VALUING FLEXIBILITY IN INFRASTRUCTURE DEVELOPMENTS: THE BOGOTA WATER SUPPLY EXPANSION PLAN

by

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Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Technology and Policy

at the

Massachusetts Institute of Technology

June 2002

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"There is no certainty in life;
Only opportunity"

Mark Twain

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ABSTRACT

This thesis aims to aid in the understanding of capital budgeting techniques for infrastructure developments. In particular, it analyzes: Net Present Value (NPV), Decision Analysis (DA) and Real Options Analysis (ROA), and compares these approaches in terms of their treatment of uncertainty, their acknowledgement of flexibility, and their usefulness for strategic decision-making.

The comparison of these alternative methodologies is based on a literature review highlighting the advantages and disadvantages of each approach, complemented by a system study of the expansion of the water supply system for Bogotá, Colombia. This study illustrates the application of each methodology and identifies the policy challenges relevant to infrastructure investment evaluation in Colombia and other emerging economies.

The study confirms the hypothesis that NPV is inadequate for the evaluation of projects in uncertain environments, mainly because it does not account for the value generated by flexibility. The study also recognizes that although the ROA approach is theoretically superior in the pricing of flexibility, its implementation requires information usually not available for infrastructure assets. This rends the results of the analyses imprecise and complicates the process of identifying an optimal strategy.

The study finds the Decision Analysis approach preferable for the evaluation of Bogotá's water supply expansion projects, based on its practicality and ease of communication. The thesis also sets forth a framework for choosing the most appropriate capital budgeting technique for other infrastructure developments. This framework is based on data quality and availability and the objective function of the analysis to be conducted.

Thesis Supervisor: Richard de Neufville
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ACKNOWLEDGMENTS

This thesis would not have been possible without the help and support of many people. First I would like to thank my advisor, Professor Richard de Neufville, for his ideas, support, guidance constructive comments, and most of all for his encouragement. The production of this thesis was one of the best learning experiences I had in MIT, to a great extent due to his unwavering support.

The information for the Bogotá Water Company case study came from the generous collaboration of many people in the EAAB and Ingetec. Without their help I could have never completed the analyses. I sincerely thank Humberto Triana, Nestor García, Diego Rentería, and Fernando Manjarrez for making time in their very busy schedules to meet with me whenever I needed, and giving me complete access to all their information. I am especially indebted to Fernando Carrizosa, not only for being my "information gathering coordinator", but also for instilling in me a very special kind of affection for the Bogotá Water Company.

I also need to thank Felipe Arango, for discussing the ideas that gave birth to this thesis with me, proofreading the document as many times as I thought were needed, and especially for his endless support and his willingness to believe in me. Along the many crises that emerged while writing this document, he was always sure I would finish on time.

Finally, I need to thank my family, my parents and my brother. They have been my pride and inspiration for my entire life. I would have never made it this far without their support. I dedicate this work to them.

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CHAPTER 1: INTRODUCTION

City planners and policy makers in developing countries face several difficulties in the process of choosing the optimal portfolio of infrastructure projects to be developed during their tenure. The difficulties stem from the uncertainties associated with such developments and the inadequacy of traditional capital budgeting techniques to value projects under these conditions. Discounted Cash Flow (DCF) based approaches, such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback period, are inherently flawed to analyze projects with future uncertainties because they do not take into account management's ability and flexibility to respond to these uncertainties in different ways. These methodologies presume one line of action from time zero, and evaluate the project as if this was fixed.

Decision Analysis (DA) and Real Options Analysis (ROA) are better suited to deal with uncertainty and to incorporate flexibility in an analysis. Both of these techniques view projects as processes that management can continually modify in the light of changes in the environment; therefore are very well suited for projects with high uncertainties, where the course of action and the array of decisions to be taken are not known in advance and are likely to change constantly (de Neufville and Neely, 2001). While Net Present Value is an all-or-nothing approach, Decision Analysis and Real Options Analysis allow for go/no-go checkpoints throughout the life of a project.

This thesis aims to improve the understanding of current valuation practices for infrastructure developments. In particular, the thesis seeks to identify the optimal approach for the financial analysis of these projects, choosing between the following capital budgeting techniques: Net Present Value, Decision Analysis, and Real Options Analysis. The comparison will cover both the theoretical advantages and disadvantages of each approach as well as real-life implementation issues that may arise in a particular context.

The question posed in this thesis is of great relevance and importance given that the rate of economic growth in any country is highly dependent on the existence of adequate infrastructure. Identifying the optimal portfolio of infrastructure projects to be developed, and maximizing the return on the infrastructure investment are therefore critical to the economic growth of developing countries. Consequently, understanding which methodologies should be used to value which projects is of utmost importance in the development process. As proposed, the thesis will be informative and useful for planners and decision makers in the national and regional planning institutes, politicians, managers of public utilities, and CEOs of large construction companies. It will provide valuable insights on how to optimize the valuation procedures for infrastructure projects.

To achieve its objectives the thesis undertakes an extensive literature review of the three capital budgeting techniques mentioned above, with the objective of revealing their limitations and advantages. This review is complemented with a case study for the expansion of Bogotá's water supply capacity. The study applies the three methodologies to the analysis of the Chingaza Expansion System in Bogotá, and identifies the implementation challenges of these approaches given the institutional framework of the Bogotá Water Company.

The thesis has both a technology and a policy component. The technology component lies in the application of the three valuation methodologies to infrastructure projects. The objective of this component is to improve the understanding of the theoretical advantages and disadvantages of each approach, the assumptions and information required for each one, and to determine the consequences that the application of each approach has on the nature of infrastructure projects. The policy component refers to the implementation feasibility of each approach, taking into account the specific institutional and cultural framework relevant to the projects being analyzed.

The thesis is divided into six chapters. Chapter 2, sets forth the problem of valuing infrastructure investments under uncertainty, provides a common background for the notions of uncertainty, robustness and flexibility, and develops the literature review of the three methodologies. This chapter examines the ability of NPV, ROA and DA to deal with uncertainty and flexibility, and explains the theoretical underpinnings supporting each approach.

Chapter 3 sets the context for the development of the study. It provides some background on Bogotá, describes the water supply problematic in the city and also the institutional framework of the water sector in Colombia.

Chapter 4 has two main parts. The first one contains the detailed methodology and assumptions required to undertake the NPV, DA and ROA analyses. The second part presents the results of the application of each methodology, specifically, the expected value of the project, the value of flexibility, and the optimal development strategy for the portfolio.

Chapter 5 explores the implementation practicality of the methodologies developed in Chapters 2 and 4. This chapter also has two parts. The first part compares the three approaches in terms of how they price flexibility, and the strategy that they propose. The second part considers the EAAB's internal capabilities, information availability and regulatory constraints that may affect the introduction of flexibility options in the company's infrastructure planning.

Finally, Chapter 6 summarizes the findings, sets forth the recommendations, identifies the limits of the analysis and suggests some additional research areas.

CHAPTER 2: CAPITAL BUDGETING TECHNIQUES FOR CAPACITY PLANNING UNDER UNCERTAINTY

2.1. INTRODUCTION: PROBLEM DESCRIPTION

The water supply industry is highly capital-intensive. It entails large, irreversible investments in production, treatment, conduction and distribution of water. Typically, these investments are characterized by long lead times, long operating lives (30 to 50 years) and matching pay off periods. These long construction, operational and payback periods complicate the process of making timing, capacity and location decisions of future facilities, as they introduce great uncertainties into the system. The most important of these uncertainties relate to demand growth, water source yield (supply uncertainty), and project economics (driven by uncertainties in construction costs, and times, due to licensing complications, financing difficulties, project miscalculations, technical problems, accidents and unforeseen failures). Moreover, the complexity of the capacity planning exercise in the water sector is increased because:

- Water is a location-specific resource and a non-tradable input (Asian Development Bank, 1999)

- Water markets are natural monopolies and as such are subject to different market imperfections

- Economies of scale are usually considerable, especially in the production and distribution stages

Traditionally, capacity planning in water supply utilities has been driven by an objective to minimize deficit risk. Although water utilities are usually aware of the various uncertainties affecting their future performance, their capacity planning exercises seldom reflect this awareness, except for demand uncertainty, which is, in fact, generally considered (Asian

Development Bank, 1999). Many times, water utilities invest considerable time and resources to develop complex and sophisticated models to project future demand. Often, these efforts are largely ineffective: after having identified several possible scenarios of demand growth, utilities choose either the likeliest or the worst (depending on their risk aversion), and using Discounted Cash Flow models, identify the projects that comprise the capacity expansion master plan. Ironically, this master plan ends up being based on a single projection of future events, even though the company invested considerable resources to identify different scenarios. Uncertainty is identified but not taken into account in the strategic planning process. This approach has four main problems:

1. It does not eliminate risks or effectively hedge them.

2. It does not guarantee an economically optimal solution.

3. It does not encourage a holistic view of the problem – thus the obtained results may not be optimal for the system as a whole.

4. It does not encourage flexibility.

The first, and overarching problem, occurs because a worse scenario of high water demand (as opposed to the expected one) may well occur and lead to water shortages or other undesired outcomes.

The second problem, economic sub-optimality, derives from the fact that, in general, capacity planning exercises are conducted solely for the purpose of minimizing deficit risk. By doing so, planners are implicitly assuming that customers value reliability above anything else, and are willing to bear any cost to achieve this objective. This assumption, which may or may not be true, leads to an incorrect valuation of the project's cost versus its benefits.

The third problem presents itself often; planners do not have a holistic perspective of a portfolio or system, but concentrate on the tactical task of analyzing a standalone project. Ideally, planners should determine the level of risk that is accepted by consumers, and optimize the cost of the project against that maximum risk. In fact, planners should not seek to optimize the cost of one project against the maximum risk, but they should strive to identify the portfolio of projects that minimizes cost for the defined level of risk of the system as a whole (i.e., supply and distribution, as opposed to only supply).

This last point cannot be stressed enough. Often, in water utilities, managers think of the decisions of water supply capacity independently from those of distribution capacity, when in reality they are completely interdependent. For example, having enough supply at the source is worthless if the distribution network does not have enough capacity to distribute the additional water to consumers. Also, the location of water supply projects may affect the costs of the distribution system to a great extent; therefore, an evaluation of a water supply project that does consider this, may lead to sub-optimal results.

The fourth problem, not encouraging flexibility, is critical since water supply projects allocate resources irreversibly. Therefore, the introduction of flexibilities in the planning and design processes that allow management to alter the manner in which the assets are used or deployed in the future, is very useful to hedge against risks and to manage costs more effectively in those cases in which the future does not turn out as is initially expected.

It is imperative that water utilities develop a new framework to guide their capacity planning decisions in a way that fosters flexibility as a hedging mechanism for all existing uncertainties, while simultaneously enabling the optimization of multiple objectives[1] of the system as a whole. Such a framework should provide water utilities with a decision plan, as opposed to the more common "master plans". The framework should not focus on the analysis of one single project to determine whether or not it is profitable or cost-effective. Instead it should deal with the collection of projects available to the utility at any point in time, to determine the optimal strategy for the different possible scenarios. In this sense, any framework that is developed

1 *Any water utility has to comply with at least two objectives: minimize risk of water deficit, and minimize cost of water to consumers*

should rely on the concepts of portfolio management. Finally, the developed framework should be easily implementable given the capabilities of the investment agencies.

This chapter analyses three different capital budgeting techniques with the purpose of determining the adequacy of each approach to value flexibility and to identify a strategy that effectively hedges risks and ensures optimality in economic terms. The chapter begins by building a common understanding of the notions of uncertainty, flexibility and robustness. It then lays out the basics of portfolio management. Following, the chapter reveals the inadequacies of traditional Discounted Cash Flow techniques to identify and evaluate the value of flexibility in a project, and sets forth the theoretical underpinnings of two alternative approaches: Decision Analysis and Real Options Analysis. The chapter identifies the advantages and disadvantages of these methodologies for the analysis of water supply expansion projects under uncertainty, both in terms of the theoretical precision of their results, and their ease of implementation in an engineering-dominated world. Most results presented in the chapter are equally valid for several other areas of infrastructure investment, but the analysis focuses on capacity planning in water utilities. The notions developed here will be applied in the following chapters to the study of the expansion of the water supply system in Bogotá, Colombia.

2.2. BASIC CONCEPTS

2.2.1. Uncertainty and Risk

The Oxford English Dictionary defines uncertainty as "Lack of sureness about someone or something. Uncertainty may range from a falling short of certainty to an almost complete lack of conviction or knowledge especially about an outcome or result". According to Dowlatadabi and Toman (1990), uncertainty is the reason why planning is difficult and why fixed plans are not optimal. In general, "uncertainty" is a generic term used to describe something that is not known, but as Ku (1995) points out, uncertainty relates to the unknown at a given point in time, although it is not necessarily the unknowable. The capacity of uncertainty to be resolved in the future is precisely the characteristic that allows it to generate value.

Naturally, a world of complete and total certainty is always ideal for planning. If all outcomes are completely certain, then management can know for sure which decisions maximize their payoffs. Yet a certain world is only idealistic. Managers must learn how to act under uncertainty and make the best out of it.

Uncertainty has a good and a bad side, relating to the possibility of returns *above* or *below* the expected (Bernake, 1983). In general, the approach towards uncertainty in infrastructure development projects is mistaken. Investment decisions are based on the bad side of uncertainty; what can be referred to as the "Bad News Principle". This means that many projects are not undertaken due to the fear that they might go wrong, or that projects are planned for the worse possible scenario. On the other hand, hope, or the "Good News Principle", usually governs the abandonment decision of bad projects. Thus, designs of infrastructure projects usually bear all the weight and costs of the bad side of uncertainty, without profiting from the potential of the good side.

The bad side of uncertainty is often referred to as risk. Merril and Wood (1991) define uncertainty as those factors not under control of management and not known with certainty, and risk as the hazard posed because of uncertainty. Ku (1995) defines risk as the bad consequence of taking action in the presence of uncertainty. Finally, Amram and Kulatilaka (1999, p8) define risk as the adverse consequence of a firm's exposure to uncertainty. Damodaran (1999) presents a more interesting view:

> Risk, in traditional terms, is viewed as a 'negative'. Webster's dictionary, for instance, defines risk as "exposing to danger or hazard". The Chinese symbols for risk, reproduced below, give a much better description of risk The first symbol is the symbol for 'danger', while the second is the symbol for 'opportunity', making risk a mix of danger and opportunity

危機

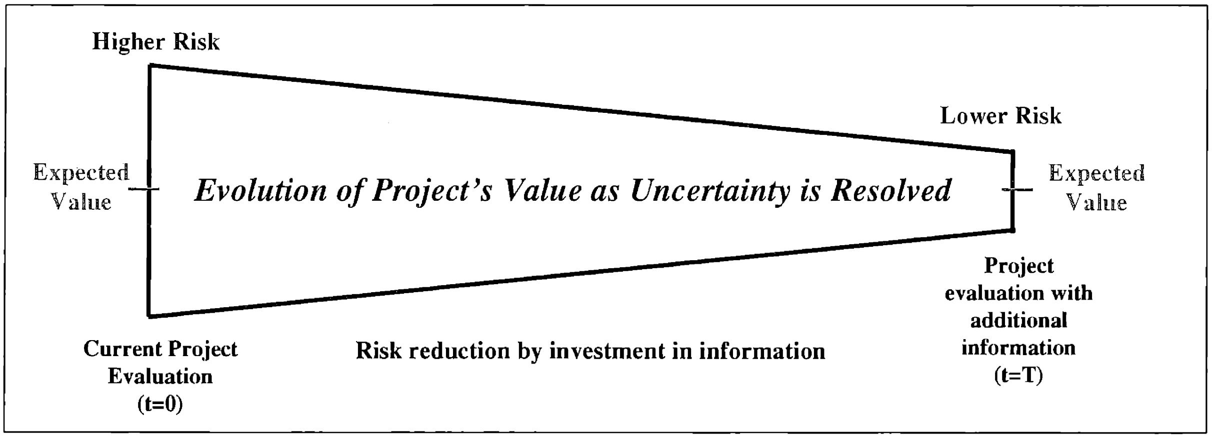

Figure 2.1. Evolution of Project's Value as Uncertainty is Resolved (adapted from Amram and Kulatilaka, 1999)

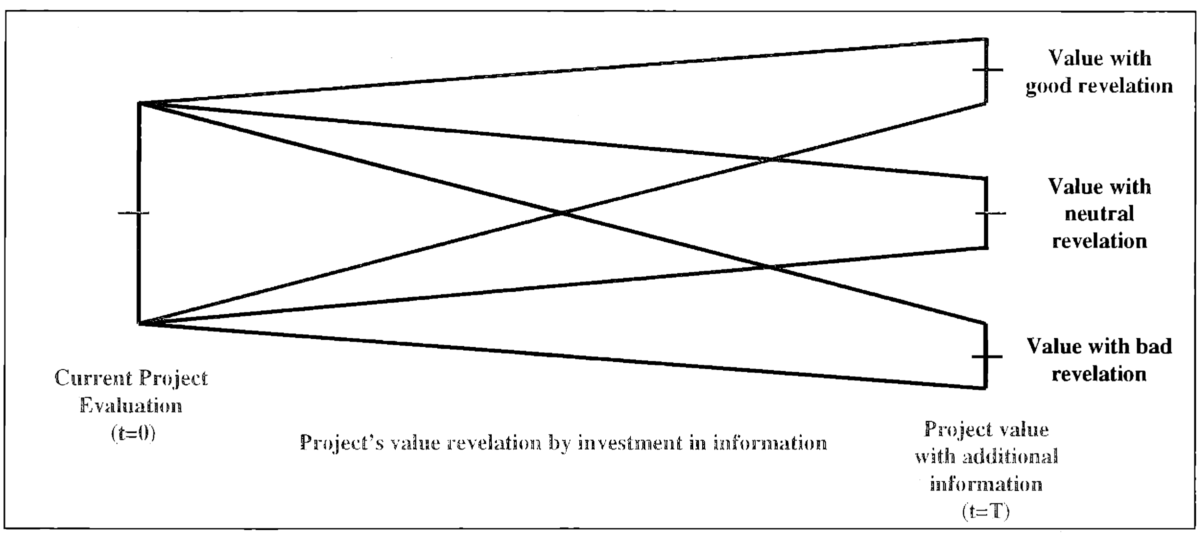

Figure 2.2. Revelation of Project's True Value as Uncertainty is Resolved (Dias, 2000)

A key difference between risk and uncertainty is the way in which they are measured. One way to measure uncertainty is in terms of the standard deviation of the project's cash flows or of the assets' value. Risk is commonly measured in economic terms.

Uncertainty can be resolved with the passage of time, but it can also be resolved by investing in information. Figure 2.1 shows how information reduces the spectrum of possibilities for the expected value of the project or asset over time, thus effectively decreasing the volatility of the expected value, and the risk of the project. But, even more important is that the resolution of uncertainty also reveals the true value of the asset, as Figure 2.2 shows.

By now, financial and commodities markets have learned how to manage both the good and bad sides of uncertainty through the use of hedging instruments such as forwards, swaps, futures, and options (calls and puts). In infrastructure projects, the ability to manage uncertainty derives from the capacity of hedging risks through the introduction of flexibility into project designs.

2.2.2. Flexibility and Robustness

According to the International Council on Large Electric Systems (1991), flexibility is the ability of a system to adapt itself quickly to new circumstances, so as to be permanently used in the best way. Flexibility refers to the ability of a system to respond to *unforeseen* changes (Evans, 1982); often, the ability to respond to foreseen or expected changes is referred to as adaptability.

Flexibility should not be confused with robustness. Robustness is the ability to satisfactorily endure all envisioned risks or contingencies. A system's ability to cope with changes is robust if it is independent of the development of future events. It is fair to say that when a system is robust it becomes insensitive or tolerant to all *expected,* unforeseen states of nature. Of course a robust system is still vulnerable to those states of nature that were not foreseen at the time of planning and design. For the purposes of this thesis, the definitions of flexibility and robustness proposed by Evans (1982) will be adopted.

> Flexibility is the inherent capability to successfully adapt to unforeseen changes. Robustness refers to the ability to endure such changes

Ku (1995) adds to this definition by stating:

> Flexibility means *the ability to change by (quickly) moving to a different state, selecting a new alternative or switching to a different production level.* Robustness on the other hand is associated with *not needing change.* While flexibility is a state of readiness, robustness is a state of being. Flexibility and robustness are not opposite or the same, but two sides of the same coin, two ways of responding to uncertainty.

Of course, flexibility and robustness are only valuable in an uncertain environment. Flexibility is important because normally the expected value of the project is the weighted average of the scenarios in the good and bad sides of uncertainty. In general flexibility allows to zero out the negative side of uncertainty, therefore improving the project's expected cost by only weighting the scenarios in the good side of uncertainty. Take the example of a traded commodity whose price fluctuates randomly with known volatility. A company in need of the commodity has several alternatives to acquire it. It can buy it in the spot market, engage in a futures or forward contract or acquire an option. If the company buys on the spot it assumes all risks of price variation (both positive and negative). On the other hand if it engages in a futures or forward contract[2], it effectively hedges the risks of price increases, but it does not acquire any flexibility to modify its future decisions according to the evolution of the price uncertainty. On the contrary, if the company buys a call option on the commodity, it is acquiring the right but not the obligation to buy certain quantity of the commodity, at a pre-determined price, on or before a certain date (for an American Call).

As uncertainty increases, the value of this option (or of the flexibility it provides) also increases, due to the fact that the option provides protection on the downside of uncertainty, but allows the

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2 *A company that buys a futures contract agrees to buy a certain quantity of a commodity, at a pre-determined price, on a specified future date. On the contrary, a company that buys a forward contract agrees to buy a certain quantity of a commodity at the spot price, to be delivered in some future date.*

company to profit from all the potential of the upside of uncertainty. Specifically, if the price volatility increases, there is a higher chance that the price is going to be below what is stipulated in the option contract; in this case the value of the option remains unchanged since the company can decide not to exercise it and buy the commodity in the spot market. But, as volatility increases the probability of the price being higher than the one stipulated also increases and so, the option becomes more valuable, since it allows its holder to buy the commodity at a lower price than would otherwise be available. Of course, an option to buy a certain commodity is only available if there is a counterpart for it, a seller who also wants to hedge against price risk and therefore is willing to sell the option. If the number of company's willing to sell the option is low then the price of the call option increases.

An example in water supply capacity planning is also illustrative. Assume that in a city with a current demand of 100 million cubic meters of water per year, city planners believe that additional demand for the following ten years may range between 30 million to 50 million cubic meters per year. Guided by a robustness principle, planners decide to build a new reservoir that will be able to provide the city with the 50 million cubic meters of water per year that it might need in the *expected* worst-case scenario.

If suddenly urban dynamics in the city change, increasing demand volatility, the range for the additional demand will widen. Let us assume that the new range is from 10 million to 70 million cubic meters. In this case, the value of the robust strategy (the reservoir with a maximum capacity of 50 million cubic meters per year) decreases. First, there is now a probability that demand will be over 50 million cubic meters and that the city will face a water deficit. Second, there is now a higher probability that the 50 million cubic meter system will be over-dimensioned. The first possibility reduces the project value by increasing deficit costs, while the second one does so by increasing opportunity costs.

If instead of guiding their strategy by the robustness principle planners decide to follow a flexible approach, they might decide to build a series of smaller, quick-to-build reservoirs. In the end, the collection of these projects may cost more than the single large reservoir (there are significant economies of scale in water supply expansion projects). Their advantage, however, is that they fabricate options, which become more valuable as uncertainty increases. For example, planners may decide to build an expansion with water production capacity of 15 million cubic meters initially. As uncertainty increases, and the range of future demand moves from 30-50 to 10-70, this option actually becomes more valuable, because the city may not need any additional expansions.

Another situation in which flexibility increases in value with uncertainty is when planners incorporate an option to abandon or re-scale a project during its construction. Thus, city planners may decide to build an expansion initially planned for a 30 million meter capacity, but they have the right to ask the contractor to scale it up or down as needed. The value of this option is greater as uncertainty increases since the option increases the holder's ability to react and profit from future unforeseen events (e.g., it allows planners to expand the project if they think demand is going to be higher, or contract it if demand is going to be lower).

Both flexibility and robustness carry a price. But whereas the costs of a robust strategy are largely known and concentrated in the present, the costs of flexibility are highly uncertain and spread out in the future. One important cost associated with robustness is the opportunity cost derived from excess capacity, or over-building. Flexibility costs are associated with "insurance-type" investments, such as redundancies, and spare parts. In general, the costs of robustness are not offset by any gains in project value, since robustness does not take advantage of the value generated by uncertainty, as does flexibility.

Taking into account flexibility for capacity planning in water utilities is of utmost importance. The task of determining the future capacity of a water supply system is plagued with uncertainty about demand, costs and supply of the existing facilities. Moreover, too much or not enough capacity translates into very high social costs. If there is not enough capacity, society has to bear the burden of a water deficit. On the other hand, over-estimates of demand and over-capacity tie-up scarce capital that could have been profitably invested elsewhere.

In the past, city governments, aid agencies, infrastructure consulting companies, and others, focused on building big to achieve economies of scale. This vision is changing: it is being recognized that in a highly unstable and uncertain environment, the downside risk of such investments is expensive. Flexibility can dramatically improve the value of an infrastructure project. The remainder of this chapter presents the basics of portfolio management and analyzes common capital budgeting techniques in the light of their suitability to handle, value and implement flexible strategies in investment agencies.

2.3. PORTFOLIO MANAGEMENT

Capacity planning consists in determining the right level of capacity needed at each point in time to fulfill demand requirements. Adequate capacity planning should not only analyze when to introduce new facilities to cope with new demand, but also when to introduce new facilities to replace old facilities that are unfavorable or uneconomic. Capacity planning is an exercise on portfolio management, more than an exercise on individual project evaluation.

Nobel Laureate Harry Markowitz developed Modern Portfolio Theory (MPT) in the 1950s as means of managing the risk and return of financial investments. As defined by Grinblatt and Titman (2001) a portfolio is a combination of investments that achieves the highest possible expected return for a given level of risk. The theory of portfolio management proposed by Markowitz (1952) assumes that investors are mean-variance optimizers; in other words, that they seek the portfolio with the lowest possible return variance for any given level of expected (mean) return.

MPT aids investors in their asset allocation decisions by building a portfolio that optimizes market risk against expected return. The theory identifies an efficient frontier of optimal portfolios for a given level of risk. MPT provides a broad context for understanding the interactions of systematic risk and reward. Portfolios are important because they reduce risk by diversification. Adequate portfolio management allows an investor to classify, estimate and control both the kind and amount of expected risk and return from its assets.

Portfolio theory differs from traditional project evaluation in that it shifts the focus of analysis from the characteristics of an individual investment opportunity to the relations between a collection of investment opportunities, and to the combination of possibilities that optimize the value of the total portfolio, and associates the expected return of this portfolio to the level of risk.

Managing a group of infrastructure projects under uncertain conditions is a lot like managing a portfolio of risky financial assets. In both cases the objective is to maximize the return to the investor for a certain level of risk[3]. Portfolio management for projects consists in determining the optimal mix of projects that will optimize the value of the assets held by the institutional investor. For example, a water utility may decide that the maximum deficit probability it is willing to accept is 1%[4]; therefore, the exercise of portfolio management should lead it to identify the combination of projects that keep deficit risk below this level, while simultaneously minimizing development and operational costs.

Portfolio management is a dynamic approach (See illustration in Figure 2.3). Investors must continually analyze their pool of projects and determine which to keep in the portfolio, which to abandon, and which to execute. Any particular portfolio, for a particular investment problem, can be represented as a dynamic cone. The spectrum of projects in the portfolio decreases over time, because as projects advance within the portfolio they can be executed or abandoned. Other projects remain in the portfolio for further consideration, but at some point these too are either executed or abandoned, until the objective of that particular portfolio is achieved.

The projects within the portfolio represent the explicit set of alternatives being considered by the company in its budget allocation exercise. The implicit set of alternatives (all those other projects that the investor could have undertaken in the past and the future possibilities) set the boundaries and minimal conditions for the portfolio evaluation[5].

The evaluation of the projects within the portfolio can be made following several capital budgeting techniques, three of those: Net Present Value, Decision Analysis and Real Options Analysis will be described in the remainder of this chapter.

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[3] *The level of risk in the portfolio is determined according to the risk preferences of the investor (risk-prone vs. risk-adverse).*

[4] *Ideally, the determination of the maximum acceptable deficit risk should be done based on the consumers' utility functions.*

[5] *For more information on implicit and explicit alternatives refer to de Neufville (1990).*

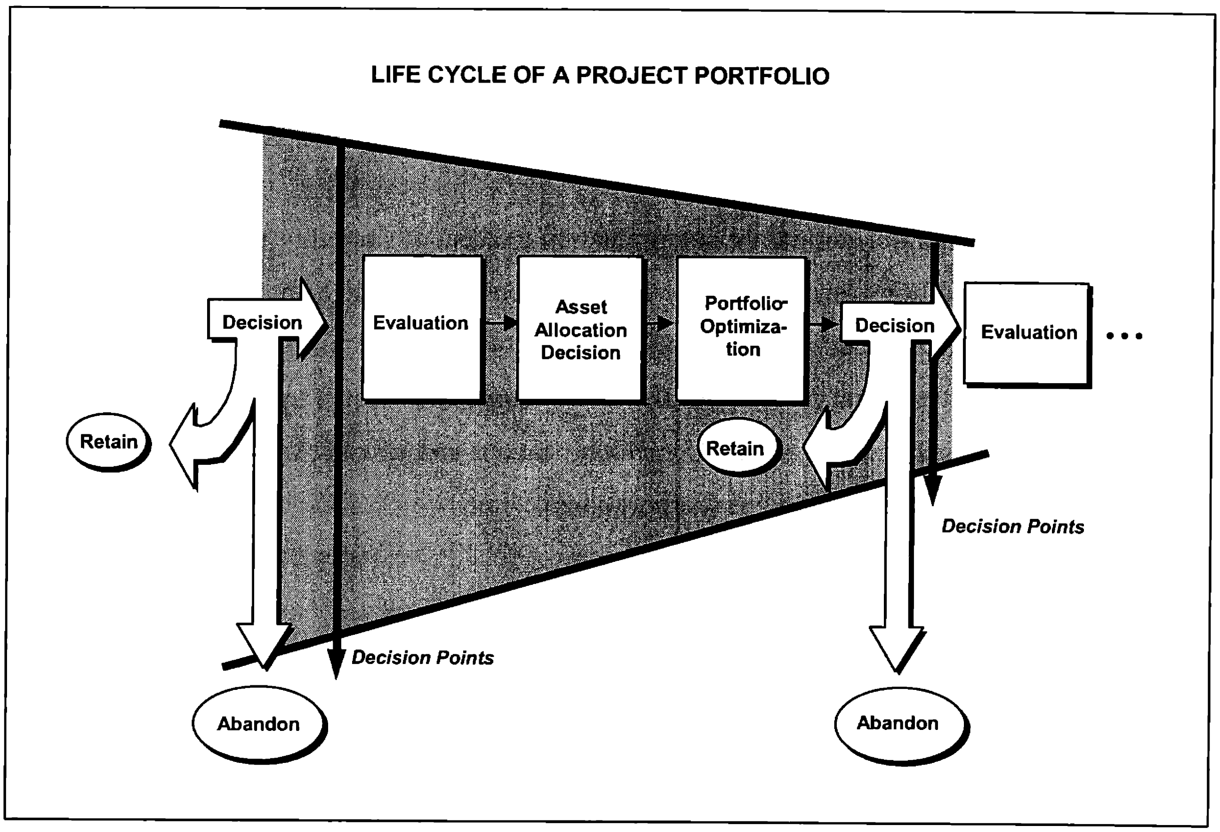

Figure 2.3. Dynamic Life Cycle of a Project in a Portfolio (adapted from Booz Allen & Hamilton, 1999a)

2.4. *NET PRESENT VALUE*

2.4.1. *Basics of Net Present Value*

Discounted Cash Flow methods have traditionally been the core of economic evaluation (de Neufville, 1990). According to the Barron's dictionary of Finance and Investment Terms (Downes and Goodman, ed., 1998), Discounted Cash Flows value future expected cash receipts and expenditures at a common date. Two of the most common DCF methods are Net Present Value and Internal Rate of Return.

NPV applies a discount rate, commonly determined by the cost of capital or the opportunity cost of funds, to represent future cash flows in their present equivalence. IRR finds the average return during the life of an investment. NPV and IRR are closely correlated, since the IRR can also be viewed as the discount rate that makes the NPV of any investment equal to zero. The remainder of this section will concentrate of the NPV method, since it is the single most widely used tool for investment decisions made by today's corporations.

Brealey and Myers (2000) define NPV as a project's net contribution to wealth. They state: *"When we calculate a project's NPV we are asking whether the project is worth more than it costs. We are estimating its value by calculating what its cash flows would be worth if a claim on them were offered separately to investors and traded in the capital markets."* To do so, NPV discounts cash receipts and expenditures to the present date, and then compares these two values, as Formula 2.1 indicates. The investment rule is to invest when NPV is greater or equal to zero. For mutually exclusive projects, the rule is to choose the one with the highest NPV.

$$\boxed{NPV = PV(RECEIPTS) - PV(EXPENDITURES)} \qquad (2.1)$$

PV(RECEIPTS) and *PV(EXPENDITURES)* are the present value of the project's revenues and costs respectively. The present value of any future quantity must be lower in the present, since a dollar now is worth more than a dollar today (Brealey and Myers, 2000). Therefore, the present value of any quantity occurring in the future (C_1) may be found by multiplying the quantity by the discount factor (see Formula 2.2).

$$\boxed{PV = Discount.Factor.*C_1} \qquad (2.2)$$

The discount factor depends on the rate of return expected on the investment *(r)*, which is the return investors expect for accepting a delayed payment. The discount factor for a payment occurring a year from now is calculated with Formula 2.3.

$$\boxed{Discount.Factor. = \frac{1}{1+r}} \qquad (2.3)$$

To bring a quantity that occurs several periods into the future to present value, the discount factor needs to be applied once for each period. If the expected rate of return remains constant in each period then Formula 2.4 can be applied, where t is the number of periods into the future where the payment or payoff occurs

$$\boxed{Discount.Factor. = \frac{1}{(1+r)^t}} \qquad (2.4)$$

The key element in the development of the NPV methodology is the identification of r, commonly known as discount rate or hurdle rate. As was explained before, the discount rate should, in theory, equal the rate of return of equivalent investment alternatives in the capital market. In practice, the rate of return can be approximated to the after-tax Weighted Average Cost of Capital (WACC), or the opportunity cost of funds.

The choice of an adequate discount rate is an ongoing debate in the finance discipline, with no definitive answers available today. There is also the problem that in practice the discount rate is generally assumed to be constant over time, when in reality the project's risk is dynamic, so the discount rate should be constantly adjusted to reflect this change in the level of risk, a process that is cumbersome, at best.

An additional drawback of NPV methodology as a project evaluation criterion is that it does not give a sense of the magnitude of the effort required to undertake the investment, and therefore, projects can only be compared through their NPV when they are also comparable in terms of the necessary investment. Also, NPV requires that all costs and benefits be assigned a monetary value, something that is hard to do for infrastructure investments where many benefits and costs are of a non-monetary nature, such as improved quality of life, or the cost of a water deficit.

All the aforementioned problems, although serious, can be dealt with and partially corrected by a careful analyst. In reality, the most serious problem of the NPV methodology lies in the fact that it is inherently inadequate to evaluate risky projects, for two main reasons:

1. It does not take into account managerial flexibility

2. It uses expected value pricing and thus may incur in the flaw of averages.

2.4.2. NPV and Flexibility

NPV does not take into account managerial flexibility because it makes implicit assumptions concerning an expected scenario of cash flows and presumes management's passive commitment to a certain "operating strategy" (Trigeorgis, ed., 1995, p.1). As Copeland and Antikarov (2001, p.73) see it, "*NPV is constrained to pre-committing today to a go or no-go decision. It uses information only available today*". Therefore, NPV systematically undervalues projects that include future decisions stages, where management's ability to adapt and revise later decisions introduces asymmetries in the distribution of a project's cash flows. The ability of management to abandon, grow, defer and/or scale up or down a project, introduces an element of flexibility in the system that may act ass protection on the downside of uncertainty, while exploiting the benefits from the upside potential. By assuming one cash flow scenario from the beginning, NPV rules out the possibility of these adaptations and therefore, does not take into account the value creation of flexibility.

2.4.3. The Flaw of Averages

Even in cases where there is no space for managerial flexibility, NPV may lead to an incorrect valuation of the project or asset if there is uncertainty. When there is uncertainty, NPV uses an expected value pricing technique. This approach has two shortcomings, one of misinterpretation and another of impreciseness.

The misinterpretation shortcoming derives from the fact that the concept of expected pricing is hard to grasp when talking about a one-time experiment (as are infrastructure investments). The expected value pricing theory states that if an experiment is repeated a very large number of times, its result will be the weighted average of the probable outcomes by the probabilities of each outcome. For example, in a hold a coin-toss game, in which we get $1 if heads, and nothing if tails, the expected gain is $0.50 when the experiment is repeated several times. But, if the experiment is played only once then the possibility of winning $0.50 is zero; you can either win $1 or nothing (Baxter and Renning, 1997).

Expected pricing may give a correct estimate of the fair price to pay for the project, asset or game, but this price is in general, not equal to the true value of the project, asset or game once the experiment is concluded. Real life projects are usually similar to a one-time coin-toss game; they are a one-time opportunity, and therefore, the use of expected pricing techniques can lead to significant mistakes in the estimation of the asset or project's value.

A second shortcoming, more serious than the first one, is that in many cases NPV may not even lead to a fair pricing of the asset or project. This result is clearly defined by Savage (2000) as the *Flaw of Averages*, which states *"Plans based on the assumption that average conditions will occur are usually wrong".* The Flaw of Averages is a layman's description of the mathematical proposition known as Jensen's Inequality.

Jensen's inequality states that average values of uncertain inputs do not always result in average outputs. Mathematically, Jensen's proposition states that if x is a random variable and $f(x)$ is a function of x, then the expected value of the function is not, in general, equal to the function of the expected value, as shown in Formula 2.5 (Dixit and Pindyck, 1994).

$$\boxed{\varepsilon[f(x)] \neq f(\varepsilon[x])} \qquad (2.5)$$

In fact, the only time that average inputs are guaranteed to result in average outputs is when the output model is a linear function of all uncertain variables. This is seldom the case. The practical implications of Jensen's inequality to the application of the NPV under uncertainty is that if management plugs in average values for the uncertain variables in the DCF model, the resulting valuation will be incorrect (since the fair price of the project is represented by the expected value of the function, and not the function of the expected values). The direction of the error depends on the shape of the function, meaning whether the Net Present Value of a project is a concave or convex function of the uncertain variables (see Formula 2.6.a and 2.6.b).

For concave functions: $$\boxed{\varepsilon[f(x)] < f(\varepsilon[x])} \qquad (2.6.a)$$

For convex functions: $$\boxed{\varepsilon[f(x)] > f(\varepsilon[x])} \qquad (2.6.b)$$

In short, NPV does not take into account the value of flexibility, and may even incorrectly price projects even in the absence of flexibility, by incurring in the flaw of averages. The following two sections explore the theoretical underpinnings of two methodologies that partially correct these limitations.

2.5. DECISION ANALYSIS

Decision Analysis has a long history of examining the value of contingent decisions in infrastructure investments. DA effectively takes into account the value of flexibility by structuring the problem in such a way that all uncertainties and their contingent decisions on those uncertainties are explicitly represented by a decision tree. A decision tree is a sequence of decision and chance nodes, ending on a terminal node. A decision node indicates a point where the decision maker faces a decision. The branches emanating from a decision node represent the options available to the decision maker; all possible choices should be represented and they have to be mutually independent.

Once the tree has been laid out, DA solves the tree backwards finding the best possible decisions at each time for all the identified states of nature. According to de Neufville (1990), DA leads to three results:

- Structures the problem, which otherwise would be very confusing due to the complexities introduced by uncertainty.

- Defines optimal choices for any period through an expected value calculation based on the consideration of the probabilities and the outcomes of each choice.

- Identifies an optimal strategy over many periods of time.

In this sense, DA corrects some of the disadvantages of NPV; mainly, DA recognizes that only uncertainty resolution reveals the most appropriate decision at each point in time, and therefore it does not pre-commit to a decision in the first time period, but identifies an array of decisions, each of which is optimal under different evolutions of the uncertainties in the project. Decision Analysis differs from NPV in that it does not base its decisions on information available today, but assumes that new information will be acquired as the project evolves and that this information may change the optimal choice for the project.

The decision rule in DA is simple: choose the one that offers the *best average value*, where "average" means expected value: a weighted average of the outcomes by their probability of occurrence (de Neufville, 1990). Nevertheless, DA uses NPV as an input and in this sense it shares some of the NPV's disadvantages. In general, the calculation of the outcome of each scenario is done through the NPV methodology. Therefore, although DA corrects the inflexibility of NPV, it still has a problem with the discount rate. DA gives an imprecise answer to the value of a project and its flexibility because it assumes a constant discount rate through the decision tree while in reality, the riskiness of the project's outcomes (its cash flows) changes based on their position in the tree.

Moreover, although DA effectively lays out a distribution of possible outcomes, which correct the interpretation shortfall of using an expected pricing technique, the risk of incorrectly pricing the asset or project remains, due to the flaw of averages. This may not be important in cases where the objective is to obtain the optimal strategy for a certain portfolio of projects, but it might become very relevant if the objective of the analysis is to price a certain flexible strategy, to determine how much should be paid for it.

2.6. REAL OPTIONS ANALYSIS

The Real Options methodology was developed, at least partly, as a response to the inadequacy of traditional methods for the evaluation of capital budgeting decisions under uncertainty, namely Net Present Value and Decision Analysis. Since its inception, the Real Options methodology has gained acceptance among the finance community, and has been applied to a variety of capital investment decisions, and recently to the evaluation of infrastructure projects. The approach, derived from the financial option pricing theory, overcomes NPV disadvantages by allowing analysts to account for non-easily quantifiable elements such as managerial flexibility and strategic interventions during the development of a project. Accounting for these elements radically changes the nature of any investment or project, by incorporating flexibility into the structure of the project itself. In addition, ROA also corrects the expected pricing inaccuracies, by determining a fairer value of flexibility through the use of arbitrage pricing techniques.

As with DA, the ROA approach is not only valuable because it prices flexibility and takes into account uncertainty, but because in theory it also sets forth decision rules that investors may apply to optimize their strategy. For example, ROA can identify the price level of a certain input that should trigger a decision to abandon production, or when to keep the option of investing in a project open, instead of exercising it immediately.

2.6.1. Conceptual Framework

A Real Option is the right, but not the obligation to take an action (e.g., deferring, expanding, contracting or abandoning a project or investment) at a predetermined cost (the exercise price), for a determined period of time (the life of the option). The term Real Options was first proposed by Stewart Myers, of the Massachusetts Institute of Technology, who translated the financial concepts of call and put options to the analysis of real assets (Myers, 1977).

ROA uses the same pricing model that is used to value financial assets; this pricing mechanism was developed by economists Robert Merton, Fischer Black and Myron Scholes in the early 1970s, and recorded in two papers: "The Pricing of Options and Corporate Liabilities" (Black and Scholes, 1973), and "The theory of Rational Option Pricing", (Merton, 1973). This theory won both Myron Scholes and Robert Merton[6] the Nobel Prize in Economics in 1997.

Real Options theory views investment opportunities as rights but not obligations. ROA assumes that if one could find a financial option similar enough to the investment opportunity at hand, then the value of the option would approximate the value of the opportunity. Since investment opportunities are usually complex and unique, it is difficult to find an option in the financial market that resembles the investment opportunity; therefore ROA constructs synthetic options that allow the valuing of real investments through arbitrage opportunities. For this to work a there needs to be a correspondence between the investment's characteristics and the variables that determine the price of a financial option (see Figure 2.4):

- Value of the Underlying Risky Asset (S)
- Exercise Price (X)
- Volatility—Standard Deviation of the value of the underlying asset (σ)
- Time to expiration of the option (t)
- Risk-free rate (r_f)

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6 *Fischer Black died in 1995 before receiving the award.*

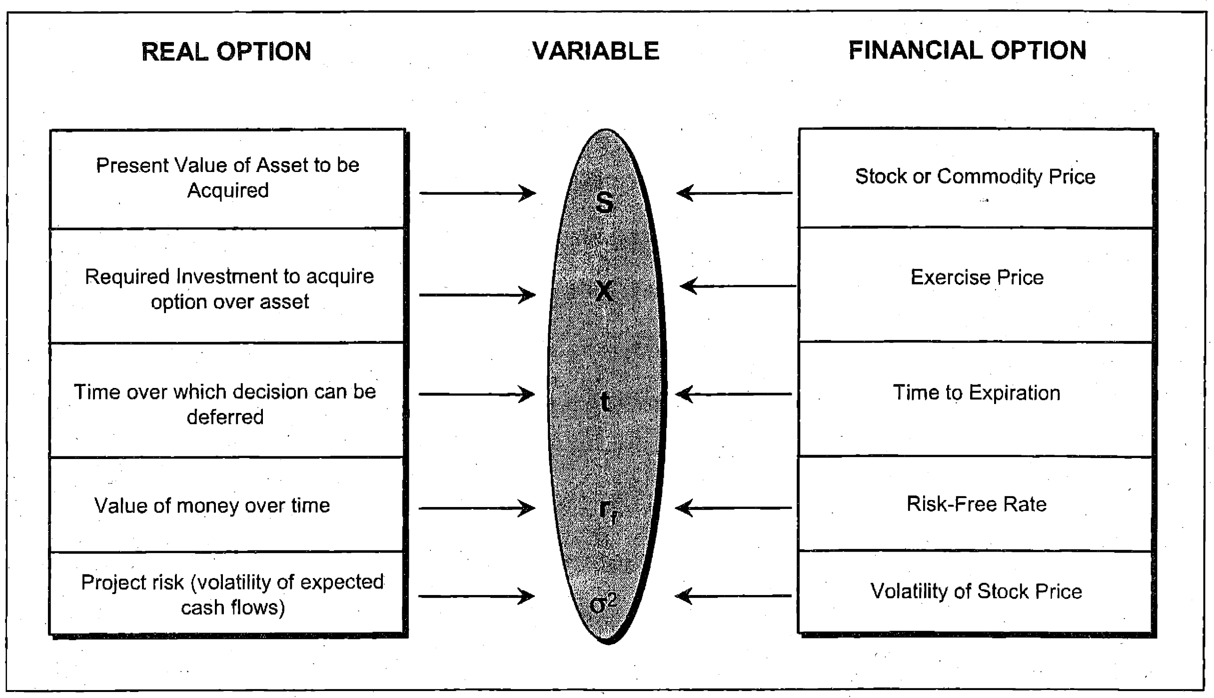

Figure 2.4. Equivalence between Real Options and Financial Options (adapted from Booz Allen & Hamilton, 1999b)

The underlying asset is the instrument on which the option is based. In a financial option, the underlying asset can be clearly determined. It is a security, like a stock or a commodity, whose parameters (value and volatility) can be directly observed in financial markets. For example, the underlying for a financial call option is the stock that the buyer of the option receives once he exercises it. The underlying asset for a real option is a more diffuse concept. Some assume the underlying asset to be the gross project value of operating cash flows without flexibility (Trigeorgis, ed., 1995, Copeland and Antikarov, 2001). Other practitioners use a relevant asset, which might be traded in the commodities' markets (Kulatilaka, 1999). The first approach has the problem that its parameters of this asset are very hard to estimate since the asset is in general not traded and therefore no information is available on its value and volatility. The second approach is problematic because the volatility of say a copper mine, is not necessarily equal to the volatility of copper prices.

A second problem of the underlying asset of real options relates to the ability of the option holder to modify the value of the underlying asset. In the case of a financial option, the owner of the option cannot affect the underlying asset (e.g., price of the stock); in this sense, financial options are a lot like side bets. Whereas on real options, management has a certain degree of control over the underlying asset on which the option is written and therefore, management's actions can heavily influence the value of the asset (Copeland and Kennan, 1998). Whether it be because of management's actions, or because of the evolution of the uncertainties, as the value of the underlying asset increases, so does the value of the option.

The exercise price is the amount of money invested to exercise the option. For a financial option the exercise price is the price that has to be paid to acquire the option. In the case of a real option it is usually the present cost of the flexibility that grants the option-like characteristics to the investment (e.g., cost of building a factory that can deal with two types of inputs and so allows a switching option, or the investment required to build a certain project that creates further growth options). As the exercise price goes up, the value of the option diminishes, since this means that flexibility becomes more expensive.

The volatility of the underlying asset also correlates positively with the value of the option. When flexibility creates downside protection, uncertainty generates additional value for the project, as it was explained in the first part of this chapter. Estimating the volatility of the underlying asset is very difficult for real options since no historical information on the returns of similar projects is available. Therefore, this estimation has to be done through an approximation, via a Monte Carlo simulation of the value of the project, the volatility of another traded asset or of a synthetic portfolio of assets. Finding this proxy is not easy and it represents the greatest theoretical difficulty of the ROA approach.

Finally, as the time to expiration of the option increases, the value of the option increases as well, since there is more opportunity to benefit from the upside of future uncertainties. And as the risk free rate goes up, so does the value of the option. There is one additional variable that may influence the value of the option and that is the existence of dividend payments. In the case of a real option this can be assimilated to the value loss during the time that the option is open (Brealey and Myers, 2000).

Real Options are classified primarily by the type of flexibility they provide, and by whether they provide upside potential or downside protection (i.e. the direction of the option). Table 2.1 presents a summarized taxonomy of real options and a guide to additional literature for each type of option.

2.6.2. Arbitrage Pricing

The main theoretical advantage of Real Options over Decision Analysis is that ROA relies on an arbitrage pricing argument, and therefore steers clear of the flaw of averages common to expected value pricing techniques. As was mentioned before, the expected pricing mechanism does not identify the fair price of an asset in certain situations. In theory, the arbitrage pricing mechanism not only *suggests* the fair price of the asset, but it *enforces* it (Baxter and Rennie, 1997).

Option	Description	Type of Flexibility	Guide to Literature
Deferral	Similar to an American Call option. Exists when management can defer the decision about the investment for a certain period of time. They are important in natural resource extraction industries, real estate development, farming and others.	Upside Potential	McDonald and Siegel (1986); Paddock, Siegel and Smith (1988); Tourinho (1979); Titman (1985); Ingersoll and Ross (1992); Dixit (1992)
Timing or Staging	Relates to the possibility of staging investments as a series of outlays to create both growth and abandonment options. Each stage can be viewed as an option on the value of subsequent stages (compound option). They are important in R&D intensive industries, capital-intensive projects and start-up ventures.	Upside Potential and Downside Protection	Brennan and Schwartz (1985); Majd and Pindyck (1987); Carr (1988); Trigeorgis (1993)
Altering Operating State	If market conditions are better than expected, a company may decide to increase its output level by investing in scaling-up the production plant either temporarily or permanently. Equally, if market conditions are adverse the firm might decide to temporarily shutdown production. Both cases are similar to call options. Important in natural resources industries where prices of output may vary constantly, commercial real estate, and in other cyclical industries such as fashion apparel and consumer goods	Upside Potential and Downside Protection	Brennan and Schwartz (1985); McDonald and Siegel (1985); Trigeorgis and Mason (1987); Pindyck (1988)
Growth	A growth option is similar to a European or American call. They exist when early investments in R&D, undeveloped land or reserves of a natural resource, information, create the opportunity of generating further revenues (I.e., developing a product and selling it in the market, exploiting the acquired reserves, and others). Growth opportunities are compound options, whose value depends on a pre-existing option.	Upside Potential	Myers (1977); Brealey and Myers (1991); Kester (1984, 1993); Trigeorgis (1988); Pindyck (1988); Chung and Charoenwong (1991)
Abandon ment	Similar to an American Put. If market conditions deteriorate, management can abandon current operations permanently and recoup the salvage value of the asset. It is important in capital-intensive industries with second-hand markets for their assets, such as the airline industry, railroads and financial services.	Downside Protection	Myers and Majd (1990), Sachdeva and Vanderberg (1993)
Switching	A combination of calls and puts that allow its owner to switch between two or more modes of operation, inputs or outputs. These options can create both product flexibility and process flexibility. They are important in facilities that are highly dependent on an input whose price varies constantly (E.g., oil, or any other commodity), and consumer electronics, toys, and autos industries where product specifications are subject to volatile demand.	Upside Potential and Downside Protection	Magrabe (1978); Kensinger (1987); Kulatilaka and Trigeorgis (1993)

Table 2.1. Taxonomy of Real Options (adapted from Trigeorgis, ed., 1995, pp. 4-5)

Arbitrage is the act of profiting from differences in price when the same security, currency, or commodity is traded on two or more markets (Downes and Goodman, 1998). Practically, arbitrage involves buying an asset at a low price in one market and immediately selling it at a higher price in another market, therefore making a risk-free profit with no net investment as the cash received from the selling is used to finance the purchase (Moles, ed., to be published 2003). In well-functioning competitive markets, arbitrage opportunities rarely exist; assets with the same payoffs, trade at the same price (aka. *Law of One Price*).

This condition is extremely helpful in the valuation of complex contingent claims and other derivative assets (financial or real), because it predicts that assets with the same risk distribution will trade at the same price. Therefore, the complex investment opportunity can be priced by replicating its payoffs with a portfolio of simple financial instruments, each of which can be easily priced. The replicating portfolio and the option produce exactly the same payoffs, thus they have the same price. Moreover, as the price of the option is determined by the non-arbitrage condition between the replicating portfolio and the contingent claim (option), the attitudes towards risk of the investors are not a factor in pricing.

The arbitrage condition allows pricing of real options by finding a portfolio of perfect substitutes that provides the same payoffs that the real asset and whose payoffs can be directly observed in the market (Dixit and Pindyck, 1994). Contingent claims, such as options present an additional difficulty since their payoff is non-linear (at expiration, an out-of-the-money option has no value, and an in-the-money-option's value is the difference between the exercise price and the option's underlying asset's value). In this case, a dynamic adjustment of the replicating portfolio over time is needed[7]. Assuming that the replicating portfolio consists of a fractional holding of the underlying asset and a certain quantity of risk-free bonds, the time adjustments to the portfolio are made by reducing or increasing the borrowing (or lending) at the risk-free rate over time (Moles, ed., to be published 2003).

The use of the arbitrage mechanism overcomes the pitfalls of expected value pricing by avoiding the flaw of averages and partially helps solve the discount rate problem. While DA battles with

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[7] *This is known as the conditional arbitrage model, which was the theory developed by Black, Scholes and Merton.*

the choice of a discount rate and the attribution of a level of risk to a certain project, ROA uses the volatility of the underlying asset to risk-adjust expected cash flows, and then discounts at the risk free rate. The question of which risk-free rate should be used is still largely unexplored.

2.6.3. Option Pricing Methodologies

There are several methodologies to value an option. First, the breakthrough work by Black, Scholes and Merton (Black and Scholes, 1973; Merton, 1973) determined a close –form solution to price European Call and Put Options on a non-dividend-paying stock. The Black-Scholes formula, as this solution is commonly referred to, is widely used in financial markets, but its constraining assumptions difficult its application to real assets (Trigeorgis, 1996). Black-Scholes is only valid for European options (options that may be exercised only at maturity), only one source of uncertainty can be taken into account (no rainbow options[8]), the option must be contingent on a single risky underlying asset (no compound options), the underlying asset pays no dividends, the current price and the stochastic process followed by the underlying asset are known (observable), the variance of the return of the underlying asset is constant through time, and the exercise price is known and constant.

The price of a real option can also be determined by identifying the partial differential equation that describes the behavior of the underlying asset (e.g., a Geometric Brownian Motion or a Markov Process) and solving this equation through the use of Ito Calculus (Dixit and Pindyck, 1994). This approach has the disadvantage that it requires a deep understanding of advanced differential calculus, which project evaluation practitioners rarely have in practice. Therefore, real options problems today are usually solved through a numerical approach.

There are three numerical procedures that can be used to value real options when exact formulas, such as Black-Scholes and other partial differential equations are either not available, not applicable or not practical to implement: Binomial Methods, Simulation and Finite Difference Methods. In essence, all numerical methods do is simulate the stochastic behavior of the

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8 *Rainbow Options are options whose value depends upon two or more uncertain variables.*

underlying asset directly, through different approximations, so that there is no need to write the partial differential equations to describe the behavior of the system.

The binomial method, developed by Cox, Ross and Rubinstein (1979), uses binomial trees to approximate the behavior of the underlying asset. These trees assume that in each time period the underlying asset moves up or down by a proportional amount. These up and down movements, and their corresponding probabilities, are determined in such a way that in a risk-neutral world the asset has the correct mean and standard deviation. The option price is then calculated starting at the end of the tree and working backwards, discounting the value of money at the risk free rate (Trigeorgis, 1996).

Simulation techniques replicate the underlying asset stochastic process by using random numbers to sample many different paths that the underlying asset's value may follow (usually this is done through a Monte Carlo simulation) in a risk-free world. For each path the option payoff is calculated and discounted at the risk-free rate. The arithmetic average of the discounted payoffs is the estimated value of the derivative (Hull, 1989). It is important to note to differentiate the Binomial and Simulation methods; the Binomial method may make use of Monte Carlo simulation to identify volatility of the underlying asset, whose behavior will then be modeled through the binomial tree. Both the Binomial and Simulation methodologies rely on the principle of risk-neutral valuation.

Finally, Finite Difference Methods find the option price by converting the stochastic partial differential equation into a set of difference equations that are then solved by iteration, in a manner similar to binomial tree approaches, since they also work back from the end of the life of the option to the beginning (Hull, 1989).

2.7. SUMMARY

To improve the value of infrastructure projects it is necessary to use the correct techniques for their planning and evaluation. Essentially, planning and evaluation process of infrastructure projects must take into account uncertainty and management's ability to respond to it. The use of adequate capital budgeting techniques not only increments the precision of the analysis but promotes the introduction of flexible elements in the investor's strategy that expand the investment opportunity's value by improving its upside potential while limiting downside losses relative to a passive managerial strategy. The adopted capital budgeting techniques should be versatile enough to take into account those options that occur naturally (such as defer, contract, shut down or abandon) and those that have to be planned and built in at some extra costs (such as expansion, switching between inputs, reducing vulnerability of a component, and defaulting).

Clearly, NPV is not an adequate technique since is assumes no flexibility in decision-making, and therefore underestimates the project's value by neglecting to consider the positive influence of management's future actions over this value. Decision Analysis does take into account managerial flexibility, but poses the problem of identifying the correct discount rate, and of the expected value type of valuation. In theory, ROA corrects these deficiencies, but the information required to solve this approach is usually hard to estimate with precision, mainly the estimation of the value and volatility of the underlying asset. Moreover, the ROA methodology poses the additional difficulty of being almost completely unknown to the engineers in charge of evaluating infrastructure investments, especially in developing countries. On the contrary, DA is already widely known within the engineering community.

In general, the available literature on real options concurs in pointing out that the most important contribution of this framework is changing the mindset of managers. According to Olmsted (1995):

> The process of performing a Real Option Analysis tends to broaden one's view of future possibilities and sharpen the logic of one's thinking about various strategic alternatives. The process itself can be more important than the particular analytic results.

In this sense, both DA and ROA are extremely valuable approaches, since they both take into account the value of flexibility and promote a change from a deterministic type of valuation to a dynamic planning process, which encourages flexible designs that effectively deal with the uncertainties in the environment, and are much more in line with Modern Portfolio Theory.

In the end, the choice between ROA and DA is particular to the type of project being analyzed, and the institution implementing it. The case study that follows in coming chapters compares the utility and applicability of ROA and DA for the analysis of the expansion of Bogotá's water supply system, and draws conclusions as to when should each approach should be used in the analysis of investment opportunities.

CHAPTER 3: BOGOTA'S WATER SUPPLY SYSTEM

3.1. INTRODUCTION

The previous chapter analyzed the theoretical advantages and disadvantages of three capital budgeting techniques: Net Present Value, Decision Analysis and Real Options, as applied to the evaluation of infrastructure projects. The literature survey identified that, in theory, both DA and ROA take into account flexibility and provide both a valuation result and a strategy to optimize the value of the project or projects being considered. The remainder of this thesis compares the adequacy and practicality of implementing these approaches in an actual case: the expansion of the water supply system in Bogotá, Colombia. In summary, the system study seeks to identify the optimal capital budgeting technique for water supply capacity planning, given the regulatory, administrative and political context of water utilities in Colombia.

This chapter lays the foundation for understanding the water supply system in Bogotá, its institutional framework, and its main challenges.

3.2. BOGOTA: BASIC FACTS

Bogotá, a 7 million people city, is the third highest capital city in the world (after La Paz and Quito). It lies 2,640 meters (8,500 feet) above sea level, on the highest plateau in the Colombian Andes, occupying 1,732 sq km (669 sq. miles). Bogotá is the political, administrative, economic and cultural center of Colombia. One in every 7 Colombians (approximately 15%) lives in Bogotá. In the 1980s and 1990s, average population growth for the city was 2.5% per year. Bogotá's density, at 3,717 persons per km^2 is one of the highest in North and Latin America (see Figure 3.1).

Figure 3.1. Map of Colombia

Average daily temperatures range between 8°C (46°F) and 20°C (68°F). Due to its close location to the equator, Bogotá has no seasons. Its mild climate, defined by altitude, is quite comfortable and stable year-round. The rainy season extends from March to May. (Alcaldía Mayor de Bogotá, 2000)

The country's constitution, rewritten in 1991, organized the country into a unitary and decentralized republic with autonomous territorial institutions. Bogotá, in the special category of "Capital District", is one of the 1,086 municipalities that constitute the political and administrative basis of the country. The city provides public services, administrates its resources, develops local infrastructure and performs additional functions delegated by the central government, such as the provision of health and education. The City Council and the Mayor, elected for a three-year period by popular vote, head the government and administration of the city. The City Council is the legislative branch of the local government; it is in charge of the supervision and control of local authorities.

Bogotá's economy is the most dynamic in the country, concentrating 30% of Colombia's Gross Domestic Product (GDP). The city is the eighth most important economy in Latin America, (Colombia as a whole being the fourth economy in importance), Bogotá's GDP is higher than that of Bolivia and Ecuador taken together (DANE, 1999). The average GDP growth rate in the 1991-1999 for the city was 3.6%, while the per capita GDP has risen to US$3,300 as compared to the country's per capita GDP of US$2,020 (World Bank, 2001).

3.3. BOGOTA'S WATER SUPPLY SYSTEM

Water resources in Bogotá have three main uses: water supply, hydro electrical generation and agriculture. Three institutions administer them: The Bogotá Water Company (EAAB, Empresa de Acueducto y Alcantarillado de Bogotá), the Bogotá Energy Company (EEB, Empresa de Energía de Bogotá) and the Cundinamarca Autonomous Regional Corporation (CAR, Corporación Autonóma Regional). This case study addresses the issue of capacity planning for water supply as managed by the EAAB.

3.3.1. Demand Side

The EAAB is responsible for providing water and sewerage services to Bogotá and its 13 adjacent municipalities: Cajicá, Chía, Cota, Facatativá, Funza, Gachancipá, La Calera, Madrid, Mosquera, Soacha, Sopó, Tocancipá and Zipaquirá. For billing purposes, the EAAB segments its users in four groups: residential, commercial, industrial, and official. Residential users are households, commercial are regular business (offices, stores, restaurants, and others), industrial comprise water-intensive industries such as soda factories and others, and official are all state and municipal institutions and all state-owned enterprises located in Bogotá. As Figure 3.2 shows, in the 1990's residential demand accounted on average for 77% of total demand, while commercial, industrial and official represented about 9%, 7% and 6% respectively (EAAB, 2000).

<u>*Residential Demand*</u>

The total population served by the EAAB as of 2002 is 1.8 million households (EAAB, 2000). Assuming an average ratio of 4.8 people per household (TEA Consultores, 1999), the total residential population served by the EAAB is 8.5 million people, 7 million in Bogotá, and 1.5 million in the surrounding municipalities, approximately. Given a per capita consumption of 132 litres per day (35 gallons per day), residential demand for water in 2002, is 411 million cubic meters per year (13 m^3/s or 297 MGD).

The drivers of residential demand are population growth, changes in per capita consumption, and price elasticity of demand. Bogotá has recently been an exception to the typical rule that per capita consumption has positive correlation to economic development (industrialized societies consume more water than developing ones). Although in the past few years the city's economy has grown substantially, per capita consumption dropped from 158 litres per person per day in 1990 to 132 litres per person per day in 2000,as can be seen from Figure 3.3 (TEA Consultores, 1999). The reason for this 16% reduction in per capita consumption in Bogotá in the last years can be traced to the water supply emergency of 1994, when one of the tunnels of the Chingaza system collapsed and the city's water supply was severely constrained.

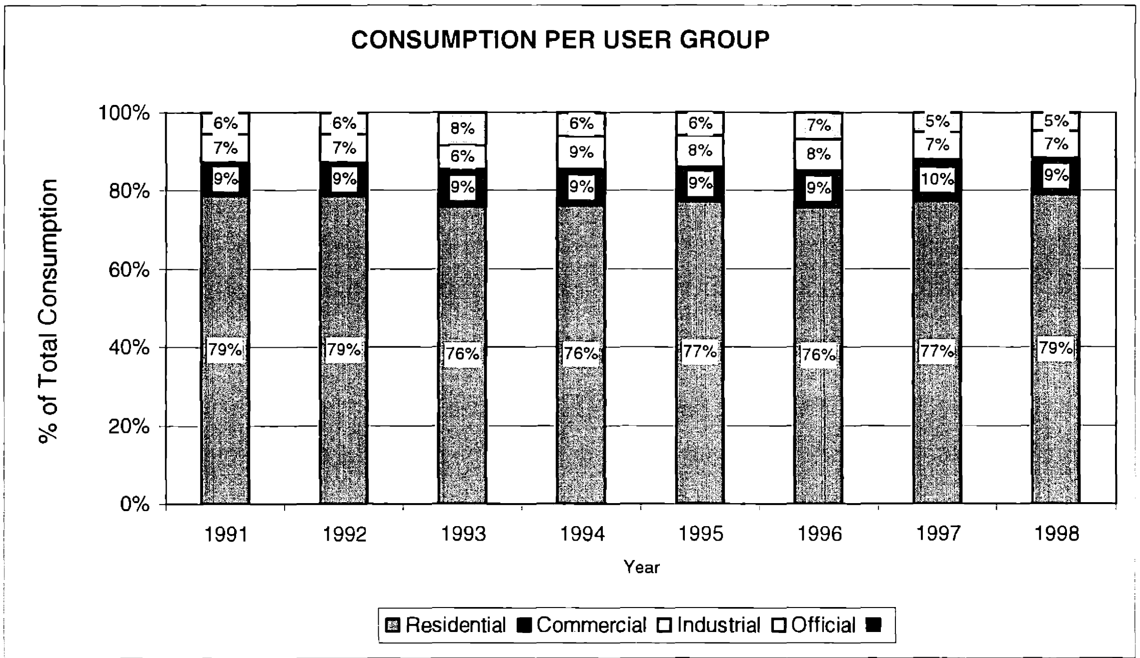

Figure 3.2. Percentage Consumption per User Group (EAAB Commercial Statistics, 2000)

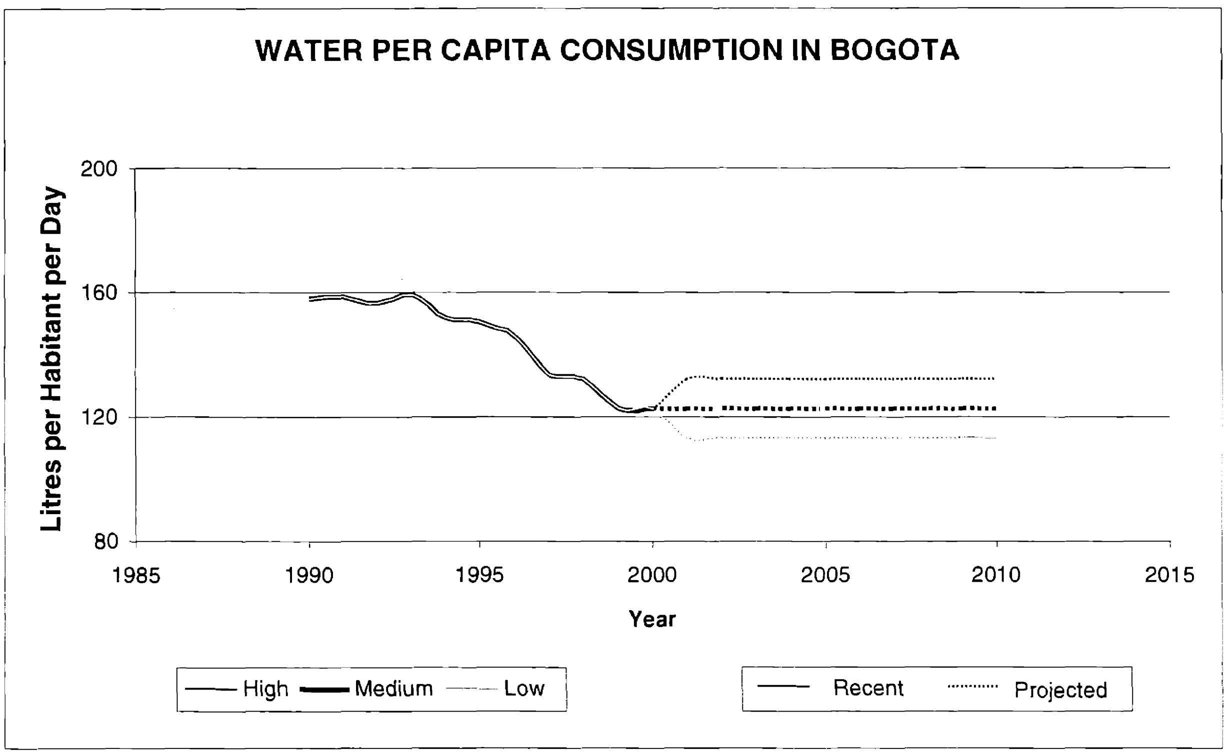

Figure 3.3. Recent and Projected Trends of Per Capita Consumption in Bogotá (adapted from Tea Consultores, 1999)

The Chingaza emergency raised awareness about the water supply problem in Bogotá, and in that sense was helpful to help promote demand-side management programs, which the EAAB had developed for a long time, but that had never received much attention. The main components of the demand-side management program were: replacement of old toilets with low consumption ones, water recycling in the industrial sector, and change of water consumption habits in the population. The program not only achieved the objective of rationalizing water use during the emergency, but it also permanently altered the consumption habits of the population, so that even after the emergency, consumption remained relatively low.

For its projections, the EAAB assumes that in the most likely scenario, the per capita consumption of the next 15 years will remain at the same levels as it is today (see Figure 3.3). This derives from the fact that the EAAB believes that the newly acquired consumption habits will remain, and also that the demand-side management program has exhausted its potential for further reducing per capita consumption.

The 1999 study conducted by TEA Consultores also estimated price elasticity of demand for the EAAB in a range between –9.6% and –22.5%. The weighted average estimated according to the population economic strata distribution is –12.5%. This means that if water prices increased 100% water demand would fall 12.5%. Since the EAAB assumes that water prices will remain constant for the next 10 years, this elasticity does not affect the estimate of residential demand. In the end, residential demand for water consumption in Bogotá appears to depend mostly on population growth. Figure 3.4 shows the EAAB's estimates of population growth; average growth for the "medium" scenario is assumed to be around 2.3% per year.

Non-Residential Demand

The industrial, commercial and official segments comprise non-residential demand. Industrial and commercial users account for 73% of this demand, while official users for the remaining 27%. Since, most of the non-residential demand is clearly associated with economic activity, the demand projections for this sector are based on projections of future economic activity in the city and surrounding municipalities.

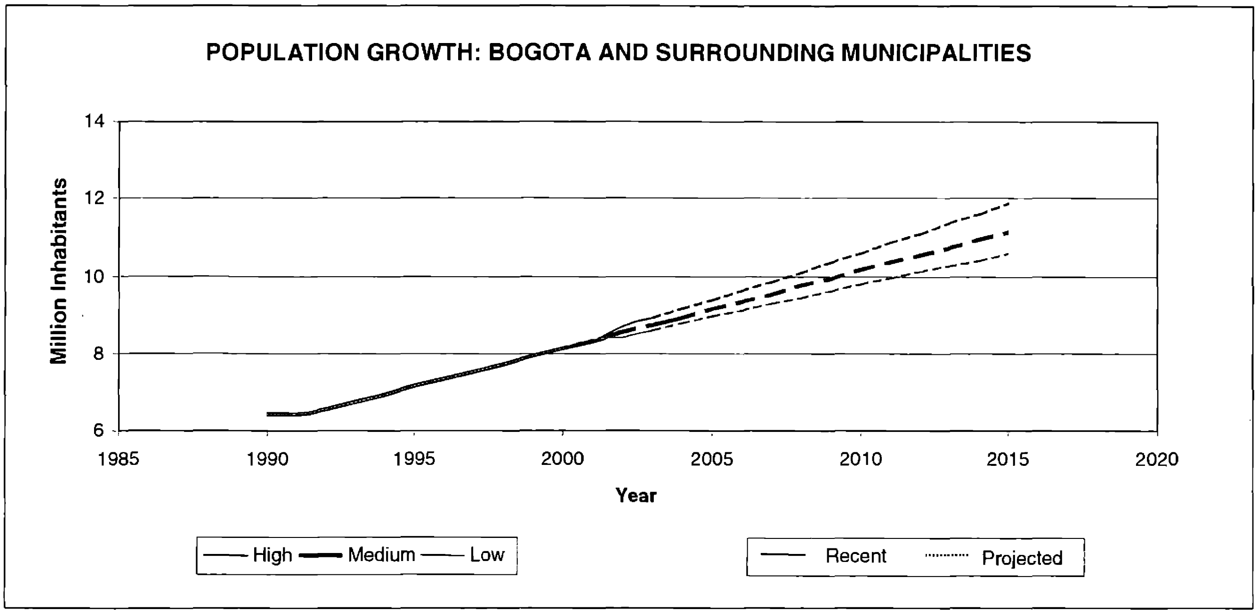

Figure 3.4. Population Growth for Bogotá and Surrounding Municipalities (adapted from TEA Consultores, 1999)

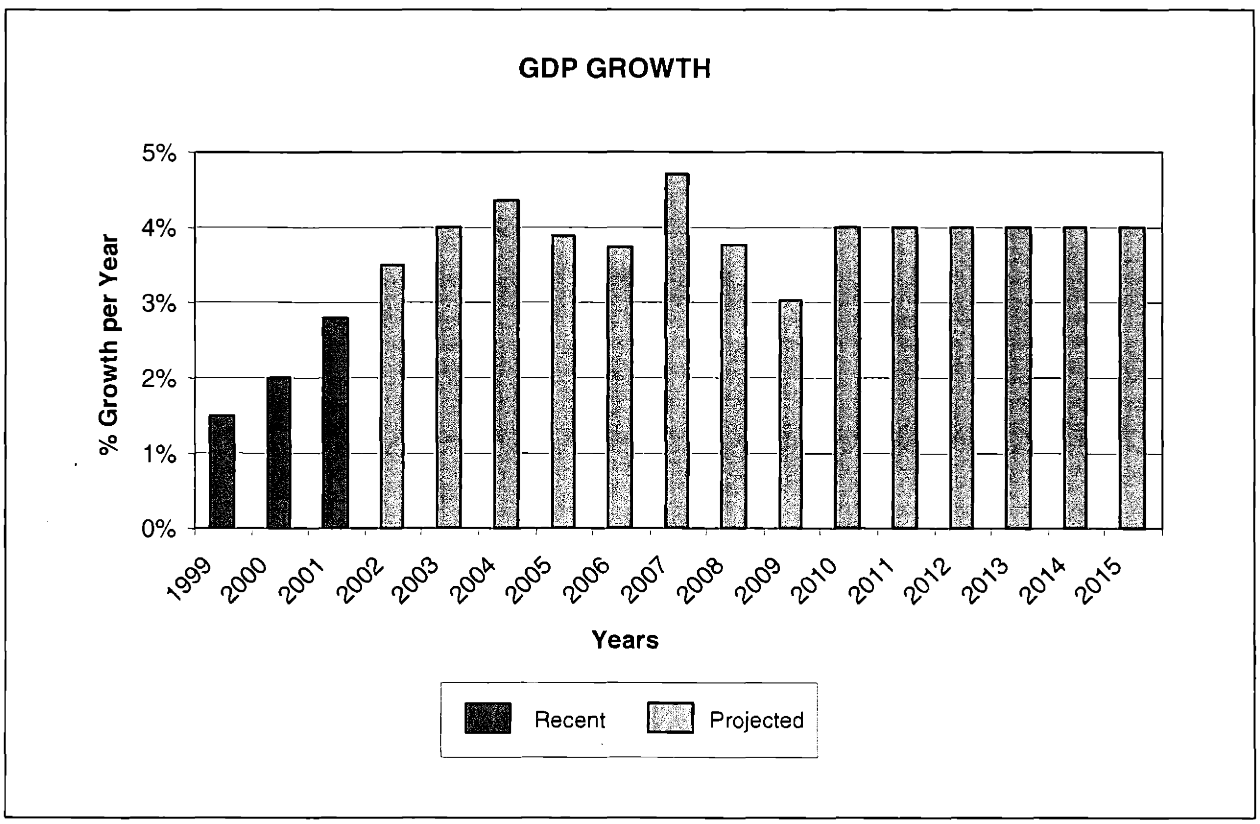

Figure 3.5. Recent and Projected Trends in GDP Growth (National Planning Department, 1999)

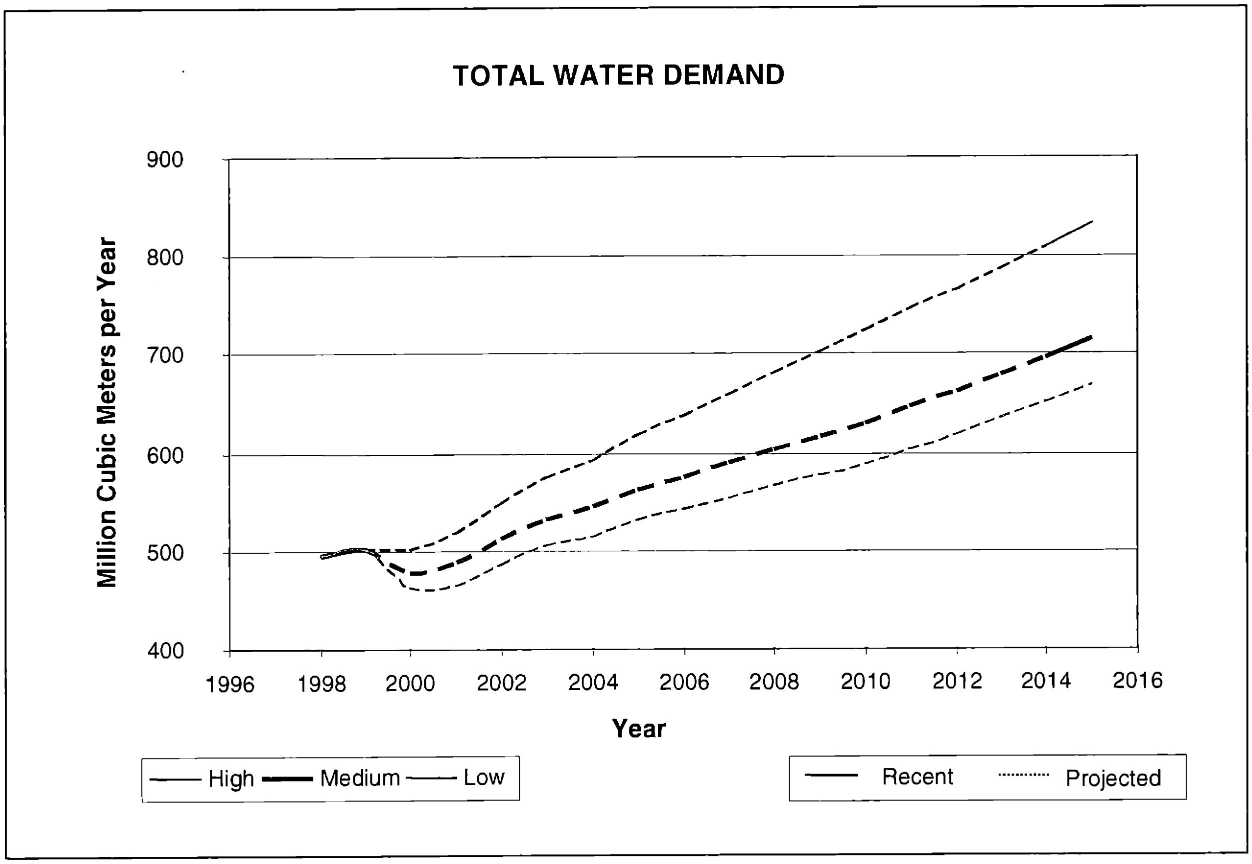

Figure 3.6. Total Water Demand Projection (adapted from TEA Consultores, 1999)

Specifically, non-residential demand is estimated as a function of GDP growth (see Figure 3.5). With these growth levels, and the projections for residential demand, non-residential demand is expected to remain about 20% of the total.

Total demand for water in 2002 is projected at 512 million cubic meters per year (16.3 m^3/s or 370 MGD). Figure 3.6 shows the expected water demand for the next fifteen years, according to TEA Consultores (1999). The average expected growth rate in the medium scenario corresponds to about 2.5% per year.

3.3.2. Supply Side

Bogotá's current water supply system is composed of three subsystems: Chingaza, Tibitoc and Tunjuelo. Each subsystem is associated with a different river basin, as Figure 3.7 shows.

Chingaza System

The Chingaza system lies northeast of Bogotá. It draws water primarily from the Chuza River. The system is composed of the Chuza reservoir, the Wiesner Treatment Plant, the San Rafael reservoir (adjacent to the plant) and the tunnels from the water sources to the reservoirs and from there to the treatment plant. This system is highly cost efficient for two reasons: all flows are gravity driven, and water quality at the source is good. Only simple treatment[9] is required before distribution to the city. The average reliable flow[10] of the system is 423 million cubic meters per year (13.4 m^3/s or 306 MGD), as estimated by Ingetec (2000).

This system is exposed to various risks. First, its location is vulnerable to guerrilla attacks[11]. Second, all underground tunnels (between the reservoirs and the treatment plant, and the

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9 *The treatment process at Wiesner involves only direct filtration (i.e. no need for flocculation or sedimentation)*

10 *Reliable flow is defined as that which has a deficit probability of less than 1%*

11 *In fact, during the period in which this thesis was being written, the FARC guerrilla attempted to blow one of the tunnels from the Chuza reservoir to the Wiesner Treatment Plant*

treatment plant and distribution system) are highly unstable and rarely maintained. The tunnel from the Wiesner Treatment Plant to the city's distribution system is particularly vulnerable.

Since Chingaza supplies almost 60% of the city's water, and that the only way to bring the water from the plant to the city's gates is through one tunnel (Usaquén tunnel), this connection is of critical importance. The 15 km tunnel, built in the 1980s, did not begin operation smoothly: two landslides caved in during the final trials. After the repairs, the tunnel has operated without interruption. Nevertheless, even if the probabilities of future failure of the tunnel are low, any maintenance work requires shutting down the water supply from Wiesner for at least a couple of days and therefore, it has never been done.

Also, the Wiesner Plant was designed for the average good quality of the Chingaza water. Consequently, the system is highly vulnerable to changes in water quality. For example, in the rainy season (March to May), Chingaza water (especially that flowing from the Blanco River) becomes turbid and cannot be treated at Wiesner. Also, the San Rafael reservoir, which feeds the Wiesner Plant when the Chingaza system shuts down, is fed by the Teusacá River, whose water is also of lower quality than that from the Chuza River. There is considerable risk of either damaging the Wiesner Plant or not being able to treat water adequately, if water from the Blanco or Teusacá rivers needs to be used to cover the city's demand. Moreover, it is reasonable to believe that the Chingaza water quality will deteriorate over time.

Tibitoc System

The Tibitoc system lies north of the city and it draws water from the Bogotá River basin (Neusa, Teusacá, and Bogotá rivers). The system consists of three reservoirs (Tominé, Sisga and Neusa) used for storage and regulation, and the Tibitoc plant itself, used for water treatment. The system's reliable flow, as estimated by Ingetec (2000), is 274 million cubic meters per year (8.7 m^3/s or 198 MGD).

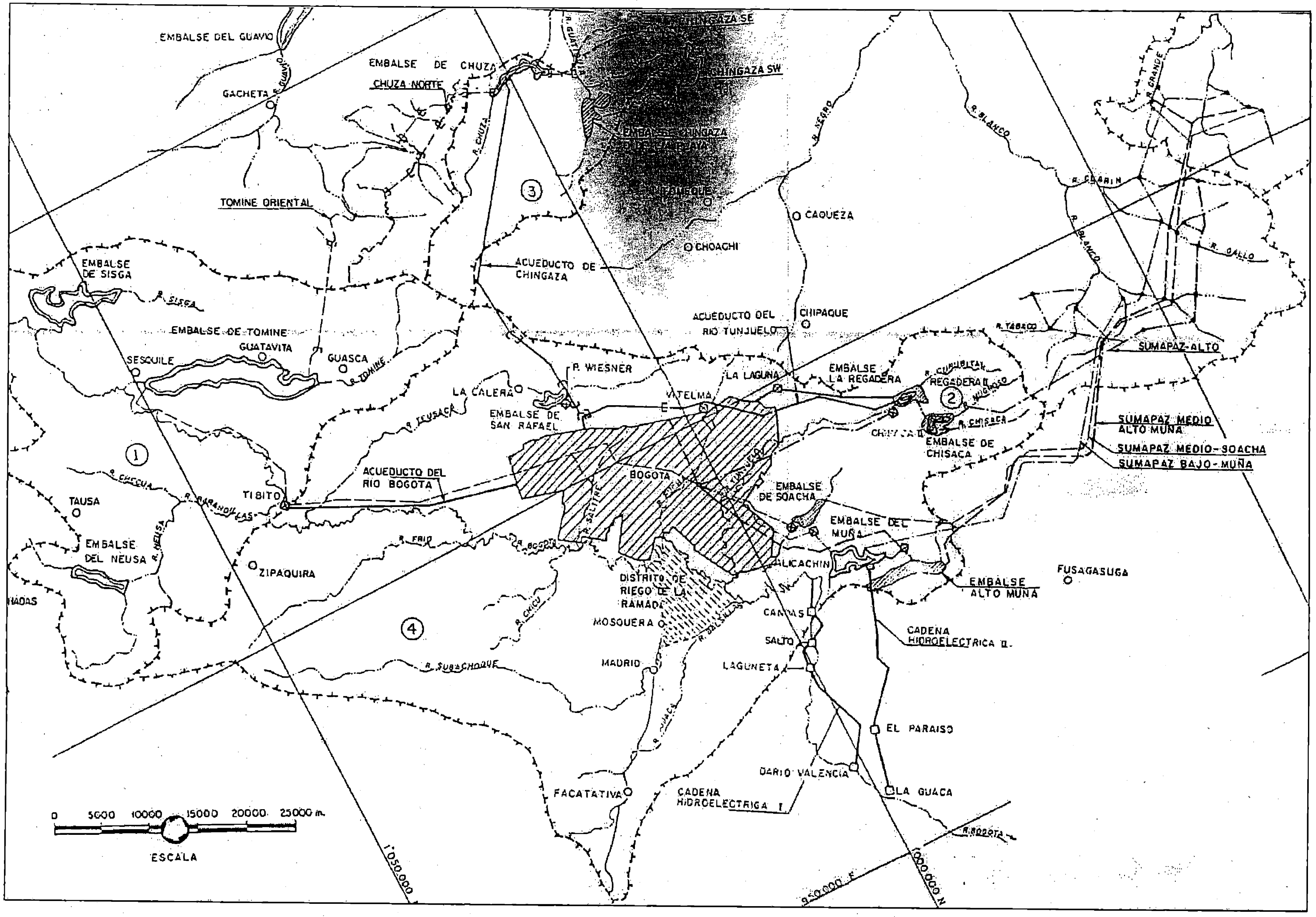

Figure 3.7. Bogotá's Water Supply System

While water from the Bogotá and Neusa rivers flows by gravity to the treatment plant, water from the Teusacá River has to be pumped. After it has been filtered, water flows to a storage tank, from where it feeds directly into the main distribution lines that transport water to the city, or is pumped 35m to a higher tank that increases conduction capacity by increasing the flow pressure. The treatment plant, built in the 1950s, is well maintained, but it requires investments to repair and replace some of its components.

The most vulnerable component of the Tibitoc system is the first 30 km of the main distribution line stretching from the treatment plant to the city's distribution network. This 1950s pipeline is beginning to show signs of severe deterioration. The system is also vulnerable to further contamination of the Bogotá River and upstream use of water for agricultural purposes, both of which may reduce water availability.

Tunjuelo System

This system lies to the southwest of Bogotá, and draws its water from the Tunjuelo River. The system is comprised by three water treatment plants (El Dorado, Vitelma and San Diego), and two small reservoirs (Chisacá and La Regadera). Although the reliable flow of this system is only 28 million cubic meters per year (0.9 m^3/s or 20 MGD), representing 4% of the system's total capacity, it is strategically important, as it supplies gravity flowing water to the city's poorest neighborhoods, which otherwise would have to be served by pumping water from Chingaza or Tibitoc, thus increasing costs enormously (Ingetec, 2000).

The system's main vulnerability is its lack of storage and regulation capacity, due to the small size of the reservoirs. Available flow fluctuates widely and constantly. The system's raw water conductions are also vulnerable, since they date from the 1930's and are located in an area where small telluric movements occur quite often.

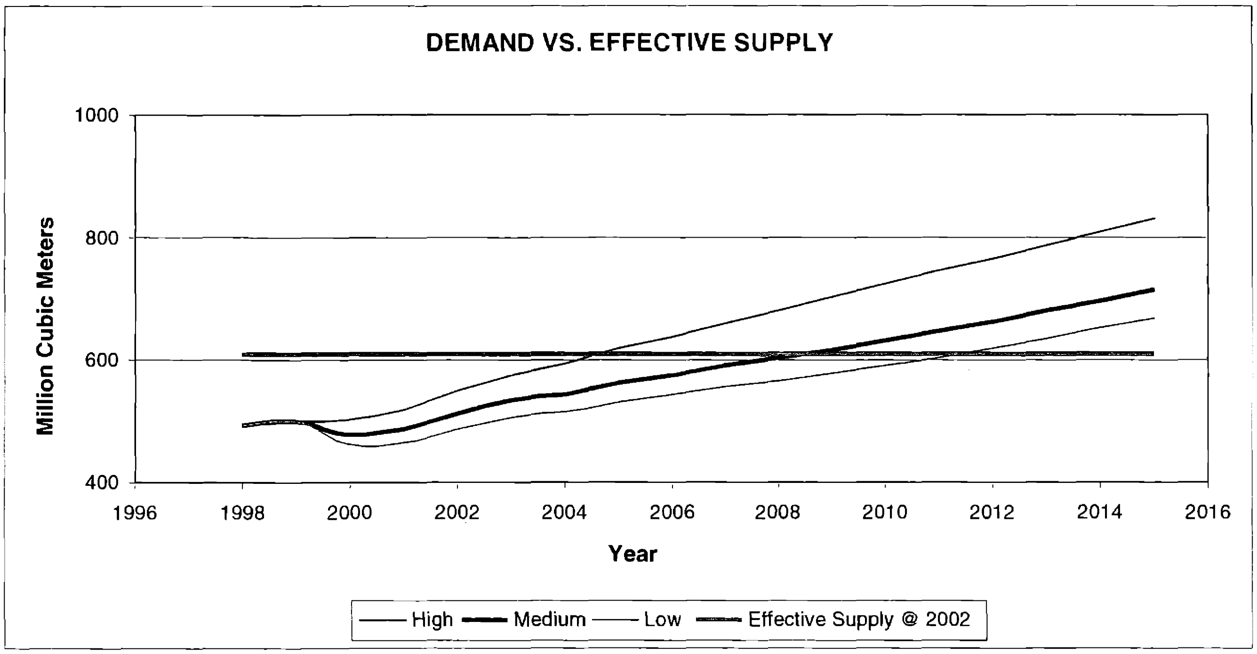

Figure 3.8. Effective Supply vs. High, Medium and Low Demand Projections (adapted from Ingetec, 2000)

3.3.3. Integrated System

The greatest advantage of Bogotá's water supply system is that it is mostly gravity fed[1]. This reduces the operational costs significantly. When there is excess capacity in the system production is optimized according to the individual costs of each plant, subject to a minimum utilization of each facility of at least 50%. This is done for purposes of labor stability, except in Tibitoc, where the concession contract allows production to drop to 30% of installed capacity.

In addition to the vulnerabilities of each sub-system discussed above, the main problem of Bogotá's water supply system is its high level of "Unaccounted-For-Water (UFW)". UFW is water that is produced and treated but not charged to the users. There are two main sources of UFW, technical losses and commercial losses. The EAAB's technical losses amount to 19% of the total water production, and they are due to leakages in the distribution system. Commercial losses, amounting to 13% of total water production, are due to illegal connections and metering mistakes (EAAB, 2000).

The Chingaza, Tibitoc and Tunjuelo system provide Bogotá with 725 million cubic meters (23 m^3/s or 525 MGD) of water every year. The EAAB is currently working on several small initiatives that will increase reliable supply to 750 million cubic meters per year (23.8 m^3/s or 543 MGD) by December 2002 (Ingetec, 2000). This case study assumes that these initiatives are already in place. Due to technical losses, the effective supply, available to fulfill the demand requirements is 609 million cubic meters per year (19.3 m^3/s or 441 MGD). This is enough to cover demand in 2002, which amounts to 512 million cubic meters per day (16.3 m^3/s or 371 MGD). Moreover, as Figure 3.8 shows, current supply capacity is enough to cover Bogotá's water needs until 2008 for a scenario of medium demand growth. For the high scenario of demand growth, effective capacity will only be enough to cover Bogotá's water needs until 2004.

Considering that the average development time for a water supply project of this magnitude is at least 3 or 4 years (if the detailed designs are already available), the EAAB has little time to make a decision about the expansion of the water supply system. In fact, if demand growth turns out to be high, the EAAB is already late to make a decision. Also, the EAAB needs to start considering the replacement of the older parts of the system such as the Vitelma and Sand Diego treatment plants (Tunjuelo system). The situation becomes even more complex because of the fact that there is no guarantee that demand will evolve according to the scenarios depicted in Figure 3.8. Moreover, there is not even certainty that the low and high scenarios represent the boundaries for demand uncertainty. In fact, demand may very well evolve in a pattern below or above these limits. This explains the relevancy of analyzing the supply expansion options available to the EAAB, under the expected demand uncertainties.

As of 2002 the EAAB has identified three possibilities for the expansion of Bogotá's water supply system (see Figure 3.7 for their location):

- Expansion of the Chingaza System
- Development of the Sumapaz System
- Exploitation of Underground Water

The expansion of the Chingaza system consists of three projects: Chuza Norte, Chingaza Sureste, and La Playa reservoir. Chuza Norte is diversion of 3.90 m^3/s of water to the existing Chuza reservoir. The main infrastructure components are 12 km of tunnel and 36.2 km of open channel. Water for the project will come from the Santa Bárbara, Chorreras, Juiquín and Balcones rivers. The project can be developed in three stages, each corresponding to a different river. The Juiquín-Balcones system is furthest from the Chuza reservoir. The Chorreras system is closer at 14 km, and the Santa Bárbara system is only 8 km away from the reservoir (Ingetec, 2000). The project also requires the enlargement of the Wiesner water treatment plant to treat the additional 123 million cubic meters per year (3.90 m^3/s or 89 MGD).

Chingaza Sureste would divert of 2.08 m^3/s of water to the existing Chuza reservoir, from the Guatiquía river system (Guájaro, Guatiquía and Blanco rivers). The main infrastructure

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12 *Only those areas of the city located above 2700 meters (approximately 151% of households) need pumping.*

components are 10.4 km of tunnels and 8.8 km of open channels. The project also comprises the expansion of the Wiesner treatment plant so that it can process the additional 66 million cubic meters (2.08 m^3/s or 47 MGD) of water supplied by this system (Ingetec, 2000).

The last component of the Chingaza expansion is the construction of the new La Playa reservoir. La Playa would improve the storage and regulation capacity of the system. It would be filled with water from La Playa and Frío rivers and have a 135 hm^3 capacity. The main infrastructure components of the system are the construction of a 90m-high dam, the temporary deviation system for the river during construction, silt sluice, open channel spillway, an auxiliary weir and the diversion of the flow of the Chingaza lagoon to the new reservoir. In addition to the regulation benefits of this reservoir, the construction of La Playa will supply an average of 1.01 m^3/s of water and it will enable the Chuza Norte and Chingaza Sureste subsystems to yield an additional 0.51 m^3/s (Ingetec, 2000).

In total the system will provide an additional 48 million cubic meters (1.52 m^3/s or 38 MGD) of water. The current project layout assumes that no additional expansions to the Wiesner plant are needed to treat the water yielded by the La Playa subsystem.

The second expansion option available to the EAAB is the development of the Sumapaz system. The Sumapaz highlands are southeast of Bogotá (see Figure 3.7). There are several alternatives to bring water by gravity from the rivers that drain the eastern and western flanks of the highlands pertaining to the upper Magdalena and Orinoco basins. Preliminary studies indicate that there is a potential to obtain over 473 million cubic meters (15 m^3/s or 342 MGD) of water from this region (Ingetec, 2000).

Thirdly, the EAAB could exploit ground water sources. Preliminary studies indicate that there is a potential to extract 47 (1.5 m^3/s or 34 MGD) million cubic meters of water from this source (EAAB, 1997).

In the year 2000 update of the Bogotá Water Supply Master Plan, the EAAB identified the Chingaza expansion alternative as optimal for the near future. In fact, neither the Sumapaz nor the ground water alternatives can be seriously considered today, since design and studies are only at a preliminary stage. Therefore, this system study will focus on the analysis of the Chingaza expansion system. It will apply Net Present Value, Decision Analysis and Real Options methodologies to determine the optimal strategy for the development of this portfolio of projects, and determine which methodology serves this purpose more adequately. The decision of which methodology is optimal is of course highly dependent on the institutional framework in which the decision is taken; hence, the next section of this chapter details the institutional and regulatory framework of the water sector in Colombia.

3.4. INSTITUTIONAL AND REGULATORY FRAMEWORK

The Bogotá Water Company (EAAB, Empresa de Acueducto y Alcantarillado de Bogotá) is considered a "Commercial and Industrial State Enterprise". This means that although the company is state-owned, it must be managed as a commercial enterprise. It must be financially viable without any Bogotá municipality aid.

The EAAB is organized into six divisions (see Figure 3.9), which report to the General Manager's Office. The Planning Division is responsible for developing the corporate strategic plan, compiling the tactical and operational plans from the other divisions, and evaluating the performance of the divisions against the units' plans. Within the Planning Division there is a Technical Planning Unit in charge of capacity expansion planning for water supply. The expansion of the distribution system is planned by the Operations Division, which is also in charge of day-to-day administration of water supply, distribution, and sewerage systems. The Technical Division develops the smaller infrastructure projects and supervises the execution of bigger ones by external contractors. The Financial Division is in charge of balancing the cash requirements of the business (investing excess cash and raising required funds), and collaborates with the Planning Division in the development of financial evaluations of all proposed projects. The Commercial Division is in charge of billing, collections and customer service. Finally, the Administrative Division provides support to all other units, in human resources, sourcing, legal, and others.

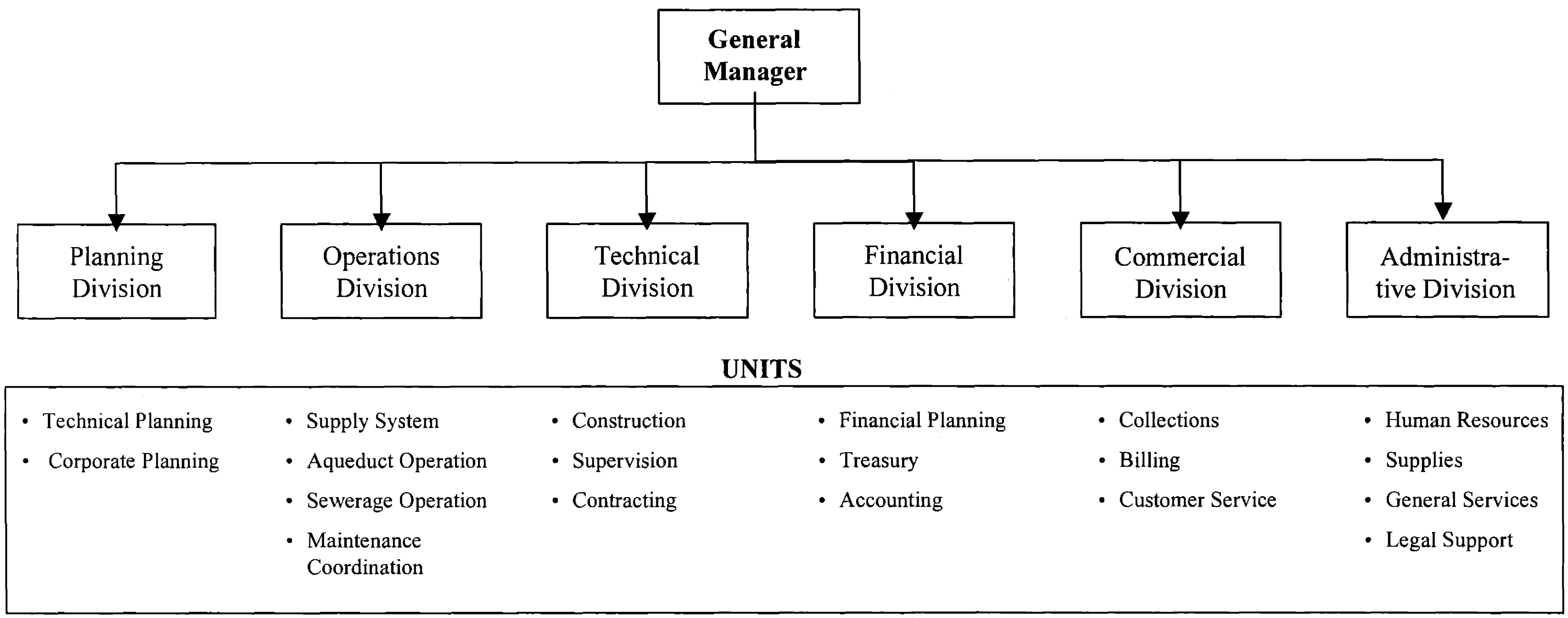

Figure 3.9. EAAB's Organizational Structure

Unlike, most other commercial business whose main objective is to make money, the EAAB core mission is to satisfy the needs of its clients, while complying with the requirements of a variety of stakeholders. In this case, the clients are the citizens of Bogotá and its surrounding municipalities. Their needs can be described in terms of three variables: coverage, quality and cost.

Firstly, the EAAB must provide coverage. It must ensure that present and future water supply needs of the city are met. Secondly, its supplied service must be of good quality; this relates to the quality of the water itself, as well as to other characteristics of the service such as water pressure, reliability of the service (how continuous the water supply is) and customer service. Thirdly, the service should be provided at the lowest possible cost, to ensure maximum accessibility to the service by all segments of the population[13].

In addition to serving its clients' needs, the EAAB must comply with the requirements imposed by other stakeholders. Some of these requirements stem from the EAAB's condition as a regulated public utility, and some from the nature of the business. The main stakeholders of the EAAB are identified and grouped in Figure 3.10.

The first group of stakeholders includes current and former employees (both retired and ex employees), and the labor union. This stakeholder group advocates labor stability, which in the end is guaranteed if the EAAB is financially viable.

The second group of stakeholders is the suppliers. Two main types can be identified: financial institutions that provide funds, and engineering firms that provide consulting services, develop detailed designs, feasibility studies, pre-feasibility studies and build some of the projects. Clearly, both factions are interested in keeping the EAAB financially viable; financial institutions, to ensure that the EAAB can repay its loans, and the engineering firms to ensure there are funds to make the payments of ongoing contracts and to develop future ones.

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[13] *Water tariffs in Bogotá are cross-subsidized, meaning that the high-income levels of the population subsidize the cost of water for low-income families.*

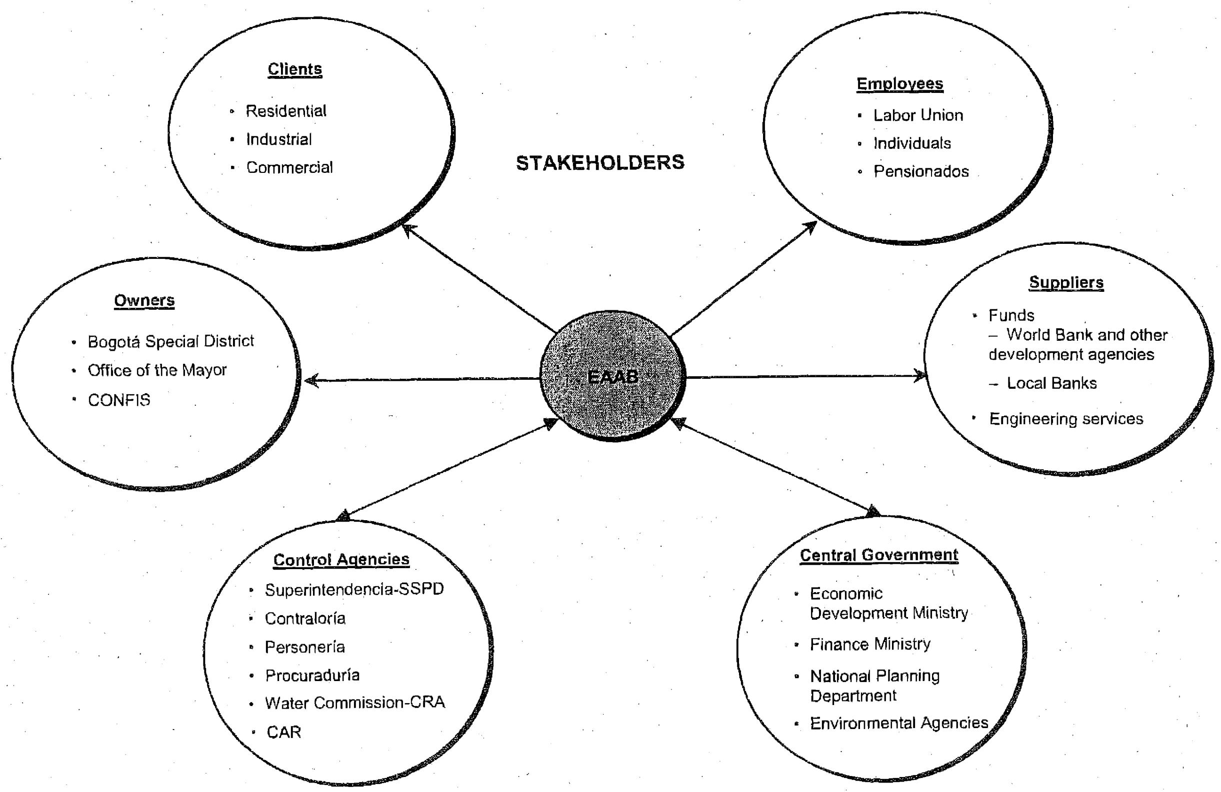

Figure 3.10. Stakeholder Identification

The third group comprises all central government agencies with responsibilities in the provision of potable water to Colombia's citizens. In 1986, the Decentralization Law transferred responsibility of operation and management of the water and sewerage systems to the municipalities. Since then, decentralization has been a major force in shaping the water and sanitation sector's structure. Nevertheless, the central government still plays an important role in overseeing supply of water to Colombian citizens. This responsibility derives directly from the new Political Constitution, enacted in 1991, which defines the responsibilities of the central government in ensuring the adequate provision of domestic public services (i.e. water, electricity, telephone, gas). In fact, the constitution devotes an entire chapter to this issue (Chapter 5: Concerning the Social Purpose of the State and of the Public Services) within its twelfth title (Title XII: Concerning the Economic and Financial Regime).

The Ministry of Economic Development, responsible for the water sector as a whole, created the Potable Water and Sanitation Directorate (DAPS, Dirección de Agua Potable y Saneamiento Básico) to comply with the indications set forth in the 1991 Constitution. The DAPS oversees the water and sanitation sector, formulates its policies and plans its development. The National Planning Department (DNP, Departamento de Planeación Nacional), the government agency in charge of the overall development plan of the country, works in conjunction with the DAPS to make sure that the sectoral development plans are in line with the overall country development plans. The New Political Constitution, in its second chapter of its twelfth title, "Concerning Development Plans", sets forth the guidelines for the substance and form of these plans.

Finally, the environmental agencies also have a constitutional responsibility to preserve environmental and natural resources (Chapter 3: "Concerning Collective Rights and the Environment" of Title II; "Concerning Rights, Guarantees and Duties), and as such have an interest over the activities of the EAAB, specifically in preserving water sources unpolluted and in ensuring a rational utilization of water resources.

In summary, the interests of this third group of stakeholders vis-à-vis the EAAB is to comply with their constitutional mandate above all, but also to use the EAAB as an instrument of social and economic development and to guarantee its financial viability. Appendix A provides a transcription of all relevant articles of the New Political Constitution.

The fourth group of stakeholders comprises control and regulatory agencies. The New Political Constitution provided the legal basis for the introduction of aggressive reforms in the water sector by clearly separating service provision and policy making, and by allowing private sector participation in the domestic public services sector. Law 142, enacted in 1994, established a specific legislative and regulatory framework for the water sector, emphasizing the efficiency of service provision through the introduction of competition and private sector participation. Relevant articles of law 142 are presented in Spanish in Appendix B.

A particularly important result of Law 142 was the establishment of three control and regulation agencies:

- Water Regulatory Commission (CRA, Comisión de Regulación de Agua Potable): It promotes competition among service providers, controls monopolies, defines tariff setting methodologies (based on standard formulas and the investment plans submitted by the operating companies) and sets service quality standards.

- Superintendence of Domestic Public Services (SSPD, Superintendencia de Servicios Públicos Domiciliarios): It is responsible for monitoring and supervising the adequacy and efficiency of the operations, establishing uniform accounting systems, supervising the administration of subsidies, and monitoring the general administration of public services companies.

- Autonomous Regional Corporations (CAR, Corporación Autónoma Regional): It handles environmental regulation and administers water rights.

In addition, the EAAB's performance is also under the scrutiny of five city agencies: the City Council, the Attorney-General's Office, the Prosecutor's Office, the Comptroller's Office and the

Public Ministry. The combined interests of these agencies are to ensure the economic and operational efficiency of the EAAB and its compliance with existing laws and regulations. Also, these control agencies are in charge of evaluating the EAAB's capacity to guarantee present and future water supply services, with low vulnerabilities, and at reasonable costs, and if necessary, propose corrective actions to ensure that this objective is met.

The company's owners comprise the fifth group of stakeholders. The Bogotá Water Company is owned by the Bogotá District. The Office of the Mayor represents all owners. The Superior Council for Fiscal Policy (CONFIS, Consejo Superior de Política Fiscal) oversees the Mayor's Office in this task. Acting in name of the Bogotá District, the primary interest of the Mayor's Office is to ensure the present and future supply of good quality and low priced water. The office is also interested in ensuring the financial viability of the company, not only as a mechanism to guarantee present and future water supply, but also out of self-interest as the city's treasury acts as lender of last resort for the EAAB, and as guarantor of the company's loans. Should the company run into financial difficulties, the Mayor's Office will have to seek the necessary resources from its limited budget, to help bring it afloat again. The role of the CONFIS is similar in the sense that it needs to keep a constant eye on the EAAB's financial situation: if the city is not able to help the company in any financial emergency, the central government will have to do so. Finally, the Office of the Mayor is also interested in using the EAAB as an instrument for urban planning and poverty alleviation.

The sixth and last group of stakeholders consists of the citizens of Bogotá. In addition to the needs already described above, they seek to minimize the negative effects of the construction of EAAB's projects on their daily lives.

In conclusion, the primary interests of the different stakeholder groups, apart from the EAAB's main objective, can be summarized as follows:

1. Ensuring the financial sustainability of the EAAB;

2. Ensuring economic and operational efficiency;

3. Using the EAAB as an instrument for regional development and for local urban planning; and

4. Guaranteeing transparency in all of the EAAB's actions.

3.5. SUMMARY

The coming administration of the EAAB, stepping into office in January 2004, will probably need to expand the capacity of Bogotá's water supply system. The only real expansion possibilities for the short-term are those of the Chingaza expansion system, since only these projects have detailed designs, environmental permits and are ready for construction. The system study presented in the following two chapters evaluates the best capital budgeting technique for the analysis of how and when to develop each stage of the Chingaza expansion system. Chapter 4 presents the detailed methodology and results from the application of each methodology, Chapter 5 presents the implementation implications of each methodology, given the institutional framework for the EAAB, which was described in this chapter, and Chapter 6 sets forth recommendations as to which methodology is better suited for the EAAB's particular situation.

CHAPTER 4: FINANCIAL EVALUATION OF THE CHINGAZA EXPANSION ALTERNATIVE: METHODOLOGY AND RESULTS

4.1. INTRODUCTION

As stated in the previous chapters, the main objective of this study is to identify the preferred approach for the financial analysis of water supply expansion projects, choosing between the following capital budgeting techniques: Net Present Value (NPV), Decision Analysis (DA), and Real Options Analysis (ROA). From the discussion in Chapter 2 it is clear that NPV does not account for managerial flexibility, and therefore it is not adequate to deal with highly uncertain situations, where management does not need to pre-commit to a certain strategy from the beginning of the project. Nevertheless, this approach will be taken into account for two reasons. First, NPV is the approach currently used by the EAAB, and by most utilities when evaluating their capacity planning decisions. Second, both ROA and DA are built upon the results of an NPV model of the project, and the NPV results will provide a baseline to compare these two approaches, which do take into account the value of flexibility.

The literature survey in Chapter 2 also shows that in theory, both DA and ROA deal effectively with uncertainty and managerial flexibility. Table 4.1 summarizes the advantages and disadvantages of each methodology, as was discussed in Chapter 2. The table shows a clear and well cut theoretical division between ROA and DA, nevertheless, the lack of empirical evidence makes it hard to determine which approach is really better in practice. Hence, the importance of the system study developed in this chapter.

The chapter begins with the description of the methodology used in each approach. It describes the methods and tools used, and details all relevant assumptions. Then the chapter presents the main results of each approach, identifying not only the portfolio's value, but also its optimal development strategy. Appendixes C to K contain the complete printouts of the models used in each case, as well as the different results. The analysis of which method is preferable for the specific case of the Bogotá Water Company is discussed in the next chapter, in the light of the EAAB's corporate culture and the external regulations to which it is accountable.

	Advantages	Disadvantages
Decision Analysis	• Takes into account managerial flexibility • More intuitive for engineers and decision makers	• Incorrect treatment of discount rate • Mostly used with discrete probabilities • Calculations can become very messy if several sources of uncertainty have to be taken into account • Expected Value type of valuation
Real Options	• Takes into account managerial flexibility • Calculations for continuous probability distributions are simpler than in DA • Values each option explicitly • Discounting done at the risk-free rate • No-arbitrage principle type of valuation	• Unclear assumptions about underlying asset • Based on financial theory not familiar to engineering and most decision makers

Table 4.1: Summary of Comparison of ROA and DA Techniques

4.2. METHODOLOGY

Traditionally, the EAAB evaluates its water supply expansion alternatives in terms of cost per cubic meter of water supplied, and chooses to build first those projects with the lowest cost per unit of water. The analysis does not take into account any revenues associated with the expansion projects, because water tariffs are supposed to be set so as to offset all investment and operation costs. Thus, in principle, the present value of project's costs minus the present value of project revenues is zero.

In the end, all costs associated with the expansion of the water supply system are transferred directly to the users via tariffs, reduced investment in other infrastructure areas, or ultimately via a water deficit in the city. Therefore, the ultimate purpose of evaluating the different water supply alternatives available to the EAAB is to choose the portfolio of projects that minimize the total cost for consumers. To obtain the cost per cubic meter of water supplied, the EAAB uses a Discounted Cash Flow (DCF) model, from which they calculate the present value of the unitary costs. This study will deal with total (instead of unitary) costs because the purpose here is not to compare different alternatives, but to identify the optimal strategy for the development of expansion of the Chingaza system, which the EAAB already defined as the lowest cost alternative for the expansion of Bogotá's waters supply capacity.

A Discounted Cash Flow (DCF) model, built in Microsoft Excel, is the cornerstone of the evaluation model. In the traditional financial analysis, the Present Cost of the project is derived directly from this model. In Decision Analysis, the DCF model is needed to estimate the value of the different outcomes in each decision node, and finally, for the Real Options Analysis, the DCF model will be used to estimate the value and variability (standard deviation) of the underlying asset, as well as the values of the exercise prices of the different options.

4.2.1. Discounted Cash Flow Model

Discounted Cash Flow models calculate the present value of investments and costs that are incurred and received at different point in times in the future, therefore making these different quantities comparable. In this way, analysts can compare the project's revenues against its costs and decide if the project's worthwhile. It was already explained that for purposes of this study, only project costs are relevant. Thus, the main components of the DCF model for the analysis of the Chingaza expansion alternative are:

- Investment costs: Include land, designs, permits and licenses, access roads, environmental and socioeconomic mitigation plans, and the infrastructure undertakings themselves.

- Operation and Maintenance Costs: The bulk of these costs is comprised by the energy and chemicals required to treat the water at the treatment plant, these costs are variable and depend entirely on the volume of water treated. Also important are some fixed O&M costs such as personnel and other administrative expenses, which depend only on the size of the treatment plant, but not on the production itself.

- Rationing Costs: The water company estimates the rationing cost for the consumers to be around US$0.80 per cubic meter of unmet demand. This corresponds to real monetary costs such as increases in the cost of water, loss of business because of the water shortage and non-monetary costs such as health hazards associated with inadequate water supply.

- Compensation for Energy Losses: It is often the case that the water used by the EAAB to supply potable water to the citizens of Bogotá, diminishes the available water for hydro electrical power generation in the surrounding municipalities, and therefore the EAAB needs to pay some kind of compensation to this municipalities. In some other cases, the contrary occurs, the water used by the EAAB is also used to produce energy, which is sold in the national energy market, and the EAAB receives some extra revenues for this concept. Although our model is cost-based, these revenues are taken into account when relevant because they effectively reduce the costs to the consumers.

For the case study at hand these all costs estimations were taken from the pre-feasibility studies of the different project components, as cited in the Ingetec (2000) report, "Actualización del Plan Maestro de Abastecimiento de Agua Potable para el Mediano y Largo Plazo".

Apart from the aforementioned variables, a very important parameter in any DCF model is the discount rate. The discount rate represents the way money now is worth more than money later. The discount rate is key for project comparison over time, because it is through this parameter that costs and benefits of a project occurring at different points in time can be compared. In his book, Applied System Analysis, de Neufville (1990) explains how the choice of discount rate is crucial because it is often a determinant of the technology employed. In general, a higher the discount rate implies a lower valuation of future benefits, thus, high discount rates are unfavorable to capital-intensive projects, whose stream of benefits spans a large number or years.

The relevance of the discount rate for DCF models, contrasts with how little the financial and economic professions really know about this parameter. As Chapter 2 explained, the choice of discount rate is still an ongoing debate with no definitive answers. In the end, the choice of a discount rate ends up being mostly a matter of judgment or intuition. The Ingetec report (2000) cites 12% as the adequate discount rate for the EAAB, without any further justification. This study will use this same value to make the results comparable. In reality, the discount rate should be different for the different type of projects analyzed (e.g., Chuza Norte vs. La Playa) because the non-diversifiable risks of each project are very different.

Also important for the DCF model is the choice of the time horizon over which the project will be analyzed. This study extends for a period of 15 years, which is enough for all projects to be developed sequentially. After this period, the operation, maintenance and deficit costs are estimated as a stable perpetuity. To facilitate the development of the DA and ROA approaches, the 15-year period has been divided in five 3-year periods, corresponding to the time periods in which the EAAB administration changes, and as such to the periods where changes and alignments to the strategy are more likely to occur.

4.2.2. Traditional NPV Analysis

Traditionally, the Net Present Value criterion is used in conjunction with DCF models to make decisions about whether or not to undertake the investment. In general, the investment rule in DCF models is to invest when the Net Present Value is larger than zero. In this study, the objective is to invest in the portfolio of projects that minimizes total present cost. Following the mainstream recommendations in project evaluation, the Net Present Cost analysis conducted in this study considers only the incremental costs associated with each project of the Chingaza portfolio, since all other costs (e.g., operation of the rest of the Chingaza system, repairs to existing infrastructure and other) are already being borne by consumers and including them in the analysis will lead to double-counting.

The DCF model, built in Microsoft Excel and used to calculate the Net Present Cost of the model, is parameterized to account for the most important uncertainties in the project's cost forecast (Appendix C contains the parameter sheet for the DCF model). In this way, the DCF model serves as the basis for sensitivity and scenario analysis. The base case scenario of Net Present Cost was calculated taken into account the most-likely values for each uncertain variable, as defined by Ingetec (2000) in "Actualización del Plan Maestro de Abastecimiento de Agua Potable para el Mediano y Largo Plazo". Table 4.2 lists these values for all relevant variables in the DCF model, and describes when, how, and for which purposes the model user should change these values.

Once the most likely values of the uncertain variables are defined, the calculation of the Net Present Cost is fairly straightforward. The investment costs are spread out according to the development schedule entered by the model user and the construction timeline of each project (which is determined in the pre-feasibility studies). The fixed O&M costs are calculated for each year based on the facilities that are already in place and the costs determined in the parameter sheet. And finally, to calculate the variable O&M, deficit and energy compensation costs, the model calculates the demand and supply of the system at each point in time and assigns a portion of the demand to each facility.

Demand is assigned through an algorithm that minimizes total operational costs, therefore in some cases, even though a certain facility might be ready to produce, it is not used if water can be produced more cheaply at another facility. The algorithm assigns demand first to the old system (Chingaza, Tibitoc and Tunjuelo), since production costs in all of these facilities are lower than in any of the Chingaza expansion components. The remaining demand is then assigned to the different components of the Chingaza Expansion, Chuza Norte, Chingaza SE, La Playa, according to their unitary costs. The assigned demand to each facility is used to calculate the variable O&M and the energy compensation costs and the unmet demand of the system is used to calculate the total deficit cost.

Uncertain Variable	Most Likely Value	Information Source and Date	Parameterization
Demand Growth	2.5% per year	This growth rate was calculated by TEA Consultores (1999) in the "Actualización de la Proyección de Demanda de Agua" based on the most likely evolution of the following factors: population growth, per capita consumption, price demand of elasticity, and GDP growth.	The DCF model allows the user to set any demand growth rate for each of the five 3-year periods of the model. The growth rate in each period is independent from the growth rates in the periods before.
Capacity of Existing System	23.8 m^3/s	This value corresponds to the capacity of the actual system with a deficit probability of less than 1%, as measured by the EAAB in the last 10 years of operation of the system.	The DCF model user can modify this value to account for drought periods, unforeseen events or terrorist attacks.
Capacity of Expanded System	7.5 m^3/s	This value corresponds to the water yield of the new sources to be processed with the Chingaza expansion, with a deficit probability of 1%, as measured by the EAAB in the last 10 years of operation of the system.	The DCF model user can modify this value to account for drought periods, unforeseen events or terrorist attacks.
Construction Start Dates	Chuza Norte I: Period 1 Chuza Norte II: Period 2 Chuza Norte III: Period 3 Chingaza SE: Period 4 La Playa: Period 5	This is the sequence identified as optimal by the EAAB and Ingetec (2000) in the "Actualización del Plan Maestro de Abastecimiento de Agua Potable para el Mediano y Largo Plazo".	The DCF model user can choose whether to build Chuza in sequential stages or in one, and when to do so. In the same way, the model user decides when Chingaza Sureste and La Playa are built.
Unaccounted For Water	19% Technical Losses	This is the value reported by the EAAB commercial and technical departments, as of December 2001.	The DCF model user can modify the percentage of unaccounted for water to take into account programs that seek to reduce technical losses.
Construction Costs	US$253 Million	This is the budget estimated in the Ingetec (2000) report "Actualización del Plan Maestro de Abastecimiento de Agua Potable para el Mediano y Largo Plazo"	The DCF model user can analyze the impact of cost overruns by incrementing the total cost of the expansion.
Fixed Operation and Maintenance	US$ 10 Million per year	These costs have been estimated based on historic values of similar facilities.	These costs are not expected to vary widely and therefore cannot be changed by the model user.
Variable Operation and Maintenance	US$0.007 per m^3/year		
Deficit Cost	US$0.80 per cubic meter of unmet demand	EAAB Technical Statistics	The model allows the user to change this cost to whichever value it deems reasonable.

Table 4.2: Assumptions on Uncertain Variables for NPV Analysis

4.2.3. *Decision Analysis*

The Decision Analysis approach has the advantage of taking into account the value of both managerial and technical flexibility. Unlike NPV, DA allows the analyst to account for the fact that the project may develop in radically different ways accordingly to how the uncertain events unfold over time. With DA, the analyst can layout all possible outcomes and calculate the expected value for the different paths through which future events may unfold. Each path describes one possible scenario for the project being analyzed.

The easiest way to perform a decision analysis is through the development of a decision tree. Simple decision trees can be easily built on conventional spreadsheets, but several commercial packages facilitate this task enormously. This study made use of the professional version of Data 3.5 by TreeAge, in conjunction with Microsoft Excel.

In general, a decision tree is a sequence of decision and chance nodes, ending on a terminal node. A decision node indicates a point where the decision maker faces a decision. The branches emanating from a decision node represent the options available to the decision maker; all possible choices should be represented and they have to be mutually independent. In our model, decision nodes are represented by a small square. A chance node indicates an event of uncertain outcome. The branches emanating from a chance node represent the possible outcomes of the event. As with decision branches, all outcomes must be represented and they have to be mutually independent. Each outcome has a probability of occurrence, and since all possible outcomes are represented and they are not overlapping, the sum of the probabilities of all branches emanating from a chance node is one. Chance nodes can have more than one stage in each branch to represent joint probabilities, while decision nodes have only one stage. In our model, a small circle represents chance nodes. Finally, terminal nodes denote final outcomes; they mark the end of a path or scenario and are represented by a small triangle. Each terminal node has a path probability associated with it, this is the combined probability of all chance branches and it represents the possibility of that particular scenario becoming true. Figure 4.1 summarizes the basic structure of a decision tree.

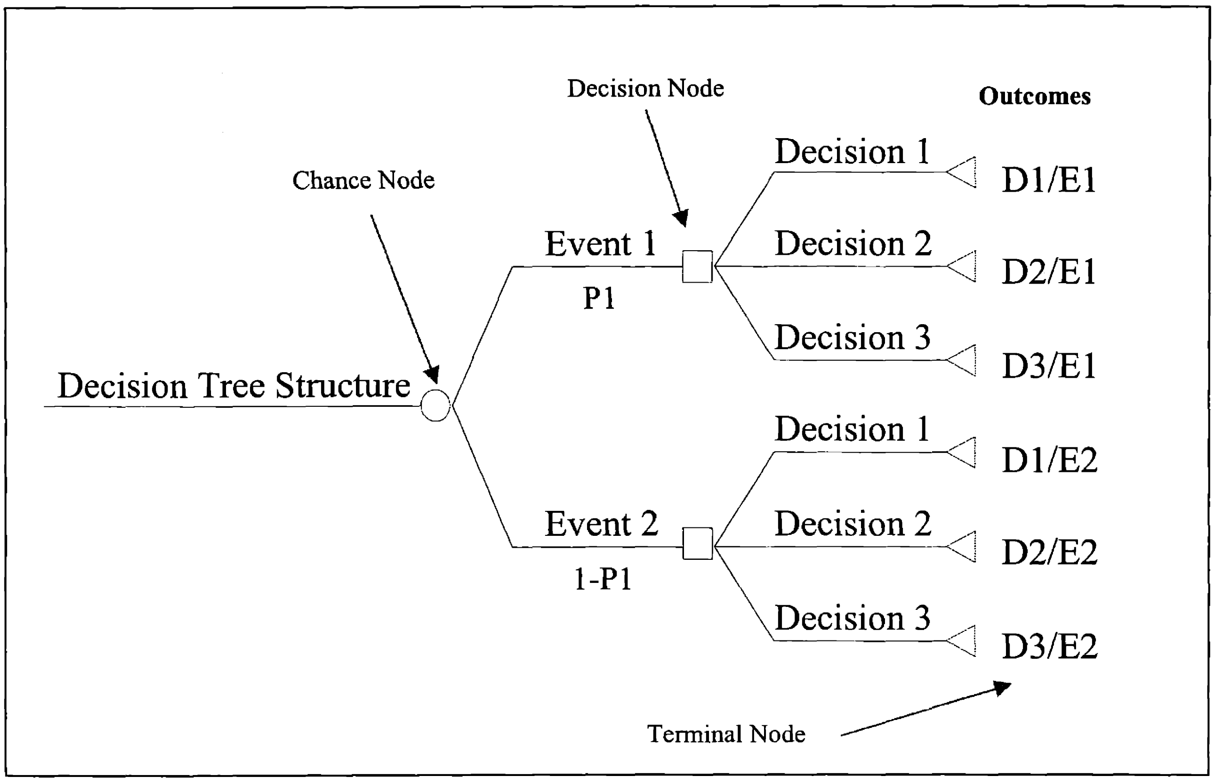

Figure 4.1. Basic Structure of a Decision Tree

A decision tree is solved working backwards (from right to left), and calculating the value of each node in the following way:

- The value of a terminal node is equal to the value of its payoff (the payoff of that scenario)
- The value of a decision node is equal to the value of its best option
- The value of a chance node is equal to its expected value, this is the weighted average of the payoffs in its branches by each branch's probability

DA allows the calculation of the expected value of the whole project before any information on how future events will unfold is available. The expected value of the project is simply the weighted average of the outcomes of all paths by their corresponding probabilities.

Apart from the theoretical deficiencies mentioned in Chapter 2, DA has one practical disadvantage. As more sources of uncertainty and decision parameters have to be taken into account, the problem becomes very complex in its implementation. In this cases the tree look more like a "messy bush" which is very difficult to understand and analyze. In our case, the number of uncertainties and the fact that it is necessary to deal with five consecutive decision periods make the analysis very complex to implement. In fact, a decision tree that accurately took into account all sources of uncertainty in every decision period would probably be very hard to solve with the computer resources normally available in today's corporate environment.

To simplify the analysis and make the process and results of applying DA more comprehensible, this study takes into account only one source of uncertainty, the demand growth rate. Moreover, following Ingetec's (2000) recommendation it only considers three possible scenarios for demand evolution: high demand growth of 3.5% with probability of 20%, medium demand growth of 2.5% with probability of 60%, and low demand growth of 1.5% per year with probability of 20%.

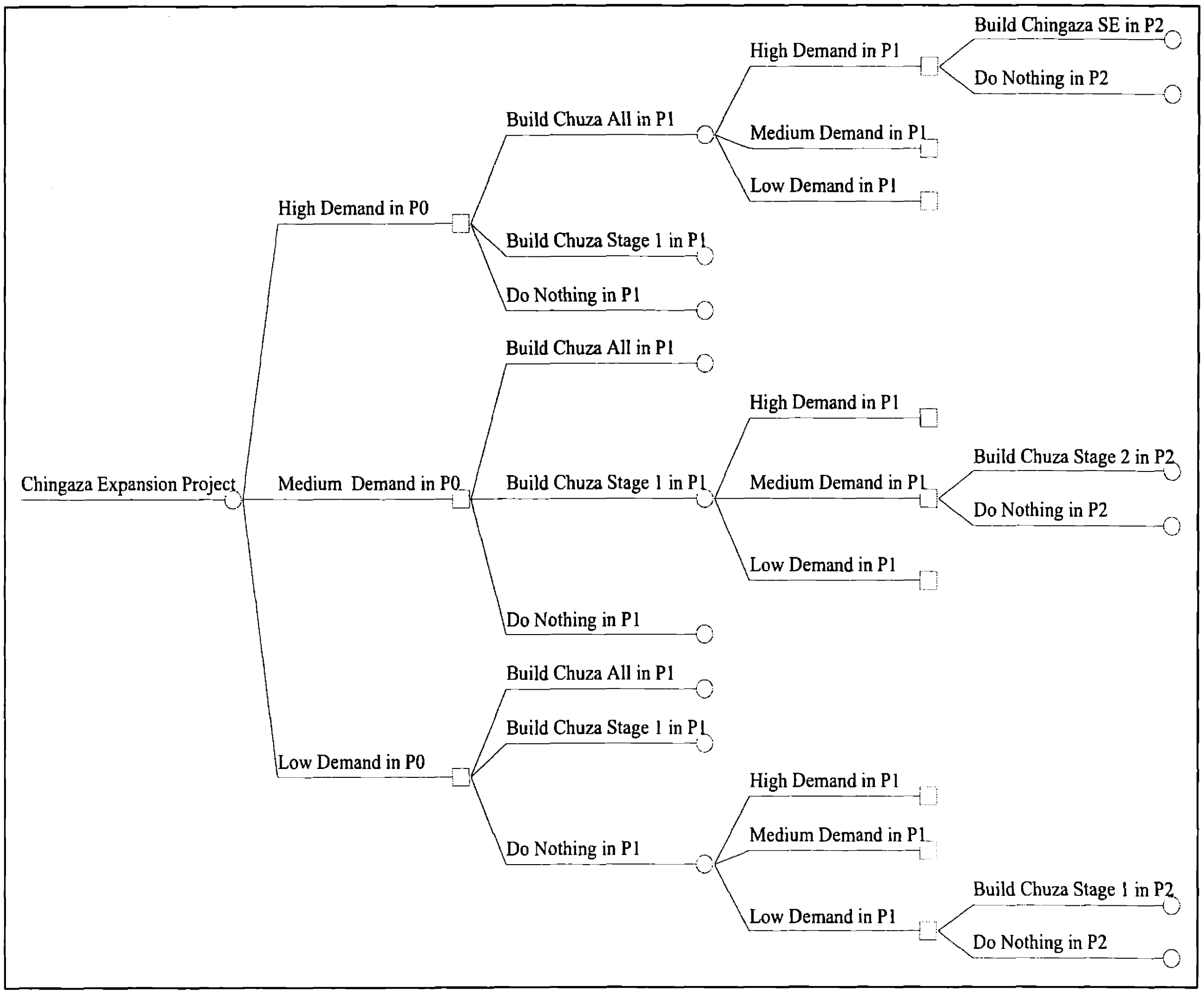

Figure 4.2. Schematic Representation of Decision Tree for Chingaza Expansion Project Periods 1 and 2

These probabilities were estimated through the frequency and judgment methods[14], combining the estimated probabilities for the different scenarios of population growth, change in per capita consumption, price elasticity of demand and GDP growth. The probabilities remain constant throughout the analysis and it is assumed that there is no path dependency in the probabilities of demand scenario, this means that a current high demand does not increase the chances of future demands being also high.

The Decision Analysis model is extended over the same five 3-year periods that were used in the DCF model. The DA model assumes the construction sequence Chuza Norte, Chingaza Sureste and La Playa is optimal, and in each period it analyzes whether or not to build the next project in the portfolio according to this optimal sequence, and to the three demand scenarios. The DA model also allows the user to analyze the decision of whether or not to build Chuza Norte in stages or as one whole project. Figure 4.2 shows a schematic representation of the tree's structure under these assumptions. The Figure partially covers periods 0 to 2, and only some of the branches are fully deployed for the sake of simplicity.

The initial node is a chance node that simulates the possible outcomes of the demand in the period from 2001 to 2003 (Period 0). In 2004 (Period 1) EAAB managers have their first opportunity for decision. They can choose between building the first stage of Chuza Norte, building all of Chuza or doing nothing. Their decision will be of course contingent on how demand evolved in the preceding term. The structure of the tree following the first decision node is fairly similar in every path. Basically, there is a chance node that lays out the possible demand scenarios and then a decision node in which managers decide to go ahead with the next project in the portfolio or to wait for another period.

Although the aforementioned simplifications make the analysis somewhat less realistic, they rend the analysis implementable. Note that even with these simplifications the total number of paths (or scenarios) number in the tree comes up to 23,328. Equation 4.1 shows how this number derives from combining three possible decisions in period 1 (Build Chuza All, Build Chuza

Stage 1, Do Nothing), two possible decisions in periods 2 to 5 (Build Next Project or Do Nothing), and three demand scenarios for periods 1 to 5 (high, medium, low).

$$\boxed{Total.Possible.Combinations = 3*(2^4)*(3^5) = 23{,}328} \qquad (4.1)$$

Software package, Data 3.5, simplifies the process of building a decision tree this big by allowing the cloning of symmetric branches in the tree, automatically calculating the payoffs, and allowing different options for the visualization of the tree itself, that facilitate the analysis of results. The time required to set up a tree this size is about 25 to 30 hours (including setting up the links of Data 3.5 with Microsoft Excel for the automatic calculation of the payoffs), with another 20 hours required for revisions. In addition, it must be taken into account that solving a tree (or rolling it back, as Data 3.5. calls it) with this many combinations takes between 15 to 45 minutes each time, depending on the computer used. Every time something is modified in the tree (E.g., changing probabilities, adding or deleting nodes or branches) or in the Excel DCF model that calculates the payoffs, the tree has to be solved again. To minimize calculation time it is recommendable to break the tree into 2 or 3 sub trees, and solve each of them independently. This involves some manual calculations on the part of the analyst to bring together the final results, but greatly simplifies the solving process and also the visualization of the results.

4.2.4. Real Options Analysis

Real Options Analysis is another method for valuing projects with high uncertainties and future decision opportunities. As was explained in Chapter 2, contrary to NPV or Decision Analysis, Real Options is not an expected value pricing technique. Instead it relies on the principle of no arbitrage to value any investment opportunity. The techniques in Real Options were derived from the pricing mechanisms applied to financial options, therefore, the calculations are much more intuitive for economist and finance practitioners than for engineers. Nonetheless, this methodology presents some important theoretical advantages over Decision Analysis and it is definitely worth considering.

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[14] *For a complete explanation of the methods to estimate probabilities refer to de Neufville (1990)*

Chapter 2 identified several methods to find the value of a Real Options: Black-Scholes formula, Partial Differential Equations, and three numerical techniques: Binomial Method, Monte Carlo Simulation and Finite Difference Methods. Although the Black-Scholes formula is the easiest way to find the value of an option, it is not applicable to this case, because the study involves compound American Options with multiple sources of uncertainty. Partial Differential Equations requires the use of sophisticated calculus, which is generally not a discipline that project evaluators in the EAAB fully understand. Finite Difference Methods also requires the use of fairly complicated calculus; therefore these two approaches are not suitable for the EAAB.

This study will approach the option-pricing problem through the binomial method. This method was chosen over the Monte Carlo simulation because its theoretical background is much more developed and easy to understand. Recalling the explanations in Chapter 2, the binomial method, developed by Cox, Ross and Rubinstein (1979), provides a simple, numerical approximation of a complex stochastic process. The key assumption is that at any period in time the value of a project can move up or down, according to the new information obtained. As the time intervals are made smaller and smaller, the results of the Binomial Method approach those of the Black-Scholes model.

An additional benefit of the binomial method is that it allows the valuation of several options, as long as they are mutually exclusive and do not make the tree path dependent. This is important because, in general, the value of a collection of options is different from the sum of the values of each independent option.

The binomial method follows the following steps to identify the value of the option:

1. Find Value and Volatility of Underlying Asset

2. Build Binomial Tree to Model the Project's Value

3. Convert Binomial Tree into Event Tree

4. Convert Event Tree into Option Payout Tree

Find Value and Volatility of Underlying Asset

As with any of the other approaches (Black-Scholes or Partial Differential Equations), the key to the application of the Binomial methodology lies in identifying the underlying asset or "twin security" that will be used to price the option. More often than not, when dealing with real options there is no priced security whose cash payouts are perfectly correlated with those of the project at hand. Chapter 2 described the two most common approximations to the underlying asset. First, if a related asset to the investment is traded, this can become the underlying asset. This approach has two serious flaws. It restricts the applications of real options to the analysis of those projects whose outcome is a commodity traded in the world market. And, even more serious is that it assumes that the volatility of the project is the same as the observed volatility of the commodity (e.g., the volatility of the value of a gold mine is the same as the volatility of the price of gold), but unfortunately this is seldom true.

Another approach, favored by Copeland and Antikarov (2001), is to approximate the value of the underlying asset to the present value of the cash flows of the project without flexibility. Supporters of this assumption state that this value is the best, unbiased estimate of the market value of the project were it a traded asset. For the analysis of the expansion of the water supply system in Bogotá, there is no underlying asset that is traded in the market (water is non-tradable good), so the study will follow the latter approach of approximating the value of the underlying asset to the present value of the cash flows of the project without flexibility. In fact, the study assumes that the underlying asset is not the present value of the project's cash flows, but only the present value of the deficit costs for the base case of development, since the option value derives directly from how it modifies this parameter. Nonetheless it is important to bear in mind that this is a very significant assumption that may alter the preciseness of the results.

It is also important to notice that the application of the binomial methodology implicitly assumes that the value of the underlying asset (i.e., the project's deficit costs) follows a Geometric

Brownian Motion, since this is the stochastic process modeled by binomial lattices. Economist Paul Samuelson (1965) proved that "the rate of return on any security will be random walk regardless of the pattern of cash flows that it is expected to generate in the future as long as investors have complete information about those cash flows" (Copeland and Antikarov, 2001). This implies that returns on companies that have cyclical cash flows will not be cyclical. The binomial method relies on this result to build the binomial tree.

The algorithms used to identify the water deficit were described at the beginning of this chapter. The DCF model that was described above is used to evaluate the deficit for the Chingaza expansion portfolio when no flexibility is taken into account. The procedure is simple, the deficit in each period is multiplied by the defined deficit cost and the values obtained in each year are discounted at the 12% discount rate to obtain the deficit's present value.

After the present value has been calculated, a Monte Carlo simulation is conducted to find the deficit's volatility. Crystal Ball, an Excel add-in that expands the spreadsheet forecasting capabilities, greatly simplifies the process of conducting this simulation. This powerful tool, works in conjunction with the DCF model that was previously developed, to define the probability distributions of the uncertain variables, link these probabilities with the spreadsheet model, and defines the forecast cells.

A Monte Carlo simulation randomly generates values for uncertain variables over and over to simulate a model. Crystal Ball implements Monte Carlo Simulation following a three-step process (Crystal Ball, 2000):

1. For every assumption cell, Crystal Ball generates a number according to the probability distribution defined by the user and places it into the spreadsheet

2. Crystal Ball recalculates the spreadsheet with the random number generate

3. Crystal Ball retrieves the value from the forecast cell and constructs a frequency chart (histogram) of the forecast variable.

In the end, Crystal Ball generates a probability distribution of the forecast variable, in our case, the present value of the deficit cost. This probability distribution shows the entire range of possible outcomes for the present value of the deficit cost and the likelihood of achieving each of them. These two values are assumed to be the value and volatility of the underlying asset (deficit cost) respectively.

In this case, the relevant uncertain variables for the simulation are demand growth rate and supply capacity of the existing and added systems. The demand growth rate varies depending on the changes in population growth, per capita consumption, price elasticity of demand and GDP. The total capacity of the system varies according to the expected yield of the different sources, and the occurrence of unforeseen events or terrorist attacks.

Following the results from TEA Consultores (1999), demand growth is assumed to follow a normal distribution, with mean 2.5% and a standard deviation of 1% (see Figure 4.3). This means that the most likely value for demand growth is 2.5% and that there is an equal probability of demand growth being above or below this value, always with a higher change of being near 2.5% than far away.

The probabilities distributions for the existing and added system supply capacity were calculated based on historic information of water yield per source, which is available since 1950 (EAAB, 2000b). Crystal Ball "distribution fitting" function automatically fits the historical data against all continuous probabilities distributions. The software performs a mathematical fit to determine the set of parameters for each distribution that best describes the characteristics of the data.

The quality of each fit is judged by the Chi-square test. Generally, a *p-value* of 0.5 in this test indicates a close fit. The "distribution fitting" function recommended a lognormal distribution for both the existing and added system supply capacity variables. The fit, measured by the Chi-square test, was 0.61, and 0.52 respectively. The distributions are shown in Figures 4.4 and 4.5.

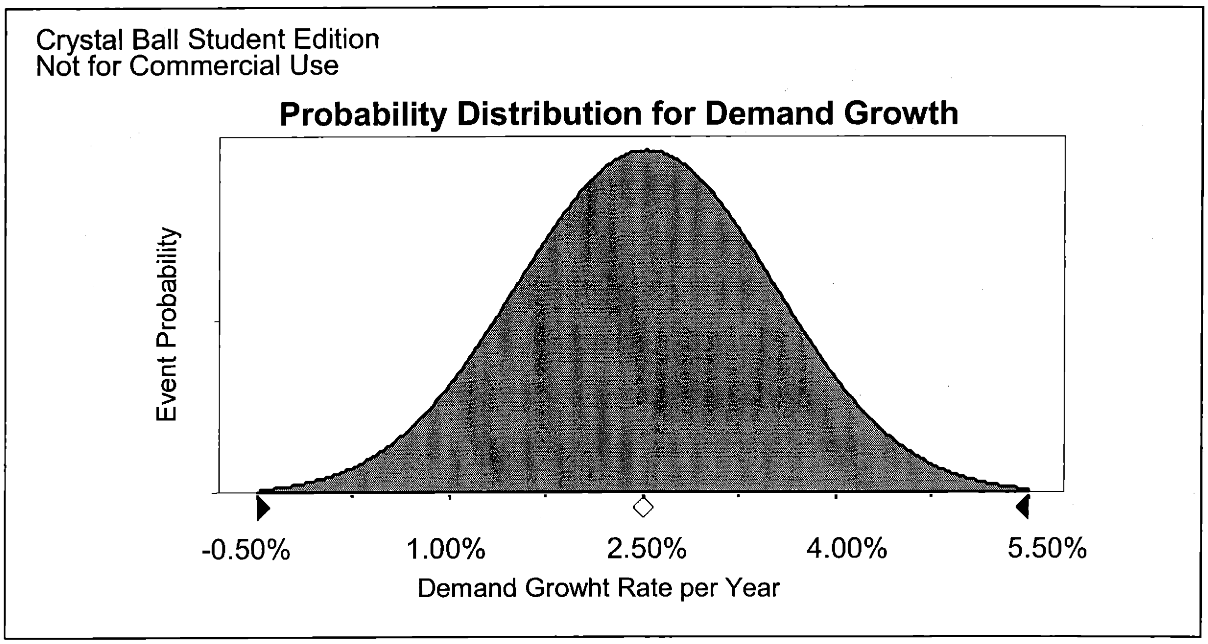

Figure 4.3. Demand Growth Probability Distribution for All Periods (adapted from Ingetec, 2000)

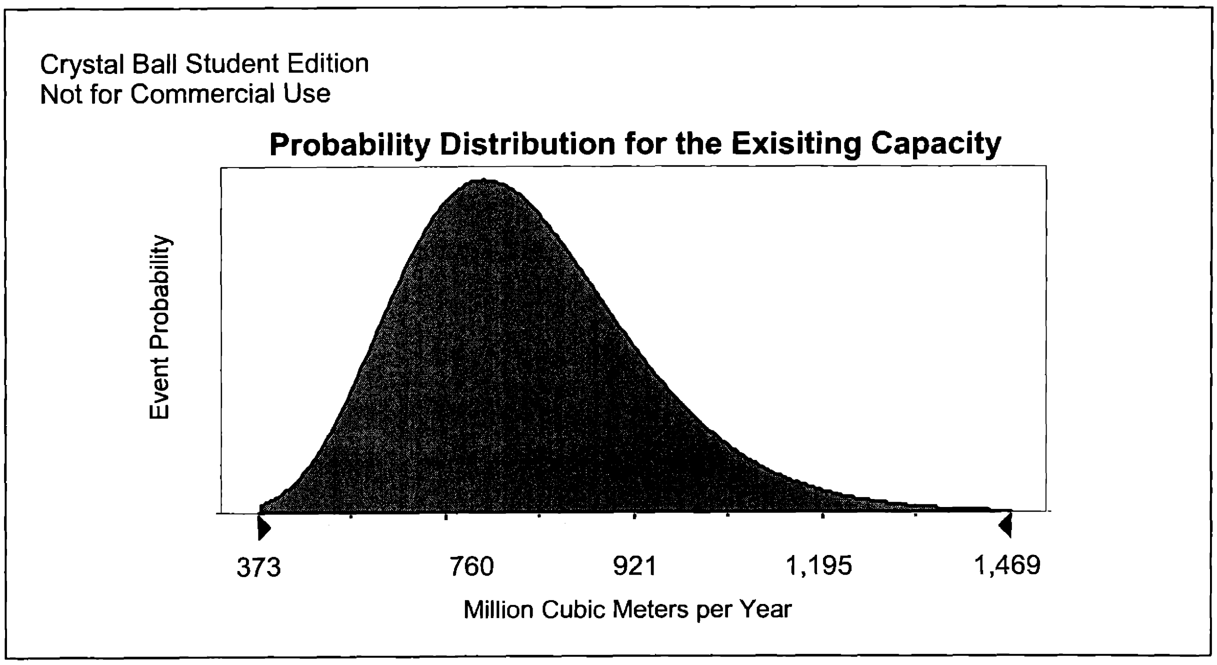

Figure 4.4. Existing Capacity Probability Distribution for All Periods (adapted from Ingetec, 2000)

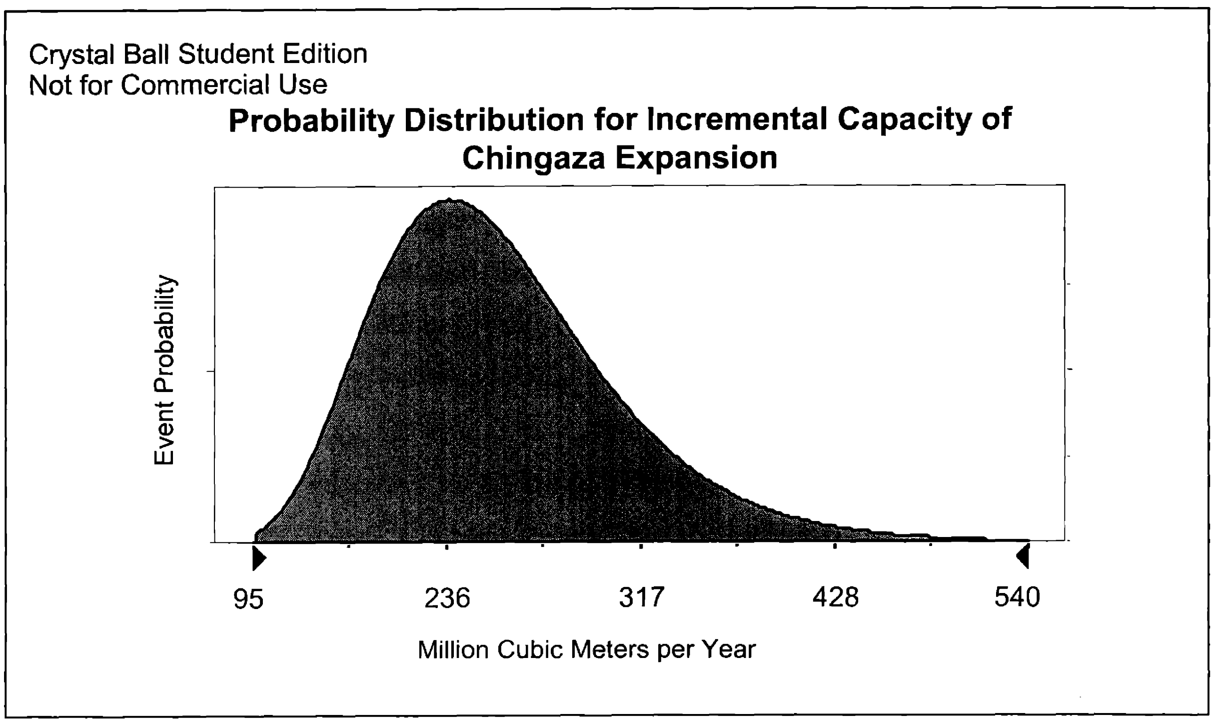

Figure 4.5 Incremental Capacity Probability Distribution of the Complete Chingaza Expansion (adapted from Ingetec, 2000)

The existing capacity has an arithmetic mean of 760 million cubic meters per year, and a standard deviation of 176 million cubic meters per year. The incremental capacity of the complete Chingaza Expansion has an arithmetic mean of 236 million cubic meters per year, and a standard deviation of 70 million cubic meters per year. The uncertainties in these probabilities distributions comprise water yield of the source due to hydrological conditions and to external factors such as terrorist attacks or unforeseen failures of the systems.

Build Binomial Tree to Model the Project's Value

The binomial approach relies on the same principles of arbitrage pricing as the Black-Scholes formula. Its advantage is that its approximation to the underlying asset's stochastic process relies only on basic algebra and therefore is more intuitive and easy to understand for non-financial professionals. The developers of the binomial approach, Cox, Ross and Rubinstein (1979) used probability theory (specifically, the results from Pascal's Triangle) to develop a binomial lattice that mimics the stochastic process of the asset's value. Once the tree is built, the mechanics for calculating the value of the option are very similar to those of folding back a decision tree. The key to the binomial methodology is the assumption that the underlying asset yields an equilibrium rate of return. The binomial approach adjusts the cash flows so that the risk-free rate can be applied.

The first step in building the binomial tree is determining whether the asset follows a multiplicative or an arithmetic series. Because the deficit cost (which is being modeled as a positive quantity), cannot become negative, the correct way to model the asset's value is through a multiplicative stochastic process. In a multiplicative stochastic process, each time period the asset's value can move up or down a certain quantity, u or d respectively, which is determined by the single estimate of the asset's volatility that was found in the preceding step, and the number of time steps per year (see Formulas 4.2 and 4.3).

Up movement: $$\boxed{u = \exp(\sigma / \sqrt{T})} \tag{4.2}$$

Down movement: $$\boxed{d = 1/u} \tag{4.3}$$

The initial value of the underlying asset is then multiplied by both the up and down movements, once each period to obtain a tree as that shown in Figure 4.6. This tree simulates the possible values for the underlying asset in each period of the analysis.

Convert Binomial Tree into Event Tree

Once the Binomial Tree has been developed, and the value of the underlying asset has been modeled, the binomial tree is converted to an event tree by incorporating the possible decisions. It is in this step that managerial flexibility is in incorporated into the analysis. To make the results comparable with the DA approach, the same type of flexibility will be taken into account: flexibility in the timing for the construction of each component of the Chingaza expansion alternative. In this case, in each node of the binomial tree, the investor can decide whether or not to build the next project in the portfolio.

Convert Event Tree into Option Payout Tree

Once the decisions available to management have been incorporated into the event tree, all that is left to do is to solve for the value of the option associated with that decision. The timing options here considered are analogous to financial call options. The option holder (the EAAB) has the right, but not the obligation, to develop the next project in the portfolio of expansion alternatives. Because in this case the objective function is to minimize total present cost, instead of maximizing net present value, the option's value is measured in terms of how much it reduces the total deficit. The cost of the option, its exercise price, is the present cost of the investment associated with that component of the expansion plan.

At any point in time, the option payoff is given by the maximum between the value of exercising the option and the value of keeping the option alive. Formula 4.4 shows the relevant expression for this study:

$$\boxed{C_t = MAX[V_t * Deficit.REduction.Percentage - InvestmentCost, C_t]} \quad (4.4)$$

where C_t is the value of the option, and V_t the value of the underlying asset in period t.

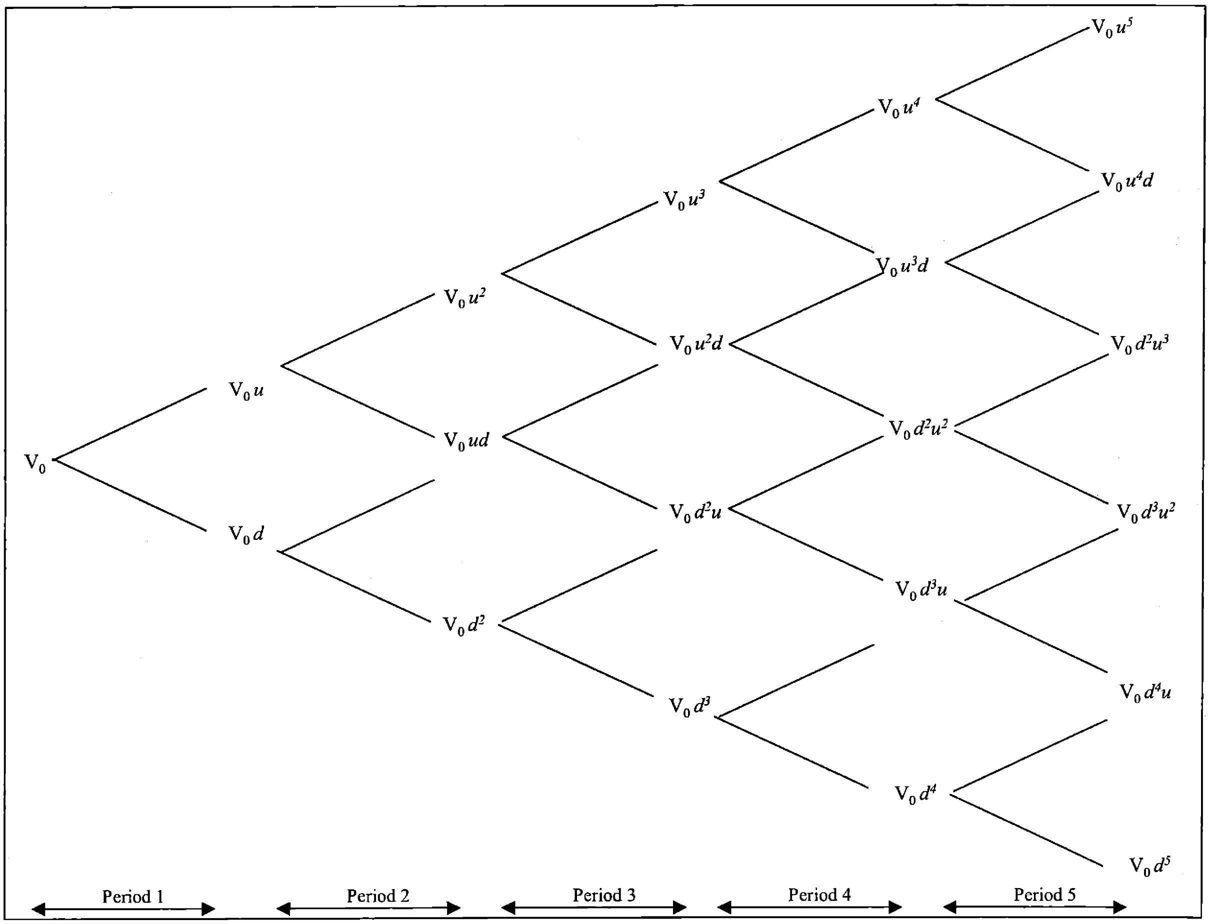

Figure 4.6. Basic Structure of Binomial Tree—Evolution of Value of Underlying Asset

The payoff calculation begins in the last period, where the value of the option is zero, since it has reached its maturity date. The replicating portfolio approach is used to calculate option value in all other periods. Based on the law of one price, this approach creates a portfolio of securities whose values have the exact same payoffs as the asset at hand, and so if the two assets (the real asset and the created portfolio) have the exact same payouts in every state of nature, then their price (or value) must be the same to prevent arbitrage profits. In the case at hand the portfolio will be composed of *m* units of the underlying asset and *B* risk-free bonds. At any point in time, the value of the option in the down state is given by Equation 4.5:

$$\boxed{C_d = m * V_t + (1 + r_f)B} \tag{4.5}$$

where C_d is the value of the option in the down state of the binomial node, V_t is the value of the underlying asset in period t, and r_f is the risk-free rate.

Since the values in the up and down state must be the same ($C_d = C_u$), the two equations can be equaled to find an expression for *m* and *B*.

$$\boxed{m = \frac{C_u - C_d}{V_0 u - V_o d}} \tag{4.6}$$

$$\boxed{B = \frac{C_d - mV_o d}{(1 + r_f)}} \tag{4.7}$$

Using these two equations it is easy to build a ROA model in an Excel spreadsheet that solves for option value. The complete formulation of the model used in this case study is presented in Appendix D. The resulting model shows the payoffs from optimal decisions, conditional on the states of nature, and the optimal strategy as well.

For the expansion of the Chingaza system there are a total of four options like the one described above. The first one allows us to expand to Chuza Norte II stage, the second one to Chuza Norte III stage, the third one to Chingaza Sureste and the fourth one to La Playa. These are simultaneous growth options because the value of each one is contingent on another option, and because the underlying option and the option on it are simultaneously available. This means that the options are not required to be sequential in time, for example, Chuza Norte stage II can be built at the same time as Chuza Norte stage I, although Chuza Norte stage II cannot be built before Chuza Norte Stage I. It is precisely this condition what makes Chuza Norte stage II a growth or expansion option over Chuza Norte stage I.

The methodology for valuing simultaneous compound options is fairly straightforward. It begins by valuing the construction of Chuza Norte stage II as a call option on the value of Chuza Norte stage I, with an exercise price equal to the investment required to build Chuza Norte stage II. The results from this valuation then become the binomial tree for the next option, which is then analyzed following exactly the same methodology that has been described in this text.

4.3. RESULTS

4.3.1. Net Present Value Analysis

As the methodology subsection explained, the final objective of this analysis is to find the strategy that minimizes the costs to the consumer of the Chingaza expansion portfolio. Because of this, instead of calculating the Net Present Value of the project (which in theory would always be zero, since tariffs should be set so as to offset all costs), the focus is only on the projects' costs. The Total Present Cost of the portfolio of projects, under the assumptions presented in Table 4.2 is **US$126 Million**. Appendix E presents a complete printout of the DCF model used to calculate this cost.

Sensitivity Analysis

Net Present Value gives a point estimate for the expected value of the project. This estimate does not take into account managerial flexibility, or the possible uncertainties over the main variables of the DCF model. A first step in recognizing these uncertainties is to conduct a sensitivity analysis. Such an analysis reveals that the Net Present Cost and Deficit Cost of the portfolio are highly sensitive to changes in the following variables:

- Discount Rate
- Construction Costs
- Existing and Incremental Capacity

For example, a reduction of 10% in the capacity of the existing system, increments total costs over 130%, and total deficit by 86%; a 10% decrease in the yield of the incremental capacity, increases total costs by 9%, and total deficit by 36%; and a 10% decrease in the discount rate causes a 15% increase in the project's costs, with no impact on the city's water deficit. Appendix F presents the complete results from the sensitivity analysis.

The problem with sensitivity analysis is that it only allows the analysis of variations in one parameter each time. Thus, it is impossible to find out what would happen if, for example, both the construction costs and the existing and incremental capacity change at the same time. Also, sensitivity analysis cannot be conducted for parameters such as demand growth and timing of the investments because of the design of the DCF model. Therefore a more complex analysis is needed to understand the combined effects of all relevant parameters of the DCF model.

Scenario Analysis

A scenario analysis conducted over the project's Present Cost base case, reveals the sensitivity of this variable towards parameters such as demand growth, and timing of the investments. For instance, Scenario No. 1, which is exactly the same as the base case in the model, except it does not build the La Playa component, has a lower Present Cost: US$120 Million. This means savings of US$6 Million by not constructing La Playa.

On the other hand, Scenario No. 2, which is exactly the same as the base case, except the demand growth is 4.0% per year instead of 2.5%, yields a higher Present Cost: US$444 Million as can be expected. Also, a scenario in which capacity goes down by 10% and construction costs go up by 10% increases the project's Present Cost by 157% to a total of US$327 Million. The complete detail for these and other scenarios is presented in Appendix G.

In short, both sensitivity and scenario analysis show the vulnerability of the NPV's Present Cost estimate. First, small changes in the uncertain variables can have significant repercussions in the project's total cost. Second, it is impossible to use NPV to define an optimal strategy. For example, the results from Scenario 1, with a lower Present Cost of US$120 Million, suggest that in certain cases, consumers might be better off by not building La Playa reservoir, a situation not considered in the EAAB's original plans. But there is no robust argument to state that this is in fact the optimal strategy.

Although scenario analysis is an initial step towards the identification of an optimal strategy for the Chingaza portfolio, it becomes impractical when many sources of uncertainty and flexibility options are relevant. In this case, to find the true optimal strategy it would be necessary to run a scenario analysis for all possible combinations of the uncertain variables, which means over 23,000 scenarios, even if the uncertain variables are limited to the demand growth rate.

Monte Carlo Simulation

One final step that can be taken to complement the results from an NPV analysis is to conduct a Monte Carlo simulation to determine the probability distribution of the Present Cost. This simulation was conducted using Crystal Ball software and following the same procedure identified in the methodology section 4.2.4. The uncertain variables considered were demand growth, existing capacity, incremental capacity and construction costs. The probabilities distributions for demand growth, existing capacity and incremental capacity are as described in section 4.2.4 of this chapter (Figures 4.3, 4.4 and 4.5).

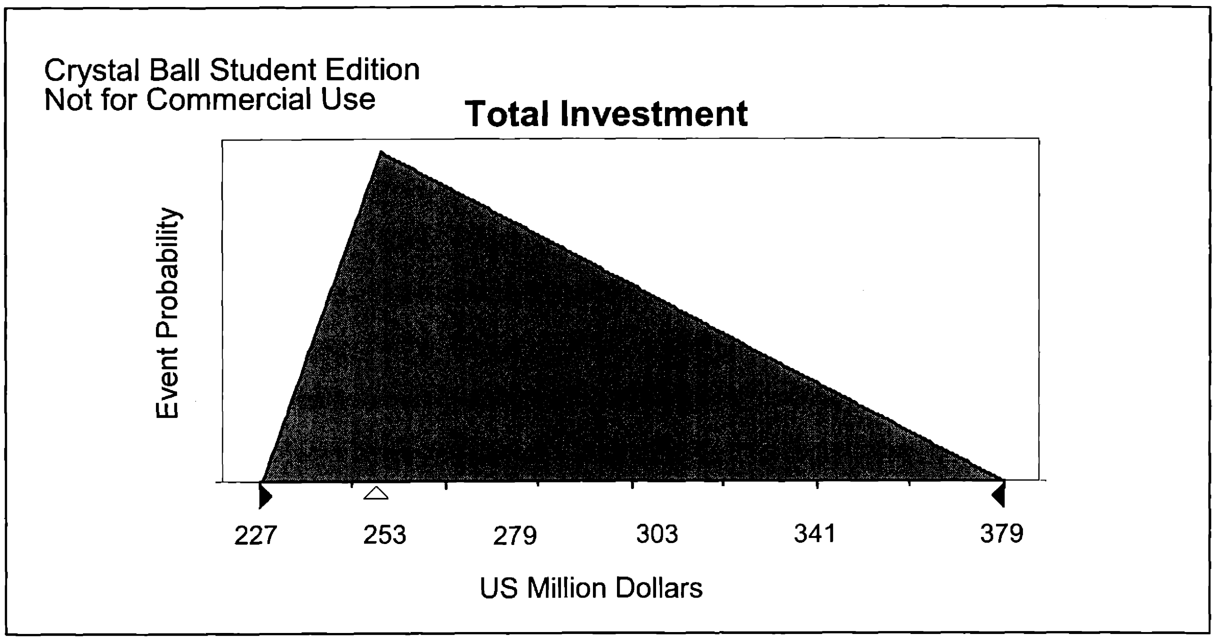

Figure 4.7. Construction Costs Probability Distribution (adapted from Ingetec, 2000)

Construction costs were modeled as a triangular distribution, assuming a likeliest value of US$253, a minimum of US$228 and a maximum of US$379 (see Figure 4.7). These values were estimated by Ingetec (2000) based on historical evidence of cost overruns and cost savings in past projects. Ingetec found that maximum cost savings ever obtained were 10%, while cost overruns went up to 50% of initial planned costs.

The Monte Carlo simulations results show an expected Present Cost for the portfolio (mean of the distribution) of US$374 Million (see Figure 4.8). This cost is almost three times higher than that estimated by the NPV methodology for the EAAB's base case. The Monte Carlo simulation also indicates that the possible values for the portfolio cost's range from US$107 Million to US$1,293 Million. Most of the variation in this probability distribution is due to the deficit cost. In fact, if we consider the probability distribution of the Present Cost without the deficit cost (see Figre 4.9), the mean cost is US$125, and the range of possible values goes from US$107 Million to US$169. The reason for this is that the more relevant uncertainties of demand growth and capacity of the existing and incremental supply is only taken into account in the deficit costs. The variation in the cost distribution without deficit depends only in the variation of the construction costs, since we are assuming that operation costs are almost certain.

The reason why the Monte Carlo simulation results are not the same as the EAAB scenario, which is based on the most likely values for every variable is the non-linearity of the payoffs of this values (which leads to the flaw of averages as explained in Chapter 2).

The results from the Monte Carlo simulation suggest that there is 80% probability of the project's cost being higher than the original EAAB estimate. These results help create awareness of the risks associated with the project, and they show how the EAAB is probably being over optimistic in their base case assumptions. The simulation portrays a more accurate description of the project's risks, and therefore it is this expected Present Cost of US$374 Million the value that will be used to compare against the results from DA and ROA. Appendix H contains the complete report of the Monte Carlo simulation.

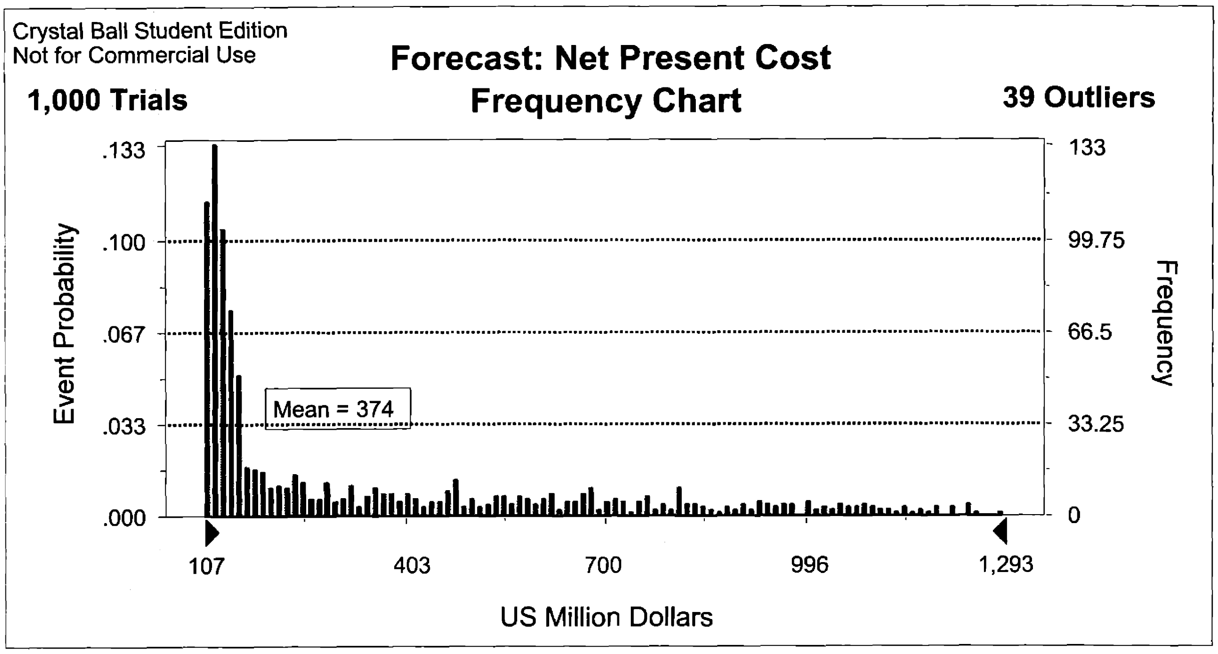

Figure 4.8. Probability Distribution of Total Net Present Cost (includes Deficit Cost at US$0.80 per Cubic Meter of Unmet Demand)

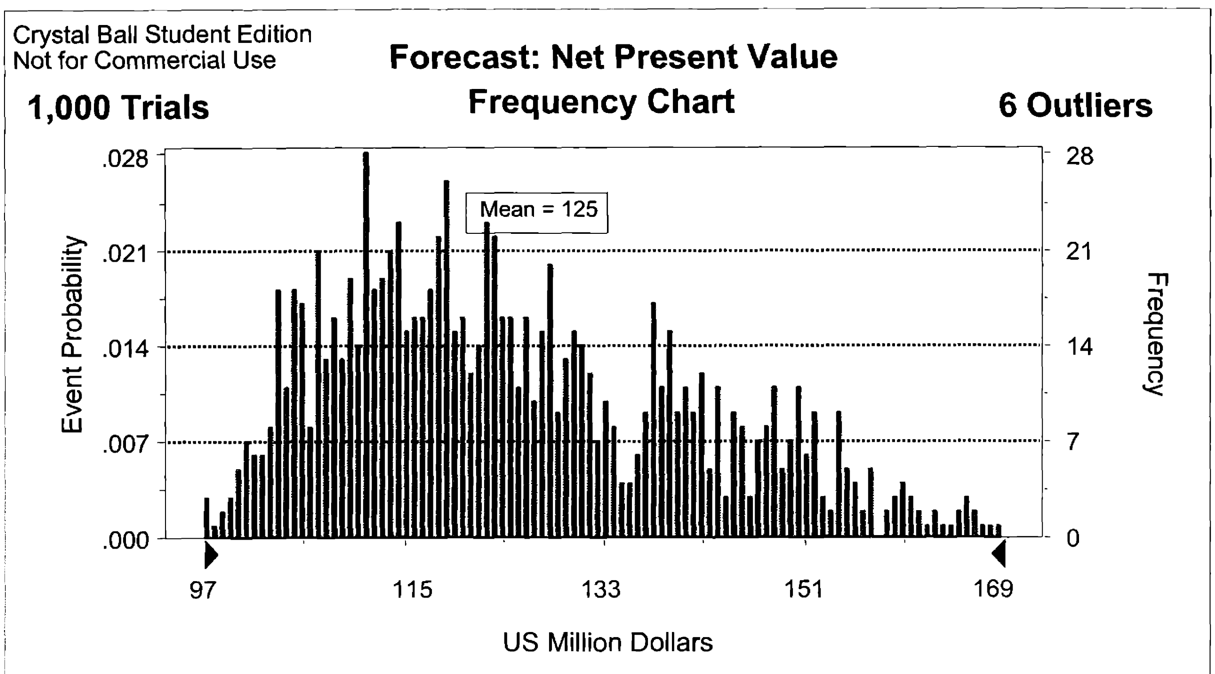

Figure 4.9. Probability Distribution of Net Present Cost without Deficit Cost

Although Monte Carlo simulation is a very useful tool to open the eyes of analysts and help them understand the uncertainties and risks relevant in the project at hand, and the probabilistic distribution of the project's value, it says nothing about the optimal strategy to deal with these uncertainties. The following subsection presents the results from Decision Analysis and Real Option, two approaches that, at least in theory. Should help the analyst devise an optimal strategy for its project.

4.3.2. Decision Analysis

Value of Flexibility

Decision Analysis takes into account all the different possible scenarios for the evolution of the uncertain variables and calculates the expected cost based on the weighted average of the payoff of each scenario and its probability of occurrence. Following this methodology, the expected cost of the Chingaza portfolio is **US$126 Million**. Although this number is the same as the NPV's estimate of the project cost, this does not mean that NPV is right. It is simply a numerical coincidence, and the relevant comparison is really between this value and the value given by the Monte Carlo simulation. In this case, the expected cost of the portfolio with no flexibility was US$374 Million, and since the value of the project with flexibility (as identified with the DA methodology) is US$126, the value of flexibility is **US$248 Million**.

These large savings come from tailoring the development strategy of the Chingaza expansion to different possible future states of the uncertain variables, instead of committing to a single plan from Period 0.

For example, Table 4.3 shows the consequences, in terms of the Present Cost, of different decision in Period 1 (2004-2006) contingent on the demand growth rate in Period 0 (2001-2003). This table shows how an incorrect decision can increment the project's cost by as much as US$15 Million, US$9 Million or US$8 Million depending on whether demand growth rate was low, medium or high, respectively.

The optimal decisions in each period are those highlighted in the table; the optimal decision is different for the different evolutions of the demand growth rate. For example, table 4.3 shows that the best decision in 2004, if demand growth in the previous period was low or medium is to build the first stage of Chuza Norte. But, if demand growth rate was high from 2001 to 2003, then the best decision in 2004 is to start construction of the complete Chuza project. By making the correct decisions in each period the EAAB can accumulate great savings.

	Demand Growth in Period 0 (2001-2003)		
Decision in Period 1 (2004-2006)	1.5%	2.5%	3.5%
Build Chuza Norte Stage I	112	125	142
Build Chuza Norte	127	131	135
Do Nothing	127	134	143

Optimal Decision

Table 4.3. Present Cost In US Million for different Decisions in Period 1 Associated with Demand Evolution in Period 0—EAAB Demand Scenarios.

It is also useful to conduct some sensitivity analysis for the results of the DA approach. In this case, it is relevant to analyze how the optimal strategy would change in each case, if the demand growth rate had a higher volatility than the one expected by the EAAB. For example, if the standard deviation of demand growth was to be 2%, instead of 1%, the new demand values would be:

- High demand growth of 4.5% with probability of 20%
- Medium demand growth of 2.5% with probability of 60%
- Low demand growth of 0.5% with probability of 20%

In this case, the optimal decision in the first period changes to Do Nothing in all cases, as can be seen in the Table 4.4. These results show how higher volatilities increment the value of flexibility, and therefore the value of waiting to invest.

	Demand Growth in Period 0 (2001-2003)		
Decision in Period 1 (2004-2006)	0.5%	2.5%	4.5%
Build Chuza Norte Stage I	US$160	US$171	US$188
Build Chuza Norte	US$131	US$141	US$156
Do Nothing	US$124	US$135	US$152

Optimal Decision

Table 4.4. Present Cost In US Million for different Decisions in Period 1 Associated with Demand Evolution in Period 0—Higher Volatility Demand Scenarios.

It is important to note that although the demand growth rate in the medium scenario is the same in Tables 4.3 and 4.4 (2.5% per year), the payoffs are not the same, because, the expected value is the weighted average of all future scenarios. Thus, the payoffs in the medium demand growth scenario of table 4.4 include the possibility of demand growth as low as 0.5% or as high as 4.5% per year, while the payoffs in table 4.3 include the possibility of demand growth of only 1.5% or 3.5%.

Cost of Flexibility

Of course, as the following chapter will explain, to realize the benefits from the flexible strategy, the EAAB has to change not only its capital budgeting technique, but also its internal processes. As can be recalled from Chapter 2, flexibility is *not* a free good. The EAAB has to pay for it. For instance, the benefits from the flexible strategy will only be realized if the EAAB can effectively monitor the demand growth rate continuously, and if all the projects in the portfolio are in such a state that their construction can start a very short time after the EAAB has identified that it is needed. This means that detailed designs, land and resettlement negotiations and financial structuring of the project must all be ready beforehand. The cost of undertaking these actions in advance is the price the EAAB has to pay for its flexibility.

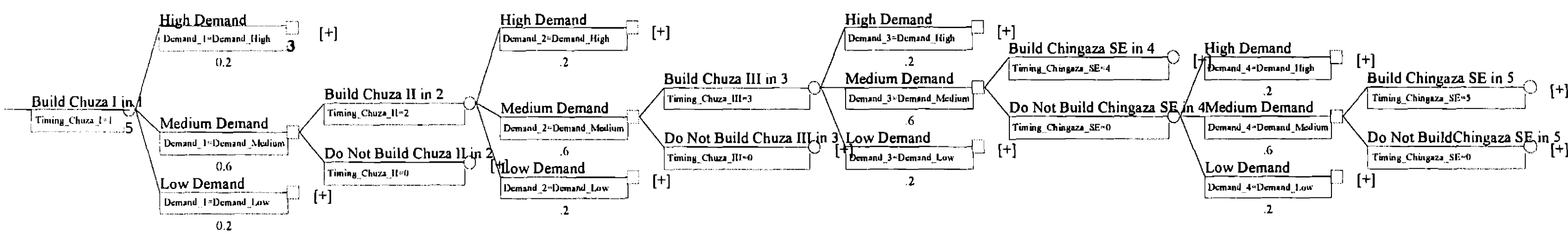

Figure 4.10. Illustration of Optimal Decision for Medium Demand Growth Rate Path

Optimal Strategy

In addition to identifying the value of flexibility, Decision Analysis allows the identification of the optimal decision path contingent on the demand growth rate evolution in the preceding period. For a path of medium growth rate in every period, the optimal decisions are (see Figure 4.10):

- Period 1: Build Chuza Norte Stage I.
- Period 2: Build Chuza Norte Stage II.
- Period 3: Build Chuza Norte Stage III.
- Period 4: Do Nothing.
- Period 5: Do Nothing.

This path has a probability of 7.8%, and the total portfolio cost associated with it is US$120 Million. As was mentioned before, these results are the same as those obtained through the scenario analysis in the NPV approach, as can be verified by looking at Scenario 3 in Appendix G.

For a path of medium growth in Period 0, and high growth from then on, the optimal decisions are:

- Period 1: Build Chuza Norte Stage I.
- Period 2: Build Chuza Norte Stage II.
- Period 3: Build Chuza Norte Stage III.
- Period 4: Build Chingaza Sureste.
- Period 5: Do Nothing.

The path probability in this case is 0.1% and the total portfolio cost is US$262 Million. Note that the decision of building La Playa in Period 5, increases the total portfolio cost to US$267 Million. Thus, it can be inferred that La Playa project decreases the value of the portfolio, for the demand growth scenarios assumed. Even when demand growth is high in all periods (3.5%), the construction of La Playa does not decrease the Present Cost of the portfolio. This is because the investment cost of La Playa is higher than the project's deficit reduction benefits.

For a path of medium growth in Period 0, and low growth from then on, the optimal decisions are:

- Period 1: Build Chuza Norte Stage I.
- Period 2: Build Chuza Norte Stage II.
- Period 3: Do Nothing.
- Period 4: Build Chuza Norte Stage III.
- Period 5: Do Nothing.

The path probability in this case is also 0.1% and the total cost of the portfolio development is US$111 Million. Appendix I contains the printouts for the complete decision trees, from which the optimal strategy for any combination of demand growth in the different time periods can be derived. In every case it is clear that a flexible strategy can greatly reduce cost of the project portfolio.

Although DA effectively values flexibility and it is a very useful tool to determine an optimal strategy for each possible demand scenario, the application of this technique is cumbersome, especially when several time periods or sources of uncertainty have to be considered. In this case, with only one source of uncertainty, five time periods and a simple go/ no-go decision in each decision node, the total number of nodes in the tree (decision, chance and terminal nodes) came up to more than 23,000. The computation of a tree this big requires a powerful personal computer, a lot of attention, and a lot of patience.

4.3.4. Real Options Analysis

Value and Volatility of Underlying Asset

The first step in the Real Options Analysis is to find the value and the volatility of the underlying asset, which in this case is the deficit cost of the project with no flexibility, through a Monte Carlo simulation. The simulation estimates an average deficit cost of US$248 Million. This value is different from the Monte Carlo estimate of US$374 obtained in section 4.3.2, because the latter comprises all project costs, while the former, entails only deficit costs. The difference between the two numbers is the Present Value of the investment and operational costs. The Monte Carlo simulation of the deficit cost also gives an estimate of the volatility of the underlying asset; the standard deviation of the distribution is 130%. The maximum value is US$1,166 and the minimum is US$0. Figure 4.11 shows the probability distribution for the deficit cost obtained from this simulation.

Binomial Tree

The estimation of the standard deviation allows us to proceed to the second step in the methodology, and calculate the up and down movements for the binomial tree, according to Equations 4.2 and 4.3. The up movement per step is equal to 1.94, and the down movement equal to 0.51. Figure 4.12 shows the binomial tree resulting from applying these movements in a multiplicative manner to the initial deficit cost. The values in each node of the tree correspond to the deficit cost for different possible future states of the uncertain variables. The risk free rate used to calculate this tree was 11%, which corresponds to the rate of medium term government bonds in the US plus the country risk for Colombia (Damodaran, 2002).

The binomial tree in Figure 4.12 is recombining, and shows that at the end of the fifth time period, the cost of the deficit, if no option is exercised (in this case, meaning that no project is executed) can range from US$6 Million to US$10.575 Million. The present value of this range is US$1.4 Million, roughly what was obtained in the Monte Carlos simulation for the deficit cost (see Figure 4.11).

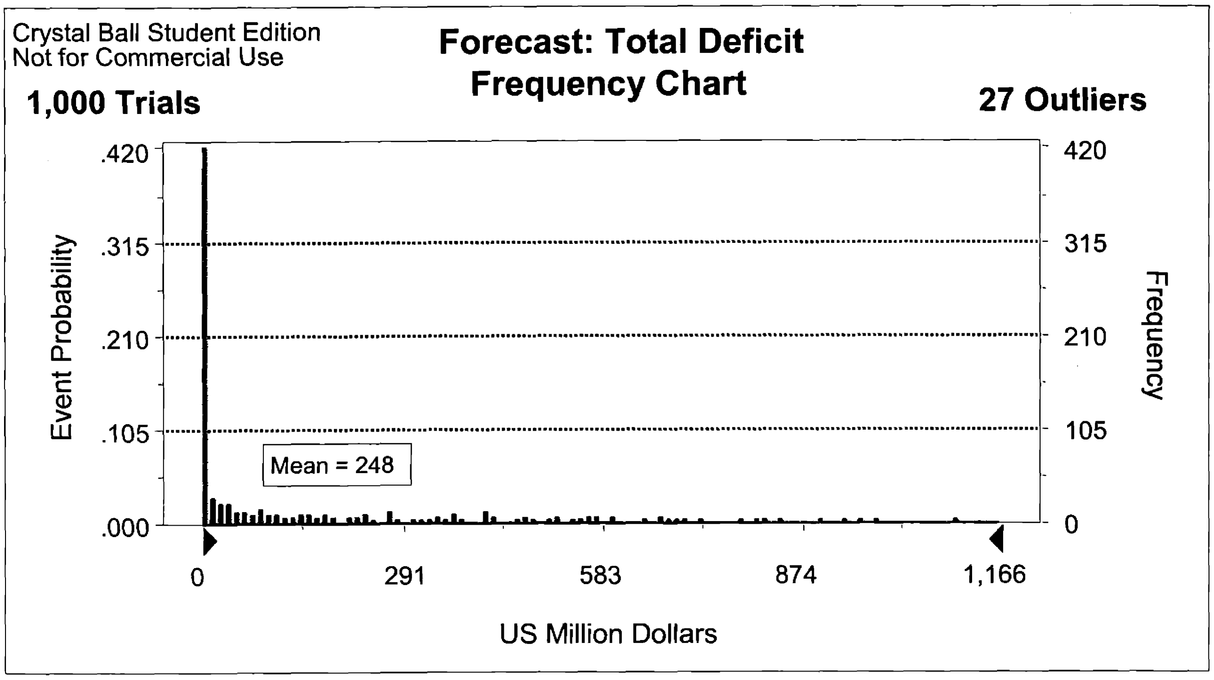

Figure 4.11. Probability Distribution of Present Deficit Cost

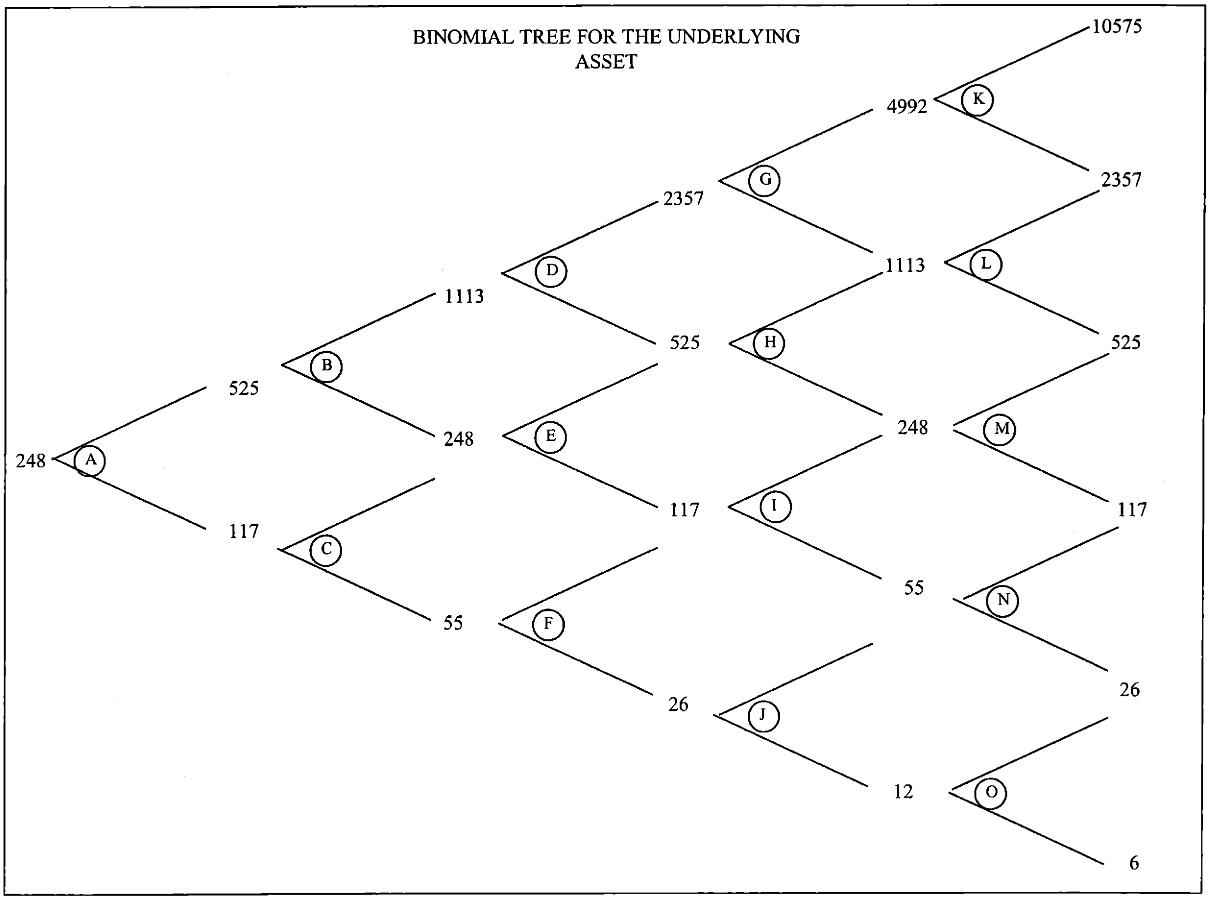

Figure 4.12. Binomial Tree Showing the Evolution of the Value of the Underlying Asset (All values in US$ Million)

Option Pricing

Now that the value of the asset is modeled, the call option over it can be priced. The first option is the right, but not the obligation to construct the second stage of Chuza Norte. The option provides us with the opportunity of reducing the deficit cost by 35%, and has an exercise price of US$30.8Million, equal to the present value of the investment cost. The payoffs of keeping the option open for each node in the binomial tree are valued by the replicating portfolio approach. These results are presented in Table 4.5.

Node	End-of-Period Payoff		Replicating Portfolio		Option Value
	Up State	Down State	m	B	
K	10,544	2,327	1.0	(22.8)	4,970
L	2,327	495	1.0	(22.8)	1,090
M	495	101	1.0	(9.0)	230
N	101	26	0.8	3.5	49
O	26	6	1.0	-	12
G	4,962	1,083	1.0	(22.8)	2,334
H	1,083	218	1.0	(22.8)	503
I	218	49	0.9	0.5	103
J	49	12	0.9	1.4	24
D	2,327	495	1.0	(22.8)	1,090
E	495	101	1.0	(9.0)	230
F	101	24	0.9	1.1	48
B	1,083	218	1.0	(22.8)	503
C	218	48	0.9	(0.4)	103
A	495	101	1.0	(9.0)	230

Table 4.5. Option Value at each node of the Binomial Tree

The option value in each node is compared with the payoffs of exercising the option (which means building the second stage of Chuza Norte) to find the decision that minimizes deficit cost. Figure 4.13 shows the event tree for the option of Chuza Norte stage II. The figure identifies when it is better to keep the option alive (do nothing) and when to exercise it (build the project). It also identifies the value of the underlying asset in US Million for the optimal decision. Thus it can be seen that the value of the option is US$30 Million, which corresponds to the difference between the value of the underlying asset with no flexibility, US$248 Million (Figure 4.12—Node A), and its value with the timing option, US$218 Million (Figure 4.13—Node A)

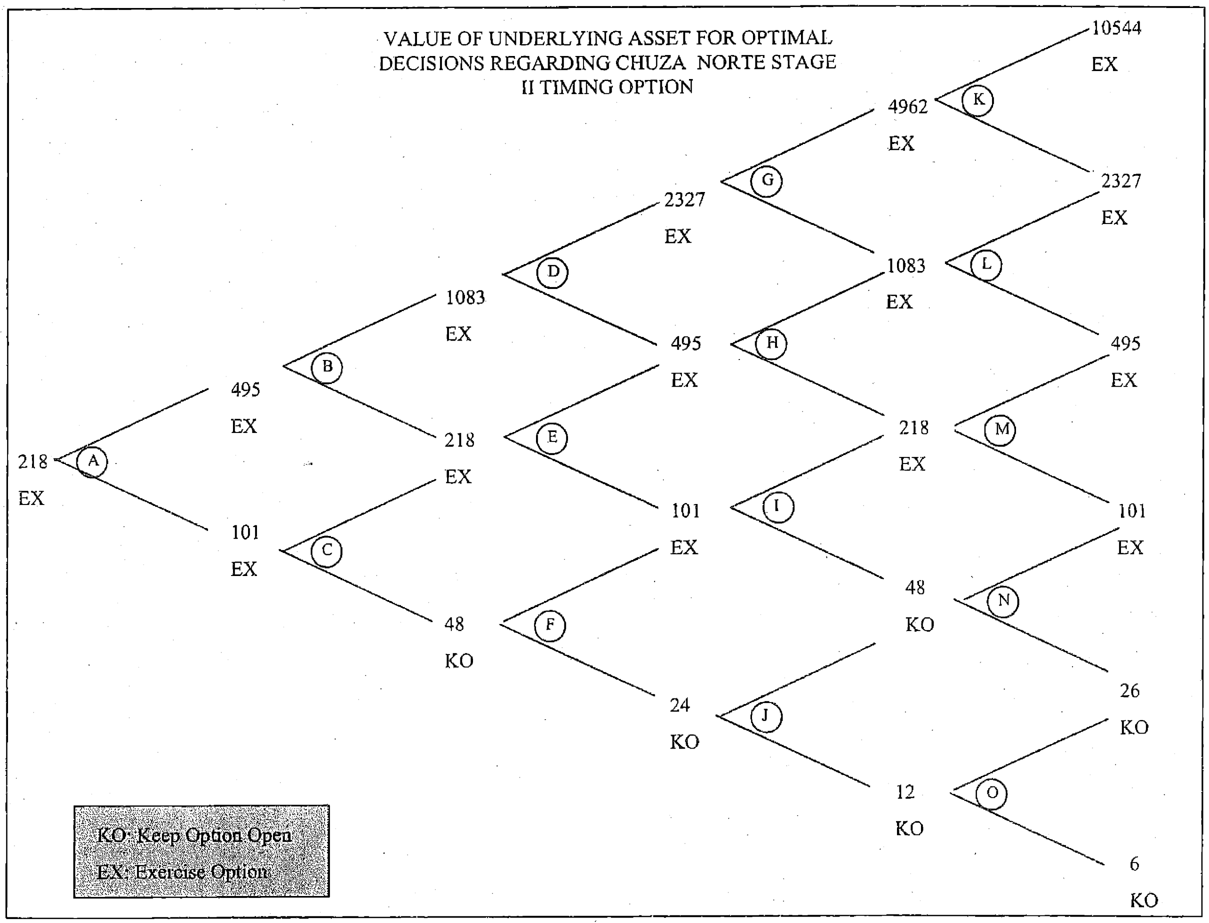

Figure 4.13. Optimal Payoffs for Chuza Norte Stage II option.

Figure 4.13 suggests that the best decision in Period 1, for all value of the underlying asset, is to exercise the option, meaning to construct Chuza Norte Stage II. This tree presents what at first glance might seem a contradictory result. In Period 3 if the evolution of the underlying asset has been always towards the down state, ROA recommends keeping the option open. Nevertheless, since the decision had to be taken in Period 1, when no information was available on the future development of the value of the underlying asset, the option was already exercised. What can be inferred from this information is that an abandonment option would probably be valuable in the down states of the value of the underlying asset, after Period 2.

Table 4.6 shows the value of the underlying asset and the optimal decisions in each point in time, for the different options of the Chingaza portfolio. This table shows that for all options subsequent to Chuza Norte II the best decision in Period 1 is to keep the option open, meaning that it is best to wait and see how the demand will behave before committing to a decision. In the case of Chuza Norte stage III and Chingaza SE, the optimal decision in Period II depends on whether the evolution of the underlying asset followed an upper or lower path. The optimal payoff trees for each of these options are presented in Appendix K.

	Chuza Norte II		Chuza Norte III		Chingaza SE		La Playa	
Node	Asset Value	Optimal Decision	Asset Value	Optimal Decision	Asset Value	Optimal Decision	Asset Value	Optimal Decision
A	218	Exercise	187	Keep.Open	164	Keep.Open	154	Keep.Open
B	495	Exercise	464	Exercise	430	Exercise	415	Keep.Open
C	101	Exercise	88	Keep.Open	77	Keep.Open	73	Keep.Open
D	1,083	Exercise	1,052	Exercise	1,018	Exercise	1,003	Keep.Open
E	218	Exercise	187	Exercise	164	Exercise	154	Keep.Open
F	48	Keep.Open	44	Keep.Open	40	Keep.Open	39	Keep.Open
G	2,327	Exercise	2,296	Exercise	2,262	Exercise	2,247	Exercise
H	495	Exercise	464	Exercise	430	Exercise	415	Keep.Open
I	101	Exercise	89	Keep.Open	80	Keep.Open	77	Keep.Open
J	24	Keep.Open	24	Keep.Open	24	Keep.Open	24	Keep.Open
K	4,962	Exercise	4,931	Exercise	10,479	Exercise	10,464	Exercise
L	1,083	Exercise	1,052	Exercise	2,262	Exercise	2,247	Keep.Open
M	218	Exercise	187	Exercise	430	Exercise	415	Keep.Open
N	49	Keep.Open	49	Keep.Open	101	Keep.Open	101	Keep.Open
O	12	Keep.Open	12	Keep.Open	26	Keep.Open	26	Keep.Open

Table 4.6. Value of Underlying Asset for Optimal Decisions for All Options of the Chingaza Expansion Portfolio.

Summary

By analyzing the option value in each case, the relative effectiveness of each project to reduce deficit costs can be determined. This ranking would be similar to ranking the alternatives by their cost per cubic meter of water produced, which can be done based on the DCF analysis of each project independently. In fact, the results obtained here are the same that the EAAB obtained in the latest Ingetec report (1999) "Actualización del Plan Maestro de Abastecimiento de Agua Potable para el Mediano y Largo Plazo", as is shown in Table 4.6.

	US$/m^3	Option Value
Chuza Norte Stage I	0.163	NA
Chuza Norte Stage II	0.186	30
Chuza Norte Stage III	0.205	31
Chingaza Sureste	0.361	23
La Playa	0.460	9

Table 4.7. Project Ranking according to Cost per Cubic Meter of Water and Option Value

The value of flexibility according to the Real Options Approach is US$93 Million. Remember that with the Decision Analysis approach this value was US$248 Million. The difference between these two numbers can be explained by differences in the pricing mechanisms of each methodology (expected value pricing vs. arbitrage pricing) and differences in the assumptions taken for each analysis.

4.4. CONCLUSIONS

Table 4.8 summarizes the results from all evaluations. This results confirm what was set forth in chapter 2, in the sense that both Decision Analysis and Real Options take into account the value of flexibility, while NPV does not. It was also evident through the development of the case study that the theory behind DA is straightforward and easy to understand for engineers, but the implementation of the approach may become fairly complex when several sources of uncertainty, or several time periods have to be considered. On the other hand, a real options analysis is fairly easy to develop, *once* the theoretical underpinnings have been understood. The theory behind ROA may be understandable for practitioners in the finance and economics discipline, but it is definitely not intuitive for engineers.

Methodology	Project Cost (US$ Million)	Value of Flexibility (US$ Million)	Strategy Definition
Net Present Value	126	-	No
Net Present Value with Monte Carlo Simulation	374	-	No
Decision Analysis	126	248	Yes
Real Options	-	90	Not Clear

Table4.8. Case Study Summary Results

To really determine which approach is best for the EAAB it is necessary to analyze not only the results presented in this chapter, but the appropriateness of each approach in the specific institutional context of the EAAB. The following chapter analyzes the advantages and disadvantages of each approach vis-à-vis the main objective of using these techniques to optimize the value of the portfolio of water supply expansion projects under uncertainty, given the institutional context in which the EAAB is immersed. Although the analysis presented in this chapter was limited to the analysis of timing options, the considerations presented in chapter 5 will be broad enough to cover other types of options such as abandonment, switching inputs, and others.

CHAPTER 5: CHOOSING THE OPTIMAL TECHNIQUE: IMPLEMENTATION CHALLENGES

5.1. INTRODUCTION

The previous chapter presented three different approaches to identify the value of flexibility in the EAAB's portfolio of water supply expansion projects: Net Present Value, Decision Analysis and Real Options. Both DA and ROA effectively incorporate uncertainty and flexibility in their analysis, but the value each approach assigns to flexibility is considerably different, because of differences in the pricing mechanisms that each method uses (Expected Value Pricing vs. Arbitrage Pricing), and the assumptions required. This chapter analyzes these approaches to identify the most suitable technique (or techniques) for the EAAB to structure and manage proactively its water supply expansion project portfolio, aligning it with its overall corporate strategy.

The first part of this chapter compares these three approaches to determine their utility as decision-making tools for the EAAB. The second part leaves aside the discussion of which approach is better to explore the strategic and operational implications of introducing flexibility alternatives in the EAAB's capacity planning exercises. This part highlights the main internal and external challenges for the introduction of these options and suggests policy changes that will enable their implementation.

5.2. COMPARATIVE ANALYSIS OF NET PRESENT VALUE, DECISION ANALYSIS AND REAL OPTIONS

5.2.1. Net Present Value

Net Present Value is probably the easiest technique to understand and develop, and certainly, the most familiar to engineers, economists and financial managers within the EAAB. According to

Schall, Sundem and Geijsbeek, in 1980 over 86% of large corporations in the United States and Europe recognized Net Present Value as their preferred criterion for project evaluation. The concepts underlying this technique, mainly discounting future cash flows to obtain present value are therefore widely known, used and accepted in today's corporate environment. And, the technique can be easily applied with the computer resources available in all of today's corporations and institutions[15].

Chapter 2 analyzed Net Present Value in detail, and identified the following disadvantages for its application, even in conditions of complete certainty:

- NPV does not take into account the scale of the projects being analyzed
- It is highly sensitive to the choice of discount rate, a parameter which is difficult to calculate with high precision.
- It requires that all benefits and costs be assigned a monetary value.

This last point is very relevant for the EAAB, since as Figure 5.1 shows, the Net Present Cost of the project is highly sensitive to changes in the deficit cost, which is mostly non-monetary. For example, if the deficit cost is assumed to be US$1 per cubic meter of unmet demand, instead of US$0.80, then the Net present Cost is increased by 20%. Moreover, the sensitivity presented in Figure 5.1 is defined for the EAAB's base case scenario. As other scenarios, where the initial deficit is higher, are analyzed the change in Net Present Cost per unit change in the Cost of Deficit is even higher, than what is presented in Figure 5.1.

The deficit cost is determined by the monetary and non-monetary costs that a water deficit implies for the citizens of Bogotá. The monetary costs include increases in the citizens' water expenditures due to increases in prices when supply is low and demand is high, transportation costs and use of more expensive sources of water (i.e. bottled water) and loss of business. The non-monetary costs include negative health effects and discomfort and inconvenience.

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15 *Such as personal computers with Microsoft Excel or other similar spreadsheets.*

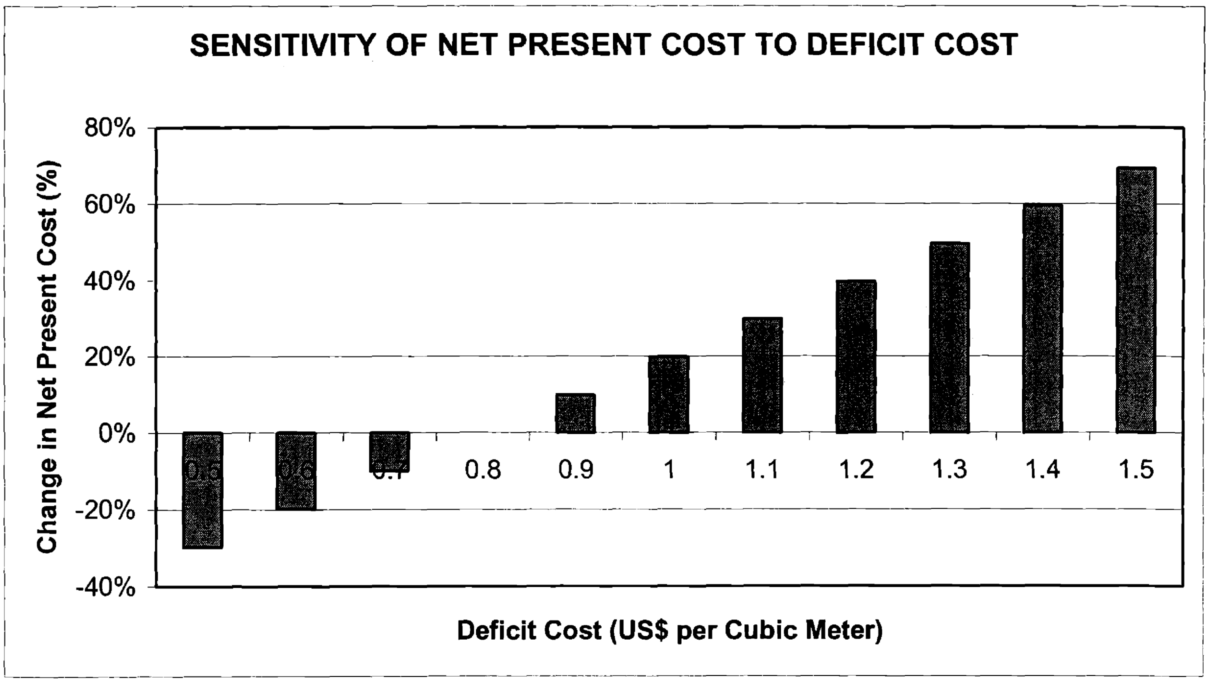

Figure 5.1. Percentage Variation of Net Present Cost for Different Levels of Deficit Cost.

In practice, the determination of the deficit cost is a difficult undertaking. For the time being, the EAAB estimates this cost at US$0.80 per cubic meter of unmet demand, assuming that the deficit cost is about two times the average cost of delivering water. Given the impact of this parameter on the project evaluation results, the EAAB could invest some resources and time into a more precise evaluation of this cost.

Chapter 4 showed that besides from the disadvantages mentioned above, the Net Present Value Technique neither takes into account the value of flexibility, nor allows the identification of an optimal strategy, when dealing with a portfolio of projects. The only information a NPV analysis gives is a point-estimate of the project's value, under the assumptions defined by the analyst. NPV does not indicate whether a higher project value could be obtained by altering the proposed strategy, or incorporating certain flexibility in the designs of the project.

Sensitivity, scenario and Monte Carlo analysis correct some of the shortcomings of plain NPV; they create awareness of the project's risks and uncertainties, identify the critical variables and the way in which they affect the expected value of the project. In short, they suggest a better point estimate of the project's expected value. But they have two shortcomings:

- They do not take into account the value of flexibility.
- They do not provide a strategy, only a point-estimate and a probability distribution of the project's value.

These criticisms about NPV do not in any way suggest that this approach should be abandoned as a capital budgeting technique. NPV, when used in conjunction of Monte Carlo, sensitivity and scenario analysis is a very useful way to obtain a quick understanding of a project's value distribution. But, more complex methods are needed to find the strategies that optimize the value of the project or portfolio being analyzed. Even more, as Chapter 4 showed, building a DCF model is a necessary step for the development of more complex analyses such as DA and ROA.

5.2.2. Decision Analysis

Decision Analysis is a tool that builds upon the results of Net Present Value. As it is usually applied, DA is a practical way of doing scenario analysis over a predetermined base case of a project's value. With DA the analyst determines the more relevant uncertain variables, sets up all possible scenarios for these uncertainties, finds the Net Present Value for each scenario, and then calculates the expected value of the project as a whole as a weighted average of each scenario's NPV and its probability of occurrence. As in NPV, one of the main assumptions in the DA approach is the choice of discount rate. In addition, DA also has to make assumptions about the probability of occurrence of each scenario. Many times there is not enough information available to scientifically determine these probabilities, so the analyst has to use whatever knowledge he has of the system and its intuition.

The main advantage of Decision Analysis is that it clearly identifies an optimal strategy for any given combination of the possible states of nature of each uncertain variable. In the study presented in the previous chapter, decision analysis allowed the identification of an optimal timing schedule for the construction of the Chuza Norte, Chingaza Sureste and La Playa projects given different evolution paths of the demand growth rate.

It is important to notice that DA can be structured to deal with multiple sources of uncertainty. For example, Figure 5.2 shows a fragment of the decision tree for the expansion of the Chingaza system, considering the supply capacity of the existing system. DA can also be used to value other options such as abandoning the projects during construction or anytime during operation and temporarily shutting down facilities. An example of how this can be incorporated in the analysis is shown in Figure 5.3. Both of these refinements increase the complexity of the problem. In fact, one of the main disadvantages of the decision analysis approach is that since it relies on laying out absolutely all of the possible scenarios, it easily becomes very cumbersome to solve. As mentioned in the previous chapter, the evaluation of the EAAB's water supply expansion portfolio, taking into account just one source of uncertainty, five periods of time and simple go/ no-go decisions in each period, ended up having more than 23,000 paths in the final tree.

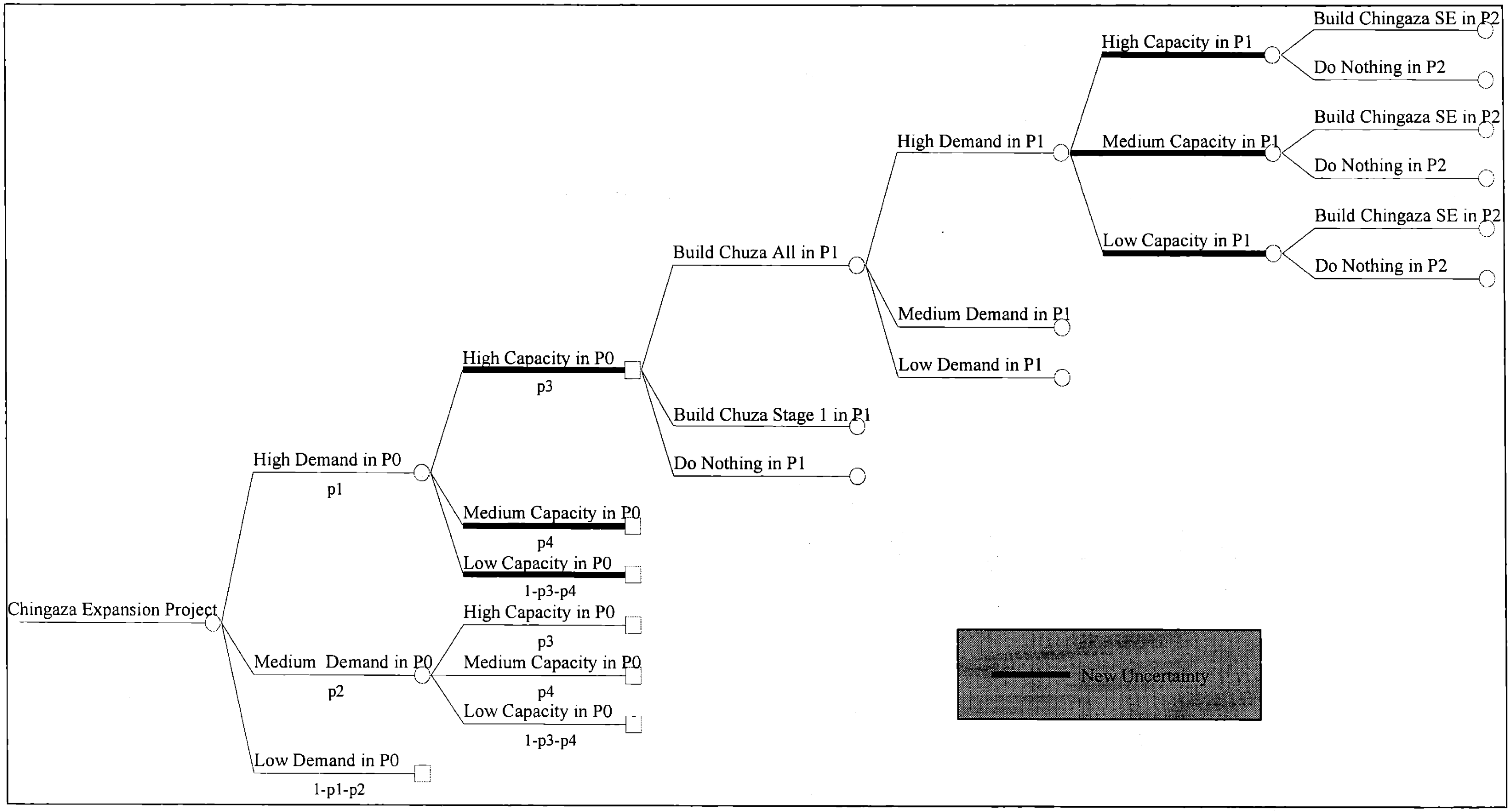

Figure 5.2. Decision Tree Structure Taking Into Account Demand and Supply Uncertainties

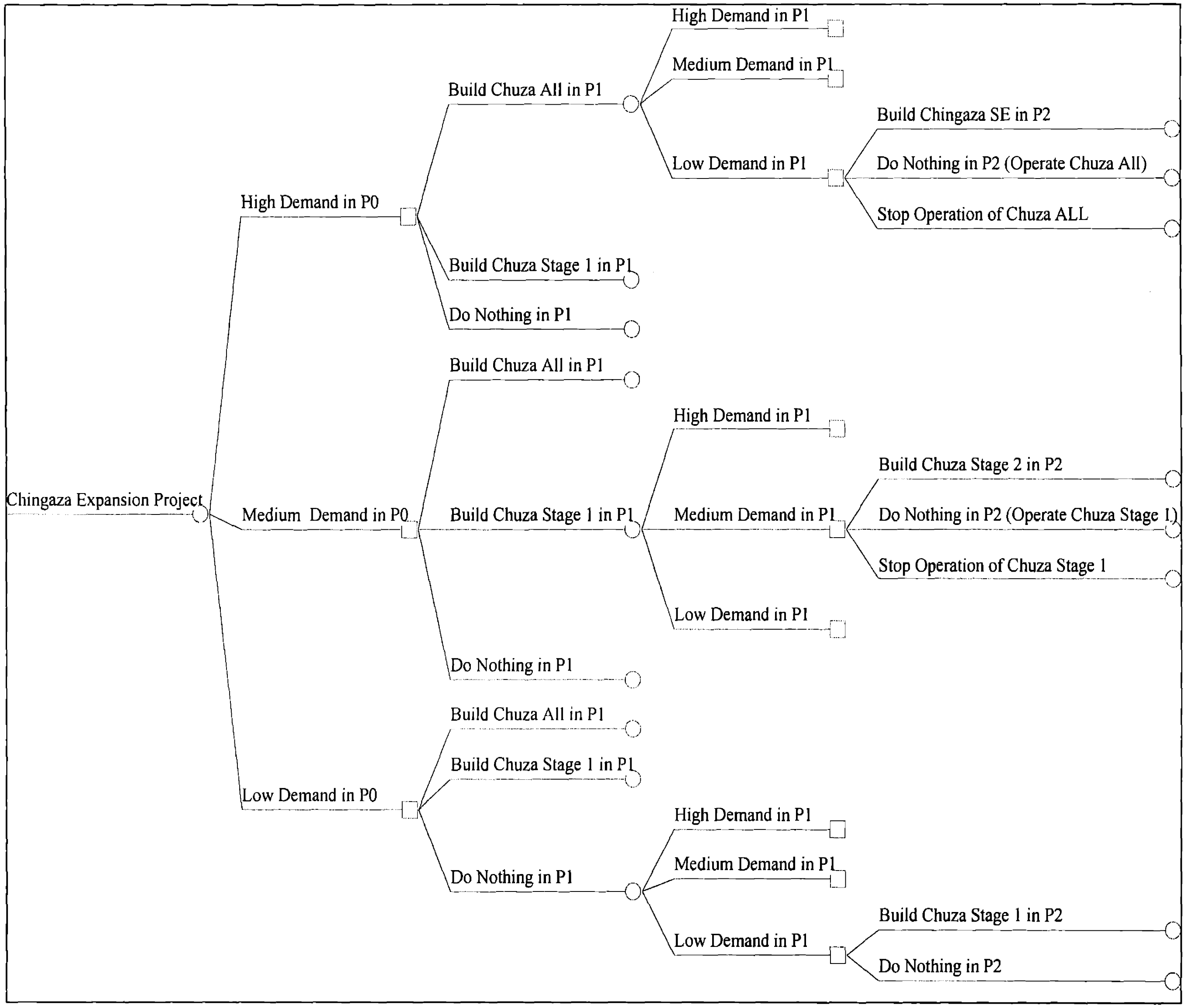

Figure 5.3. Decision Tree Structure With Shutting Down Option

For a problem like this, the use of specialized decision analysis software becomes mandatory. The EAAB's access to this type of software is very limited, not because of budget constraints (since the software itself is not that expensive) but because the packages are not commercialized in Colombia, and the engineers and economists in the EAAB do not know about their existence.

Assuming that the EAAB could acquire one of these software packages, the process of structuring and solving the tree would be greatly simplified, but other problems relating to the size of the tree would remain. To start, the mere size of the tree increases the probability of overseeing errors, and the software packages available in the market do not have algorithms that facilitate the revision of the model. Thus, the revision of the model becomes a complex and long task. Second, when the number of nodes and branches in the decision tree is low, the graphical representation of the decisions, which lies at the heart of the DA approach, is extremely powerful and useful. But, as the complexity of the tree increases, the graphical representation becomes more a disadvantage than an advantage. Even finding a certain path in the tree might become very hard, whether it is on the computer screen or on a multiple-page printout of the tree. Finding the optimal strategy for the path that was identified is harder still.

In any case, even with the disadvantages mentioned above, a careful analyst, with the appropriate tools should be able to develop this approach for any project within the EAAB, and obtain a set of robust and coherent results, since the concepts underlying DA are basically the same as those in an NPV analysis.

In reality, the main weakness of decision analysis lies not in its complexity, but precisely in the theory that it relies on: expected value pricing. The most relevant problems of this theory were discussed in detail in Chapter 2. The two most relevant issues emerging from that discussion are highlighted here. First, Decision Analysis uses a constant discount rate through the life of the project, when in reality the risk of the project changes with time, and with the different scenarios being considered, and the discount rate should reflect this.

Second, as Net Present Value, Decision Analysis is an expected value pricing technique. Because of this, the value of flexibility derived from a DA model may not be completely accurate.

Developing a Monte Carlo simulation for each scenario in the decision tree and using these values to calculate the payoffs instead of the values from the basic DCF model can correct this problem.

The inaccuracies in the value of flexibility can become a serious drawback of the DA model if the EAAB intends to use this estimated value of flexibility to make a decision on how much to pay for it. In this case, relying on the DA estimate can lead the EAAB to waste resources by paying too much for an option that is really worth less. But, if the objective of the DA model is to determine the optimal strategy for the EAAB to follow, then the exact value of flexibility is not as important, as the mere recognition of the options available, and the comparison of the project's value in the different scenarios using the identified flexibility.

5.2.3. Real Options

Compared to DA, Real Options Analysis has almost the contrary advantages and disadvantages. To start, if the theory behind Decision Analysis is simple to understand or almost intuitive for engineers, the theory behind Real Options is complex and almost completely unknown to them. This implies that the analysis is not only difficult to develop, but that its results are hard to trust, since the mechanisms used to obtain these results are not clear to the analysts or decision makers.

On the other hand, one could say that once the theory is understood, the application of the methodology to complex problems such as the one presented in Chapter 4, is fairly straightforward. First of all, it can be setup easily in an Excel spreadsheet, without the need for any additional software. Second, ROA allows the incorporation of many sources of uncertainty without increasing the complexity of the calculations, since these uncertainties can be combined into one single measure of volatility. Third, the incorporation of additional time periods, or additional options also does not really increase the complexity of the calculations, as happens in DA.

An additional advantage of the ROA methodology is that its results can be much more clearly presented than the DA results. One compacted decision tree shows how much the option is worth for every state of the underlying asset and whether or not it should be exercised. .

Finally, Real Option analysis has the additional advantage, at least in theory, that it gives a better estimate of the value of flexibility in the project or portfolio at hand, since it prices it through the non-arbitrage condition and not through expected value. In practice, the results from Real Options may be as far off from reality as the results from Decision Analysis due to the assumptions that have to be made regarding the following variables:

- Underlying Asset: The underlying asset is the variable on which the price of an option depends. In financial options, the underlying asset is a security, such as a share of stock, or a bond. Because these assets are traded in the market, their price and rate of return's volatility can be easily observed. In real options, the underlying asset is a tangible asset, such as a project. The price of this asset and the volatility of its rate of return are not so easily identifiable, since in general the asset is not openly traded in the market. In this case it is assumed that the underlying asset is the value of the project's deficit, without flexibility, but even this value is hard to determine with precision.

- Volatility of the Underlying Asset: The volatility of the underlying asset is also hard to determine. As was explained in Chapter 4, the best way to do so is through a Monte Carlo simulation of the rate of return of the underlying asset. To develop this simulation, strong assumptions about the probability distributions of the uncertain variables have to be made.

- Risk-free Rate: Even if this is easier to do than picking a discount rate, its determination still involves a process of "guessing", especially for markets outside the US, where bond rates are not monitored as strictly, and when the country risk has to be taken into account.

- Option payoffs: Finally, estimating the option payoffs is not a straightforward task either, at least in the EAAB. In this situation, the value of the option lies in its potential to reduce the existing deficit, but this deficit reduction is not constant throughout the different states of nature, so the option payoffs must be modeled as variable, and this increases the complexity of the methodology and decreases its preciseness.

In fact, some authors such as Hubilek and Schacher (1999) and Damodaran (2000) warn practitioners of the dangers of interpreting the results from an option-pricing model when the options are valued over assets that are not traded. Hubilek and Schacher (1999) state:

> It needs to be noted that when applying the Real Options methodology to options over underlying assets that are not traded relying on a non-arbitrage argument may be a fallacy since preferences and subjective probabilities might come into play.

In addition, ROA presents the disadvantage that it is hard to derive an operational strategy from its results. For example, Figure 5.4 shoes that the best decision in node H (Period 4), when the underlying asset has a value of US$495 Million, is to exercise the option. Since the binomial tree is recombining, and the up and down movements correspond to a combination of several sources of uncertainty combined in one measure of volatility, it is very hard to identify the states of the uncertain variable that lead to this asset value, and therefore it is hard to specify an operational strategy from this results.

With Decision Analysis, the strategy was straightforward. For example, it could easily be determined that if demand growth in Period 0 was low, then the best strategy was to build Chuza Norte stage I. In the Real Options case it can be identified that for an asset value of US$495 the option of building Chuza Norte stage II, should be exercised but it is hard to determine to which conditions of demand, supply, and construction times and costs this value corresponds.

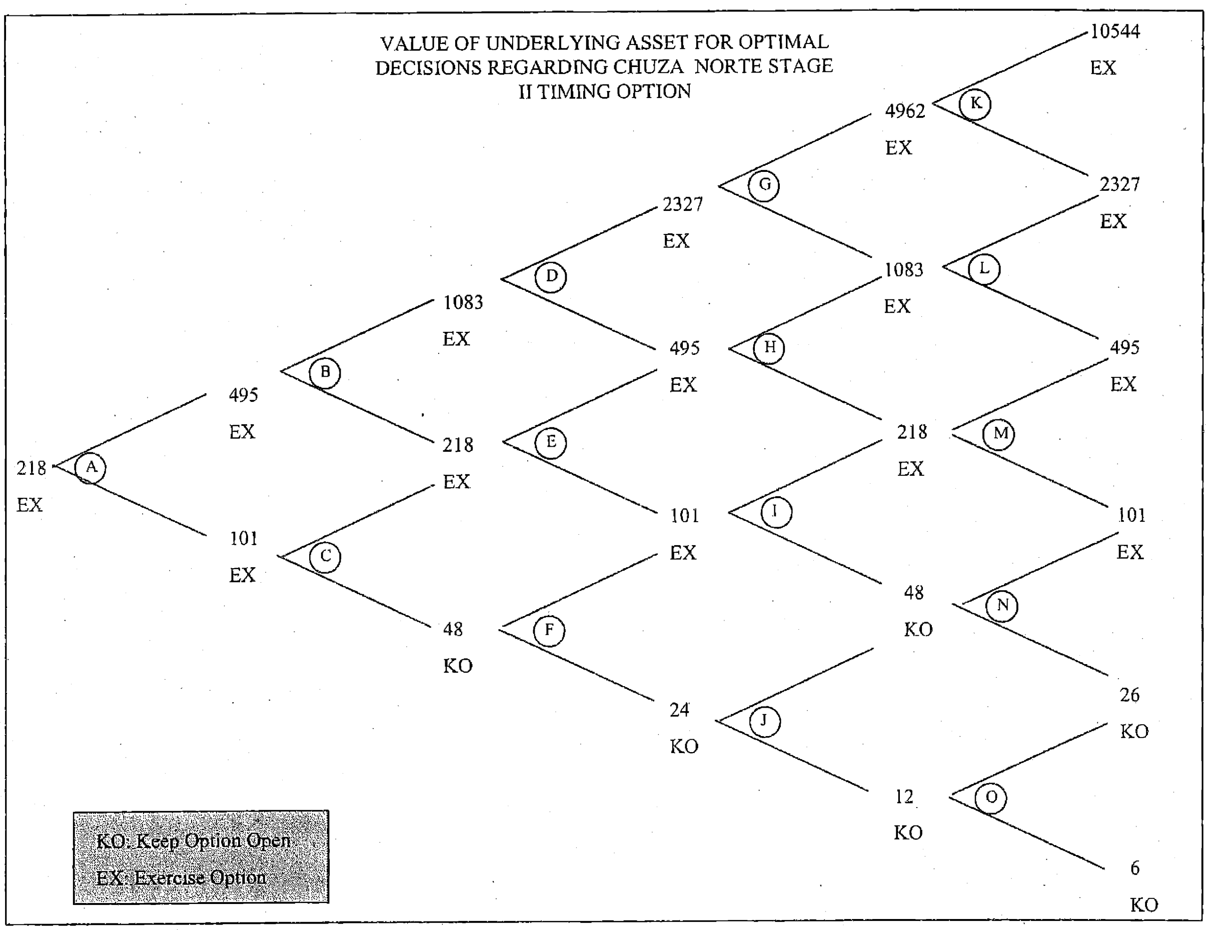

Figure 5.4. Optimal Payoffs for Chuza Norte Stage II Option

ROA does provide a strategy when the value of the underlying asset can be directly observed, as is generally the case, as is generally the case for financial assets and commodities. For example, an investor holding a call option on a certain dividend-paying stock can observe the stock price in the market every day (or practically as often as he wants: every hour, every minute) and make the decision of when to exercise the option. In the case of a non-traded real asset, the value of the underlying asset cannot be directly observed, and its translation to observable variables (such as the development of the demand growth rate) is often burdensome. This has severe implications for the way the EAAB manages its information requirements. With DA it is clear that the EAAB needs to focus on monitoring demand growth, but with Real Options it is hard to know which parameters are more relevant, and thus to identify where the EAAB should focus its investments in information.

5.2.4. Summary

It is clear that one of the main differences between ROA and DA in practice is the kind of assumptions that have to be made to undertake the analysis. As table 5.1 shows, DA makes assumptions about the discount rate, the probabilities for each scenario of the uncertain variables and the project's payoffs. Real Options makes assumptions about the risk-free rate, the volatility and value of the underlying asset, and the option payoffs.

REQUIRED ASSUMPTIONS	
DECISION ANALYSIS	**REAL OPTIONS**
Discount Rate	Risk-Free Rate
Probabilities for each scenario	Volatility of Underlying Asset *and* Value of Underlying asset
Project Payoffs	Option Payoffs

Table 5.1. Comparison of Required Assumptions

These differences are critical, because the choice of which method is more suitable to a certain situation depends to a great extent on the quality of the information available to make each of the aforementioned assumptions. For example, for a financial asset it might be very hard to determine the probability of the asset value being a certain amount, but it might be easier to find the expected volatility of the assets value. On the contrary, in the case of the EAAB it is very hard to find the value and volatility of the deficit cost, while the estimation of the probability following a high, medium or low path can be estimated with a higher accuracy. Chapter 6 presents a framework that will help in deciding when to use ROA or DA based on the quality of the information available.

In the end, whether the methodology used to price flexibility and identify an optimal strategy is Real Options or Decision Analysis is not as important as the mere recognition that there is value to be derived from uncertainty and flexibility. This recognition has several implications on the way the EAAB conducts its affairs. The following section will analyze how the EAAB has to redesign its internal and external processes to enable the implementation of flexible strategies and designs.

5.3. IMPLEMENTATION CHALLENGES

5.3.1. Introduction

In Chapter 4, ROA and DA were applied to the analysis of timing options, but these techniques may also serve to value other type of options such as abandoning construction, contracting production or shutting down a facility, switching inputs for water treatment, and reducing the vulnerability of the project by building redundancies in the system. In general, managers within the EAAB are skeptical about such possibilities. In interviews conducted on January of 2002, most of them agreed that, regulatory issues, legal impediments, and the EAAB's internal resistance to change would halt the implementation of such techniques. This mentality is summarized in one of the EAAB's vice-presidents comments:

> *"The regulatory framework for the sector makes it impossible to think about flexibility. We have a hard time explaining our investment plan and decisions as it is right now to the controlling agencies. If we tell them that we do not*

know which projects we are going to build in the future we would be in for some very serious trouble; they will probably accuse us of not knowing what we are doing, inefficiency, and in the worst case, corruption."

Another vice-president commented:

"Look, the truth is that we are only here for three years at most. Changing the planning mentality will take us more time than that, and nobody will notice. We are measured by what we execute, we need to build things, that is what the mayor wants, what the city council wants, and that is what people notice. See, the water infrastructure is still so far behind what it should be, that any project we build is a step forward. Yes, we know that it is possible to save some resources if we developed a better strategy, but the money is available now, and we do not know if it is going to be available later."

Other managers, as well as engineers from the water supply division, and from engineering consultant companies that work with the EAAB, expressed similar concerns. Summarizing, they seem to believe that the main challenges for the implementation of a capital budgeting technique tat encompasses flexibility, are:

- Legal constraints
- Increased risk for citizens
- Labor inflexibilities
- Rigidity of current planning environment and Static Financial Processes
- Unsuitable internal and external incentives

The following pages present an objective analyses of each of these challenges, trying to understand how real they are and what mechanisms can be put in place to overcome them.

5.3.2. Legal Barriers

A careful analysis of the institutional and legal framework in Colombia indicates that there is no real legal constraint for the introduction of a more flexible and dynamic approach to water supply planning in the EAAB. As Chapter 3 explains, the regulatory framework for the water supply sector is defined by the following legislation:

- Colombian Constitution
- Law 142 of 1994 (partially modified by Law 286 of 1996)
- Law 80 of 1993 (partially modified by Law 689 of 2001)
- Anti-Corruption Statute (Title XXV of the Colombian Criminal Code of Law)

Although each of these elements of the Colombian legislation affect, in one way or another, how the EAAB conducts its investment evaluation processes, none limit its ability to introduce flexibility into these processes.

Colombian Constitution

The Colombian Constitution defines the responsibilities of the central government in ensuring the adequate provision of domestic public services. It identifies the areas where state intervention is justified, and stresses the fact that *"Public services are inherent to the social purpose of the state. It is the duty of the state to ensure their efficient provision to all the inhabitants of the national territory"* (Constitución Política de Colombia, 1991, art. 365).

The Constitution also determines that *"The law will determine the duties and rights of users, the regime of their protection, and their form of participation in the management and funding of the state enterprises that provide the service. Similarly, the law will define the participation of the municipalities or their representatives in the entities and enterprises that provide domestic public services. It is the responsibility of the President of the Republic to stipulate, subject to the law, the general policies of administration and efficiency control of domestic public services and to exercise through the Office of the Superintendent of Domestic Public Services the control, inspection, and supervision of the entities that provide them."* (Constitución Política de Colombia, 1991, articles 369 and 370).

As Chapter 3 showed, such articles in the Constitution imply that centralized agencies such as the DAPS (from the Economic Development Ministry), the National Planning Department, and the Environmental Agencies, supervise and regulate the development of the water supply sector. As a consequence, the EAAB cannot independently set the water supply policies it deems convenient. These policies have first to be approved by the appropriate centralized agency and then they can be executed by the EAAB.

In practice, the centralized agencies are concerned primarily with avoiding a water deficit, so their supervisory power is reflected in the setting of a maximum deficit criterion. This criterion reflects the maximum deficit probability that is allowed, and all regional water companies have to design their water supply master plans to comply with this requirement. The notion of a maximum probability for the deficit does not undermine the ability of the EAAB to follow a flexible approach to capacity planning. It only means that this becomes one additional constraint for the system, and only those strategies complying with this maximum probability of deficit will be taken into account. The compliance with the maximum deficit criterion can also be guaranteed by increasing the deficit cost to such a level so as to make strategies that comply with the maximum deficit optimal.

The articles in the Constitution also allow the central government to intervene in the planning processes of regional water companies when the evidence of economies of scale makes it clear that two or more utilities should come together for the development of a certain project. Again, this power of the centralized agencies does not diminish the need or the capacity of the EAAB to conduct its capacity planning exercises accounting for flexibility. It only implies that the supply and demand parameters in the evaluation change to encompass the new region, but the approach, and its rationale, remain as robust and needed as before.

Law 142 of 1994 and the Tariff Setting Procedures

Law 142, enacted in 1994, established a specific legislative and regulatory framework for the water sector, emphasizing in the efficiency of service provision through the introduction of competition and private sector participation. This law covers a wide range of issues pertinent to the operation of both public and private companies in the country. Nevertheless, the aspects more relevant to our study are those related to the tariff setting procedures, as described in articles 87, 90 and 92[16]. Their highlights are:

- Tariffs for state-owned utilities should be determined as to cover all operational, maintenance and administrative costs, assuming the company operates under the efficiency standards defined by the relevant regulatory commission (the CRA in the water sector case), but not allowing for any profit[17].

- Tariffs will also compensate the investment cost of expansion projects, as long as these investments follow a minimal expansion cost plan.

- Tariff levels should be enough to allow state-owned utilities to use state-of-the-art equipment, technologies and administrative systems, whenever these will help improve the quality, continuity and reliability of the service.

- Tariffs should be set following the principles of efficiency, financial sustainability, neutrality, solidarity and transparency. The dominant principles

16 *The complete text of these articles can be found in Appendix B. None of the relevant articles were modified with the enactment of Law 286 of 1996.*

are those of efficiency and financial sustainability. In no case should tariff levels violate these principles by transferring to the consumer the costs of inefficient operation, nor be too low as to drive an efficient company into financial distress.

- Each tariff should relate to a certain service coverage and level. Any changes in these conditions should be reflected in a tariff change.

In general, the spirit of the law was to use tariffs not only as an instrument for cost recovery, but also as pressure for the improvement of operational and administrative efficiency in all utilities. The law specifically states that the costs of inefficient operation cannot be transferred to the consumer, and that all expansion has to be based on the minimal cost criterion. The introduction of a capital budgeting technique does not in any way contravene these objectives. In fact, it can be said that it reinforces them. Nevertheless, managers within the EAAB seem to have the idea that a flexible approach does not comply with the minimal cost criterion mandated by the law, as can be observed from the following statement:

> *"...building flexibility has a cost, then this in its own is enough to show that we would not be following the minimal cost criterion. For example, if we build 3 or 4 smaller treatment plants instead of one big one, the total cost will be higher in the first case..."*

The flaw in this argument lies in the fact that under uncertainty there is no assurance that one plan will fit the minimal cost criterion for all possible states of nature. In reality, as was seen in Chapter 5, the minimal cost alternative changes for the different scenarios. So, theoretically, only an approach that takes into account all relevant uncertainties and flexibilities will lead to an overall minimal expansion cost. The EAAB can make the case that the introduction of a dynamic planning technique reinforces the spirit and objectives of the law. But, since the EAAB's decisions will be reviewed by several regulatory and control agencies, it is extremely important

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17 *Tariffs for privately owned utilities allow for a certain profit.*

that the analyses and the framework used to support those decisions are clear and comprehensible to all relevant audiences.

The introduction of a dynamic approach to capital budgeting does pose some theoretical and practical difficulties for the calculation of the investment component of the tariff. Since it assumes that the EAAB does not know for certain which investments it will execute each period, or how much will these investments cost. In practice, the result from acknowledging the uncertainty from the start would not differ much from the actual situation, where the EAAB presents a tariff structure proposal based on the most-likely scenario, and then constantly solicits revisions to this structure to account for variations in that scenario. Figure 5.5 shows the tariff setting procedure currently applied by the EAAB.

The first step consolidates the individual investment plans of each division in a 15-year investment plan that is approved by the EAAB's management team, its board of directors, the Bogotá City Council, the DNP and DAPS. The Corporate Planning Division of the EAAB then determines the corresponding annuity that would be necessary to receive in terms of tariff income to payback the project costs over its economic useful life. This analysis is done on a per-project basis and as explained before, is based on the most-likely scenario projections of total cost. The annuities for all projects are then added, and the EAAB determines the amount of tariff revenues it needs each year to pay for its planned investments. The EAAB consolidates this information with the revenues required to pay for operation, maintenance and administration and presents a tariff structure proposal for a 5-year period to the Water Regulatory Commission (CRA). Every five years, the EAAB revises its estimates, accounting for future foreseen changes, and also correcting for past misalignments of planned versus executed investments.

There is little reason why this approach would not work if the EAAB recognizes the uncertainties from the beginning of the process. The EAAB could continue to present its initial tariff proposal based on what it believes to be the most-likely scenario[18], and revise its projections after a certain period of time.

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18 *As seen in Chapter 4, this most-likely scenario should be determined using Monte Carlo simulation or a similar technique, to really reflect the way in which the project's value may vary with the different uncertainties.*

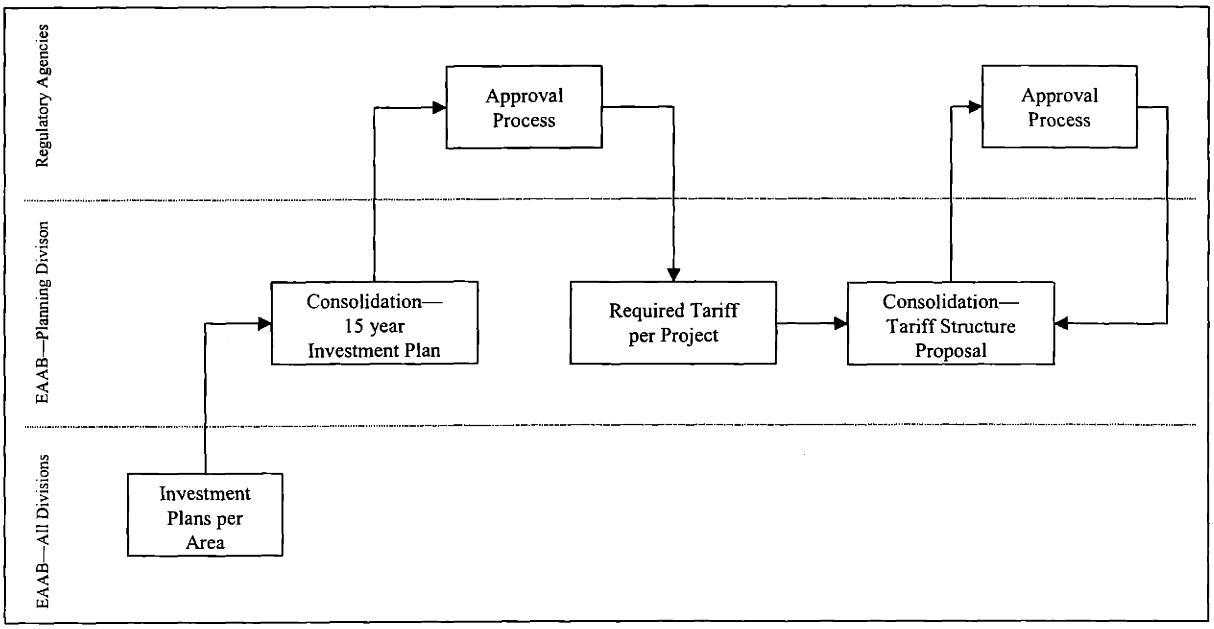

Figure 5.5. Tariff setting procedure (Adapted from EAAB, 2000)

If investments were put-off, or abandoned, then tariffs should be revised downwards, while if they were brought forward in time or scaled-up the tariffs should be revised upwards to account for these extra costs.

In any case it is advisable for the EAAB to align its tariff revision cycle with its planning cycle. In this way, each time management reviews the state of the uncertain variables, and decides on the investment plan for the next 3-year period, it can revise the tariff structure as well. Of course, it may not be optimal to revise tariffs as often as every 3 years, so the EAAB might choose to do so every six. What is most important is that the tariff revision procedures are made often enough to ensure the financial viability of the EAAB and to tranfer any available savings to the consumers as early as possible.

Law 80 of 1993

Law 80 of 1993 (Ley de Contratación Estatal) governs state issued contracts. This law was enacted with the purpose of attaining the principles of transparency, economy and responsibility in all contracts by state agencies. To protect contractors and prevent corruption, this law effectively limited the capacity of state agencies to modify, unilaterally terminate, declare advanced expiration, or interpret a contract. Nevertheless, this only implies that the EAAB must take care when drafting its contracts to include the necessary provisions that will allow them to pursue flexibility options such as abandoning a project during construction, shutting down, scaling-up or scaling-down a facility, but it does not limit either on the use of dynamic capital budgeting techniques, or on the execution of the available options. Moreover, law 80 of 1993 definitely does not affect the implementation of timing options such as the ones analyzed in Chapter 4.

Anti-Corruption Statute

The case of the anti-corruption statute is worth examining in more detail since it does present a relevant challenge to the implementation of certain types of options. One manager when asked about the option of scaling down operations, abandoning a project mid-way through construction or temporarily shutting down one of the water supply facilities, if it was discovered that demand had not evolved as expected, said:

> *"WHAT??? And go to jail? I assure you, there is no single manager within the EAAB, or any public institution in Colombia, who would be willing to consciously abandon a project during construction, even if he thought that continuing would mean putting good money after bad. See, the thing is, you would probably be accused of corruption, and if you were not sent to jail, at least you would be heavily fined."*

Because of the corruption scourge, the Colombian state has been very careful in the definition of all crimes against public administration. These corruption crimes are described in the fifteenth title of the Colombian Code of Criminal Law (see Appendix L for the complete transcription of the title), and include, prevaricate, bribery, misappropriation of public funds, illicit enrichment, authority abuse, misuse of information and influence trafficking, among others. The punishments range from 1 to 12 years of jail, and fines up to US$7 Million[19].

As believed by the EAAB managers, it is true that criminal charges could be brought against them in case of abandoning a project mid-way through construction, or even during operation. The Attorney-General's Office could use a charge of misappropriation or misuse of public funds, as described in the first chapter of the fifteenth title of the Colombian Code of Criminal Law. The most serious charge that could be brought against them is that of "Peculado Culposo", which is applied to any public servants whose actions may lead to damages, or value loss to public assets.

In fact, jurisprudence relevant to this legislation has some examples of public officers charged with peculate and patrimonial detriment, in situations similar to those the EAAB could face when implementing certain flexibility options, although it is not clear whether the public servants in those cases were really acting in good faith or not.

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19 *This value corresponds to 50,000 monthly minimum wages*

In fact, the existence of the anti-corruption statute does not constitute in itself a legal impediment to the implementation of flexibility in water supply expansion projects. The only real consequence of this legislation is that it reinforces the need to develop the appropriate project valuation tools, so as to be able to prove that the options taken are in the best interest of the Bogotá citizens and not an act of corruption. Thus, developing a clear, transparent, simple, and efficient methodology for valuing flexibility and evaluating projects under uncertainty becomes even more relevant than before.

It can be concluded that the current Colombian legislation poses no insurmountable barriers for the adoption of a capital budgeting approach that accounts for uncertainty and the value of flexibility, or for the inclusion of more flexibility into the designs and planning processes of water supply expansion projects. Table 5.2 summarizes the impact of the different relevant legislations and the type of flexibility options they are most likely to affect.

Legislation	Impact	Options
New Political Constitution	Sets limits as to maximum probability of deficit allowed	Timing options
Law 142	Invokes minimal cost criterion	Timing options and other flexibility options such as breaking down projects into smaller components and including redundancies in the design of the system
Law 80	Rigidity in contracts	Abandonment, scaling up or down options
Anti-Corruption Statement	Threat of corruption prosecution	Abandonment options

Table 5.2. Impact of Relevant Legislation and Type of Options Affected

5.3.3. Increased Risk for Citizens

In general, managers at the EAAB, public officials in the Office of the Mayor, and engineers at consultant companies working for the EAAB, believe that a dynamic approach to capacity planning is synonym with increasing the risk of water deficit. Under this understanding it is not surprising that the DNP, CRA and other regulatory agencies reject the idea. But this is a huge misconception. The capital budgeting approaches that account for uncertainty and flexibility, can be defined for any level of risk that the EAAB and the centralized planning agencies wish to cope with. And as for flexibility, if anything, it reduces both the vulnerability of the system (therefore reducing the risk of a water deficit) by improving its capacity to react rapidly to unforeseen events, and the required expenditures by rationalizing the excess capacity in the scenarios in which this capacity is not needed.

Thus, a methodology such as DA or ROA allows the EAAB to identify, understand, and proactively manage the risks of their business, according to any criteria that they deem reasonable. For example, in the case study presented in the previous chapter, the deficit cost can be set at different levels that relate to different deficit probabilities.

5.3.4. Labor Inflexibilities

Any management team of the EAAB must work within the limits set by the Labor Union Agreement[20]. This agreement not only raises labor costs considerably over the average for the industry, but it severely constrains management's ability to manage the company's human resources. For instance, the Labor Union Agreement fixes staff numbers for each division of the EAAB, determines Human Resources Processes such as recruiting, training, dismissing, performance evaluations and personnel planning, and sets overtime policies and performance incentives. The Labor Union Agreement has been in place for the past 55 years and has hardly changed, except for a notorious increase in employee' benefits. Therefore, the policies and procedures set in this agreement are obsolete and rend all change processes within the EAAB enormously difficult, since they pose great challenges to the change of the company's human resources.

Specifically interesting to the case of embedding flexibility in the design of water supply facilities is the fact that the rigidity of the staff numbers and the firing procedures limit the value of some options like abandoning, shutting down or scaling down a facility, since, in the best

[20] *Of course management can try to change the Labor Agreement, but this task, apart from being very difficult, is also not the focus of the thesis so we will not contemplate this possibility.*

case, the human resources cost will still have to be incurred, and it might not even be possible to shut down one of this facilities if there is nothing else to do with the staff employed in it. One EAAB manager stated:

> *"Yes, we realize that many times the optimal decision should be to shut down the production of a certain facility, we know that, but the EAAB's labor inflexibilities make this decision impossible."*

Another important implication of the labor inflexibility is the very low turnover of human resources in the company. This makes it hard for the EAAB to reinvent itself, or even to introduce new techniques, procedures, analysis in any area of the organization, since the organization's employees do not have the knowledge or capabilities to do so. The average time of employment in the EAAB today is 15 years. Most employees have been working for a long time in the company, most of them without attending any training courses, or relating to professional groups in their areas, so they rarely have the opportunities to innovate, or incorporate state-of-the-art techniques and procedures. This fact poses some challenges to the introduction of a new capital budgeting technique, challenges that could be surmounted by the development of a good training and information program to create awareness about the importance of this change and to prepare employees for its implementation.

Finally, the organizational structure of the EAAB also complicates the process of managing projects holistically, as part of a portfolio, since the responsibility for the planning process of water supply capacity is spread out among different units of the water company (Planning, Technical and Operational), which rarely communicate among themselves. If the EAAB wants to benefit from an integrated planning process it has to improve the communication between its organizational units.

5.3.5. Rigidity of Current Planning Environment and Static Financial Processes

In the past, the EAAB has regarded the decisions concerning the expansion of the water supply system as a mere capacity planning exercise, an engineering-dominated task. The EAAB's current planning process clearly emphasizes in robustness and not in flexibility. The process does not account for the major uncertainties in the environment, does not evaluate risks associated with these uncertainties, and therefore does not value flexibility.

The approach deals with uncertainty of demand by forecasting, setting reserve margins and optimizing or fitting a capacity expansion plan against the selected scenario. The process is completely deterministic; it does not take into account the uncertainty associated with the decision environment. The defined scenarios are treated as reality, thus creating an illusion of certainty over the numbers, which is completely mistaken. Moreover, the process assumes that investments are irreversible and cannot be shifted over time. Finally, future developments of the investment being analyzed are also not taken into account in this framework. Therefore the EAAB undervalues the investments that have future growth or abandonment opportunities.

The only risk that the EAAB takes into account in the planning of water supply projects is deficit risk. In fact, the whole strategic planning process for the water supply division is driven primarily by this criterion. Although the consideration of the deficit risk is in itself a good aspect of the planning process, since this is definitely the most relevant risk both as perceived by the EAAB and the consumers, the way in which the risk is considered leads to sub-optimal decisions in the investments. The main issue is that the deficit risk is considered deterministically, therefore leading the water supply division to plan its future investments on a worse case scenario basis. As was discussed in Chapter 2, such approach to planning has two main drawbacks: it does not effectively reduce all supply risks and it increments the economic risks of the system. The supply risk is not completely eliminated for various reasons:

- The EAAB does not have the economic resources to build its investments for the worst possible scenario; some risk is in fact accepted

- The focus of the attention is on the availability of water, but other parts of the system, such as the conduction and distribution networks, remain highly vulnerable and might affect the actual supply of water to the consumers as shows the example in Box 5.1.

- The system is not designed to deal with unforeseen or even gradual changes—the mentality is focused on large, rigid, state-of-the-art water supply facilities, that cannot be adapted easily to changes in the demand and supply conditions

Box 5.1.
For the past 10 years the Bogotá water supply system has had an average excess capacity of 30%, but the system is still highly vulnerable to terrorist attacks and unforeseen failures of the conduction tunnels. For example, during July of 1994 a collapse in the Chingaza main conduction tunnel almost caused severe water rationing in the city. The water was available at the source, but the vulnerability of the distribution system, made it impossible to get it to the consumers.

Economic risks derive from the fact over-estimates of demand and over capacity tie up scarce capital, and increase the probability of investors not recovering their investments. If demand growth were not as high as expected, tariff revenues would not cover investment costs, and the EAAB might run into financial difficulties.

In fact, this is exactly what happened in the 1980s. After some years of heavy infrastructure investments, the company simply could not raise enough revenues to repay its financial obligations, to the point that the city government had to bail it out if these difficulties. The economic risks may also be translated to the consumers in terms of higher water prices (since the investment cost has to be spread out over less output) or less investment in other critical areas such as sewerage or water treatment.

The other guiding principle for the EAAB's capacity planning process is the notion of expansion at minimal cost. Of course, as seen before, under conditions of uncertainty it is hard to know which is the minimal cost approach, but the EAAB firmly believes in economies of scale, and seeks to build facilities that under the projected demand and supply scenarios, have the lowest possible unitary cost. In any case, the reliance of the EAAB on these two criteria: minimize deficit and minimize unitary cost, coupled with other internal and external incentives has led the EAAB to build water supply facilities which are generally considered as state-of-the-art facilities in engineering terms, but often not optimal in economic terms. By focusing on robustness, the EAAB guarantees a result that is optimal in the anticipated future, but not necessarily optimal in the actual future.

In this planning environment it is in effect very difficult to take advantage of the value created by flexibility. The EAAB needs to switch from this deterministic perspective to a dynamic planning approach, focusing on the concepts of decision analysis under uncertainty and project portfolio optimization. In short, the EAAB needs to embrace option thinking at all levels of planning in the organization. Changing the capital budgeting techniques for the analysis of water supply expansion projects is a first step in this direction. By analyzing the investment projects under this new lens, the EAAB will not only gain valuable insight as to the advantages of flexibility, and the benefits of systematically considering uncertainty in their analysis, but it will begin to build the capabilities required to diffuse these tools throughout the organization.

These capabilities include:

- Portfolio Analysis and Management
- Decision Analysis Theory
- Probability and Statistics
- Simulation Techniques and Sensitivity Analysis

To succeed in this undertaking, the EAAB must not only acquire these capabilities, it must also improve the quality of the information available to decision makers, since, as Chapter 4 demonstrated, the results of any project evaluation tools are completely dependent on the quality of the information available to the analyst.

Also, to incorporate flexibility in the analysis the EAAB needs to modify its financial planning procedures. Under a flexible approach it cannot be determined exactly how the financing needs are going to be. For example, every path in the decision tree entails a different scenario of financing needs, as does every branch of the binomial tree in a Real Options analysis. Thus the EAAB needs to evolve from a financing strategy based on a per-project basis, to negotiating complete lines of credit for the development of the whole portfolio and use the credit according to the real needs. In short, the financing processes need to become dynamic as well.

5.3.6. Unsuitable Internal and External Incentives

One final challenge to the implementation of flexibility in the EAAB is the inadequacy of the performance evaluation mechanisms and incentive systems. These issues have been touched upon briefly in the previous sections but it is useful to summarize them here. In first place, the incentive system internal to the EAAB is considered. On one hand, managers are evaluated in terms of the "financial execution" of their respective areas. This means that there are rewarded based on how much of their proposed budget they actually spend, without any serious consideration as to whether or not the executed investments were adequate in terms of cost, quality and needs served.

On the other hand, all other employees in the EAAB, who are covered by the Labor Union Agreement, are rewarded on the basis of seniority and not on performance. This leads to very low turnover, with the unpleasant consequence of not allowing the incorporation of new employees to the company who are the vehicle for bringing in new ideas and tools, and fresh knowledge of best practices and state-of-the-art procedures.

The management team is also influenced by external incentives, mainly of political nature. These political incentives favor bigger investments (with low flexibilities), which in general are more visible to the communities, and in theory, minimize deficit risk as much as possible. These political incentives are very difficult to change, as are the ones imposed by the Labor Union

Agreement. The solution is to rely on managers who understand why these incentives are inadequate, and are willing to go against them, while at the same time they try to create a new incentive system.

5.4. CONCLUSIONS

There is no question that the incorporation of flexibility in the planning and design processes of the EAAB can greatly improve the value of the company's water supply project portfolio, by better tailoring the development of the supply infrastructure to the real developments of demand and supply. The introduction of this flexibility is not an easy task, and although it faces no legal barriers, it does imply a radical change in the way the EAAB usually conducts business. The successful implementation of such approach will depend, to a great extent, on the choice of the capital budgeting technique used to value the flexibility in each project. Among others, the technique will define how understandable and trustable are the results of the evaluations for the EAAB managers, the control agencies, and the Bogotá citizens; the price the EAAB should pay for the flexibility; and the type of information that should be monitored in order to exercise the optimal strategy.

Both Decision Analysis and Real Options take the value of flexibility into account. Decision Analysis gives a better idea of the strategy that optimizes the value of the project or portfolio, while Real Options Analysis, with the caveat that enough and accurate information about the underlying asset and its volatility is available, gives a better estimate of the value of flexibility. In any case, by complementing Net Present Value with a method that takes into account the value of flexibility, the EAAB can:

- Understand that uncertainty is not always a risk to be avoided but a source of valuable opportunities to be exploited

- Adopt a proactive stance towards risk

- Induce far more flexibility into design, whose value can now be determined through these new capital budgeting techniques

From the analyses presented in Chapters 4 and 5 it can be inferred that the differences between ROA and DA are both theoretical and practical. The decision of which technique is optimal will depend to a great extent on the availability of information to conduct each approach, and of course to the purpose of the analysis, as the next chapter will explain.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Capital budgeting techniques are key to the development and management of any project portfolio. These techniques are often the most important tool managers have for decision-making. By virtue of identifying the project's expected value, these techniques help managers decide which projects to undertake, and when to do so. But the identification of a project's value is not a simple task. More often than not, projects are subject to uncertainties that make their valuation more an art than a science. Because traditional capital budgeting techniques are usually unsuited to deal with these uncertain situations, managers frequently resort to their intuition for decision-making.

However, it is precisely when a project's outcome is uncertain, and when management has the flexibility to adapt and revise its decisions in response to unexpected developments in the variables that determine the project's value, that intuition is harder to grasp. In these cases, obtaining an understanding of projects' value for the different possible states of nature can dramatically improve the success probabilities of a company's strategy. Uncertainty makes the capital budgeting process more difficult because its existence implies that neither costs nor revenues can be estimated with precision, therefore there is always a possibility that the estimated project value is wrong. Thus, uncertainty creates risks. But, remember that risk, as defined by the Chinese, means danger as well as opportunity (Damodaran, 2001).

Infrastructure investments not only are subject to high uncertainties (i.e., demand, supply, and cost uncertainties), but their long lead and construction times, long operating lives, long payoff periods, and sequential nature, exacerbate the implications of these uncertainties in the projects' value. The emphasis on building robust systems, as a response to uncertainty is not adequate since it does not effectively eliminate all risks, does not guarantee an overall economically optimal solution, and does not encourage flexibility. As financial and economic resources for infrastructure investments become more limited, it becomes imperative for agencies to broaden their investment planning philosophy from focusing entirely on risk elimination, to becoming a decision-making tool, with the objective of optimizing the social and economic returns of the projects.

Flexibility, the inherent capability to adapt successfully to unforeseen changes (Evans, 1982), allows agencies to tailor their investment strategies to the actual events, not to the *expected* ones, and in this sense it allows them to protect themselves and their consumers against uncertainty's bad side, while at the same time, ensuring a more economically efficient solution, by profiting from its upside when applicable.

In an uncertain environment what investors need, more than a one-point-estimate of the project's value is a strategy that shows the optimal decisions to make for each possible future. Traditional capital budgeting techniques such as NPV, IRR and Payback Period are often inadequate to value investment opportunities, not because they do not take into account uncertainty, but because they neither take into account the value of flexibility nor they neither provide a strategy, but only a point-estimate of the project's value.

This chapter sets forth some recommendations as to which capital budgeting techniques can be used to take into account the value of flexibility and provide an indication of the optimal strategy to follow. The first part of the chapter focuses on those recommendations particular to the EAAB. The second part builds on these results to develop a framework that allows the extrapolation of the results to other areas of infrastructure investment.

6.1. RECOMMENDATIONS FOR THE EAAB

Table 4.8 in Chapter 4 summarized the results from the three approaches, showing the point estimates of the project's value, the value of flexibility and whether or not they provided a strategy. Table 6.1 compares the three approaches in these same terms. This table shows that the only information we obtain from applying the Net Present Value methodology is a point estimate of the project's cost. Flexibility is not taken into account, and an optimal strategy cannot really be determined from the results obtained. Moreover, the point estimate of US$126 Million is probably inaccurate, since it is calculated by plugging in the average (most probable) estimates of all relevant variables in the present cost formula, and thus incurs in the flaw of averages.

		CAPITAL BUDGETING TECHNIQUES		
		Net Present Value	Decision Analysis	Real Options Analysis
OBJECTIVE FUNCTION	Point Estimate of Project Value	YES (US$126M)	YES (US$126M)	NOT CLEAR
	Obtain Strategy	NO	YES	NO
	Price Flexibility	NO	YES (US$248M)	YES (US$93M)

Table 6.1. Proposed Framework for deciding between ROA and DA

A more precise estimate of the project cost is the one obtained through the Monte Carlo simulation. This methodology corrects the flaw of averages; it estimates the expected present cost of the project, by randomly taking into account different probable values of the relevant variables (e.g., demand growth, production yield, project costs). In this case, the expected value of the function is US$374 Million. Bearing in mind that the results here presented are stated in terms of present costs, the NPV methodology (function of the expected values) gives a higher estimate of the project's value than the Monte Carlo simulation (expected value of the function), thus confirming Jensen's inequality:

$$\varepsilon[f(x)] < f(\varepsilon[x])$$

The Monte Carlo simulation creates awareness of the project's risks, by identifying the probability distribution of the project's value and it even gives a much accurate point-estimate of this value. Nevertheless, Monte Carlo neither takes into account the value created by flexibility nor gives information about the optimal strategy to follow in the different possible future states.

Decision Analysis, takes into account the value of flexibility. In this case, DA accounts for the fact that the EAAB management does not have to pre-commit to building the complete expansion of the Chingaza system, but that it can time the investments according to the evolution of demand growth, and in some cases might not even need to build some of the sub-components of the system. The value of the flexibility in the timing of the projects amounts to US$248

Million. Note that DA also gives a point-estimate of the project's costs, which in this case amounts to US$126 Million. Although this number is the same as the NPV's estimate of the project cost, this does not mean that the NPV is right. The coincidence is merely numerical. The important comparison is between the value of the project with flexibility (DA estimate) and the *true* value of the project without flexibility as estimated by the Monte Carlo simulation. This difference determines the value of flexibility. In addition to valuing flexibility, DA also identifies the optimal strategy for the different possible futures.

The Real Options approach indicates a value of flexibility of US$93 Million, US$155 Million lower than the DA estimate. The difference between both estimates is due to theoretical differences between the approaches, mainly the consequence of pricing by expected value and pricing by the non-arbitrage condition, and to the different assumptions that are required in each case, as explained in Chapter 5 (see Table 5.1).

In this particular case ROA does not give a point estimate of the project's cost, due to the fact that the underlying asset used in the analysis was assumed to be only the project's deficit. Therefore, the value obtained after the ROA analysis is the value of the Chingaza System deficit cost, but not of its total costs. Another disadvantage of ROA is that although it gives some indication as to when each project should be built in the different possible futures, the translation of this information to an understandable strategy is hard to do. Specifically, ROA states for which levels of the value of the underlying asset should each option be kept open or exercised. Identifying the particular demand and supply conditions that lead to each value of the underlying asset is a complex task.

To be acceptable as a decision-making tool, a capital budgeting technique must be clear and transparent so that it is understood by managers making the decisions and by regulatory agencies supervising these decisions, accurate enough so these managers have confidence in its results, and simple enough so that the analysis can be performed routinely within the company, and the information required can be gathered at reasonable costs. Under these considerations it seems that as in the leap from theory to practice, ROA loses most of its advantages.

First, the data required for a Real Options Analysis is not easily available for infrastructure projects. The quantity and type of assumptions required for the development of the analysis is such, that the numerical results of the value of flexibility are not necessarily more credible than those of Decision Analysis (even if this methodology may incur in the flaw of averages).

Second, the concepts behind ROA may be intuitive for managers in the financial sector, but are definitely unfamiliar to engineers, and it could be said that might even seem mysterious to lawyers in the regulatory agencies. Given that the EAAB will need to explain clearly its decisions and results to several regulatory agencies, using a methodology to conduct the analysis whose concepts can be easily grasped by these audiences its of supreme importance.

Third, the claim that ROA helps identify an optimal strategy may be true for assets whose value can be directly observed in the market, but is certainly less clear for underlying assets that are not traded, and whose value depends on a complex combination of uncertain variables.

Therefore, this thesis recommends the use of Decision Analysis for the evaluation of capacity expansion investments in the Bogotá Water Company. For Decision Analysis to be useful as a decision making tool, the EAAB has to make several changes to its internal procedures and modify its corporate culture to incorporate option thinking. Specifically the EAAB should:

- Invest in information: Monitor demand growth rates, supply capacity of the existing system, and evaluate deficit cost more precisely.

- Align tariff revision cycle with strategic planning process.

- Train employees in capital budgeting under uncertainty, and invest in software tools that facilitate these processes.

- Unify responsibility for planning process in one division to enable holistic management of capacity expansion project portfolio.

6.2. GENERALIZED FRAMEWORK

The methodology recommendation for the EAAB presented in the previous section is based on the results of the system study, the analysis of the EAAB's institutional framework and the theoretical review of the three capital budgeting techniques. Although, this recommendation is somewhat specific to the EAAB, it can be extrapolated to other geographies and to other areas of infrastructure investments under uncertainty.

On one hand, there is no reason to believe that the results here presented are geographic-specific. Whether in Colombia, or anywhere else in the world, the challenges to the implementation of ROA for water supply capacity planning remain the same. First, water is a non-traded input and therefore the value of the underlying asset will be equally hard to estimate anywhere. Second, the existence of various sources of uncertainty determining demand and supply for water will always make it harder to translate the option decision trees into a strategy. Third, even in industrialized countries, such as the US, or others in Europe, Real Options remains largely unknown in the engineering profession. In general, for the exercise of capacity planning in water utilities, Decision Analysis is a more appropriate tool than Real Options Analysis.

The extension of these recommendations to other areas of infrastructure investment is somewhat harder than the geographical extrapolation, since the optimal capital budgeting technique choice is very specific to the project being assessed. For example, for the exercise of capacity planning in electrical utilities DA might be a better methodology since the issues are largely similar to those of water utilities: several uncertainties and need for a clear strategy. Nevertheless, electricity is a traded input, therefore, an electrical utility trying to find the value of a specific flexible technique to determine whether or not is worth it, might be better off by performing a Real Options Analysis since the answer may be more accurate given that there is historical market information on the value of the underlying asset.

Similarly, in the analysis of the development of an oil field or an oil distribution system, since the underlying asset is traded and enough historical information is available to determine its value and volatility. The analysis of a toll road is another interesting example, in this case, even if the underlying asset is not traded, the relevant uncertainties can be combined in one single parameter, the traffic level, which is easily observable at any point in time. Therefore, the option decision tree resulting from the ROA can give a clear indication of the optimal strategy. However, the availability of information to accurately value the underlying asset will be highly country dependent, and therefore, in some cases DA will be more advisable than ROA and vice versa.

From these considerations it can be concluded that the decision between ROA and DA for valuing flexibility in infrastructure investments depends of two factors:

- Data availability and quality
- Objective function of the analysis

Data availability and quality refers basically to the fact of whether or not there is market information on the value of the underlying asset. A traded asset does not necessarily mean that the asset is traded in the financial or commodities market every day, but that some economic activity exists, and therefore the market value of the asset can be identified. An example is the value of a company, companies are not usually traded, but the Mergers and Acquisitions activity in a certain industry may give an indication of the market value of the company.

Objective function refers to the purpose to which the analysis is being conducted. Two cases are considered: to price flexibility, or to derive a strategy or a dynamic plan to optimise the value of an investment portfolio. Table 6.2 sets forth the recommendations as to when to use ROA vs. DA given the objective function and the quality of the information available.

In general, ROA is a more precise approach to valuing flexibility; therefore as long as good quality information is available, it should be preferred. Also, ROA gives a strategy if the underlying value of the asset can be directly observed or measured in the market. In these cases, ROA presents the additional advantage of being simpler to conduct than DA, in terms of the calculations needed. For the cases where the underlying asset is not traded, and no accurate proxy can be found so the analyst would be better off following a DA approach.

		DATA QUALITY (INFORMATION FOR UNDERLYING ASSET)		
		Traded	Not Traded, but Market Value Proxy Available	No Market Info Available
OBJECTIVE FUNCTION	Obtain Strategy	ROA (Oil Field)	ROA/DA (Toll Road)	DA (Water Utility)
	Price Flexibility	ROA (Electrical Utility)	ROA (Toll Road)	DA (Water Utility)

Table 6.2. Proposed Framework for deciding between ROA and DA

Of course the decision between ROA and DA is also contingent on the capabilities of the agency performing the analysis. The framework described above is based on theoretical considerations of which approach is better. Practical considerations might change the choice of an optimal technique. In any case, no matter the methodology used, the most important lesson to be derived from the issues presented in this thesis is that the introduction (and valuation) of flexibility can radically change the perspectives of investors over a certain project.

As Amran and Kulatilaka (1999) state, *"Real Options are a way of thinking"*. The greatest value of both DA and ROA comes not from the specific results they yield but from the fact that they incorporate strategic behavior issues into investment analysis. But, although the argument that many investments can benefit from flexibility options has great allure, there is a grave danger that this argument will be used to justify poor investments. Not all infrastructure investments have options embedded in them, and not all flexibility options, even if they do exist, have value. Institutions in charge of infrastructure investments need to learn to recognize flexibility opportunities, identify their value and incorporate them into their planning processes and engineering designs only when it is profitable to do so.

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APPENDIX A: EXCERPTS FROM COLOMBIAN POLITICAL CONSTITUTION

TITLE II

CONCERNING RIGHTS, GUARANTEES, AND DUTIES

CHAPTER 3

CONCERNING COLLECTIVE RIGHTS AND THE ENVIRONMENT

Article 78. The law will regulate the control of the quality of goods and services offered and provided to the community as well as the information that must be made available to the public in their marketing.

Those who in the production and marketing of goods and services may jeopardize the health, safety, and adequate supply to consumers and users will be held liable in accordance with the law.

The state will guarantee the participation of the consumer organizations in the study of the provisions that concern them. In order to enjoy this right the organizations must be of a representative nature and observe internal democratic procedures.

Article 79. Every person has the right to enjoy a healthy environment. The law will guarantee the community's participation in the decisions that may affect it.

It is the duty of the state to protect the diversity and integrity of the environment, to conserve areas of special ecological importance, and to foster education for the achievement of these ends.

Article 80. The state will plan the handling and use of natural resources in order to guarantee their sustainable development, conservation or replacement. Additionally, it will have to prevent and control the factors of environmental deterioration, impose legal sanctions, and demand the repair of any damage caused. In the same way, it will cooperate with other nations in the protection of the ecosystems located in the border areas.

Article 81. The manufacture, importation, possession, and use of chemical, biological, or nuclear weapons are prohibited, as is the introduction into the national territory of nuclear and toxic wastes.

The state will regulate the importation and exportation of genetic resources and their use, in accordance with the national interest.

Article 82. It is the duty of the state to protect the integrity of public space and its assignment to common use, which has priority over the individual interest.

Public entities will participate in the profits generated by their urban planning activities and will regulate the use of the soil and the urban air space in order to protect the common interest.

TITLE XII

CONCERNING THE ECONOMIC AND FINANCIAL REGIME

CHAPTER 2

CONCERNING DEVELOPMENT PLANS

Article 339. There will be a National Development Plan consisting of a general plan and a plan of investments of the national public entities. The general plan will include long-term national purposes and objectives, the goals and priorities of intermediate-term state activities, and the strategies and general orientation of economic, social, and environmental policy to be adopted by the government. The public investment plan will deal with the multi-year budgets of the main programs and plans of national public investment and specify the financial resources required for their execution.

The territorial entities will elaborate and adopt in a coordinated manner development, plans with the national government with the purpose of securing the efficient use of their resources and the adequate execution of the functions assigned to them by the Constitution and the law. The plans of the territorial entities will consist of a strategic plan and an intermediate- and short-term plan of investments.

Article 340. There will be a National Planning Council made up of the representatives of the territorial entities and of the economic, social, ecological, community, and cultural sectors. The Council will have a consultative character and will serve as a forum for the discussion of the National Development Plan.

The members of the National Council will be designated by the President of the Republic from lists presented to him/her by the authorities and organizations of the entities and sectors referred to in the previous clause, and who will have to be or will have been involved in the above-noted activities. Their term will be of eight years, and each four years the Council will be replaced in part in the form established by law.

In the territorial entities there will also be planning councils, in accordance with the law.

The National Council and the territorial planning councils constitute the National Planning System.

Article 341. The government will elaborate the National Development Plan with the active participation of the planning authorities, the territorial entities, and the Superior Council of the Judicature and will submit the corresponding plan to review by the National Planning Council; after listening is the opinion of the Council it will proceed to effect those amendments that it considers appropriate and will present the plan to Congress within six months following the initiation of the respective presidential term.

Based on the report that the joint committees of economic affairs draw up, each group will discuss and evaluate the plan in plenary session. Disagreements about the content of the general part, if there are any, will not prevent the government from executing the proposed policies in matters falling under its jurisdiction. However, should the government decide to amend the general part of the plan, it must follow the procedure indicated in the article that follows.

The National Investment Plan will be issued by means of a law, which will take precedence over other laws; consequently, its dictates will constitute mechanisms sufficient for its execution and will supplant existing ones without the need for issuing further laws. Nevertheless, in the annual budgetary laws it will be possible to increase or decrease the shares and resources approved in the planning law. If Congress does not approve the National Public Investment Plan within three months following its presentation, the government may pass it by a decree having the force of law.

The Congress may modify the National Public Investment Plan provided the financial balance is maintained. Any increment in authorizations of indebtedness requested in the governmental plan or the inclusion of investment plans not contemplated in it require the approval of the national government.

Article 342. The corresponding organic law will regulate the drafting, approval, and execution of the development plans and will provide the appropriate mechanisms for the harmonization and alignment of the official budgets with them. It will also determine the organization and functions of the National Planning Council and of the territorial councils, as well as procedures to allow citizens' participation in the discussion of the development plans and the subsequent modifications, in accordance with what is established in the Constitution.

Article 343. The national planning entity stipulated in the law will be responsible for the planning and organization of the systems for the evaluation of the management and performance of the public administration, regarding both policy and investment plans, under the terms that it dictates.

Article 344. The departmental planning organs will evaluate the management and performance of the planning, development, and investment programs of the departments and municipalities and will participate in the preparation of the budgets of the latter within the limits stipulated by the law.

In each case, the national planning organ may, in a selective manner, carry out the evaluation of any territorial entity.

CHAPTER 5

CONCERNING THE SOCIAL PURPOSE OF THE STATE AND OF THE PUBLIC SERVICES

Article 365. Public services are inherent to the social purpose of the state. It is the duty of the state to ensure their efficient provision to all the inhabitants of the national territory.

Public services will be subject to the juridical regime determined by the law, may be provided by the state directly or indirectly, by organized communities, or by individuals. In any case, the state is responsible for the regulation, control, and application of such services. If for reasons of sovereignty or social interest, the state, by means of a law approved by the majority of the members of both chambers upon the initiative of the government, should decide to assign to itself specific strategic or public service activities, it must first indemnify fully those individuals who by virtue of the said law are deprived of the exercise of a lawful activity.

Article 366. The general welfare and improvement of the population quality of life are social purposes of the state. A basic objective of the state's activity will be to address unsatisfied public health, educational, environmental, and potable water needs.

For this purpose, public social expenditures will have priority over any other allocation in the plans and budgets of the nation and of the territorial entities.

Article 367. The law will determine the relative jurisdictions and responsibilities for domestic public services, their provision, quality, and financing, and the schedule of rates, which will take into account the following criteria: cost, cooperation, and the redistribution of revenues.

Domestic public services will be provided directly by each municipality when the technical and economic characteristics of the service and the general benefits of the services indicate it to be possible and advisable, and the departments provide support and coordination.

The law will determine the entities competent to determine rates.

Article 368. The nation, departments, districts, municipalities, and decentralized entities may grant subsidies in their respective budgets so that individuals with lower incomes may pay rates of domestic public services that cover their basic needs.

Article 369. The law will determine the duties and rights of users, the regime of their protection, arid their form of participation in the management and funding of the state enterprises that provide the service. Similarly, the law will define the participation of the municipalities or their representatives in the entities and enterprises that provide domestic public services.

Article 370. It is the responsibility of the President of the Republic to stipulate, subject to the law, the general policies of administration and efficiency control of domestic public services and to exercise through the Office of the Superintendent of Domestic Public Services the control, inspection, and supervision of the entities that provide them.

APPENDIX B: EXCERPTS FROM LAW 142 OF 1994

LEY 142 DE 1994

"Por la cual se establece el régimen de los servicios públicos domiciliarios y se dictan otras disposiciones"

EL CONGRESO DE COLOMBIA

DECRETA:

TITULO PRELIMINAR

CAPITULO I

Artículo 1.- Ambito de aplicación de la ley. Esta ley se aplica a los servicios públicos domiciliarios de acueducto, alcantarillado, aseo, energía eléctrica, distribución de gas combustible, telefonía fija pública básica conmutada y la telefonía local móvil en el sector rural; a las actividades que realicen las personas prestadoras de servicios públicos de que trata el artículo 15 de la presente ley, y a las actividades complementarias definidas en el Capitulo II del presente título y a los otros servicios previstos en normas especiales de esta ley.

Artículo 2.- Intervención del Estado en los servicios públicos. El Estado intervendrá en los servicios públicos, conforme a las reglas de competencia de que trata esta ley, en el marco de lo dispuesto en los artículos 334, 336, y 365 a 370 de la Constitución Política, para los siguientes fines:

2.1. Garantizar la calidad del bien objeto del servicio público y su disposición final para asegurar el mejoramiento de la calidad de vida de los usuarios.

2.2. Ampliación permanente de la cobertura mediante sistemas que compensen la insuficiencia de la capacidad de pago de los usuarios.

2.3. Atención prioritaria de las necesidades básicas insatisfechas en materia de agua potable y saneamiento básico.

2.4. Prestación continua e ininterrumpida, sin excepción alguna, salvo cuando existan razones de fuerza mayor o caso fortuito o de orden técnico o económico que así lo exijan.

2.5. Prestación eficiente.

2.6. Libertad de competencia y no utilización abusiva de la posición dominante.

2.7. Obtención de economías de escala comprobables.

2.8. Mecanismos que garanticen a los usuarios el acceso a los servicios y su participación en la gestión y fiscalización de su prestación.

2.9. Establecer un régimen tarifario proporcional para los sectores de bajos ingresos de acuerdo con los preceptos de equidad y solidaridad.

Artículo 3.- Instrumentos de la intervención estatal. Constituyen instrumentos para la intervención estatal en los servicios públicos todas las atribuciones y funciones asignadas a las entidades, autoridades y organismos de que trata esta ley, especialmente las relativas a las siguientes materias:

3.1. Promoción y apoyo a personas que presten los servicios públicos.

3.2. Gestión y obtención de recursos para la prestación de servicios.

3.3. Regulación de la prestación de los servicios públicos teniendo en cuenta las características de cada región; fijación de metas de eficiencia, cobertura y calidad, evaluación de las mismas, y definición del régimen tarifario.

3.4. Control y vigilancia de la observancia de las normas y de los planes y programas sobre la materia.

3.5. Organización de sistemas de información, capacitación y asistencia técnica.

3.6. Protección de los recursos naturales.

3.7. Otorgamiento de subsidios a las personas de menores ingresos.

3.8. Estímulo a la inversión de los particulares en los servicios públicos.

3.9. Respeto del principio de neutralidad, a fin de asegurar que no exista ninguna práctica discriminatoria en la prestación de los servicios.

Todas las decisiones de las autoridades en materia de servicios públicos deben fundarse en los motivos que determina esta ley; y los motivos que invoquen deben ser comprobables.

Todos los prestadores quedarán sujetos, en lo que no sea incompatible con la Constitución o con la ley, a todo lo que esta ley dispone para las empresas y sus administradores y, en especial, a las regulaciones de las comisiones, al control, inspección y vigilancia de la Superintendencia de Servicios Públicos, y a las contribuciones para aquéllas y ésta.

Artículo 4.- Servicios Públicos Esenciales. Para los efectos de la correcta aplicación del inciso primero del artículo 56 de la Constitución Política de Colombia, todos los servicios públicos, de que trata la presente ley, se considerarán servicios públicos esenciales.

Artículo 5.- Competencia de los municipios en cuanto a la prestación de los servicios públicos. Es competencia de los municipios en relación con los servicios públicos, que ejercerán en los términos de la ley, y de los reglamentos que con sujeción a ella expidan los concejos:

5.1. Asegurar que se presten a sus habitantes, de manera eficiente, los servicios domiciliarios de acueducto, alcantarillado, aseo, energía eléctrica, y telefonía pública básica conmutada, por empresas de servicios públicos de carácter oficial, privado o mixto, o directamente por la administración central del respectivo municipio en los casos previstos en el artículo siguiente.

5.2. Asegurar en los términos de esta ley, la participación de los usuarios en la gestión y fiscalización de las entidades que prestan los servicios públicos en el municipio.

5.3. Disponer el otorgamiento de subsidios a los usuarios de menores ingresos, con cargo al presupuesto del municipio, de acuerdo con lo dispuesto en la ley 60/93 y la presente ley.

5.4. Estratificar los inmuebles residenciales de acuerdo con las metodologías trazadas por el Gobierno Nacional.

5.5. Establecer en el municipio una nomenclatura alfa numérica precisa, que permita individualizar cada predio al que hayan de darse los servicios públicos.

5.6. Apoyar con inversiones y demás instrumentos descritos en esta ley a las empresas de servicios públicos promovidas por los departamentos y la Nación para realizar las actividades de su competencia.

5.7. Las demás que les asigne la ley.

Artículo 6.- Prestación directa de servicios por parte de los municipios. Los municipios prestarán directamente los servicios públicos de su competencia, cuando las características técnicas y económicas del servicio, y las conveniencias generales lo permitan y aconsejen, lo cual se entenderá que ocurre en los siguientes casos:

6.1. Cuando, habiendo hecho los municipios invitación pública a las empresas de servicios públicos, no haya habido empresa alguna que se ofreciera a prestarlo;

6.2. Cuando, no habiendo empresas que se ofrecieran a prestar el servicio, y habiendo hecho los municipios invitación pública a otros municipios, al Departamento del cual hacen parte, a la Nación y a otras personas públicas o privadas para organizar una empresa de servicios públicos que lo preste, no haya habido una respuesta adecuada;

6.3. Cuando, aún habiendo empresas deseosas de prestar el servicio, haya estudios aprobados por el Superintendente que demuestren que los costos de prestación directa para el municipio serían inferiores a los de empresas interesadas, y que la calidad y atención para el usuario serían, por lo menos, iguales a las que tales empresas podrían ofrecer. Las Comisiones de Regulación establecerán las metodologías que permitan hacer comparables diferentes costos de prestación de servicios.

6.4. Cuando los municipios asuman la prestación directa de un servicio público, la contabilidad general del municipio debe separarse de la que se lleve para la prestación del servicio; y si presta mas de un servicio, la de cada uno debe ser independiente de la de los demás. Además, su contabilidad distinguirá entre los ingresos y gastos relacionados con dicha actividad, y las rentas tributarias o no tributarias que obtienen como autoridades políticas, de tal manera que la prestación de los servicios quede sometida a las mismas reglas que serían aplicables a otras entidades prestadoras de servicios públicos.

En el evento previsto en el inciso anterior, los municipios y sus autoridades quedarán sujetos, en lo que no sea incompatible con la Constitución o con la ley misma, a todo lo que esta ley dispone para las empresas y sus administradores y, en especial, a las regulaciones de las comisiones y al control, inspección, vigilancia y contribuciones de la Superintendencia de servicios públicos y de las comisiones. Pero los concejos determinarán si se requiere una junta para que el municipio preste directamente los servicios y, en caso afirmativo, ésta estará compuesta como lo dispone el artículo 27 de ésta ley.

Cuando un municipio preste en forma directa uno o mas servicios públicos e incumpla las normas de calidad que las comisiones de regulación exijan de modo general, o suspenda el pago de sus obligaciones, o carezca de contabilidad adecuada después de dos años de entrar en vigencia esta ley o, en fin, viole en forma grave las obligaciones que ella contiene, el Superintendente, en defensa de los usuarios y para proteger la salud y bienestar de la comunidad, además de sancionar los alcaldes y administradores, podrá invitar, previa consulta al comité respectivo, cuando ellos estén conformados, a una empresa de servicios públicos para que ésta asuma la prestación del servicio, e imponer una servidumbre sobre los bienes municipales necesarios, para que ésta pueda operar.

De acuerdo con el artículo 336 de la Constitución Política, la autorización para que un municipio preste los servicios públicos en forma directa no se utilizará, en caso alguno, para constituir un monopolio de derecho.

Artículo 7.- Competencia de los departamentos para la prestación de los servicios públicos. Son de competencia de los departamentos en relación con los servicios públicos, las siguientes funciones de apoyo y coordinación, que ejercerán en los términos de la ley, y de los reglamentos que con sujeción a ella expidan las asambleas:

7.1. Asegurar que se presten en su territorio las actividades de transmisión de energía eléctrica, por parte de empresas oficiales, mixtas o privadas.

7.2. Apoyar financiera, técnica y administrativamente a las empresas de servicios públicos que operen en el Departamento o a los municipios que hayan asumido la prestación directa, así como a las empresas organizadas con participación de la Nación o de los Departamentos para desarrollar las funciones de su competencia en materia de servicios públicos.

7.3. Organizar sistemas de coordinación de las entidades prestadoras de servicios públicos y promover, cuando razones técnicas y económicas lo aconsejen, la organización de asociaciones de municipios para la prestación de servicios públicos, o la celebración de convenios interadministrativos para el mismo efecto.

7.4. Las demás que les asigne la ley.

Artículo 8.- Competencia de la Nación para la prestación de los servicios públicos. Es competencia de la Nación:

8.1. En forma privativa, planificar, asignar, gestionar y controlar el uso del espectro electromagnético.

Esto es función del Ministerio de Comunicaciones. Decretos 1900 y 1901 de 1990 y 2122 de 1992.

8.2. En forma privativa planificar, asignar y gestionar el uso del gas combustible en cuanto sea económica y técnicamente posible, a través de empresas oficiales, mixtas o privadas.

8.3. Asegurar que se realicen en el país, por medio de empresas oficiales, mixtas o privadas, las actividades de generación e interconexión a las redes nacionales de energía eléctrica, la interconexión a la red pública de telecomunicaciones, y las actividades de comercialización, construcción y operación de gasoductos y de redes para otros servicios que surjan por el desarrollo tecnológico y que requieran redes de interconexión, según concepto previo del Consejo Nacional de Política Económica y Social.

8.4. Apoyar financiera, técnica y administrativamente a las empresas de servicios públicos o a los municipios que hayan asumido la prestación directa, así como a las empresas organizadas con participación de la Nación o de los Departamentos para desarrollar las funciones de su competencia en materia de servicios públicos y a las empresas cuyo capital pertenezca mayoritariamente a una o varias cooperativas o empresas asociativas de naturaleza cooperativa.

8.5. Velar porque quienes prestan servicios públicos cumplan con las normas para la protección, la conservación o, cuando así se requiera, la recuperación de los recursos naturales o ambientales que sean utilizados en la generación, producción, transporte y disposición final de tales servicios.

8.6. Prestar directamente cuando los departamentos y municipios no tengan la capacidad suficiente, los servicios de que trata la presente ley.

8.7. Las demás que le asigne la ley.

Artículo 9.- Derecho de los usuarios. Los usuarios de los servicios públicos tienen derecho, además de los consagrados en el Estatuto Nacional del Usuario y demás normas que consagren derechos a su favor, siempre que no contradigan esta ley, a:

9.1. Obtener de las empresas la medición de sus consumos reales mediante instrumentos tecnológicos apropiados, dentro de plazos y términos que para los efectos fije la comisión reguladora, con atención a la capacidad técnica y financiera de las empresas o a las categorías de los municipios establecida por la ley.

9.2. La libre elección del prestador del servicio y del proveedor de los bienes necesarios para su obtención o utilización.

9.3. Obtener los bienes y servicios ofrecidos en calidad o cantidad superior a las proporcionadas de manera masiva, siempre que ello no perjudique a terceros y que el usuario asuma los costos correspondientes.

9.4. Solicitar y obtener información completa, precisa y oportuna, sobre todas las actividades y operaciones directas o indirectas que se realicen para la prestación de los servicios públicos, siempre y cuando no se trate de información calificada como secreta o reservada por la ley y se cumplan los requisitos y condiciones que señale la Superintendencia de Servicios Públicos Domiciliarios.

Parágrafo. Las comisiones de regulación, en el ejercicio de las funciones conferidas por las normas vigentes, no podrán desmejorar los derechos de los usuarios reconocidos por la ley.

Artículo 10.- Libertad de empresa.- Es derecho de todas las personas organizar y operar empresas que tengan por objeto la prestación de los servicios públicos, dentro de los límites de la Constitución y la ley.

Artículo 11.- Función social de la propiedad en las entidades prestadoras de servicios públicos. Para cumplir con la función social de la propiedad, pública o privada, las entidades que presten servicios públicos tienen las siguientes obligaciones:

11.1. Asegurar que el servicio se preste en forma continua y eficiente, y sin abuso de la posición dominante que la entidad pueda tener frente al usuario o a terceros.

11.2. Abstenerse de prácticas monopolísticas o restrictivas de la competencia, cuando exista, de hecho, la posibilidad de la competencia.

11.3. Facilitar a los usuarios de menores ingresos el acceso a los subsidios que otorguen las autoridades.

11.4. Informar a los usuarios acerca de la manera de utilizar con eficiencia y seguridad el servicio público respectivo.

11.5. Cumplir con su función ecológica, para lo cual, y en tanto su actividad los afecte, protegerán la diversidad e integridad del ambiente, y conservarán las áreas de especial importancia ecológica, conciliando estos objetivos con la necesidad de aumentar la cobertura y la costeabilidad de los servicios por la comunidad.

11.6. Facilitar el acceso e interconexión de otras empresas o entidades que prestan servicios públicos, o que sean grandes usuarios de ellos, a los bienes empleados para la organización y prestación de los servicios.

11.7. Colaborar con las autoridades en casos de emergencia o de calamidad pública, para impedir perjuicios graves a los usuarios de servicios públicos.

11.8. Informar el inicio de sus actividades a la respectiva Comisión de Regulación, y a la Superintendencia de Servicios Públicos, para que esas autoridades puedan cumplir sus funciones. Las empresas que a la expedición de esta ley estén funcionando deben informar de su existencia a estos organismos en un plazo máximo de sesenta (60) días.

11.9. Las empresas de servicios serán civilmente responsables por los perjuicios ocasionados a los usuarios y están en la obligación de repetir contra los administradores, funcionarios y contratistas que sean responsables por dolo o culpa sin perjuicio de las sanciones penales a que haya lugar.

11.10. Las demás previstas en esta ley y las normas concordantes y complementarias.

Parágrafo. Los actos administrativos de carácter individual no sancionatorios que impongan obligaciones o restricciones a quienes presten servicios públicos y afecten su rentabilidad, generan responsabilidad y derecho a indemnización, salvo que se trate de decisiones que se hayan dictado también para las demás personas ubicadas en la misma situación.

Artículo 12.- Deberes especiales de los usuarios del sector oficial. El incumplimiento de las entidades oficiales de sus deberes como usuarios de servicios públicos, especialmente en lo relativo a la incorporación en los respectivos presupuestos de apropiaciones suficientes y al pago efectivo de los servicios utilizados, es causal de mala conducta para sus representantes legales y los funcionarios responsables, sancionable con destitución.

Artículo 13.- Aplicación de los principios generales. Los principios que contiene este capítulo se utilizarán para resolver cualquier dificultad de interpretación al aplicar las normas sobre los servicios públicos a los que esta u otras leyes se refieren, y para suplir los vacíos que ellas presenten.

TITULO V

REGULACION, CONTROL Y VIGILANCIA DEL ESTADO EN LOS SERVICIOS PUBLICOS

CAPITULO I

CONTROL SOCIAL DE LOS SERVICIOS PUBLICOS DOMICILIARIOS

Artículo 62.- Organización. En desarrollo del artículo 369 de la Constitución Política de Colombia, en todos los municipios deberán existir " Comités de Desarrollo y Control Social de los Servicios Públicos Domiciliarios" compuestos por usuarios, suscriptores o suscriptores potenciales de uno o más de los servicios públicos a los que se refiere esta ley, sin que por el ejercicio de sus funciones se causen honorarios.

La iniciativa para la conformación de los comités corresponde a los usuarios, suscriptores o suscriptores potenciales. El número de miembros de los comités será el que resulte de dividir la población del respectivo municipio o distrito por 10.000, pero no podrá ser inferior a cincuenta (50). Para el Distrito Capital el número mínimo de miembros será de doscientos (200).

Para ser miembro de un " Comité de Desarrollo y Control Social", se requiere ser usuario, suscriptor o suscriptor potencial del respectivo servicio público domiciliario, lo cual se acreditará ante la Asamblea y el respectivo Comité, con el último recibo de cobro o, en el caso de los suscriptores potenciales, con la solicitud debidamente radicada en la respectiva empresa.

La participación de un usuario, suscriptor o de un suscriptor potencial en todas las Asambleas y deliberaciones de un "Comité de Desarrollo y Control Social" será personal e indelegable.

Los Comités se darán su propio reglamento y se reunirán en el día, lugar y hora que acuerden sus miembros según registro firmado por todos los asistentes que debe quedar en el Acta de la reunión.

Una vez constituido un comité, es deber de las autoridades municipales y de las empresas de servicios públicos ante quien soliciten inscripción reconocerlos como tales. Para lo cual se verificará, entre otras cosas que un mismo usuario, suscriptor o suscriptor potencial no pertenezca a más de un comité de un mismo servicio público domiciliario.

Cada uno de los comités elegirán, entre sus miembros y por decisión mayoritaria, a un "Vocal de Control", quien actuará como su representante ante las personas prestadoras de los servicios públicos de que trata la presente ley, ante las entidades territoriales y ante las autoridades nacionales en lo que tiene que ver con dichos servicios públicos. Este "vocal" podrá ser removido en cualquier momento por el comité, en decisión mayoritaria de sus miembros.

Las elecciones del Vocal de Control podrán impugnarse ante el Personero del Municipio donde se realice la Asamblea de elección y las decisiones de éste serán apelables ante la Superintendencia de Servicios Públicos.

En las elecciones a que se refiere el presente artículo, será causal de mala conducta para cualquier servidor público y, en general, para cualquier funcionario de una persona prestadora de uno o varios de los servicios públicos a que se refiere la presente ley, entorpecer o dilatar la elección, coartar la libertad de los electores o intervenir de cualquier manera en favor o en contra de los candidatos.

Corresponderá al alcalde de cada municipio o distrito velar por la conformación de los comités.

Artículo modificado por el artículo 10° de la ley 689 de 2001.

Artículo 63.- Funciones. Con el fin de asegurar la participación de los usuarios en la gestión y fiscalización de las empresas de servicios públicos domiciliarios, los comités de desarrollo y control social de los servicios públicos domiciliarios ejercerán las siguientes funciones especiales:

63.1. Proponer a las empresas de servicios públicos domiciliarios los planes y programas que consideren necesarios para resolver las deficiencias en la prestación de los servicios públicos domiciliarios.

63.2. Procurar que la comunidad aporte los recursos necesarios para la expansión o el mejoramiento de los servicios públicos domiciliarios, en concertación con las empresas de servicios públicos domiciliarios y los municipios.

63.3. Solicitar la modificación o reforma de las decisiones que se adopten en materia de estratificación.

63.4. Estudiar y analizar el monto de los subsidios que debe conceder el municipio con sus recursos presupuestales a los usuarios de bajos ingresos; examinar los criterios y mecanismos de reparto de esos subsidios; y proponer las medidas que sean pertinentes para el efecto.

63.5. Solicitar al Personero la imposición de multas hasta de diez salarios mínimos mensuales, a las empresas que presten servicios públicos domiciliarios en su territorio por las infracciones a esta ley, o a las normas especiales a las que deben estar sujetas, cuando de ella se deriven perjuicios para los usuarios.

Artículo 64.- Funciones del "vocal de control". Los vocales de los comités cumplirán las siguientes funciones:

64.1. Informar a los usuarios acerca de sus derechos y deberes en materia de servicios públicos domiciliarios, y ayudarlos a defender aquellos y cumplir éstos.

64.2. Recibir informes de los usuarios acerca del funcionamiento de las empresas de servicios públicos domiciliarios, y evaluarlos; y promover frente a las empresas y frente a las autoridades municipales, departamentales y nacionales las medidas correctivas, que sean de competencia de cada una de ellas.

64.3. Dar atención oportuna a todas las consultas y tramitar las quejas y denuncias que plantee en el comité cualquiera de sus miembros.

64.4. Rendir al comité informe sobre los aspectos anteriores, recibir sus opiniones, y preparar las acciones que sean necesarias.

Es obligación de las empresas de servicios públicos domiciliarios tramitar y responder las solicitudes de los vocales.

Artículo 65.- Las autoridades y la participación de los usuarios. Para la adecuada instrumentación de la participación ciudadana corresponde a las autoridades:

65.1. Las autoridades municipales deberán realizar una labor amplia y continua de concertación con la comunidad para implantar los elementos básicos de las funciones de los comités y capacitarlos y asesorarlos permanentemente en su operación.

65.2. Los departamentos tendrán a su cargo la promoción y coordinación del sistema de participación, mediante una acción extensiva a todo su territorio.

En coordinación con los municipios y la Superintendencia, deberán asegurar la capacitación de los vocales dotándolos de instrumentos básicos que les permitan organizar mejor su trabajo y contar con la información necesaria para representar a los comités.

65.3. La Superintendencia tendrá a su cargo el diseño y la puesta en funcionamiento de un sistema de vigilancia y control que permita apoyar las tareas de los comités de desarrollo y control social de los servicios públicos domiciliarios. Deberá proporcionar a las autoridades territoriales, el apoyo técnico necesario, la tecnología, la capacitación, la orientación y los elementos de difusión necesarios para la promoción de la participación de la comunidad.

Artículo 66.- Incompatibilidades e inhabilidades. Las personas que cumplan la función de vocales de los comités de desarrollo de los servicios públicos domiciliarios, sus cónyuges y compañeros permanentes, y sus parientes dentro del tercer grado de consanguinidad, segundo de afinidad y primero civil, así como quienes sean sus socios en sociedades de personas, no podrán ser socios ni participar en la administración de las empresas de servicios públicos que desarrollen sus actividades en el respectivo municipio, ni contratar con ellas, con las comisiones de regulación ni con la Superintendencia de Servicios Públicos.

La incompatibilidad e inhabilidad se extenderá hasta dos años después de haber cesado el hecho que le dio origen.

La celebración de los contratos de servicios públicos o, en general, de los que se celebren en igualdad de condiciones con quien los solicite, no da lugar a aplicar estas incompatibilidades o inhabilidades.

Artículo modificado por el artículo 11° de la ley 689 de 2001.

TITULO VI

EL REGIMEN TARIFARIO DE LAS EMPRESAS DE SERVICIOS PUBLICOS

CAPITULO I

CONCEPTOS GENERALES

Artículo 86.- El régimen tarifario. El régimen tarifario en los servicios públicos a los que esta ley se refiere, está compuesto por reglas relativas a:

86.1. El régimen de regulación o de libertad.

86.2. El sistema de subsidios, que se otorgarán para que las personas de menores ingresos puedan pagar las tarifas de los servicios públicos domiciliarios que cubran sus necesidades básicas;

86.3. Las reglas relativas a las prácticas tarifarias restrictivas de la libre competencia, y que implican abuso de posición dominante;

86.4. Las reglas relativas a procedimientos, metodologías, fórmulas, estructuras, estratos, facturación, opciones, valores y, en general, todos los aspectos que determinan el cobro de las tarifas.

Artículo 87.- Criterios para definir el régimen tarifario. El régimen tarifario estará orientado por los criterios de eficiencia económica, neutralidad, solidaridad, redistribución, suficiencia financiera, simplicidad y transparencia.

87.1. Por eficiencia económica se entiende que el régimen de tarifas procurará que éstas se aproximen a lo que serían los precios de un mercado competitivo; que las fórmulas tarifarias deben tener en cuenta no solo los costos sino los aumentos de productividad esperados, y que éstos deben distribuirse entre la empresa y los usuarios, tal como ocurriría en un mercado competitivo; y que las fórmulas tarifarias no pueden trasladar a los usuarios los costos de una gestión ineficiente, ni permitir que las empresas se apropien de las utilidades provenientes de prácticas restrictivas de la competencia. En el caso de servicios públicos sujetos a fórmulas tarifarias, las tarifas deben reflejar siempre tanto el nivel y la estructura de los costos económicos de prestar el servicio, como la demanda por éste.

87.2. Por neutralidad se entiende que cada consumidor tendrá el derecho a tener el mismo tratamiento tarifario que cualquier otro si las características de los costos que ocasiona a las empresas de servicios públicos son iguales. El ejercicio de este derecho no debe impedir que las empresas de servicios públicos ofrezcan opciones tarifarias y que el consumidor escoja la que convenga a sus necesidades.

87.3. Por solidaridad y redistribución se entiende que al poner en práctica el régimen tarifario se adoptarán medidas para asignar recursos a "fondos de solidaridad y redistribución", para que los usuarios de los estratos altos y los usuarios comerciales e industriales, ayuden a los usuarios de estratos bajos a pagar las tarifas de los servicios que cubran sus necesidades básicas.

87.4. Por suficiencia financiera se entiende que las fórmulas de tarifas garantizarán la recuperación de los costos y gastos propios de operación, incluyendo la expansión, la reposición y el mantenimiento; permitirán remunerar el patrimonio de los accionistas en la misma forma en la que lo habría remunerado una empresa eficiente en un sector de riesgo comparable; y permitirán utilizar las tecnologías y sistemas administrativos que garanticen la mejor calidad, continuidad y seguridad a sus usuarios.

87.5. Por simplicidad se entiende que las fórmulas de tarifas se elaborarán en tal forma que se facilite su comprensión, aplicación y control.

87.6. Por transparencia se entiende que el régimen tarifario será explícito y completamente público para todas las partes involucradas en el servicio, y para los usuarios.

87.7. Los criterios de eficiencia y suficiencia financiera tendrán prioridad en la definición del régimen tarifario. Si llegare a existir contradicción entre el criterio de eficiencia y el de suficiencia financiera, deberá tomarse en cuenta que, para una empresa eficiente, las tarifas económicamente eficientes se definirán tomando en cuenta la suficiencia financiera.

87.8. Toda tarifa tendrá un carácter integral, en el sentido de que supondrá una calidad y grado de cobertura del servicio, cuyas características definirán las comisiones reguladoras. Un cambio en estas características se considerará como un cambio en la tarifa.

87.9. Cuando las entidades públicas aporten bienes o derechos a las empresas de servicios públicos, podrán hacerlo con la condición de que su valor no se incluya en el cálculo de las tarifas que hayan de cobrarse a los usuarios de los estratos que pueden recibir subsidios, de acuerdo con la ley. Pero en el presupuesto de la entidad que autorice el aporte figurarán el valor de éste y, como un menor valor del bien o derecho respectivo, el monto del subsidio implícito en la prohibición de obtener los rendimientos que normalmente habría producido.

Parágrafo 1. Cuando se celebren contratos mediante invitación pública para que empresas privadas hagan la financiación, operación y mantenimiento de los servicios públicos domiciliarios de que trata esta ley, la tarifa podrá ser un elemento que se incluya como base para otorgar dichos contratos. Las fórmulas tarifarias, su composición por segmentos, su modificación e indexación que ofrezca el oferente deberán atenerse en un todo a los criterios establecidos en los artículos 86, 87, 89, 90, 91, 92, 93, 94, 95 y 96 de esta ley. Tanto éstas como aquellas deberán ser parte integral del contrato y la Comisión podrá modificarlas cuando se encuentren abusos de posición dominante, violación al principio de neutralidad, abuso con los usuarios del sistema. Intervendrá asimismo, cuando se presenten las prohibiciones estipuladas en el artículo 98 de esta ley. Con todo las tarifas y las fórmulas tarifarias podrán ser revisadas por la comisión reguladora respectiva cada cinco (5) años y cuando esta ley así lo disponga.

Parágrafo 2. Para circunstancias o regímenes distintos a los establecidos en el parágrafo anterior, podrán existir metodologías tarifarias definidas por las comisiones respectivas. Para tal efecto, se tomarán en cuenta todas las disposiciones relativas a la materia que contiene esta ley.

Artículo 88.- Regulación y libertad de tarifas. Al fijar sus tarifas, las empresas de servicios públicos se someterán al régimen de regulación, el cual podrá incluir las modalidades de libertad regulada y libertad vigilada, o un régimen de libertad, de acuerdo a las siguientes reglas:

88.1. Las empresas deberán ceñirse a las fórmulas que defina periódicamente la respectiva comisión para fijar sus tarifas, salvo en los casos excepcionales que se enumeran adelante. De acuerdo con los estudios de costos, la comisión reguladora podrá establecer topes máximos y mínimos tarifarios, de obligatorio cumplimiento por parte de las empresas; igualmente, podrá definir las metodologías para determinación de tarifas si conviene en aplicar el régimen de libertad regulada o vigilada.

88.2. Las empresas tendrán libertad para fijar tarifas cuando no tengan una posición dominante en su mercado, según análisis que hará la comisión respectiva, con base en los criterios y definiciones de esta ley.

88.3. Las empresas tendrán libertad para fijar tarifas, cuando exista competencia entre proveedores. Corresponde a las comisiones de regulación, periódicamente, determinar cuándo se dan estas condiciones, con base en los criterios y definiciones de esta ley.

CAPITULO II

FORMULAS Y PRACTICAS DE TARIFAS

Artículo 89.- Aplicación de los criterios de solidaridad y redistribución de ingresos. Las comisiones de regulación exigirán gradualmente a todos quienes prestan servicios públicos que, al cobrar las tarifas que estén en vigencia al promulgarse esta ley, distingan en las facturas entre el valor que corresponde al servicio y el factor que se aplica para dar subsidios a los usuarios de los estratos 1 y 2. Igualmente, definirán las condiciones para aplicarlos al estrato 3. Los concejos municipales están en la obligación de crear "fondos de solidaridad y redistribución de ingresos", para que al presupuesto del municipio se incorporen las transferencias que a dichos fondos deberán hacer las empresas de servicios públicos, según el servicio de que se trate, de acuerdo con lo establecido en el artículo 89.2 de la presente ley. Los recursos de dichos fondos serán destinados a dar subsidios a los usuarios de estratos 1, 2 y 3, como inversión social, en los términos de esta ley. A igual procedimiento y sistema se sujetarán los fondos distritales y departamentales que deberán ser creados por las autoridades correspondientes en cada caso.

89.1. Se presume que el factor aludido nunca podrá ser superior al equivalente del 20% del valor del servicio y no podrán incluirse factores adicionales por concepto de ventas o consumo del usuario. Cuando comiencen a aplicarse las fórmulas tarifarias de que trata esta ley, las comisiones sólo permitirán que el factor o factores que se han venido cobrando, se incluyan en las facturas de usuarios de inmuebles residenciales de los estratos 5 y 6, y en las de los usuarios industriales y comerciales. Para todos estos, el factor o factores se determinará en la forma atrás dispuesta, se discriminará en las facturas, y los recaudos que con base en ellos se hagan, recibirán el destino señalado en el artículo 89.2 de esta ley.

89.2. Quienes presten los servicios públicos harán los recaudos de las sumas que resulten al aplicar los factores de que trata este artículo y los aplicarán al pago de subsidios, de acuerdo con las normas pertinentes, de todo lo cual llevarán contabilidad y cuentas detalladas. Al presentarse superávits, por este concepto, en empresas de servicios públicos oficiales de orden distrital, municipal o departamental se destinarán a "fondos de solidaridad y redistribución de ingresos" para empresas de la misma naturaleza y servicio que cumplan sus actividades en la misma entidad territorial al de la empresa aportante. Si los "fondos de solidaridad y redistribución de ingresos" después de haber atendido los subsidios de orden distrital, municipal o departamental, según sea el caso, presentaren superávits, estos últimos se destinarán para las empresas de la misma naturaleza y servicio con sede en departamentos, distritos o municipios limítrofes, respectivamente. Los repartos se harán de acuerdo a los mecanismos y criterios que establezcan las comisiones de regulación respectivas. Los superávits, por este concepto, en empresas privadas o mixtas prestatarias de los servicios de agua potable o saneamiento básico y telefonía local fija, se destinarán a los "fondos de solidaridad y redistribución de ingresos" del municipio o distrito correspondiente y serán transferidos mensualmente, de acuerdo con los mecanismos que establezcan las comisiones de regulación respectivas. Los superávits, por este concepto, en empresas privadas o mixtas prestatarias de los servicios de energía eléctrica y gas combustible irán a los fondos que más adelante se desarrollan en este mismo artículo.

89.3. Los recaudos que se obtengan al distinguir, en las facturas de energía eléctrica y gas combustible, el factor o factores arriba dichos, y que den origen a superávits, después de aplicar el factor para subsidios y sólo por este concepto, en empresas oficiales o mixtas de orden nacional, y privadas se incorporarán al presupuesto de la nación (Ministerio de Minas y Energía), en un "fondo de solidaridad para subsidios y redistribución de ingresos", donde se separen claramente los recursos y asignaciones de estos dos servicios y que el congreso destinará, como inversión social, a dar subsidios que permitan generar, distribuir y transportar energía eléctrica y gas combustible a usuarios de estratos bajos, y expandir la cobertura en las zonas rurales preferencialmente para incentivar la producción de alimentos y sustituír combustibles derivados del petróleo.

Ver Artículo 5º de la ley 286 de 1996..

89.4. Quienes generen su propia energía, y la enajenen a terceros o asociados, y tengan una capacidad instalada superior a 25.000 Kilovatios, recaudarán y aportarán, en nombre de los consumidores de esa energía equivalente, al fondo de "solidaridad y redistribución de ingresos" del municipio o municipios en donde ésta sea enajenada, la suma que resulte de aplicar el factor pertinente del 20% a su generación descontando de esta lo que vendan a empresas distribuidoras. Esta generación se evaluará al 80% de su capacidad instalada, y valorada con base en el costo promedio equivalente según nivel de tensión que se aplique en el respectivo municipio; o, si no lo hay, en aquel municipio o distrito que lo tenga y cuya cabecera esté más próxima a la del municipio o distrito en el que se enajene dicha energía. El generador hará las declaraciones y pagos que correspondan, de acuerdo con los procedimientos que establezca la comisión de regulación de energía y gas domiciliario.

89.5. Quienes suministren o comercialicen gas combustible con terceros en forma independiente, recaudarán, en nombre de los consumidores que abastecen y aportarán, al fondo de "solidaridad y redistribución de ingresos" de la nación (Ministerio de Minas y Energía), la suma que resulte de aplicar el factor pertinente del 20%, al costo económico de suministro en puerta de ciudad, según reglamentación que haga la comisión de regulación de energía y gas domiciliario. El suministrador o comercializador hará las declaraciones y pagos que correspondan, de acuerdo con los procedimientos que establezca la misma comisión.

89.6. Los recursos que aquí se asignan a los "fondos de solidaridad y redistribución de ingresos" son públicos. Por lo tanto, quienes hagan los recaudos estarán sujetos a las normas sobre declaración y sanciones que se aplican a los retenedores en el decreto 624 de 1989 y en las normas concordantes o que lo sustituyan; pero deberán hacer devoluciones en el momento en que el usuario les demuestre que tiene derecho a ellas. La obligación de los retenedores que hagan el cobro del factor o factores se extinguirá y cobrará en la forma prevista para las obligaciones que regulan las normas aludidas, en lo que sean compatibles con esta ley y con la naturaleza de los cobros respectivos; y las moras se sancionarán como las moras de quienes están sujetos a las obligaciones que regulan tales normas.

89.7. Cuando comiencen a aplicarse las fórmulas tarifarias de que trata esta ley, los hospitales, clínicas, puestos y centros de salud, y los centros educativos y asistenciales sin ánimo de lucro, no seguirán pagando sobre el valor de sus consumos el factor o factores de que trata este artículo. Lo anterior se aplicará por solicitud de los interesados ante la respectiva entidad prestadora del servicio público. Sin excepción, siempre pagarán el valor del consumo facturado al costo del servicio.

Ver Artículo 5° de la ley 286 de 1996..

89.8. En el evento de que los "fondos de solidaridad y redistribución de ingresos" no sean suficientes para cubrir la totalidad de los subsidios necesarios, la diferencia será cubierta con otros recursos de los presupuestos de las entidades del orden nacional, departamental, distrital o municipal. Lo anterior no obsta para que la nación y las entidades territoriales puedan canalizar, en cualquier tiempo, a través de estos fondos, los recursos que deseen asignar a subsidios. En estos casos el aporte de la nación o de las entidades territoriales al pago de los subsidios no podrá ser inferior al 50% del valor de los mismos.

Parágrafo. Cuando los encargados de la prestación de los servicios públicos domiciliarios, distintos de las empresas oficiales o mixtas del orden nacional o de empresas privadas desarrollen sus actividades en varios municipios de un mismo departamento, los superávits a los que se refiere el artículo 89.2 de esta ley, ingresarán a los "fondos de solidaridad y redistribución de ingresos" del respectivo municipio. Cuando su prestación se desarrolle en municipios de diferentes departamentos, los excedentes ingresarán a los fondos del respectivo municipio

Artículo 90.- Elementos de las fórmulas de tarifas. Sin perjuicio de otras alternativas que puedan definir las comisiones de regulación, podrán incluirse los siguientes cargos:

90.1. Un cargo por unidad de consumo, que refleje siempre tanto el nivel y la estructura de los costos económicos que varíen con el nivel de consumo como la demanda por el servicio;

90.2. Un cargo fijo, que refleje los costos económicos involucrados en garantizar la disponibilidad permanente del servicio para el usuario, independientemente del nivel de uso.

Se considerarán como costos necesarios para garantizar la disponibilidad permanente del suministro aquellos denominados costos fijos de clientela, entre los cuales se incluyen los gastos adecuados de administración, facturación, medición y los demás servicios permanentes que, de acuerdo a definiciones que realicen las respectivas comisiones de regulación, son necesarios para garantizar que el usuario pueda disponer del servicio sin solución de continuidad y con eficiencia.

90.3. Un cargo por aportes de conexión el cual podrá cubrir los costos involucrados en la conexión del usuario al servicio. También podrá cobrarse cuando, por razones de suficiencia financiera, sea necesario acelerar la recuperación de las inversiones en infraestructura, siempre y cuando estas correspondan a un plan de expansión de costo mínimo. La fórmula podrá distribuir estos costos en alícuotas partes anuales.

El cobro de estos cargos en ningún caso podrá contradecir el principio de la eficiencia, ni trasladar al usuario los costos de una gestión ineficiente o extraer beneficios de posiciones dominantes o de monopolio.

Las comisiones de regulación siempre podrán diseñar y hacer públicas diversas opciones tarifarias que tomen en cuenta diseños óptimos de tarifas. Cualquier usuario podrá exigir la aplicación de una de estas opciones, si asume los costos de los equipos de medición necesarios.

Artículo 91.- Consideración de las diversas etapas del servicio. Para establecer las fórmulas de tarifas se calculará por separado, cuando sea posible, una fórmula para cada una de las diversas etapas del servicio.

Artículo 92 .- Restricciones al criterio de recuperación de costos y gastos de operación. En las fórmulas de tarifas las comisiones de regulación garantizarán a los usuarios a lo largo del tiempo los beneficios de la reducción promedia de costos en las empresas que prestan el servicio; y, al mismo tiempo, darán incentivos a las empresas para ser mas eficientes que el promedio, y para apropiarse los beneficios de la mayor eficiencia.

Con ese propósito, al definir en las fórmulas los costos y gastos típicos de operación de las empresas de servicios públicos, las comisiones utilizarán no solo la información propia de la empresa, sino la de otras empresas que operen en condiciones similares, pero que sean mas eficientes.

También podrán las comisiones, con el mismo propósito, corregir en las fórmulas los índices de precios aplicables a los costos y gastos de la empresa con un factor que mida los aumentos de productividad que se esperan en ella, y permitir que la fórmula distribuya entre la empresa y el usuario los beneficios de tales aumentos.

Artículo 93.- Costos de compras al por mayor para empresas distribuidoras con posición dominante. Al elaborar las fórmulas de tarifas a las empresas que tengan posición dominante en un mercado, y cuya principal actividad sea la distribución de bienes distintos proporcionados por terceros, el costo que se asigne a la compra al por mayor de tales bienes o servicios deberá ser el que resulte de la invitación pública a la que se refiere el art;iculo 35, y en ningún caso un estimativo de él.

Artículo 94.- Tarifas y recuperación de pérdidas. De acuerdo con los principios de eficiencia y suficiencia financiera, y dada la necesidad de lograr un adecuado equilibrio entre ellos, no se permitirán alzas destinadas a recuperar pérdidas patrimoniales. La recuperación patrimonial deberá hacerse, exclusivamente, con nuevos aportes de capital de los socios, o con cargo a las reservas de la empresa o a sus nuevas utilidades.

Artículo 95.- Facultad de exigir aportes de conexión. Los aportes de conexión pueden ser parte de la tarifa; pero podrán pagarse, entre otras formas, adquiriendo acciones para el aumento de capital de las empresas, si los reglamentos de estas lo permiten.

Se prohibe el cobro de derechos de suministro, formularios de solicitud y otros servicios o bienes semejantes. Pero si una solicitud de conexión implicara estudios particularmente complejos, su costo, justificado en detalle, podrá cobrarse al interesado, salvo que se trate de un usuario residencial perteneciente a los estratos 1, 2, 3.

Artículo 96.- Otros cobros tarifarios. Quienes presten servicios públicos domiciliarios podrán cobrar un cargo por concepto de reconexión y reinstalación, para la recuperación de los costos en que incurran.

En caso de mora de los usuarios en el pago de los servicios, podrán aplicarse intereses de mora sobre los saldos insolutos, capitalizados los intereses, conforme a lo dispuesto en la ley 40 de 1990.

Las comisiones de regulación podrán modificar las fórmulas tarifarias para estimular a las empresas de servicios públicos domiciliarios de energía y acueducto a hacer inversiones tendientes a facilitar a los usuarios la mejora en la eficiencia en el uso de la energía o el agua, si tales inversiones tienen una tasa de retorno económica suficiente para justificar la asignación de los recursos en condiciones de mercado.

Artículo 97.- Masificación del uso de los servicios públicos domiciliarios. Con el propósito de incentivar la masificación de estos servicios las empresas prestatarias de los mismos otorgarán plazos para amortizar los cargos de la conexión domiciliaria, incluyendo la acometida y el medidor, los cuales serán obligatorios para los estratos 1, 2 y 3.

En todo caso, los costos de conexión domiciliaria, acometida y medidor de los estratos 1, 2 y 3 podrán ser cubiertos por el municipio, el departamento o la nación a través de aportes presupuestales para financiar los subsidios otorgados a los residentes de estos estratos que se beneficien con el servicio y, de existir un saldo a favor de la persona prestadora del servicio, se aplicarán los plazos establecidos en el inciso anterior, los cuales, para los estratos 1, 2 y 3, por ningún motivo serán inferiores a tres (3) años, salvo por renuncia expresa del usuario.

Artículo 98.- Prácticas tarifarias restrictivas de la competencia. Se prohibe a quienes presten los servicios públicos:

98.1. Dar a los clientes de un mercado competitivo, o cuyas tarifas no están sujetas a regulación, tarifas inferiores a los costos operacionales, especialmente cuando la misma empresa presta servicios en otros mercados en los que tiene una posición dominante o en los que sus tarifas están sujetas a regulación.

98.2. Ofrecer tarifas inferiores a sus costos operacionales promedio con el ánimo de desplazar competidores, prevenir la entrada de nuevos oferentes o ganar posición dominante ante el mercado o ante clientes potenciales.

98.3. Discriminar contra unos clientes que poseen las mismas características comerciales de otros, dando a los primeros tarifas más altas que a los segundos, y aún si la discriminación tiene lugar dentro de un mercado competitivo o cuyas tarifas no estén reguladas.

La violación de estas prohibiciones, o de cualquiera de las normas de esta ley relativas a las funciones de las comisiones, puede dar lugar a que éstas sometan a regulación las tarifas de quienes no estuvieren sujetas a ella, y revoquen de inmediato las fórmulas de tarifas aplicables a quienes prestan los servicios públicos.

CAPITULO III

DE LOS SUBSIDIOS

Artículo 99.- Forma de subsidiar. Las entidades señaladas en el artículo 368 de la Constitución Política podrán conceder subsidios en sus respectivos presupuestos de acuerdo a las siguientes reglas:

99.1. Deben indicar específicamente el tipo de servicio subsidiado.

99.2. Se señalará la entidad prestadora que repartirá el subsidio.

99.3. El reparto debe hacerse entre los usuarios como un descuento en el valor de la factura que éste debe cancelar, conforme a lo dispuesto en esta ley y en las ordenanzas y acuerdos según el caso.

99.4. El Presidente y los gobernadores podrán suspender a los alcaldes cuando sean negligentes en la aplicación de las normas relativas al pago de los subsidios; o cuando las infrinjan de cualquier otra manera.

99.5. Los subsidios no excederán, en ningún caso, del valor de los consumos básicos o de subsistencia. Los alcaldes y los concejales tomarán las medidas que a cada uno correspondan para crear en el presupuesto municipal, y ejecutar, apropiaciones para subsidiar los consumos básicos de acueducto y saneamiento básico de los usuarios de menores recursos y extender la cobertura y mejorar la calidad de los servicios de agua potable y saneamiento básico, dando prioridad a esas apropiaciones, dentro de las posibilidades del municipio, sobre otros gastos que no sean indispensables para el funcionamiento de éste. La infracción de este deber dará lugar a sanción disciplinaria.

99.6. La parte de la tarifa que refleje los costos de administración, operación y mantenimiento a que dé lugar el suministro será cubierta siempre por el usuario; la que tenga el propósito de recuperar el valor de las inversiones hechas para prestar el servicio podrá ser cubierta por los subsidios, y siempre que no lo sean, la empresa de servicios públicos podrá tomar todas las medidas necesarias para que los usuarios las cubran. En ningún caso el subsidio será superior al 15% del costo medio del suministro para el estrato 3, al 40% del costo medio del suministro para el estrato 2, ni superior al 50% de éste para el estrato 1.

99.7. Los subsidios sólo se otorgarán a los usuarios de inmuebles residenciales y a las zonas rurales de los estratos 1 y 2; las comisiones de regulación definirán las condiciones para otorgarlos al estrato 3.

99.8. Cuando los Concejos creen los fondos de solidaridad para subsidios y redistribución de ingresos y autoricen el pago de subsidios a través de las empresas pero con desembolsos de los recursos que manejen las tesorerías municipales, la transferencia de recursos se hará en un plazo de 30 días, contados desde la misma fecha en que se expida la factura a cargo del municipio. Para asegurar la transferencia, las empresas firmarán contratos con el municipio.

99.9. Los subsidios que otorguen la Nación y los departamentos se asignarán, preferentemente, a los usuarios que residan en aquellos municipios que tengan menor capacidad para otorgar subsidios con sus propios ingresos. En consecuencia y con el fin de cumplir cabalmente con los principios de solidaridad y redistribución no existirá exoneración en el pago de los servicios de que trata esta ley para ninguna persona natural o jurídica.

Parágrafo 1. La tarifa del servicio público de electricidad para los distritos de riego construidos o administrados por el Incora y que sean menores a 50 hectáreas, se considerarán incorporados al estrato 1 para efecto de los subsidios a que halla lugar.

Artículo 100.- Presupuesto y fuentes de los subsidios. En los presupuestos de la Nación y de las entidades territoriales, las apropiaciones para inversión en acueducto y saneamiento básico y los subsidios se clasificarán en el gasto público social, como inversión social, para que reciban la prioridad que ordena el artículo 366 de la Constitución Política. Podrán utilizarse como fuentes de los subsidios los ingresos corrientes y de capital, las participaciones en los ingresos corrientes de la Nación, los recursos de los impuestos para tal efecto de que trata esta ley, y para los servicios de acueducto, alcantarillado y aseo los recursos provenientes del 10% del impuesto predial unificado al que se refiere el articulo 7 de la ley 44 de 1990. En ningún caso se utilizarán recursos del crédito para atender subsidios. Las empresas de servicios públicos no podrán subsidiar otras empresas de servicios públicos.

CAPITULO IV

ESTRATIFICACION SOCIOECONOMICA

Artículo 101.- Régimen de estratificación. La estratificación se someterá a las siguientes reglas.

101.1. Es deber de cada municipio clasificar en estratos los inmuebles residenciales que deben recibir servicios públicos. Y es deber indelegable del alcalde realizar la estratificación respectiva.

101.2. Los alcaldes pueden contratar las tareas de estratificación con entidades públicas nacionales o locales, o privadas de reconocida capacidad técnica.

101.3. El alcalde adoptará mediante decreto los resultados de la estratificación y los difundirá ampliamente. Posteriormente los notificará a la Superintendencia de Servicios Públicos Domiciliarios.

101.4. En cada municipio existirá una sola estratificación de inmuebles residenciales, aplicable a cada uno de los servicios públicos.

101.5. Antes de iniciar los estudios conducentes a la adopción, el alcalde deberá conformar un Comité permanente de estratificación socioeconómica que lo asesore, cuya función principal es velar por la adecuada aplicación de las metodologías suministradas por el Departamento Nacional de Planeación.

101.6. Los alcaldes de los municipios que conforman áreas metropolitanas o aquellos que tengan áreas en situación de conurbación, podrán hacer convenios para que la estratificación se haga como un todo.

101.7. La Nación y los departamentos pueden dar asistencia técnica a los municipios para que asuman la responsabilidad de la estratificación; para realizar las estratificaciones, los departamentos pueden dar ayuda financiera a los municipios cuyos ingresos totales sean equivalentes o menores a los gastos de funcionamiento, con base a la ejecución presupuestal del año inmediatamente anterior.

101.8. Las estratificaciones que los municipios y distritos hayan realizado o realicen con el propósito de determinar la tarifa del impuesto predial unificado de que trata la ley 44/90, serán admisibles para los propósitos de esta ley, siempre y cuando se ajusten a las metodologías de estratificación definidas por el Departamento Nacional de Planeación.

101.9. Cuando se trate de otorgar subsidios con recursos nacionales, la Nación podrá exigir, antes de efectuar los desembolsos, que se consiga certificado de la Superintendencia de Servicios Públicos Domiciliarios, en el sentido de que la estratificación se hizo en forma correcta. Cuando se trate de otorgar subsidios con recursos departamentales, cada Departamento establecerá sus propias normas.

101.10. El Gobernador del Departamento podrá sancionar disciplinariamente a los alcaldes que por su culpa no hayan realizado la estratificación de los inmuebles residenciales en los plazos establecidos por Planeación Nacional, o no hayan conseguido que se haga y notifique una revisión general de la estratificación municipal cuando la Superintendencia de Servicios Públicos Domiciliarios, en el plazo previsto lo indique.

101.11. Ante la renuencia de las autoridades municipales, el Gobernador puede tomar las medidas necesarias, y hacer los contratos del caso, para garantizar que las estratificaciones estén hechas acordes con las normas; la Nación deberá, en ese evento, descontar de las transferencias que debe realizar al municipio las sumas necesarias y pagarlas al Departamento.

101.12. El Presidente de la República podrá imponer sanción disciplinaria a los Gobernadores que, por su culpa, no tomen las medidas tendientes a suplir la omisión de las autoridades municipales en cuanto a realización de los actos de estratificación; podrá también tomar las mismas medidas que se autorizan a los gobernadores en el inciso anterior.

101.13. Las sanciones y medidas correctivas que este artículo autoriza podrán aplicarse también cuando no se determine en forma oportuna que la actualización de los estratos debe hacerse para atender los cambios en la metodología de estratificación que se tuvieron en cuenta al realizar la estratificación general de un municipio; o, en general cuando se infrinjan con grave perjuicio para los usuarios las normas sobre estratificación.

Parágrafo. El plazo para adoptar la estratificación urbana se vence el 31 de diciembre de 1994 y la estratificación rural el 31 de julio de 1995.

Artículo 102.- Estratos y metodología. Los inmuebles residenciales a los cuales se provean servicios públicos se clasificarán máximo en seis estratos socioeconómicos así: 1) bajo-bajo, 2) bajo, 3) medio-bajo, 4) medio, 5) medio-alto, y 6) alto.

Para tal efecto se emplearán las metodologías que elabore el Departamento Nacional de Planeación, las cuales contendrán las variables, factores, ponderaciones y método estadístico, teniendo en cuenta la dotación de servicios públicos domiciliarios. Ninguna zona residencial urbana que carezca de la prestación de por lo menos dos servicios públicos domiciliarios básicos podrá ser clasificada en un estrato superior al cuatro (4)

A este artículo le fue adicionado un inciso por el artículo 16 de la ley 689 de 2001.

Artículo 103.- Unidades espaciales de estratificación. La unidad espacial de estratificación es el área dotada de características homogéneas de conformidad con los factores de estratificación. Cuando se encuentren viviendas que no tengan las mismas características del conglomerado, se les dará un tratamiento individual.

Artículo 104.- Recursos de los usuarios. Toda persona o grupo de personas podrá solicitar revisión del estrato que se le asigne. Los reclamos serán atendidos y resueltos en primera instancia por el comité de estratificación en el término de dos meses y las reposiciones por la Superintendencia de Servicios Públicos Domiciliarios.

Artículo modificado por el artículo 17 de la ley 689 de 2001.

CAPITULO V

LAS FORMULAS TARIFARIAS

Artículo 124.- Actuación administrativa. Para determinar las fórmulas tarifarias se aplicarán las normas sobre régimen tarifario de las empresas de servicios públicos previstas en esta ley, las normas del Código Contencioso Administrativo, y las siguientes reglas especiales:

124.1. La coordinación ejecutiva de la comisión de regulación respectiva impulsará toda la actuación; sin embargo, cuando corresponda a la comisión como autoridad nombrar peritos, el nombramiento corresponderá a la comisión misma.

124.2. Si la actuación se inicia de oficio, la comisión debe disponer de estudios suficientes para definir la fórmula de que se trate; si se inicia por petición de una empresa de servicios públicos, el solicitante debe acompañar tales estudios. Son estudios suficientes, los que tengan la misma clase y cantidad de información que haya empleado cualquier comisión de regulación para determinar una fórmula tarifaria.

Artículo 125.- Actualización de las tarifas. Durante el período de vigencia de cada fórmula, las empresas podrán actualizar las tarifas que cobran a sus usuarios aplicando las variaciones en los índices de precios que las fórmulas contienen. Las nuevas tarifas se aplicarán a partir del día quince del mes que corresponda, cada vez que se acumule una variación de, por lo menos, un tres por ciento (3%) en alguno de los índices de precios que considera la fórmula.

Cada vez que las empresas de servicios públicos reajusten las tarifas, deberán comunicar los nuevos valores a la Superintendencia de servicios públicos, y a la comisión respectiva. Deberán, además, publicarlos, por una vez, en un periódico que circule en los municipios en donde se presta el servicio, o en uno de circulación nacional.

Artículo 126.- Vigencia de las fórmulas de tarifas. Las fórmulas tarifarias tendrán una vigencia de cinco años, salvo que antes haya acuerdo entre la empresa de servicios públicos y la comisión para modificarlas o prorrogarlas por un período igual. Excepcionalmente podrán modificarse, de oficio o a petición de parte, antes del plazo indicado cuando sea evidente que se cometieron graves errores en su cálculo, que lesionan injustamente los intereses de los usuarios o de la empresa; o que ha habido razones de caso fortuito o fuerza mayor que comprometen en forma grave la capacidad financiera de la empresa para continuar prestando el servicio en las condiciones tarifarias previstas.

Vencido el período de vigencia de las fórmulas tarifarias, continuarán rigiendo mientras la comisión no fije las nuevas.

Artículo 127.- Inicio de la actuación administrativa para fijar nuevas tarifas. Antes de doce meses de la fecha prevista para que termine la vigencia de las fórmulas tarifarias, la comisión deberá poner en conocimiento de las empresas de servicios públicos las bases sobre las cuales efectuará el estudio para determinar las fórmulas del período siguiente. Después, se aplicará lo previsto en el artículo 124.

I. EXPENSES

Energy Revenues (or Energy Compensations)

	Bogotá River System				Guavio System			
	Generation Capacity (%)	Conversion Factor (kWh/m3)	Price (US$/kWh)	Revenue (US$/m3)	Generation Capacity (%)	Conversion Factor (kWh/m3)	Price (US$/kWh)	Revenue (US$/m3)
Chuza (Unique Stage)	80%	4.00	0.028	0.090	-100%	2.70	0.028	(0.076)
Chuza I	80%	4.00	0.028	0.090	-100%	2.70	0.028	(0.076)
Chuza II	80%	4.00	0.028	0.090	-100%	2.70	0.028	(0.076)
Chuza III	80%	4.00	0.028	0.090	-100%	2.70	0.028	(0.076)
Chingaza SE	80%	4.00	0.028	0.090	0%	2.70	0.028	-
La Playa	30%	4.00	0.028	0.034	0%	2.70	0.028	-

Assumptions

The generation capacity is defined as the percentage of total water produced that is used for energy generation

The price is the price received by the EAAB for the production of energy, and the price paid by the EAAB as a compensation in the cases where its use of water constrains the production of energy

The revenue is the revenue (or cost) obtained from energy sales (or compensations) per cubic meter of water produced

Notes

Only revenues corresponding to energy sales will be taken into account because these directly diminish the cost for the consumers.

The tariff revenues are not taken into account because these are variable and if correctly set, will only make the NPV zero

The focus of the analysis is to find the projects that minimize costs for consumers, therefore only expenditures and energy revenues are considered

Investment Plan (US$)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total Investment
Chuza (Unique Stage)	26,332,127	48,347,003	48,347,003			123,026,134
Chuza I	11,311,880	14,361,572	14,361,565			40,035,017
Chuza II	4,202,362	19,958,600	19,164,572			43,325,534
Chuza III	12,689,914	40,645,234	-			53,335,147
Chingaza SE	10,305,648	17,191,850	9,452,260	11,459,760	11,459,760	59,869,278
La Playa	1,864,057	23,704,420	30,388,970			55,957,447
Total Investment						252,522,423

Assumptions:

Year 1 corresponds to the first year of the period in which the project is initiated

All values are in US Dollars of 1999

Source:

Ingetec (1999) Actualización Plan Maestro Abastecimiento para el Mediano y Largo Plazo

Notes:

The detailed cronogramas, budgets and investment plans can be observed in Appendix A

Operation & Maintenance Costs (per year)

	Fixed (US$)	Variable (US$/m3)
Chuza (Unique Stage)	3,690,784	0.008
Chuza I	1,201,051	0.008
Chuza II	1,299,766	0.008
Chuza III	1,600,054	0.008
Chingaza SE	1,796,078	0.008
La Playa	559,574	-

Assumptions:

Chuza's fixed costs are 3% of total invesment and Chingaza's 1%. These values were obtained from historical records in similar facilities

Source:

Ingetec (1999) Actualización Plan Maestro Abastecimiento para el Mediano y Largo Plazo

Cost of Unserved Demand (US$ per Cubic Meter of Unserved Demand)

	Cost (US$/m3)
For all facilities	0.80

Source:

Ingetec (1999) Actualización Plan Maestro Abastecimiento para el Mediano y Largo Plazo

EAAB (2000) Commercial and Planning Statistics

II. AUXILIARY VARIABLES

Incremental Capacity Supplied by the System

	m3/s	m3/year
Chuza (Unique Stage)	3.90	122,990,400
Chuza I	1.04	32,797,440
Chuza II	1.29	40,681,440
Chuza III	1.57	49,511,520
Chingaza SE	2.08	65,594,880
La Playa	1.52	47,934,720
Total	7.50	236,520,000

Assumptios

The total incremental capacity includes the capacity from small actions to optimize the operation of the Chingaza system

Source:

Ingetec (1999) Actualización Plan Maestro Abastecimiento para el Mediano y Largo Plazo

Capacity Supplied by Existing System

	m3/s	m3/year
Chingaza		
Tibititoc		
Otros		
Total	23.8	750,556,800

Source: EAAB Technical Statistics

Construction Schedule

	Period 1	Period 2	Period 3	Period 4	Period 5
Chuza (Unique Stage)					
Chuza I	YES				
Chuza II		YES			
Chuza III			YES		
Chingaza SE				YES	
La Playa					YES

Assumptions:

Construction begins in the first year of the period marked YES

	Years
Timing for Chuza	0
Timing for Chuza I	1
Timing for Chuza II	2
Timing for Chuza III	3
Timing for Chingaza SE	4
Timing for La Playa	5

Construction Times

	Years
Chuza (Unique Stage)	3
Chuza I	3
Chuza II	3
Chuza III	2
Chingaza SE	5
La Playa	3

Assumptions:

Chuza's fixed costs are 3% of total invesment and Chingaza's 1%. These values were obtained from historical records in similar facilities

Source:

Ingetec (1999) Actualización Plan Maestro Abastecimiento para el Mediano y Largo Plazo

Calculation of year in which capacity becomes available.

	Year
Chuza (Unique Stage)	3000
Chuza I	2007
Chuza II	2010
Chuza III	2012
Chingaza SE	2018
La Playa	2019

Unaccounted For Water

	%
Commercial Losses	13%
Technical Losses	19%

Source:

EAAB Commercial and Technical Statistics

TEA Consultorlas (1999) Acutalización de la Pryección de la Demanda de Agua

Calculation of year in which construction starts

	Year
Chuza (Unique Stage)	3000
Chuza I	2004
Chuza II	2007
Chuza III	2010
Chingaza SE	2013
La Playa	2016

Discount Rate	12%

Source:

EAAB Planning and Financial Statistics

Average Demand Growht per Year for Different Scenarios

	Scenario
Demand High	3.50%
Demand Medium	2.50%
Demand Low	1.50%

Initial Demand in 2002 m3/year	511,829,280

	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5
Demand Growth Rate	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015	2015-on

APPENDIX D: FORMULATION REAL OPTIONS MODEL

I. INPUT AND CALCULATED PARAMETERS

Input Parameters:	Symbol	
Period Risk-Free Rate (%)	*rf*	0.32375319
PV Underlying Asset (US$ Million)	V_o	248
Exercise Price (US$ Million)	*X*	=43.325534/1.12^3
Life of Option (periods)	*t*	5
Annual Standard Deviation (%)	σ	1.3
Calculated Parameters:		
Up movement per step	*u*	=EXP(C8*(1/3)^(1/2))
Down movement per step	*d*	=1/C11
Risk-neutral probability of up state	*p*	=(1+C4-C12)/(C11-C12)
Risk-neutral probability of down state	*q*	=1-C13

II. BINOMIAL TREE FOR THE UNDERLYING

Chuza II

	0	**1**
0	=IF($B20>C$19,0,($C$5*($C$11^(C$19-$B20))*($C$12^$B20)))	=IF($B20>D$19,0,($C$5*($C$11^(D$19-$B20))*($C$12^$B20)))
1		=IF($B21>D$19,0,($C$5*($C$11^(D$19-$B21))*($C$12^$B21)))
2		
3		
4		
5		

III. EVENT TREE

a. Option Value

	0	1	2
0	=MIN(C20-C28+$C$6,G83)	=MIN(D20-D28+$C$6,G80)	=MIN(E20-E28+$C$6,G76)
1		=MIN(D21-D29+$C$6,G81)	=MIN(E21-E29+$C$6,G77)
2			=MIN(E22-E30+$C$6,G78)
3			
4			

b. Decisions

	0	1	2
0	=IF(C45=C38, "Exercise","Keep.Open")	=IF(D45=D38, "Exercise","Keep.Open")	=IF(E45=E38, "Exercise","Keep.Open")
1		=IF(D46=D39, "Exercise","Keep.Open")	=IF(E46=E39, "Exercise","Keep.Open")
2			=IF(E47=E40, "Exercise","Keep.Open")
3			
4			
5			

IV. OPTION VALUE CALCULATION (Replicating Portfolio)

	End-of-Period Payoff		*Replicating Portfolio Parameters*		*Option Value*
Node	*Up State*	*Down State*	*m*	*B*	
K	=H38	=H39	=(C65-D65)/(H20-H21)	=(H39-E65*H21)/(1+$C$4)	=E65*G20+F65
L	=D65	=H40	=(C66-D66)/(H21-H22)	=(H40-E66*H22)/(1+$C$4)	=E66*G21+F66
M	=D66	=H41	=(C67-D67)/(H22-H23)	=(H41-E67*H23)/(1+$C$4)	=E67*G22+F67
N	=D67	=H42	=(C68-D68)/(H23-H24)	=(H42-E68*H24)/(1+$C$4)	=E68*G23+F68
O	=D68	=H43	=(C69-D69)/(H24-H25)	=(H43-E69*H25)/(1+$C$4)	=E69*G24+F69
G	=G38	=G39	=(C71-D71)/(G20-G21)	=(D71-E71*G21)/(1+$C$4)	=E71*F20+F71
H	=D71	=G40	=(C72-D72)/(G21-G22)	=(D72-E72*G22)/(1+$C$4)	=E72*F21+F72
I	=D72	=G41	=(C73-D73)/(G22-G23)	=(D73-E73*G23)/(1+$C$4)	=E73*F22+F73
J	=D73	=G42	=(C74-D74)/(G23-G24)	=(D74-E74*G24)/(1+$C$4)	=E74*F23+F74
D	=F38	=F39	=(C76-D76)/(F20-F21)	=(D76-E76*F21)/(1+$C$4)	=E76*E20+F76
E	=D76	=F40	=(C77-D77)/(F21-F22)	=(D77-E77*F22)/(1+$C$4)	=E77*E21+F77
F	=D77	=F41	=(C78-D78)/(F22-F23)	=(D78-E78*F23)/(1+$C$4)	=E78*E22+F78
B	=E38	=E39	=(C80-D80)/(E20-E21)	=(D80-E80*E21)/(1+$C$4)	=E80*D20+F80
C	=D80	=E40	=(C81-D81)/(E21-E22)	=(D81-E81*E22)/(1+$C$4)	=E81*D21+F81
A	=D38	=D39	=(C83-D83)/(D20-D21)	=(D83-E83*D21)/(1+$C$4)	=E83*C20+F83

APPENDIX E: DCF MODEL RESULTS

	PERIOD 1			PERIOD 2			PERIOD 3			PERIOD 4			PERIOD 5		
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
PROJECT REVENUES (US$ Million)															
Incremental Energy Sales	-	-	-	-	-	*7,550*	*260,950*	*520,685*	*786,914*	*1,059,799*	*1,339,505*	*1,626,204*	*1,659,706*	*1,659,706*	*1,659,706*
Energy Sales Chuza (Unique Stage)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy Sales Chuza I	-	-	-	-	-	7,550	260,950	459,164	459,164	459,164	459,164	459,164	459,164	459,164	459,164
Energy Sales Chuza II	-	-	-	-	-	-	-	61,521	327,750	569,540	569,540	569,540	569,540	569,540	569,540
Energy Sales Chuza III	-	-	-	-	-	-	-	-	-	31,094	310,801	597,500	631,002	631,002	631,002
Energy Sales Chingaza SE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy Sales La Playa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL REVENUES PER YEAR	-	-	-	-	-	**15,099**	**521,900**	**1,041,371**	**1,573,828**	**2,119,597**	**2,679,010**	**3,252,409**	**3,319,413**	**3,319,413**	**3,319,413**
PROJECT COSTS (US$ Million)															
Investment Costs	*11,311,880*	*14,361,572*	*14,361,565*	*4,202,362*	*19,958,600*	*19,164,572*	*12,689,914*	*40,645,234*	-	*10,305,648*	*17,191,850*	*9,452,260*	*13,323,817*	*35,164,180*	*30,388,970*
Chuza Unique Stage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chuza I	11,311,880	14,361,572	14,361,565	-	-	-	-	-	-	-	-	-	-	-	-
Chuza II	-	-	-	4,202,362	19,958,600	19,164,572	-	-	-	-	-	-	-	-	-
Chuza III	-	-	-	-	-	-	12,689,914	40,645,234	-	-	-	-	-	-	-
Chingaza SE	-	-	-	-	-	-	-	-	-	10,305,648	17,191,850	9,452,260	11,459,760	11,459,760	-
La Playa	-	-	-	-	-	-	-	-	-	-	-	-	1,864,057	23,704,420	30,388,970
Fixed O&M Costs	-	-	-	-	*1,201,051*	*1,201,051*	*1,201,051*	*2,500,817*	*2,500,817*	*4,100,871*	*4,100,871*	*4,100,871*	*4,100,871*	*4,100,871*	*4,100,871*
Chuza Unique Stage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chuza I	-	-	-	-	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051	1,201,051
Chuza II	-	-	-	-	-	-	-	1,299,766	1,299,766	1,299,766	1,299,766	1,299,766	1,299,766	1,299,766	1,299,766
Chuza III	-	-	-	-	-	-	-	-	-	1,600,054	1,600,054	1,600,054	1,600,054	1,600,054	1,600,054
Chingaza SE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
La Playa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	PERIOD 1			PERIOD 2			PERIOD 3			PERIOD 4			PERIOD 5		
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Variable O&M Costs	-	-	-	-	-	*4,314*	*149,114*	*297,535*	*449,665*	*605,599*	*765,432*	*939,260*	*948,404*	*948,404*	*948,404*
Chuza Unique Stage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chuza I	-	-	-	-	-	4,314	149,114	262,380	262,380	262,380	262,380	262,380	262,380	262,380	262,380
Chuza II	-	-	-	-	-	-	-	35,155	187,286	325,452	325,452	325,452	325,452	325,452	325,452
Chuza III	-	-	-	-	-	-	-	-	-	17,768	177,600	341,429	360,573	360,573	360,573
Chingaza SE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
La Playa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rationing Costs	-	-	-	-	-	-	-	-	-	-	-	-	*12,502,513*	*26,966,541*	*41,792,169*
TOTAL COSTS PER YEAR	**11,311,880**	**14,361,572**	**14,361,565**	**4,202,362**	**21,159,651**	**20,369,937**	**14,040,078**	**43,443,585**	**2,950,482**	**15,012,118**	**22,058,152**	**14,482,391**	**30,875,605**	**67,179,995**	**77,230,413**
FREE CASH FLOW TO CAPITAL	(11,311,880)	(14,361,572)	(14,361,565)	(4,202,362)	(21,159,651)	(20,354,837)	(13,518,178)	(42,402,214)	(1,376,653)	(12,892,521)	(19,379,142)	(11,229,982)	(27,556,192)	(63,860,583)	(73,911,001)
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount Factor	0.893	0.797	0.712	0.636	0.567	0.507	0.452	0.404	0.361	0.322	0.287	0.257	0.229	0.205	0.183
Present Value	(10,099,893)	(11,448,957)	(10,222,278)	(2,670,677)	(12,006,554)	(10,312,394)	(6,114,937)	(17,125,543)	(496,435)	(4,151,047)	(5,571,040)	(2,882,457)	(6,315,168)	(13,067,140)	(13,503,264)
NET PRESENT VALUE	(125,844,778)														

IV. SENSITIVITY ANALYSIS

	Base Case	NPV		Base Case	Average Deficit
		(125,844,778)			0.94%
Discount Rate	8%	(169,555,747)		8%	0.94%
	9%	(156,787,759)		9%	0.94%
	10%	(145,350,928)		10%	0.94%
	11%	(135,083,325)		11%	0.94%
	12%	(125,844,778)		12%	0.94%
	13%	(117,513,728)		13%	0.94%
	14%	(109,984,556)		14%	0.94%
	15%	(103,165,330)		15%	0.94%
	16%	(96,975,884)		16%	0.94%

	Base Case	NPV	As % of average capacity		Base Case	Average Deficit
		(125,844,778)				0.94%
Capacity Existing System	600,445,440	(631,228,876)	80%		600,445,440	15.88%
	637,973,280	(458,093,415)	85%		637,973,280	11.20%
	675,501,120	(291,683,147)	90%		675,501,120	6.63%
	713,028,960	(170,668,198)	95%		713,028,960	2.86%
	750,556,800	(125,844,778)	100%	132%	750,556,800	0.94%
	788,084,640	(113,395,206)	105%		788,084,640	0.20%
	825,612,480	(112,660,957)	110%		825,612,480	0.00%
	863,140,320	(114,554,759)	115%		863,140,320	0.00%
	900,668,160	(115,228,778)	120%		900,668,160	0.00%

		NPV			Average Deficit
	Base Case	(125,844,778)	As % of average capacity	Base Case	0.94%
Capacity of Expansion	189,216,000	(149,093,477)	80%	189,216,000	2.07%
	201,042,000	(143,009,682)	85%	201,042,000	1.77%
	212,868,000	(137,092,774)	90%	212,868,000	1.49%
	224,694,000	(131,175,866)	95%	224,694,000	1.20%
	236,520,000	(125,844,778)	100%	236,520,000	0.94%
	248,346,000	(122,208,796)	105%	248,346,000	0.76%
	260,172,000	(118,572,814)	110%	260,172,000	0.58%
	271,998,000	(115,724,276)	115%	271,998,000	0.44%
	283,824,000	(114,149,929)	120%	283,824,000	0.36%

		NPV			Average Deficit
	Base Case	(125,844,778)	As % of planned budget	Base Case	0.94%
Construction Costs	227,270,180	(114,260,066)	90%	227,270,180	0.94%
	252,522,423	(125,844,778)	100%	252,522,423	0.94%
	277,774,665	(137,429,490)	110%	277,774,665	0.94%
	303,026,907	(149,014,202)	120%	303,026,907	0.94%
	328,279,149	(160,598,914)	130%	328,279,149	0.94%
	353,531,392	(172,183,626)	140%	353,531,392	0.94%

		(125,844,778)	% Change Cost	% Change NPV
Deficit Costs	0.5	(118,951,941)	38%	5.5%
	0.6	(121,249,554)	25%	3.7%
	0.7	(123,547,166)	13%	1.8%
	0.8	(125,844,778)	0%	0.0%
	0.9	(128,142,391)	-13%	-1.8%
	1	(130,440,003)	-25%	-3.7%
	1.1	(132,737,615)	-38%	-5.5%
	1.2	(135,035,228)	-50%	-7.3%
	1.3	(137,332,840)	-63%	-9.1%
	1.4	(139,630,452)	-75%	-11.0%
	1.5	(141,928,065)	-88%	-12.8%

APPENDIX G: SCENARIO ANALYSIS

Scenario Summary	Current Values:	No La Playa	High Demand Growht	No La Playa and Chingaza
Changing Cells:				
T_La_Playa	5	0	5	0
Dem_0	2.50%	2.50%	4.00%	2.50%
Dem_1	2.50%	2.50%	4.00%	2.50%
Dem_2	2.50%	2.50%	4.00%	2.50%
Dem_3	2.50%	2.50%	4.00%	2.50%
Dem_4	2.50%	2.50%	4.00%	2.50%
Dem_5	2.50%	2.50%	2.50%	2.50%
T_Chingaza_SE	4	4	4	0
Result Cells:				
$C$229	125,844,778	119,852,422	415,436,316	119,899,318

Notes: Current Values column represents values of changing cells at time Scenario Summary Report was created. Changing cells for each scenario are highlighted in gray.

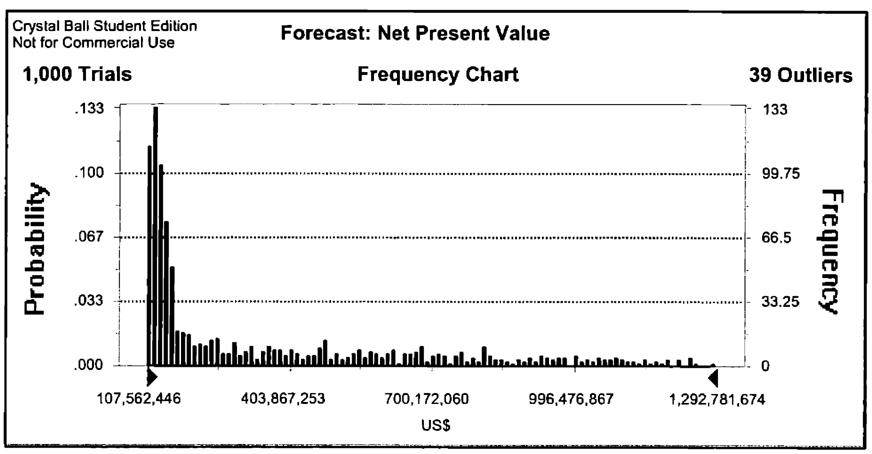
APPENDIX H: MONTE CARLO ANALYSIS FOR NET PRESENT VALUE

Crystal Ball Report
Simulation started on 5/1/02 at 18:12:06
Simulation stopped on 5/1/02 at 18:15:09

Forecast: Net Present Value **Cell: C229**

Summary:
Display Range is from 107,562,446 to 1,292,781,674 US$
Entire Range is from 102,788,241 to 1,944,212,043 US$
After 1,000 Trials, the Std. Error of the Mean is 11,021,678

Statistics:	Value
Trials	1000
Mean	373,720,821
Median	175,760,261
Mode	---
Standard Deviation	348,536,051
Variance	1E+17
Skewness	1.54
Kurtosis	4.75
Coeff. of Variability	0.93
Range Minimum	102,788,241
Range Maximum	1,944,212,043
Range Width	1,841,423,802
Mean Std. Error	11,021,677.69



Forecast: Net Present Value (cont'd) **Cell: C229**

Percentiles:

Percentile	US$
0%	102,788,241
10%	117,247,737
20%	126,513,134
30%	137,307,794
40%	148,870,501
50%	175,760,261
60%	275,424,047
70%	446,766,439
80%	649,020,886
90%	934,296,744
100%	1,944,212,043

End of Forecast

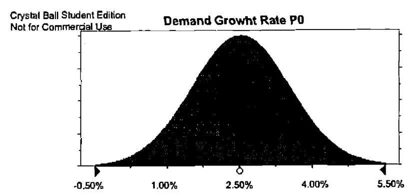
Assumptions

Assumption: Demand Growht Rate P0 **Cell: C221**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

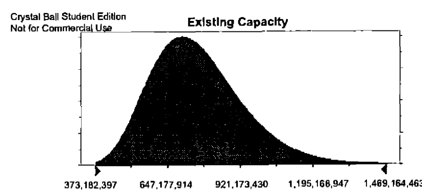


Assumption: Existing Capacity **Cell: C222**

Lognormal distribution with parameters:

Mean	760,017,000
Standard Dev.	175,874,157

Selected range is from 0 to +Infinity

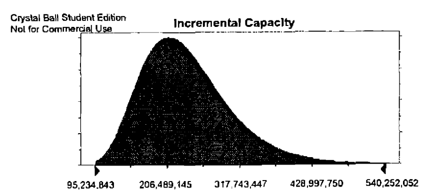


Assumption: Incremental Capacity **Cell: C223**

Lognormal distribution with parameters:

Mean	236,520,000
Standard Dev.	69,877,600

Selected range is from 0 to +Infinity

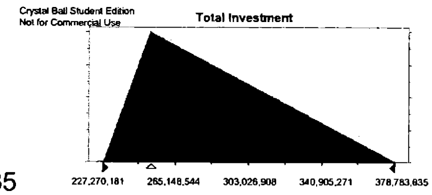


Assumption: Total Investment **Cell: C224**

Triangular distribution with parameters:

Minimum	227,270,181
Likeliest	252,522,423
Maximum	378,783,635

Selected range is from 227,270,181 to 378,783,635

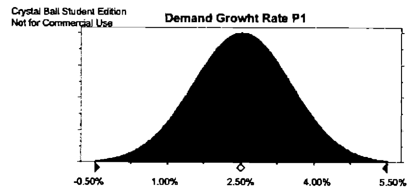


Assumption: Demand Growht Rate P1 **Cell: D221**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

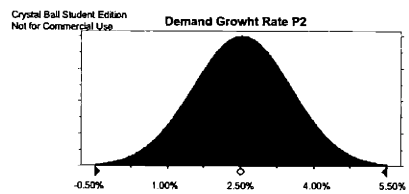


Assumption: Demand Growht Rate P2 **Cell: E221**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

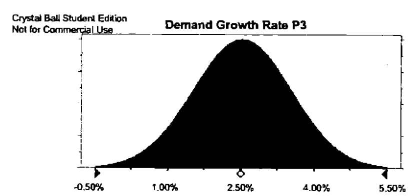


Assumption: Demand Growth Rate P3 **Cell: F221**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

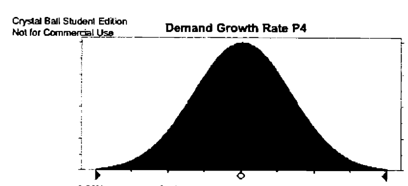


Assumption: Demand Growth Rate P4 **Cell: G221**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

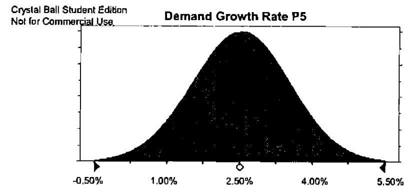


Assumption: Demand Growth Rate P5 **Cell: H221**

Normal distribution with parameters:

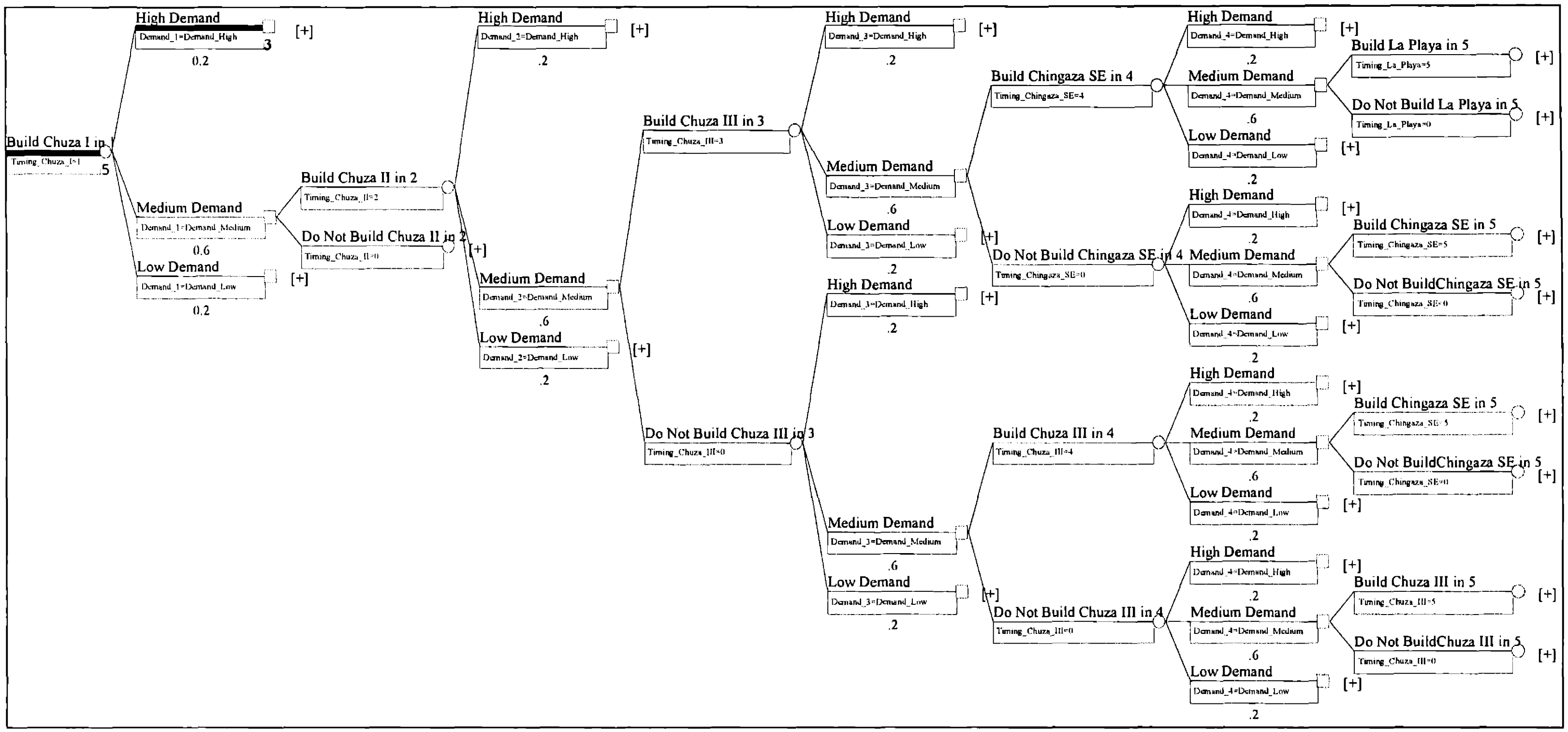
Mean	2.50%
Standard Dev.	1.00%

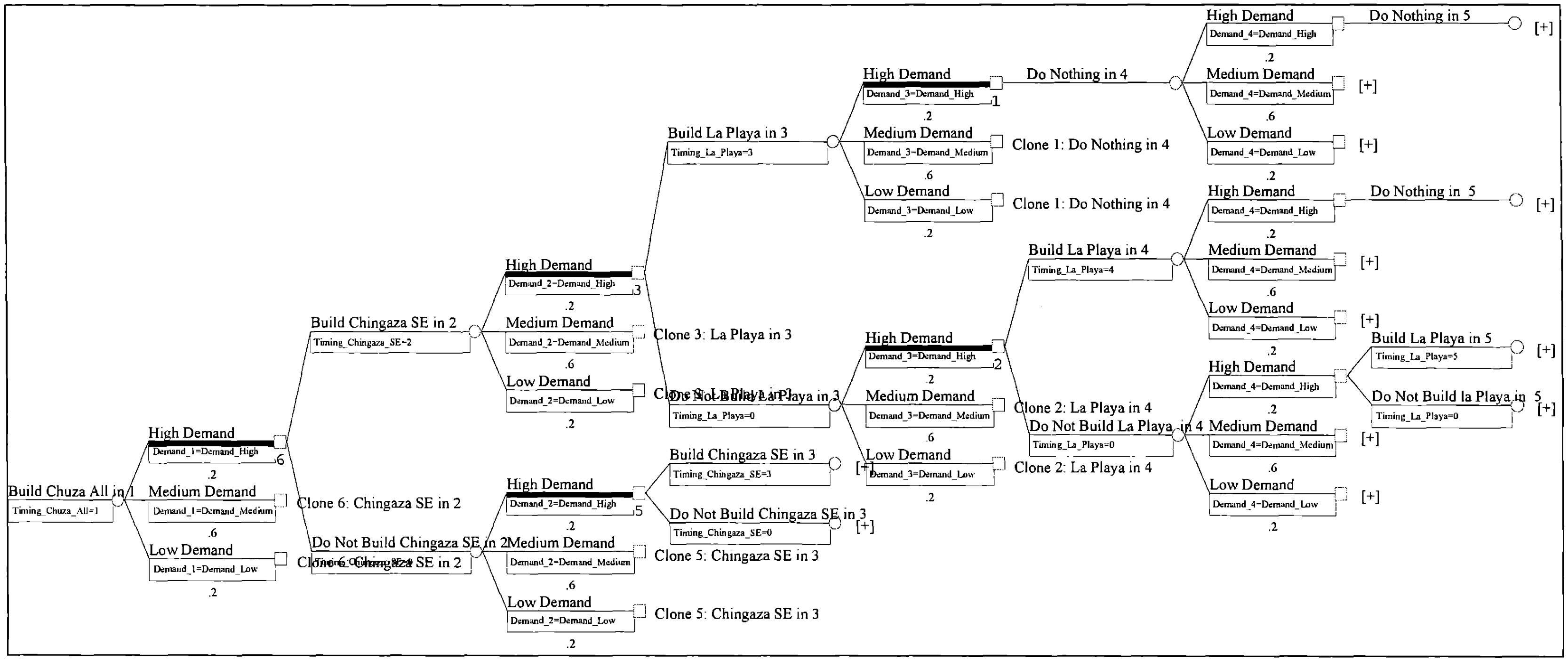
Selected range is from -Infinity to +Infinity

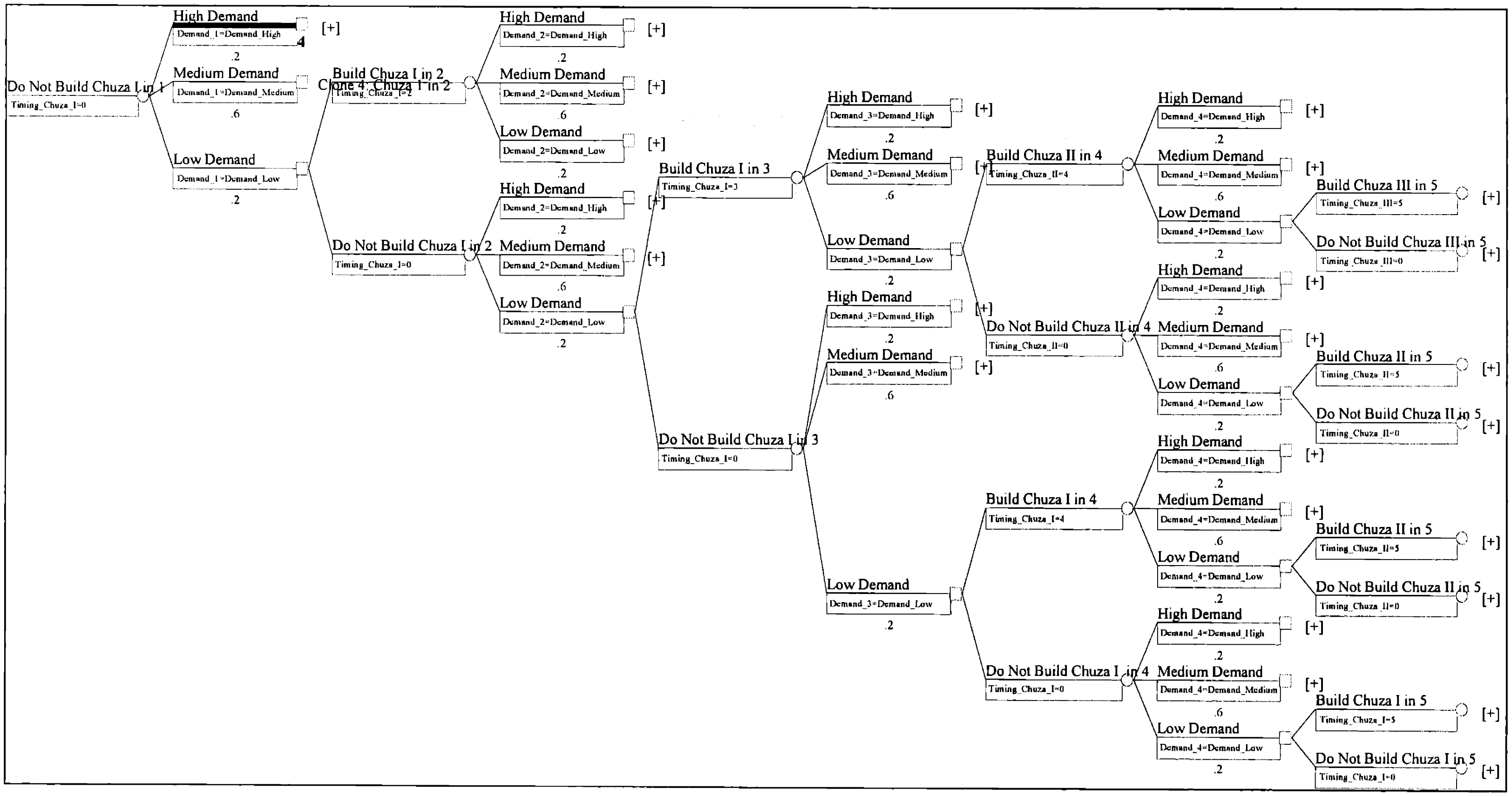


End of Assumptions

APPENDIX I: DECISION TREES




Build Chuza All in 1
Timing_Chuza_All=1
High Demand
Demand_1=Demand_High
Medium Demand
Demand_1=Demand_Medium
Low Demand
Demand_1=Demand_Low
Build Chingaza SE in 2
Timing_Chingaza_SE=2
Clone 6: Chingaza SE in 2
Do Not Build Chingaza SE in 2
High Demand
Demand_2=Demand_High
Medium Demand
Demand_2=Demand_Medium
Low Demand
Demand_2=Demand_Low
Build La Playa in 3
Timing_La_Playa=3
Clone 3: La Playa in 3
Do Not Build La Playa in 3
Timing_La_Playa=0
Build Chingaza SE in 3
Timing_Chingaza_SE=3
Do Not Build Chingaza SE in 3
Timing_Chingaza_SE=0
Clone 5: Chingaza SE in 3
Demand_3=Demand_High
Demand_3=Demand_Medium
Demand_3=Demand_Low
Do Nothing in 4
Clone 1: Do Nothing in 4
Build La Playa in 4
Timing_La_Playa=4
Clone 2: La Playa in 4
Do Not Build La Playa in 4
Demand_4=Demand_High
Demand_4=Demand_Medium
Demand_4=Demand_Low
Do Nothing in 5
Build La Playa in 5
Timing_La_Playa=5
Do Not Build la Playa in 5
[+]


Do Not Build Chuza I in 1
Timing_Chuza_I=0
High Demand
Demand_1=Demand_High
.2
Medium Demand
Demand_1=Demand_Medium
.6
Low Demand
Demand_1=Demand_Low
.2
Build Chuza I in 2
Clone 4: Chuza I in 2
Timing_Chuza_I=2
Do Not Build Chuza I in 2
Timing_Chuza_I=0
High Demand
Demand_2=Demand_High
Medium Demand
Demand_2=Demand_Medium
Low Demand
Demand_2=Demand_Low
Build Chuza I in 3
Timing_Chuza_I=3
Do Not Build Chuza I in 3
Timing_Chuza_I=0
High Demand
Demand_3=Demand_High
Medium Demand
Demand_3=Demand_Medium
Low Demand
Demand_3=Demand_Low
Build Chuza II in 4
Timing_Chuza_II=4
Do Not Build Chuza II in 4
Timing_Chuza_II=0
Build Chuza I in 4
Timing_Chuza_I=4
Do Not Build Chuza I in 4
Timing_Chuza_I=0
High Demand
Demand_4=Demand_High
Medium Demand
Demand_4=Demand_Medium
Low Demand
Demand_4=Demand_Low
Build Chuza III in 5
Timing_Chuza_III=5
Do Not Build Chuza III in 5
Timing_Chuza_III=0
Build Chuza II in 5
Timing_Chuza_II=5
Do Not Build Chuza II in 5
Timing_Chuza_II=0
Build Chuza I in 5
Timing_Chuza_I=5
Do Not Build Chuza I in 5
Timing_Chuza_I=0
[+]

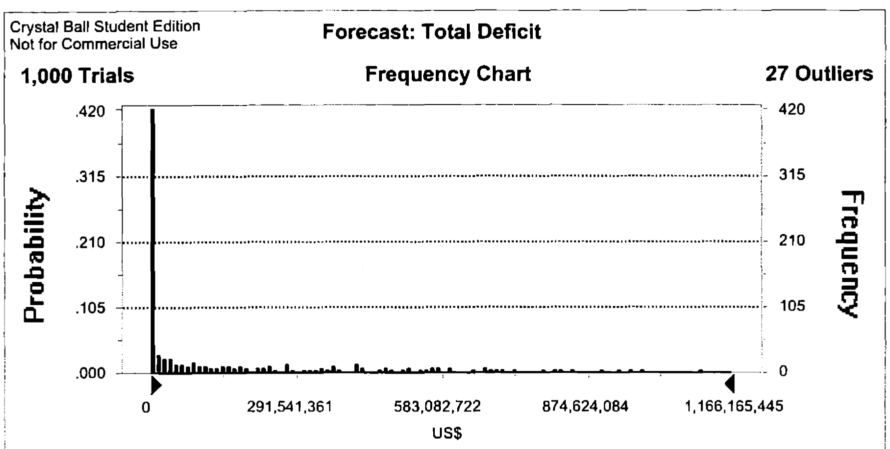
APPENDIX J: MONTE CARLO ANALYSIS FOR DEFICIT COST

Crystal Ball Report
Simulation started on 5/1/02 at 18:49:38
Simulation stopped on 5/1/02 at 18:50:01

Forecast: Total Deficit **Cell: C172**

Summary:
Display Range is from 0 to 1,166,165,445 US$
Entire Range is from 0 to 1,795,819,097 US$
After 1,000 Trials, the Std. Error of the Mean is 11,088,960

Statistics:	Value
Trials	1000
Mean	248,367,501
Median	52,846,204
Mode	0
Standard Deviation	350,663,695
Variance	1E+17
Skewness	1.54
Kurtosis	4.72
Coeff. of Variability	1.41
Range Minimum	0
Range Maximum	1,795,819,097
Range Width	1,795,819,097
Mean Std. Error	11,088,959.68



Forecast: Total Deficit (cont'd) **Cell: C172**

Percentiles:

Percentile	US$
0%	0
10%	0
20%	0
30%	0
40%	7,128,063
50%	52,846,204
60%	155,458,143
70%	321,209,578
80%	523,587,754
90%	806,435,715
100%	1,795,819,097

End of Forecast

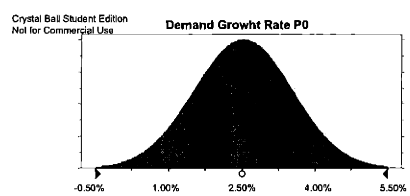
Assumptions

Assumption: Demand Growht Rate P0 **Cell: C162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

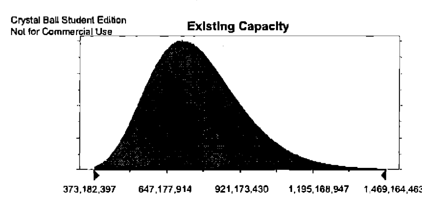


Assumption: Existing Capacity **Cell: C163**

Lognormal distribution with parameters:

Mean	760,017,000
Standard Dev.	175,874,157

Selected range is from 0 to +Infinity

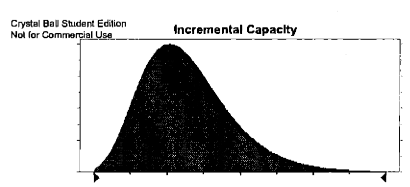


Assumption: Incremental Capacity **Cell: C164**

Lognormal distribution with parameters:

Mean	236,520,000
Standard Dev.	69,520,000

Selected range is from 0 to +Infinity

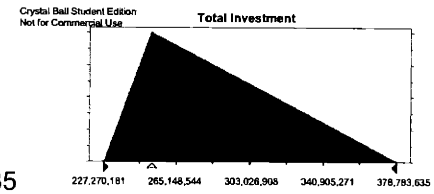


Assumption: Total Investment **Cell: C165**

Triangular distribution with parameters:

Minimum	227,270,181
Likeliest	252,522,423
Maximum	378,783,635

Selected range is from 227,270,181 to 378,783,635

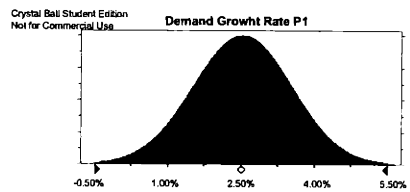


Assumption: Demand Growht Rate P1 **Cell: D162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

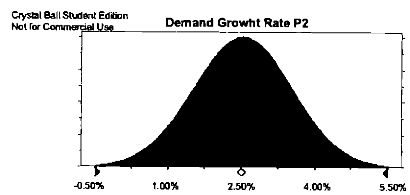


Assumption: Demand Growht Rate P2 **Cell: E162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

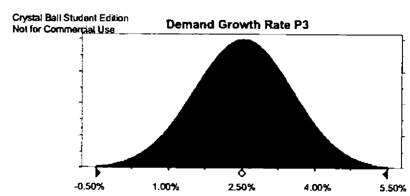


Assumption: Demand Growth Rate P3 **Cell: F162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

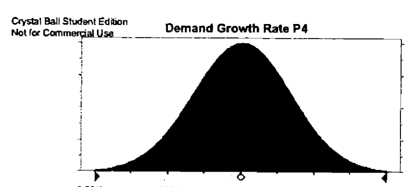


Assumption: Demand Growth Rate P4 **Cell: G162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity

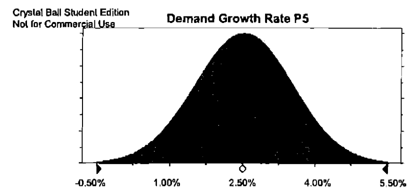


Assumption: Demand Growth Rate P5 **Cell: H162**

Normal distribution with parameters:

Mean	2.50%
Standard Dev.	1.00%

Selected range is from -Infinity to +Infinity



End of Assumptions

APPENDIX K: REAL OPTIONS RESULTS

I. INPUT AND CALCULATED PARAMETERS--CHUZA STAGE II

Input Parameters:	Symbol	
Period Risk-Free Rate (%)	rf	0.32
PV Underlying Asset (US$ Million)	V_o	248.00
Exercise Price (US$ Million)	X	30.84
Life of Option (periods)	t	5.00
Annual Standard Deviation (%)	σ	1.30
Calculated Parameters:		
Up movement per step	u	2.12
Down movement per step	d	0.47
Risk-neutral probability of up state	p	0.52
Risk-neutral probability of down state	q	0.48

II. BINOMIAL TREE FOR THE UNDERLYING--CHUZA STAGE II

	0	**1**	**2**	**3**	**4**	**5**
0	248	525	1,113	2,357	4,992	10,575
1		117	248	525	1,113	2,357
2			55	117	248	525
3				26	55	117
4					12	26
5						6

III. EVENT TREE--CHUZA STAGE II

a. Option Value

	0	**1**	**2**	**3**	**4**	**5**
0	218	495	1,083	2,327	4,962	10,544
1		101	218	495	1,083	2,327
2			48	101	218	495
3				24	49	101
4					12	26
5						6

b. Decisions

	0	**1**	**2**	**3**	**4**	**5**
0	Exercise	Exercise	Exercise	Exercise	Exercise	Exercise
1		Exercise	Exercise	Exercise	Exercise	Exercise
2			Keep.Open	Exercise	Exercise	Exercise
3				Keep.Open	Keep.Open	Exercise
4					Keep.Open	Keep.Open
5						Keep.Open

IV. OPTION VALUE CALCULATION (Replicating Portfolio)--CHUZA STAGE II

	End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Node	Up State	Down State	m	B	
K	10,544	2,327	1.0	(22.8)	4,970
L	2,327	495	1.0	(22.8)	1,090
M	495	101	1.0	(9.0)	230
N	101	26	0.8	3.5	49
O	26	6	1.0	-	12
G	4,962	1,083	1.0	(22.8)	2,334
H	1,083	218	1.0	(22.8)	503
I	218	49	0.9	0.5	103
J	49	12	0.9	1.4	24
D	2,327	495	1.0	(22.8)	1,090
E	495	101	1.0	(9.0)	230
F	101	24	0.9	1.1	48
B	1,083	218	1.0	(22.8)	503
C	218	48	0.9	(0.4)	103
A	495	101	1.0	(9.0)	230

I. INPUT AND CALCULATED PARAMETERS--CHUZA STAGE III

Input Parameters:	Symbol	
Period Risk-Free Rate (%)	rf	0.32
PV Underlying Asset (US$ Million)	V_o	217.84
Exercise Price (US$ Million)	X	35.12
Life of Option (years)	t	5.00
Annual Standard Deviation (%)	σ	1.15
Calculated Parameters:		
Up movement per step	u	1.94
Down movement per step	d	0.51
Risk-neutral probability of up state	p	0.57
Risk-neutral probability of down state	q	0.43

II. BINOMIAL TREE FOR THE UNDERLYING--CHUZA STAGE III

	0	**1**	**2**	**3**	**4**	**5**
0	218	495	1,083	2,327	4,962	10,544
1		101	218	495	1,083	2,327
2			48	101	218	495
3				24	49	101
4					12	26
5						6

III. EVENT TREE--CHUZA STAGE III

a. Option Value

	0	**1**	**2**	**3**	**4**	**5**
0	187	464	1,052	2,296	4,931	10,514
1		88	187	464	1,052	2,296
2			44	89	187	464
3				24	49	101
4					12	26
5						6

b. Decisions

	0	1	2	3	4	5
0	Keep.Open	Exercise	Exercise	Exercise	Exercise	Exercise
1		Keep.Open	Exercise	Exercise	Exercise	Exercise
2			Keep.Open	Keep.Open	Exercise	Exercise
3				Keep.Open	Keep.Open	Exercise
4					Keep.Open	Keep.Open
5						Keep.Open

IV. OPTION VALUE CALCULATION (Replicating Portfolio)--CHUZA STAGE III

	End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Node	*Up State*	*Down State*	*m*	*B*	
K	10,513.50	2,295.84	1.00	(23.33)	4,938.80
L	2,295.84	464.26	1.00	(23.33)	1,059.20
M	464.26	100.82	0.92	5.73	206.65
N	100.82	26.10	1.00	0.07	48.92
O	26.10	5.82	1.00	-	12.32
G	4,931.24	1,051.65	1.00	(23.33)	2,303.39
H	1,051.65	186.95	1.00	(23.33)	471.82
I	186.95	48.92	0.82	6.67	89.33
J	48.92	12.32	1.00	0.03	23.61
D	2,295.84	464.26	1.00	(23.33)	1,059.20
E	464.26	89.33	0.95	(5.18)	202.09
F	89.33	23.61	0.85	2.67	43.52
B	1,051.65	186.95	1.00	(23.33)	471.82
C	186.95	43.52	0.85	2.15	87.58
A	464.26	87.58	0.96	(6.83)	201.40

I. INPUT AND CALCULATED PARAMETERS--CHINGAZA SE

Input Parameters:	Symbol	
Period Risk-Free Rate (%)	rf	0.32
PV Underlying Asset (US$ Million)	V_o	186.95
Exercise Price (US$ Million)	X	42.00
Life of Option (periods)	t	5.00
Annual Standard Deviation (%)	σ	1.15
Calculated Parameters:		
Up movement per step	u	1.94
Down movement per step	d	0.51
Risk-neutral probability of up state	p	0.57
Risk-neutral probability of down state	q	0.43

II. BINOMIAL TREE FOR THE UNDERLYING--CHINGAZA SE

	0	**1**	**2**	**3**	**4**	**5**
0	186.95	464.26	1,051.65	2,295.84	4,931.24	10,513.50
1		87.58	186.95	464.26	1,051.65	2,295.84
2			43.52	89.33	186.95	464.26
3				23.61	48.92	100.82
4					12.32	26.10
5						5.82

III. EVENT TREE--CHINGAZA SE

a. Option Value

	0	**1**	**2**	**3**	**4**	**5**
0	164	430	1,018	2,262	4,897	10,479
1		77	164	430	1,018	2,262
2			40	80	164	430
3				24	49	101
4					12	26
5						6

b. Decisions

	0	1	2	3	4	5
0	Keep.Open	Exercise	Exercise	Exercise	Exercise	Exercise
1		Keep.Open	Exercise	Exercise	Exercise	Exercise
2			Keep.Open	Keep.Open	Exercise	Exercise
3				Keep.Open	Keep.Open	Keep.Open
4					Keep.Open	Keep.Open
5						Keep.Open

IV. OPTION VALUE CALCULATION (Replicating Portfolio)--CHINGAZA SE

	End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Node	*Up State*	*Down State*	*m*	*B*	
K	10,479.50	2,261.83	1.00	(25.69)	4,905.56
L	2,261.83	430.26	1.00	(25.69)	1,025.96
M	430.26	100.82	0.91	7.13	176.59
N	100.82	26.10	1.00	-	48.92
O	26.10	5.82	1.00	-	12.32
G	4,897.24	1,017.64	1.00	(25.69)	2,270.15
H	1,017.64	163.52	0.99	(15.98)	442.61
I	163.52	48.92	0.83	6.28	80.44
J	48.92	12.32	1.00	-	23.61
D	2,261.83	430.26	1.00	(25.69)	1,025.96
E	430.26	80.44	0.93	(2.20)	172.23
F	80.44	23.61	0.86	2.41	40.05
B	1,017.64	163.52	0.99	(15.98)	442.61
C	163.52	40.05	0.86	1.95	77.34
A	430.26	77.34	0.94	(3.56)	171.60

I. INPUT AND CALCULATED PARAMETERS--LA PLAYA

Input Parameters:	Symbol	
Period Risk-Free Rate (%)	*rf*	0.32
PV Underlying Asset (US$ Million)	V_o	163.52
Exercise Price (US$ Million)	*X*	39.86
Life of Option (years)	*t*	5.00
Annual Standard Deviation (%)	σ	1.15
Calculated Parameters:		
Up movement per step	*u*	1.94
Down movement per step	*d*	0.51
Risk-neutral probability of up state	*p*	0.57
Risk-neutral probability of down state	*q*	0.43

II. BINOMIAL TREE FOR THE UNDERLYING--LA PLAYA

	0	1	2	3	4	5
0	163.52	430.26	1,017.64	2,261.83	4,897.24	10,479.50
1		77.34	163.52	430.26	1,017.64	2,261.83
2			40.05	80.44	163.52	430.26
3				23.61	48.92	100.82
4					12.32	26.10
5						5.82

III. EVENT TREE--LA PLAYA

a. Option Value

		0	1	2	3	4	5
	0	154	415	1,003	2,247	4,882	10,464
	1		73	154	415	1,003	2,247
9.19	**2**			39	77	154	415
	3				24	49	101
	4					12	26
	5						6

b. Decisions

	0	1	2	3	4	5
0	Keep.Open	Keep.Open	Keep.Open	Exercise	Exercise	Exercise
1		Keep.Open	Keep.Open	Keep.Open	Keep.Open	Exercise
2			Keep.Open	Keep.Open	Keep.Open	Keep.Open
3				Keep.Open	Keep.Open	Keep.Open
4					Keep.Open	Keep.Open
5						Keep.Open

IV. OPTION VALUE CALCULATION (Replicating Portfolio)--LA PLAYA

	End-of-Period Payoff		*Replicating Portfolio Parameters*		*Option Value*
Node	*Up State*	*Down State*	*m*	*B*	
K	10,464.36	2,246.69	1.00	(11.44)	4,885.80
L	2,246.69	415.12	1.00	(11.44)	1,006.21
M	415.12	100.82	0.95	3.50	159.50
N	100.82	26.10	1.00	-	48.92
O	26.10	5.82	1.00	-	12.32
G	4,882.10	1,002.50	1.00	(11.44)	2,250.39
H	1,002.50	154.32	0.99	(6.09)	421.18
I	154.32	48.92	0.92	2.97	76.95
J	48.92	12.32	1.00	-	23.61
D	2,246.69	415.12	1.00	(11.44)	1,006.21
E	415.12	76.95	0.97	(0.61)	157.46
F	76.95	23.61	0.94	1.10	38.68
B	1,002.50	154.32	0.99	(6.09)	421.18
C	154.32	38.68	0.94	0.89	73.33
A	415.12	73.33	0.97	(1.19)	157.17

APPENDIX L: EXCERPTS CRIMINAL CODE OF LAW

TÍTULO XV.

DELITOS CONTRA LA ADMINISTRACIÓN PÚBLICA

CAPÍTULO PRIMERO

DEL PECULADO

ARTÍCULO 397 - Peculado por apropiación. El servidor público que se apropie en provecho suyo o de un tercero de bienes del Estado o de empresas o instituciones en que éste tenga parte o de bienes o fondos parafiscales, o de bienes de particulares cuya administración, tenencia o custodia se le haya confiado por razón o con ocasión de sus funciones, incurrirá en prisión de seis (6) a quince (15) años, multa equivalente al valor de lo apropiado sin que supere el equivalente a cincuenta mil (50.000) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas por el mismo término.

Si lo apropiado supera un valor de doscientos (200) salarios mínimos legales mensuales vigentes, dicha pena se aumentará hasta en la mitad. La pena de multa no superará los cincuenta mil salarios mínimos legales mensuales vigentes.

Si lo apropiado no supera un valor de cincuenta (50) salarios mínimos legales mensuales vigentes la pena será de cuatro (4) a diez (10) años e inhabilitación para el ejercicio de derechos y funciones públicas por el mismo término y multa equivalente al valor de lo apropiado.

ARTÍCULO 398 - Peculado por uso. El servidor público que indebidamente use o permita que otro use bienes del Estado o de empresas o instituciones en que éste tenga parte, o bienes de particulares cuya administración, tenencia o custodia se le haya confiado por razón o con ocasión de sus funciones, incurrirá en prisión de uno (1) a cuatro (4) años e inhabilitación para el ejercicio de derechos y funciones públicas por el mismo término.

ARTÍCULO 399 - Peculado por aplicación oficial diferente. El servidor público que dé a los bienes del Estado o de empresas o instituciones en que éste tenga parte, cuya administración, tenencia o custodia se le haya confiado por razón o con ocasión de sus funciones, aplicación oficial diferente de aquella a que están destinados, o comprometa sumas superiores a las fijadas en el presupuesto, o las invierta o utilice en forma no prevista en éste, en perjuicio de la inversión social o de los salarios o prestaciones sociales de los servidores, incurrirá en prisión de uno (1) a tres (3) años, multa de diez (10) a cincuenta (50) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas por el mismo término.

ARTÍCULO 400 - Peculado culposo. El servidor público que respecto a bienes del Estado o de empresas o instituciones en que éste tenga parte, o bienes de particulares cuya administración, tenencia o custodia se le haya confiado por razón o con ocasión de sus funciones, por culpa dé lugar a que se extravíen, pierdan o dañen, incurrirá en prisión de uno (1) a tres (3) años, multa de diez (10) a cincuenta (50) salarios mínimos legales mensuales vigentes e inhabilitación para el ejercicio de funciones públicas por el mismo término señalado.

ARTÍCULO 401 - Circunstancias de atenuación punitiva. Si antes de iniciarse la investigación, el agente, por sí o por tercera persona, hiciere cesar el mal uso, reparare lo dañado o reintegrare lo apropiado, perdido, extraviado, o su valor, la pena se disminuirá en la mitad.

Si el reintegro se efectuare antes de dictarse sentencia de segunda instancia, la pena se disminuirá en una tercera parte.

Cuando el reintegro fuere parcial, el juez deberá, proporcionalmente, disminuir la pena en una cuarta parte.

ARTÍCULO 402 - Omisión del agente retenedor o recaudador. El agente retenedor o autorretenedor que no consigne las sumas retenidas o autorretenidas por concepto de retención en la fuente dentro de los dos (2) meses siguientes a la fecha fijada por el Gobierno Nacional para la presentación y pago de la respectiva declaración de retención en la fuente o quien encargado de recaudar tasas o contribuciones públicas no las consigne dentro del término legal, incurrirá en prisión de tres (3) a seis (6) años y multa equivalente al doble de lo no consignado sin que supere el equivalente a cincuenta mil (50.000) salarios mínimos legales mensuales vigentes.

En la misma sanción incurrirá el responsable del impuesto sobre las ventas que, teniendo la obligación legal de hacerlo, no consigne las sumas recaudadas por dicho concepto, dentro de los dos (2) meses siguientes a la fecha fijada por el Gobierno Nacional para la presentación y pago de la respectiva declaración del impuesto sobre las ventas.

Tratándose de sociedades u otras entidades, quedan sometidas a esas mismas sanciones las personas naturales encargadas en cada entidad del cumplimiento de dichas obligaciones.

Parágrafo. El agente retenedor o autorretenedor, responsable del impuesto a las ventas o el recaudador de tasas o contribuciones públicas, que extinga la obligación tributaria por pago o compensación de las sumas adeudadas, según el caso, junto con sus correspondientes intereses previstos en el estatuto Tributario, y normas legales respectivas, se hará beneficiario de resolución inhibitoria, preclusión de investigación, o cesación de procedimiento dentro del proceso penal que se hubiera iniciado por tal motivo, sin perjuicio de las sanciones administrativas a que haya lugar.

ARTÍCULO 403 - Destino de recursos del tesoro para el estímulo o beneficio indebido de explotadores y comerciantes de metales preciosos. El servidor público que destine recursos del tesoro para estimular o beneficiar directamente o por interpuesta persona, a los explotadores y comerciantes de metales preciosos, con el objeto de que declaren sobre el origen o procedencia del mineral precioso, incurrirá en prisión de dos (2) a cinco (5) años, en multa de cien (100) a quinientos (500) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas por cinco (5) años.

En la misma pena incurrirá el que reciba con el mismo propósito los recursos del tesoro, o quien declare producción de metales preciosos a favor de municipios distintos al productor.

CAPÍTULO SEGUNDO

DE LA CONCUSIÓN

ARTÍCULO 404 - Concusión. El servidor público que abusando de su cargo o de sus funciones constriña o induzca a alguien a dar o prometer al mismo servidor o a un tercero, dinero o cualquier otra utilidad indebidos, o los solicite, incurrirá en prisión de seis (6) a diez (10) años, multa de cincuenta (50) a cien (100) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

CAPÍTULO TERCERO

DEL COHECHO

ARTÍCULO 405 - Cohecho propio. El servidor público que reciba para sí o para otro dinero u otra utilidad, o acepte promesa remuneratoria, directa o indirectamente, para retardar u omitir un acto propio de su cargo, o para ejecutar uno contrario a sus deberes oficiales, incurrirá en prisión de cinco (5) a ocho (8) años, multa de cincuenta (50) a cien (100) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

ARTÍCULO 406 - Cohecho impropio. El servidor público que acepte para sí o para otro, dinero u otra utilidad o promesa remuneratoria, directa o indirecta, por acto que deba ejecutar en el desempeño de sus funciones, incurrirá en prisión de cuatro (4) a siete (7) años, multa de cincuenta (50) a cien (100) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

El servidor público que reciba dinero u otra utilidad de persona que tenga interés en asunto sometido a su conocimiento, incurrirá en prisión de dos (2) a cinco (5) años, multa de treinta (30) a cincuenta (50) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas por cinco (5) años.

ARTÍCULO 407 - Cohecho por dar u ofrecer. El que dé u ofrezca dinero u otra utilidad a servidor público, en los casos previstos en los dos Artículos anteriores, incurrirá en prisión de tres (3) a seis (6) años, multa de cincuenta (50) a cien (100) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

CAPÍTULO CUARTO

DE LA CELEBRACIÓN INDEBIDA DE CONTRATOS

ARTÍCULO 408 - Violación del régimen legal o constitucional de inhabilidades e incompatibilidades. El servidor público que en ejercicio de sus funciones intervenga en la tramitación, aprobación o celebración de un contrato con violación al régimen legal o a lo dispuesto en normas constitucionales, sobre inhabilidades o incompatibilidades, incurrirá en prisión de cuatro (4) a doce (12) años, multa de cincuenta (50) a doscientos (200) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a doce (12) años.

ARTÍCULO 409 - Interés indebido en la celebración de contratos. El servidor público que se interese en provecho propio o de un tercero, en cualquier clase de contrato u operación en que deba intervenir por razón de su cargo o de sus funciones, incurrirá en prisión de cuatro (4) a doce (12) años, multa de cincuenta (50) a doscientos (200) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a doce (12) años.

ARTÍCULO 410 - Contrato sin cumplimiento de requisitos legales. El servidor público que por razón del ejercicio de sus funciones tramite contrato sin observancia de los requisitos legales esenciales o lo celebre o liquide sin verificar el cumplimiento de los mismos, incurrirá en prisión de cuatro (4) a doce (12) años, multa de cincuenta (50) a doscientos (200) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a doce (12) años.

CAPÍTULO QUINTO

DEL TRÁFICO DE INFLUENCIAS

ARTÍCULO 411 - Tráfico de influencias de servidor público.- El servidor público que utilice indebidamente, en provecho propio o de un tercero, influencias derivadas del ejercicio del cargo o de la función, con el fin de obtener cualquier beneficio de parte de servidor público en asunto que éste se encuentre conociendo o haya de conocer, incurrirá en prisión de cuatro (4) a ocho (8) años, multa de cien (100) a doscientos (200) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

CAPÍTULO SEXTO

DEL ENRIQUECIMIENTO ILÍCITO

ARTÍCULO 412 - Enriquecimiento ilícito. El servidor público que durante su vinculación con la administración, o quien haya desempeñado funciones públicas y en los dos años siguientes a su desvinculación, obtenga, para sí o para otro, incremento patrimonial injustificado, siempre que la conducta no constituya otro delito, incurrirá en prisión de seis (6) a diez (10) años, multa equivalente al doble del valor del enriquecimiento sin que supere el equivalente a cincuenta mil (50.000) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de seis (6) a diez (10) años.

CAPÍTULO SÉPTIMO.

DEL PREVARICATO

ARTÍCULO 413 - Prevaricato por acción. El servidor público que profiera resolución, dictamen o concepto manifiestamente contrario a la ley, incurrirá en prisión de tres (3) a ocho (8) años, multa de cincuenta (50) a doscientos (200) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas de cinco (5) a ocho (8) años.

ARTÍCULO 414- Prevaricato por omisión. El servidor público que omita, retarde, rehuse o deniegue un acto propio de sus funciones, incurrirá en prisión de dos (2) a cinco (5) años, multa de diez (10) a cincuenta (50) salarios mínimos legales mensuales vigentes, e inhabilitación para el ejercicio de derechos y funciones públicas por cinco (5) años.

ARTÍCULO 415 - Circunstancia de agravación punitiva. Las penas establecidas en los Artículos anteriores se aumentarán hasta en una tercera parte cuando las conductas se realicen en actuaciones judiciales o administrativas que se adelanten por delitos de genocidio, homicidio, tortura, desplazamiento forzado, desaparición forzada, secuestro, secuestro extorsivo, extorsión, rebelión, terrorismo, concierto para delinquir, narcotráfico, enriquecimiento ilícito, lavado de activos, o cualquiera de las conductas contempladas en el título II de este Libro.