Sustainable Development: Implementation in Urban Water Systems

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Sustainable Development

Implementation in Urban Water Systems

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Abstract - Using a system dynamics approach, the thesis introduces the idea of *Viability Loops*, the balancing loops in a dynamic system that serve to check the reinforcing mechanisms. It is also argued that sustainability is neither a system state nor a static goal to be achieved. It is an *ideal* of development efforts in a system. The thesis argues that sustainable development is a process in which the *Viability Loops* are kept healthy. This process deals with evolutionary changes where the end point is not known in advance. Thus, measuring sustainable development does not make sense. Rather, systems should be monitored for sustainable development by means of process indicators.

Principles are required to be fostered to deal with the issue of sustainable development and to fulfill the normative level of the society – known as morality – as well as the natural rules – identified as god given causal relations. In the thesis, principles of sustainable development adapted for water resources systems are suggested based on the principles of The Natural Steps (TNS) to address physical relations of nature, and system basic orientors to treat both environmental and humanitarian aspects of the issue.

It is also argued that triggering a social learning process would be the most suitable strategy for sustainable development. To this end, backcasting is recommended as a suitable tool, and model building is regarded as promotion of the learning process rather than a means of forecasting.

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Doctoral Thesis

Sustainable Development

Implementation in Urban Water Systems

by

Ali Bagheri

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Sustainable development:
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به بینندگان آفریننده را — نبینی مرنجان دو بیننده را
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ستودن نداند کس او را چو هست — میان بندگی را ببایدت بست
خرد را و جان را همی سنجد اوی — در اندیشه سخته کی گنجد اوی
بدین آلت رای و جان و زبان — ستود آفریننده را کی توان
به هستیش باید که خستو شوی — ز گفتار بی کار یکسو شوی
پرستنده باشی و جوینده راه — به ژرفی به فرمانش کردن نگاه
توانا بود هر که دانا بود — ز دانش دل پیر برنا بود

حکیم ابوالقاسم فردوسی

To my dear wife, Maryam,
and
To my lovely daughter, Bita,

Who really make my life Sustainable

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ABSTRACT

As *Sustainable development*, a widely used but poorly understood term, challenges traditional scientific values such as prediction and control, scientists have tried to manipulate the concept to promote their own particular agendas. Thus, it has suffered from misrepresentation which has prevented the concept from being fully implemented at a practical level.

It is asserted that traditional fragmented and mechanistic science is unable to cope with sustainability issues, and that there is no *equilibrium* or *optimal* point for an evolving system since the optimum is also moving. Therefore, approaches advocating engineering, linear, and mechanistic paradigms to define sustainability do not make much sense. Instead, we need to resort to non-linear thinking, more commonly referred to as systems thinking. Thus, *System Dynamics*, one branch of systems thinking which operates in a whole-system fashion, is put forward as a powerful methodology to deal with the issue.

Using a system dynamics approach, the thesis introduces the idea of *Viability Loops*, the balancing loops in a dynamic system that serve to check the reinforcing mechanisms.

It is also argued that sustainability is neither a system state nor a static goal to be achieved. It is an *ideal* of development efforts in a system. Ideals come from ethics and values, and they are indeed non-quantifiable.

Sustainable development is perceived as a dynamic process evolving through a learning process, and not as any kind of *optimum* or *end-state* of a system. Neither is it adoptable to strategies based on command and control, fixed goals, and predictability. It, therefore, refers to the goal of fostering adaptive capabilities to respond to changes while simultaneously creating opportunities for the next generation to find a variety of options to meet their needs.

The thesis argues that sustainable development is a process in which the *Viability Loops* are kept healthy. This process deals with evolutionary changes where the end point is not known in advance. According to this perception, measuring sustainable development does not make sense. Rather, systems should be monitored for sustainable development by means of process indicators.

Principles are required to be fostered to deal with the issue of sustainable development and to fulfill the normative level of the society –known as morality– as well as the natural rules –identified as god given causal relations. In the thesis, principles of sustainable development adapted for water resources systems are suggested based on the principles of The Natural Steps (TNS) to address physical relations of nature, and system basic orientors to treat both environmental and humanitarian aspects of the issue respectively.

It is argued that triggering a social learning process would be the most suitable strategy for sustainable development. To this end, backcasting is recommended as a suitable tool, and model building is regarded as a promotion of the learning process rather than a means of forecasting.

SAMMANFATTNING

Hållbar utveckling är ett ofta använt begrepp, som många inte riktigt förstår eftersom det går på tvärs mot traditionella vetenskapliga begrepp som förutsägelse och styrning. Många vetenskapsmän har tolkat begreppet på sätt som gynnar den egna agendan. Dessa vantolkningar har lett till att begreppet inte kommit till användning i praktisk planering.

Avhandlingen hävdar att traditionell, fragmenterad och mekanistisk vetenskap inte kan hantera frågor kring hållbar utveckling eftersom det inte finns något jämviktstillstånd eller någon optimal trajektoria i ett dynamiskt system. Det handlar om en process, som ständigt utvecklas. Angreppssätt, som bygger på ingenjörstekniska, lineära eller mekanistiska paradigm blir inte meningsfulla. Istället måste vi ta till icke-lineär metodik dvs systemanalys. I avhandlingen utnyttjas System Dynamics, en variant av systemanalys, som möjliggör arbete utifrån ett helhetsperspektiv

Utifrån detta perspektiv definieras loopar för livskraft. De är de negativa återkopplingar, som ger ett system en balanserad utveckling.

Vidare hävdas att hållbar utveckling varken kan definieras som något specifikt systemtillstånd eller som något statiskt mål. Det är ett ouppnåeligt ideal, som systemet bör sträva att utvecklas mot. Idealet utvecklas också i takt med att arbetet hela tiden ger nya kunskaper och nya världsbilder. Eftersom idealen hämtas från ett etiskt förhållningssätt är de kvalitativa och inte kvantitativa.

Hållbar utveckling behandlas som en dynamisk process, som utvecklas genom en kontinuerlig lärandeprocess. Det är således inte något, som kan kommenderas fram. Hållbar utveckling handlar om att skapa en anpassningsförmåga, som gör att systemet kan reagera på förändringar och samtidigt skapa förutsättningar för nya och bättre handlingsalternativ.

I avhandlingen hävdas att hållbar utveckling handlar om en process där man ser till att hålla looparna för livskraft i gott skick. Denna process är evolutionär, vilket gör att man inte kan göra några förutsägelser rörande olika framtida tillstånd. Utifrån denna ståndpunkt blir det meningslöst att försöka mäta hållbarhet. Snarare bör man utnyttja processindikatorer för att se om utvecklingen går åt rätt håll.

Det finns principer, som man måste följa för att kunna skapa en hållbar utveckling. Det handlar dels om grundläggande naturlagar, dels om samhällets grundläggande moraliska och etiska värderingar.

Avhandlingen förordar principer för hållbar vattenhantering, som grundar sig på Det Naturliga Stegets formuleringar om vad naturen tål och några etiska principer för hantering av sociala och miljömässiga aspekter.

Det hävdas att tillskapandet av sociala läroprocesser är den viktigaste strategiska frågan i arbetet för hållbar utveckling. Planering bör bygga på önskvärda framtida scenarier och analyser av hur man kan tänkas ha tagit sig dit. Detta resonemang leder till att modeller mer ses som intressanta verktyg för lärandeprocesser än som instrument för förutsägelser om framtida tillstånd.

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LIST OF ARTICLES

The following papers are covered within the thesis:

I. Hjorth, Peder; Bagheri, Ali; (2006), ***Navigating towards sustainable development: A system dynamics approach***, *Futures*, *38(1)*, 74-92.

II. Bagheri, Ali; Hjorth, Peder; (2006), ***Sustainable development: Concepts & principles, application to water resources systems***, *Journal of Environmental Policy & Planning* (under review).

III. Bagheri, Ali; Hjorth, Peder; (2006), ***Monitoring for sustainable development: A systemic framework.*** *International Journal of Sustainable Development* (accepted).

IV. Bagheri, Ali; Hjorth, Peder; (2006). ***A framework for process indicators to monitor for sustainable development: Practice to an urban water system.*** *Environment, Development and Sustainability* (in press).

V. Bagheri, Ali; Hjorth, Peder; (2006). ***Planning for sustainable development: A paradigm shift towards a process-based approach.*** *Sustainable Development* (under review).

The following papers are not included in the thesis:

Bagheri, Ali; Hjorth, Peder; (2005), ***A system dynamics approach to promote sustainable urban water management: The concept of viability loops.*** The XII World Water Congress, 22-25 November, New Delhi, India.

Bagheri, Ali; Baradaran N. Mohammad R.; Sarang Amin; Hjorth, Peder; (2005), ***A system dynamics approach to analyze water resources systems***, In Jun B.H., Lee S.I., Seo I.W., and Choi G.W. (editors) (2005), *Proceedings of XXXI IAHR Congress*, COEX, Seoul, Korea, September 11~16, pp. 4991-5000.

Chapter 1. INTRODUCTION

1.1. The objectives and scope of work

The general objective of the present thesis is to contribute to *implementing sustainable development in a practical term in public management and planning with a particular focus on urban water systems*. In response to the above general objective, the following questions are considered as the research questions:

i. What methodology can be adopted to help understand the concept of sustainable development in a practical way?
ii. How can the practical definition of sustainable development be theorized?
iii. What is a practical framework to deal with sustainable development in the management issues?
iv. How can a system, such as an urban water system, be evaluated for sustainable development?
v. What are the strategies to be adopted to plan systems, such as an urban water system, for sustainable development?

1.2. The thesis structure and appended articles

The thesis is structured based upon the five appended articles, which attempt to provide answers to the research questions. The main topics and inter-relations among the articles are demonstrated in Figure 1.1. A brief summary of each article appears in the following paragraphs.

Addressing the first question, ***Paper I*** – which will be referred to as ***P1*** in this thesis – deals with the methodology adopted in the research. It argues that traditional fragmented and mechanistic science is unable to cope with issues about sustainability, as these are often related to complex, self-organizing systems. In the paper, sustainable development is seen as an unending process defined neither by fixed goals nor by specific means of achieving them. It is argued that, in order to understand the sources of and the solutions to modern problems, linear and mechanistic thinking must give way to non-linear and organic thinking, more commonly referred to as systems thinking. System Dynamics – one of the branches of systems thinking – which operates in a whole-system fashion, is put forward as a powerful methodology to deal with issues of sustainability. Based on the system dynamics approach to promote the process of learning, the paper introduces the idea of *Viability*

Loops to define sustainable development in a practical term. Viability loops are defined as the key loops in the real world dynamisms and are responsible for the viability of all ecosystems including human based ecosystems. Sustainable development is, then, defined as a process in which the viability loops can remain intact.

In response to the second question, in ***Paper II*** – which will be referred to as ***P2*** in this thesis – sustainability is regarded as an ideal which belongs to the normative level of a society. The paper argues that to be able to practice the concept of sustainability in the field of water resources, we need to respect the basic principles of sustainable development, a concept that is tightly linked to the Brundtland Commission and Agenda 21 and must not be subject to arbitrary interpretations. In the paper, sustainable development is considered as a dynamic process, and principles are suggested to be applied in water resources systems. The suggested principles are underpinned by The Natural Step principles, which are grounded in the laws of thermodynamics as to address the physical relations of nature, as well as moral values to treat both environmental and humanitarian aspects of the issue respectively. The idea of *Viability Loops* has been adopted to give a practical definition of sustainable development in accordance with developing the capability of perceiving and adapting to changes and creating a variety of opportunities for the future.

Responding to the third question, ***Paper III*** – which will be referred to as ***P3*** in this thesis –argues that sustainable development should be considered as an unending process rather than a state. Due to its process nature, it is meaningless to talk about measuring sustainability in terms of static, performance indicators dealing with system states. Rather, the paper proposes a systemic framework to monitor systems for sustainable development using dynamic, process indicators. Using the framework, it has been shown that a set of theoretically anticipated viability loops, in the form of a market-technology balancing mechanism to keep the system sustainable via the signals coming from scarcity of water resources and also increase in wastewater generation which result in increase in costs of water services, do not function in practice. They are hampered by lack and/or distortion of information.

Paper IV – which will be referred to as ***P4*** in this thesis – attempts to address the fourth question to develop a framework to deal with monitoring systems for sustainable development and its practice in an urban water system. Using a system dynamics approach, the paper adopts the systemic monitoring framework suggested in the previous paper to define process indicators to monitor systems for sustainable development. To illustrate the application of the framework, its practice in the urban water system of Tehran, the capital of

Iran, is provided as a case study, albeit with some unavailable data. Here, four typical viability loops are discussed. The results of this application show that the flows of informative signals are lacking. Adopting the process indicators, the paper shows that the gaps between the public perceptions of water abundance, the costs of water provision and energy utilizations, and what is going on in the reality are getting wider. This indicates that the viability loops are not functional enough to produce effective changes to offset the reinforcing mechanisms. The sustainable development of the system is impaired due to the persistence of those reinforcing mechanisms.

Finally, ***Paper V*** – which will be referred to as ***P5*** in this thesis – aims to respond to the fifth question. It is argued in the paper that prevailing approaches of planning and strategy making, which are traditionally used to deal with the states of systems in terms of fixed goals, fail to acknowledge the process nature of sustainable development. Using a system dynamics approach and relying on the idea of *Viability Loops*, the paper aims to illustrate a practical implementation of sustainable development in an urban water system. Based on three dynamic structures found in a case study of Tehran urban water system, the paper argues that planning for sustainable development should be 'process-based' – rather than 'fixed-goal' – oriented. By means of process indicators, it is shown that the urban water system of Tehran is in un-sustainable territory. The malfunctioning process of social learning is considered to be the most important challenge in the system. Thus, unlike the traditional approaches of strategy making to set fixed goals related to either supply-side or demand-side management, it is argued that triggering a social learning process constituting of both 'surface' and 'deep' learning loops with full involvement of all stakeholders as well as planners would be the most suitable strategy for sustainable development. The social learning process aims to consolidate sustainability as a dynamic ideal based on proactive perception of environmental change. To this end, backcasting is recommended as a suitable tool and the process of model building is regarded as a means of learning rather than of forecasting.

Paper I
Navigating towards sustainable development: A system dynamics approach
(*Futures, 2006, 38(1), 74-92*)

- System dynamics is adopted as the research methodology,
- The idea of Viability Loops is proposed to define sustainable development in a practical term.

Paper II
Sustainable development: Concepts & principles, application to water resources systems
(*J. of Environmental Policy & Planning, 2006, under review*)

- Water is valued as a means of sustainable development,
- The systems orientors based on ethics and The Natural Step principles grounded in the laws of Thermodynamics have been adopted to propose the principles of sustainable development adapted for water resources systems.

Paper III
Monitoring for sustainable development: A systemic framework
(*International Journal of Sustainable Development, 2006, accepted*)

- It is argued that due to process nature of sustainable development, it does not make sense to measure sustainability in terms of static, performance indicators,
- A systemic framework is proposed to monitor systems for sustainable development based on dynamic, process indicators.

Paper IV
A framework for process indicators to monitor for sustainable development: Practice to an urban water system
(*Environment, Development and Sustainability, 2006, in press*)

- It is shown how process indicators can be developed to monitor an urban water system for sustainable development using a system dynamics approach and based on the idea of Viability Loops,
- A case study is carried out on the urban water system of Tehran.

Paper V
Planning for sustainable development: A paradigm shift towards a process-based approach
(*Sustainable Development, 2006, under review*)

- It is argued that the ‘fixed-goal’ approach of planning cannot capture the process nature of sustainable development,
- Instead, strategy making and planning should be ‘process-oriented’,
- Triggering the process of social learning is suggested as the most suitable strategy for sustainable development.

Figure 1.1. Overview of the appended articles

Chapter 2. METHODOLOGY

2.1. Introduction

Concerning the first research question, which asks about the methodology to be adopted to understand the concept of sustainable development in a practical way, the thesis introduces systems thinking as the philosophy, and the system dynamics approach as the methodology which are appropriate to deal with complex issues such as sustainability. It is also argued that the approach of the conventional science will not lead to a sustainable development due to the following considerations.

First, the classical science is dominated by the concepts of *equilibria* and *optimality* and fails to perceive and treat changes easily. It is grounded in the Newtonian vision of the world, which implies that the elements making up the variables are reduced to a 'machine' by a mathematical model which represents the system in terms of a set of differential equations governing its variables. The simplistic assumption that there would be only one solution of those differential equations leads up to the idea of 'equilibrium'. But, that is not valid for open systems, even in physical systems. When they get open to flows of matter and energy there is not necessarily a unique final state identified as 'optimal'. It is why we cannot imagine a predictable future for open systems. To cope with such situations, we have to come up with a new understanding of science suitable for the 'post-normal' age (Funtowicz & Ravetz, 1993). Conventional mathematic systems; which are capable of functioning, but not of evolving, do not contain the capacity for structural change in open systems (Clark et al., 1995).

Second, the fragmentation in science leaves some of the issues – mostly related to complex and organic systems – lie on the white borders and not be dealt with. Humankind now needs to move from the age of reductionist science to an age of synthesis or integrative science (Cairns, 2003). As Max-Neef (2005) defines our times, "we know very much, but understand very little". What is needed is a form of trans-disciplinary thinking that focuses on the connections among fields as well as sectors and interests; that involves the development of new concepts, methods and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation (Robinson, 2004).

Third, the way the classical science treats uncertainty is through forecasting. However, when dealing with sustainability, we cannot look into the future with any degree of certainty. Every forecast is related to probabilities and is doomed not to come true; instead, we have to go through assumptions based upon possibilities to get prepared for possible futures.

Finally, science and technology need to be supported by moral values which are dealt with as ethics. As Cairns (2003) asserts, “Science can show what probably is done; technology can show what might be done; but ethics can help humankind decide what should be done”.

Modern science is characterized by ever-increasing specialization. As a result, it has delivered lots of knowledge but very little understanding. Basically, classical science, be it chemistry, biology, psychology, or the social sciences, has focused on isolation of elements of the observed universe. The common belief has been that if we know everything about the parts, we will understand the whole. However, to create understanding, it is not enough to just study parts or processes in isolation. All this knowledge is, thus, in dire need of synthesis through some kind of multilevel and multi-dimensional graph of interconnections. This is a clear indication that traditional science is based on fragmentation and, thus, is totally inadequate to deal with a holistic concept such as sustainable development. Indeed, an examination will show that science and technology are almost exclusively concerned with treating the ‘symptoms’ and not the ‘cause’ (Nath, 2003).

2.2. Shifting from mechanistic linear thinking towards dynamic non-linear thinking

Human conventional thinking model is based on a mechanical image of the world and a linear causality to explain the phenomena. This linear causal thinking, which is the basis of our knowledge of nature and our understanding of major scientific laws, assumes that certain causes are acting together linearly to result in an event. This paradigm assumes that there is no feedback from the outcome to the inputs in an organic system (Figure 2.1).

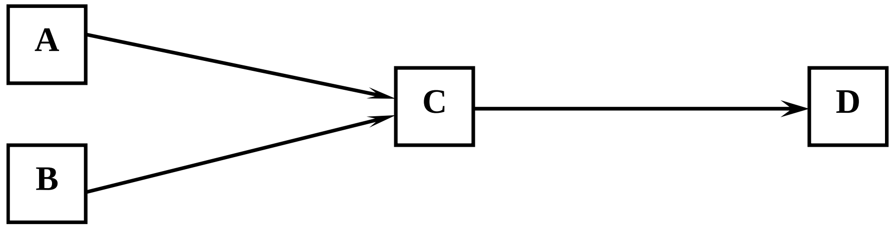


Figure 2.1. Linear causal thinking

The way linear causal thinking – or as Holling & Meffe (1996) called it *command and control* – solves problems is either through control of the processes that lead to the problem (*e.g.* good hygiene to prevent diseases), or through amelioration of the problem after it occurs. This paradigm implicitly assumes that the problem is well bounded, clearly defined, relatively simple and linear with respect to cause and effect. Dealing with natural resources, the linear causal thinking makes us perceive the varying and highly complex natural systems as engineered structures susceptible to manipulations with predictable and well controlled results.

Managing the future is a 'wicked' problem, meaning that it has no definitive formulation and no conclusively 'best' solutions and, furthermore, that the problem is constantly shifting. Obviously, however, one cannot even begin to purposefully shape the future without social goals.

The past is the only guide we have for constructing believable stories about the future. Although the past will never repeat itself, there is a sense in which everything yet to happen will be like something from the past at some level of detail. However, not in a predictable way, and we must beware of making sharp predictions.

A dynamic system model does not predict the future! Its task is to give a valid description of possible system behavior under a given range of conditions (scenarios). It can therefore be used for finding acceptable management solutions.

In contrary to linear causal relations, circular causation — where a variable is both the cause and effect of another — has become the norm, rather than the exception. The world has become increasingly interconnected, and endogenous feedback causal loops now dominate the behavior of the important variables in our social and economic systems. Thus, fragmentation is now a distinctive cultural dysfunction of society (Kofman & Senge, 1993).

In order to understand the source and the solutions to modern problems, linear and mechanistic thinking must give way to non-linear and organic thinking, more commonly referred to as systems thinking — a way of thinking where the primacy of the whole is acknowledged. Richmond gives the following definition of 'Systems Thinking': *"Systems Thinking is the art and science of linking structure to performance, and performance to structure – often for purposes of changing structure (relationships) so as to improve performance"* (Richmond, 1994).

In systems terms, changing structure means changing of the *information* links in a system, the content and timeliness of the data that actors in the system have to work with, and the goals, incentives, costs, and feedbacks that motivate or constrain behavior. The same combination of people, institutions, and physical structures can behave completely differently, if its actors can see a good reason for doing so, and if they have freedom to change.

2.3. System dynamics

One branch of systems thinking is called System Dynamics (SD), which operates in a whole-system fashion while largely avoiding jargon and convoluted explanations. It combines the theory, methods, and philosophy needed to analyze the behavior of systems not only in management, but also in other fields such as environmental change, politics, economic behavior, medicine, and engineering. It draws on a wide variety of disciplines to provide a common foundation for understanding and influencing how things change over time.

SD is a thinking model and simulation methodology that was specifically developed to support the study of dynamic behavior in complex systems. The methodology, developed by Forrester (Forrester, 1961) and refined over the last decades, was initially applied in industrial and business systems management. The scope and uses of system dynamics have since been expanded to a diversity of problems such as pressures on sustaining quality improvement efforts in corporations, diabetes in man, the savings and loan crisis, and river basin resource planning (Kelly, 1998; Sterman, 2000).

Much of the art of SD modeling is about discovering and representing the feedback processes, which – along with stock and flow structures, time delays, and nonlinearities – determine the dynamics of a system (Sterman, 2000). The understanding of these processes is then used to draw causal loop diagrams (CLDs). CLD is a powerful graphic tool to see the relationships among a system’s parts and their interactions with each other.

SD is also a method to enhance learning in complex systems (Sterman, 2000), another important aspect of SD. Attempting to draw CLDs is a useful process for gaining better understanding of a system’s mechanisms and feedback links. Going through a learning process will help us to update our decision rules and our mental models of the real world. This will provide a supportive attitude to set dynamic values as moving targets for evolving organic systems.

Another important feature of SD lies in its applicability in building and running simulation models to analyze system performance under different scenarios. In most cases it is enough to identify a system by means of its CLDs, serving as a qualitative model. However, one may go further and build up a quantitative model and run it to simulate system behavior through time under different scenarios. Such analyses offer a good decision support tool for strategy/policy making.

One feature that is common in all systems is that a system's structure determines the system's behavior. System dynamics links the behavior of a system to its underlying structure. System structures can generally be characterized by means of a set of elementary archetypes. All archetypes are combinations of simple *Reinforcing* and *Balancing* loops. A reinforcing loop enhances everlasting growth or decline; while a balancing loop has an attenuating effect and, thus, generates a goal seeking behavior.

2.4. Self-organizing systems: The idea of *Viability Loops*

Basically, linear systems, as seen in industrial assembly lines, thrive on order, top-down command and control management based on distinct hierarchical structures. The end product is known and knowable. Given causes lead to predictable results, each and every time. However, systems involving humans can not be considered sensibly unless and until the nature of cooperation and participation in the processes involved has been determined. Here, we have a family of systems involving numerous components that interact with each other and the whole system in a manner that cannot be discerned by observing the activities of the internal elements themselves. Due to a complex web of feedback mechanisms, change, and cause and effect are not due to a single one-way sequential line of events, but reflect interactive influence through feedback loops from all over the system, including its environment. Such systems, characterized as non-linear or complex, can produce completely unexpected results, even if we have advanced understanding of the original system conditions.

A complex system usually has numerous negative feedback loops that help it self-correct under different conditions and impacts. One of the big mistakes we make is to strip away these 'emergency' response mechanisms because they are not used often and they appear to be costly. In the short run, we see no effect from doing this. In the long term, we drastically narrow the range of conditions over which the system can survive (Meadows, 1999).

Reinforcing or positive feedback loops are sources of growth or decline. A system with an unchecked reinforcing loop will ultimately collapse. For example, the more the soil erodes, the less vegetation it can support, and, the fewer roots and leaves to soften rain and runoff, the more soil erodes.

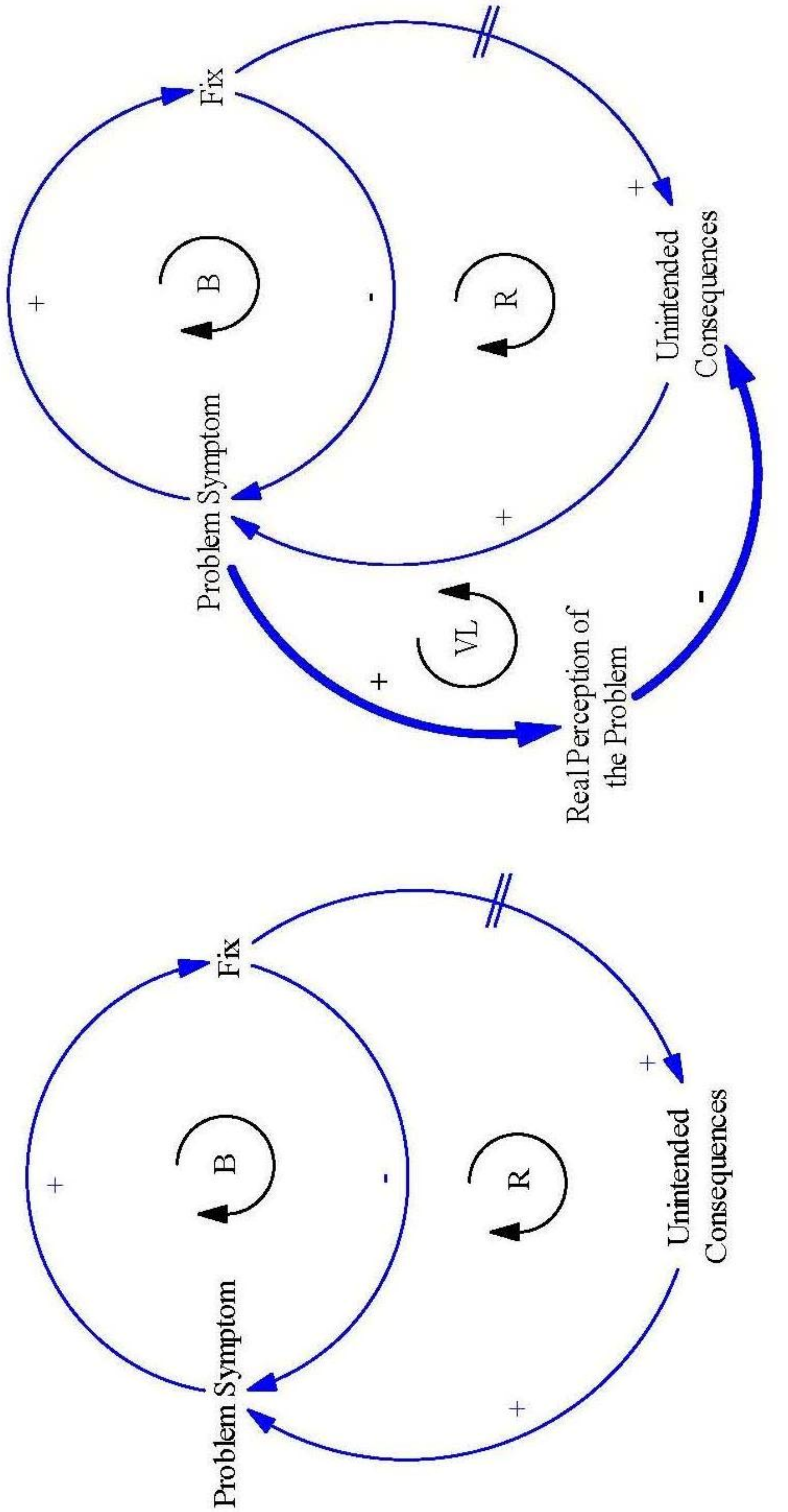
Information structure is an important feedback mechanism with high-leverage. If you make information go to places it did not go before, it may well cause people to behave differently.

Missing feedback is one of the most common causes of system malfunction. As Meadows points out, we humans have a systematic tendency to avoid accountability for our own decisions and that is why so many feedback loops are missing (Meadows, 1999). Thus, adding or restoring information can be a powerful intervention, usually much easier and cheaper than rebuilding physical infrastructures.

In any complex system, some kind of self-organizing mechanisms are working to keep the system in balance according to the stocks of resources and carrying capacity of the system. In terms of the system dynamics approach, the critical balancing or negative feedback loops need to self-correct the system by adjusting reinforcing or positive feedback loops. The key elements in those critical balancing mechanisms which are called *Viability Loops* in ***P1***, are the development and the flow of information/knowledge and/or matter/energy to keep the system in balance.

Care should be taken that not every negative feedback loop can be considered as a viability loop. Not only do some negative feedback mechanisms support balancing of systems, but they may also enhance the reinforcing mechanisms. For instance, in a *Fixes that back fire* archetype (Figure 2.2.a) fixes in the negative feedback loop allow the problem symptom to be alleviated; while, those fixes result in the promotion of the reinforcing loop and consequently the emergence of unintended consequences, which eventually will worsen the problem symptom. This problem is especially prevalent in slowly changing systems where linear thinking may work in the short term while triggering serious problems in the long run. Obviously, this kind of feedback is not considered as a functional part of a viability loop.

On the other hand, adding an information link into the archetype to build up a real perception of the problem can act as a viability loop (VL), which will hamper the growth or decline due to the reinforcing mechanism (Figure 2.2.b). In chapters 3, 4, and 5, it will be shown how the idea of viability loops can be adopted to help provide with more practical understanding of the issue of sustainable development and implementing the concept in management and planning.



a. There is no Viability Loop to control the reinforcing mechanism

b. A Viability Loop (VL) is added to control the reinforcing mechanism

Figure 2.2. The difference between a negative feedback loop and a viability loop

Chapter 3. SUSTAINABLE DEVELOPMENT: CONCEPTS & PRINCIPLES

3.1. Sustainability as an ideal

Based on the traditional linear thinking, scientists tend to assume that society and social institutions have an ‘end-state’, a fixed target towards which they are evolving. Contrary to such ideas, in response to the second research question which is about how to theorize sustainable development, it is argued in ***P2*** that sustainability is neither a state of the system to be increased or decreased, nor a static goal or target to be achieved. It is an ‘*ideal’* of development efforts in a system. Ideals come from the ethics and values and they are indeed non-quantifiable. They should be perceived as desired ends that one, it is hoped, approaches indefinitely even if one can never achieve them completely (Mittroff & Linstone, 1993). This concept makes sustainability a moving target which is continuously getting enhanced as our understanding of the system improves.

3.2. Sustainable development: An evolutionary process of adapting to changes and creating new opportunities

Characterized with uncertainties, changes, and complexity, the issue of sustainable development is considered as a dynamic process which is evolving through a learning process and not as any kind of ‘optimum’ or ‘end-state’ of a system. Neither is it adoptable to strategies based on command and control, fixed goals and predictability (Holling & Meffe, 1996; Rammel et al., 2004).

Holling (2004) clarifies the meaning of sustainable development as: “s*ustainability is the capacity to create, test, and maintain adaptive capability. Development is the process of creating, testing, and maintaining opportunity. The phrase that combines the two, sustainable development, therefore refers to the goal of fostering adaptive capabilities while simultaneously creating opportunities*”.

Recalling evolutionary concepts in terms of development, it is implied that a sustainable society should be flexible enough to understand changes and to learn how to adapt to changes in terms of innovations and creating new opportunities (Rammel, 2003). The evolutionary paradigm has to be oriented towards processes and structural change. This is related to innovations in a social evolutionary perspective, rather than equilibria or defined states of the environment (Ring, 1997). As Cary (1998) states, “*sustainability is not a* *fixed ideal, but an evolutionary process of improving the management of systems, through improved understanding and knowledge. Analogous to Darwin's species evolution, the process is non-deterministic with the end point not known in advance*".

In an evolutionary system associated with continual development, there cannot be any 'best' state, or a stable 'equilibrium', or an 'optimal' path of development. The economic neoclassical approach to innovations is largely based on the ideas of predictability, optimality and equilibria, which, as a complete contradiction to an evolutionary understanding, prevents any comprehensive approach to sustainable development (Rammel, 2003). The neoclassical equilibrium growth theory, assumes all the agents to be identical, with the same rationality, and following the same paths to optimize their utilities.

Furthermore, to create new opportunities and innovations, we have to learn how to learn. In this sense, the basic requirement is '*adaptive flexibility'* which is the ability to address changing conditions through a process of continuous adaptive learning and the possibility to initiate new development trajectories (Rammel, 2003).

Our social memory in terms of our culture, which Dawkins (1976) called *Memes*, evolve and are transmitted through generations. They will underpin the value system in a society based on which the ideals such as sustainability emerge. To promote innovation and creation of opportunities in our social system, it is crucial to encourage evolving ideals.

According to Keiner (2004) the concept of sustainability should be tied to the concept of evolutionability. Keiner (2004) defines the concept of '*evolutionable development*' as the development that "*meets the needs of the present generation and enhances the ability of future generations to achieve well-being by meeting their needs free of inherited burden*". This implies that sustainability has to enable strategies to deal with uncertainties, unpredictable and non-optimizing changes, and evolving properties as well as with a continuous process of adapting economic development to altered social and ecological conditions (Rammel & van den Bergh, 2003).

Our descendants are entitled to inherit good heritage *i.e.* we should leave less burden than we inherited ourselves; so, the today's generation should transform its heritage from burden to gain which can be in the form of opportunities to offer new resources and to find substitutes for those resources that are non-renewable (Keiner, 2004).

In addition to creating new opportunities, next generations anticipate us to foresee the impacts of our technology and policies, and to enact appropriate remedies while the time is available to act effectively (Partridge, 2003).

3.3. A system dynamics perspective: The idea of *Viability Loops*

In contrary to looking at sustainable development as a static state, which implies that its goals may conflict (see *e.g.* Lamberton, 2005; and Munda, 2005), the idea of *Viability Loops*, indicated in ***P1***, is adopted to define sustainable development as a process in which the viability loops in a dynamic system are functional to check the reinforcing mechanisms. This process will serve to keep the system in balance through both perceiving and adapting to changes and creating new resources and opportunities by redirecting the flows of capital, energy, information, and knowledge to innovate and to deal with new challenges. To this end, we need to improve the system capacity to understand changes, find ways to adapt to changes, and promote innovations to create new opportunities and resources for the next generation.

To see if a system is meeting the sustainability requirements, we should look for the viability loops and keep them healthy to prevent exponential growth or decline due to reinforcing mechanisms. In this way, system dynamics approach and its CLD analysis offer a convenient tool. It is essential to identify dominant archetypes in the system. Often, the viability loops are hampered, which causes damage to the basic resources of the system. Likely causes are that these viability loops have been ignored or that they have been blocked due to omission of an essential link or a delay or distortion in information/knowledge flow.

3.4. A link between the empirical and the normative levels of a socio-environmental system

According to Max-Neef's hierarchy of science, there are four levels of scientific areas (Max-Neef, 2005). The first or *empirical* level is associated with the areas such as Physics, Biology and Economics which would explain *What exists* in the world. The fields such as engineering, agriculture and commerce which are situated in the second or *pragmatic* level are dealing with *What we are capable of doing*. In the third or *normative* level, the areas of science such as law, planning and politics will explain *What it is we want* *to do*. Finally, in the fourth or *value* level, the fields such as philosophy and ethics will deal with *What we should do*; or, *How we should do what we want to do*.

When talking about sustainable development, we are standing in the normative level to plan our systems to work in accordance with sustainability. However, it is required to follow governing laws of nature as well as social ideals coming from *empirical* and *value* levels respectively. To evolve, we have to improve the *value* level in our society while we discover new facts in the *empirical* level. The *value* level may evolve via learning processes within both intra and inter-generations. The human dimension of sustainability requires the development of methods of deliberation and decision making that actively engages the relevant interests and communities in thinking through and deciding upon the kind of future they want to try and to create (Robinson, 2004).

The differences in views about the meaning and value of sustainability are rooted partly in different philosophical and moral conceptions of the appropriate way to conceive of the relationship between humanity and nature (Robinson, 2004). This implies that sustainability is not fundamentally a scientific or technical issue; it is a political act, an issue of human behavior, and negotiation over preferred futures, under conditions of deep contingency and uncertainty (*ibid*).

How we treat the environment is fundamentally determined by our attitude to nature, which in turn is shaped by our worldview and moral values (Nath, 2003). To promote sustainable development, a renaissance in our moral values is needed.

There are two extreme attitudes to nature. One is the school of economic growth, which believes that nature has no intrinsic value. It is of value only if it benefits humans (Nath, 2003). The school is supported by the simplistic principle that man has power over the Earth and is entitled to use and exploit it to his own benefit (Decleris, 2000). Grounded in the Platonic worldview, the other school is the school of deep ecology, which acknowledges the intrinsic value of nature, and of all things within it for its own sake (Lesser et al., 1997 in Nath, 2003). The school indicates a return to simple ways of managing nature by focusing on evolution, ecosystems, and in particular on conservation of species, without placing any special weight on human being.

Both of the schools suffer from deficient logical method. The first, which is purely analytical, isolates man from his environment and examines his economic action in its own right and over a relatively short time scale (4 to

30 years). The second is indeed holistic, but is in reality pseudo-systemic because while it focuses on ecosystems, it cuts short the hierarchy of systems and completely ignores the unique qualities which distinguish mankind from all other living systems (Decleris, 2000).

Yet, that is the main problem since man is different from other living systems and man-made systems have special characteristics and potentialities, which must be taken into account. That vital perception gave birth to the school of *sustainable development.* The school of 'sustainable development' represents the most efficient approach to the fundamental problem of relations between man-made systems and ecosystems, not because it is between the two extremes, but because it is based on integral systemic logic. The rules of sustainable development also constitute a learning curve: man must learn to coexist and co-evolve with ecosystems (Decleris, 2000).

3.5. Principles of sustainable development

The Brundtland Commission offered what has become one of the most widely used definitions of sustainable development. The United Nations Conference on Environment and Development, held in Rio de Janeiro (1992), refined and developed the ideas from the Brundtland Commission which resulted in a declaration constituting 27 principles of sustainable development. Although emphasizing nature, the principles are primarily based on anthropocentric normative values. The principles were refined and developed at the Social Summit in 1995 and at the Habitat Conference in 1996. Since then, there has been continuous erosion and undermining of the concept of sustainable development. This was evident at the Rio+5 assessment in 1997, where most governments backed down from their previous commitments.

The principles worked out by the Natural Step Foundation are found to be more promising. The Natural Step (TNS) is a set of non-prescriptive and ideal oriented principles developed to guide human decision-making and design. These principles, reached by the consensus of numerous Swedish scientists, identify the basic system principles necessary for life.

TNS was founded in 1989 by the Swedish oncologist Karl-Henrik Robèrt. Taking the moral principle that '*destroying the future capacity of the Earth to support life is wrong*' as given, Robèrt and his colleagues finally reached an agreement on the following four principles necessary for a sustainable society based on the laws of thermodynamics (Holmberg, 1995; Holmberg et al., 1996; Azar et al., 1996; Robèrt *et al.*, 1997; Robèrt, 2000):

"Principle 1 (Stored deposits). Substances from earth's crust must not systematically increase in nature.

In the sustainable society, fossil fuels, metals and other minerals must not be extracted at a faster rate than their slow redeposit and reintegration into the earth's crust.

Principle 2 (Synthetic compounds and other societally produced material). Substances produced by society must not systematically increase in nature.

In the sustainable society, substances must not be produced at a faster pace than they can be broken down and be integrated into the cycles of nature or be deposited into the earth's crust.

Principle 3 (Ecosystem manipulation). The physical basis (air, soil, water, sunlight, organisms) for productivity (growth and reproduction) and diversity (biodiversity) of nature must not be systematically deteriorated.

In a sustainable society we cannot harvest or manipulate the ecosystem in such a way that productive capacity and diversity systematically deteriorate.

Principle 4 (Socio-economic considerations). Fair and efficient use of resources with respect to meeting human needs.

Humanity must prosper with a resource metabolism meeting system conditions 1- 3. This condition is necessary in order to get social stability and cooperation for making changes in due time. In practical terms in today's situation it implies increased technical and organizational efficiency throughout the whole world, including a more resource-efficient lifestyle particularly in the wealthy sectors of society. Furthermore, it implies improved means of dealing with population growth."

Being grounded in ethics, the system orientors suggested by Bossel follow a similar methodology as the principles of TNS; except that the latter are grounded in the natural laws but the former go back to ethics. Bossel's ethics reads: "*All people should have their needs satisfied so they can live in dignity, in healthy communities, while ensuring the minimum adverse impact on natural systems, now and in the future*" (Peet & Bossel, 2000). Bossel defined the following characteristics as the basic orientors of the systems (Bossel, 1996, 1999): **existence** related to the *normal environmental state*, **effectiveness** related to the *scarcity of resources* ,**freedom of action** and **security** related to the *environmental variety*, **adaptability** related to the *environmental change*, **coexistence** related to the interests (orientors) of *other* (actor), and psychological needs for human systems.

3.6. Principles of sustainable development adapted for water resources systems

A vast literature review on water and sustainable development is provided in ***P2***. Any assertion on the issue is rooted in the paradigm that 'how water is valued'.

Since the International Conference on Water and the Environment in Dublin in 1992, the notion of '*water as an economic good*' has been widely accepted among water resources managers. That is based on the principle that people are 'economic men' who respond rationally to financial incentives and disincentives (Grimble, 1999). The concept implies two schools of thought, one maintains that water should be priced at its economic value and the other one interprets the concept to mean that decisions on the allocation and use of water should be based on a multi-sectoral, multi-interest and multi-objective analysis in a broad societal context, involving social, economic, environmental, and ethical considerations (Savenije, 2002).

Water serves a various number of purposes ranging from domestic water demand, agricultural and industrial water demands through aesthetic, recreational, and environmental water uses, to waste disposal. This multiplicity of water uses make it to be considered as both a private and a public good according to its excludability – the degree to which users can be excluded – and subtractability – the degree to which consumption by one user reduces the possibility for consumption by others – natures in each purpose (Liu *et al.*, 2003). As they indicate, for instance, if water is used for recreation in a lake it would be regarded as a public good due to its low excludability and subtractability; while, if the water in the lake is allocated to supply water for a region it would turn to be a more private good due to its increase in excludability.

On the other hand, international law, international agreements and evidences from the practice of States strongly and broadly support the '*human right*' to a basic water requirement (Gleick, 1998). Although in the most popular covenants and international declarations the right to water is not explicitly mentioned, it is implicitly implied due to the principle of protection of human rights to life, to the enjoyment of a standard of living adequate for health and well-being, of protection from disease and to adequate food. However, the right to access to water for basic needs was explicitly recognized by the statement of the United Nations Water Conference in Mar del Plata in 1977 (United Nations, 1977 in Gleick, 1998). That statement was supported then by the Declaration on the Right to Development (DRD) (United Nations, 1986 in Gleick, 1998) and the Convention of the Right of the Child (CRC)

(United Nations, 1989 in Gleick, 1998). However, the amount of water required to meet human basic needs is debated to vary from 3-5 to 50 liters per capita per day.

In this thesis, it is believed that mechanisms and policies related to water services can mobilize other mechanisms and influence the process of sustainable development. Water has an essential and unique role to integrate different sectors of society, economy and environment. Not only does it have an economic role, but also it can play a social role as it initiates population migrations, political conflicts, and civilization settlements as well as its crucial role in ecological systems. So, here it is proclaimed that ***water is a means of sustainable development***. However, it is argued that economic tools should be applied to keep market mechanisms active to generate effective signals to make technology to innovate and man to adapt to changes in the real world.

Since sustainable development deals with man as well as environment, in the present thesis both Bossel's systems orientors originated from ethics – as the principles associated with the *value* level – and the principles of TNS – as those associated with the nature physical laws in the *empirical* level – are adopted to initiate principles of water resources sustainable development. In ***P2***, the principles of sustainable development in water resources systems are suggested by customizing the above basic principles as below:

I. Exploitation of water resources in a basin must not violate its natural, hydrological balance.

Withdrawal from local water resources in a basin as well as water transfer from/to other basins must be carried out in accordance with the natural regime of hydrology in the region.

II. Waste disposal into nature – due to either water or energy consumption – must not exceed the environment carrying capacity.

The environment carrying capacity must be concerned so as not to let wastes be accumulated in the ecosystem in terms of contaminants.

III. Persistent damages to the ecosystem due to water services must be prevented.

Regarding water resources systems, manipulations in the ecosystem must not result in persistent impacts which will be carried on to the next generation as a burden.

IV. The system must be capable of adapting to changes to equitably distribute and efficiently use water.

It is crucial to understand changes and learn how to adapt to changes effectively.

V. ***There must be various opportunities for human to be able to meet her/his water needs.***

It is not our responsibility to meet the needs of the next generation; rather, we must leave a variety of options for them to be capable of meeting their own needs by themselves.

We can resort to the above principles in order to implement sustainability in the development efforts associated with water resources systems. Furthermore, rather than focusing on a topic-by-topic research agenda, we need to identify the overarching principles, and recognize the limitations of discipline-based perspectives and acknowledge the need to integrate across physical, chemical, biological, and social sciences when dealing with water problems of relevance to society.

Chapter 4. MONITORING FOR SUSTAINABLE DEVELOPMENT

4.1. Monitoring for sustainable development rather than measuring sustainability

As it is indicated in ***P3***, to respond to the third research question which is about practicing sustainable development in management issues, since sustainability is a moving target or a dynamic ideal, and not a static state of the system to be considered as a fixed point which is normally quantified in terms of state variables related to the system performance, it does not make sense to measure it to see how far the system is from the sustainable state.

Rather, the process *i.e.* the sustainable development in a system, which is an ongoing process, needs to be regarded as part and parcel of everyday work; and the system, thus, should be monitored for sustainable development using process indicators – rather than performance indicators – to see if the process is going on properly. Process indicators explain the dynamic status of the system and can provide a projection of its future, while, performance indicators refer to the state of the system and will afford only a static picture of it which is somehow related to its past.

A suggested framework to monitor a system for sustainable development is explained in ***P3***. In the framework, viability loops are focused on as the key actors to define monitoring indicators in a system.

The process of monitoring should lead to results which can be applied in decision and policy making. The process of policy making would then be to develop strategies to trigger or enhance the hampered viability loops, so that, they can control the reinforcing mechanisms in the system. Indeed, it works in a learning process to make corrective, new decisions.

4.2. A systemic framework to monitor systems for sustainable development

The structure of the suggested framework to monitor systems for sustainable development is depicted in Figure 8 of ***P3***. According to that structure, the framework suggests that the following steps should be carried out:

- Determination of the system boundaries in accordance with the system purpose,
- Derivation of principles for sustainable development based on the system values or ideals and laws of nature,

- Assertion of essential questions related to the system conditions and its long-term goals,
- Building up a qualitative dynamic model using Causal Loop Diagrams (CLDs) based on the essential questions,
- Identification of the viability loops through the CLDs,
- Appointing indicators associated with the viability loops, and
- Evaluation of the trends of indicators.

4.2.1 System boundaries

The first step in the process of monitoring is to precisely determine the 'system boundaries'. It is very important to limit the issues which are supposed to be focused on. It is not possible to put every element in the world into consideration. The boundaries of the system are determined in accordance with the system purpose and should contain the elements which effectively interact with each other to fulfill that purpose. Depending on the system purpose, boundaries of a system can even include actors out of the system physical borders.

4.2.2 Principles of sustainable development

As it was described in Chapter 3, each system is based on a set of values or ideals as well as physical laws which are forming the goals and constraints that are not achievable, but the system is hoped to approach them. The manifestation of system values is through principles which are grounded in ethics and scientific theories.

In this step, the principles of sustainable development based on The Natural Step (TNS) principles and the Bossel's system orientors, which have been adapted in Chapter 3 to be applied to water resources systems, are adopted. Those principles address the physical nature of the issue as well as the ethical aspect.

4.2.3 System essential questions or system conditions

P3 argues that in order to put system principles into practice, we should develop system conditions based on those principles. Violation of any of the system conditions results in un-sustainability. System conditions are identified by essential questions that will direct the definition of associated causal loop diagrams. Each question or condition should correspond to a dynamic structure in the CLD and vice versa.

Adopting TNS principles and Bossel's systems' orientors in this thesis, ***P3*** proposes the following essential system questions to touch environmental as well as humanitarian aspects of sustainable development:

i) Are the human basic needs such as food, education, health, … met?
ii) Are the resources in the system – in terms of sources and sinks – not deteriorating?
iii) Are the carrying capacity and basic life supporting systems of the environment enhanced?
iv) Is the accumulation of wastes in nature reducing?
v) Is the capacity of environment to provide life services for man enhancing?

4.2.4 Looking at the CLD of system conditions, searching for viability loops

Based on the essential questions, the feedback structure of the system is captured by drawing its causal loop diagram. It should be noted that all the essential questions or system conditions should correspond to the dynamic mechanisms in the CLD and vice versa.

Having drawn the CLD of system conditions, we will be able to identify system viability loops, which exist or should exist, to keep the system in balance. Some of those viability loops might be missing in the real world systems. ***P3*** introduces examples of dynamic mechanisms and their associated viability loops in water resources systems.

4.2.5 Definition of process indicators to monitor the system

Indicators are means to measure and/or monitor. They are used for two purposes. One purpose is to measure the progress towards the system objectives or targets. In this case, they are usually referred to as *Performance Indicators*. The problem with this kind of indicators is that sometimes we forget what the objective is and just worry about the indicators. The other purpose is to use indicators to monitor the function of a system and to control that it does not violate the basic vital constraints. This kind of indicators is usually referred to as *Process Indicators*.

A good indicator alerts you to a problem before it gets too bad and helps you recognize what needs to be done to fix the problem. Indicators of sustainable development point to areas where the links between the economy, environment and society are weak. They allow you to see where the problems areas are and help show the way to fix those problems.

Desired characteristics and qualities of indicators are explained in ***P3***. Regarding sustainable development, we need to monitor the process in terms of the health status of the system viability loops; hence, we are not looking for the system performance indicators. The indicators of sustainable development in a system are used to show how well the viability loops are functioning to keep the balancing process healthy. They should be related to the feedbacks produced by the viability loops.

Chapter 5. THE URBAN WATER SYSTEM IN TEHRAN: A CASE STUDY

5.1. Introduction

Attempting to respond to the fourth research question, which is about implementation of sustainable development, ***P4*** starts with a review of prevailing methods for the evaluation of urban water systems regarding their sustainability. Some researchers try to capture sustainability in a single indicator *e.g.* through exergy analysis or economic analysis. However, other frequently used methodologies, such as Life Cycle Assessment (LCA) or system analysis, include multiple indicators (Balkema et al., 2002).

Unlike most of the reviewed methods which are based on performance indicators to measure sustainability in an urban water system, in this thesis, the proposed systemic monitoring framework for sustainable development is adopted to define process indicators in a case study on Tehran urban water system.

An urban water system is usually referred to as the elements which are interacting with each other regarding the following three areas: water supply and distribution, wastewater collection and management, and management of storm water sewage. Following the steps of the monitoring framework suggested in Chapter 4, the thesis considers the system boundaries limited to the first two functions. Hence, the system boundaries which are depicted in Figure 2 of ***P4***, are assumed to contain the city area and its water resources and consumers regarding water supply and wastewater disposal. The other sub-systems are considered exogenous.

When monitoring a system, it is very important to precisely define the objectives of monitoring. These objectives are identified by embedding basic questions which will address the system principles and help to identify the viability loops in the system. In other words, "*the first question to be answered is not **what do we want to measure?**, as one is often tempted to do, but rather, **what question do we want to answer?***" (Bertrand-Krajewski et al., 2000).

Adopting the principles of sustainable development for water resources systems adapted in Chapter 3 and customizing the basic questions regarding sustainable development of water resources systems, suggested in Chapter 4, the following specified conditions are proposed in ***P4*** to serve to address the goals of an urban water system:

i. Is the system improving its capability to meet the human water needs in an equitable way?
ii. Are the stocks of system resources, *i.e.* water and energy, deteriorating?
iii. Is the waste generation overburdening the waste assimilation capacity of the system?

5.2. Viability loops in an urban water system

Based on the above conditions for an urban water system, dynamic feedback structures are built up, which can be visualized via CLDs. Those CLDs should be looked at to discover reinforcing mechanisms where viability loops are needed to control them. This will lead to identification of viability loops and eventually to the indicators that can serve to monitor the functional status of those viability loops.

P3 and ***P4*** discuss some dynamic mechanisms existing in an urban water system. One typical mechanism in an urban water system, which originates from an engineering thinking supporting a supply-side oriented policy in public utilities management, is found to be dominated by a *Fixes that back fire* archetype. This dynamic structure is working to meet the increasing water demand in the city through provision of more resources (Figure 3 in ***P3***).

P4 argues that, usually, reinforcing loops in the above mechanism are not checked. What is missing is a negative feedback, where the increasing trend of *Utilized Water* causes alarm about the resource limitation to meet inhabitants' demands and, thereby, triggers efforts to improve the efficiency of water management and water use (Figure 3 in ***P4***).

To create this negative feedback, there is a need to increase the public awareness, to promote real understanding of socio-economic and environmental constraints on additional water transfer to the city and/or over-exploitation of the local resources. This can be achieved by making the public aware of the difference between water resources real abundance and their current perception. Thus, creating an information flow about *The Ratio of Water Resources Availability in the Basin to those Provided*, a viability loop can be created to provide a negative feedback which will be responsible to adjust the reinforcing limbs of the loop (Figure 3 in ***P4***).

Following the supply-side oriented policy, another mechanism can be identified which is working to allocate more water to the city from resources out of the basin. A reinforcing dynamism in this mechanism, recognized as the *Success to the successful* archetype, is found to support this mechanism. In that archetype, allocating more resources to an actor rather than to other parties makes that actor to succeed more and the other actors to fail (Figure 6 in ***P3***).

To hamper the reinforcing loop in the *Success to the successful* structure, it is required to develop a negative feedback loop that causes limitations to water allocations from external resources. Numerous case studies show that the marginal cost of water supply rises sharply as over-exploitation of water resources and/or water transfers are needed from increasingly distant sources. According to economic theories, higher prices would lead to reductions of consumption. Thus, awareness of actual costs and political resistance towards cost recovery would be useful indicators of the health of this viability loop.

The new flow of information through *Water Transfer Marginal Costs* and *Water Withdrawal Marginal Costs* which can result in the *Public Awareness of Water Provision Costs* will form a viability loop to keep the associated reinforcing limbs in the *Success to the successful* structure in check. That viability loop aims to offset the supply-side oriented strategies in water utilities by emergence of information flows to influence water provision efforts (Figure 4 in ***P4***).

In some cases, viability loops do exist in the system; but, they are hampered by distortion of information, which causes those balancing loops to change into reinforcing mechanisms. This effect is usually seen in relation to the exploitations of resources and/or recycling of generated wastes in the system. For instance, there usually exists a viability loop to lead the technology to save energy and water by improving their utilization efficiency in an urban water system. ***P3*** discusses how a market-technology mechanism will be working here to generate signals about the scarcity of energy and water resources to promote the technology to get improved (Figures 5 & 6 in ***P4***; and Figures 10 & 11 in ***P3***). However, this type of viability loop is usually hampered because of distortion in the information about the real cost of energy resources and water services. This misleading signal is due to the information time delays in the system, the time needed to develop new technologies and also wrong policies such as misallocation of public subsidization.

Relevant indicators would then be based on movements towards more pro-poor policies and on the permissiveness of the institutional system and its capacity to evaluate the impact of forthcoming innovations. The gap between actual cost of energy and/or water services and what is supposed to be paid by consumers is the signal which shows misleading perception of the public about the relative costs. While this gap, which is filled with public subsidization, is getting wider it means that the balancing mechanism in the viability loop is not functional.

The latter type of viability loop can be applicable to control overloading sinks or carrying capacity of the environment due to the waste generation as well. Generated wastes, in the forms of either wastewater or any kind of pollution due to the energy use, will result in increase of environmental costs which eventually lead the relative costs of water and energy utilizations to rise. The same market-technology mechanisms, discussed above, are expected to act here as the viability loop to adjust the generation of wastes by guiding the technology to improve the efficiencies of water and energy utilizations. Nevertheless, the information distortion due to the system time delays and misleading policies will usually hamper the proper function of such viability loops.

5.3. Case study: Monitoring Tehran urban water system for sustainable development

5.3.1 Introduction

Tehran, the capital of Iran, has experienced a rapid growth during the past 50 years. Its population has grown from 1.04 million in 1950 to about 7 million in 2001. Since Tehran is not situated close to any main stream, it has been relying on the water transferred from North-western and North-eastern neighboring basins as well as on the local underground resources to meet its water demand. Before any water resources development in Tehran, water used to be supplied only from the local aquifers via 26 Qanats with a total discharge of 700 lit/s. Today, water consumption in Tehran is about 900 MCM/yr which is provided from the water transferred from three reservoirs out of Tehran basin as well as the local aquifers (Tehran Water & Wastewater Co., 2001).

The domestic wastewater system in Tehran has been based on absorbent wells, which are dug in the alluvial layer as deep as about 20-30 m. The wastewater is disposed through sanitary sewage systems into those wells and is self-purified in the ground porous media. The treated wastewater is the major source to recharge groundwater resources; however, water is pumped partly out of the ground to keep the groundwater table in a normal level due to the huge amount of water transfer into the basin. Since few years ago, a wastewater collection network and a treatment plant have been being constructed, that is supposed to get all the domestic wastewater gathered, treated and transferred for irrigation the agricultural areas in the south of Tehran.

5.3.2 Process indicators to investigate the health of viability loops

The development of public utilities in Tehran has been dominated by a supply-side oriented strategy. This strategy includes water sector as well as other public sectors, and has caused a continuous increasing trend in the number of population and consequently a growing demand for public services as well. Figure 5.1 shows how the population and water consumption in Tehran as well as its water supply capacity have been increasing during the past decades.

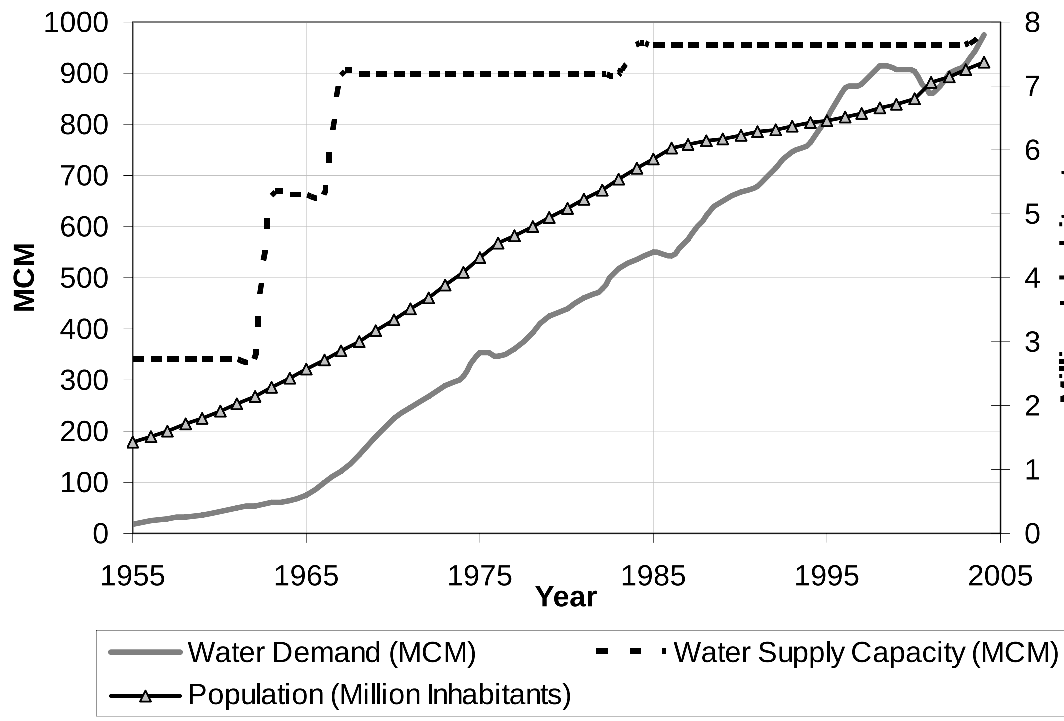


Figure 5.1. The growing population, water consumption and water supply capacity in Tehran

During the past decades, the public have believed that water would be provided from any resources no matter how much renewable water is available through the local resources. The major part of water for Tehran is provided through transferring from the neighboring basins while the local aquifers contribute only in 40% of water provision.

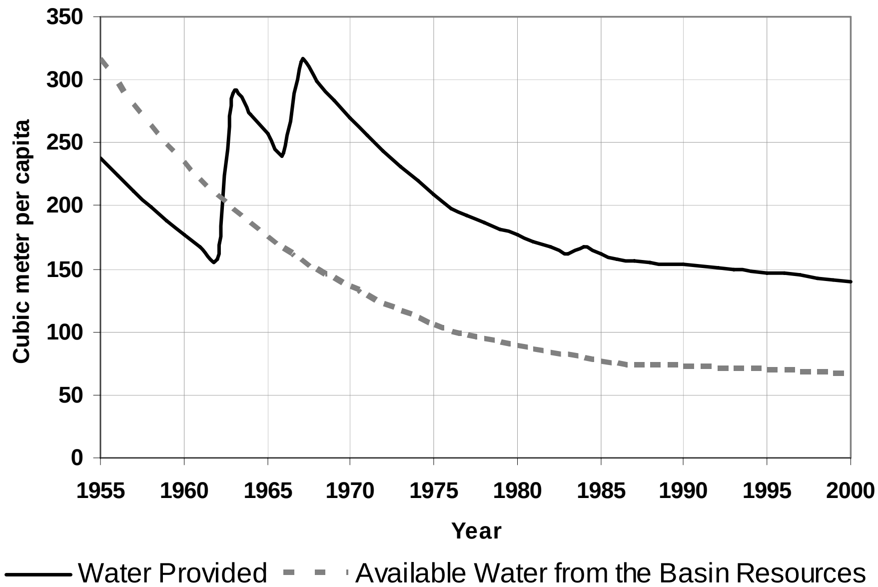
What is occurring in reality is that the available renewable water, coming from the local resources, per capita has been declining due to the population growth. Despite decreasing local availability of water per capita, the public perception of water abundance in the city is different due to water provision from other basins as well as over-pumping the aquifers. Furthermore, although the water administrators try to encourage the consumers to decrease their consumption, people are not indeed correctly informed about the state of water resources abundance in the area. The gap between the real water abundance in Tehran and what is perceived by the public is visualized via using the *available renewable water per capita from the local resources* as the indicator of water abundance in the area, and the *provided water resources per capita* as a surrogate indicator for the public perception of water abundance. As depicted in Figure 5.2a, it is seen that the gap has continued to persist even in the recent years, which indicates that no viability loop is effectively functional enough to influence the associated reinforcing limb.

On the other hand, provision of more water through transferring and over-pumping has led to increase in marginal costs of water services both due to resource exploitation and waste disposal. In spite of increases in water services costs, water tariffs have not risen in prices accordingly. As a consequence, no information has been propagated to influence the efforts for water provision and no signals have been generated to direct investments to improve the technology of water use. Figure 5.2b shows the gaps between the water tariffs, or the cost of water services which is supposed to be paid by a household, for an average water consumption of 24 m^3/month, and the cost of water withdrawal and also the final cost of water after treatment and delivery during 1996 till 2004 in Tehran. The widening gaps indicate that the viability loops to offset water provision and exploitation of water resources are not so healthy to influence the reinforcing limbs effectively.

A similar problem exists with the energy issue. Any form of energy which is used to withdraw, treat and distribute water is highly subsidized. That hampers the functional status of the market-technology mechanism to promote the viability loop associated with conservation of energy resources. The energy pricing policies have not been following a directing strategy, and for several years, they have been dominated by the inflation rate in the country economy. A comparison between the average rise in the energy prices and the inflation rate during 1992 till 2004 in Iran is depicted in Figure 5.2c. The fluctuating difference between these two rates inhibits the technology to pursue its way in investment on improvement in energy utilization.

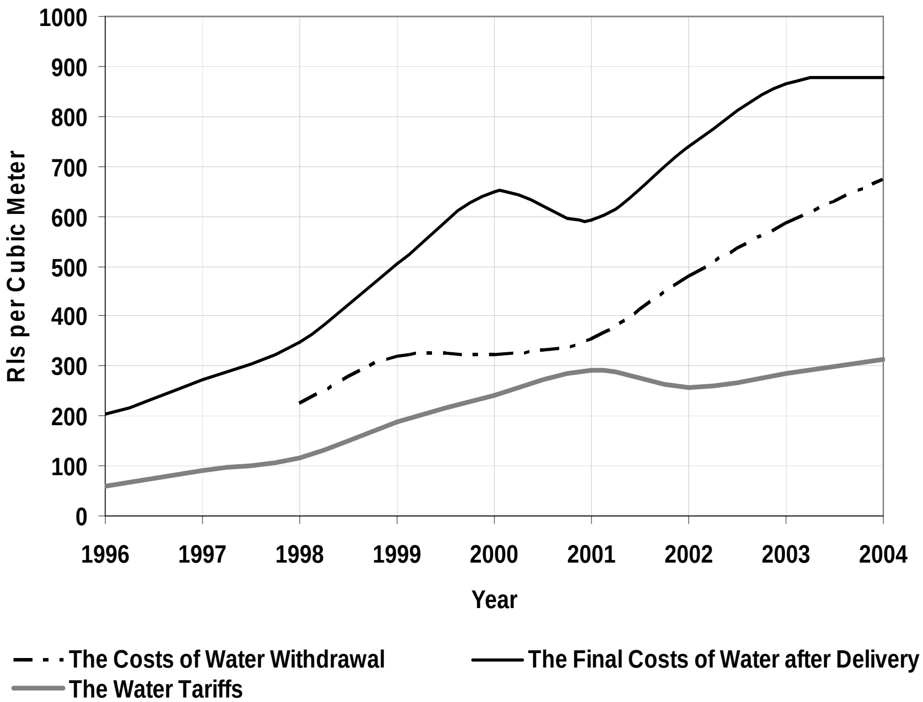
Evaluation of the indicators demonstrated in Figure 5.2 associated with sustainable development of Tehran urban water system reveals that the development within the system has not been in a sustainable path. This un-sustainable development will result in consequences which can be regarded as symptoms of socio-economic problems in the city.

Care should be taken not to confuse indicators of sustainable development with problem symptoms in a system. Problem symptoms are consequences of malfunctioning and unhealthy status of mechanisms which are involved to take care of the process of sustainable development. Indicators are means to check if those mechanisms are healthy. They can be used as leverage points to trigger strategies and policies to treat ill viability loops.

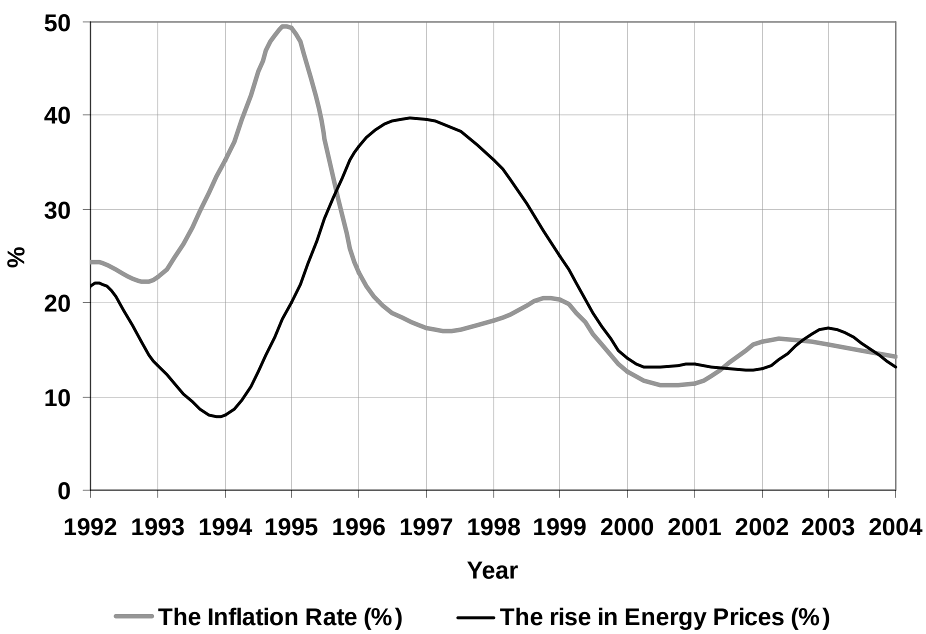


a. The gap between renewable water availability in Tehran and the public perception (Ref. Data from Tehran Water & Wastewater Co.)

Figure 5.2. The process indicators to monitor sustainable development in Tehran urban water system



b. The gaps between the costs of water services and the water tariffs in Tehran for average consumption of 24 m3/month (Ref. Data from National Water & Wastewater Co. of Iran)



c. The gap between the annual inflation rate and the average rise in the energy prices per year in Iran (Ref. Data from the Central Bank of Iran)

Figure 5.2. The process indicators to monitor sustainable development in Tehran urban water system (Continued)

Chapter 6. STRATEGIES FOR SUSTAINABLE DEVELOPMENT

6.1. Introduction

In response to the fifth research question which is about strategies to plan a system for sustainable development, the main focus of ***P5*** is on initiating a shift in planning paradigms from fixed-goal approaches towards process-based approaches to adopt strategies for sustainable development. To better understand the issue, it is applied into a case study on the urban water system of Tehran.

Processes have key roles in sustainable development in terms of definition, practice, and planning. ***P5*** argues that the most important process in organic systems is the process of learning. Involving all stakeholders in the process will result in social learning, which makes the system to perceive and adapt to change and to evolve its values. Hence, in the present thesis, triggering the process of social learning and participation of stakeholders in the process is recognized as the strategy for sustainable development in *e.g.* the urban water system of Tehran.

6.2. The approach to uncertainty in the conventional planning

The traditional view of planning paradigms such as strategic planning is to set a long-term direction based on well founded predictions, analysis of options, and key decisions about the future of a system (Brueck, 2005). The attributes of that approach of planning, which is commonly known as 'Linear (Optimal)' planning, are: focus on (optimal) output, command and control planning through fixed policies, top-down central planning, effective hierarchical organizations, and scientific knowledge (Moberg & Galaz, 2005).

The way optimal planning deals with future and uncertainty is through prediction and preparation. The paradigm of prediction and preparation involves passive adaptation to an environment which is believed to be out of our control. In contrary, the other paradigm is design and invention, which involves active control of a system's environment (Ackoff, 1979a). As Ackoff (1979a) asserts, there is a greater need for decision-making systems that can learn and adapt effectively than there is for optimizing systems that cannot.

Science now needs to cope with many uncertainties in policy issues of risk and the environment. This implies that we have to move beyond the 'normal' sciences – which is characterized as an extension of laboratory, puzzle-solving approaches that externalize uncertainty and are not appropriate to address complex global environmental problems – to 'post-normal' sciences characterized as a strategy to deal with environmental issues in which there are high uncertainties, various and conflicting values, and in which urgent decisions are needed (Funtowicz & Ravetz, 1993; Tognetti, 1999).

Thus, we now need to move beyond the reductionist thinking to expansionism – a doctrine produced by systems thinking – to foster the capacity to address complex, evolving systems whose main attribute is uncertainty. In contrast to reductionism, expansionism states that ultimate understanding of anything is an ideal that can never be attained but we strive to approach it. According to this paradigm, *understanding*, unlike knowledge, is a flow from larger to smaller systems; not, as *analysis* assumes, from smaller to larger (Ackoff, 1979a).

As Karlsson (2005) asserts, science changes what is possible to think. When the boundaries of our thought expand, we re-evaluate our desires and values. It is not possible to predict what we will know, or wish, in the future.

6.3. Dealing with the future by backcasting rather than by forecasting

In long-term planning dealing with organic systems, it is more appropriate to address potential futures through backcasting than by means of forecasting. Backcasting, or normative forecasting, is an approach, or as Höjer & Mattsson (2000) calls it an attitude, which involves the development of normative scenarios aimed at achieving desired end-points; while, forecasting intends to provide the most likely projection of future. Unlike forecasting that relies almost entirely on causality (Dreborg, 1996), backcasting is intended to suggest the implications of different futures not based on their likelihood, but, based on the other criteria which might be associated with values and norms such as social or environmental desirability (Robinson, 2003, 1988, 1982).

In the first generation of backcasting one used to impose normative conditions in advance; while, in the recent generation of backcasting desired futures emerge as a product of the process of analysis and engagement. They are thus the product of a social learning process that is inherently open and unpredictable (Robinson, 2003).

6.4. Evolutionary planning to adapt to change through social learning

In an evolving system where change is inherent, we cannot judge about the future of the system based upon its past or present states; instead, we need to look at the processes which are going on and are expected to bring about changes and new states into the system in the future. Regarding evolution in the human society, innovation and adaptation, rather than optimization (since the 'optimum' is also moving), have a crucial role.

Norms and values in a system do not remain stagnant, but are emergent features of the communication and learning processes in the system (Tognetti, 1999). Indeed, the learning will result in adaptive response to uncertainties.

The increasing role of human dimension, high uncertainties, and the need to more integrated approaches in resource management and sustainable development imply that management is not to find the optimal solution to one problem; instead, it is a continuous learning process focusing on communication questions, perspective sharing, and development of adaptive group strategies for problem solving. This attitude of learning is expected to lead in perceiving, adapting to, and creating responses to environmental challenges. It is more than just public participation or learning in a group setting.

As Pahl-Wostl (2002) asserts, we need to come to a polycentric understanding of policy making which is based on the idea that decision making involves processes of social learning. In this understanding, we should leave the traditional planning methods to shift from '*What*' to '*How*' or from a '*goal-based optimization framework'* to a '*process-based multi-scale approach guided by a target/vision*'. The most important product in planning is the process. Thus, unlike medical doctors who diagnose the ailments of others and prescribe for them, planners, like teachers, should facilitate others' learning to plan for themselves (Ackoff, 1979b).

An important tool to enhance social learning is the process of developing models (Pahl-Wostl & Hare, 2004). In traditional modeling one person or a group of experts build the model and just explain the results to policy makers; however, in order to be within the process of learning it is required that both policy makers and all stakeholders as well as experts be involved in the process of model building. Thus, the main function of modeling could be a means for learning rather than for prediction.

The ‘process’ of building a model is always useful, because it generates new knowledge about the system, its components, and interactions between them. Thus, the modeling process is even more important than the result. The result can be more useful, less useful, or entirely useless. As W. Deming described it, “All models are wrong, some models are useful” (McCoy 1994).

6.5. Planning for sustainable development: learning from doing

Planning for sustainable development implies planning for learning. We should keep going through a dynamic process to learn from our mistakes and past experiences, and get prepared for different possible futures. The process of learning should result in creating new knowledge and values which will initiate changes rooted in the social culture.

Compared with conventional ‘Command-and-Control’ management, sustainable management needs to become more integrated, flexible and resilient. Regarding water systems, sustainable freshwater management is, in fact, a continuous ‘Learning-by-Doing’ process to meet environmental uncertainty. That is, we must learn to live with change through an active, adaptive management approach that is diversified and open for renewal (Moberg & Galaz, 2005). In this process public participation and collaborative learning are extremely important processes which need to be fully understood and acknowledged. Adaptive freshwater management requires a focus on processes and interactions between parts at different temporal and special scales, experiments, monitoring, evaluation, feedback, and fostering organizations to deal with change, and knowledge (scientific and local) diversity (Moberg & Galaz (2005).

In order to plan for a systemic sustainability we need be dynamic and prescriptive, not static and descriptive. Monitoring of the present and past is static unless it connects to policies and actions and to the evaluation of different futures (Holling, 2001).

Relying on the idea of viability loops, the thesis defines planning for sustainable development to constitute of mapping the dynamic feedback structures of the system in question and then identification of viability loops which exist or should exist in the system. The process of planning then goes on to develop strategies and policies to keep the viability loops functional and/or to activate the missing ones. This process is anticipated to lead to enhanced learning, perceiving changes, promoting adaptability, and creation of new opportunities in the system.

6.6. Strategies for sustainable development in Tehran urban water system

Strategies are means to define the direction of policies and actions in a system. Different worldviews will result in different values to establish strategies. The variety of values will eventually lead to different monitoring mechanisms, indicators, and evaluations. The indicators of monitoring are indeed filters that select which kind of data we are interested in receiving from our environment and which we wish to eliminate.

That is why we cannot find an abstract and objective way to evaluate strategies and policies in a complex socio-economic system. Each observer can criticize policies just according to his or her own values and worldview. However, it is possible that proponents of different value systems may reach an agreement on a common strategy or policy in spite of their different worldviews.

Lindblom (1978) states that the only way we can evaluate strategies and policies is by means of consensus or agreement by policy makers and administrators. We cannot consider a policy to be wrong; however, what we can say is how much better another policy may work in comparison with the status quo. Of course, this comparison will be based on our own values and will vary under different circumstances.

Assuming sustainability as a value within the urban water system of Tehran, we can see from Chapter 5 that the system is already in un-sustainable territory, *i.e.* the viability loops which are responsible to keep the system in balance are missing or impaired. Therefore, it is crucial to adopt strategies to promote the process of sustainable development in the system.

Unlike the prevailing ‘fixed-goal’ approaches of strategy making, which focus on options for either supply-side or demand-side management, we argue that strategies for sustainable development of Tehran urban water system should focus on processes. Relying on the new generation of backcasting, we believe that the sustainability strategies should emphasize a social learning process and involvement of all stakeholders within the process.

As it is explained in ***P1*** and ***P5***, there are two loops in a learning process. According to Figure 6.1, in the ‘surface loop of learning’, information feedback is collected on the functional status of viability loops and change within the system. The information is processed and then policies and decisions are made based on the result of the information analysis. The decisions are put into actions to rectify the system. While the system is likely to change due to environmental change, awareness of these changes is created by the information feedback via this loop, and adaptation policies will emerge and get implemented. The surface loop of learning will make the system to evolve and to adapt to changes.

The surface loop of learning is underpinned by two crucial elements which are ‘*Decision rules & structures*’ and ‘*Indicators & monitoring system*’ (Figure 6.1). Those two main elements are originally rooted in the ‘*Worldview & mental models*’, which all evolve in another learning loop, called as the ‘deep loop of learning’. In the latter loop, the information feedback helps to perceive the system change. The perception of change will make our worldview to evolve. This will eventually lead to improved understanding of environment and enhanced value system. Hence, the definition of desired sustainable future of the system can be improved continuously, leading to modified system conditions and essential questions. Eventually, the ‘*Decision rules & structures*’, and the ‘*Indicators & monitoring system*’ will be changed according to the modified system conditions and will result in new policies for and information feedback from the system in question.

The most important issue in the learning process is involvement of the all stakeholders in every stage of the two loops. That aims to create a process of social learning, which will consolidate sustainability as a dynamic value in the society and will facilitate making and implementation of policies supporting sustainable development in accordance with environmental change.

Unlike the conventional strategies, it is argued that the strategy for sustainable development should be defined as triggering the process of social learning based on its two deep and surface loops of learning, and involvement of all stakeholders in the process. All policies and plans should be adopted in accordance with that strategy to get towards the sustainable territory.

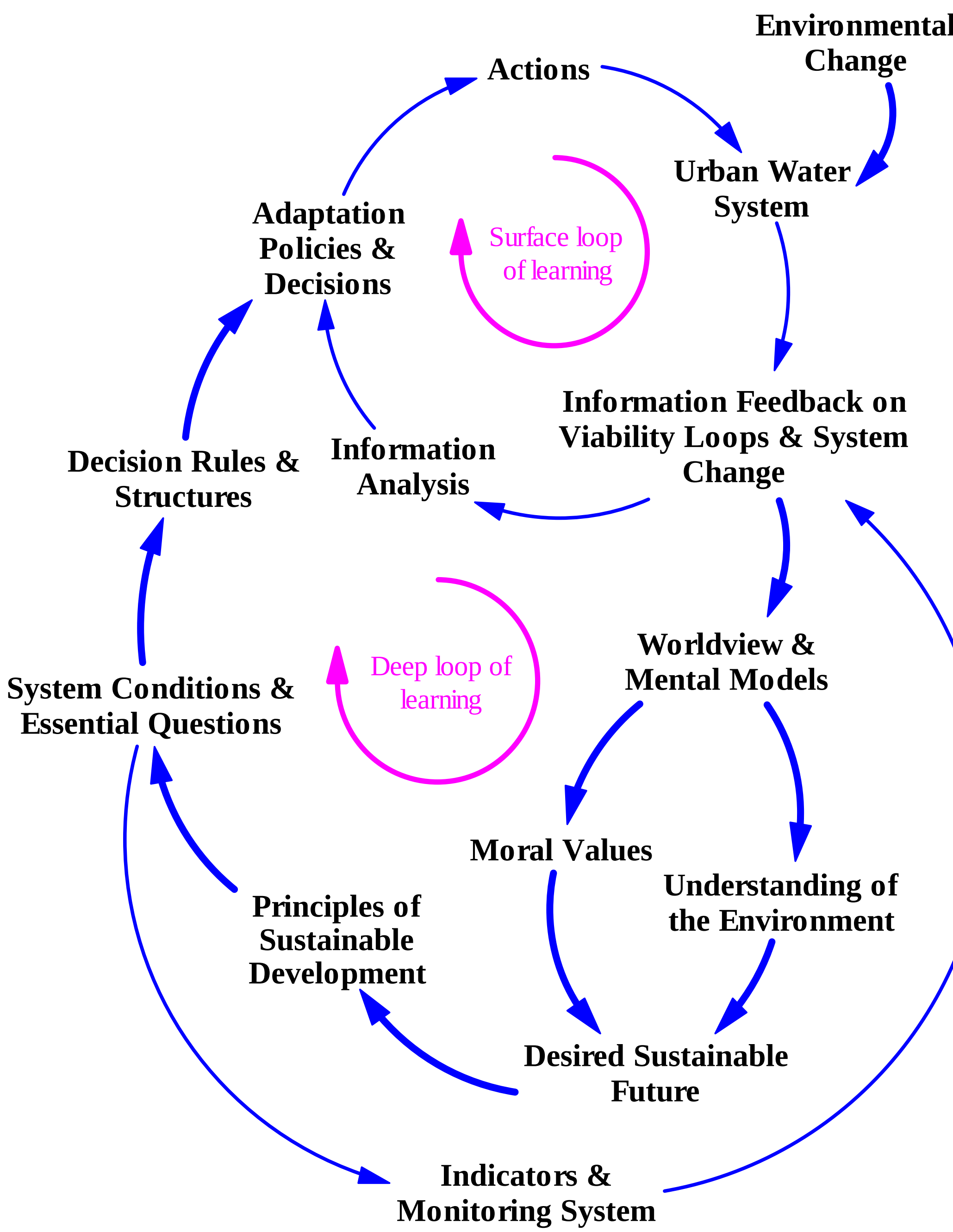


Figure 6.1. The process of learning for sustainable development in an urban water system

Chapter 7. CONCLUSIONS

In spite of its simple, holistic definition, sustainable development risks to become a meaningless buzzword since most scientists are stuck in reductionist thinking. Many attempts have been made to put the concept into practice. However, rather than providing practical guidance, these attempts merely show that there are widely different perceptions of the concept of sustainable development.

Classical science solves problems by breaking them down and then focusing on the isolated elements. This paradigm, which assumes that problems are limited and well defined, is no more useful to face complex systems.

Sustainable development is an issue of complex evolving systems. Dealing with sustainable development requires moves across the boundaries of different branches of science and humanities. A shift of paradigm from fragmentation in science to holism is required. To achieve such a shift, linear and mechanistic thinking must give way to non-linear and organic thinking, more commonly referred to as systems thinking. Systems thinking is a way of understanding reality that emphasizes the relationships among a system's parts, rather than the parts themselves.

Any natural system is run under the control of some balancing mechanisms, negative feedback loops, or *Viability Loops*, as they are called in this thesis. The role of these viability loops is to keep the system working everlastingly. Viability loops are critical balancing loops in dynamic systems that keep the system in balance by checking uncontrolled growth or decline. Usually, delays due to learning time, information flow and its distortion, misunderstanding of the concept of sustainable development, and high costs cause the viability loops to malfunction.

To give a practical meaning to sustainable development – regarding the terminology of the system dynamics approach – the idea of viability loops is adopted to indicate that sustainable development is a process in which the viability loops are kept healthy and functional. Thus, planning for a sustainable development would be to identify the viability loops in the system, and to direct efforts towards keeping these loops in a healthy state.

Therefore, if we base our analysis on a holistic vision of human and natural interactions, heterogeneity, and uncertainty, we arrive at the conclusion that to be able to deal with sustainable development, we need to acknowledge the following essential system properties: Bounded rationality, limited certainty, limited predictability, indeterminate causality, and evolutionary change.

In contrast to some other views that see sustainability as an end-state for systems, which should be grasped, the thesis argues that sustainability is a value which is continuously evolving. It is not a goal in its traditional sense, but it is an ideal towards which we strive to move; however, it is not fully achievable.

The ideal of sustainability is underpinned by both physical rules, which govern nature, and moral values, which are initiated from the normative level of our society. Therefore, as we understand more about the real world and as our ethical values evolve, the ideal of sustainability will evolve too. That makes it a dynamic moving target.

Sustainable development, hence, is a process to help us perceive and adapt to changes in our environment and provide a variety of options and opportunities for our descendants to enable them to meet their own needs. This process will promote the mechanism of learning to both understand and adapt to changes and also will encourage innovations to create opportunities for the next generations to have new resources. In this term, sustainability embraces the concept of evolutionary; thus, it is regarded as an evolving ideal in systems with no end known in advance.

To address the issue of sustainable development, we have to move beyond the classical science to come to more integrated inter-disciplinary areas and rely upon possible assumptions, instead of probable forecasts, to get prepared for our future. To develop our worldviews we need to improve our understanding of the real world as well as the value system of our society.

In this thesis, the principles of The Natural Step, which are grounded in the laws of thermodynamics to address the physical part of nature, and the system orientors suggested by Bossel – as the principles addressing moral values – are adapted to come up with principles of sustainable development for water resources systems.

Although water has economic attitudes and it is also concerned as one of the essential human needs and/or human rights, the thesis argues that water is a means of sustainable development.

A system dynamics approach is considered as an appropriate tool – but of course not the only one – to deal with sustainability. Using a system dynamics approach and its graphic tool of causal loop diagram analysis, the thesis showed that the health status of viability loops in systems can be regarded as indicators of their sustainability.

Due to the process nature of sustainable development, it does not make sense to talk about its measuring in terms of static indicators associated with the state or performance of a system. Rather, systems should be monitored for sustainable development by the means of dynamic indicators associated with the process. Monitoring indicators should address the basic system questions upon which the viability loops are constructed. The outputs of the monitoring process should lead to development of policies and decisions serving to activate or enhance hampered viability loops. The monitoring process should also be a part of a learning mechanism which eventually results in deep understanding of and improvement in our decision rules and worldview.

Using the suggested framework in the thesis to monitor systems for sustainable development, the thesis showed that a set of theoretically anticipated viability loops, in the form of a market-technology balancing mechanism to keep the system sustainable via the signals coming from scarcity of water resources and also increase in wastewater generation, which result in increase in costs of water services, do not function in practice. They are hampered by lack of information and by friction caused by the required response time and the time needed for technology to adapt to evolving market conditions.

Investigating the viability loops in the urban water system of Tehran, the thesis showed that the flows of informative signals are lacking. Adopting the process indicators, we can see the gaps between the public perceptions of water abundance, the costs of water provision and energy utilizations, and what is going on in the reality have been getting wider. This indicates that the viability loops are not functional enough to come to effective changes to offset the reinforcing mechanisms. The sustainable development of the system is conquered due to the persistence of those reinforcing mechanisms.

Contrary to conventional planning approaches, the thesis argues that planning for sustainable development implies focus on processes, instead of on fixed goals. It advocates the use of new generation of backcasting, which involves all stakeholders as well as planners in the process of envisioning a desired sustainable future and to implement practices to navigate towards it. This is suggested to be the most suitable approach to achieve sustainable development of a system.

The process of social learning is recognized as the most important process which will make a system evolve. The public participation in the process is also essential. To this end, backcasting is recommended as a suitable tool, and model building is regarded as a means to promote the learning process rather than a means of forecasting.

SUGGESTED TOPICS FOR FUTURE RESEARCHES

1. Investigating different case studies to search for dynamic mechanisms and viability loops in different water resources systems.
2. Looking for practical action plans to implement strategies of sustainable development.
3. Analyzing other public utilities systems other than water sector to investigate their issue of sustainable development and to suggest relevant strategies.
4. Coming up with integrated strategies and action plans in different cases for urban and regional planning and management in accordance with sustainable development of different sectors.
5. Social learning and adaptation to environmental changes for sustainable development.
6. Revising water resources development plans using a process-based approach in accordance with the issue of sustainable development.
7. Investigating policies and methods to promote evolvement of sustainability as a value based on the process of social learning.
8. Implementing the process of strategy and policy making for sustainable development in a pilot scale, particularly in water resources systems.
9. Comparing and analyzing experiences for implementation of sustainable development in different countries and regions.
10. Re-organizing water governance systems regarding the issue of sustainable development applying a process-based oriented paradigm.
11. Investigating barriers in the process of social learning for sustainable development in different areas and case studies.
12. Evaluating water resources systems for sustainable development due to their vulnerability to global environmental change.

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Appendix. ARTICLES

The following papers are covered within the thesis:

I. Hjorth, Peder; Bagheri, Ali; (2006), ***Navigating towards sustainable development: A system dynamics approach***, *Futures*, *38(1)*, 74-92.

II. Bagheri, Ali; Hjorth, Peder; (2006), ***Sustainable development: Concepts & principles, application to water resources systems***, *Journal of Environmental Policy & Planning* (under review).

III. Bagheri, Ali; Hjorth, Peder; (2006), ***Monitoring for sustainable development: A systemic framework.*** *International Journal of Sustainable Development* (accepted).

IV. Bagheri, Ali; Hjorth, Peder; (2006). ***A framework for process indicators to monitor for sustainable development: Practice to an urban water system.*** *Environment, Development and Sustainability* (in press).

V. Bagheri, Ali; Hjorth, Peder; (2006). ***Planning for sustainable development: A paradigm shift towards a process-based approach.*** *Sustainable Development* (under review).