figure 13: Average Historical Flow for *Meher* (Feb-Jun) Crop Season and two Scenario Sample Predictions



<u>Sensitivity Analysis</u>

The four uncertainties: demand for corn, price of corn, corn yield and water levels were included in the model; however, they have different effects on the result. A sensitivity analysis helps determine which uncertainties are the main driving forces in the result. The sensitivity analysis for the first year cash flow is shown for the flexible and inflexible designs in Figure 14. The graphs below show by how much a particular value changes when the input changes by +1 standard deviation. First, notice that the key driving uncertainties are the price and yield of corn. Demand does not play a role as it is always much greater than the capacity and the water level is incorporated as a minimal penalty. These assumptions can be changed if a more detailed analysis is desired. Figure 14 states that if the corn price changes by $28/MT (1 standard deviation), than the first year cash flow for the flexible design will increase by $766,000 and the inflexible first year cash flow will increase by $3.1 Million. Furthermore, if the yield increases 0.8 MT/ha, the first year cash flow for the flexible will increase by $1.88 Million and the inflexible will increase by $7.5 Million.

Figure 13: Sensitivity Analysis for First Year Cash Flow in Flexible and Inflexible Design



3.1 Setting up the Model

To compare the deterministic, inflexible and fixed design options, I set up the projects in an excel worksheet with cash flow as shown in the scenario in Figure 3. The main differences between the deterministic and inflexible system is the incorporation of uncertainty. The inputs for the deterministic case are the average values as shown below:

Table 2: Deterministic Values

Deterministic Inputs	
Average corn price	$116/MT
Average demand	1558 MT/ha
Average flow	4805 MCM
Average corn production	1.4 MT/ha

Since the deterministic model uses the same average every year, it does not incorporate the possibility of water shortages, smaller crop yields or fluctuating demands and prices. In the inflexible design, the seasonal water flow level, the demand for corn, the price of corn and the production of corn become random values determined from the distributions described before.

The main difference between the fixed and the flexible model is starting with 20,000 ha instead of 80,000 and having the option to expand. There could be several expansion criteria; however, for purpose of this study the expansion rules are defined as follows:

Expansion Rule:

- Start with 20,000 ha instead of 80,000 ha
- Assume no additional upfront cost or cost to exercise flexibility

If the following conditions are all met, then expand by 20,000 ha:

1. The price of corn is greater than $63 (in deterministic model this price gives NPV of 0) and
2. The demand for corn this year is greater than last year (increasing demand) and
3. The average percent change in water flow in last two years is greater than 0 (increasing water level) and
4. Land size has not reached capacity of 80,000 ha

Worksheet Explanation

To determine the ENPV, I set up an excel worksheet to estimate the discounted value of each year's cash flow.

- The **total corn yield** is the land size times the production yield minus a yield penalty if there is low water levels (0.9% decrease in yield for 1% average decrease in last 2 years)

- The **revenue** equals the total yield times the price of corn.

- The **cash flows** represent the total benefits minus the total costs. The total costs were described before on a per hectare basis (Table 1: Assumed Costs)

- In the sample worksheet, variables in green are stochastic and are described by distribution uncertainty parameters.These cash flows are then discounted with a 12% discount factor to account for the opportunity cost of capital and bring back the cash flows to present day so that we can compute the Net Present Value. This is one of the metrics that will be used to compare the performance of the fixed versus the flexible design

The following figures have excerpts of the spreadsheet analysis and show one example scenario. The figures depict the baseline analysis for the fixed deterministic case and one scenario for the inflexible and flexible cases with numbers drawn from distributions.

Figure 4: Deterministic Case and Baseline Result

DETERMINISTIC Year	0	1	2	3	4	5...	19	20
Avg Monthly Water Level (MCM)		4805	4805	4805	4805	4805	4805	4805
Demand for Ethiopia (MT corn)		1558000	1589160	1620943	1653362	1686429	2225208	2269712
Price of Corn ($/MT)		116	116	116	116	116	116	116
Production (MT corn/ha)		1.4	1.4	1.4	1.4	1.4	1.4	1.4
Land Size (ha)		80000	80000	80000	80000	80000	80000	80000
Total Yield (MT corn)		112000	112000	112000	112000	112000	112000	112000
Revenue		12992000	12992000	12992000	12992000	12992000	12992000	12992000
Fixed Irr. System Cost (US $ 419.9	33592000.00							
Land Lease Cost (US $ 8.15/ha)		652000	652000	652000	652000	652000	652000	652000
Variable Irr. Cost (US $ 30.88/ha)		1976329	1976329	1976329	1976329	1976329	1976329	1976329
Cost of Production (fertilizer, seeds, labor, $US 40		3200000	3200000	3200000	3200000	3200000	3200000	3200000
Cash Flow		**7163671**	**7163671**	**7163671**	**7163671**	**7163671**	**7163671**	**7163671**
DCF	0.12	53508639.32						
NPV		$19,916,639	Average		$19,916,639.32			
B/C		1.59	p(<=0)		0.00			

Figure 4: One Scenario in the Inflexible Case

INFLEXIBLE Year	0	1	2	3	4	5..	19	20
Avg Seasonal Water Level (MCM)	4763.58	4807.11	4825.63	4920.26	4632.91	4708.40	5139.82	4737.91
Avg change in water level in last 2 years			0.00%	0.01%	-0.11%	-0.10%	-0.06%	-0.42%
Demand for Ethiopia (MT corn)	3000000.00	1323541.71	1821993.61	796699.88	914454.92	895696.55	977584.79	1391571.27
Price of Corn ($/MT)	167.27	94.76	108.11	169.47	103.01	121.89	162.50	119.72
Production (MT corn/ha)		1.58	0.12	0.86	2.36	0.85	1.21	1.33
Land Size (ha)		80000.00	80000.00	80000.00	80000.00	80000.00	80000.00	80000.00
Total Yield (MT corn)		126457.09	9698.96	68832.42	188993.36	67566.36	96998.24	105809.21
Revenue		11982621.89	1048531.93	11664723.96	19468996.42	8235348.92	15762481.55	12667724.61
Fixed Irr. System Cost (US $419.9/ha)	33592000.00							
Land Lease Cost (US $ 8.15/ha)		652000.00	652000.00	652000.00	652000.00	652000.00	652000.00	652000.00
Variable Irr Cost (US $ 30.88/ha)		1976326.97	1976320.00	1976320.00	1976320.00	1976320.00	1976320.00	1976320.00
Cost of Production ($US 40/ha)		3200000	3200000	3200000	3200000	3200000	3200000	3200000
Cash Flow		**6154294.92**	**(4779788.07)**	**5836403.96**	**13640676.42**	**2407028.92**	**9934161.55**	**6839404.61**
DCF	0.12	57721326.93						
ENPV		$24,129,326.93	Average		$20,051,384.30			
B/C (profitability index)		1.72	p(<=0)		10.87%			

Figure 5: One Scenario in the Flexible Case

FLEXIBLE Year	0	1	2	3	4	5..	19	20
Avg Monthly Water Level (MCM)	3541	4807	4826	4920	4633	4708	5140	4738
Avg change in water level in last 2 years			0.14%	0.01%	-0.11%	-0.10%	-0.06%	-0.42%
Demand for Ethiopia (MT corn)	3000000	1323542	1821994	796700	914455	895697	977585	1391571
Price of Corn ($/MT)	167	95	108	169	103	122	163	120
Production (MT corn/ha)		2	0	1	2	1	1	1
Land Size (ha)		20000	20000	40000	40000	40000	80000	80000
Expand?			expand					
Expansion Size		0	20000	0	0	0	0	0
Total Yield (MT corn)		31614	2425	34416	94497	33783	96998	105809
Revenue		2995655	262133	5832362	9734498	4117674	15762482	12667725
Fixed Irr. System Cost (US $419.9/ha)	8398000							
Land Lease Cost (US $ 8.15/ha)		163000	163000	326000	326000	326000	652000	652000
Variable Irr Cost (US $ 30.88/ha)		494087	494080	988160	988160	988160	1976320	1976320
Cost of Production (fertilizer, seeds, labor, $US 40/ha)		800000	800000	1600000	1600000	1600000	3200000	3200000
Cash Flow		**1538568**	**-1194947**	**2918202**	**6820338**	**1203514**	**9934162**	**6839405**
DCF	0.12	39714989.45						
ENPV		$31,316,989.45	Average		$16,649,535.64			
B/C (profitability index)		4.73	p(<=0)		1%			

4.0 Results

Table 3 summarizes the results and figure 15 shows the VAR/G curves for the deterministic, inflexible, and flexible designs using 10,000 iterations and the assumptions described before. The deterministic method which does not account for uncertainty and uses average input values has a net present value of $19.92 million. The inflexible system has an expected net present value of $20.12 million. This difference between the deterministic and the inflexible system shows that this is not purely a linear system and using average estimates may not account for everything. The flexible system had the lowest expected net present value at $16.76 million. This occurs because the capacity is limited by the smaller sized land plots, but the demand is such that the farm could always sell what it produces.

Figure 15: Comparing ENPV

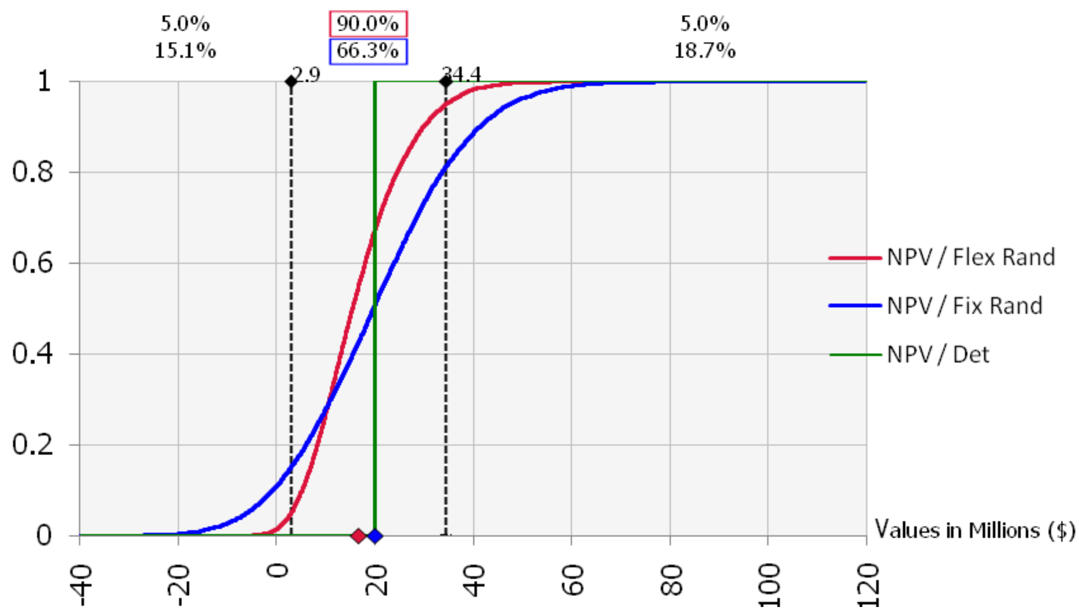


Table5: Summary of Comparison Metric Results

	ENPV	P(<=0)	Min	Max	5%	95%
Deterministic	$19.92M	-	-	-	-	-
Inflexible	$20.12M	10.54%	$-31.14M	$125.65M	$-6.3M	$47.62M
Flexible	$16.76M	1%	$-9.28M	$74.38M	$2.79M	$33.88M

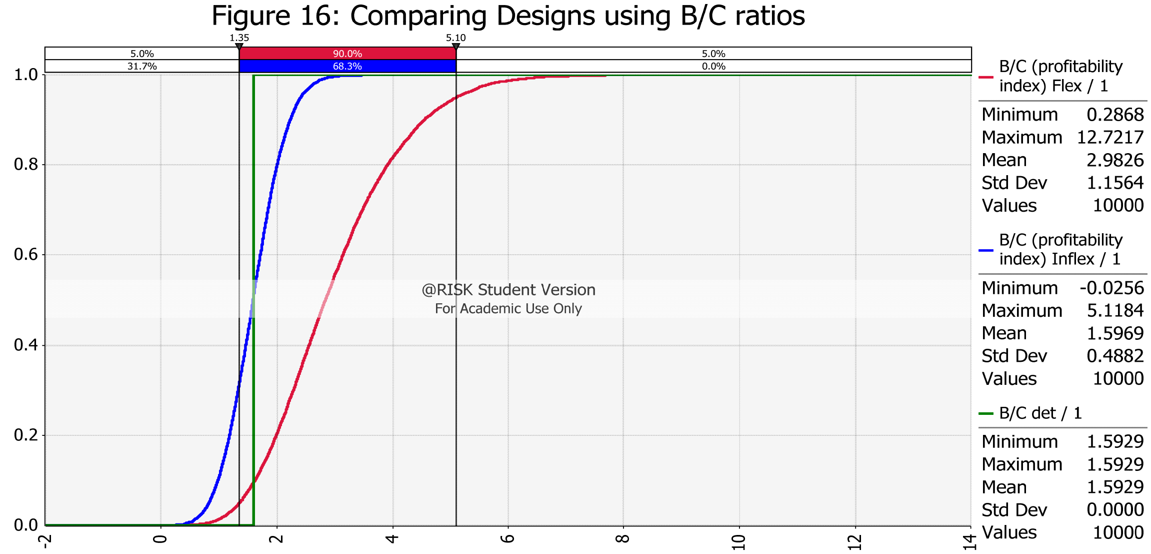
The flexible system, however, serves the purpose of limiting loses and it succeeds as is evident by the change in the probability of making less than zero. In terms of the potential to lose money, the flexible system cuts the probability of loss to 1%, where the inflexible has close to an 11% chance of losing money. For risk-seeking individuals, the inflexible system may seem better because of the big range. It has the possibility of having an NPV of up to $125.65 million, where the maximum for the flexible system is only $74.38 million. If using the 5th percentile measure, the flexible system is better, but at the 95th percentile, the inflexible is better.

The VAR/G curve shows that the flexible design limits the lower gains and tightens the curve around the expected value. The fixed design has a bigger range, thus it has possibilities to realize greater values. The decision as to whether to design a flexible or fixed irrigation scheme will depend on the risk tolerance of the decision maker. The deterministic scheme is not recommended as it is only one possible scenario and thus, the project manager would not be prepared for any surprises brought on by uncertainty.

In the flexible design, it is interesting to note that even though the cash flows for a year of expansion could be negative, the decision to expand and increase capacity resulted in higher cash flows in future years. This demonstrates that having a long-term view can result in a successful project even if it comes with a short-term immediate cost.

Another comparison metric is the benefit cost ratio, which can serve as a profitability index when comparing projects with different initial costs as is the case in this example because the costs are based on a per hectare basis. Figure 16 shows the cumulative distribution for the B/C ratios of the different schemes. The initial investment or capital expenditure for 80,000 hectares is $33,592,000 ($419.9/ha) and for 20,000 hectares it is $8,398,000. In this case the flexible design looks stochastically dominant as it has the smaller investment upfront. The flexible design incurs the land lease and higher costs when it expands, but it due to the expansion criteria, it only expands when conditions are favorable therefore ensuring that it can limit any losses.

Figure 16: Comparing Designs using B/C ratios



5.0 Discussion

Comparing these two irrigation schemes showed that the conventional wisdom that "bigger is better" for large long term projects, may not always true. In fact, small projects may have economic advantages depends on the cost and benefit values assumed and the evaluation metric. Although large projects may be able to benefit from economies of scales, building to huge capacities that may not be realized until many years from today, can result in large losses due to unused capacity. Small projects, on the other hand, can benefit by placing limits on losses since they are designed for a more feasible capacity and if the small projects have the option to expand, they can increase capacity when conditions are favorable. This project showed that neither method is an "all-time" best. The choices depend on the risk tolerance of the project manager as well as the metric used to evaluate the projects as shown in Table 6. The deterministic model is not recommended as it can over or under estimate risks and does not prepare the project manager for different scenarios.

Table 6: Preferred Project Depending on Evaluation Metric

	Inflexible	Flexible
ENPV	X	
P(<=0)		X
Min		X
Max	X	
5%		X
95%	X	
B/C		X

A more detailed analysis, similar to this one, could help inform the Ethiopian Irrigation Drainage Project. As there are currently disputes between Ethiopia and Egypt, a smaller project may be more easily accepted by Egypt and limit potential losses for Ethiopia making it mutually beneficial. Furthermore, a win-win situation could be modeled in which a coasian bribe is used by the two countries so that they can both attain the water security, agricultural development and drought prevention that they seek. This bribe could be the strike price of an option and would incorporate many flexibility designs to find the maximum net benefit for the country from the many projects it could develop. The other country could pay for this flexibility and hold the option to dictate the expansion rules. This irrigation project is just a small sample of what could be analyzed in order to understand and plan for better development in the Nile Basin region.

This application portfolio project gave me better understanding of flexibility on and in projects as well as a hands-on experience to test and design my own simulation. This project helped me become more familiar with the @Risk software that is used in the industry and strengthened my understanding of sampling distributions. The portfolio also convinced me of how sensitive projects are to the evaluation metric and why it is important to understand the limitations and advantages of different evaluation metrics.

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