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Development of a Sustainable Water Resource Financing Mathematical Model for Donors and End-Users

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DEVELOPMENT OF A SUSTAINABLE WATER RESOURCE FINANCING MATHEMATICAL MODEL FOR DONORS AND END-USERS

by

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ABSTRACT

Development of a Sustainable Water Resource Financing Mathematical Model for Donors and End-Users

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Rural villages and underdeveloped communities represent the largest group challenged by poor water supply and sanitation with inequalities in resources to adequately implement potential solutions and even more with their high risk level of financing, funding is particularly challenging for water projects. Innovative financing alone will not eliminate the burdens of rural villages and underdeveloped communities. The purpose of this thesis is to address the lack of sustainable water financing of water projects in rural areas using a novel framework of a mathematical model based on "system dynamics" using optimal feedback control theory to maximize the performance of a water project. This is achieved by using feedback loops that allow for a real-time adjustment of the input parameters. The case model presented considers a renewable water supply system for a rural village where the user's willingness to pay along with demand drive the performance indicators to simulate how decision makers can make real-time decisions on how to manage financing instruments and long-term debt. The results of the study are the first step to the mathematical framework of optimal control of cash flows. Future research is aimed at applying optimal control using ordinary differential equations and stochastic differential equations which is presented in theoretical form.

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CHAPTER 1

INTRODUCTION

Water is the basis of life; central to the material and cultural well-being of societies worldwide (Shiva, 2002). Civilizations have risen and fallen with the changing water (Roy, 2011). Given that water is such a precious commodity to society, where less than two-thirds of the Earth's surface covered by water, managing this finite resource is essential to our future well-being. Our water challenges lie within the lack of development in poor countries, rather than the absence of available water (Segerfeldt, 2005). These challenges arise with the inability to produce and distribute safe water in countries that lack sufficient infrastructure development (Segerfeldt, 2005).

The most common water-uses consist of drinking, cooking, bathing, cleaning, and agricultural usage. The most crucial is domestic water use but industry consumes twice the amount than households (Cosgrove & Rijsberman, 2000). There are one billion people without access to water within a 15-minute walk of their homes and 25 million people that die each year from contaminated water (Roddick, 2004). Currently there are more than 2 billion people that have no sanitation system (Frerot, 2011). Furthermore, the UN estimates that in less than 20 years, 5 billion people will live in areas where it will be impossible or nearly impossible to collect water for basic sanitation, cooking, and drinking needs, if we continue with current water consumption trends (Roddick, 2004).

In 2000 the United Nations Development Programme (UNDP) established the Millennium Development Goals (MDGs), which specified targets for sustainable access to safe drinking water and basic sanitation provisions for 2015 (UNDP, 2011). Much progress has been made but many countries still fall short of these goals. As we approach 2015, 235 million people will not meet the drinking water provisions and 700 million people from 74 countries will not achieve basic water sanitation (Frerot, 2011).

1.1 Water Financing

Water serves as a resource and a service which must be developed, managed, and distributed. Both the resource and service aspects require financing which is currently found to be deficient due to its lack of sustainability (Winpenny, 2003). Water infrastructure is financed by three different sources: water users usually through some form of water billing arrangement, taxpayers, and aid donors. Financing water infrastructure requires monies to be spent on financing long-term physical assets. These include but are not limited to present cash flows or reserves on water projects or by loans or equity, which must be repaid by sources from users, taxpayers or donors (Winpenny, 2003). Sources of water funds (Winpenny, 2003):

- Water users
- Informal suppliers
- Public water authorities and utilities
- Private companies
- Non-governmental organizations (NGOs) and local communities
- Local banks and other financial institutions
- International banks and export credit agencies

- International aid from multilateral and bilateral sources
- Environmental and water funds
- National central and local governments

The discussions of financing water policies and water regimes have steadily been at the forefront of global environmental politics (Porter & Brown, 2006). A central concern to comply with obligations stipulated under environmental treaties or environmental projects, such as the MDGs, set to improve social and economic conditions in the world's poorest countries, are the need for financial and technical assistance of water projects in developing countries. These challenges will be continually encountered throughout the debate of global environmental policy. Improving financial resources for advancing water infrastructures is a major obstacle of compliance for implementing water projects, as well as addressing the lack of financial and technical resources to fulfill project obligations, which are the key to project effectiveness (Porter & Brown, 2006). Ultimately, the success of water programs lies within innovative approaches to financing.

Much debate has recently occurred over the role of donors in the water market, especially concerning the private sector which is presently involved in less than 10% of the MDGs drinking water provisions (Frerot, 2011). Official development assistance (ODA) has been the principal source of funding for developing countries since World War II, especially in leveraging other financial flows such as bank loans or bond financing (Ketkar and Ratha, 2006). ODA has primarily been allocated in projects for water supply and sanitation projects of large systems and policies as shown in Figure 1 (Ketkar and Ratha, 2006). Examining how water projects are segmented based on credit risk potential exposes the limitations of available financing in the sector. Figure 2 points out the exposed areas of financing not covered by the private sector of larger scale projects, where the risk associated is considered to be too high for investments and generally does not meet the guidelines of ODA investments. For smaller scale projects with high risks, microloans are the financing instrument utilized and are not considered for any other type of funding structure. The main objective of microfinance has been to improve and increase the flow of funds to high risk and low income clients in developing countries (Schicks and Rosenberg, 2011).

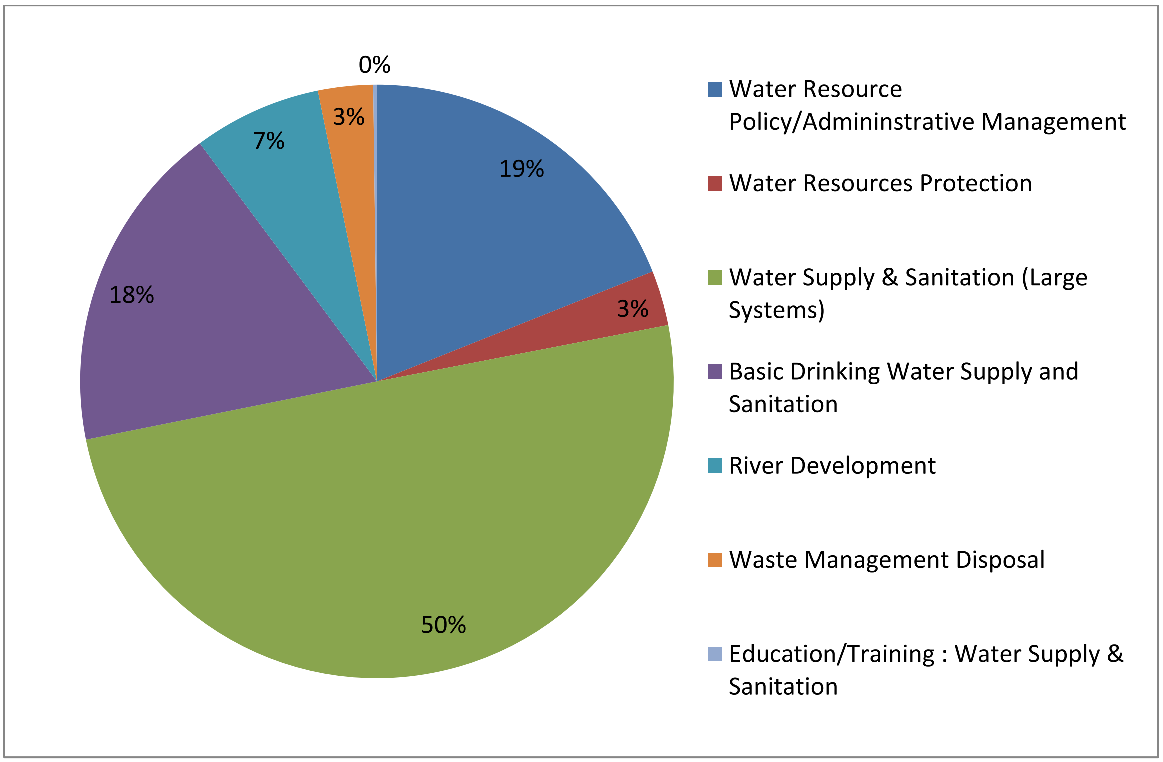

Figure 1.1. Breakdown of ODAs for Water by Project Type (Ketkar and Ratha, 2006)

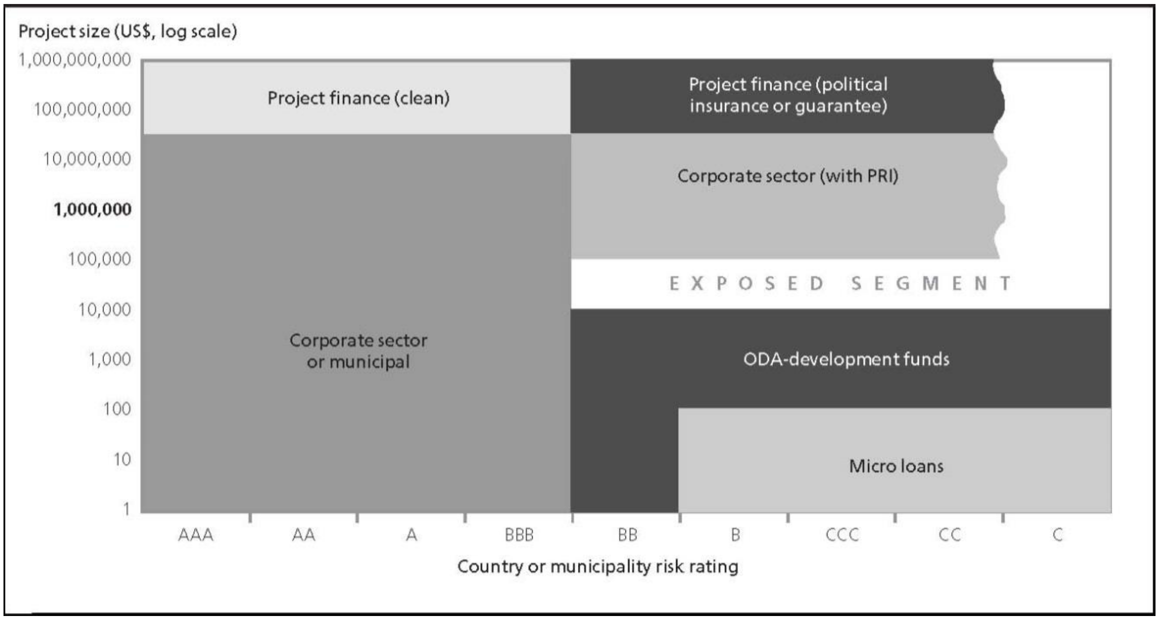

Figure 1.2. Water Projects Segmentation, Financing Options (Winpenny, 2003)

"Developing countries have always looked for new and innovative ways of raising finance" (Ketkar & Ratha, 2009, p.2). When trying to understand the meaning of innovative financing there is no universal definition available. For this thesis the definition provided by the World Bank will be used (Sandor, Scott & Benn, 2009):

> "Innovative financing involves non-traditional applications of solidarity, Public-Private Partnerships (PPP), and catalytic mechanisms that (i) support fundraising by tapping new sources and engaging investors beyond the financial dimension of transactions, as partners and stakeholders in development; or (ii) deliver financial solutions to development problems on the ground" (p.3).

The definition points out that the way we manage our water resources must include all the stakeholders, so that they, the investors and end-users, have the power to manage their own resources, respectively. Water financing should focus on being more responsive to all the stakeholders and not biased to just the investor or only the end-users, so that the projects can be more effective in distribution, management, and maintenance of the water resources. If there is a monetary stake, the water usage, service needs, and expectations of users will influence the financial instruments implemented in the project model. Empowering the communities to be a stakeholder can lead the way to improving designs and operations of local water resources, making them more sustainable. Because stakeholders have different stances on which they base terms set forth for financing, it is necessary to evaluate these conditions by each stakeholder in an effective model that can measure both the risk and financing terms.

1.2 Problem Statement

Rural villages and underdeveloped communities represent a large portion of the population faced by the challenges of poor water supply and sanitation but vary widely amid economic resources and water resource models (Cardone and Fonseca, 2006). However, due to the high risk level of financing water projects in these communities, funding is particularly challenging. Additionally, many water projects have been found to lack sustainability. Water For People (WFP), an NGO aiming to address sustainable coverage of water and sanitation, found that as many as 50% of the Water, Sanitation and Hygiene (WASH) projects completed by all service and faith-based organizations have not demonstrated sustainability within five years of their completion, indicating that many WASH projects are not designed or implemented to be sustainable (WASRAG, 2008). Further research of

WFP in 2010 observed that “successful water and sanitation interventions actually get into the financial details that will influence supplies over time. Unfortunately most organizations shy away from this challenge because it is hard and time consuming. This is short sighted of course, and projects fail because NGOs dodge this hard work by making the case that communities suffer not just from water poverty but also from cashlessness in this particular paradigm” (Breslin, 2010 p. 67).

1.2 Purpose/Research Question

The purpose of this thesis is to address the lack of sustainable water financing of water projects in rural areas by a novel framework. The proposed mathematical model is based on “system dynamics” and uses optimal feedback control theory to maximize the performance of a water project. This is achieved by using feedback loops that allow for a real-time adjustment of the input parameters.

1.3 Scope

The scope of this thesis is to:

1. Assess all of the stakeholder’s willingness and ability to pay rather than idealistic projections and expectations to identify parameters to measure objectives of an ideal water project

2. Target rural and underdeveloped communities

3. Focuses on borrower-lender financing strategies to optimize usage of funds to facilitate the definition of appropriate terms for water financed projects for an ideal return and success of the project for all stakeholders

4. Demonstrate the need to integrate system dynamics with optimal control theory with feedback loops using ordinary differential equations or stochastic differential equations

1.4 Objectives

The objectives of this thesis are to:

1. Propose a mathematical model as a basis of a theoretical framework for sustainable financing mechanisms of water projects funded by groups like NGOs, philanthropic donors, and investors

1.5 Outline of the Thesis

The thesis is organized into seven chapters; examining the infrastructure of water financing for the development of the framework for the mathematic model in a system dynamics approach.

1. Chapter 1 introduced the challenges of water financing in general and in particular pertaining to rural communities. It further discusses the objective of this thesis and current financing mechanisms of water projects to demonstrate the need for creating a sustainable and practical mathematical model for water financing.

2. Chapter 2 presents the examination of the stakeholders involved in the cash flow of monies distributed and financed for water projects. What are their objectives and interests in funding water projects? Evaluation of how to manage donor expectations without sacrificing the needs of the benefactors of these projects.

3. Chapter 3 discusses and evaluates current financing structures of water projects. The applied financial instruments are examined in terms of their applicability, potential, and limitations for water financing.

4. Chapter 4 assesses the benefactors of water projects financed by the donors discussed in Chapter 2. The benefactors are investigated with respect to weighing impact with long-term benefits and losses for stakeholders.

5. Chapter 5 presents the framework of optimal water financing. Current water financing frameworks are reviewed and details of the proposed model are discussed.

6. Chapter 6 demonstrates the functionality of the framework through analysis of a model case for which flexible financing terms that are measurable, clearly defined, and manage stakeholder expectations with appropriate time scales that are adjustable as needed to achieve objectives set forth by the project, are created. The results of the model results are discussed in detail.

7. Chapter 7 summarizes the results of the research presented in this thesis.

CHAPTER 2

DONORS

2.1 Background

When examining the donor profiles of the water sector, there are two categories of financial support: Internal Financing Agencies (IFAs) and External Financing Agencies (EFAs). IFAs generally constitute of national governments whereas EFAs comprise of NGOs, charitable organizations, philanthropic donors, and investors (Hamdy, 2002). Donors aim to benefit rural and underdeveloped communities that focus on borrower-lender financing strategies to optimize the usage of funds. Donor investments in the water sector are provided in the following Figure 2.1. The figures represent financial contributions from major bilateral and multilateral donors of water supply, sanitation, irrigation and water resources (Hamdy, 2002).

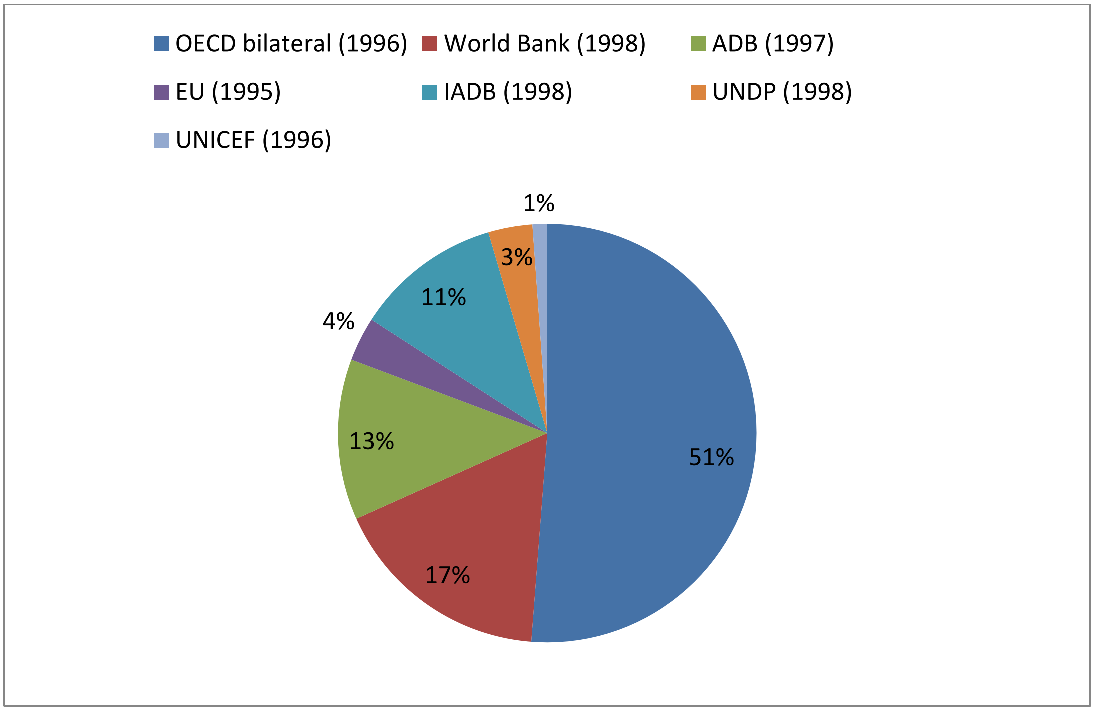

Figure 2.1. Donor Investments in the Water Sector in bn US$ (Source: Hamdy, 2002)

A closer examination of where the funds derive in the water sector was conducted in the "Financing Water For All Report" chaired by Michel Camdessus. By assessing the source of funds the data and figures can be incorporated into an appropriate platform for the demand and supply side. The following is a breakdown of the water funds source analysis from the report (Winpenny, 2003):

- Water users
  - Include households, farmers, and industry. Householder consumers in rural areas and especially in poorer urban districts invest available cash, labor, and materials in wells, pipes, essential sanitation, and other basic necessities. Farmers tend to invest largely in tubewells, pumps, and surface irrigation systems facilitated by member

associations and user groups. In some cases farmers can sell surpluses of water in the open market. Industry and business will commonly develop their own water supplies and treatment facilities, which in some cases support the local communities. Tariffs are also a form of water subsidy for water infrastructure to support the general population demands and supply.

- Informal suppliers
    - Where there is a lack of infrastructure from the public services or investors, there are those that will provide water in bulk from tankers, containers and bottles.

- Public water authorities and utilities
    - Consist of funds from regular spending and investments from revenues generated by user charges, loans or public subsidies.

- Private companies
    - Include local or foreign funds from resources such as public utilities and equity investments.

- Non-governmental organizations and local communities
    - These groups raise funds from private contributions, donations or grants.

- Local banks and other financial institutions

    - These institutions offer short-term (up to three years) to medium-term (three to ten years) loans at market rates.

- International banks and export credit agencies
    - Provide larger capacities of finance than traditional local establishments that entail corporate guarantees or projected cash flow analysis.

- International aid from multilateral and bilateral sources
    - Consist of loans based on concessional terms or grants.

- Multilateral Financial Institutions
    - Consist of loans with near-market terms.

- Environmental and water funds
    - Contain a variety of expenditures such as earmarked tax funds, directed credit funds, and green funds.

- National central and local governments
    - Provide subsidies, guarantees of loans, and proceeds of bond issues.

The water sector tends to generally obtain funds through government budgets which are the largest contributors, development agencies which consist of bilateral, multilateral and NGOs along with domestic based private operators and a limited amount from the international private sector (Cardone and Fonseca, 2006). The Organisation for Economic Co-operation and Development (OECD) created the Development Assistance Committee (DAC) to measure international aid flow. The official DAC for Official Development Assistance (ODA) specifies "money flows to countries on Part I of the DAC List of Aid Recipients (developing countries) and to multilateral institutions for flows to Part I aid recipients" (Clermont, 2006). The ODA is provided by agencies, state, and local governments or by third parties involved in distribution of funds. Each transaction must meet two conditions:

a. The transaction is administered with the promotion of the economic development and welfare of developing countries as its main objective; and

b. Is given special consideration and contains a grant element higher than 25% (calculated at a discount rate of 10 per cent). The definition of a grant element is calculated as "the difference between the face value of the loan and the discounted present value of the service payments the borrower will make over the lifetime of the loan, expressed as a percentage of the face value" (Clermont, 2006).

2.2 ODA Source of Funds

ODA is made up of grants and concessional loans to support socio-economic development from a government of a donor country directly to a developing country or a multilateral agency. A significant issue in the development of cooperation of this aid is the allocation of ODA and the classification by region, country, sector or focus area. Donors' allocations largely are directed by their governing policy resulting in conservative allocations, where established obligations tend to stay at same levels with limited changes through small adjustments (OECD, 2009).

ODA can be in the form of a bilateral or multilateral transaction. For a transaction to be considered bilateral it must remain under control of two parties: the donor country and the recipient country. An exception is made when the aid is passed through NGOs or international aid organizations but is under the control of the donor country. Unlike a bilateral contribution of two parties, a multilateral ODA consists of donations from OEDC member countries to international organizations working with the recipient country for aid, where they may provide all or part of the activities involved with the aid (Clermont, 2006).

ODA multilateral sources relatively stayed at 600 million dollars through the late 1990s which began to rise and accounted for 85% of commitments until the mid-1990s. An increase of multilateral grants is the most recent trend in multilateral grants. ODA for water funded by multilateral aid commitments was 25% at the beginning of the 1990s but has gradually risen to 30% of late, which indicates a change in policy of donors moving from bilateral policies and supporting more efforts of international institutions in the water sector (Clermont, 2006).

There have also been bilateral aid increases in commitments from 1.9 billion dollars in 1990 to 2.4 billion dollars in 2002 (Clermont, 2006). Many bilateral grants are outpacing the issuance of bilateral loans, which indicates that grant terms are more favorable for lender-borrowers than loans. These trends can be observed of bilateral and multilateral commitments in the following figure:

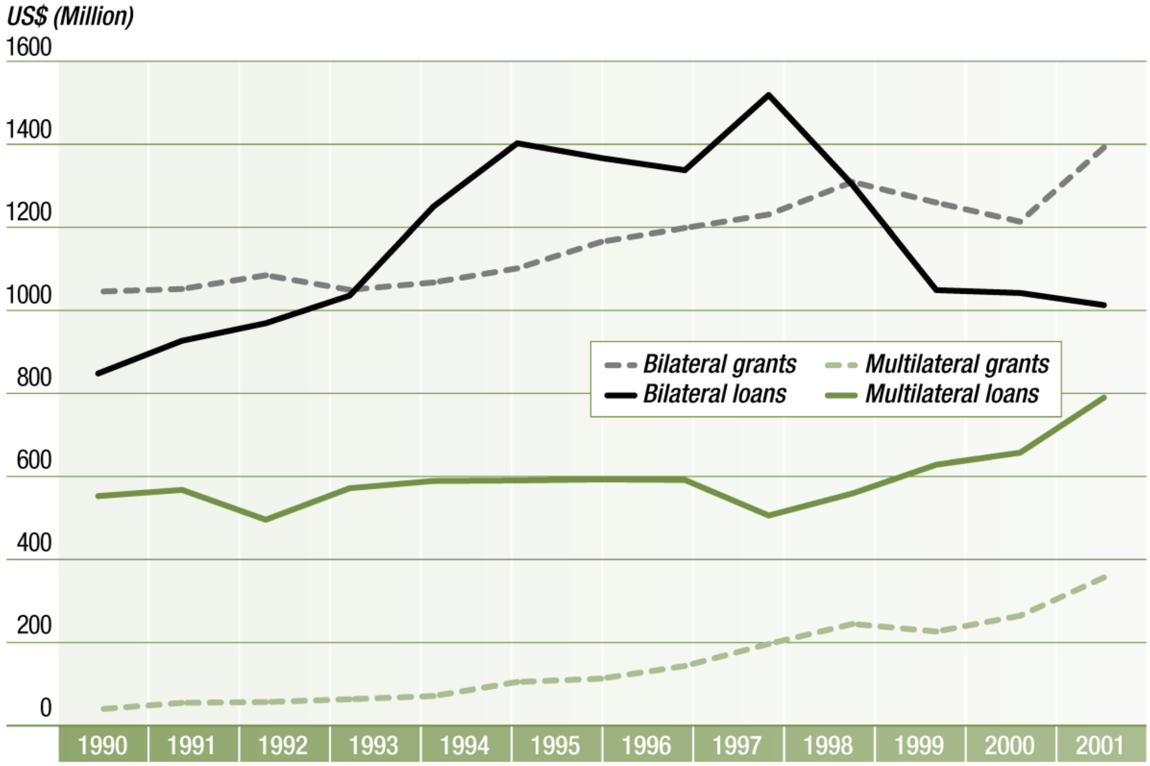

Figure 2.2. Bilateral and Multilateral Annual ODA Commitments for Water as Loans and Grants (5-year moving average in 2003 constant dollars) (Source: Clermont, 2006

When reviewing the donor countries of ODA in Figure 2.3, seventy percent of the water aid comes from only 5 donors: Japan, IDA, Germany, United States, and France (OECD, 2009).

	Commitments, USD million			% of Donor Total		% All Donors		Disbursements, USD million	
	03-04	05-06	07-08	05-06	07-08	05-06	07-08	05-06	07-08
Australia	40.4	7.5	17.4	1	1	0	0	24.8	15
Austria	26.4	22.6	31.3	7	8	0	0	16.8	20.7
Belgium	27.3	76	99.5	8	8	1	1	48.4	52.2
Canada	122	35.9	35.8	2	1	1	0	63.5	42.2
Denmark	201.9	150.2	26.8	11	3	2	0	122.9	100
Finland	12.7	53.5	42.3	10	8	1	1	9.2	27
France	232.1	224.1	387.2	4	6	3	5	233.3	182.4
Germany	493.8	538	770.9	9	10	8	11	432.7	510.4
Greece	1.8	1	1.9	1	1	0	0	1	1.9
Ireland	25	19.8	23.3	5	4	0	0	19.8	23.3
Italy	42.8	76.8	112.7	9	13	1	2	40.8	37.9
Japan	911.8	1800.1	1922.5	20	17	26	27	721.6	1078.9
Luxembourg	17.9	15.2	16.7	9	9	0	0	15.2	16.7
Netherlands	171.1	400.6	383.4	10	11	6	5	151.6	297.8
New Zealand	2.1	4.7	1.6	2	1	0	0	2.9	2.9
Norway	31.8	49.2	48.3	2	2	1	1	46.9	48.4
Portugal	1.5	1.9	1	1	0	0	0	1.9	1
Spain	96.2	70.7	370.2	4	12	1	5	78.6	346.8
Sweden	62.9	113.9	67.3	5	5	2	1	77	66.5
Switzerland	42	60.2	41.8	7	5	1	1	41.5	44.5
United Kingdom	66	116.9	209.6	3	3	2	3	79.3	128.6
United States	596.2	948.7	644.1	5	3	14	9	1057.6	397.2
Total DAC Countries	***3225.7***	***4787.7***	***5255.5***	***8***	***7***	***69***	***73***	***3287.3***	***3442.3***
AfDF	191.9	299.6	271.1	22	19	4	4	74.6	173.1
AsDF	178	224.3	141.1	17	9	3	2	..	..
EU Institutions	495.8	877.3	377	8	3	13	5	385.8	447.1
IDA	939.4	739.4	1107.5	11	11	11	15	683.3	731.7
IDB Sp.Fund	0	25.6	32.8	6	12	0	0	..	..
IFAD	4.8	7.1	2.9	2	1	0	0	..	..
GEF	..	..	1.4	..	1	..	0	..	1.4
UNDP	3.4	2.2	2.1	0	0	0	0	2.2	1.5
UNICEF	21.4	25	43.7	5	6	0	1	25	43.7
UNECE	..	..	0.7	..	7	..	0	..	0.7
Total Multilateral	***1834.7***	***2200.5***	***1980.3***	***10***	***8***	***31***	***27***	***1170.9***	***1399.3***
Total	***5060.4***	***6988.1***	***7235.8***	***8***	***7***	***100***	***100***	***4458.2***	***4841.7***

Figure 2.3. ODA Commitments by Countries and Amounts (Source: OECD, 2010)

The amount of ODA allocated for the water sector per capita appears to be determined by three principal factors (Clermont, 2006):

• The demographic weight of the country: ODA is representative of a relationship between the borrower and lender, where the number of projects is not proportional to the population of the country. The data reflects that for a heavily populated country, there is less ODA for water per capita distribution.

• The economic and political stability of the country: There is a minimum level of political and economic stability required for the country to receive funding because of the long-term commitment and scope of the project.

• Geopolitical objectives: The concerns of the donor countries are founded on the geostrategies of the recipient country as well as the prior and geographical relations between donors and recipients.

2.3 What is the private sector?

The private sector contains a wide range of individuals and groups, even though they do not provide official development assistance, they act as service and funding providers that include for-profit private sectors, foundations, NGOs, voluntary aid, and support, as well as private academia groups (OECD, 2011). With the development of private foundations playing an increasing role in the financing arena, it is necessary to bring the public and private sectors together through mechanisms such as public-private partnerships. There is an emerging recognition of the private sectors role in creating income growth and poverty reduction within partner countries to improve frameworks for financing (OECD, 2011).

There are currently no exact figures of the private flows in the marketplace. The OECD DAC collects data on grants by private voluntary agencies, private flows at market terms, and bilateral ODA through NGOs. According to 2007 data, the scale of development operations of the world's foundation is roughly USD 5 billion annually, with US-based foundations playing the major role, European-Asian foundations contributing as well with an estimation of international grants by the European foundation of 600 million USD annually and 400 million USD annually for Asian foundations (OECD, 2011). The following Table 2.2 is the latest tracking of private flows published by the OECD in June 2011.

Grants by Private Voluntary Agencies (Total DAC countries)	2005	2006	2007	2008
	14,712	14,648	17,866	23,655

Private Flows at Market Terms (long-term) (1 to 4) (Total DAC countries)	2005	2006	2007	2008
	179,559	194,761	312,475	121,224
1. Direct investment	100,622	127,925	180,293	178,140
2. Private export credits	5,563	3,137	13,161	6,572
3. Securities of multilateral agencies	40	2,789	-9,737	-9,983
4. Bilateral portfolio investment	73,335	60,910	128,759	-53,504

Bilateral ODA: Grants and grant-like contributions of which are contributions to NGOs (Total DAC countries)	2005	2006	2007	2008
	1,017	1,779	2,037	2,516

Figure 2.4. Data on Private Flows in USD Millions (Source: OECD, 2011)

2.4 Other Funding Sources

Other sources of funding considered by the water sector include: (OECD, 2009)

- Global taxes on currency transactions and energy use.

- Voluntary private sector contributions through donations, global lotteries, premium bonds or global funds.

- The International Finance Facility, which set up a pilot program on immunization in January 2006 with the support of France, Italy, Norway, Spain, Sweden, and the United Kingdom. Solidarity taxes on air tickets. Currently nine countries have adopted this tax, and the proceeds are mainly used to fund accelerated access to HIV/AIDS, tuberculosis, and malaria drugs through other aid organizations.

- Advanced Market Commitments to provide incentives for the development of vaccines important to developing countries.

- Sovereign wealth funds, established either from export receipts earned from a nonrenewable resource or from very high corporate or household saving rates and surpluses. These funds could become major sources of development finance.

2.5 Donor Objectives and Interest in Funding Water Projects

Much of the donor base for OAD is rooted in the foundation of improving water supply and sanitation in line with the MDGs, targeting countries most in need (OECD and WWC, 2008). However, donors choose different reasons for such aid that can be as simple as wanting to improve the borrower's economic development whether it is to further their own political, strategic or commercial interests, maintaining historical and cultural ties, or to demonstrate their humanitarian aid (World Bank, 1985). Humanitarian aid can be in the form of interventions to save lives in an emergency context that can pertain to water, health and education that is not factored as OAD contributions (OECD and WWC, 2008). These objectives can affect how aid is given as well as reduce the effectiveness of financial flows promoting development (World Bank, 1985).

A study published by the World Bank in the 1980s observed the role of non-development considerations in determining ODA distributions. These results showed that DAC donors generally required the recipient or borrower to purchase goods and services from the donor country, whereby 43 percent of aid given in the form of "tying" was bilateral ODA and another 11 percent was partially tied (World Bank, 1985). The World Bank acknowledged in their findings that the percentages reported were most likely understated as to the volume of actual tied aid. The implications of these ties suggested in their findings that the value of the loans were reduced by 15 to 20 percent but was more likely a higher percentage unaccounted, which intern reduced the quality of goods and services, higher and inefficient given the true needs of the borrower (World Bank, 1985).

Financial flows that contribute to water infrastructure investments can have benefits with the private sector and should not be overlooked because of inefficiencies of existing financial structures. Governments have used private businesses to improve the access of water and sanitation services and experience has shown that when the goals are managed among stakeholders that these partnerships can overcome obstacles and achieve results (Payen, 2006).

2.6 How to Manage Donor Expectations

In discussing how to manage donor expectations within financing structures, it is imperative to have new and existing donors with the coordination of the borrowers and aid recipients to bring forth the discussions of funding, planning, management and reporting systems to achieve the goals of the agreed upon water project. These concerns are not just limited to the water sector and financing. In examining the Global Fund that was established in 2002 to address health issues of AIDS, Tuberculosis, and Malaria and its designs of internal controls and management systems of the funds infrastructure, participants acknowledged that it had a high profile in servicing the recipients of aid to undertake the objectives of the fund. However, these challenges of managing expectations were magnified by the effect of weak health systems, limited capacity, and competing demands for governments, partners and for the Global Fund itself (Brugha et al, 2004). There is a need for transparent dialogue between stakeholders in managing expectations with not only donors but all interested parties.

CHAPTER 3

FINANCIAL STRUCTURES

There are four traditional forms of financing instruments used in the water sector: grants, loans, equity, and debt (GTZ, 2006). The following forms are defined as followed adapted from the "Financing Infrastructure in the Water and Wastewater Sector" report compiled by GTZ:

- Grants: Facilitated through public budgets. Primary funders are international donors to national governments to fund water sector development. In turn national governments disperse the grant for national sector priorities or allocate funds to local governments or utilities.

- Loans: Distributed to parties involved in the water sector from donors or private investors through the banking system (national and international).

- Equity and Debt: Funds generated through the capital market facilitated by private investors, governments and International Finance Institution (IFIs) where they are allocated to municipalities or utilities in the water sector. Donors have played a limited role in the use of equity and debt instruments; however they are increasing their profile in these areas.

A breakdown of the sources of water sector financing mechanisms is further illustrated in the following figure.

Sources of Finance ↳Instruments	Intermediaries ↳Instruments	Users of Finance ↳Instruments
Donors and IFIs • Grants • Loans **Private Investors** • Loans • Debt/equity **Public-Private partnerships** • Grants • Loans • Debt/equity	**Public budgets** (budgetary finance) **Banking system** (bank lending) **Insurance market** (risk guarantee schemes) Guarantees **Capital market** (Investment agencies)	**National governments** • Grants • Loans **Municipal governments** • Grants • Loans • Debt/equity **Utilities** • Grants • Loans • Debt/equity • Tariff revenue

Table 3.1 Sources of Water Sector Financing Mechanisms (Source: GTZ, 2006)

A range of potential sources of financing and instruments is listed for potential ways of meeting the demands of the lender-borrowers in the water sector (Cardone and Fonseca, 2006)

- User fees or tariffs
- Domestic taxes
- Grants
- Loans
- Micro-credit/micro-finance
- Environmental charges
- Dedicated or special purpose fund
- Bond markets
- Equity
- Direct private investment

- Mixed credits and export funds
- Voluntary finance schemes
- Guarantees
- Debt swaps

Most of these arrangements are based on the premise that the cost of recovery will be absorbed from user's representative of residential, commercial, industrial or from the government. In order for the recipient to obtain funding they must demonstrate credit worthiness, whereby they are required to exhibit appropriate governance structures, recordkeeping of accounting, and financial documents, historical cash flows, establish the means to manage the debt with past performance along with any other economic considerations placed by the donor (Cardone and Fonesca, 2006).

When there is a lack of adequate funding due to these financial barriers it can create unintended consequences in the water markets. This is classified as the "vicious downward spiral" by the CEO Panel (2003) and illustrated in the following figure.

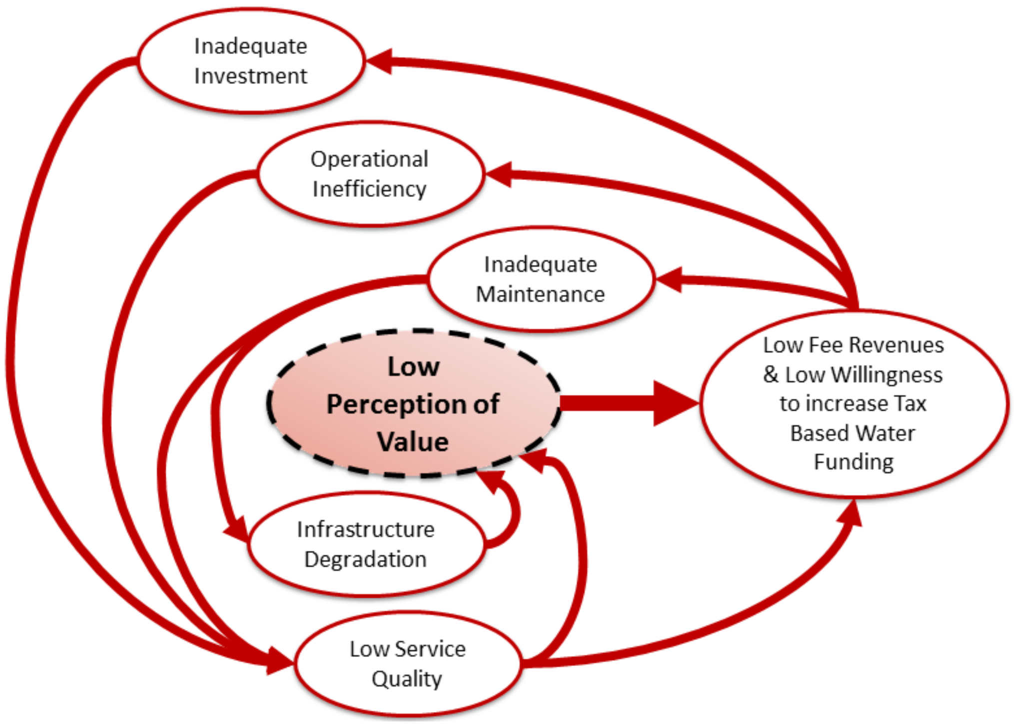

Figure 3.1. Vicious Downward Spiral (Source: Moss et al, 2003)

Donors have various instruments available for financing, but primarily use grants and loans. Additionally, donors can enter into a type of PPP providing financing together with a private source. For the water sector specifically, 72% of ODA financing comes from grants whereas the remaining 28% are derived from loans (GTZ, 2006). From the donors reviewed in Chapter 2, Germany and France are the predominant providers of loan ODA in the water sector. From the total amount of loans provided between the period of 1997-2001, France provided 58%, while Germany provided 36% (Clermont, 2006).

The majority of loans provided are for large-scale water supply and sanitation projects. 72% of all loans provided between 1997 and 2001 were for large-scale water supply and sanitation projects. While EC, Belgium, and Italy provided 100% of their loans for large-scale water supply and sanitation, and 100% of loans from Spain were for water resources protection, France and Germany provided loans to several sub-sectors such as small scale water supply and sanitation, water resources management, river development, and agricultural water resources, among others (GTZ, 2006).

There are many benefits of having donors provide financing opportunities and assistance to other countries or groups in need. These benefits of foreign assistance range from providing a constructive policy dialogue of policy changes, promoting sufficient development, to facilitating financing in the markets (GTZ, 2006). As discussed in Chapter 2, the foreign assistance provided by donors can create certain amount of dependence which is a negative incentive for donors to promote self-sustainable solutions for the future. Focus should be given on emphasizing policy reforms, developing flexible financing instruments that meet precise objectives of the end-users and coordinate joint efforts as much as possible where available (World Bank, 1985).

There is a movement by donors to reform their lending and financing policies to expand financing options available to developing markets by suggesting innovative and new financing tools. Other alternative financing policies include using local banks as co-financers or intermediaries to improve the banking sector and build financial capacity. The World Bank and IFC have created a Bank-IFC Municipal Fund to assist in lending at the sub-sovereign level that does not require sovereign guarantees (GTZ, 2006).

3.1 Private Investment

The private finance water sector investment potential tends to be higher in larger population centers where the risk is perceived to be much less when considering the recovery cost of the venture. Areas of population under 500 that are considered rural, household finance and microfinance are the preferred financing option over traditional private financing because of the small size and scope of the project (Baletti and Raymond, 2005). Some of the reasons for PPPs lack of investments were compiled by the World Bank. It was noted that even though more attractive investments may be presented to the private sector they generally still will not materialize based on risk profiles and observance of market principles chosen by the PPP. One reason cited by the World Bank was the preference of PPPs having a strong bias for large size projects with high transaction costs. Other considerations by PPPs included country settings and business climate conditions where favor is given to countries with adequate sovereign risk ratings (Baletti and Raymond, 2005).

From the report compiled by the World Bank, the following were listed as reasons for lack of PPP in markets and is provided (Baletti and Raymond, 2005):

- Capital intensity, with high, up-front investments combined with long payback periods and low sector returns

- Risk of political pressure on tariffs

- Weak or inconsistent regulation, lack of transparency, and perceived risk of regulatory capture

- Sub-sovereign risk – local government entities standing counterparty to bulk water sale agreements while having a poor collection records, suboptimal financial conditions, and weak credit

- Water unaccounted for, water loss, inadequate distributions networks in a state of disrepair, and the lack of investment funding to remedy the same thus threatening long0term project viability

- Foreign exchange risk, with mismatch between local currency revenues and foreign currency financing

- Forms of credit backstop (for example, sovereign counter-guarantees for financial obligations of subnational entities being scaled back in the face of decentralization, ratings agencies reviews and downgrades)

- Lack of local government access to bank and capital markets due to absence of central government authorization, and competition for scarce financial resources

- Aversion of private insurers and reinsurers to providing bond insurance and political risk insurance to subnational entities in developing countries due to lack of transparency, poor financial condition of reference entity, and absence of credit rating.

In taking a closer look at financing potential in the private water markets, we can observe the highest investments currently are needed in the rural and village communities (Baletti and Raymond, 2005). This is illustrated by the World Bank's Figure (Figure 3.2) for private sector potential in different water markets.

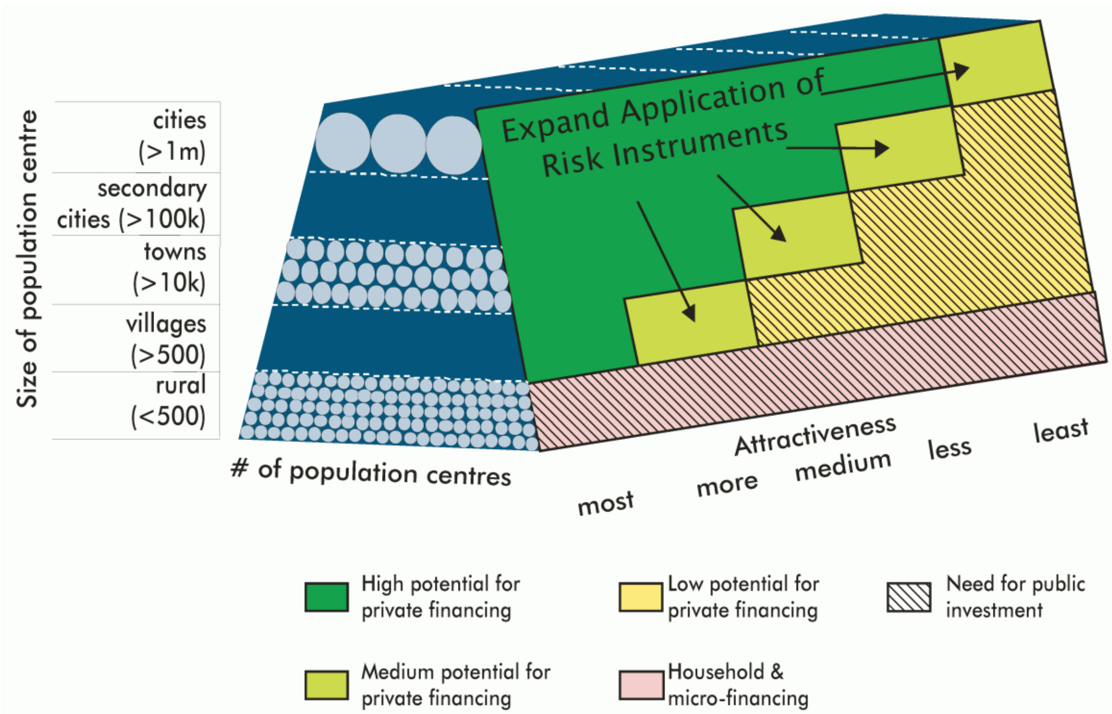

Figure 3.2. Private Sector Potential in Different WSS Markets. (Source: Baletti and Raymond, 2005)

3.2 Innovative Financing – Looking Beyond Traditional Financing Flows

There is a need to manage existing and potential resources in a sustainable manner that is accountable and manageable by all the stakeholders. What drives innovative financing is the need for new financial resources and effective use of those resources.

The concept of innovative financing in the marketplace has recently emerged as a creative way to meet the shortfalls of existing investment structures. It addresses the question of who can provide financing as well as how financing can be supplied and demanded. The World Bank defines innovative financing as an approach that meets three conditions (World Bank, 2010):

1. Generation of additional development funds by seeking new funding sources or engaging with new partners

2. Enhancing the efficiency of financial flows that reduce delivery time and/or costs, specifically for emergency needs and crisis situations; and

3. Creating more results-oriented financial flows that link funding flows to measurable performance on the ground

These concepts are illustrated in Figure 3.3, showing the overlapping opportunities of funding in the water market sector. By understanding these overlapping opportunities there can be more effective dialogue between stakeholder's negotiations of the financial structures implemented for water projects. These understandings are critical in designing the most appropriate and efficient financing mechanisms that will mutually benefit the stakeholders.

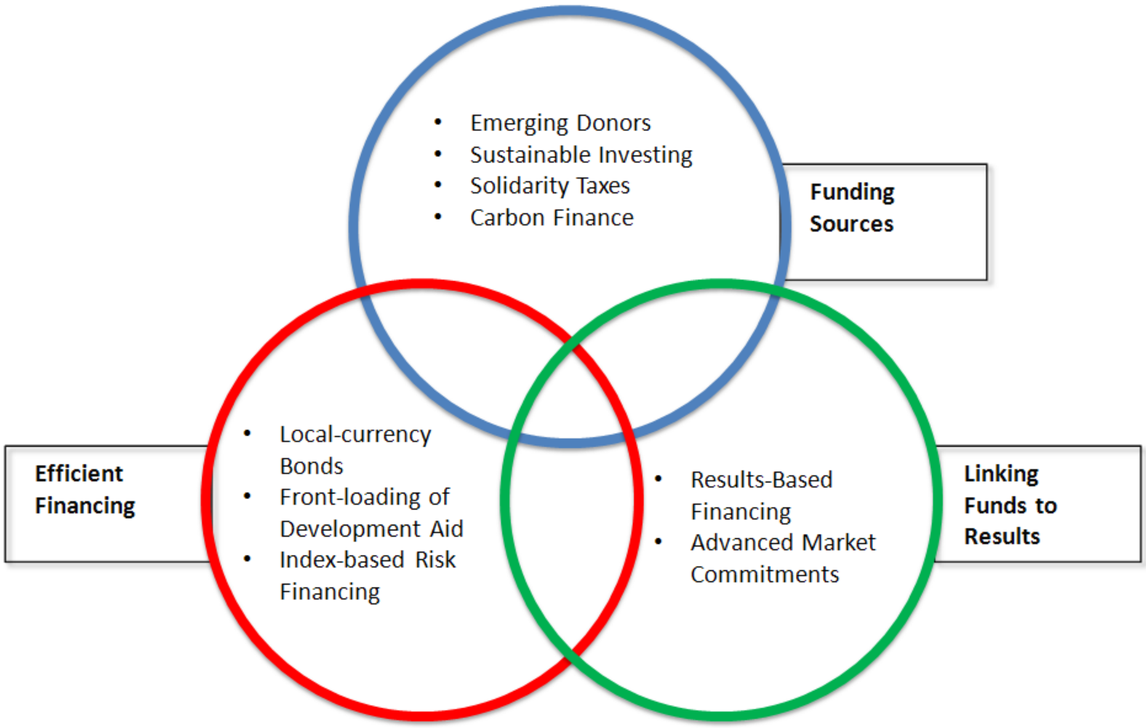

Figure 3.3. Innovating Financing Role for Water Projects (Source: World Bank, 2010)

The use of innovation has the ability to reduce pressures of existing resources facilitating sustainable principals (Hemmelskamp, Rennings, & Leone, 2000). Sources of potential innovative financing can include the following (Cardone and Fonesca, 2006):

- PRSC
- Public-Private Partnerships (PPP)
- MDG-based Planning
- SWAP (donor funding)
- Domestic financial intermediary

- Local Banking Sector
- Microfinance
- Credit Cooperatives

- Public Sector Financial Agencies
  - Public Banks issuing loans to municipalities

In assessing the most practical and efficient financing strategy that is sustainably viable, we can look towards the World Bank's assessment of indicators in the public and private sector to understand borrower's options. Figure 3.4 illustrates these options at the various levels of PPP financing.

Creditworthy in Tested Currency Conditions	Country Conditions and Developed Financial Markets
Marginally Creditworthy	Reliable Refinancing Sources & Security for Loans
Sustainable Cost Recovery	Anticipates Long-Term Cost Impacts (that is, FX, asset reevaluation)
Cost Recovery	Profitable in Any Given Year, But Not Sustainable in Long Term
Pay-As-You-Go Recovery of Cash	Capital Subsidies
Unviable Loss-Making Utilities	Capital & Operational Subsidies

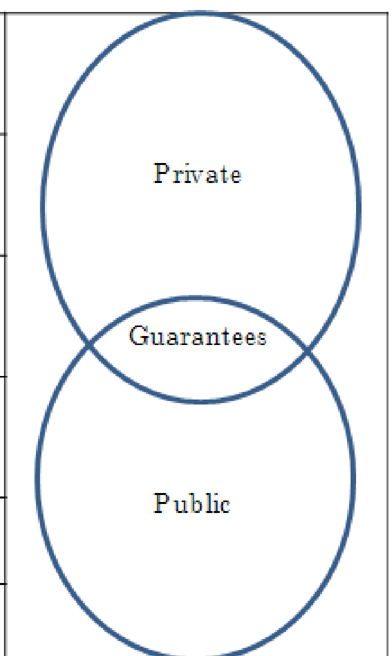

Figure 3.4. Financing Options at Different Levels of Financial Sustainability (Source: Baletti and Raymond, 2005)

We can use Table 3.2 to summarize the applied financial instruments of their applicability and ideal targets for water projects. It is important to determine these factors so that they are not overlooked in available financing or concerns of the PPP sector, which then can contribute to designing stakeholder perspectives for tasked to address all the likely challenges facing stakeholders. These concerns should not be limited to just only these concerns, but rather initiate the discussion of all potential concerns in question.

Financing Instruments	Appropriate for What Local Conditions	Target (water user, national/local government, community, utility, etc.)
Grants	Non-performing utilities; absence of local financial market; weak national government with limited fiscal decentralization. Grant financing best used as a tool to support the involvement of the poor, to build capacity for sub-sovereign and private sector water actors; provide initial start-up capital for community funds, revolving loans and other types of funds for the water sector.	Local government; utility
Donor loans	Can be applied to many actors within a country in different ways. Innovative: loans to sub-sovereigns or private sector (particularly to build commercial or institutional lending capacity)' lending in local currency	National and municipal governments
Bank loans	Stable financial market with clear legal framework and repayment capacity of borrower; regulatory body to ensure effective tariffs; stable utility balance sheet	National and municipal governments
Micro-finance loans	Community participation and capacity-building; provision of start-up capital; community monitoring	Local community utility; user
Equity	Can be applied only to a public LTD or private utility – need a shareholder board in place. Fiscal decentralization, stable or developing financial market with clear legal framework	Utility
Municipal Bonds	Sufficient debt capacity of local government; security mechanism for purchasers of bond (guarantee mechanism development of secondary market to sell bond for example); capacity in municipality to successfully design and administer bond; minimum municipal credit rating BBB of higher, positive market conditions	Municipal government
Private finance (loans, debt or equity)	Sound legal and regulatory framework; guarantee schemes to protect investors; guarantees against sovereign risk, foreign exchange risk; low transaction cost thresholds; capacity-building of domestic private sector in some cases; stability cash flow	Local government; utility
Pooled financing and revolving funds	Pooling is favorable where conditions are not yet ripe for commercial lending or private investors, as individual company balance sheets may be weak. Need a project planning cycle in place; clear default and loan guidelines; combination of stronger and weaker borrowers; initial start-up capital for loan	Local governments
Guarantees	Guarantees for agencies to work in higher risk projects/sectors; guarantees and lines of credit to domestic banks (could be provided from donor finance, private sector, national government, etc.) as well as private sector to encourage involvement sector	Private sector, banks

Table 3.2. Summary of Applied Financial Instruments and Applicability (Source: GTZ, 2006)

CHAPTER 4

END-USERS, RECIPIENTS AND BORROWERS

Local communities and groups have the most at stake with water resources and the underlying theme is effective management to their overall sustainability (Brooks, 2002). Individuals, villages, communities, and governments are necessary stakeholders to establish efficient, equitable and sustainable water resource management. When providing basic water services such as water supply, sanitation, waste treatment, and sewage for urban and rural areas, it will begin with the end-users and communities (Van Hofwegen, 2006). As discussed in Chapter 2, donors have tasked themselves to meet the challenges of the MDGs set forth by the UNDEP for water compiled in 2003.

	Water	Sanitation
UN global estimate of those without access	1.2 billion	2.5 billion
By 2015, this number would grow to at least	1.5 billion	3 billion
The International Development Target is to reduce this by half by 2015	750 million	1.5 billion
This means that each year for the next 13 years, the following have to be connected	57.692 million	115.385 million
This means that roughly each day for the next 13 years, the following have to be connected	158,601	316,122

Table 4.1. Targets to meet Millennium Development Goals (Source: Moss et al, 2003)

From the review of donors in Chapter 2, the majority of ODA commitments of water investments are mainly derived from bilateral donors. Of the list compiled by the OECD of the 30 donors, 60% of monies stem from four donors and 80% originates from eight donors. Figure 4.2 is the analysis of ODA recipients from donors distributed aid from 1990-2004 (Van Hofwegen, 2006).

Receivers	Donors												
	Japan	IDA	Germany	USA	France	EC	AsDF	Netherlands	Denmark	UK	Others (20 donors)	Total	Percentage
India	62	126	11	2	5	1	-	19	2	19	10	257	8,1
China	146	36	15	0,3	12	2	-	5	3	4	28	251	8,0
Egypt	15	5	15	77	19	4	-	7	4	10	11	168	5,3
Vietnam	34	47	5	0,03	7	0,1	29	5	6	0,4	17	150	4,8
Indonesia	75	-	4	0,2	3	2	-	6	1	0,1	13	104	3,3
Turkey	50	-	30	0,03	7	5	-	-	-	-	0,5	102	3,2
Morocco	17	-	24	1	19	18	-	0,003	-	-	4	83	2,6
Palest. Adm. Areas	3	1	12	39	4	3	-	1	-	3	6	71	2,3
Philippines	56	-	2	0,4	1	-	4	1	2	-	3	69	2,2
Jordan	8	-	20	29	2	1	-	0,1	-	1	4	66	2,1
Bangladesh	4	18	0,1	2	2	0,1	9	9	10	6	5	65	2,1
Ghana	4	21	5	0,1	3	3	-	3	11	6	10	65	2,1
Peru	44	-	13	0,2	2	0,002	-	0,3	-	0,1	3	62	2,0
Iraq	0,01	-	0,2	57	-	1	-	0,1	0,1	1	3	61	1,9
Pakistan	9	16	2	0,02	3	0,3	26	1	-	1	2	61	1,9
Sri Lanka	28	5	2	0,02	2	-	15	0,2	3	1	2	57	1,8
Tunisia	17	-	19	-	14	3	-	1	-	-	1	54	1,7
Tanzania	2	9	8	0,03	1	3	-	4	4	1	19	50	1,6
Thailand	45	-	0,3	0,04	0,2	-	-	0,0002	1	0,1	1	47	1,5
Mexico	43	-	0,1	0,04	0,2	-	-	-	-	0,1	2	45	1,5
Others (154 recipients)	251	161	156	21	107	111	32	46	43	31	298	1226	1,4
Total	912	445	362	229	211	157	115	108	90	84	443	3156	40,1
Percentage	28,9	14,1	11,5	7,3	6,7	5,0	3,7	3,4	2,8	2,7	14,0		

Table 4.2. Principal Donors and Recipients of ODA for Water, in Average Annual Commitments for the Period 1990-2004 (millions of 2003 constant US Dollars)(Source: Van Hofwegen, 2006)

In assessing the perceptions of the needs and wants of the end-users or recipients of water it becomes evident that the more successful the good or service is delivered, the higher the probability it will be taken for granted (Moss et al, 2003). A Maslow hierarchy of needs was constructed by the CEO Panel in 2003 and the following Figure 4.3 illustrates the water needs of users.

Figure 4.1. What People Want with Water (Source: Moss et al, 2003)

Given that the value of water will vary from use, to users, and places, market values are not the same as pricing because people will always have different values. These differences of values range from small to large known as "value divides" (Moss et al, 2003). These value divides between stakeholders are important, because they must be aligned in some manner, if sustainable water management solutions are to be found. By understanding that solutions that do not all have a consensus will not prevail in the long-term, because stakeholders will undermine the process along with political shifts (Moss et al, 2003). The way people value water is based on a variety of factors that constantly evolve and necessitate collaboration between the stakeholders (Brooks, 2002).

Using a full-cost approach to pricing of water infrastructure, that is, the consumers are charged the full cost of water services from use to collection, treatment and wastewater disposal to recognize the full value of water with the cost of externalities should be developed based on the stakeholder's valuation of water and overall objectives of the project (Cosgrove and Rijsberman, 2000). It was noted in the proceedings of a local workshop in Katmandu in financing water harvesting schemes that users themselves were obligated to provide funds for local construction whether by contributions of cash, in-kind, or labor for the project and often times were built by the users themselves. The maintenance and organizations would then fall to the responsibility of the users as well (Banskota and Chalise, 2000). "This approach to valuing water will encourage infrastructure investments and private sector involvement and provide the revenue to cover the costs of operation and maintenance" (Cosgrove and Rijsberman, 2000, p. 2).

There is no practical sense of a "best practice" policy for water resource management. "This is because the world is heterogeneous, with different cultures, social norms, climatic patterns, skewed availability of water and financial resources, management capacities, institutional structures and levels of corruption" (Tortajada and Biswas, 2011, p.9). Given that these values vary amid stakeholders in varying degrees, it is fundamental to construct a framework to conceive these values. The CEO Panel (2003) designed a “water dialogue space” pattern representing the value perspectives and stakeholders to aid in the construction of identifying common ground for value differences and divides (Moss et al, 2003) as illustrated in Figure 4.2 and 4.3.

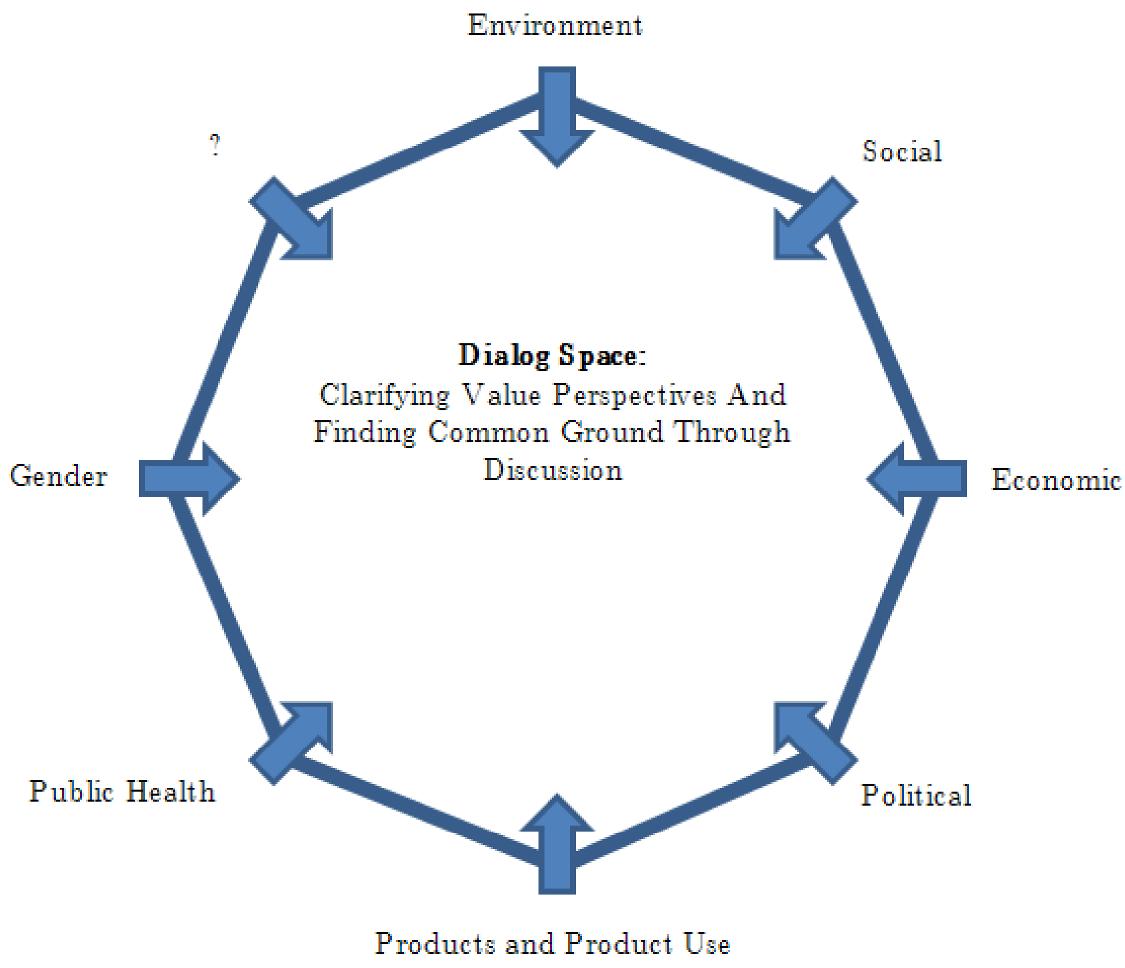

Figure 4.2. Dialogue Space and Value Perspectives (Source: Moss et al, 2003)

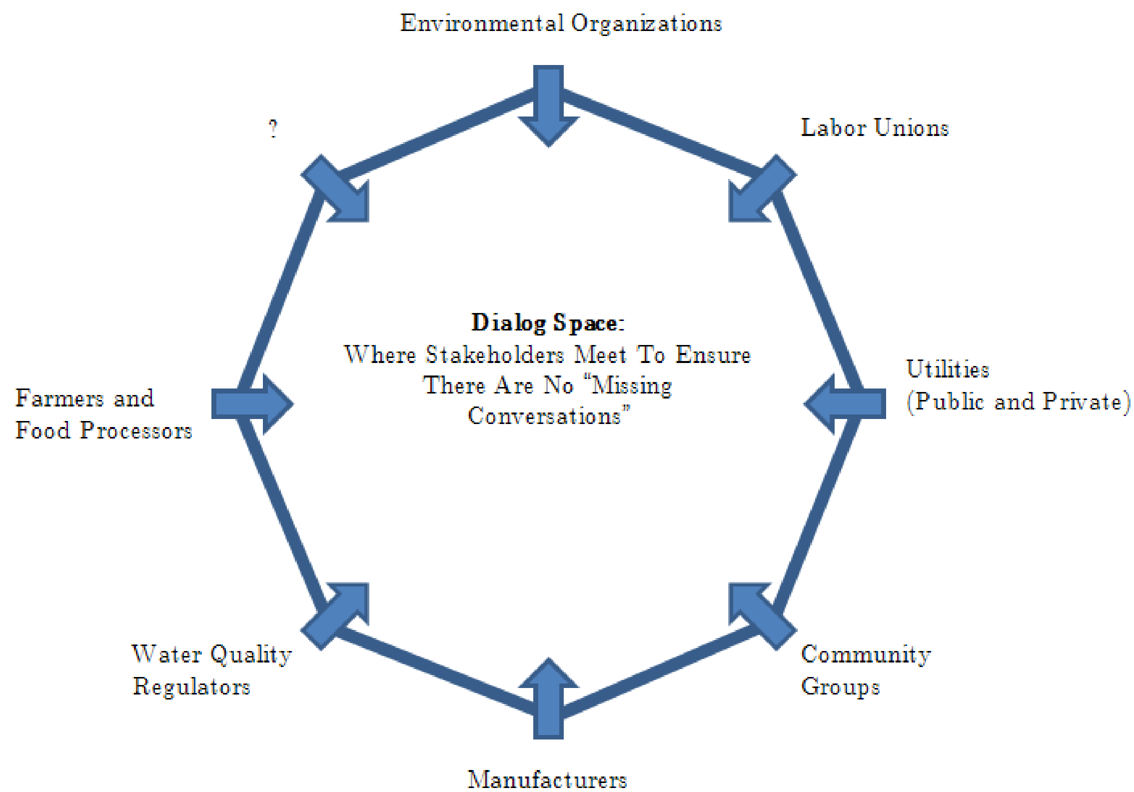

Figure 4.3. Dialogue Space and Stakeholders (Source: Moss et al, 2003)

The panel furthered the pattern with a stakeholder mapping progression for stimulating the process of valuing water and water governance amongst the water sector. The first step in the blueprint is to identify water users where the services and activities can then be outlined. The third step identifies the subject to ideas and prevailing interests of the stakeholders. These spheres are overlapping and can identify potential challenges of conflict, improve dialogue discussions and strengthen common interests amongst the stakeholders. The last step of the system yields shared outcomes for society, environment, and economy, which are essential to sustainable development. This platform provides a framework for identifying the relative rights, roles and responsibilities of stakeholders when addressing water challenges (Moss et al, 2003).

Users / Customers
Domestic
Industrial
Commercial
Agriculture
Etc.

Organiser/Governor
Mayor
Municipal Administration
Regulators
State Authorities
Etc.

Operator/Supplier
Employees
Subcontractors
Suppliers
Financiers
Etc.

Figure 4.4. Mapping Stakeholders – Step 1 (Source: Moss et al, 2003)

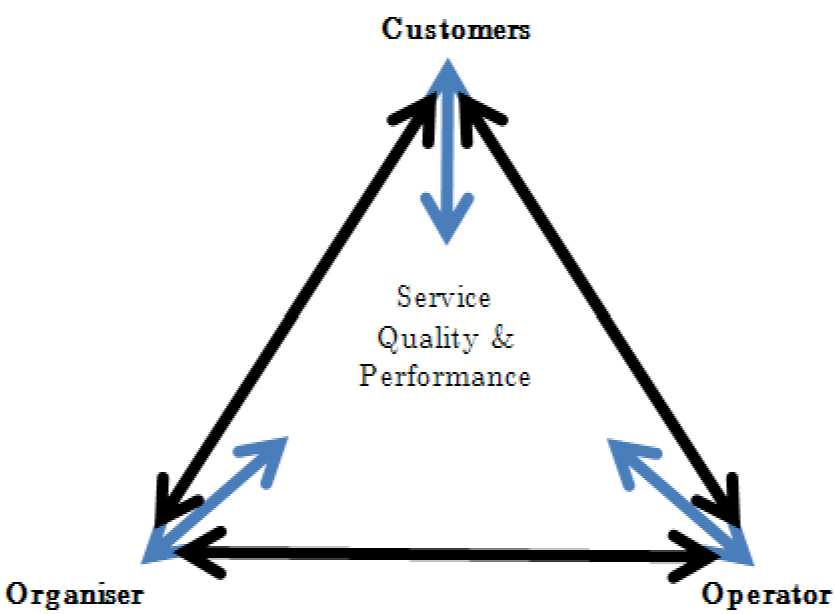

Figure 4.5. Mapping Stakeholders – Step 2. (Source: Moss et al, 2003)

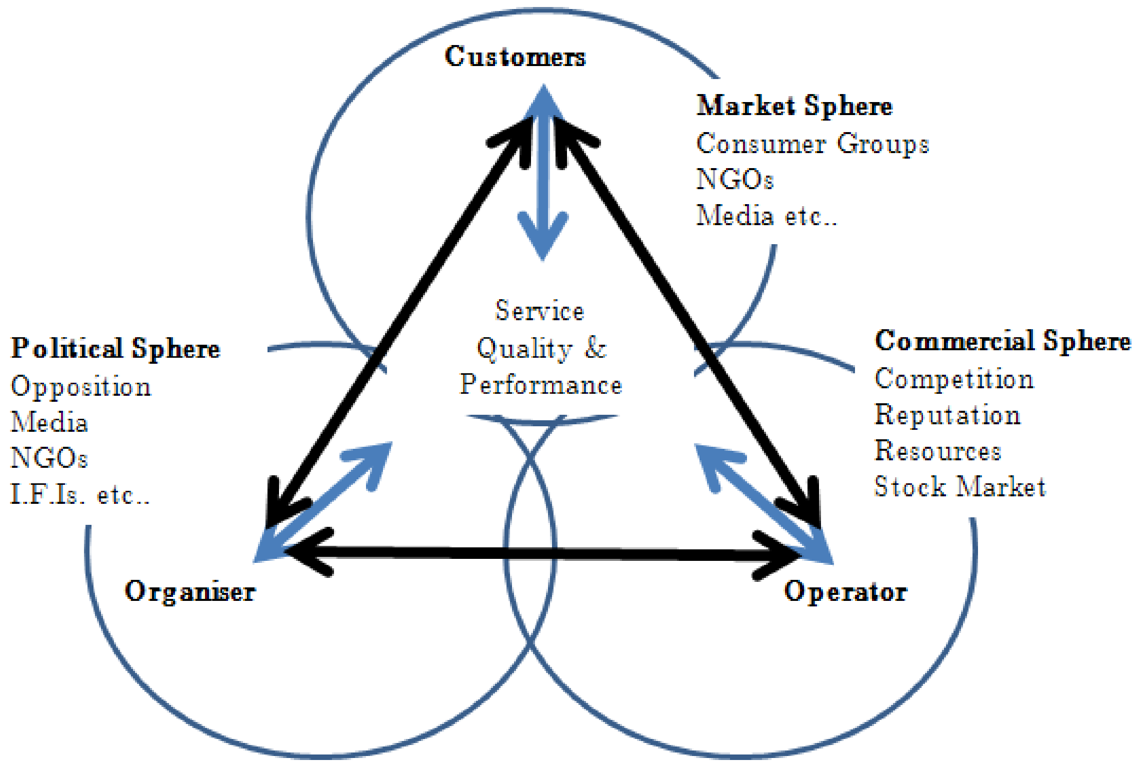

Figure 4.6. Mapping Stakeholders – Step 3. (Source: Moss et al, 2003)

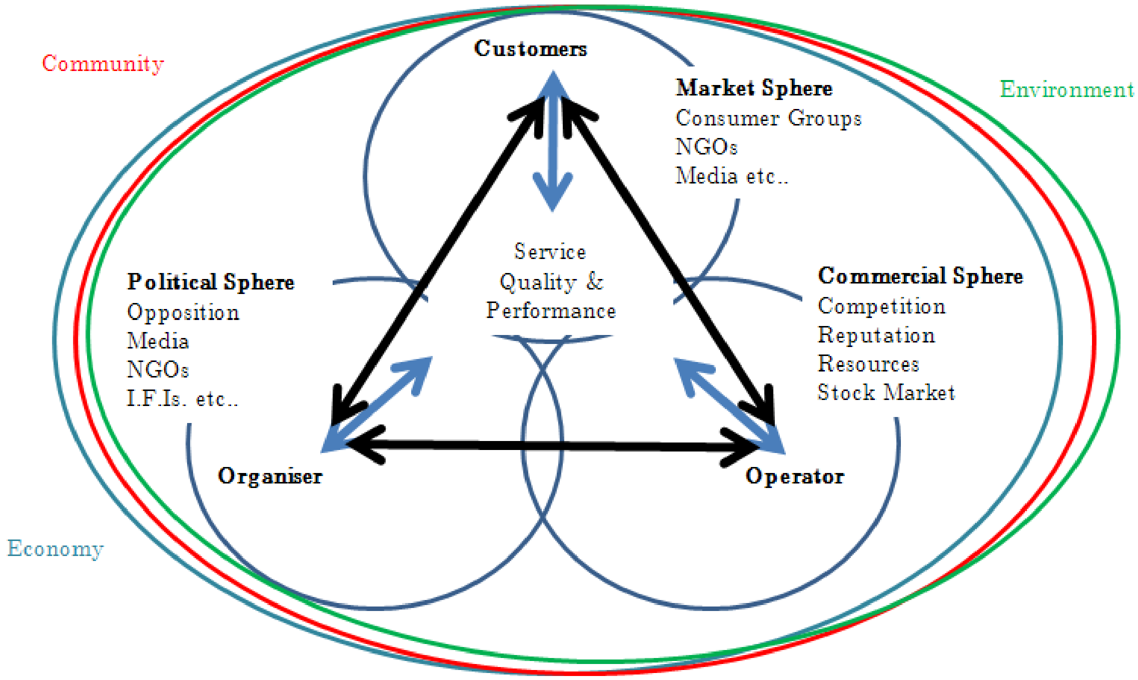

Figure 4.7. Mapping Stakeholders – Step 4. (Source: Moss et al, 2003)

It has been observed by the International Development Research Centre (IDRC) that "smaller and less complicated approaches are more likely to be adopted and put to lasting use than grand designs of integrated resource management" (Brooks, 2002).

CHAPTER 5

HOW TO OPTIMIZE WATER FINANCING

Water crisis historically is viewed from the imbalance of water supply and demand but should include the pervasive gaps of economic and institutional dimensions of water resource development, allocation, use, and management to properly design, initiate, and sustain these changes within the ongoing debate of water, both nationally and internationally (Saleth and Dinar, 2004). ODA has faced trends of losses in the 1990s after gains in the 1970s and 1990s and recent gains in 2000. The following Figure5.1 demonstrates these trends for the period between 1971 and 2006:

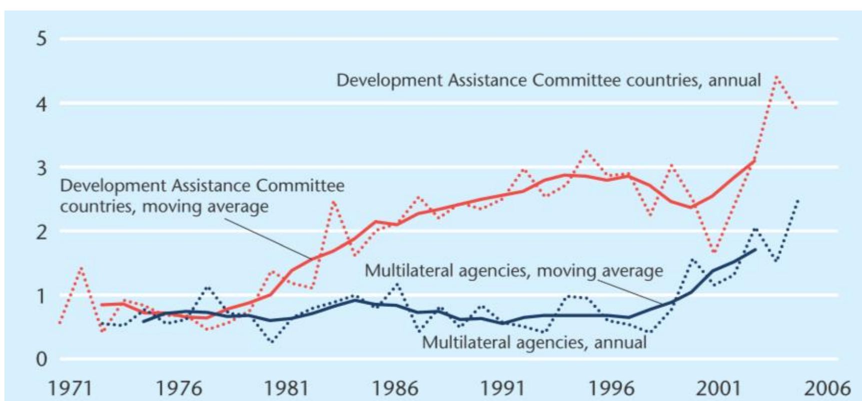

Figure 5.1. Official development assistance in billion $ to the water supply and sanitation sector from 1971 to 2006. (Source: UNESCO, 2009)

These economic trends of increases and declines result from the inefficient use of water resources, poor management, and water shortages along with the increasing environmental and financial costs associated with managing water (Saleth and Dinar, 2004). Even if new solutions were applied such as technology, it still is not enough to overcome the challenges in the current models of water resource management (Frerot, 2011). Given that the financial and economic contributions largely contribute to the success in this sector, the answers lie within the framework of water policies, water technology, and water financing which shape the design and implementation of the water resources (Saleth and Dinar, 2004). In the following, three currently used frameworks for water projects are reviewed and a novel framework for sustainable water financing is proposed.

5.1 Integrated Water Resource Management (IWRM)

IWRM is a decision making tool for development and management of water resources for a variety of uses, that takes into account the needs and desires of numerous stakeholders and users, giving governance and sustainability of water systems (Van Hofwegen and Jaspers, 1999). It was developed by the Inter-American Development Bank (IDB) to address financing issues, which have been largely overlooked by literature in the water governance and sector development. (Rees, Winpenny and Hall, 2008). The analytical framework of IRWM is presented in Figure 5.1. It has been proposed that, feedback loops should be used to include interaction with finance, where considerations are made with whom and how to finance for the present and the future. Presently finance is considered a missing component of IWRM plans or is referenced for increased demands, when the argument could be made that every country or benefactor has the need for additional financing (Rees, Winpenny and Hall, 2008). Infrastructure planning that gives consideration to the dynamics of financing will be more likely to generate adequate funding and maintain the credibility amongst constituents. The framework presented in this thesis was therefore tailored to be able to allow for dynamic and flexible financing in order to resolve the challenges of current water financing.

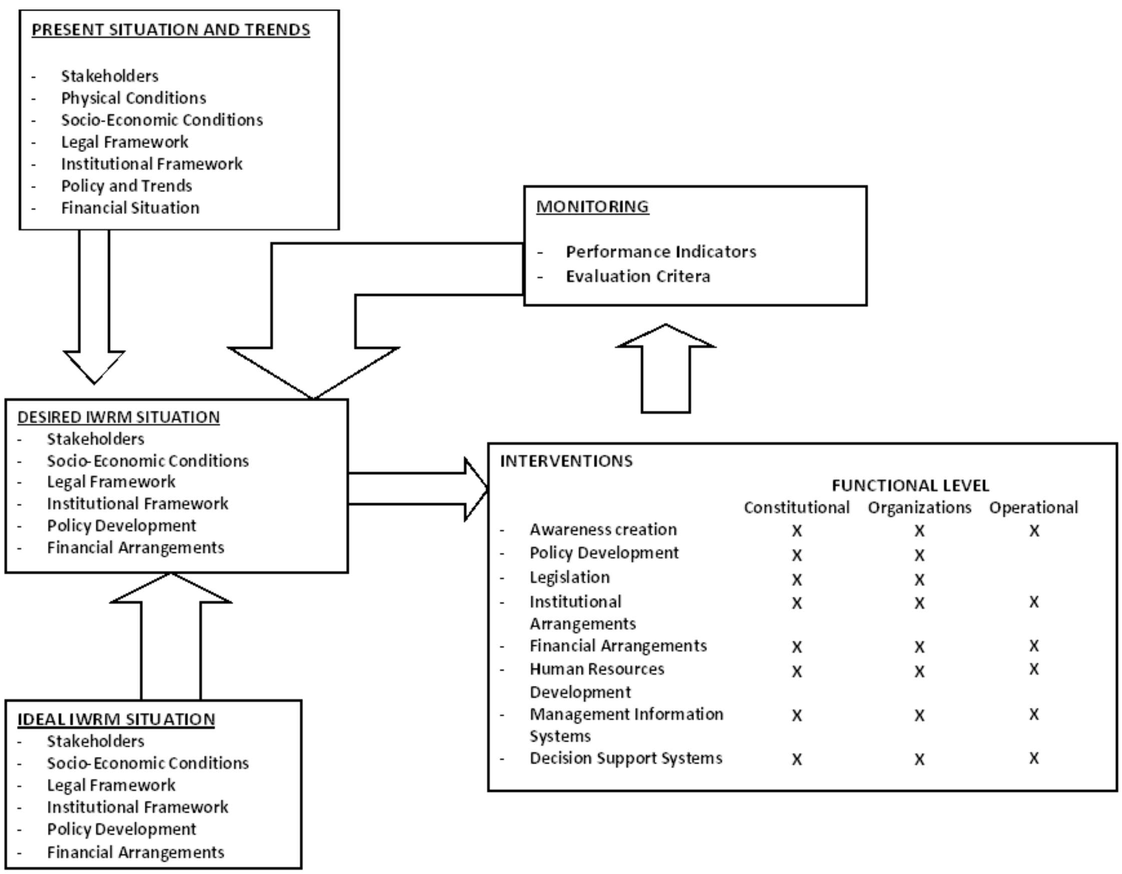

Figure 5.2. Analytical Framework for Integrated Water Resource Management (IWRM). (Source: Van Hofwegen and Jaspers, 1999)

5.2 OECD

The OECD is claimed to be the most experienced international organization with financing strategies in the water sector since the 1990s and has been at the forefront of these discussions at conferences, publishing books, and policy briefs on the matter (COWI, 2007). For the purposes of this thesis, the OECD water financing applied framework and methodology will be examined as the foundation for the qualitative framework proposed in this chapter.

5.2.1 SMART TARGETS

The OECD created a financing strategy that established SMART: Specific, Measureable, Agreed, Realistic and Time-bound, so that these targets are incorporated in the public budget where they can be regularly monitored and evaluated (EUWI, 2007). The OECD methodology places its focus on the operational costs and the ability of the users to pay the operational costs directly associated with the service level desired (EUWI, 2007). OECD methodology does not focus on the project level but rather the strategic and program levels (EUWI, 2007). The SMART framework is the foundation for the development of the quantitative tool FEASIBLE, which forecasts what a water project would cost taking into account the likelihood of available funds (EUWI, 2010).

5.3 FEASIBLE

Financing for Environmental, Affordable and Strategic Investments that Bring on Large-scale Expenditure Model (FEASIBLE) was designed in 1999 as a collaboration between the OECD and COWI, a consultant firm specializing in engineering, environmental science, and economics (OECD, 1999). FEASIBLE initially started out as an excel spreadsheet and has evolved into a computer-based tool that considers the expenditure needs (in terms of investment and operation and management expenditure needs) to meet specific and time bound targets of financing by grants, loans, user charges, and public subsidies. The expenditures can be applied to water supply, wastewater, and sanitation or waste sector projects (Fonseca, Dube and Verhoeven, 2011).

FEASIBLE uses generic cost functions to establish investment and operation with maintenance expenditure needs based on inputs from existing physical infrastructure and the future physical infrastructure desired to meet the intended targets (Fonseca, Dube and Verhoeven, 2011). Costs functions can be adapted with local relative prices or default values for the scenario along with infrastructure values for regions or municipalities. Debt terms and services can be specified to borrowing terms which can then be cross-examined with user charges to determine affordability. This comparison determines where financing gaps exist between the expenditures needs given by a set of goals with available financing (OECD, 2004).

The FEASIBLE financial gap results imply (DANCEE and OECD, 2004):

1. Future supply of finance assumptions from user charges, public budgets and donors are insufficient for the scope of the project; or

2. The scope of the future service level is elaborate or beyond the limits of future supply or financing; or

3. A combination of (1) and (2)

The FEASIBLE model has four main components (DANCEE and OECD, 2004):

1. General Information: information pertaining to the geographic area, region, municipality, and groups of municipalities with the basic macro-economic data of the scenario.

2. Expenditures: projected environmental expenditures that include operation and maintenance, reinvestments, renovations and new investments in infrastructure that are based on current situations and service level targets of users.

3. Finance Supply: existing and future supply of finance from user charges, public budgets, loans, and grants.

4. Financing gaps/results: aggregated results on financing gaps and selected technical parameters are available for assessments.

Based on the inputs, FEASIBLE creates a baseline scenario to evaluate and establish strategic development. The structure of FEASIBLE is illustrated in Figure 5.3 and the methodology overview of FEASIBLE is presented in Figure 5.4.

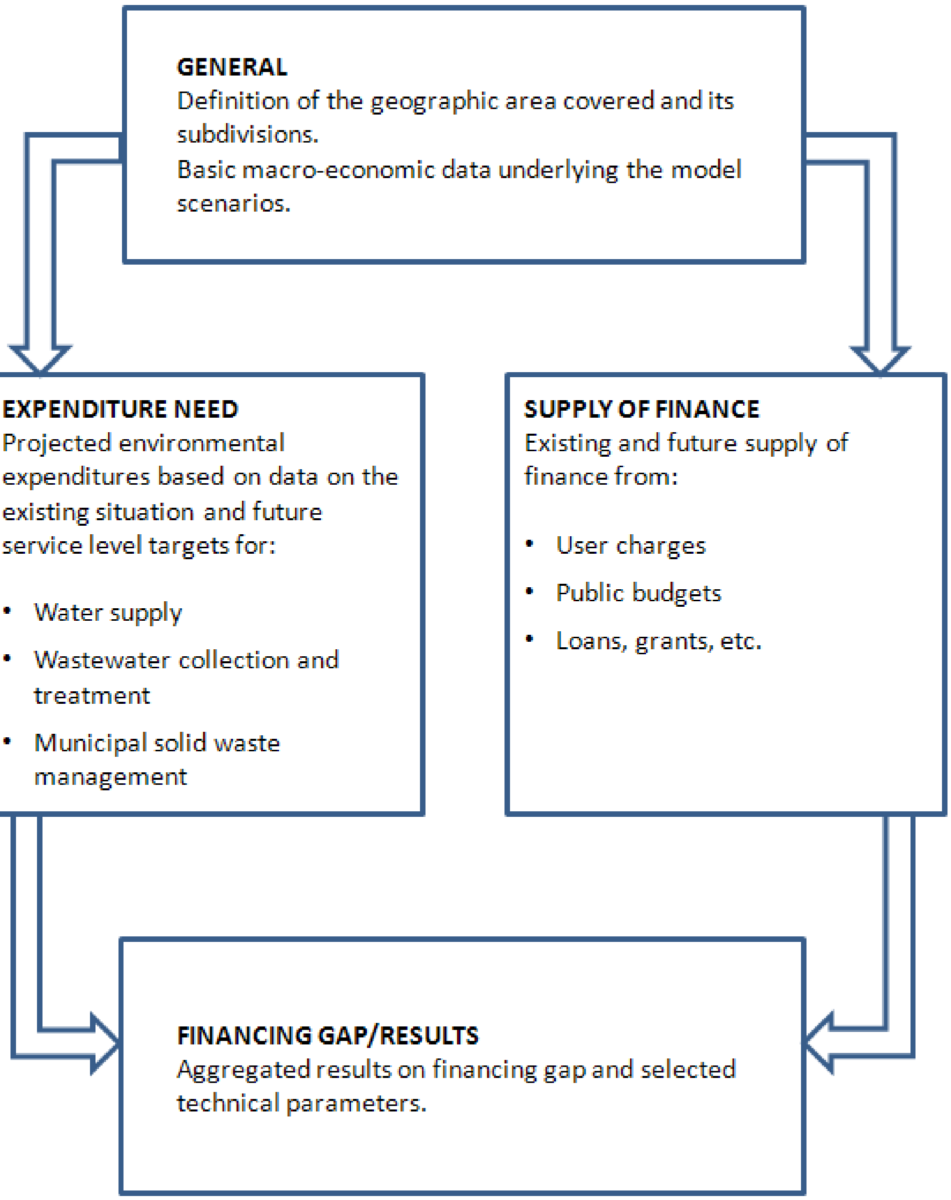

Figure 5.3. Structure of FEASIBLE (EUWI, 2010)

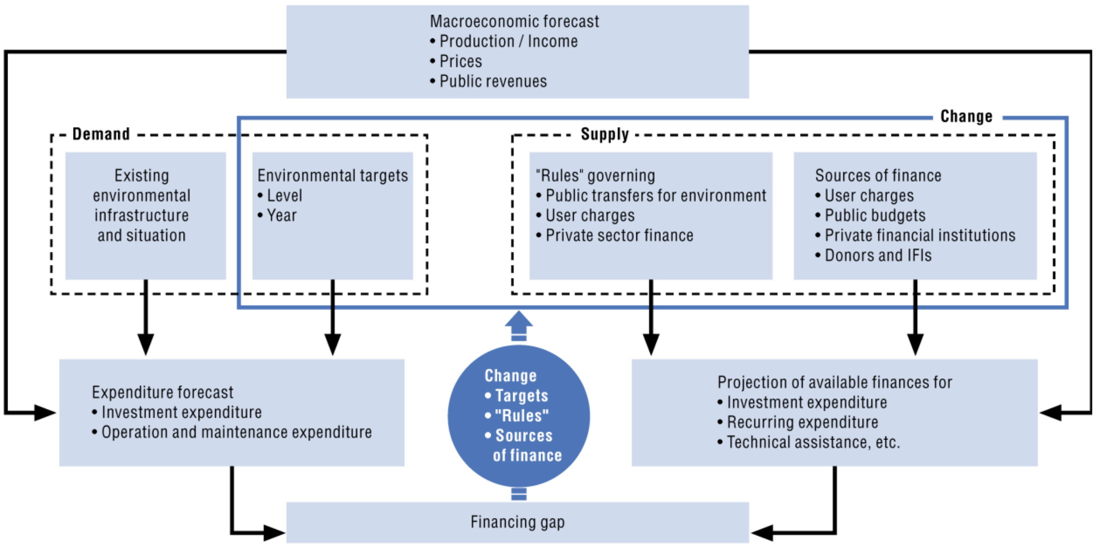

Figure 5.4. Methodology overview of FEASIBLE Source: OECD, 2007

5.4 Proposed Model – Optimization of Water Financing (OWF)

The above discussed models approach financing mechanisms in ways that costs are being calculated. The purpose of the herein proposed Optimization of Water Financing (OWF) model is to create flexible financing terms through a feedback loop system that uses the most current or real-time depiction of a life cycle analysis (LCA) of the water project. The financing terms will be linked to the LCA results through the on-going feedback loops within the model which can be continuously modified to mutually benefit the stakeholders.

In order to meet the above objectives, the OWF uses the System Dynamics (SD) method for the LCA of the water project. Thus far the application of SD in financing of the water sector has only been considered within the last few years and only within the scope of research papers. Bianchi and Montemaggiore (Bianchi and

Montemaggiore, 2008) used SD for strategic design and planning for a project in a municipal water company. Their case study shows that SD can significantly improve the planning process, identification of causal relationships between policy and performance. It further helps to better communicate strategy with stakeholders, handling the demand profile and seasonality factors. In a recent paper by Rehan et al. (Rehan et al, 2011) the authors use a SD approach to develop a demonstration model for water and wastewater network management that is financially self-sustainable over the long-run. The authors find that existing infrastructure management systems and tool are not sustainable and that a SD approach is a viable method for modeling the management of water and wastewater networks. The strength of using SD lies in particular in the ability to model complex systems with many interconnections and feedback loops (Rehan et al, 2011). SD can resolve common shortcomings of models like unidirectional causality that for example is unable to distinguish delays between actions and their impact on performance (Akkermans and van Oorschot, 2005). SD has been found to be a well-grounded, flexible and realistic approach to deal with uncertainties in water resource management (WRM) and therefore provides a crucial tool in adaptive management thereof (Winz, Brierley, & Trowsdale, 2009). In the following the basics of SD will be reviewed and the methodology of OWF discussed.

5.4.1 System Dynamics

System Dynamics (SD) is a method used to describe the behavior of complex systems over time. It was developed in the 1950th by Jay W. Forrester at the Massachusetts Institute of Technology (Forrester, 2007) and finds wide ranging applications in the fields of management, engineering, and computer science. Systems dynamics can furthermore play a role in making strategic decisions (Gary, Kunc, Morecroft & Rockart, 2008). SD uses chains of relationships that are constructed based on physical flows (cash, materials, etc.) and information flows (Wolsenholme, 1982). The foundation of SD is rooted in systems that are each linked through conditions of system variables, which are unknown variables from identified conditions of other system variables. This creates an environment of uncertainty that is adapted into our mathematical model to describe the random nature of the development of stakeholder interests.

Both qualitative and quantitative analysis is used in our approach, as illustrated in Figures 5.5 and 5.6. Figure 5.5 shows the generalized SD approach adapted from E. F. Wolstenholme (1982 and 1983).

System Description: Qualitative Analysis	Quantified Analysis Using Continuous Simulation Techniques		
	Stage 1	Stage II	Stage III
1. Current Financial Models 2. Using physical, cash, and information flows 3. Examine water financing feedback loop structure	1. Examine the behavior of all system variables over time. 2. Examine the validity and sensitivity of the model to changes in: (i) Structure; (ii) Policies (iii) Delays and uncertainties	Examine alternative structures and control policies base on: (i) Intuitive ideas; (ii) Control theory analogies; (iii) Control theory algorithms	Optimize system parameters
To provide: (i) A perspective on water financing or symptoms of the water financing market (ii) A qualitative analysis on which to base recommendations for water financing change	Provide a quantified assessment of alternative ways of improving system performance		

Figure 5.5. Systems Dynamic Approach for Water Resource Financing – Optimization Framework (adapted from Systems Dynamic Methodology, Wolstenholme, 1983)

When applied to water financing, the three stages of the quantitative analysis can be modeled as depicted in Figure 5.6.

	Stage 1	Stage 2	Stage 3
Water Financing	Definition of: • Objectives • Variables	Definition and application of relevant modeling techniques: • Mathematical models • Financing instruments • Expenditure models	Definition and implementation of: • Performance measure • Feedback loops • Feedback control

Figure 5.6. Stages of Systems Dynamic Methodology for Water Financing Sector (Adapted from Systems Dynamic Methodology, Wolstenholme, 1983)

For the implementation of the framework, a mathematical optimization method called Optimal Control Theory (OCT) is used. The objective of OCT is to determine a control function that will cause a process to satisfy constraints and at the same time minimize (or maximize) a performance measure (Kirk, 1970). This can be achieved by usage of a closed-loop feedback control structure as schematically shown in Figure 5.7. The usage of a feedback structure allows for controlling complex and dynamic systems that change over time. In Figure 5.7 the "controller" and the "system" are connected such that they both influence each other. Through the "measurement" component the state of the system can be compared to the desired state. By feeding this information back into the loop, corrective actions can be taken to approach the desired state of the system.

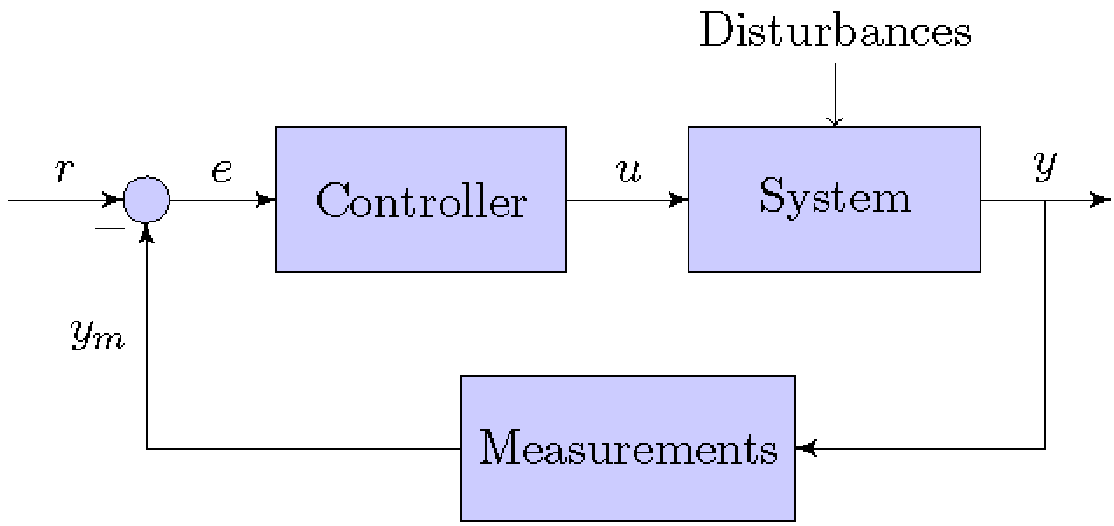

Figure 5.7. Basic Feedback Control Theory (Texample.net, 2006)

It is this basic feedback loop structure that is adapted in this thesis to create an optimal water financing framework.

5.4.2 OWF Methodology

The OWF feedback loop structure is depicted in Figure 5.8 and makes use of the following variables:

1. r = reference, which is the ideal outcome of a water project
2. u = variation of control variables
3. y = performance parameter being measured
4. e = error (reference – actual)

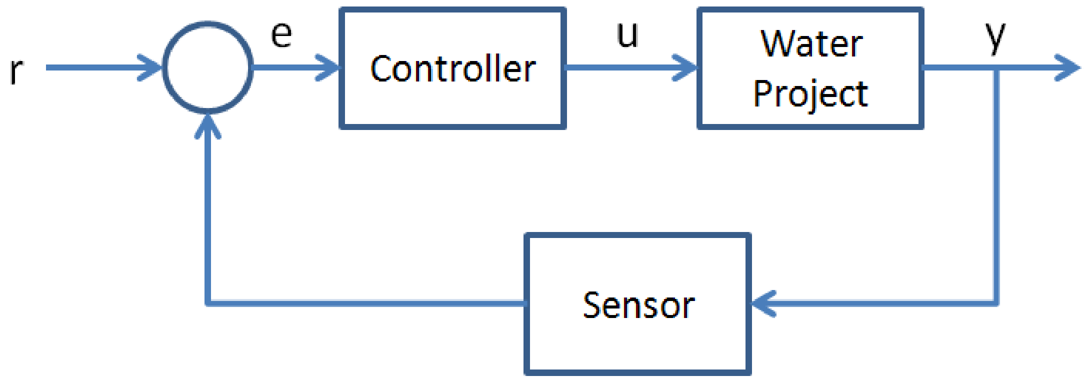

Figure 5.8. OWF Feedback Control Theory

In the schematic, the reference (r), defines the input parameters describing the ideal outcome of a water project, as determined by stakeholder interests. Through the input point (e), the parameters enter the controller which controls the variation of control variables (u) that regulate the water project. The measured output (y), describes the actual state of the system, which is fed into the sensor. The sensor compares the actual state of the system with the desired state and computes the error (e), which is then fed into the controller to change the control parameters to minimize the error. The loop is continuously repeated, allowing the system to approach the ideal outcome.

The feedback control structure can be implemented using the method of Dynamic Programming (DP), which leads to a functional equation that can be solved by a computer (Kirk, 1970). DP is widely used in engineering to determine the control signals that will cause a process to satisfy the physical constraints and at the same time minimize or maximize the performance criterion (Kirk, 1970). Differential equations are used to find the optimum control function that maximizes the performance. For the purpose of the OWF framework optimal control using ordinary differential equations (ODE) and stochastic differential equations (SDE) are considered. In the following we will discuss the basic framework of the two approaches. The description of the ODEs is based on the "Optimal Control Theory" written by Kirk (Kirk, 1970), while we refer to the lecture by Evans from UC Berkley (Evans, 1983) for SDEs.

Optimal control using ODE can be achieved using the Hamilton-Jacobi-Bellman equation which is a non-linear partial differential equation. The control function of the OWF can be described by the state equation (Kirk, 1970):

$$\dot{\boldsymbol{x}}(t) = \boldsymbol{a}(\boldsymbol{x}(t), \boldsymbol{u}(t), t) \text{ (Eq. 5.1)}$$

With $\mathbf{x}(t)$ being the state vector of the system and $\mathbf{u}(t)$ the control vector. The state equation is to be controlled to maximize or minimize the performance measure (Kirk, 1970):

$$J = h(\boldsymbol{x}(t_f), t_f) + \int_{t_0}^{t_f} g(\boldsymbol{x}(\tau), \boldsymbol{u}(\tau), \tau) d\tau, \text{ (Eq. 5.2)}$$

where h and g are specified functions, t_0 and t_f are fixed, and τ is a dummy variable of integration (Kirk, 1970). In order to determine the function that for example minimizes J, the following equation needs to be solved (Kirk, 1970):

$$J^*(x(t), t) = min_{t \leq \tau \leq t_f} \left\{ \int_{t}^{t_f} g(x(\tau), u(\tau), \tau) d\tau + h(x(t_f), t_f) \right\} \text{ (Eq. 5.3)}$$

After applying Bellman's optimality principal, this equation yields the Hamilton-Jacobi-Bellman (HJB) equation, whose solution gives us the optimal feedback control (Kirk, 1970):

$$0 = J_t^*(x(t), t) + H(x(t), u^*(x(t), J_x^*, t), J_x^*, t) \text{ (Eq. 5.4)}$$

The solution of the HJB equation yields J^*, which is the optimum value of our performance measure. In order to find the optimal solution, we will need to find the control law that minimizes the performance measure, J. In order to do so we must first specify a performance measure, which is a mathematical expression of all terms that need to be minimized. Using J and the Hamiltonian H, defined as (Kirk, 1970):

$$H(\boldsymbol{x}(t), \boldsymbol{u}(t), J_x^*, t) \triangleq g(\boldsymbol{x}(t), \boldsymbol{u}(t), t) + J_x^{*T}(\boldsymbol{x}(t), t)[\boldsymbol{a}(\boldsymbol{x}(t), \boldsymbol{u}(t), t)] \text{ (Eq. 5.5)}$$

In case of an unconstrained control, the necessary condition that the optimal control must satisfy is (Kirk, 1970):

$$\frac{\partial H}{\partial u} = 0$$

From this equation we can derive $u^*(t)$, the optimal control function. The control function can then be substituted in the HJB equation. Furthermore, the boundary value for the partial differential equation (PDE) can be found by setting $t = t_f$. From Eq. 5.3, it is apparent that the boundary condition I (Kirk, 1970)s:

$$J^*\left(x(t_f), t_f\right) = h\left(x(t_f), t_f\right) \text{ (Eq. 5.6)}$$

One way to solve the HJB equation is to guess a form for the solution to see if it can be modified or adjusted to satisfy the differential equation and the boundary conditions. Once the solution is found then the optimal control law can be specified (Kirk, 1970). While this approach is viable for simple cases, one is generally unable to find a solution this easily. In general the HJB equation must be solved by numerical techniques. Such techniques that involve an approximation to the exact optimization will be employed in the OWF, as discussed in Chapter 6.

The second method is the use of controlled SDEs. The following is based on the lecture notes of Evans (Evans, 2011). SDEs differ from ODEs in that they contain a "white noise" term that causes random fluctuations (Evans, 2011). Stochastic dynamic programming is of particular importance, as it provides reasonable solutions to account for uncertainties of water resource systems planning (Luo, 2007). A SDE can be written as (Evans, 2011)

$$d\boldsymbol{X}(t) = \boldsymbol{f}\left(\boldsymbol{X}(t), \boldsymbol{u}(t)\right)dt + \sigma\, d\boldsymbol{W}(t), t_0 \leq t \leq t_f \text{ (Eq. 5.7)}$$

The expected payoff functional has the form (Evans, 2011)

$$P_{x,t}[\boldsymbol{u}(\cdot)] \coloneqq E\left\{\int_{t_0}^{t_f} r\left(\boldsymbol{X}(\tau), \boldsymbol{u}(\tau)\right)d\tau + g(\boldsymbol{X}(T))\right\}. \text{ (Eq. 5.8)}$$

In contrast to the deterministic model discussed earlier, the stochastic functional contains an expectation value E that describes the random nature of P (Evans, 2011).

The value function can be defined as $v(x,t) \coloneqq sup P_{x,t}[\boldsymbol{u}(\cdot)]$

Simply, we are obtaining the supremum (maximum) of P, our payoff function. In order to do so, the method of dynamic programming can be employed. The first step is to find a PDE that is satisfied by v, which is then used to design an optimal control u^* (Evans, 1983).

To find a solution we consider that u is any control function that is used for the time interval $t \leq \tau \leq t+h$ and that the optimal control function is used thereafter. Then

$$v(x,t) \geq E\left\{\int_t^{t+h} r\big(\boldsymbol{X}(\tau), \boldsymbol{u}(\tau)\big)d\tau + v(\boldsymbol{X}(t+h), t+h)\right\} \text{ (Eq. 5.9)}$$

In the case of optimal control the inequality becomes equality, if we take $\mathbf{u}(\tau) = \mathbf{u}^*(\tau)$. To find the differential of Eq. 5.9, Itos chain rule (see for example Evan, 1983) can be used to yield:

$$dv(\boldsymbol{X}(\tau), \tau) = v_t(\boldsymbol{X}(\tau), \tau)d\tau + \nabla_x v \cdot \big(\boldsymbol{f} d\tau + \sigma d\boldsymbol{W}(\tau)\big) + \frac{\sigma^2}{2}\Delta v\, d\tau \text{ (Eq. 5.10)}$$

Plugging Eq. 5.10 into Eq. 5.9 one derives

$$0 \geq E\left\{\int_t^{t+h}\left(r\big(\boldsymbol{X}(\tau), \boldsymbol{u}(\tau)\big)d\tau + v_t(\boldsymbol{X}(\tau), \tau) + \nabla_x v \cdot \big(\boldsymbol{f} d\tau + \sigma d\boldsymbol{W}(\tau)\big) + \frac{\sigma^2}{2}\Delta v\right) d\tau\right\}$$

(Eq. 5.11)

Dividing Eq. 5.11 by h and letting h approach 0 ($h \rightarrow 0$) one obtains the stochastic HJB equation:

$$max_{u \in U} \left\{ v_t + f \nabla_x \mathrm{v} + \frac{\sigma^2}{2} \Delta v + r \right\} = 0 \text{ (Eq. 5.12)}$$

Hence, the value function v(x,t) has been shown to solve the HJB PDE.

The solution of the stochastic HJB equation yields v(x,t), the optimum value of the payoff functional P. The goal is to find the control law that maximizes the performance measure, P. In case of an unconstrained control, the necessary condition that the optimal control must satisfy is:

$$\frac{\partial H}{\partial u} = \frac{\partial (\boldsymbol{f}(\boldsymbol{X}(t), \boldsymbol{u}(t)) \nabla_x \mathrm{v} + \frac{\sigma^2}{2} \Delta v + r(\boldsymbol{X}(\tau), \boldsymbol{u}(\tau)))}{\partial u} = 0$$

(Eq. 5.13)

As discussed for the ODE, we can derive $u^*(t)$, the optimal control function. The control function can then be substituted in the HJB equation. Furthermore, the boundary value for the PDE can be found by setting $t = t_f$. From Eq. 5.8, it is apparent that the boundary condition is (Evans, 2011):

$$v(x, t_f) = supP_{x,t}[\boldsymbol{u}(\cdot)] = g(\boldsymbol{X}(t_f)) \text{ (Eq. 5.14)}$$

In Chapter 6, the functionality of optimal feedback control will be demonstrated using a simplified model that is stochastic and controllable using a PID controller to achieve ideal optimal performance. For the optimum OWF model, the simplified model needs to be expanded using the OTC and dynamic programming.

In either case, the inputs and outputs of OWF need to use indicators to determine the parameters to measure. OWF adapts indicators from the International Benchmarking Network for Water and Sanitation Utilities (IBNET) Toolkit. A detailed description of each indicator is attached as Appendix B. The following is a list of indicators given by IBNET (2011):

- Service coverage

- Quality of Service

- Water consumption and production

- Billings and collections

- Non revenue water

- Financial Performance

- Metering practices

- Assets

- Pipe network performance

- Affordability of services

- Costs and Staffing

- Process indicators

These indicators should be initiated and compiled by the borrower or end-user first with the appropriate stakeholders who then facilitate a discussion to negotiate the financing terms with the lender which also may occur with the collaboration of an NGO or charitable organization. The results from the inputs/outputs of the indicators then can create a simulated cash flow for the borrower and lender that are optimized for efficient flexible financing terms with feedback loops. Examples of this information feedback between stakeholders is illustrated in Figure 5.9

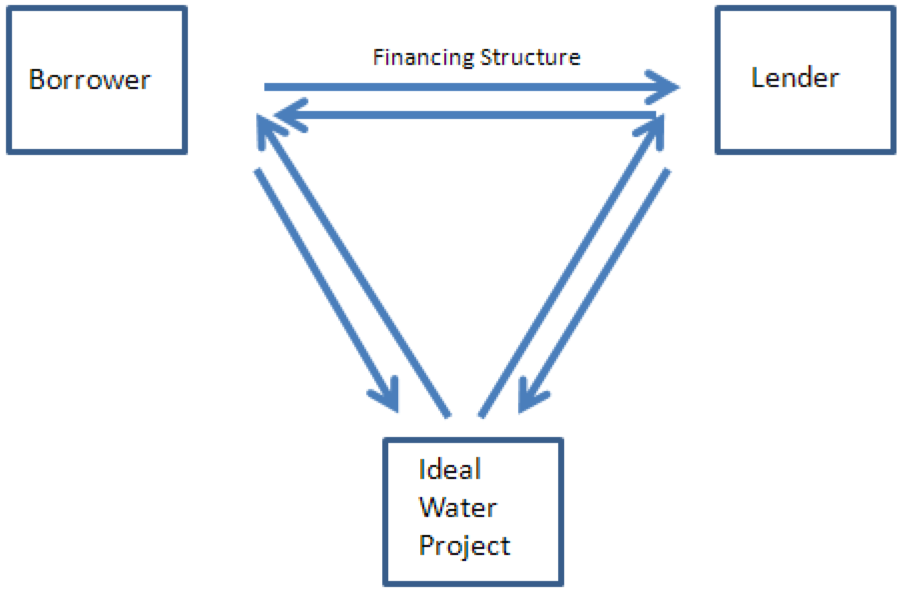

Figure 5.9. Information Feedback between Stakeholders (Source: Cap-Net, GWP, & EUIW, 2008)

The goals of financing OWF for the end-user stakeholders ultimately are to have water paying for water, and only water (Cap-Net, GWP, & EUIW, 2008). Other targets adapted from the EU Water Imitative (EUWI) with the Global Water Partnership and Cap-Net of the UN economic sustainability of water management framework includes:

- Ensuring sufficient revenue to deliver services in the long term
- Ensuring sufficient revenues supporting improved quality of services
- Ensuring sufficient revenues extending service coverage, specifically to low-income consumers

- Ensuring better use of scarce water resource and management of wastewater disposal conserving the natural environment

Additionally the training guide cited external and internal factors that should be monitored on an ongoing basis for sustainability of water resource management listed in Table 5.1

External Factors	Internal Factors
• Government support • Autonomy • Understanding of external risks • Understanding of economic base	• Financial and credit management • Management quality/capacity • Operational performance • Strategic planning and internal transformation • Human resources and utilization of private sector • Customer relations

Table 5.1. Internal and external factors to support utility transformation
(Source: Cap-Net, GWP, & EUIW, 2008)

The importance of this analysis of this methodology, OWF, provides guidance in moving from “what is” to “what should be” in determining the objectives of the methodology (Wolstenholme, 1983).

Reference Input	Objective
Which costs must be covered?	Payment, cash Purchase of hardware and tools Running costs for project System expansion Financing repayment
Which funds should be used?	Community contributions User contributions Interest from community savings External funds (donors, NGOs, national governments, etc.)
Which tariffs should be used?	Flat tariffs irrespective of amount used Flat tariff per consumer where payments depend of the number of persons in the household; not amount used Tariff per unit of water drawn Low tariff for low-income households High tariff for high income households Low tariff for the first few units per person with higher tariff for subsequent units per person
How to collect contributions?	User contributions to establish a separate water project funded deposit account User fees through metered connections, payments at the water point or weekly/monthly payment to the treasurer Submitting proposals for external funding
When is an appropriate time to collect contributions?	Monthly At the beginning of the fiscal year As and when required After a crop or other productive activity
What to do in a default scenario?	Analyses causes of cash flow non-payments Restructure cash flow payments Improve services Determine if and when to cut losses
Where funds should be deposited?	Community account Dedicated account in a bank In objects that can serve as investment
What should be taken into consideration to administer the funds?	Receipts for accounting Financial control Authorization to draw money from the bank account Comments and recommendations of the users
Who should administer the funds?	Community committee Community accountant External accountant
How to pay for staff for are responsible for operations and management	In cash or in-kind After a task has been fulfilled On a monthly basis Every year, after a crop or other productive activity

Figure 5.10. Elements of Financing Mechanisms in OWF (Adapted from Cap-Net, GWP, & EUIW, 2008)

CHAPTER 6

THEORETICAL CASE MODEL AND MATHEMATICAL MODEL

In this chapter the inputs and outputs of the OWF model are discussed based on a case model. Furthermore, the feasibility of the OWF model discussed in Chapter 5 is demonstrated using a simplified model. In particular, the ability of the model to react to the random fluctuation of inputs and the use of feedback control to optimize the performance, as defined by the stakeholders, is shown. Furthermore we demonstrate how the OWF model could mitigate potential shortfalls and challenges of the project to make it more financially sustainable.

6.1 Water Project Selection

For the foundation of the theoretical case model a water project carried out by Enersol, a non-profit organization working with water pumps powered by renewal energy sources in the Dominican Republic since 1993 was used. Enersol works with the Associate for the Development of Solar Energy (ADESOL) to develop projects in rural communities.

Using the case study based on Enersol's model for renewable energy for rural community water supply, the proposed water project suggests that a solar powered water pumping system with water treatment and water holding tank system should be used (Graham and Johnson, 2000). This decision was also derived by considering site selection parameters based on the technical note by Charey et al (Chaurey, et al, 1993). Solar furthermore was chosen over gas and wind as it is economically and logistically more favorable, as corroborated by a case study by

Cloutier (Cloutier, 2011). Solar pump systems have been proven to be reliable, cost-efficient, and to deliver high performance (Meah, 2006). Solar systems have a higher upfront cost that can be handled financially by designing parameters of a cash flow that take advantage of user's willingness to pay (Singh, et al, 1993).

For water projects using renewal energy sources the size and feasibility of a system design is driven by 3 parameters (Graham and Johnson, 2000):

1. The daily water demand
2. The vertical distance water is pumped
3. The availability of renewable energy resources

A sample case is taken from Enersol and ADESOL's work, where the feasibility of the above parameters is given. The case is examined and its inputs are adapted into the OWF model framework. The case community will be called Esperanza for our sample case.

6.2 Esperanza Profile

Esperanza's initial population is 237. The local access to water is critical because of the surrounding arid areas and poor surface water that require on average two and half hours or more to obtain access to drinking water (Source: Graham and Johnson, 2000). Table 6.1 lists the assumed systems parameters of the desired water project:

Parameter	Assumption
Daily water demand	Approximately 30 liters per person per day. Water for household uses only.
Insolation (energy source)	5 kWh per m^2 per day
Water storage capacity	3 days minimum
Distribution system	Metered-pay
Population growth	2% annually

Table 6.1. Design parameters of Esperanza project (adapted from Graham and Johnson, 2000)

The base case model stipulated ADESOL would maintain ownership of the water pumping equipment and the power source (solar modules) with the use of tariffs to manage the costs of the system.

Using the general approach of ADESOL's project development for implementation, the following steps were taken (Source: Graham and Johnson, 2000):

1. Community visits to evaluate the feasibility of project
2. Perform studies as necessary to determine project feasibility
3. Meetings with community to discuss conditions of a feasible project
4. Wait for community to make a decision
5. Hold workshops to assist community with development of a water board
6. Develop water well
7. Develop civil works
8. Install photovoltaic (PV) system with local solar support
9. Inaugurate water system
10. Post-installation technical assistance

The community's responsibilities included:

1. Daily system operation
2. Maintenance of civil works
3. Collection of monthly payments
    i. Insurance policy
    ii. Financed payments

6.3 Esperanza System Challenges and Design

The Esperanza project faces several challenges pertaining to site selection, appropriate technology, water quality standards, community participation, and adequate financing. By utilizing the water dialogue space between stakeholders for the process of valuing water and governance from Chapter 4, these challenges can be discussed and managed among the stakeholders for sustainable development. Because communities are ever changing and dynamic, financial flexibility must be inherent in both the physical aspects of the project, as well as the financing model applied. In simulating the mapping process of stakeholders detailed in Chapter 3, and using Enersol's Esperanza project (Source: Graham and Johnson, 2000) as the case study, the following challenges to determine the assumptions and decisions of our base case were established:

1. Site selection: the community was able to properly identify a location for the project with sufficient infrastructure to support the system. Site location determined adequate well resources to avoid

previous issues of wells running dry and additional costs in generating new wells for failed wells.

2. Appropriate technology: the selection of a PV system requires less technical knowledge and maintenance or repairs but should account for reputation of technology. Reliability of manufacture product information is needed for reasonable maintenance and repairs of equipment and materials.
3. Costs of systems: the majority of the system, over the course of its lifetime, is up-front. Incremental costs usually account for 15-25% of the total life cycle costs. Cost recovery and planning for long-term care of the system is an integral part of designing a feasible water system.
4. Technical designs: typical PV systems tend to require less technical knowledge. However, technical materials are generally difficult to find locally when problems arise with the PV systems that either requires a minor repair that a local technician can handle or a system component replacement. A new set of skills were needed for the installation pumps, controllers and module systems. The construction of civil works required further skills as well as training.
5. System maintenance: PV systems usually involve less maintenance and repairs compared to traditional groundwater well pump designs. Maintaining adequate supply of parts and materials is needed to account for balancing the annual costs.
6. Timescales: timing of project review, design and implementation was an important factor in selecting the ideal water project. The water system was chosen to account for development of a budget plan for realistic time frames. The most difficult areas were

centered on the required time necessary to implement the system, community participation and development of payment of the financing model.

7. Price of water service: In determining the ideal method of billing for users, a meter-payment option was selected to manage water use by the residents for controlling waste and minimizing water losses. By selecting this method of billing the willingness to pay (WTP) can ideally meet the water demand to reach the true costs of the water system. The WTP depends on the user's monthly household income and is a critical factor in meeting the financial obligations of the debt service.
8. Water quality: past water quality results have not met household consumption standards. Due to the poor quality users choose not to consume enough water to support the investment of the project which significantly lowered the WTP. Water quality testing and monitoring is included in the project design to meet user standards in the community.

6.4 Esperanza Project Financing

Understanding the system cost over time (life cycle costs) from the onset is one the major challenges facing the rural community due to the lack of experience with financing and technology. Initial costs depend on how the cash outlay is structured using subsidized or non-subsidized systems. Esperanza's subsidies ranged from various donated time from non-profit groups or vendors, to discounted materials and equipment yielding a total project cost for the financing loan of $15,068USD. By distinguishing the costs associated for the PV water pumping system into four areas (1) the initial capital cost or cash outlay, (2) life cycle cost (LCC), (3) cost on a per beneficiary basis, and (4) cost per volume (m^3), these can be used as parameters to determine project feasibility and to tailor specific terms to manage expectations and overall financial performance (Graham and Johnson, 2000).

An LCC model was developed to include the initial, operating, and replacement costs of the PV water systems over the expected project life. Although solar modules are expected to work for 20-30 years, a ten year life cycle was used due to the multitude of variable factors that can affect a system's appropriateness for a specific community (Graham and Johnson, 2000).

The LCC analysis also assumed these additional costs in the Esperanza base case:

- A contract is given to a local solar company to maintain the system.
- An insurance policy provided by the NGO covers the pump/controller.
- A community member is paid to perform civil works repairs.
- The pump and the controller are replaced after 7 years.
- ADESOL charges an annual fee for on-going technical assistance and administration.

The financial parameters used in the LCC are listed in Table 6.2.:

Return of equity	30%
Percentage borrowed	100%
Commercial interest rate	20%
Inflation rate	12%
Year of analysis	20

Table 6.2. Financial parameters of the Life Cycle Cost (Source: Graham and Johnson, 2000)

The initial cost of the equipment, system and project were calculated over the twenty year life cycle. The LCC analysis is highly sensitive to the inputs so the numbers are provided as rough estimates (Graham and Johnson, 2000).

The quality of the long-term system care of a system is only a fraction of the initial investment made. It is important to design models for rural water supply that have components for cost recovery and plan for long-term care of the system given that each one is interdependent of each other. One solution is to utilize insurance contracts to hedge against variable costs and market risks. Enersol has an insurance policy for borrowers that allow the burden of annual costs to be hedged with an agreed flat fee and any costs above that amount are born by the insurer. Should the project not exceed the amount of the fees paid to the insurer, it is not refunded to the borrower. A flexible financing model could be adapted to monitor and manage variable costs and market risks by closely analyzing the cash flows income to debt.

Esperanza pays a monthly insurance fee for a policy on the water pumping system. If the system fails ADESOL is responsible for the repair or replacement costs. This fee was included with the monthly payment of annual service fee made to ADESOL. ADESOL requires that communities make payments in their offices or they will cutoff water supply when payments are not made on time (Source: Graham and Johnson, 2000).

Esperanza's monthly payments over a 5 year period are expected to cover an estimated 30-50% of the initial capital investment in the PV water pumping equipment (Source: Graham and Johnson, 2000). The willingness to pay is impacted by the water quality delivered by the PV system. If the water is not considered suitable for drinking or cooking, the willingness to pay will decrease reducing the likelihood of the user fees to cover the initial capital investment. Analysis from studies conducted on rural water supply systems indicate that over the long term, with additional households connected to the water systems there will be a demand and willingness to pay for the improved service (Singh, et al, 1993). Additional investments will be needed in filters and technology to bring the water quality to acceptable standards which in turn will drive up the costs of the overall system. These additional investments can also negatively impact the willingness to pay and must be relayed to the end-user by in proportion to the average household income.

6.5 Research Design

The objective of the case model is to determine whether the proposed theoretical mathematical framework can facilitate sustainable financing strategies to optimize usage of funds. The studied parameters and indicators used for the cash flow analysis are detailed in Appendix E. A total of three cash flows were compiled for the cash flow analysis. Cash flow A uses the Esperanza base case model previously discussed in this chapter. Cash flow B simulates the Esperanza base case but assumes that the village pays for the real arising costs rather than using an insurance payment. Using the assumption of 15-25% maintenance cost over the life time of the project and the theoretical mathematical model we demonstrate that the overall project costs are significantly lower in the OWF model. Cash flow C presents the OWF framework to replicate a cash flow that uses a feedback loop to manage financial disturbances in order to optimize usage of funds for a desired rate of return and warrant sustainability of the Esperanza water project. Cash flow C's structure is described in greater detail in the next section.

6.6 Cash Flow C: OWF Case Model

The OWF model for Esperanza's Case C used the underlying assumptions and the true project data (e.g. the amount of water produced) of the base case model, A, to incorporate a feedback loop system using a current or real-time depiction of the LCA of the case. The financing terms were linked to the true project cost and results of the cash income through on-going feedback loops within the model which are continuously modified to meet the expectation of the ideal water project among the stakeholders.

The System Dynamics (SD) process of linking conditions of system variables, which are unknown from identified conditions of other system variables, is adapted mathematically to describe the random nature of stakeholder interests. SD is implemented using a performance measure, feedback loops and feedback control.

The signals of the control system of a feedback loop structure as shown in Figure 5.8, for OWF's case model are defined as:

r = setpoint (reference: the ideal outcome of the water project)

u = revenue offset factor (variation: control variable)

y = operational cash flow (performance parameter being measured)

e = error (setpoint − operational cash flow)

The feedback control structure was first implemented by using a rule-based system design methodology where the rules are treated as the decision variables (Liu, Zabinsky & Kohn, 2010). The output is continually used in the forecasting of the control system to correct the desired behavior (Liu, Zabinsky & Kohn, 2011). The operation rules are a subset of rules determined by the managers of the system to directly model operations using their expertise (Liu, Zabinsky & Kohn, 2010). By having OWF behave using rule-based logic for the revenue offset factor, u, the system can appropriately respond to the ideal water financing for the stakeholders.

The rule-based system design was then improved by replacing it with a proportional-integral-derivative (PID) controller that is a very effective method to keeping the process variable closely within a setpoint (VanDoren, 2003). PID controllers are generally used to control systems with linear response and can be highly unstable for non-linear systems, like the herein discussed case. The process variables were manually adjusted to yield the best control behavior for the nonlinear time invariant water project. The cash flow uses a PID controller to adjust the revenue offset factor using the following mathematical formula:

$$\begin{aligned} &proportional\ gain * current\ error + accumulated\ error * integral\ gain \\ &\quad + derivative\ gain * (current\ error - previous\ error) \end{aligned}$$

The gain parameters are used to adjust the behavior of the PID controller to fluctuation of the operational cash flow (OC) of the system. The errors relate to the difference of the OC and the desired setpoint of the system. The later can be defined by the stakeholders to achieve a particular project revenue goal. In our case, the OC is the negative of the sum of the differences of the monthly actual cost-assumed cost and the monthly actual cost-project income. The monthly amount billed (MAB) is rule based to inhibit overshooting of the PID control loop in the event of large random cost spikes. The MAB therefore first compares the amount to be charged to the maximum amount for which the WTP is non-zero. If the amount is larger than the WTP, only the maximum amount is charged and the remaining cost is rolled over to the next billing cycle. This is only the case when the project cost drastically increases, as in the case of a pump failure. If the amount is within a range of non-zero WTP, the PID controller provides a factor by which the MAB is multiplied. Using the feedback control loop describes above, the PID controller adjust the MAB such that the operational cash flow is continuously adjusted to approach the desired setpoint. Cash flow risk distribution commonly is controlled by the timing of payments which substantiates the use of the controller to modify the billing costs for the project (Garden and Creese, 2000).

By using the revenue offset factor to adjust the amount billed and hence the cash income in the next billing cycle, the revenue from the user's fees can facilitate in the cost recovery of the project and manage the overall risk for stakeholders. As described above the control loops considers the optimum price point the users are willing to pay, adjusting the unfunded liability balance using forward billing until that amount is no longer a liability. Any disturbances encountered in the cash flow such as poor water quality and replacement costs of technology and material are examples of how this is factored into the billing arrangement through the revenue offset factor.

The indicators used in PID program are:

1. Actual costs less the assumed max costs
2. Actual costs less the actual income
3. Operational cash flow measure

6.7 Cash Flow Analysis

Hypothesis: the existing cash flow analysis is adequate to determine feasibility and financial sustainability of water projects.

Null hypothesis: proposed mathematical model using optimal feedback control theory to maximize the performance of a water project.

In considering the structure of the hypothesis and the cash flow analysis used for the data, the three cases were used to determine the significance of the proposed OWF framework. The sample size consisted of the initial year to start up the project and 19 year cash flow broken into the monthly payments for a 20 year project (228 months). Because cash flow risk occurs when the project is implemented, a period to period approach is best in cash flow analysis (Garden and Creese, 2000). However, the first year was not factored into the financial pro forma arranged between the borrower and lender it was not included in our cash flow analysis.

All of the data and information needed for calculating the projected cash flows were taken from the base case, Esperanza. Considering the structure of the cash flow hypothesis and collected data, a one-way ANOVA, f-test was applied for data analysis.

6.8 Results and Discussion

Results of 100 runs of the cash flows of Case A, B, and C were analyzed using the ANOVA analysis included in the Microsoft Excel Analysis ToolPak. This analysis provides a variety of statistical results for data analysis and hypothesis testing.

In addition, the operational cash flow, along with its two constituents the differences of actual cost – assumed cost (Indicator 1) and actual cost – income (Indicator 2), is plotted for comparison.

The results for Case A and Case B are plotted in Figure 6.1 and listed in Table 6.3. As case A relates to the initial water project, the variation seen all cash flows is rather low. Indicator 1 shows a steady decline due to a 7% discount rate, which in turn leads to a slow increase of the operational cash flow over the course of the project. The total project cost for case A is $ 22,016.58, which corresponds to about 1% revenue.

Case B is based on the assumptions used in Case A, but includes random monthly costs that correspond to the 15-25% assumed for maintenance cost over the life cycle. A PID controller with setpoint of 50 is used to flexibly adjust the operational efficiency. The cash flows in Case B show an overshooting of the control loops in the beginning months. This is due to the non-linearity of the system and could be mitigated by using different control gain parameters at the beginning of the project. Since the goal of this section is to show the general functionality of a system using a control loop, this error will not be neglected hereafter. Despite the randomness in the cost, the cost factors in the right panel of Figure 6.1 are fairly constant with low overall noise, considering that the deviations are stemming for a total of 100 runs. The setpoint in Case B was set to yield a slightly higher return rate (2%) as compared to Case A. The total cost for Case B was calculated to $16,261.38 which is significantly less than for Case A, $22,0618.58. The comparison shows that a water project with real-life cost factors that are random can be successfully run when using a control loop approach, especially due to the possibility of flexible adjustments of finance terms, as will be demonstrated in Case C. The Case C proof aims to maximize the results of optimal water quality, WTP, water demand, reducing overall costs, and the potential of the ideal water project. These results help achieve the notion of "water pays for water and only water" (Cap-Net, 2008).

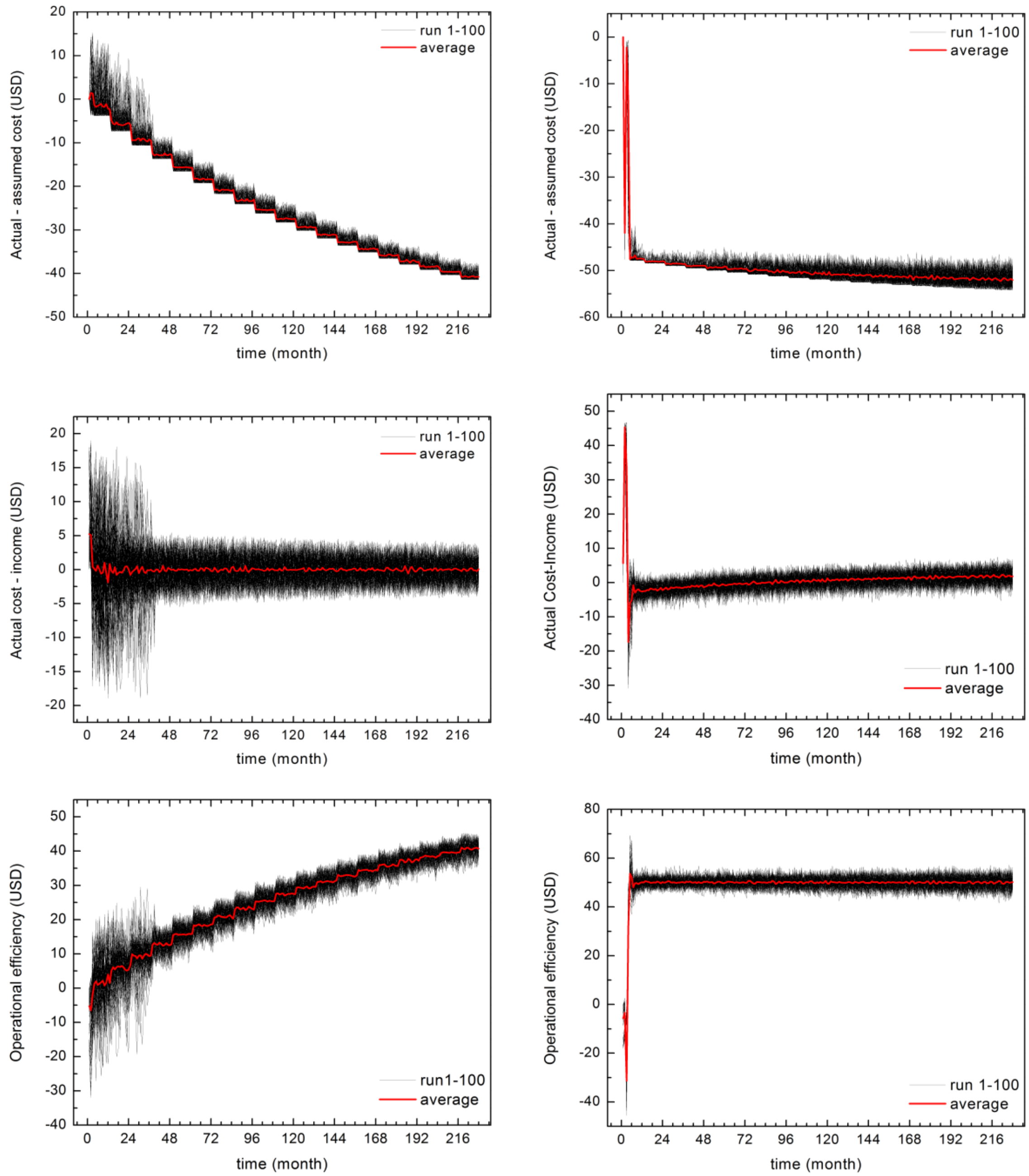

Figure 6.1. Cash flows of base case, Case A (left) and Case B(right)

Table 6.3. Summary of Anova Analysis of Case A

Groups	*Count*	*Sum*	*Average*	*Variance*
Actual/assumed cost	22800	18147.2	0.80	0.009
water prod/water demand	22800	33184.8	1.46	0.037
water cost/moving average	22800	22549.3	0.99	0.001
cash income/debt service	22800	22797.7	1.00	0.001
H_2O operating costs/pop served	22800	2562.1	0.11	0.003
Actual-assumed cost	22800	-571153.1	-25.05	141.647
actual cost - income	22800	403.1	0.02	7.316
Operational cash flow	22800	570750.0	25.03	150.922

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28653554.63	8.00	3581694.33	107473.66	0.00	1.94
Within Groups	6838247.29	205191.00	33.33			
Total	35491801.93	205199.00				

Table 6.4. Summary of Anova Analysis of Case B

Groups	*Count*	*Sum*	*Average*	*Variance*
Actual/assumed cost	22800	13564.2	0.59	0.002
water prod/water demand	22800	33191.9	1.46	0.037
water cost/moving average	22800	22534.3	0.99	0.001
cash income/debt service	22800	22629.1	0.99	0.003
H_2O operating costs/pop. served	22800	440.0	0.02	0.000
Actual-assumed cost	22800	-1133738.3	-49.73	30.895
actual cost - income	22800	13196.4	0.58	22.090
Operational cash flow	22800	1120541.9	49.15	62.441

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	111513220	8	13939153	1086458	0	1.938459
Within Groups	2632581.26	205191	12.82991			
Total	114145802	205199				

In Case C additional disturbances are introduced that would under normal circumstances impose tremendous challenges for a water project if not stall it. The disturbances enter the system as higher random costs at random intervals costs relating to investments necessary to maintain water quality. The latter costs are modeled such the probability of them occurring is higher after specific time periods. This can be clearly seen by the areas of high fluctuations in the cash flows depicted in Figure 6.3. Despite the severe impact of the disturbances, the control loop is able to balance the operational cash flow by taking into account the WTP and by spreading the total cost over several billing cycles. The overall project cost of $22,242.53 is comparable to the Case A, $22,016.58, while a return of 13% was achieved.

Table 6.5. Summary of Anova Analysis of Case C

Groups	*Count*	*Sum*	*Average*	*Variance*
Actual/assumed cost	22800	21405.5	0.94	0.412
water prod/water demand	22800	33219.1	1.46	0.038
water cost/moving average	22800	22549.9	0.99	0.001
cash income/debt service	22800	21650.6	0.95	0.211
H_2O operating costs/pop. served	22800	2625.8	0.12	0.065
Actual-assumed cost	22800	-171186.6	-7.51	6208.830
actual cost - income	22800	115949.0	5.09	5227.751
Operational cash flow	22800	55237.6	2.42	13243.603

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2067046.65	8	258380.8	94.21962305	3.7E-157	1.938459
Within Groups	562700416	205191	2742.325			
Total	564767463	205199				

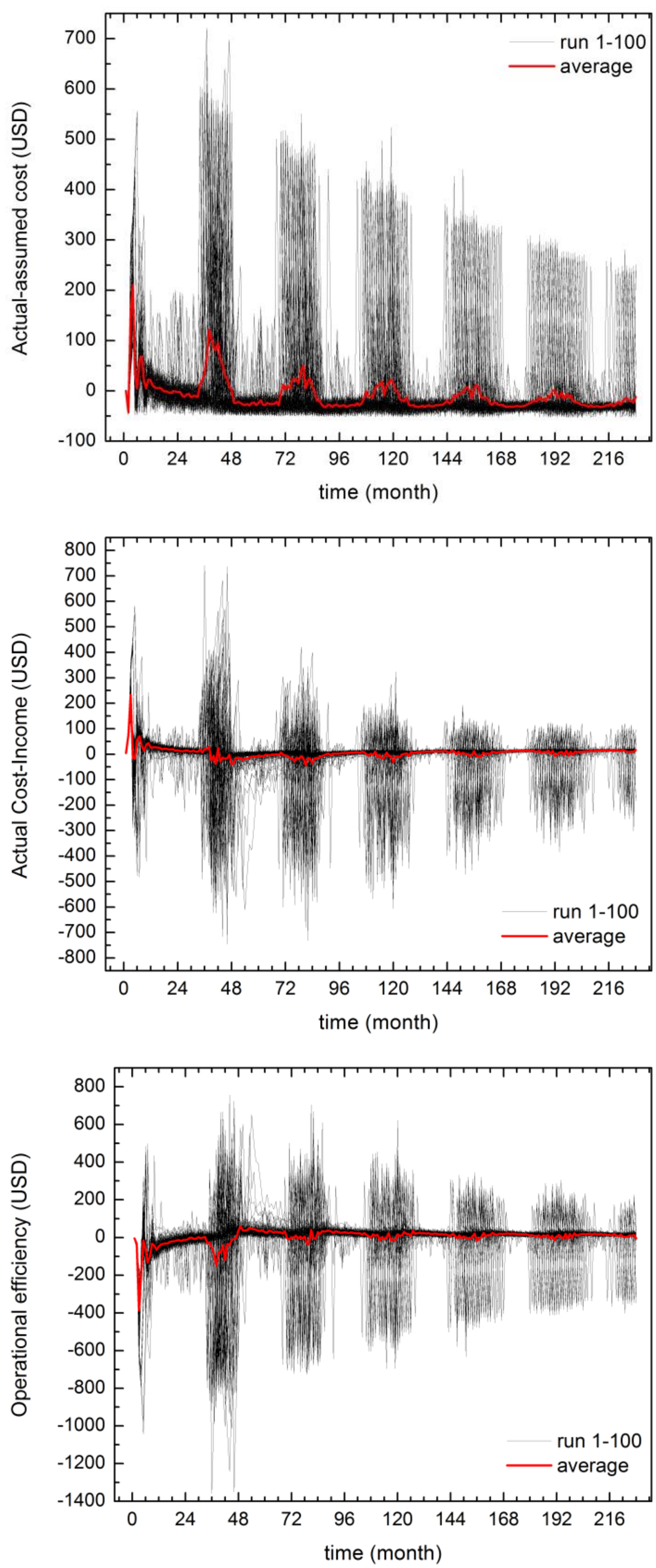

Figure 6.2. Cash flows of Case C

The results show that control loops are a means for flexible financing of water projects, which can significantly improve the performance of such a system and the sustainability of the project overall.

6.9 Future Work of Mathematical Model

To demonstrate the functionality and output of the OWF model using optimal control, a stochastic version of the logistic model (also called Verhulst-Pearl model) was programmed in the programming language Matlab. The results of this preliminary model are only hypothetical and meant as a proof of concept rather than relating to the earlier discussed Cases A-C. Future work will focus on this model. The Verhulst-Pearl model describes the growth of population under the influence of limiting factors like resources. Therefore, it is similar to a water financing project whose objective is to maximize the performance under the influence of limiting factors. The basic logistic model is expanded to react to the random fluctuation of inputs. Furthermore feedback control is introduced to optimize the performance.

The logistic model was established by Verhulst to model population growth and can be written in form of a differential equation:

$$\frac{dy}{dt} = \mu \cdot y\left(1 - \frac{y}{M}\right) = \mu y - \frac{\mu y^2}{M} \text{ (Eq. 6.1)}$$

With M as the maximum size of the population and μ as a parameter; the term μy describes the growth, while the second term $\mu y^2 M^{-1}$ limits the growth due to constraints like lack of resources.

The random nature of the input variables can be introduced by adding the stochastic term σ dW(t) which describes the random nature and leads to:

$$\frac{dy}{dt} = \mu \cdot y\left(1 - \frac{y}{M}\right) + \sigma dW_t \text{ (Eq. 6.2)}$$

Furthermore, in order to maximize the payoff function feedback control is introduced by the control term u(t):

$$\frac{dy}{dt} = \mu \cdot y\left(1 - \frac{y}{M}\right) + \sigma dW_t + u(t) \text{ (Eq. 6.3)}$$

In the uncontrolled version (Eq. 6.2) the model approaches a long-term mean value, while the value of the performance function can be influenced in the controlled model (Eq. 6.3). The latter gives us a model that flexibly adjusts parameters using a feedback control term to maximize expectations between stakeholders. Over time, OWF will approach the desired outcome of stakeholders where it is mutually beneficial. The idea of OWF is to show that the action of control will change how the system progresses and the control design needs to come up with the best strategy.

As mentioned in Chapter 5, the solution of stochastic differential equations usually requires numerical techniques that approximate the solution. The model uses the Euler-Maruyama (EM) method to solve the SDE.

The EM approximation to the true solution is the Markov chain y defined as follows (Kloeden and Platen, 1992):

- partition the interval $[0, T]$ into N equal subintervals of width δ ¿ 0:
- $0 = \tau_0 < \tau_1 < \ldots < \tau_N = T \; and \; dt = \frac{T}{N}$
- set $Y_0 = x_0$;
- recursively define Y_n for $1 \leq n \leq N$ by $Y_{n+1} = Y_n + \theta(\mu - y_n)dt + \sigma * \sqrt{dt} *$

dW_n , where $\Delta d = W_{\tau_{n+1}} - W_{\tau_n}$

The above mathematical model was programmed in Matlab code. In the following examples of various runs are discussed.

Figure 6.3 shows the uncontrolled variation of a stochastic function with time. To show the effects of the parameters μ and σ on the dynamics of the model, μ was increased from top to bottom. It is clearly visible that the system approaches the steady state faster at higher values of μ. The value of σ was varied between 0.1 on the left and 0.5 on the right side. The parameter σ can be used to describe the magnitude of the changes that are to be modeled (compare noise level in Figure 6.3).

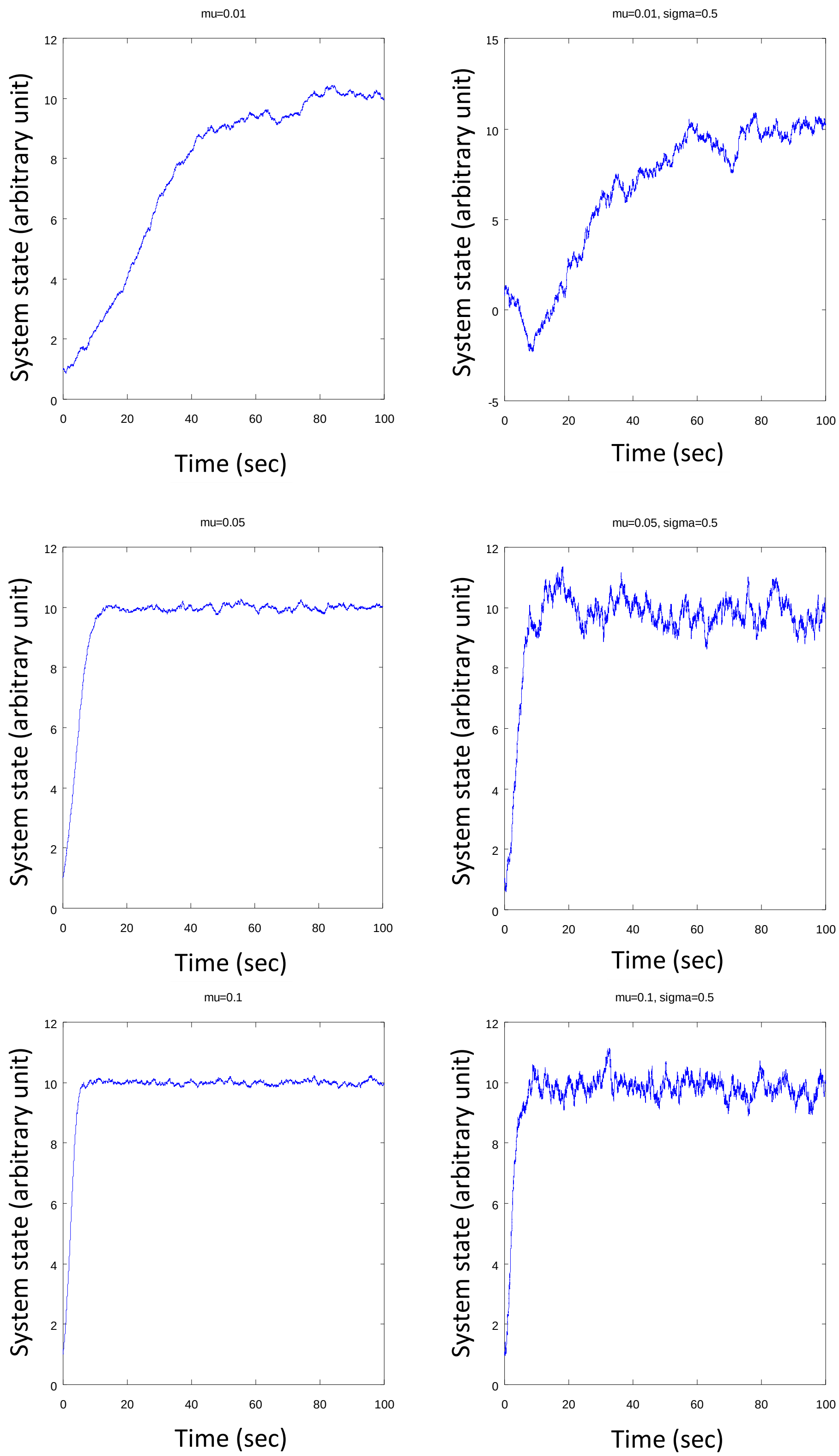

Figure 6.3. Result of an uncontrolled stochastical function with increasing value of μ from top to bottom for $\sigma = 0.1$ on the left and 0.5 on the right.

The comparison between the left and right side of Figure 6.3 shows that a larger value of σ leads to a larger response of the overall system behavior. Hence, this parameter can be used to define the magnitude of various inputs on the overall system.

In Figure 6.4 an example of a control feedback loop is presented for the case of a well-defined change (left) and multiple random changes (right). As described in the previous chapters, the idea of the model is to react flexible to changes of the input variables. On the left panel a defined change was introduced at a specific point in time. The result shows how the system adapts to the new condition. On the right hand side the amount of change was varied randomly (as reflected in the varying height of the steps in the output function).

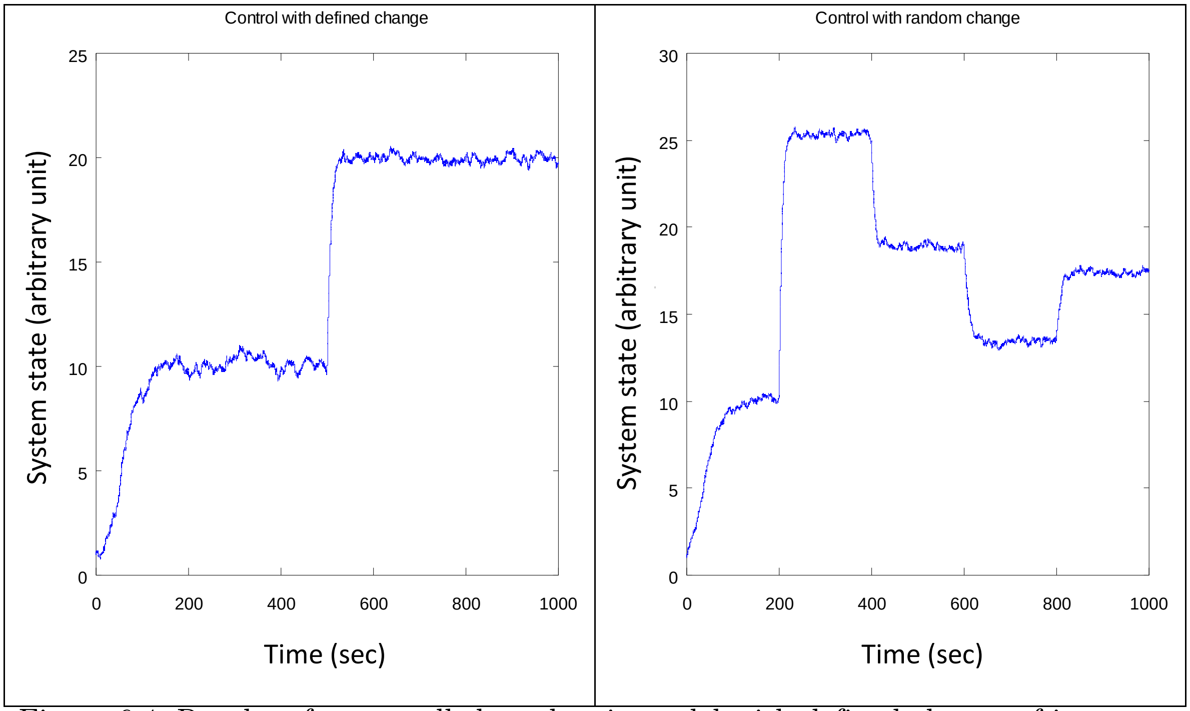

Figure 6.4. Results of a controlled stochastic model with defined change of input (left) and random change of input (right).

In order to apply this model to the theoretical model case, specific functions representing each input will need to be defined. The outcome of such a refined model will yield a financing model that can flexibly react to any changes in the input functions.

CHAPTER 7

CONCLUSIONS

The United Nations Development Programme (UNDP) established the Millennium Development Goals (MDGs) to address the issue of sustainable access to safe drinking water and basic sanitation provisions of water by 2015. The UNDP estimates that currently just fewer than 900 million people lack access to safe water, where 8 out of 10 of those persons are living in rural areas along with just over 2.7 billion people lack access to basic sanitation (UNDP, 2011).

Water infrastructure traditionally is financed by three types of sources: water users through a billing arrangement, tax payers and donors. Official development assistance (ODA) has been the key source for developing countries in leverage financial flows. The discussion of financing water policies and water regimes is highly debated amongst all give that the challenges of financial and technical assistance will continue to be at the forefront of the water sector debate. In considering these challenges due to the uncertainty in sector, water financing should be more inclusive of stakeholders expectations, such as the borrower, in determining the cash flow of monies distributed and invested in projects for their benefit "Involving the end user in project planning and implementation is essential to establishing community ownership and commitment to funding long-term maintenance which is an essential element of sustainable projects" (WASRAG, 2008, p.24).

The main idea presented in this thesis was to provide a framework for a mathematical model for sustainable financing mechanisms of water projects funded by groups like non-governmental agencies (NGOs), philanthropic donors, and investors. The objective of the model is to benefit rural and underdeveloped communities to focus on borrower-lending financing strategies to optimize the usage of funds.

The financial markets rely on investment science whereby applying scientific tools to investments in qualitative analysis, such as the character of those involved, and quantitative analysis which uses mathematics, finance, statistics, and computer science modeling. With the increase of investment science in the financial markets, they have by and large overlooked the importance of effective control mechanisms that fundamental to dynamic systems dependent on feedback loops to stabilize expected market changes (McMahon, 2011). It can be said that borrowers do not always make sensible or logical decisions as studied in behavioral economics arguing the conventional wisdom views of borrowers acting rationally and acting out in their benefit (Shicks and Rosenberg, 2011). We are all viewing the cash flow investment from our own individual perspective which is not necessarily aligned with all of the stakeholders.

Cash flow analyses are metrics that have circular references like feedback loops that will always be unstable regardless of market stability or declines. This amplification of the feedback loop occurs over periods of time that can either be days, weeks, months, quarters, or years resulting in disconnects between borrowers and lenders of financial models. As observed by McMahon of the scientific concepts failed to be integrated in finance and economics, "we have incorporated the mathematical concept of equilibrium in our metrics, but we neglected to realize the importance of other scientific phenomena, such as momentum, amplification, feedback loops, control theory, and the uncertainty principle. We have relied on our metric outputs as if efficient markets do not need stabilizers and behavioral finance phenomena are inconsequential and strategic opportunities for wise investors. Economic and financial models assume investors are rational and will pursue utility maximization, but behavioral factor often alter expected outcomes, sometimes to a severe degree" (p. 54).

7.1 Results

With the theoretical mathematical model given with our initial results reaffirms the need to integrate control mechanism in dynamic systems dependent on feedback loops, to manage the fluctuating markets between borrowers and lenders. Applying investment science to water financing is a logical means of providing guidance of how things are in the present, to the potential possibility of how things should be within the dialogue of stakeholders. Ultimately, the framework gives what people want with water; "water pays for water and only water" (Cap-Net, 2008).

7.3 Future Work

The framework presented in thesis focuses on a development for sustainable water financing mathematical model for borrowers and lenders. The theoretical framework aids in the discussion of how can financing can really become innovative financing through a stochastic dynamic programming (SDP). SDP is an optimization approach taking into account the uncertainties of the system dynamic model of water financing. In the future we hope to expand this theoretical framework to include water projects financed using this mathematical model and systems dynamic approach of qualitative and quantitative properties to further the movement of innovative financing between borrowers and lenders. Additionally, we hope to apply the results of the framework to other investment sectors of borrowing and lending.

APPENDIX A: IBNET INDICATORS

IBNET Indicator Definitions

SERVICE INDICATOR	UNIT	DEFINITION
1.1 Water Coverage	%	Population with access to water services (either with direct service connection or within reach of a public water point) as a percentage of the /total population under utility's nominal responsibility
1.2 Water Coverage – Household Connections	%	*Sub-set of 1.1*
1.3 Water Coverage – Public Water Points	%	*Sub-set of 1.1*
2.1 Sewerage Coverage	%	Population with sewerage services (direct service connection)as a percentage of the total population under utility's notional responsibility

Notes

Coverage is a key development indicator. All coverage indicators are impacted by whether the data on population and household size is up to date and accurate. The need to estimate the population served by public water points and/or the number of households per connection may affect the confidence that can be placed in the water coverage measure.

Utilities are encouraged to provide a description what implicit assumptions are underlying their water and sewerage coverage estimates, including the number of people using public water points and household connections.

WATER CONSUMPTION AND PRODUCTION INDICATOR	UNIT	DEFINITION
3.1 Water Production 3.2 Water Production	litres/person/ day m3/conn /month	Total annual water supplied to the distribution system (including purchased water, if any) expressed by • population served per day and • connection per month.
4.1 Total Water Consumption 4.2 Total Water Consumption	litres/person/ day m3/conn /month	Total annual water sold expressed by population served by • Population served per day • connection per month
Water consumption split by customer type: 4.3 Residential Consumption 4.4 Industrial / commercial Consumption	%	Shows the split of total water consumption into four customer type categories

4.5 Consumption by Institutions & others 4.6 Bulk treated supply		
Residential consumption: 4.7 Residential Consumption 4.8 Residential Consumption – connections to mains supply 4.9 Residential consumption - public water points	litres/person/ day	Shows the average water consumption per person per day by customer category

Notes

The preferred water consumption indicator is expressed in terms of litres/person/day. However there are data issues with the use of this indicator, namely

- lack of accurate total consumption data (especially when metering is not universal)
- lack of up-to-date census data, or other relevant survey data, to determine (i) household size; (ii) sharing of connections between households; and (iii) number of households using public water points

Inter utility comparisons will be more difficult, however, given the different mix of household sizes and dwellings served by one connection. This is especially the case between utilities in different countries, but it is not necessarily the case that household size, and dwellings per connection, or use of public water points are more similar within a country.

The accuracy of service populations may need improvement, but will not be directly available from utilities unless the utilities undertake analysis to understand their consumer profiles.

NON-REVENUE INDICATOR	UNIT	DEFINITION
6.1 Non-Revenue Water	%	Difference between water supplied and water sold (i.e. volume of water "lost") expressed as a percentage of net water supplied
6.2 Non-Revenue Water	m3/km/day	Volume of water "lost" per km of water distribution network per day
6.3 Non-Revenue Water	m3/conn/day	Volume of water "lost" per water connection per day.

Notes

Non-revenue water represents water that has been produced and is "lost" before it reaches the customer (either through leaks, through theft, or through legal usage for which no payment is made). Part of this "lost" water can be retrieved by appropriate technical and managerial actions. It can then be used to meet currently unsatisfied demand (and hence increase revenues to the utility), or to defer future capital expenditures to provide additional supply (and hence reduce costs to the utility).

The IWA distinguish between non-revenue water (%) and unaccounted for water, with the latter not including legal usage that is not paid for. The indicators are usually measured in m3/conn/day. The difference is usually small, and the

IBNET Toolkit therefore only uses non-revenue water as an indicator.

There is a debate as to the most appropriate measure of non-revenue water. A percentage approach can make utilities with high levels of consumption, or compact networks, look to be better performing than those with low levels of consumption or extensive networks. To capture these different perspectives the reporting of three measures of non-revenue water has become the norm.

METERING PRACTICES INDICATOR	UNIT	DEFINITION
7.1 Metering level	%	Total number of connections with operating meter/ total number of connections, expressed in percentage
8.1 % sold that is metered	%	Volume of water sold that is metered/ Total volume of water sold, expressed in percentage

Notes

Metering of customers is considered good practice. It allows customers the opportunity to influence their water bills, and provides utilities with tools and information to allow them to better manage their systems.

The indicators provide two separate perspectives on the issue, both of which are relevant in their own right. Taken together the indicators provide insights into the effectiveness of a metering installation strategy (the ratio of indicator (8)/(7) indicates the extent to which a utility is targeting large water users as the highest priority).

PIPED NETWORK INDICATOR	UNIT	DEFINITION
9.1 Pipe Breaks	breaks/km/yr.	Total number of pipe breaks per year expressed per km of the water distribution network
10.1 Sewer System Blockages	blockages/km/ yr.	Total number of blockages per year expressed per km of sewers

Notes

The number of pipe breaks, relative to the scale of the system, is a measure of the ability of the pipe network to provide a service to customers.

The rate of water pipe breaks can also be seen as a surrogate for the general state of the network, although it reflects operation and maintenance practices too. It must be recognized, however, that highly aggregated reporting can hide the fact that sections of the network may be perpetually failing, whilst much of the remainder is in reasonable condition. Break rates for different materials, diameters or time periods laid can show where breaks are concentrated.

Sewer blockages are, likewise, a measure of the ability of the sewer network to provide a service to customers. Blockages can reflect a number of issues including the effectiveness of routine operations and maintenance activities, the hydraulic performance of the network, and the general condition of the pipes. Bursts include failures on mains, service pipes where they are the Utility's responsibility, or at joints or fittings that are found by visible signs of water, not through leak detection by Utility staff. Sewer blockages include all blockages or collapses that occur in sewers or drains that are the Utility's responsibility, whatever action is needed to clear them.

COSTS AND STAFFING	UNIT	DEFINITION

INDICATOR		
11.1 Unit Operational Cost Water and Wastewater (W&WW)	US$/m3 sold	Total annual operational expenses[1]/Total annual volume sold.
11.2 Unit Operational Cost Water and Wastewater	US$/m3 produced	Total annual operational expenses[1]/Total annual water produced.
11.3 Unit Operational Cost – Water only	US$/m3 sold	Annual water service operational expenses[1]/Total annual volume sold.
11.4 Operational Cost Split - % Water	%	Split of the total cost into water and wastewater
11.5 Operational Cost Split - % Wastewater	%	
11.6 Unit Operational Cost – Wastewater	US$/WW pop served	Annual wastewater operational expenses[1]/ Population served
12.2 Staff W&WW/'000 water and wastewater connections	#/'000 W&WW conn	Total number of staff expressed as per thousand connections
12.1 Staff Water /'000 Water connections	#/'000 W conn	
12.2 Staff Wastewater/'000 Wastewater connections	#/'000 WW conn	
12.4 Staff W&WW/'000 W&WW pop served	#/'000 W&WW pop served	Total number of staff expressed as per thousand people served
12.3 Staff Water/'000 Water pop served	#/'000 W pop served	
12.6 Staff Wastewater/'000 Wastewater pop served	#/'000 WW pop served	
12.7 Staff % Water	%	
12.8 Staff % Wastewater		
13.1 Labor Costs vs. Operational Costs	%	Total annual labor costs (including benefits) expressed as a percentage of total annual operational costs.
13.2 Electrical Energy Costs as percentage of Operational Costs	%	Annual electrical energy costs expressed as a percentage of total annual operational costs.
14.1 Contracted-out service costs as percentage of operational costs	%	Total cost of services contracted-out to the private sector expressed as a percentage of total annual operational[1] costs.

Notes

Note 1: Annual operating expenses exclude depreciation, interest and debt service

Unit operational costs provide a "bottom line" assessment of the mix of resources used to achieve the outputs required. The preferred denominator related to operational costs is the amount of water sold. This ratio then reflects the cost of providing water at the customer take off point.

Lack of universal metering, lack of accurate household meters, and a focus in the past on water production mean that an alternative measure of operational cost per cubic meter of water produced is also relevant in the short term.

Staff costs are traditionally a major component of operating costs. Understanding staffing levels can often give a quick guide to the extent of any over-manning in a water utility. While it is preferable to be able to allocate staff time to either water or wastewater services, this information is sometimes not available. Comparisons are best made between utilities which offer the same scope of service both in terms of total size, and mix of water and sewer service. Note that where outside contractors are used (see indicator 14.1), staff number comparisons should take this into account.

The number of people served per connection varies from country to country, and from utility to utility, depending on the housing stock and different approaches to service connections. To facilitate international comparisons a denominator of population served has also been included.

The relative importance of staff costs compared to total costs is captured in indicator 13.1. Utilities are often over staffed and this measure provides insights into the impact of possible changes in future staff numbers. Indicator 14.1 quantifies the degree to which outside (private) contractors are used to provide the utility service.

QUALITY OF SERVICE INDICATOR	UNIT	DEFINITION
15.1 Continuity of Service	Hrs/day	Average hours of service per day for water supply.
15.2 Customers with discontinuous supply	%	The percentage of customers with a water supply that is discontinuous during normal operation.
15.3 Quality of water supplied: nr of tests for residual chlorine	% of # required	The number of tests carried out on samples taken from the distribution system, as a % of the number required by the standard that applies. This may exceed 100%. NB: Operational samples, or any others that were not taken to check compliance with the standard, are excluded.
15.4 Quality of water supplied: samples passing on residual chlorine	%	The percentage of samples tested for residual chlorine that pass the relevant standard
16.1 Complaints about W&WW services	% of W&WW conn	Total number of W&WW complaints per year expressed as a percentage of the total number of W&WW connections
17.1 Wastewater – at least primary treatment	%	Proportion of collected sewage that receives at least primary treatment, i.e. involving settlement with the intention of removing solids, but not biological treatment. Both lagoon and mechanical treatment can be included, where appropriate.
17.2 Wastewater primary treatment only	%	Proportion of collected sewage that receives primary treatment only, i.e. involving settlement with the

		intention of removing solids, but not biological treatment. Both lagoon and mechanical treatment can be included, where appropriate.
17.3 Wastewater secondary treatment or better	%	Proportion of collected sewage that receives at least secondary treatment, i.e. removing oxygen demand as well as solids, normally biological. Both lagoon and mechanical treatment can be included, where appropriate.

Notes

Historically there has been limited attention paid to measures that capture the quality of service provided to customers. This, in fact, should be a particular focus of performance measurement.

The measures presented above are a limited first step in the process of capturing information on quality of service. Complaints, while relatively easy to track, give only a glimpse of actual company performance - consumers may have become accustomed to poor service and not complain. In other instances it may be difficult for customers to report complaints. Capturing at least some customer derived data, however, is considered to be an important starting point.

Collection of wastewater does not mean that the waste is fully treated before discharge back to the environment. The wastewater treatment indicators will provide an understanding of the amount of effluent that is treated before being discharged.

A more comprehensive set of quality of service indicators could be developed but the likelihood of the data being collected by utility managers is limited in the short term. Expansion of the set is therefore a medium to long term objective.

BILLING AND COLLECTIONS INDICATOR	UNIT	DEFINITION
18.1 Average Revenue W&WW	US$/m3 water sold	Total annual W&WW operating revenues expressed by annual amount of water sold and by the number of connections.
18.2 Average Revenue W&WW	US$/W conn./yr.	
18.3 Average Revenue – water only	US$/m3 water sold.	Operating revenues (W only) expressed by annual amount of water sold.
18.4 Revenue Split - % water	% of total for W&WW	Percentage split of total revenue into water and wastewater
18.5 Revenue Split - % wastewater		
18.6 Water revenue – residential	% of total water revenue	Percentage split of water revenue by customer type
18.7 Water revenue – industrial/commercial		
18.8 Water revenue – institutions & others		
18.9 Water revenue – bulk treated supply		

18.10 Wastewater revenue per person served	US$/person served	Operating revenues (WW only) expressed per person served
20.2 Residential fixed component of tariff *20.5 Residential fixed component of tariff - water* 20.6 Residential fixed component of tariff - wastewater	% of average bill	Any fixed component of the residential tariff as a proportion of the average tariff per connection per year. Water & wastewater together, and separated if possible.
21.1 Ratio of industrial to residential tariff 21.2 Ratio of industrial to residential tariff - water 21.3 Ratio of industrial to residential tariff - wastewater	ratio	The average charge (per m3) to industrial customers compared against the average charge (per m3) to residential customers. Water & wastewater together, and separated if possible.
23.1 Collection Period	Days	(Year-end accounts receivable/Total annual operating revenues) * 365
23.2 Collection ratio	%	Cash income / Billed revenue as a %

Note 1. W = water service, WW = wastewater / sewerage service

Notes

Billing customers and getting paid are two different things. The effectiveness of the collections process is measured by the amount of outstanding revenues at year end compared to the total billed revenue for the year, in day equivalents, and by the total amount collected as a percentage of the billed amount.

FINANCIAL PERFORMANCE INDICATOR	UNIT	DEFINITION
24.1 Operating Cost Coverage	ratio	Total annual operational revenues/Total annual operating costs
25.1 Debt Service Ratio	%	Cash income / Debt service * 100

Notes

These two indicators have been selected from a much larger range of financial indicators (which include leverage, liquidity, profitability and efficiency ratios). They help answer two important questions: (i) Do revenues exceed operating costs? and (ii) Does the utility's income enable it to service its debts?

ASSETS INDICATOR	UNIT	DEFINITION
27.1 Gross Fixed Assets – water & wastewater	US$/W&W Wpop served	Total gross fixed W&WW assets per W&WW populations served.
27.2 Gross Fixed Assets - water	US$/W pop served	Total gross fixed assets per population served, separately for water (W) and wastewater (WW).
27.3 Gross Fixed Assets – wastewater	US$/WW pop served	

Note: Gross fixed assets are defined to include work in progress.

Notes

The capital intensity of the utility is indicated by the gross fixed asset value per capita served. Unfortunately there is often limited information available about asset values and until more emphasis is placed on this item the values derived must be treated with caution.

No investment indicators are included as they tend to differ widely from one year to another due to the lumpiness of the investments. At a more detailed level, comparisons of unit costs for particular items of equipment can be very useful; but this is beyond the scope of IBNET.

AFFORDABILITY OF SERVICES INDICATOR	UNIT	DEFINITION
19.1 Total revenues per service pop/GNI	% GNI per capita	Total annual operating revenues per population served/National GNI per capita; expressed in percentage
19.2 Monthly water bill for a household consuming 6m3 of water per month through a household or shared yard tap (but excluding the use of standposts)?	US$/year	Cost in local currency to a household per month of 6m3 water / Exchange rate with US$ * 12
20.1 Residential fixed component of tariff 20.3 Residential fixed component of tariff - water 20.4 Residential fixed component of tariff - wastewater	US$/conn./ yr.	Any fixed component of the residential tariff (total amount). Water & wastewater together, and separated if possible.
20.2 Residential fixed component of tariff *20.5 Residential fixed component of tariff - water* 20.6 Residential fixed component of tariff - wastewater	% of average bill	Any fixed component of the residential tariff as a proportion of the average tariff per connection per year. Water & wastewater together, and separated if possible.

Notes

Average tariffs need to be put in the perspective of affordability. Household income data, however, is not easy to obtain. The indicator selected here, therefore, compares average per capita tariffs as a proportion of per capita GNI. The GNI (Atlas method based) will be for the whole country, and not reflect local variations, but is the most appropriate consistent measure currently available for most countries. In case specific household data is available, this data could be commented upon separately.

Some utilities use fixed charge components within the residential tariff (i.e. irrespective of the amount of water consumed). Such tariffs can adversely affect low volume water consumers. They also protect the revenue stream to the utility in periods when consumption is highly variable. Comparison of the fixed component with the average tariff will give an indication of the relative weight of the fixed and variable component of a water bill.

There may be a cross subsidy between industrial consumers and residential consumers. The ratio of the average charges (per m3) to industrial and residential customers provides some quantification of this subsidy. Subsidies are complex and this ratio provides only a simplistic assessment of the situation in any utility.

For many, the cost of connecting to the piped network can be a significant financial hurdle. Comparing connection charges will provide insights into the level to which this hurdle has been raised. It is a particular issue when seeking to connect poorer sections of the community. The indicator provides the absolute level and as a proportion of national GNI per capita.

PROCESS INDICATOR	CATEGORIES
P.1 What best describes the utility's planning process?	A. Setting budgets for next year B. A multi-year plan that identifies targets and resources for change and improvement C. Neither of the above (Describe....)
The management of your utility undertakes the following:	
HR.1 Has a skills and training strategy for all staff?	Yes / No
HR.2 Has an annual appraisal and target setting system for managers?	Yes / No
HR.3 Has an annual appraisal and target setting system for all staff?	Yes / No
HR.4 Has a reward and recognition program for all staff?	Yes / No
HR.5 Has the ability to recruit and dismiss staff (within an agreed plan)?	Yes / No
R.1 Who has general oversight of the utility's services and prices?	A. Local, regional or national government department B. Independent board of stakeholders C. Independent service & price regulator D. Other (Describe....)
What are the main sources of finance for investment?	
F.1 Grants or Government transfers to the utility?	Yes / No
F.2 Borrowing from International Financial Agencies (multi or bi laterals)?	Yes / No
F.3 Government owned banks?	Yes / No
F.4 Commercial banks or bond holders?	Yes / No
C.1 Does the utility offer more than one level of service for household or shared water supplies?[1]	Yes / No / Not applicable
C.2 Does the utility offer more than one level of sanitation or sewerage service/ technology for households?[2]	Yes / No / Not applicable
C.3 Does the utility offer a flexible / amortized repayment option to spread the costs of connection to the water and/or sanitation network?	Yes / No / Not applicable
C.4 – See 19.2	

How does the utility find out the views of its customers? C.5.1 Letters, telephone calls etc from customers C.5.2 Inviting customers' views through radio, TV or other publicity C.5.3 Questionnaire survey C.5.4 Other	Yes / No Yes / No Yes / No Yes / No (Describe...)

Context information	
Density of water connections	#/km
Density of sewer connections	#/km

The context factors are distinct from process indicators in that they are, in the short to medium term, beyond the influence of the utility.

Information on the services provided is essential to interpreting the indicator values. The size of the Utility is also relevant, as large utilities can benefit from economies of scale.

The connection density indicates whether the area served by the utility is dense and urban, or more dispersed. In areas where many households are not yet connected, it helps to assess the likely costs and benefits of extending the network.

Note 1. Excluding free standpipes
Note 2. Excluding free public toilets

APPENDIX B

MATLAB CODE

Uncontrolled Scenario

```
tBegin=0;
tEnd=100;
dt=.01;

t=tBegin:dt:tEnd;
N=length(t);
IC=1;
mu=0.1;
sigma=0.5;

y=zeros(N,1);
y(1)=IC;
for i=2:length(y)
  y(i)=y(i-1)+dt*(mu*y(i-1)*(10-y(i-1)))+sigma*sqrt(dt)*randn;
end

plot(t,y)
ylabel('state of the system')
        xlabel('time')
        title(''mu=0.05, sigma=0.5'')
```

APPENDIX C

MATLAB CODE

Controlled Version with Defined Changes

```
tEnd=1000;
dt=.01;

t=tBegin:dt:tEnd;
N=length(t);
IC=1;
mu=0.005;
sigma=0.1;
b=1;
u=0;
du = 1;
cnt=0;

y=zeros(N,1);
y(1)=IC;
for i=2:length(y)
if cnt == 50000
u = u + du;
cnt = 0;
else
cnt = cnt +1;
endif
  y(i)=y(i-1)+dt*(mu*y(i-1)*(10-y(i-1)))+dt*b*u+sigma*sqrt(dt)*randn;
end

plot(t,y)
ylabel('state of the system')
xlabel('time')
title("Control with defined change")
```

APPENDIX D

MATLAB CODE

Controlled Version with Random Changes

```
tEnd=1000;
dt=.01;

t=tBegin:dt:tEnd;
N=length(t);
IC=1;
mu=0.005;
sigma=0.1;
b=1;
u=0;
du = u+du;
cnt=0;

y=zeros(N,1);
y(1)=IC;
for i=2:length(y)
if cnt == 20000
u = abs(randn);
cnt = 0;
else
cnt = cnt +1;
endif
   y(i)=y(i-1)+dt*(mu*y(i-1)*(10-y(i-1)))+dt*b*u+sigma*sqrt(dt)*randn;
end

plot(t,y)
ylabel('state of the system')
xlabel('time')
title("Control with random change")
```

APPENDIX E

Cash Flow Parameter	Definition/Assumptions
Costs	Variable costs, range from 20-40%, based on financing arrangement with vendor and community
Present Value	Real discount rate of 7.1%
Total PV	Cumulative total of present value
Population	The initial population is 237 with a 2% annual growth rate
Water Pumped	Cumulative total of water pumped in m^3
Water produced per month	Water pumped per month in m^3
Assumed cost per m^3	Assumed maximum cost per m^3
Actual cost per m^3 and month	Actual monthly cost / water pumped in that month
Investment per person	Total present value cost per person
Total Investment	Investment per person * population (same as Total PV)
Volume of water production/per person and day in m^3	Water produced/population
Cost of volume of water produced per day	Water produced per month * water cost
Daily water demand per person (m^3)	Random value between 15 and 20 Liter.
Monthly water demand in m^3	Daily water demand * days per month * population
Water cost	Total PV/water pumped (cumulative)
Moving average	The average cost of water from the initial month to the current month
Cost of daily water demand	Water cost * daily demand of water per person
Cost of daily water demand	Water cost * daily demand of water per person*population
Assumed max cost	Maximum cost taken from initial model case
Assumed max cost per day and person	Maximum cost/days per month*population
Actual cost	Monthly amortization of initial project cost + monthly costs+ previous unfunded liability + present value for the time period
Project balance	Cumulative Assumed cash income – present value
Actual cost per day and person	Actual cost/population*days per month
Months left in project	The time period remaining in the cash flow
Amount billed	Rule based decision based on project costs (see detailed discussion in 6.6.
Unfunded liability forward billing	Cumulative difference of cash income and actual cost if billed amount was not met.
Billed cost per day per person	Amount billed/population*days per month
Assumed cash income	Amount billed * Willingness to Pay
Net income	Assumed cash income – actual costs
Unfunded liability	Present value of amount billed – assumed cash income
Debt Service Ratio (percent)	Assumed cash income/actual cost
Project Financing loss /gain amount	Sum of assumed cash income – Sum of total present cost
Project financing loss/gain in percent	project financing loss/gain amount*100/sum of total present value

Revenue offset factor	proportional gain ∗ current error + accumulated error ∗ integral gain + derivative gain ∗ (current error − previous error)
Percentage of passing water standards	Stochastic modeling of water quality degradation with time
Additional investment – Water quality	The additional investment amount needed in a year if the water quality standard falls below 87%
Average household income	The average household income per month and person
Billed cost/income	Billed cost per day per person/average household income per day
Annual water operating costs/population served	Present Value/population
Willingness to Pay (WTP)	Ranges stepwise from 0 to 100% depending on the fraction of billed cost/income and fluctuates randomly: Billed cost over income — Willingness to pay [0..0.01[— 100-95% [0.01….03[— 100-85% [0.03..0.05[— 95-70% [0.05..0.07[— 80-65% [0.07..∞ — 0%
Disturbance	Models random project cost between 0 to 55 USD per month for most month and 0 to 300 USD for a minor random fraction over the course of the project
Actual - assumed cost	Actual cost – assumed cost
Actual cost - income	Actual cost – assumed cash income
Operational cash flow measure	Performance measure as described in Chapter 6.6
Setpoint	Reference setpoint (ideal water project)
Error	Setpoint – operational cash flow
Accumulated error	Current error + previous error balance
K	Proportional gain that causes a change to the output proportional to the current error value
Ti	Integral term is the sum of the direct error over time giving the accumulated offset that should have been corrected earlier
Td	Derivative gain that considers the rate of change of the error

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