Etiology Study of Diarrhea in Children
A Study Case in Casco Urbano Honduras

A System Dynamics Approach for Policy Development

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Abstract

Diarrhea has been a major contributor for infant morbidity and infant mortality in developing countries, Honduras with no exception. This paper explores a case study on the illness rate of diarrhea in children in a rural community in Honduras called Casco Urbano. The purpose of this thesis is to explore the different possible causes of this problem in this specific community and search for feasible policies that can be implemented. The method used in this paper is the System Dynamics methodology by building a model that intends to reproduce the problematic behavior. The structure and behavior of the model was used to explore the feedbacks between the water quality, hygienic habit adoption and prevalence of the disease in respect with the illness rate of diarrhea in children from the community. The System Dynamics method facilitated the policy design to improve the problem in hand. The policies included adjustment of water fee and reinforcing hygienic habits which resulted to be a helpful insight in how the situation could improve. This model and paper however do not intend to solve the diarrhea illness rate in this community. It can use as an insight of feedbacks that might not be considered presently.

Key Words: Diarrhea, illness rate, System Dynamics, model, simulation, feedback, policy design, Honduras.

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1. Introduction

Diarrhea has been a major cause of mortality and morbidity in children all over the world. In spite of the great efforts being done to reduce morbidity, results have been poor [1]and the prevalence of diarrhea seems to keep elevating especially in developing countries such as Honduras.

Reports in Honduras, even when are incomplete of data still point that one of four children die from diarrhea[2]. The insufficient water coverage and poor water quality are factors that add to the morbidity of this disease, especially in children. Rural areas are the leading targets for a high prevalence of diarrhea in children because there is even less coverage of water. Casco Urbano, a small rural community in the eastern part of Honduras currently faces a high illness rate of diarrhea amongst children. The causes for this problem and possible solutions will be discussed in later chapters.

This first chapter explains the definition of diarrhea, its causes and the ways of prevention.

1.1 Diarrhea

Diarrhea is the one of the main causes for morbidity and infant mortality in developing countries, including Honduras. In 1998, The World Health Organization reported that diarrhea killed about 2.2 million people, to who most were infants under 5 years old. Each year, there are about 4 billion cases of diarrhea worldwide (WHO 2009). In 2009, 181853 cases per 10,000 habitants were reported and in 2010, 190574 cases were reported per 10,000 habitants in Honduras[3].

Diarrhea is the passage of loose or liquid stools more frequently than normal in an individual. It is a major symptom of gastrointestinal infection. Depending on the kind of infection diarrhea can be watery in cholera for example or passed with blood like in dysentery. This kind of infection can last from days to weeks. Persistent diarrhea can develop into a severe diarrhea case where there is much fluid loss, becoming very dangerous for the individual. Infants and young children are more vulnerable to this disease than adults. Diarrhea is also correlated with other infections such as malaria and measles WHO (2009).

1.2 Causes of Diarrhea

Diarrhea is an infection caused by a host of bacterial, viral and parasitic organisms which can be found and spread by contaminated water. This kind of infection becomes more common when there are poor sources of clean drinking water[4]. The lack of hygienic habits while cooking and cleaning is very important for the prevention of it.

Water used for domestic purposes that is contaminated with feces from humans or animals contains microorganisms that can cause diarrhea. It can also be spread from person to person due to poor personal hygiene. Food can also be a source of diarrhea. If the food has been irrigated with contaminated water or animals like fish that can live in contaminated waters can carry bacteria that causes diarrhea. (WHO 2009)

1.3 Preventive Action

The morbidity of diarrhea can reduced through the following preventive actions[5]:

- Constant access to safe drinking water
- Improve sanitation
- Improve sanitation and hygienic habits
- Health and hygiene education

Treatment for diarrhea includes (Bardales, Garcia 1991):

- Avoiding dehydration by drinking more fluids than usual, making sure that the fluids is not contaminated.
- Oral rehydration salt solutions
- Continuous feeding of healthy foods
- Consulting the nearest health worker

2. Literature Review

The different studies made in Honduras on diarrhea are found in this section. The current situation of diarrhea in Honduras is also presented. The use of System Dynamics is explained later in the chapter. The different researches done in different topics in the System Dynamics that were of interest and use in this paper are mentioned as well.

2.1 Diarrhea in Honduras

The study of diarrhea in Honduras has been going since the 1980s. The access to these studies can be very difficult since most of them are not available to the public. Most of the studies that have been done have not been digitalized making the access to them even harder. There are some papers that have open for public use and those have been used in this paper.

In 1983 a study was done by three doctors that worked in the public health sector of Honduras. Their purpose was to make an in in-depth research on the etiology of diarrhea in children from the age of 0 to 5 years old in the course time of 11 months. Their study had the purpose to study the bacteriological aspect of the diarrhea and its main causes. The research presented very important findings. 10%-20% of children who have diarrhea die before the age of 5. In most of the diarrhea cases studied by Nimer (1983), there was fecal material found in the water the children were exposed to.

Another study was then made in 1990. This research study focused on the study of the illness rate of diarrhea in three communities from Honduras for one year. Two of the communities were rural communities outside Tegucigalpa, the capital of Honduras. The third one was a marginal neighborhood in the city. The nutrition of the children, source of water, use of latrine and social economic level were taken into account by Figueroa (1990).

The illness rate presented to be higher in the communities where there was a doubtful source of water. In one of the rural areas, people would take water from the nearest river without disinfecting the water. The cases of diarrhea were more common in the communities with no usage of latrine. The overall conclusion of the study is that the illness rate in children was higher in communities where there was a suspicious source of water and poor practice of hygienic and sanitation habits. (Figueroa 1990)

2.2 Water Supply and Sanitation Coverage in Honduras

Water supply and sanitation coverage in Honduras has been improving throughout the years. Most urban areas have access to water and sanitation systems. Many rural areas in the country however, have still no access to a water system with running water. It is difficult to know the exact coverage of water and sanitation systems throughout the country, due to the mismatch of information from different sources[6]. In 2001 a survey was conducted by the Entity of Statistics in Honduras [7]reporting that Honduras had reached 80% water coverage of its population, 70% of the people in the country live in rural areas. These figures are much higher than what the World Health Organization has reported in 2006 through the Joint Monitoring Program. Their data reported 46% coverage in urban areas and a 54% in rural areas [8.] Figure 1 shows the Map of Sanitation Coverage in Honduras (ERSAPS 2006).

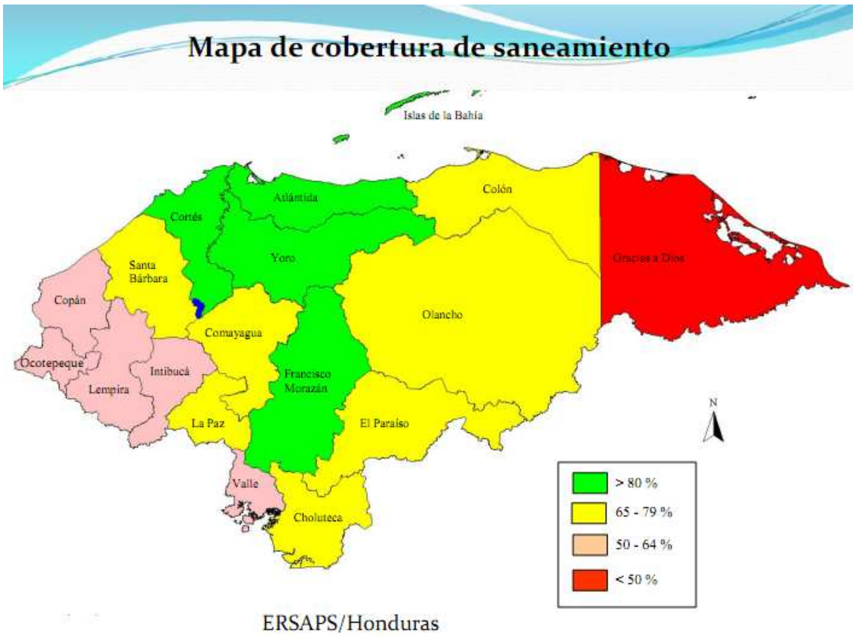

Figure 1 Map of Sanitation Coverage Honduras 2010

2.3 Quality of Water in Honduras

In spite of the improvement in the distribution of the water, the quality of such is not being prioritized. The same study made in 2001 indicating the coverage of water in Honduras also revealed that the water quantity and quality are not adequate to the required standards of the Ministry of Health in Honduras (ERSAPS 2006). It suggests that the existing infrastructure is a serious health risk to citizens. An astounding 90% of the water supply is contaminated and unreliable. The same study found that 44% of the water provided is effectively disinfected and that there is a lack of adequate and constant water quality control and monitoring, especially in rural areas. (ERSAPS 2006)

2.4 Water Related Diseases and Sanitation in Honduras

Water related diseases have been the main cause of morbidity and the primary cause of infant mortality in Honduras. Both the lack of access to water and the poor quality of it are the main causes to water related diseases. The inadequate handle of excrete waste and bad water treatment has been the main contributors in the illness rate of diseases such as diarrhea which has been the main cause of morbidity and second cause of infant mortality in the country[9].The Secretary of Health has made several efforts to help improve the infant mortality and morbidity. Despite of their efforts, the most common water related diseases are Diarrhea, Dysentery, Hepatitis A and Cholera (Secretary of Health 2011).

2.5 Responsibility for water and sanitation in Honduras

2.5.1 SANAA

Sanaa is the National Autonomous Water and Sanitation Service. It is a government funded institution created in 1961. Sanaa has been in charge of planning, constructing, operating and creating policies for water and sanitation projects throughout the country. By 1993, Sanaa was operating 42 urban water systems, including Tegucigalpa, La Ceiba, Puerto Cortes, and others. The workload of Sanaa and its lack of capacity to manage all municipalities led to separation of some municipalities to work independently. They requested to have full rights and control of their own water systems, such as San Pedro Sula. It was a slow process due to the resistance of Sanaa. In 2003 the Framework Law completed the process of transfer full control of 32 water systems to their respective municipality.

Although Sanaa is not the main operator, it is still the main executor of water systems and sanitation projects in rural areas of the country. Nowadays, attempts to have special technicians for operation, maintenance, water and sanitation to help and give follow-ups to rural communities. Sanaa does not count with much funding, reducing the use of these technicians and support to rural communities.

2.5.2 Secretary of Health

Secretary of Health in Honduras is responsible for formulating, designing, controlling and to evaluate norms, policies, plans and national programs related to health. They are also in charge of promoting a culture of healthy life with adequate living habits as well as intervening in matters of risk and collective damage to the health of the citizens. The Secretary of Health is suppose to be involved in water and sanitation regulations, solid waste management, vaccination campaigns and encouraging hygienic practices. They have established different strategies to reduce infant mortality. Due to the lack of resources, any work or support becomes very limited.

2.5.3 Municipalities

There are several municipalities around the country that are in charge entirely of their water system. This means that they are in charge of the distribution and quality of the water to the communities that are part of that municipality. Each municipality has the responsibility of planning, developing and operating the water and sanitation system.

2.5.4 Water Boards

By law, communities are proper owners of their water systems. In rural communities water systems are under the responsibility and control of the Juntas Administradoras de Agua or Water Boards. There are about 5000 water boards in the rural areas of Honduras. These water boards are consisted of members of the same community. The water boards have the legal obligation of serve the adequate water services to the community assuring that people receive constant and clean water. The water board is in charge of charging a right water fee in order to keep it running and cover for maintenance expenses. This water fee is a crucial part of keeping a sustainable water system. However, the water board must consider the average income in the community making sure they do not set a fee that people cannot pay. The water board is also responsible for the protection of the water source[10].

2.5.5 Sanitation Committee

A Sanitation Committee must be formed from other members of the community with the purpose of supporting the Water Board with education to the users. The sanitation committee must educate people in the following topics:

- Good hygienic habits at home such as washing their hands
- Proper use of the latrine
- Importance of protection of the water source for the community
- The form of water disinfection used
- The importance of paying an adequate water fee
- The benefits of clean drinking water
- The consequences of infected drinking water
- Ways of avoiding contamination of water

Each community determines how each committee will operate according to the needs in the community.

Both the Water Board and the Sanitation Committee are volunteers from inside the communities. Therefore, they do not receive a salary for the work they do.

2.6 System Dynamics Approach

System Dynamics has been used before to approach infectious diseases and epidemics. The AIDS model in Tanzania (Heindenberger 1992) is an example of the use of System Dynamics to build a model for policy design. This model as many others have used a generic structure for modeling infectious diseases.

Sterman (2000) presents a generic structure for modeling diseases. The generic structure for modeling an infectious disease is the SIR. The SIR stands for S for susceptible, I for infectious and R for recovery. The SIR model captures the basic process of the infection. It also does not account for births, deaths or migration.

Pruyt (2009) adapted the SIR structure to model a cholera outbreak in Zimbabwe. This cholera model suggests a loss of that susceptible get infected with cholera. Then once they are infected, the sickness can be mildly or heavily infected. At some point people recover. Pruyt (2009) suggests that the recovered become susceptible due to immunity loss. This new adaptation of the SIR model can be implemented to modeling diarrhea giving that diarrhea behaves in the similar way.

As mentioned before, the information people obtain from the causes and ways of preventing diarrhea are crucial for taking control of an outburst. The adoption of information is important for the diarrhea illness rate. The Replacement Purchases model uses the Bass diffusion model adding a discard flow from Adopters to Potential Adopters (Sterman 2000). This model suggests that the Adoption Rate be influenced by word of mouth and adoption for advertising. The model in this paper adapts the Replacement Purchase model (Sterman 2000) in order to have potential adopters becoming adopters and adopters becoming potential adopters to diffuse information.

The aging chain from Sterman (2000) is of interest for this paper. Forrester's (1969) uses aging chain for three different components of a city in Urban Dynamics. This paper adopts Forrester's (1969) aging chain for different parts of the elements that contribute to the illness rate. The aging chain can also be seen in Butler and Mat (2000) application of aging chain to model population in different age groups. The model used by Butler and Mat (2000) is also adapted in this paper for the modeling of the population.

3. Case Study

This chapter refers to the case study this paper is presenting. The case study is described from the field work done, background, problem statement and hypothesis.

3.1 Field Research

In order to elaborate this study paper field research had to be done. The municipality of Chinda and its corresponding communities were visited for a time of 6 six weeks to study the past and current situation in the communities. In these 6 weeks of research most of the communities in Chinda were visited as well as the schools. There were interviews with the water boards and sanitation committees to learn about their work execution and how they are planning to keep the water system running properly. The research was also intended to recognize the main health problems in the community, which in this case it was diarrhea in children. The field work revealed the many weaknesses in the water boards. Weaknesses were also found in the sanitation committees and the municipality authorities had. One of the main problems in these communities is that the Health Center keeps little or no track of the number of cases of diarrhea or any other sickness. Nevertheless, much was learned from this research in order to elaborate different hypothesis of why there is many children with diarrhea in the communities.

The following section elaborates the background information of the municipality of Chinda. It also goes into detail on one of the communities that have been chosen for this study.

The appendix section… contains pictures from the field work done in Chinda.

3.2 Background

3.2.1 Chinda Honduras

The study case presented in this paper is inspired from a municipality called Chinda, located on the western part of Honduras. Chinda is a small municipality located in the department of Santa Barbara, Honduras. The area of Chinda consists of fourteen rural communities with a population of about 5000 people. Most of the population in Chinda belongs to the Lenca Indians, an ethnic group who farms for a living. This area is well known for growing coffee and grains. The average monthly income is around US 150$, which equals to about 3000.00 Lempiras.

Chinda consists of fourteen communities below:

- Barrio Nuevo
- Casco Urbano
- Cablotal
- El Limon
- El Retiro
- El Tule
- El Zapotal
- La Chuchilla Chol
- La Cueva
- La Majada
- Las Breas
- Platanares
- Rio Cañas
- San Rafael

This small municipality has had a slow development due to lack of infrastructure and damages still seen from the catastrophe of Hurricane Mitch in 1999.The location of this municipality contributes to the slow development of the communities. The access to Chinda is very limited. In summer days or good weather, one can access the communities in four wheel drive vehicles. In rainy season, roads become difficult to drive in and in some cases the roads are completely washed away.

3.2.1 Water and Sanitation in Chinda

Before 2007, no community in Chinda had any infrastructure for the distribution of water. The source of water came from carrying water in buckets from the Ulua River which crosses most of the communities in Chinda. The Ulua River is one of the largest rivers in the country and it crosses most of the western part of Honduras. This river has been and still is the main source of water for Chinda.

In 2007 a non government organization called Water for People or WFP came to Chinda. This NGO is a worldwide organization that helps communities such as Chinda to obtain an infrastructure for water distribution. The municipality of Chinda has now 95% water and sanitation coverage[11]. Water for people with collaboration with the communities had the goal of improving the water and sanitation coverage from the communities. WFP provided support to develop the technical design for the water and sanitation systems. They also included a hygiene education program within the communities with the purpose of training the water committees in charge and the users as well. The communities now have infrastructure for water distribution and each home has latrine. The water board and sanitation committee have been trained by WFP how to manage the water system. They have also been trained on the information that needs to be reinforced to the people of the communities.

3.3 Casco Urbano

The case study presented in this paper will specifically study one of the communities from Chinda. This community is called Casco Urbano. Casco Urbano is the biggest community in Chinda. Its population in 2010 was about 1300 people. The situation in the community of Casco Urbano is very similar to the situation in the other thirteen communities in Chinda. This community was chosen out of the 13 because in the field study done for this paper, this was the community that was mostly visited and interacted with.

3.3.1 Water Board and Sanitation Committee in Casco Urbano

The community of Casco Urbano has had a water board and sanitation committee since 2008. The project of Casco Urbano did not start running until 2009. However, during the time that the system was being built the water board and sanitation committee were being trained by WFP. The trainings for the board and committee were targeted to teach them the use of the water infrastructure that was being built, the proper maintenance it required and the collaboration of the community. An important part of this training was the calculation of the water fee. The community would pay a fixed fee in order to cover for the expenses required to keep the system running and distribute clean water. Their job now is to make sure they are charging the adequate fee and to encourage people to pay it. The sanitation committee has most of the responsibility of encouraging people to pay. They also have other tasks to promote hygienic and sanitation habits in the community.

3.3.2 Hygiene and Sanitation in Casco Urbano

Part of the field work done for this paper was to observe the hygienic and sanitation habits in the communities. Before the help of Water for People, there were little or no latrines in the community. This means that people would defecate out in the open. The few latrines in the community were in the school or in some homes.

When WFP came to this community there was also poor practice of washing hands. Some people knew the importance of washing their hands, however didn’t practice it. Children at school were taught of the importance of washing their hands. But, the lack of running water in the school toilets and the poor implementation of habits at home made it difficult for children to enhance this important habit.

Now in 2011, the school in the community and most of the homes has access to running water. The sanitation committee in Casco Urbano has set a plan of visiting homes on a regular basis in order to remind people of the importance of hygienic practices. They have elaborated a plan of how to teach people of sanitation habits and the benefits. The pictures of the sanitation committee can be seen in the appendix…

3.3.3 Quality of Water in Casco Urbano

A running water system, as mentioned before, does not ensure the quality of the water if the water is not treated properly. Figure 2 shows the results of water test qualities made in 2007 and 2010 funded by Water For People. Nevertheless, even with a system in place, water supply is not continuous and the quality of the water is poor due to the inadequate disinfections. As a result, most of the people in Chinda do not have reliable drinking water.

Water Quality Results Casco Urbano				
No	Parameters	2009	2010	Permissible
1	pH	7,22	7,27	6,5 - 8,5
2	Color	17	81,06	1,0 - 15
3	Turbidity	4,16	91,8	1,0 - 5
4	Alkalinity	42	26,79	
5	Hardness	44	32,5	400,00
6	Coliform (total)	12033	2800	0,00
7	Coliform (fecal)	121	1100	0,00

Figure 2 Water Quality Test Results Casco Urbano

3.3.4 Health in Casco Urbano

In the research done for this paper, the Health Center of the Casco Urbano was visited. The health center had a staff of 4 women whom which 3 were available in most visits. They were asked for the records of different sickness such as diarrhea and dengue. They claimed to have them but no records were ever shown. They did however, comment on the high illness rate of diarrhea in children. Even though they did not keep or want to show the records of the cases they have recorded, they did confirm there was a problem with diarrhea in children in the community.

4. Problem Definition

Casco Urbano is a rural community that has had no access to clean and running water until recently in 2009. When an NGO came to this community there was no infrastructure for water distribution. People had little or no knowledge of hygienic habits. There had been a considerable number of diarrhea cases in Casco Urbano for a long time. It is very difficult to know the precise numbers of cases because the Health Center in this community keeps poor records of the cases.

By 2009 Casco Urbano had a new pipe infrastructure connected from a source of water to tank storage and finally connected to each home in the community. A water board was formed to take control of the water system. A sanitation committee was also formed to reinforce important habits to the people in Casco Urbano. Both the board and the sanitation committee received several trainings from WFP about the way the new infrastructure functioned, how to give it maintenance, calculating costs and adequate tariffs, how to disinfect the water properly, and what are the important hygienic and sanitation habits people must acquire to keep this system going.

After 2 years of having a new water distribution infrastructure and implementing education to the community, they seem to still have a problem with sick children, specifically with diarrhea. There is a high incidence of the diarrhea cases in Casco Urbano. After the efforts of installing a new water distribution infrastructure and implementing educational programs there are still many children getting sick per week from diarrhea and which in some cases, these cases lead to death.

4.1 Reference Mode

The graph on figure 3 represents the reference mode used in this paper. The reference mode is the problem represented in a time graph that shows the development of the problem over time. The reference mode in this case is the number of cases of diarrhea that are occurring per week in the community of Casco Urbano.

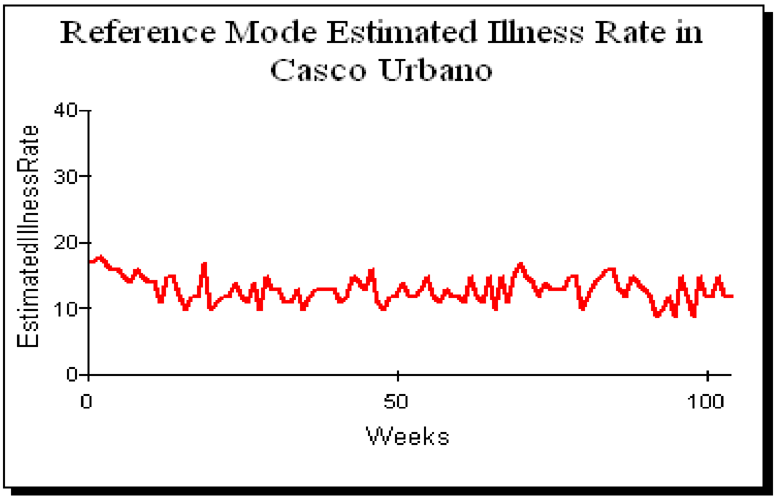

Figure 3 Reference Mode Estimated Illness Rate Casco Urbano

Figure 3 shows the reference mode. The values used in the reference mode are values estimated from the Health Department data base and they are referred to as *EstimatedIllnessRate*. The *EstimatedIllnessRate* represent the number of cases per week in Casco Urbano. The reference mode goes from 0 to 104 weeks, which is from 2009 to 2010 (Secretaria de Salud 2011). The community of Casco Urbano keeps no record of the diarrhea cases. However, there is a diarrhea problem and the community is aware. For the purposes of this study the data estimated from the Health Department data is the only available.

5. Dynamic Hypotheses

There are different hypotheses to explain the problem of the illness rate of diarrhea cases in infants in the rural community of Casco Urbano. A description of the different hypothesis is first presented. A causal loop diagram is then presented to illustrate the hypothesis and the different feedbacks in how they are assumed to affect the infection rate.

The research question for this paper is:

What is causing the illness rate of diarrhea cases on infants in Casco Urbano?

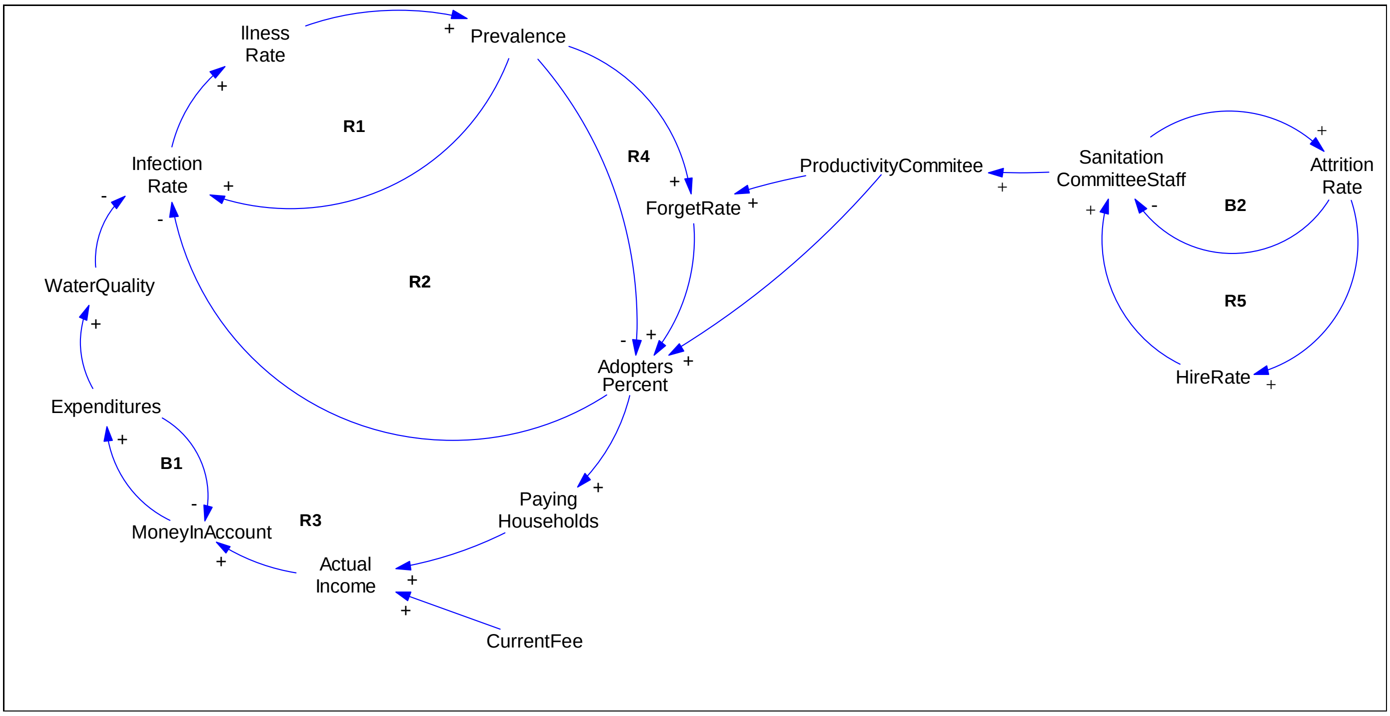

Figure 4 Hypotheses Causal Loop Diagram

Figure 4 illustrates the causal loop diagram that represents the dynamic hypotheses that are proposed in this paper. Each hypothesis will be explained below.

H1: The prevalence of the illness increases the infection rate.

Diarrhea is a kind of disease that is transmitted through a fecal-oral route (WHO 2009). The fecal-oral route is a form of transmission in which bacteria or germs in fecal particles from one host are introduced into the cavity of another potential host.

When children are sick and use the latrines at school or at home, they leave the bacteria that induces diarrhea in the stool of the latrine. If they do not wash their hands, the bacteria are left in the objects they are in contact with. This means that the more prevalence of diarrhea there is the more children are bound to get infected.

Loop R1 in figure 4 can illustrate this hypothesis in the system. As the *InfectionRate* increases, the *IllnessRate* increases. When there is more children sick with diarrhea, they expose others to become infected as well. In other words when the *IllnessRate*, increases the *Prevalence* increases, which will increase the *InfectionRate* even more. This kind of behavior creates a reinforcing feedback. In this case, this kind of positive feedback is only enlarging the problem of diarrhea in children.

H2: The lack of adoption of hygienic and sanitation habits increases the infection rate.

Diarrhea is not only caused by drinking contaminated water or prevalence, but also the lack of hygiene. The lack of hygienic and sanitation practices, especially hand washing with soap, is a major contributor to diarrhea infection rate (WHO2009). An estimated 88% of diarrhea cases worldwide are attributed to unsafe drinking water and poor hygienic and sanitation habits.[12]

The enforcing of hygienic practices in Casco Urbano has been much stronger after the infrastructure for water distribution was installed. But as the proverb says, “old habits die hard”, the community of Casco Urbano is still lagging behind the implementation of hygienic and sanitation habits in their daily life. Even though they have received talks and training on the importance of such habits, the infection rate of diarrhea in the community does not decrease.

The practice of the adequate hygienic and sanitation habits will also help improve the quality of the water. People in the community would be more aware of the importance of the quality of the water, contributing to the necessary means to obtain clean and running water.

R2 in figure 4 is the reinforcing loop that represents this hypothesis. The *AdoptersPercent* depends on the *ProductivityCommittee* which is the productivity of the sanitation committee and the Prevalence. It is assumed that if the *Prevalence* is increasing, there are more people not adopting the proper habits. The less adopters there are, the more probabilities there are of children becoming infected. The adults are the potential adopters in this case. This again would increase the *IllnessRate*.

H3: The infection rate for diarrhea increases when the drinking water is contaminated.

Cases of diarrhea in children in rural communities where there is a piping system have an average of 4% of sick children per week. Rural Communities with doubtful sources of water can have up to 30% of sick children per week. However, if the water received from a piped system is not disinfected properly, the incidence in the cases of diarrhea tends to increase (Figueroa 1990).

Casco Urbano has an infrastructure for the distribution of drinking water. Children in the community are still getting sick nevertheless due to the poor disinfection of the water. The water that is being reached to the homes is contaminated, affecting the children’s’ health by causing diarrhea.

The method to disinfect water used in Casco Urbano is adding Clorox to the water. It seems however, that the water is not being properly disinfected, causing illness rate of diarrhea to increase.

R3 is the reinforcing loop for the third hypothesis in figure 4. When the productivity of the committee is good, then that encourages people to pay their water fee. If the water board has enough money from the money collected from the water fee being paid, then they can repair and disinfect the water properly. When the water is disinfected properly that would decrease the *InfectionRate.* As an effect, the *IllnessRate* would go down.

5.1 Model Assumptions

The model has been designed and simulated under different assumptions. There are six sectors in the model with different assumptions in each one. The Time for the model is measured in weeks. The number of cases used as the reference mode used in this paper are the estimated results from 2009 and 2010, adding up to a total of 104 weeks or 2 years. The other assumptions have been grouped according to the sector they influence. The assumptions for each sector are described below.

5.2 Population Sector

The community that is being studied is called Casco Urbano, located in the department of Santa Barbara, Honduras. This small rural community is part of the municipality of Chinda, Santa Barbara. The population is divided into three stages. Figure 5 shows the age groups and their population respectively. The *BirthRate* is estimated to be 3%.[13]

Variable Name	Population
TotalSusceptibMaturationRate	550
PopulationInFormerHouseholds	370
AdultPopulationInNewHouseholds	400
CommunityPopulation	**1320**

Figure 5 Population Casco Urbano 2009 (WFP2011)

The *AgeOfNon_Susceptible* is the age of the study group taken in this study. For this purpose it has been assumed to be 15. That means that children from 0 to 15 years are being taken as susceptible.

The *AgeOfMarrying* is the age assumed that people marry or form new homes. This is assumed at the age of 25 years. The *Life_Time* is considered to be 70 years old. (INE2011)

It is assumed that the *PersonsPerHousehold* is 6 people. This is an average number of people per home in rural areas of the country (INE 2011).

5.3 Illness Sector

The disease of diarrhea on the susceptible children was divided into three stages. In each stage children con recover, continue being sick or die from it. The first stage the *Max_DurationOfDisease_1* is the maximum time for a child to be sick during the first stage. This is assumed to be 1 week. The mortality rate called *Mortality_1* in stage one is 2%.The second stage was children who were sick for a longer time. The *Max_DurationOfDisease_2* for stage 2 is considered to be 2.5 weeks. The mortality rate or *Mortality_2* is 4%. In the third stage the *Max_DurationOfDisease_3* is assumed to be 10 weeks. *Mortality_3* is estimated to be 10%.

The maximum time for a child to loss immunity is in the third stage. *TimeToLe_Imm_3* is the time of immunity loss in the third stage and it is 34 weeks. *TimeToLose_Imm_2* is half of *TimeToLose_Imm_3* and *TimeToLose_Imm_1* is half of *TimeToLose_Imm_2.*

The probability of children to recover or the *Prob_Recovery_1* in stage one is assumed to be 70%. In stage two the probability to recover or *Prob_Recovery_2* is 50%.

These assumptions were taken from the study made by Figueroa (1990) on child diarrhea in Honduras.

5.4 Sanitation Committee

The *SanitationCommitteStaff* is the stock that represents the staff in the sanitation committee. It is initially consisting of 5 people. As mentioned before, the sanitation committee has the responsibility of visiting each home to teach and reinforce hygienic and sanitation habits and the importance of maintaining a sustainable water system. Each member has the goal of visiting 5 different homes per week and this is referred to as *ProductivityPerStaffMemeberPerWeek.* The *MinimumVisitsPerHomePerYear* every home should get is 10 visits per year by a staff member. The water boards of Casco Urbano and its sanitation committee have predetermined this kind of workload according to the availability of the sanitation committee. It is important to remember that neither the sanitation committee nor the water board receive a salary. This work is voluntary from the same people in the community. Therefore, they adjust to the time the members have available. They also agree the *WorkWeeks* will 45 weeks a year. *AdjustmentTimeStaff* is considered to be 12 weeks. The *AttritionTime* is the estimated time a staff member serves the sanitation committee. This *AttritionTime* is assumed to be 1.5 years or 78 weeks.

5.5 Adoption Sector

The sanitation committee visits a number of homes per week. These people visited become adopters of important information for maintaining the water system and its benefits. It is presumed that there is an additional word of mouth effect with a contact rate of people per person. The *ContactRate* is the number of people that is estimated for each member of the community will share information on sanitation habits with. This contact rate is estimated to be 3 people per person. The *AdoptionRate* is the person's persuasiveness to induce the people he or she has contact with about adopting healthy habits. In this case the *AdoptionRate* is considered to be 0.001

5.6 Income and Expenditure Sector

The community has different expenses in order to provide clean water to the inhabitants. There are fixed expenses and expenses that change depending on the needs for reparation. *TotalFixedCost* include expenses such as 600 Lempiras for the *PlumberPayment*. This is a fixed salary that has been previously agreed with the plumber and the water board. Other costs have been estimated beforehand. *AdministrativeCosts* are set to be 300 Lempiras, *TravelExpenses* are about 300, and a *Maintanace* budget is set for 600 Lempiras. The cost for the purchase of Clorox is the *DesiredWeeklyExpendituresForClorox.* This is the amount of money per week that the community should be spending in order to be disinfecting the water efficiently. The *DesiredWeeklyExpendituresForClorox* is calculated from a test to measure how fast the tank fills up from the pipes that come from the source of water by filling measuring the time it takes to fill up a 5 gallon bucket in the tank. This test has been done previously determining a value. The *TimeToFillBucket* is 3 seconds. According to this value a table determines the flow of water into the tank or the *FlowOfWaterToTank.* The flow then determines the amount of Clorox required every 4 days by another table called *CloroxEvery4Days* which can also be found in the appendix of this paper. The *RequiredClorox* is then the amount of Clorox determined by the table of *CloroxEvery4Days* multiplied times 2 to determine the weekly use. The *PriceCloroxPerLb* is then multiplied by the estimated *CloroxEvery4Days* to determine the *DesiredWeeklyExpendituresForClorox.*

There is also a *SavingsMargin* which is a percentage of the total costs to keep for savings in case of emergencies. The *SavingsMargin* has is 10% of the total costs.

In order to cover all expenses, a goal has been determined for the coverage of the bank account. The *DesiredAccountCoverage* is the coverage of money in weeks the account should have, which is estimated to be 1 week.

5.7 Pipe Sector

The Pipe Sector in this model intends to replicate the way the pipes in the system are reported to be damaged, the process of being ordered, delivered, removing the old pipes and installing the new ones. Pipes can be damaged by accidents such as landslides and cattle herding.

The *FunctionalPipes* are the pipes that the system has. It is initialized in 100 pipes. The pipe system has been designed to last for twenty years. Due to this, the average lifetime of a pipe or the *AvgLifetimePipe* is considered to be twenty years or 1040 weeks.

The plumber in the community is responsible to check on the pipes on a weekly base. If any pipes are found to damaged or obsolete he must report them to the Water Board. The plumber will then report two kinds of pipes, the obsolete pipes and the damaged pipes. The damaged pipes will have priority over the obsolete, since the obsolete can still function. Therefore the time assumed for the *TimeToReportFunctionalPipesDamaged* is 1.5 weeks. The time assumed for the *TimeToReportObsoletePipes* is 4 weeks.

A *FractionOfFunctionalPipesDamaged* has been assumed. This is the fraction of the total number of pipes that are not obsolete that are found to be damaged. This value will change in the different tests done, but for an initial value it is assumed to be 0.001.

The *FractionOfObsoletePipesDamaged* is considered to be 10 times as much as the *FractionOfFunctionalPipesDamage.* This is because the obsolete pipes should have a higher probability of becoming damaged due to their depreciation. After the pipes have been reported, they are then ordered and delivered. The assumed *DeliveryTime* is 1 week.

To replace the pipes that have to be removed for the reason that they are damaged or obsolete the indicated time to do this replacement or the *IndReplacementTime* is 1 week after they have been delivered.

6. Model Description

In this section model will be described in detail. The model built has 6 sectors. The first sector is the Population Sector. This sector has been structured to represent the population of Casco Urbano in three different age groups adopting the aging chain (Sterman 2000). The second sector is the Illness Sector. The third sector is the Sanitation Committee Sector. This sector's structure represents how the sanitation committee manages their staff and how that affects the productivity of the committee. The fourth sector is the Adopters' Sector. This sector follows the main idea of the bass diffusion model presented by Sterman(2000). The fifth sector is the Pipe Sector. The Pipe sector is the structure of the way the water board manages the pipes in the system, from the moment they are reported to when they are ordered and replaced. The sixth sector is the Expenditure Sector. This sector means to reproduce the behavior of the water committee with the way they manage their income and how the expenditures are being done.

A picture of the entire model can be observed in Appendix A of this paper.

6.1 Testing the Model

Sterman (2000) suggest a various number of tests than can be done to a model. Testing the model is the way of gaining confidence in the model. Testing the model cannot be seen as a validation process of such. Testing the model however aims to build confidence in the level of usefulness the model has. It is important to remember that all models are wrong Sterman (2002), but it doesn't mean they are not useful.

6.1.1 Boundary of the model

The model contains the necessary structure that explains recreates the behavior of the real life situation. Additional structure for the policy analysis was added, still within the necessary structure that the problem needs.

6.1.2 Structure Assessment

The model reproduces values that are consistent with real life values. Each equation has been checked to make sure they are not violations of physical laws (Sterman 2000) under different kinds of conditions.

6.1.3 Dimensional Consistency

Each variable has been checked with their respective equation. The unit consistency was part of checking the equations. They have also been checked comparing them to the real life case, making sure that they are concurrent.

6.1.4 Extreme Condition Test

Extreme condition testing was done in several parts of the model before and after policy was added to the structure. In all cases the model was robust, meaning it still behaved in a realistic way. The results for the extreme condition tests done will be presented in the section where they have been done.

6.1.5 Integration Error Test

The simulation in this model uses a very small time step due to the small time measurement being used. It has been tested under higher and lower time steps. The model was not sensitive to the time step that was used.

6.1.6 Sensitivity Analysis

Different parts of the model were tested for sensitivity in different scenarios. The tests show the different responses the model had to the sensitivity test. The results for these tests will be shown in their respective section.

6.1.7 System Improvement Test

The ultimate goal of modeling is to solve a problem Sterman(2000). Different policies were added to the structure of this model in order to try to improve the current situation. The policies are tested and resulted are presented in later sections.

The model in this paper has been tested under many assumptions, conditions and tests suggested by Sterman (2000). These tests give confidence on taking the decision of using the model and how well it replicates the real situation in Casco Urbano in relation to what affects the illness rate of diarrhea in children in the community.

6.2 Population Sector

The population sector in the model intends to show the dynamics in the population growth. There are three stocks divided by age group. The *TotalInfantPopulation* stock is the population the age group between 0-15 years. Children in this stock will become 15 year old teenagers through the *TotalSusceptibMaturationRate* and the *AgeOfNon_Susceptible.* Some children will not survive due to infant mortality and exit the stock through the *Tot_Infant_Mortality_Rate.* It is important to mention that the only cause for infant mortality considered in this paper is due to the diarrhea disease. The *Births* is the inflow to the *TotalInfantPopulation* deriving from the *TotalInfantPopulation* and *BirthRate*.

The children that mature to becoming teenagers are now in the *PopulationInFormerHouseholds.* It is assumed that people on average in rural areas form get married and form new homes at the age of 25 making this transition through the *PopulationEnteringNewHouseholds* and the *AgeOfMarrying.* The new homes are now in the *AdultPopulationInNewHouseholds* stock. The average lifetime for a person in Honduras is 70 years represented by the variable *Life_Time*. These adults will stay in the stock until they reach 70 and exit through the *DeathRate*.

The deaths in each level of age in the population sector are not considered until they are 70 years old. It is important to mention that the the death rates from 15 to 70 irrelevant for this study.

The total population of the community is accumulated in the variable called *CommunityPopulation* where the three population stocks are added. To establish the number of homes or *Households* the *CommunityPopulation* is divided by the *PersonsPerHousehold.* Figure 6 shows the Population structure that has been described in this section.

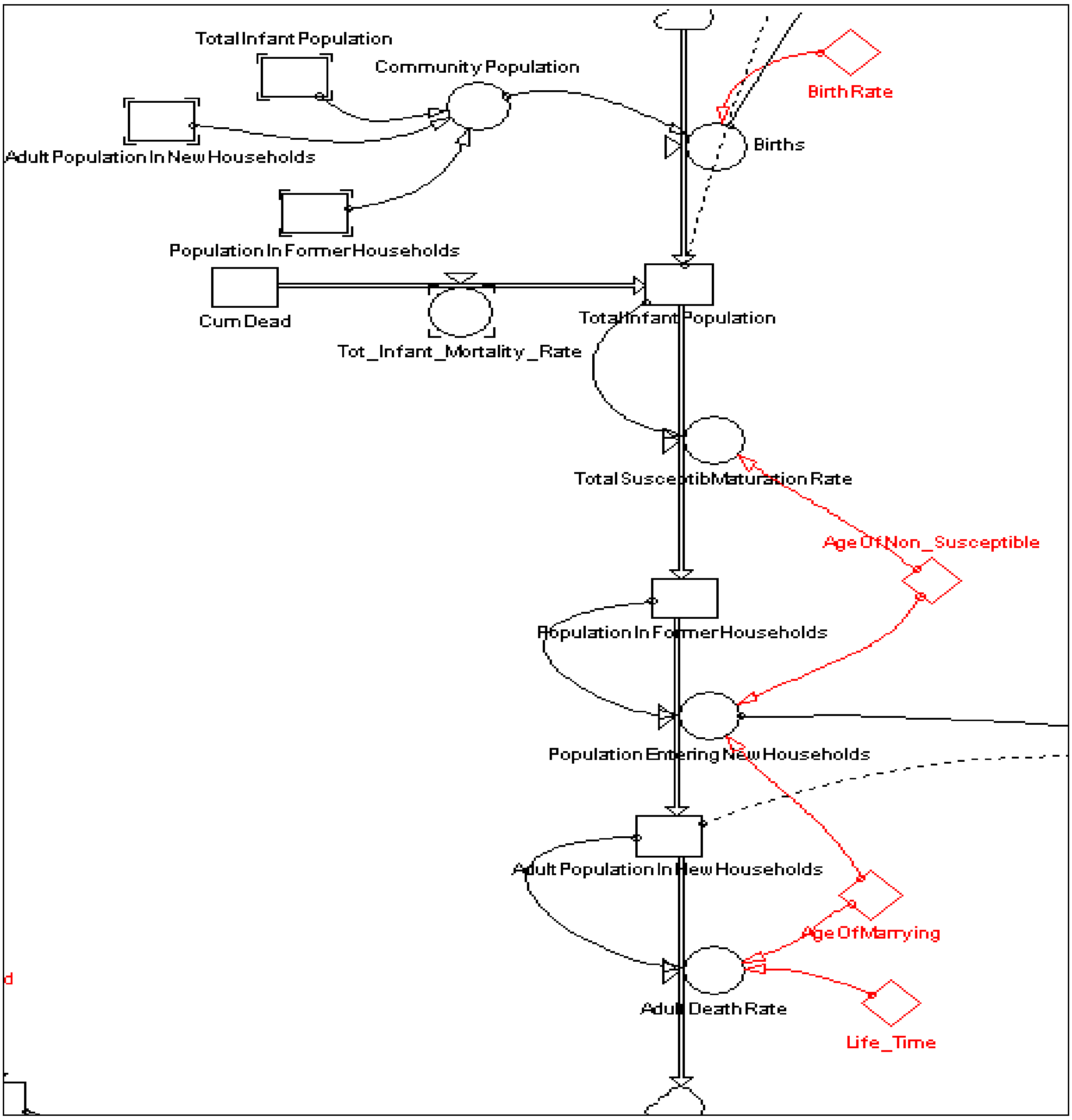

Figure 6 Population Sector Structure

The structure of the population sector has been divided into age groups. The behavior of the population sector is generated by the different reinforcing and balancing loops in it. The causal loop diagram in figure 7 illustrates the different reinforcing loops and balancing loops in the population sector.

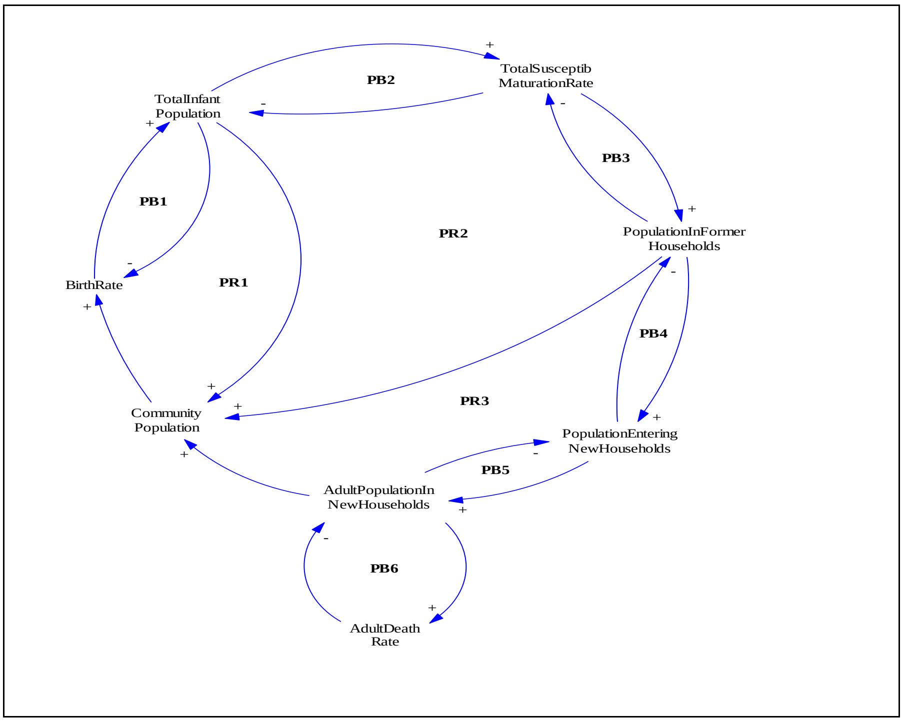

Figure 7 Population Sector Causal Loop Diagram

In the causal loop diagram one can identify the different balancing and reinforcing loops in the Population Sector. The biggest reinforcing loop is the population starting from the *BirthRate* which increases the *TotalInfantPopulation*, increasing the *PopulationInFormerHouseholds*, increasing *AdultPopulationIn New Households,* increasing the *CommunityPopulation* which increases the *BirthRate*.

The negative feedback in the Population Sector is driven by the population moving from one stock to another. For example, when the *TotalInfantPopulation* become 15 they leave that stock to join the *PopulationInFormerHouseholds*, reducing the number of children in the *TotalInfantPopulation.*

The positive and negative feedback in the system create a slow exponential behavior in the population. Figure 8 shows the results of the simulation for the behavior of each age group.

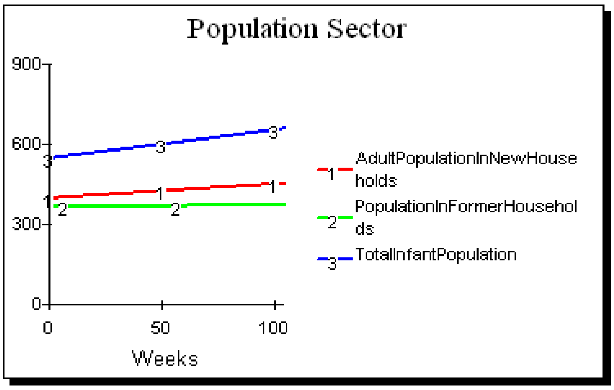

Figure 8 Population Sector by Age Groups Behavior

The graph in figure 8 shows that overall the different age groups have a slow steady growth. The *TotalInfantPopulation* and the *PopulationInFormerHouseholds* show a slower growth compared to the *AdultPopulationInNewHouseholds.* What this means is that in the time of 2 years, the children in the *PopulationInFormerHouseholds*, who are 15, are becoming adults and going into the *AdultPopulationInNewHouseholds.*

The population has increased from less than 1300 people to 1500 people in two years. Figure 9 shows the growth in the community of Casco Urbano.

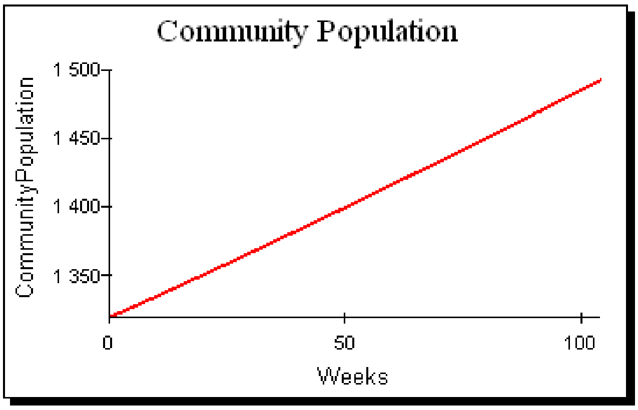

Figure 9 Community Population Behavior

6.3 Illness Sector

As mentioned before, the illness rate of diarrhea has been a problem in this community for some time. The Illness sector is set to explain the dynamics behind the diarrhea cases. This sector of the model goes through the process of children becoming susceptible to diarrhea, the development of the disease, recovering, loss of immunity and becoming susceptible again. It also demonstrates the children that do not become susceptible again because they die from the disease. Diarrhea as an illness for this case study has been divided into three stages of infection and will each be explained. Each stage of the disease has a mortality rate, recovery rate or continuing being sick, by which they would move to the next stage of the disease. By the third stage, the children will either become part of the mortality rate or fully recover. When the children recover they then lose their immunity returning to being part of the susceptible group.

The *Current_Infant_Susceptible_Pop* stock is the population of children that are susceptible to diarrhea. The stock is initialized with the initial *TotalInfantPopulation.* The *Current_Infant_Susceptible_Pop* is the same rate as the *BirthRate.* The *Current_Infant_Susceptible_Pop* has two outflows; the children that are becoming teenagers and do not get sick through the *SusceptibleRetirementRate.* These children do not enter the Illness Sector therefore it is not considered if they sick. The *IllnessRate* accounts for the children that enter the illness dynamic sector. The *IllnessRate* depends on the *InfectionRate.* The *InfectionRate* determines the probability of infection a child has to obtain diarrhea. The *InfectionRate* is determine different effects; *EffOfPrevalenceOnProbOfInfection,* *WaterQualityEffectOnInfectionRate*, and *EffAdoptionOnProbToGetInfected.* These effects will explain in their belonging sectors. There is a minimum infection rate called *Reference_Illness_Probability*.

The first stage *Stage1_IllPopulation* accounts for the children who are sick for one week. *RecoveryRate_1* shows the children that recover in 1 week. Once these children recover they lose their immunity and become susceptible again. In *Stage1_IllPopulation* there is a *Mortality_Rate_1* that accounts for about 2% of the sick children. The mortality rate in this first stage is considered low because the severity of the diarrhea is low.

TransferStage1_2 is the flow of children from the first stage that are still infected with the disease to the second stage referred to as *Stage2_IllPopulation*. In this stage it is estimated that children will be sick for an additional 2.5 weeks. Just like stage 1, children will recover through the *RecoveryRate_2,* die from the disease *Mortality_Rate_2* or continue with the disease. The mortality rate in the second stage is higher than stage 1 with 4%.

The children that continue being sick go to the third and last stage. *Stage3_IllPopulation* accounts for the children in the most severe stage where they are sick for 10 more weeks. *The Mortality_Rate_3* in this stage is the highest with a 10% of the ill children in the third stage. The children that become well again go through the *RecoveryRate_3.*

The recovery rates are determined by many factors. *Pop_Transf_From_1* is the population that is being transferred to the different outflows of *Stage1_IllPopulation.* It is determined by the *Stage1_IllPopulation* and the *Max_DurationOfDisease_1. RecoveryRate_1* is the *Prob_Recovery_1* multiplied by 1- *Mortality_1* and the *Prob_Recovery_*1. *1- Mortality_1* represents the children that do not die from the disease.

The *TransferStage1_2* is then the *Pop_Transf_From_1* multiplied by 1- *Mortality_1* and 1- *Prob_Recovery_*1. 1- *Prob_Recovery_*1 represents the children are not dying or recovering.

RecoveryRate_2 and *TransferStage2_3* are calculated with same approach as *RecoveryRate_1* and *TransferStage1_2.* The third stage is also calculated with the same approach as *RecoveryRate_2* with the exception that there is no probability of recovery since the children that do not die are expected to recover.

When the children go through the recovery period they become part of the three stocks of recovery according to the stage of the disease when they recovered in. *Recovered_1, Recovered_2* and *Recovered_3* present all the children that recovered from diarrhea. These children will stay in these stocks until they have lost their immunity or they become older than 15. In this case, the outflows of *SusceptibleRetirementRate, SusceptibleRetirementRate1*, *SusceptibleRetirementRate2* and *SusceptibleretiremenRatet3* account for the children that has recovered but will not become susceptible again because they are no longer considered in the study group. In order to know how many children are retiring or becoming older than 15 in each stage of the sickness it is necessary to know the total children not sick or the *TotalNon_Ill.* The *TotalNon_Ill* and the *Recovered_1, Recovered_2* and *Recovered_3* determine the *RecoveredFraction1, RecoveredFraction2* and *RecoveredFraction3*. They also determine the *NonIllFraction.* The *TotalSusceptibMaturationRate* multiplied by the *NonIllFraction, RecoveredFraction1, RecoveredFraction2*, *RecoveredFraction3* and *TotalNon_Ill* determine the *SusceptibleRetirementRate, SusceptibleRetirementRate1*, *SusceptibleRetirementRate2*, and *SusceptibleretiremenRate3* respectively*.*

The children that do recover become immune and return to the *Current_Infant_Susceptible_Pop* stock. *TimeToLose_Imm_1, TimeToLose_Imm_*2 andTimeToLose*_Imm_3* determine the time to lose immunity in each stage of the disease. The children go through the *ImmunityLossRate1, ImmunityLossRate2, ImmunityLossRate3* in the time to loss their immunity according to the stage and become susceptible to the disease again. Figure 10 illustrates the stock and flow structure of the Illness Sector.

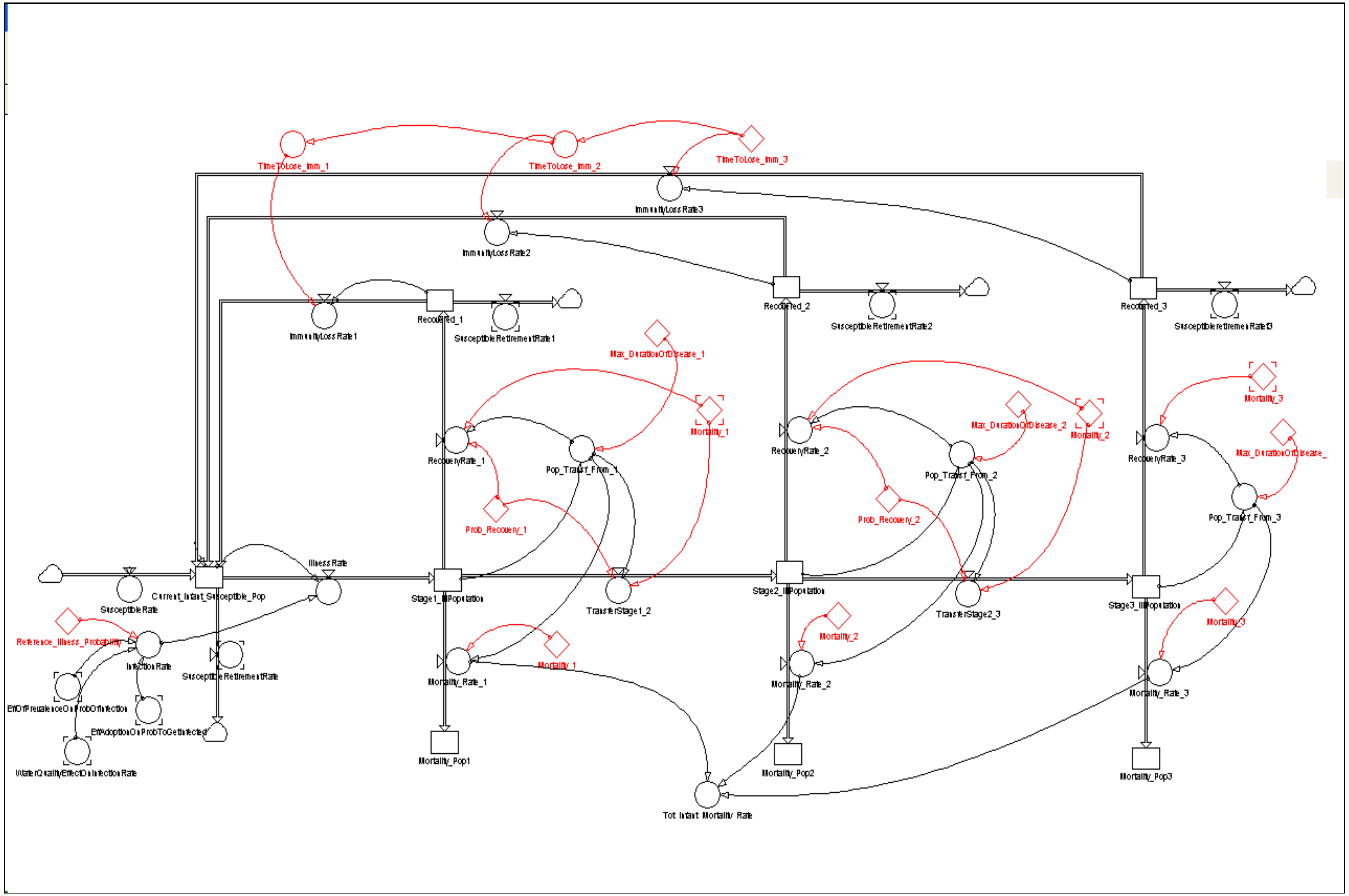

Figure 10 Structure Illness Sector

The causal loop diagram in figure 11 demonstrates all the feedback in the Illness Sector. The causal loop illustrates the different positive and negative feedback loops in the system. The major reinforcing loops in the Illness Sector are the R1, R2, and R3 where children are moving from each stage, then recovering and losing their immunity becoming susceptible to diarrhea again. The balancing loops counteract the positive behavior in the system. The dynamics of the system arise from the collaboration of both positive and negative feedback.

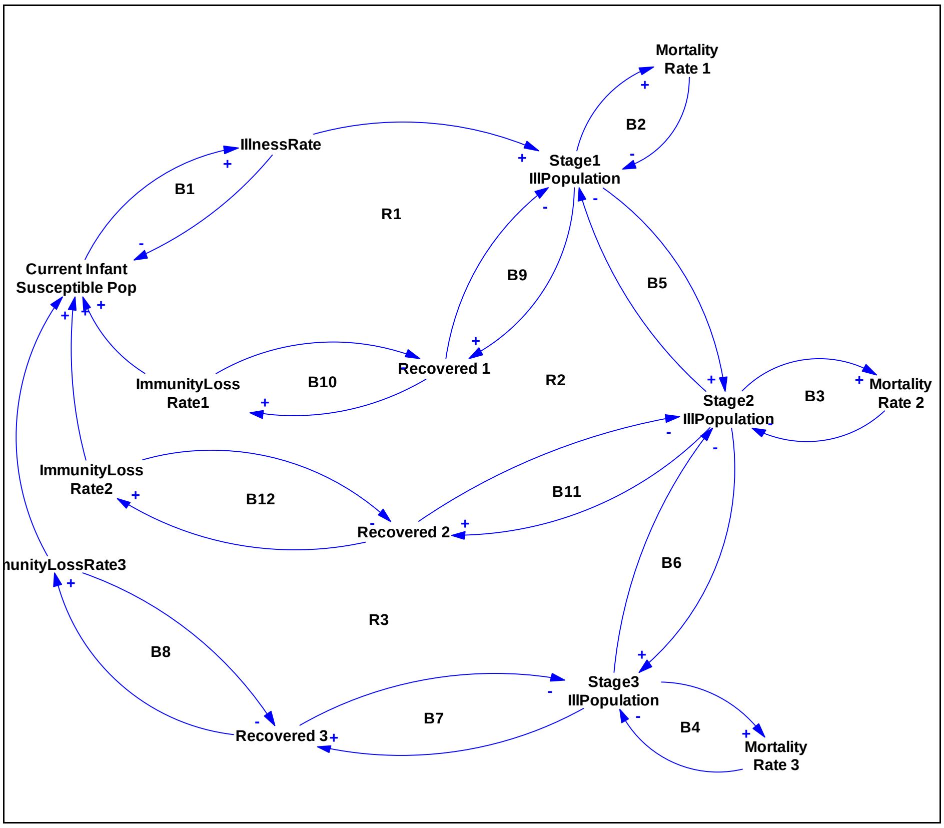

Figure 11 Illness Sector Causal Loop Diagram

From the causal loop diagram in figure 11 one can observe that the *IllnessRate* increases the *Stage1_IllPopulation*. The children in the first stage can recover, die or continue being sick moving to the second stage. The same process happens in *Stage2_IllPopulation* and *Stage3IllPopulation.* The children that recover will become susceptible again on various times depending on the stage of illness they recover from.

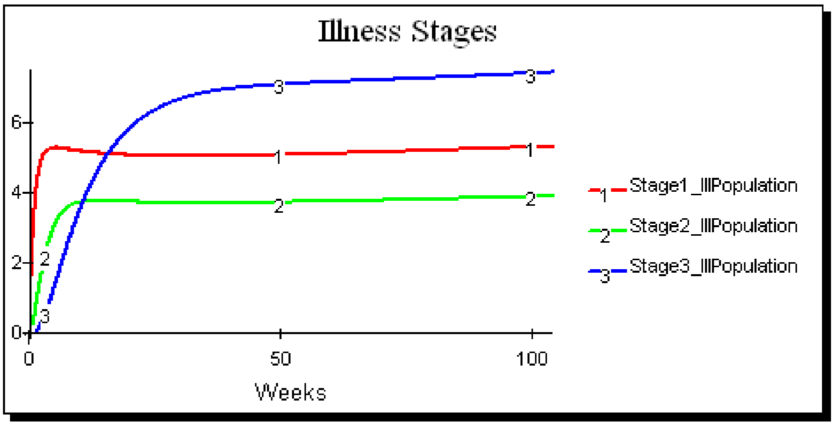

Figure 12 Illness Stages

Figure 12 demonstrates the behavior in illness stages. The number of children in the Stage 1 starts to increase faster than the next two stages. It quickly stabilizes due to the short time the children are sick in this stage. Stage two starts to increase quickly after stage 1. The time the children are sick in this stage is not that long either, so the number of children in stage 2. The number of children in stage three gradually starts to rise. Stage 3 overgrows the number of children in Stage 1 and 2. This is because children are sick for a much longer time and accumulate.

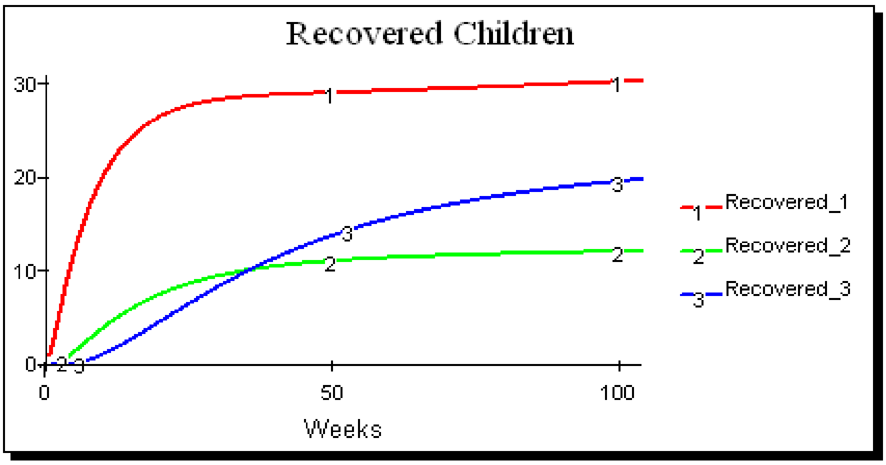

Figure 13 Recovered Children

The graph in figure 13 demonstrates the behavior on the recovery stages. The children that recover the fastest are the children in stage 1 in the *Recovered_1* stage. The children from the *Recovered_2* stage start to recover followed by the children in Recovered_*3* stage. The number of children that recover from *Recovered_3* is higher than the children in *Recovered_2* because they lose their immunity in a much longer time. So although they are sick for the longest, their time to loss immunity is longer.

6.3.1 Prevalence

The *Total_Ill* is the variable that shows the total children ill in the system. This is the summation of *Stage1_IllPopulation*, *Stage2_IllPopulation* and *Stage3_IllPopulation.* The *TotalNon_Ill* accounts for the non ill children in the system. This is determined by the summation of *Current_Infant_Susceptible_Pop, Recovered_1, Recovered_2*, and *Recovered_3.* The *Prevalence* variable shows the prevalence of the sickness between the ill and the non ill children. It is calculated by dividing the *Total_Ill* by *TotalNon_Ill.* Figure 14 shows the structure of the Prevalence.

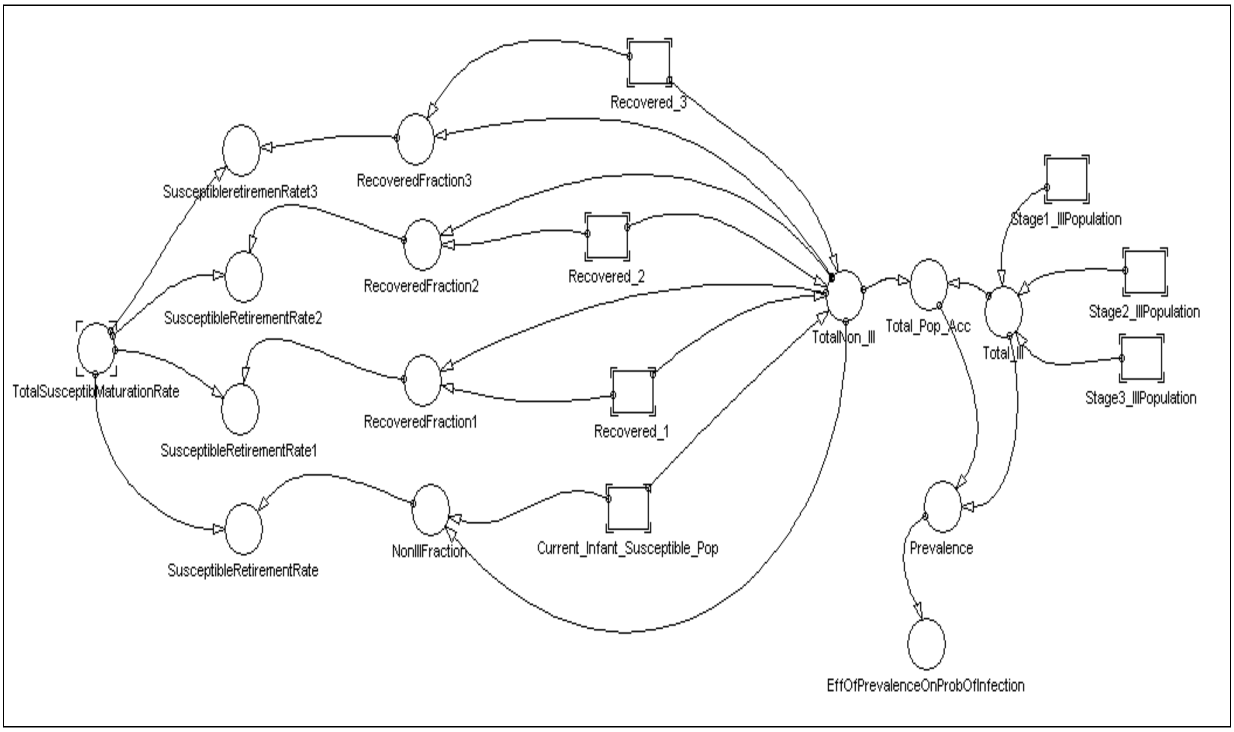

Figure 14 Prevalence Structure

The *IllnessRate* and *Total_Ill* create a reinforcing loop. As the *IllnessRate* increases it increases the *Total_Ill*. This reinforcing loop increases the *Prevalence*. When the *Total_Ill* start to increase, it decreases the number of *TotalNon_Ill,* meaning that more people are getting sick. The *Total_Ill* has an increasing effect on the *Prevalence and TotalNon_Ill* has a negative effect on the *Prevalence*. Due to this, when the more children get sick, the *Prevalence* is higher, and then it drops because the number of ill children go down and the number of non ill children go down reducing the *Prevalence* of the disease. Figure 15 represents the causal loop diagram for the Illness sector.

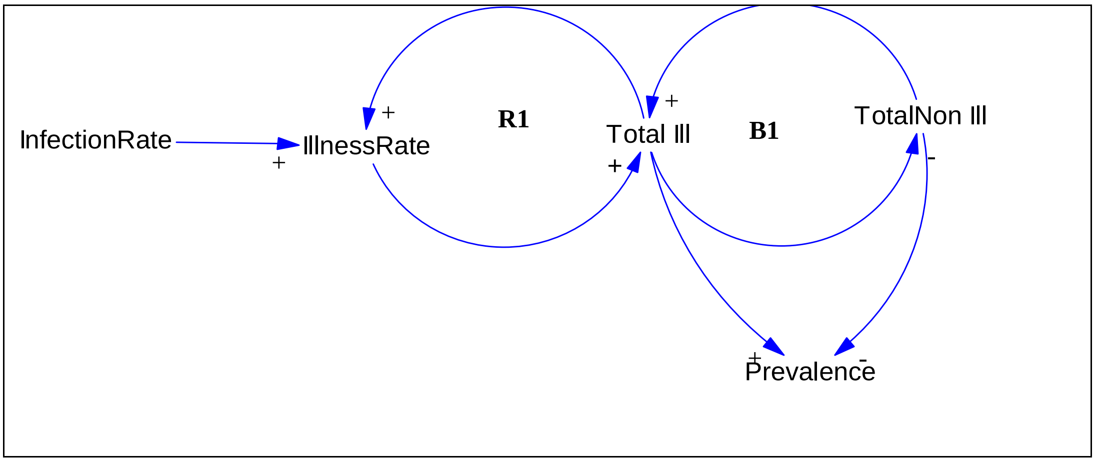

Figure 15 Prevalence causal loop diagram

The graph in figure 16 represents the behavior of the *Prevalence*. As the number of children getting sick increases the *Prevalence* starts to increase. It starts slowing down because some children are becoming to recover. After some time it stabilizes.

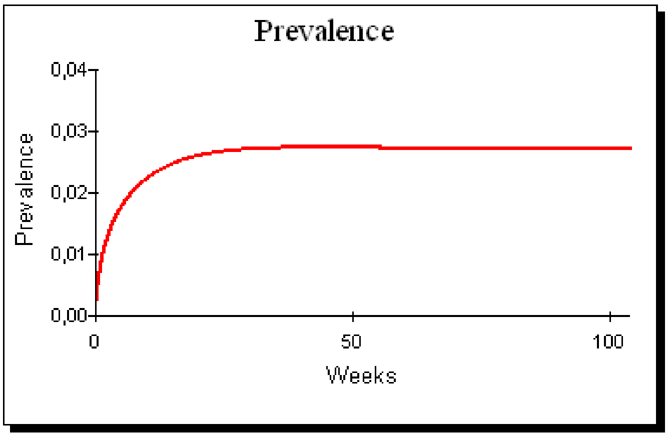

Figure 16 Prevalence behavior

6.4 Adoption Sector

The adoption sector presents the dynamics of how adults in the community become adopters of knowledge. This sector also shows how people tend to forget what they have adopted and become potential adopters again.

The stock of *Potential_Adoptors* represents the adults that are potential adopters of information. The *Potential_Adoptors* stock initializes with the same initial value as the *AdultPopulationInNewHouseholds*. It has an inflow that stand for new adopters or *NewAdoptersRate*. The *Potential_Adoptors* has two outflows. The *PotentialAdoptersDeathRate* is the potential adopters that die while still being potential adopters. In the second outflow potential adopters to become adopters go through the *LearningRate.* The *LearningRate* is the people per week that go from being potential adopters to adopters. It consists of two forms of adoption. The first adoption comes from the *AdoptionFromCommitee.* The *AdoptionFromCommitee* presents the potential adopters that become adopters because of the work the committee is doing in each household. This is done by a *CommitteeEffect,* a nonlinear relationship, which comes from the *ProductivityCommitee.*

The second way of becoming adopters is through the word of mouth. The variable *AdoptionFrom_W_of_M* presents the amount of people that are part of the *LearningRate* to become adopters from the word of mouth technique. The *AdoptionRate* and *ContactRate* form the *AdoptionFrom_W_of_M.* The *LearningRate* becomes the sum of *AdoptionFromCommitee* and *AdoptionFrom_W_of_M.*

The stock of *Adopters* is the cumulative potential adopters learning from either the committee or word of mouth. The *Adopters* are the people that have been learning about sanitation habits and how to keep the sustainable system to not only to have clean and running water, but to reduce the cases of diarrhea in children. However, *Adopters* have a propensity to forget what they have been taught. The *Adopters* have an outflow that accounts for the people dying while being adopters. This is the *AdoptersDeathRate*. The *Adopters* that forget the implementation of habits go through the *ForgetRate.* This *ForgetRate* is influenced by the *ProductivityCommitee* and by the *Prevalence*. They both have a nonlinear effect that affects the *ForgetRate*. The *ProductivityCommiteEffonForgetRate* is assumed that the more productive the committee is the less people forget. The *PrevalenceEffOnForgetRate* assumes that the more *Prevalence*, the more people are forgetting. The *Adopters* that are forgetting become *Potential_Adopters* again. The structure for the Adoption Sector is shown in figure 17.

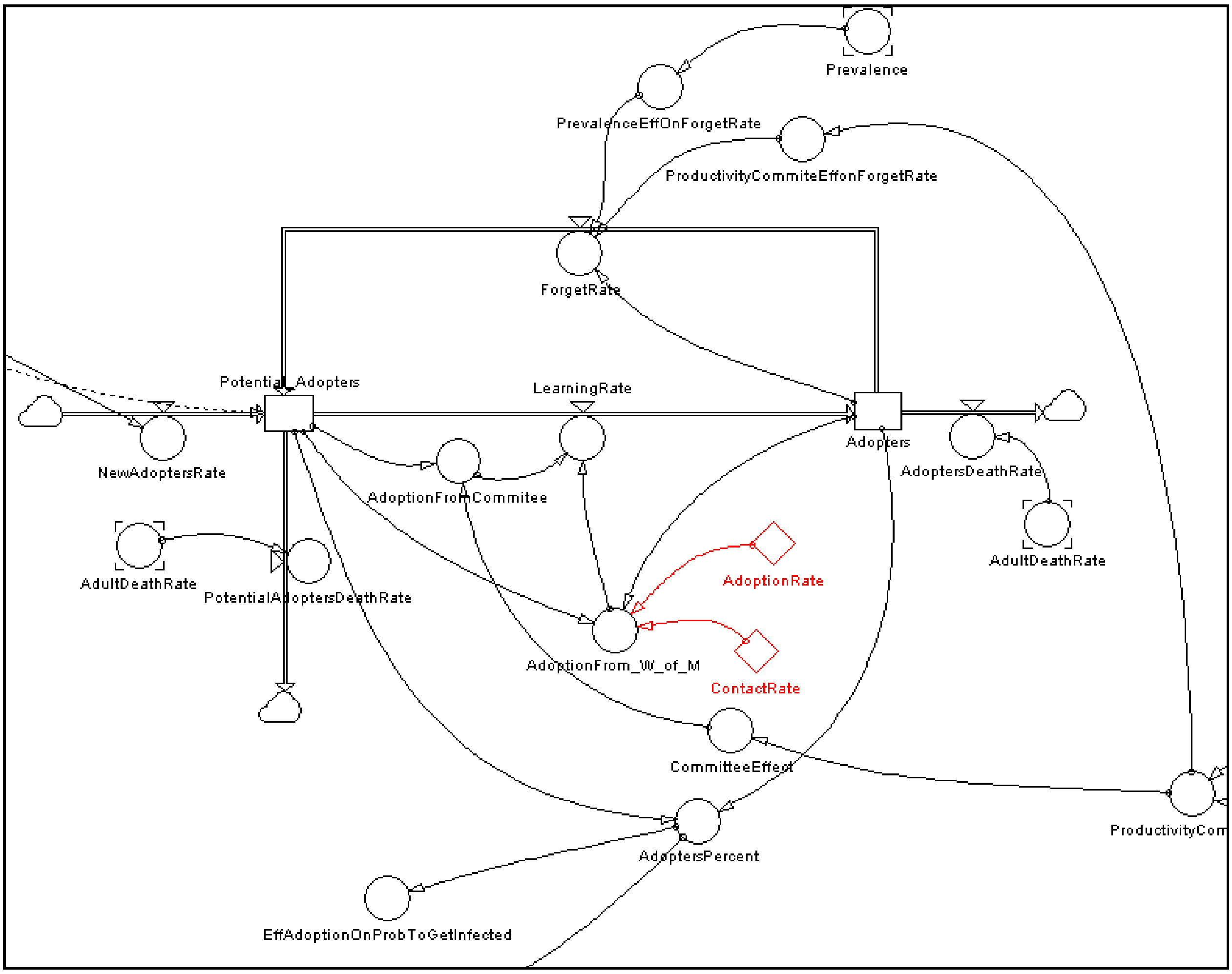

Figure 17 Structures for Adoption Sector

The causal loop diagram for the Adopters Sector is illustrated in figure 18. The *Potential_Adopters* become Adopters through the *LearningRate*. There are two ways that people go through the *LearningRate*. People can become adopters from the *AdoptionFromCommittee* and *AdoptionFromW_of_M*. The *AdoptionFromCommittee* will depend from the *ProductivityCommittee* discussed in the Sanitation Committee Sector. The *AdoptionFromW_of_M* depends on the *ContactRate* and *AdoptionRate* discussed previously. When people have become Adopters they will become *Potential_Adopters* when they have forgotten about the sanitation habits to practice. The major reinforcing loop in the Adopters Sector is R2 where people went from *Potential_Adopters* through the *LearningRate* into becoming Adopters and the Adopters becoming Potential_Adopters again through the *ForgetRate*. The balancing loops in the LearningRate make sure that there are not more people learning than the number of *Potential_Adopters.*

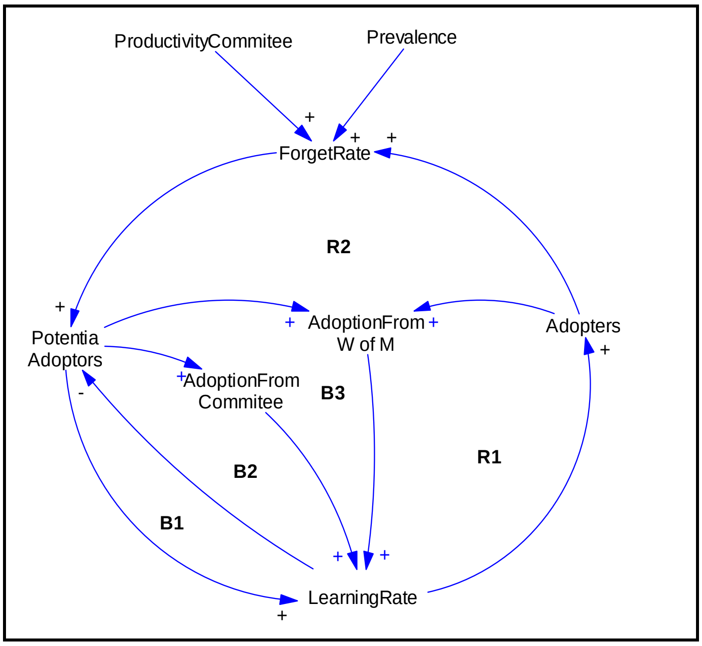

Figure 18 Adopter Sector Causal Loop Diagram

The behavior for the Adoption Sector is shown on figure 19. As the Adopters start to increase, the *Potential_Adopters* start to decrease. When the Adopters are greater than the *Potential_Adopters* the *Adopter*s stock becomes stable. The *Potential_Adopters* stabilize for some time but start increasing slowly again.

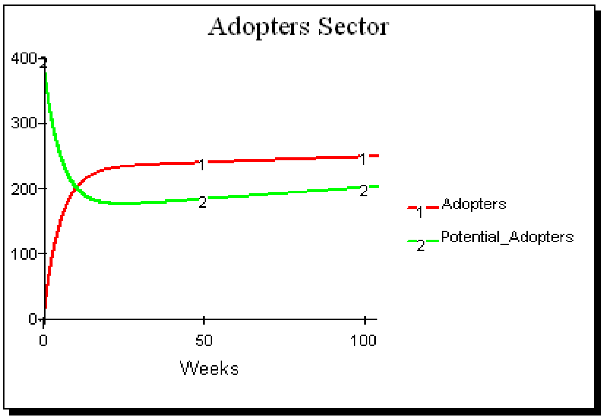

Figure 19 Adopters Sector

6.5 Sanitation Committee Sector

The sanitation committee as explained before is in charge of visiting homes to reinforce information on good sanitation habits and the actions required to keep a sustainable water system.

The staff in the sanitation committee is represented by the stock called *SanitationCommitteeStaff.* Each member is assumed to stay in the committee for about 1.5 years. The *AttritionRate* represents the outflow of the staff members that leave the committee. To replace the staff that leaves the *SanitationCommitteeStaff* has an inflow called *HireRate.* This hire rate accounts for the replacement of the staff that has left the committee. The *AdjustmentTimeStaff* is considered to be 12 weeks.

The *ProductivityPerStaffMemeberPerWeek* has been predetermined to be 5 visits per week per staff member. The *TotalStaffProductionPerWeek* is then the number of staff multiplied by the *ProductivityPerStaffMemeberPerWeek.* The goal is for the *TotalStaffProductionPerWeek* to be equal to the desired production per week or the *DesHouseholdVisitedPerWeek.* The *DesHouseholdVisitedPerWeek* is the desired number of homes the total staff should visit according to the number of *Households*, *DesVisitsPerHouseholdPerYear* and the *MinimumVisitsPerHomePerYear.* The *DesVisitsPerHouseholdPerYear* is the number of visits each home should have per year. It is a set goal driven by the *MinimumVisitsPerHomePerYear* which is 10 visits per household per year. The structure for the Sanitation Committee Sector is presented in figure 20.

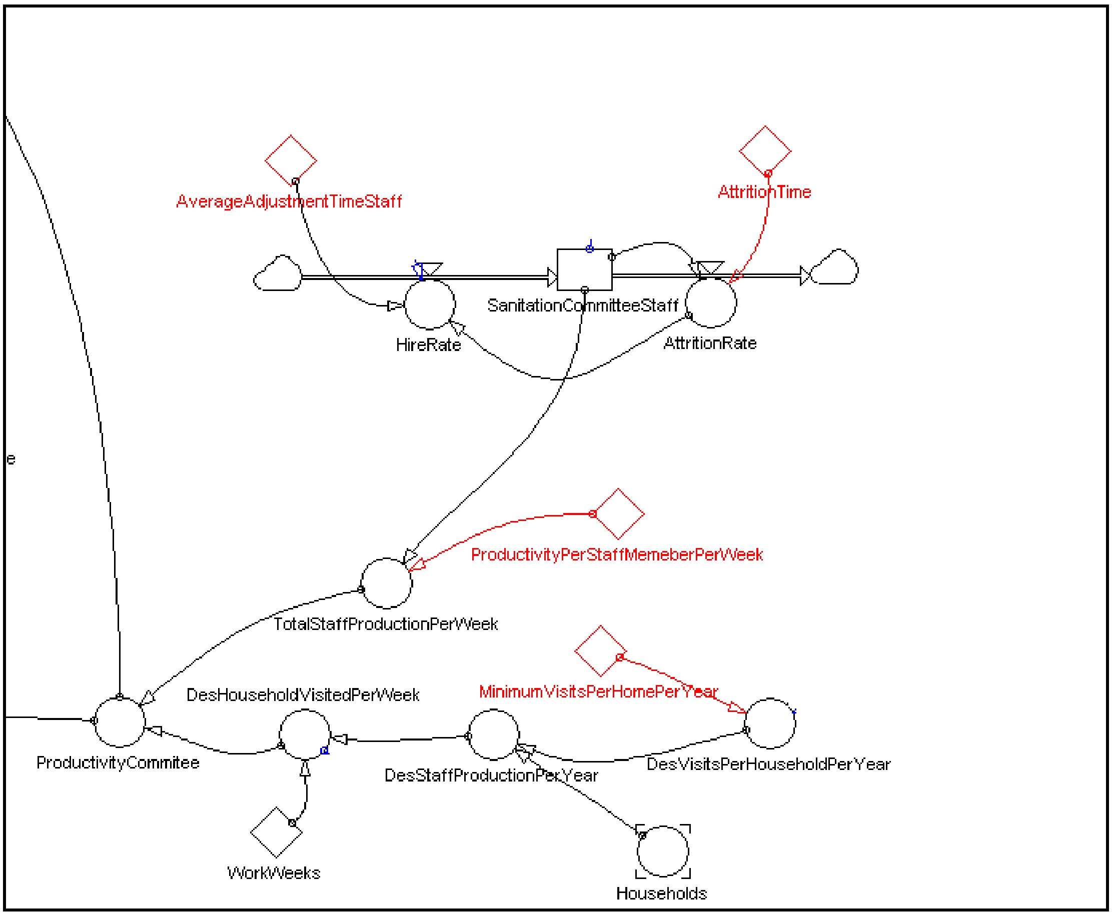

Figure 20 Sanitation Committee Staff Structure

The causal loop diagram for the Sanitation Committee Sector is shown on figure 21. The *SanitationCommitteeStaff* is keeping constant due to the balancing and reinforcing loop. The committee is only replacing the *AttritionRate* through the *HireRate,* keeping a constant number of staff members.

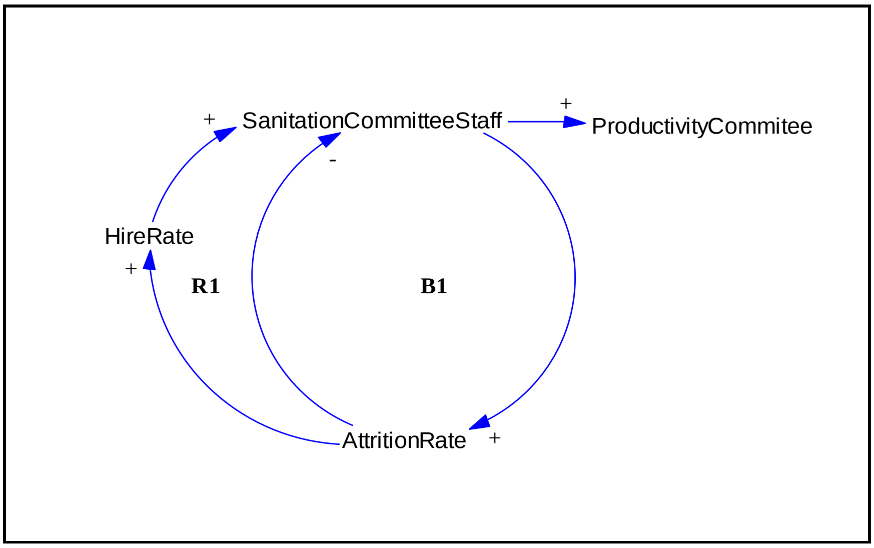

Figure 21 SanitationCommitteeStaff Causal Loop Diagram

The behavior for the stock of *SanitationCommitteeStaff* is shown on the graph on figure 22. The *SanitationCommitteeStaff* is constantly 5 because the committee is only replacing the *AttritionRate* keeping the number of staff in a constant number.

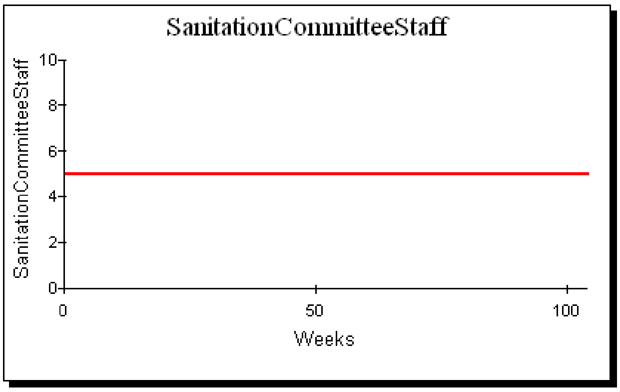

Figure 22 SanitationCommitteeStaff

6.6 Pipe Sector

The pipe sector corresponds to the management of the pipe replacement. The *FunctionalPipes* is the stock that represents the total number of functioning pipes in the system. Some of the *FunctionalPipes* become damaged through the *FunctionalPipesDamageRate.* This rate is the number of functional pipes that are becoming damaged. The damaged pipes are then *UnreportedsDamagedPipes.* This stock accounts for all the pipes that are damaged but not reported to the Water Board.

Pipes can also become obsolete through the *Pipe_Depreciation_Rate.* The pipes that become obsolete are then part of the *ObsoletePipes*. The *ObsoletePipes* can be damaged and become part of the *UnreportedsDamagedPipes* through the *ObsoletePipesDamageRate.* *ObsoletePipes* can also become part f the *R*eportedObsoletePipesToBeReplaced stock through the *ReportedObsoleteDamagedPipesRate.* Once the *ObsoletePipes* are *ReportedObsoletePipesToBeReplaced* they can still be damaged and add up to the *UnreportedsDamagedPipes*. If they are not damaged, they are then *OrderedObsoletePipesToRemove.* The *OrderRateObsoletePipes* is the rate at which the pipes are ordered per week. Ordering obsolete pipes will be described later on. The *OrderedObsoletePipesToRemove* even if they have been ordered can still be damaged. The *DamagedOrderedObsoletePipesToRemovRate* accounts for the number of pipes that have been ordered and are then damaged. These pipes become part of the *UnreportedsDamagedPipes.* If they are not damaged while they are ordered, they are removed after they have been delivered. The *RemovalOfObsoletePipeRate* is the rate at which the obsolete pipes that have been ordered and undamaged are removed.

The *UnreportedsDamagedPipes* is then the total number of pipes that have not been reported and are damaged. This stock accumulates the *FunctionalPipesDamageRate, ObsoletePipesDamageRate, ReportedObsoletePipesDamageRate,* and *DamagedOrderedObsoletePipesToRemovRate.* At this point, these are the pipes the plumber has counted to be damaged and needed to be replaced. The plumber then reports the damaged pipes to the Water Board. The *ReportedPipesRate* is the number of pipes the plumber is reporting to be damaged. Once the pipes are reported they are then part of the *ReportedDamagedPipesToBeReplaced* stock. The water board is now responsible for ordering the pipes in the *ReportedDamagedPipesToBeReplaced* and *ReportedObsoletePipesToBeReplaced* stocks. When the pipes have been ordered, the *OrderRateDamagedPipes* and

OrderRateObsoletePipes determine the *OrderedDamagedPipesToRemove* and *OrderedObsoletePipesToRemove*. The orders rates help determine the pipes that have been ordered and can then be removed. In other words, the *RemovalOfDamagedPipeRate* and *RemovalOfObsoletePipeRate* are done after the pipes have been ordered.

The priority the water board in what pipes to replaced is to replace the all the *ReportedDamagedPipesToBeReplaced.* These damaged pipes in the system cause more problems in the distribution and quality of the water than *ReportedObsoletePipesToBeReplaced.* The obsolete pipes are probably old but still functioning.

The *TotalPipesToFix* is calculated by adding the *ReportedDamagedPipesToBeReplaced* and *ReportedObsoletePipesToBeReplaced*. The *CostOfPipesToRepair* is then determined by multiplying the *TotalPipesToFix* by the *PricePerPipe.* At this point the cost of repairing all the pipes has been estimated without taking any decision on what pipes to replace. This will depend on the money available to invest in pipes. *InvestmentInNewPipes* is the money accessible for the investment in pipes. The *InvestmentInNewPipes* is explained in the Expenditure Sector. The *OrderRateDamagedPipes* is then the number of pipes that can be ordered per week according to the money in *InvestmentInNewPipes.* This means that the Water Board will only order the number of pipes from the *ReportedDamagedPipesToBeReplaced* that they can afford. To decide how many *ReportedObsoletePipesToBeReplaced* can be ordered, the *DamagedPipesOrdered* is calculated. The *InvestmentDamagedPipes* is the investment done for damaged pipes. The *InvestmentInNewPipes* subtracts the money spent on *InvestmentDamagedPipes*. This turns into the *InvestmentInNewPipesOP* which is then money available for investing in obsolete pipes. The *OrderRateObsoletePipes* is then the *InvestmentInNewPipesOP* divided by the *PricePerPipe.*

When the orders for both the damaged and obsolete pipes are done they become *ReplacementDamagedPipeOrdersPlaced* and *ReplacementObsoletePipeOrdersPlaced*. These are stocks that account for all the pipes, damaged or obsolete which have been ordered. After they have been ordered they are *ReplacementDamagedPipeOrdersExecuted* and *ReplacementObsoletePipeOrdersExecuted*. These rates are the orders that have been executed and are in process of delivery. Once delivered, they become the stocks of *ReplacementDamagedPipeOrdersToBeSatisfied* and *ReplacementObsoletePipeOrdersToBeSatisfied*. The pipes in these stocks have been delivered and waiting to be installed.

To replace the pipes delivered, the capacity to install them must be determined. The *DesiredReplacementCapacityDP* is the desired replacement capacity to replace the *ReplacementDamagedPipeOrdersToBeSatisfied* and the *DesiredReplacementCapacityOP* is the desired replacement capacity for the *ReplacementObsoletePipeOrdersToBeSatisfied*.

The *AdjustmentForCapacity* is the *DesiredReplacementCapacityDP* minus the *ReplacementCapacityDP* . The *ReplacementCapacityRate* is the *AdjustmentForCapacityDP* divided by the CapacityAdjustmentTime*.* The *ReplacementCapacityRate* accumulates capacity for replacing the pipes in the *ReplacementCapacityDP* stock.

The capacity for the replacement of obsolete pipes is calculated in the same way with its respective variables.

The *ReplacementDamagedPipeOrdersSatisfied* and *ReplacementObsoletePipeOrdersSatisfied* are the rate at which the pipes that have been delivered have been replaced according to the capacity for replacing them. These pipes after being installed become part of the *FunctionalPipes* in the system. Figure 23 represents the structure of the Pipe Sector.

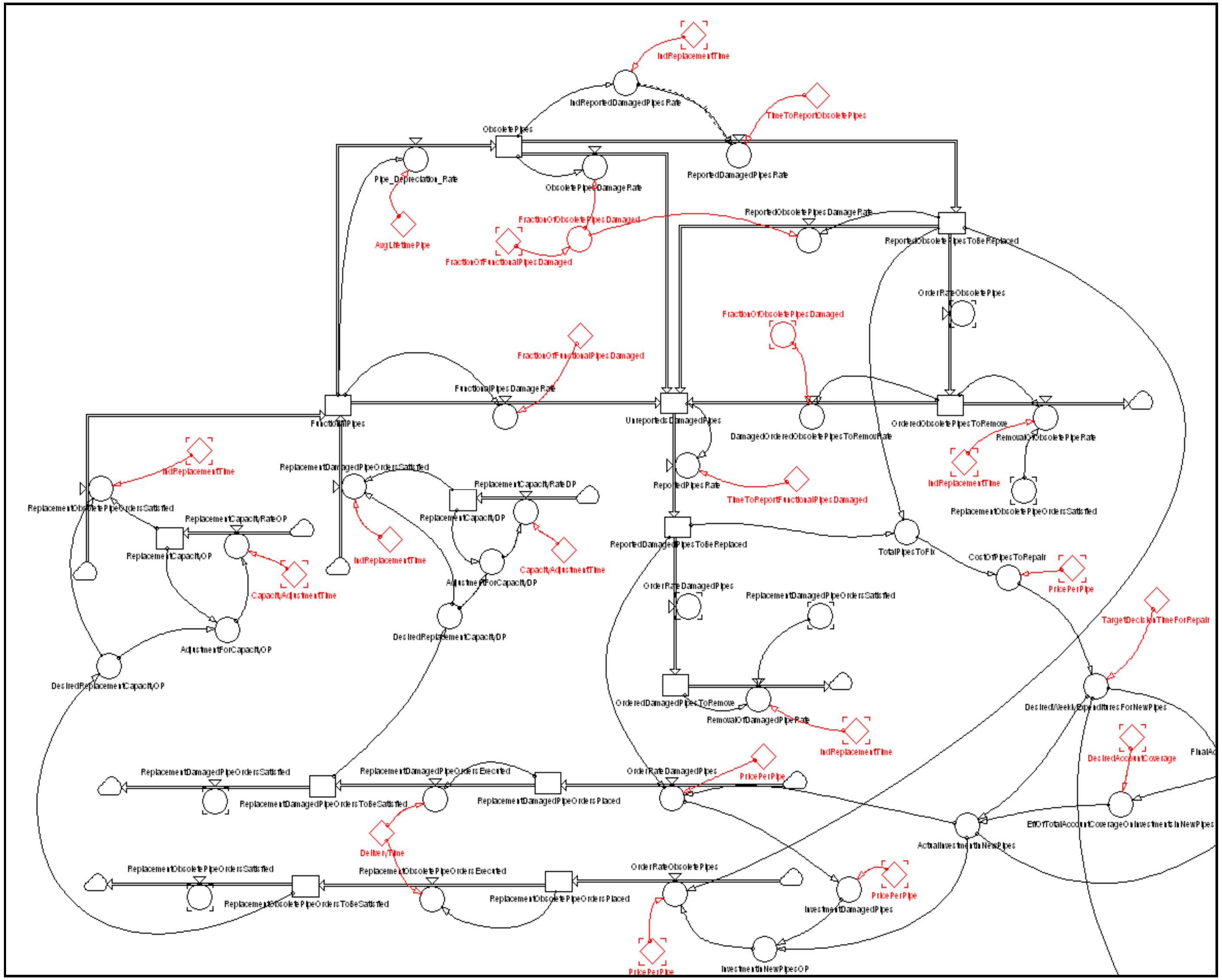

Figure 23 Pipe Sector Structure

The causal loop diagram on figure 24 represents the dynamics of the Pipe Sector. *FunctionalPipes* can become *ObsoletePipes* or *DamagedPipes*. Once they have been reported by the plumber to the water board, the water board orders the pipes. The pipes are then delivered. When the pipes are delivered the *ReportedDamagedPipes* and *ReportedObsoletePipes* are removed to be replaced by the new pipes that been ordered and delivered. The *ReplacementObsoletePipesOrdersSatisfied* and *ReplacementOfDamagedPipesOrdersSatisfied* are then the new pipes installed, which become *FunctionalPipes.*

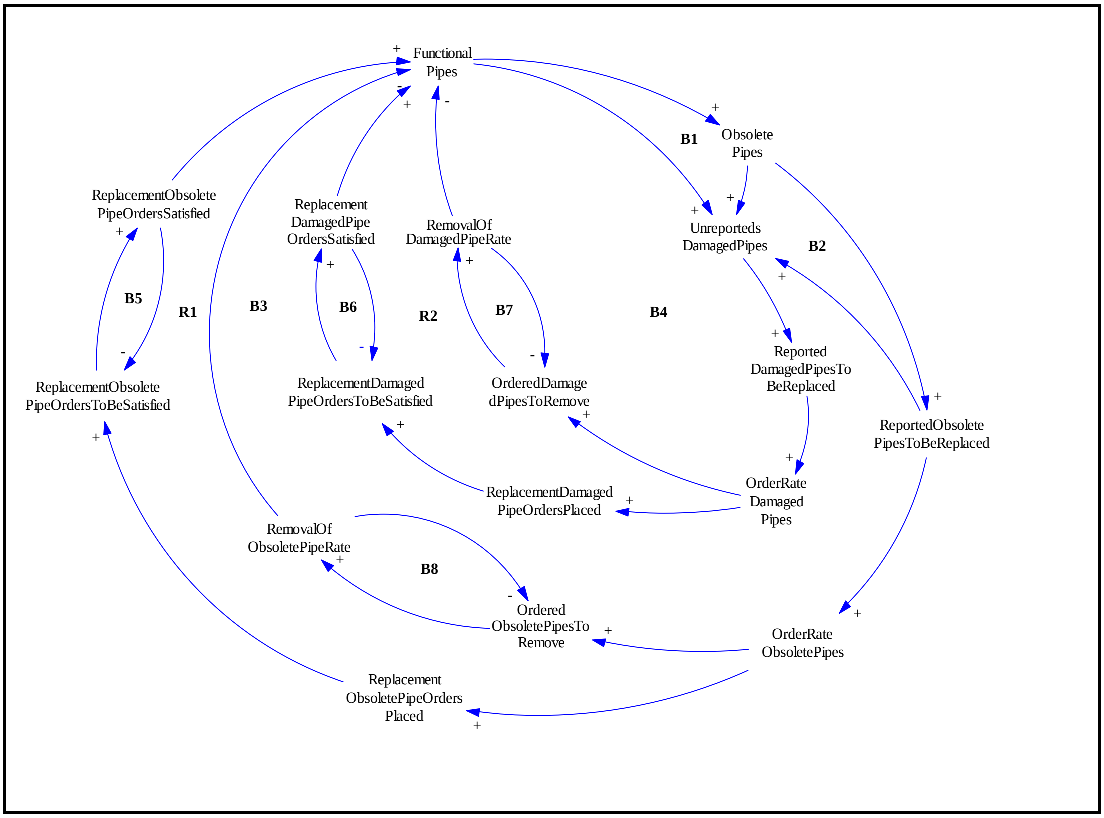

Figure 24 Pipe Sector Causal Loop Diagram

6.7 Income and Expenditure Sector

The Expenditure Sector demonstrates the different expenses the community has in order to provide clean and running water and the source of income to cover for these expenses. The Water Board from the community is in charge of calculating and handling the collection of the money and the payment of the expenditure.

There are three major expenses for this water system. The first expenses are the *TotalFixedCost.* As mentioned in the assumption of the model, these are costs that have been estimated previously by the water board. The second expense is the *ActualCloroxExpenditures*. This is the actual amount of money spent in Clorox every week. The third expense is the *InvestmentInNewPipes* which is the amount of money spent on replacing pipes, whether they are damaged or obsolete. In order for the Water Board to be able to cover for these expenses there must be an income of money.

The *MoneyInAccount* is the money the water board has available in order to cover for the expenses of the water system. The *ActualIncome* is the rate that reports the inflow of income the water board is receiving per week. The *ActualIncome* is the number of *PayingHouseholds* multiplied by the *CurrentFee.* The outflow to the *MoneyInAccount* is the *Expenditures* that are being done per week. To determine the *Expenditures* the water board must first determine how much money will be spent on what.

The first expenses that are covered are the *TotalFixedCost*. The TotalFixedCostsAccountCoverage is the division of the *MoneyInAccount* by the *TotalFixedCost. EffOfAccountOnTotalFixedExpenditures* is then the minimum of the *TotalFixedCostsAccountCoverage* divide by *DesiredAccountCoverage* and 1 to determine the actual coverage for the *TotalFixedCost.* The actual coverage for the fixed caused is the *ActualTotalFixedExpenditures*. The next expense to be covered is the Clorox expenses. *AfterFixedCostsAccountCoverage* determines the money available for the *DesiredWeeklyExpendituresForClorox* after the *TotalFixedCost* have been covered. The *EffOfAccountBeforeCoverageOnCloroxExpenditures* is the minimum of the AfterFixedCostsAccountCoverage divided by the DesiredAccountCoverage and 1 to create an effect to determine the *ActualCloroxExpenditures.*

The third expense to cover is the investment in pipes. The *FinalAccountCoverage* is the money left after the fixed costs and Clorox expenditures have been covered. The *DesiredWeeklyExpendituresForNewPipes* is the *CostOfPipesToRepair* described in the Pipe Sector divided by the *TargetDecisionTimeForRepair*. The *FinalAccountCoverage* is then the MoneyInAccount minus the ActualTotalFixedExpenditures minus *ActualCloroxExpenditures* divided by the *DesiredWeeklyExpendituresForNewPipe*. The *EffOfTotalAccountCoverageOnInvestmentsInNewPipes* is the minimum of the FinalAccountCoverage divided by the DesiredAccountCoverage and 1 to establish the *ActualInvestmentInNewPipes.*

The Expenditures is then the sum of *AfterFixedCostsAccountCoverage, ActualCloroxExpenditures* and *ActualInvestmentInNewPipes.* Figure 25 shows the structure for the Expediture Sector.

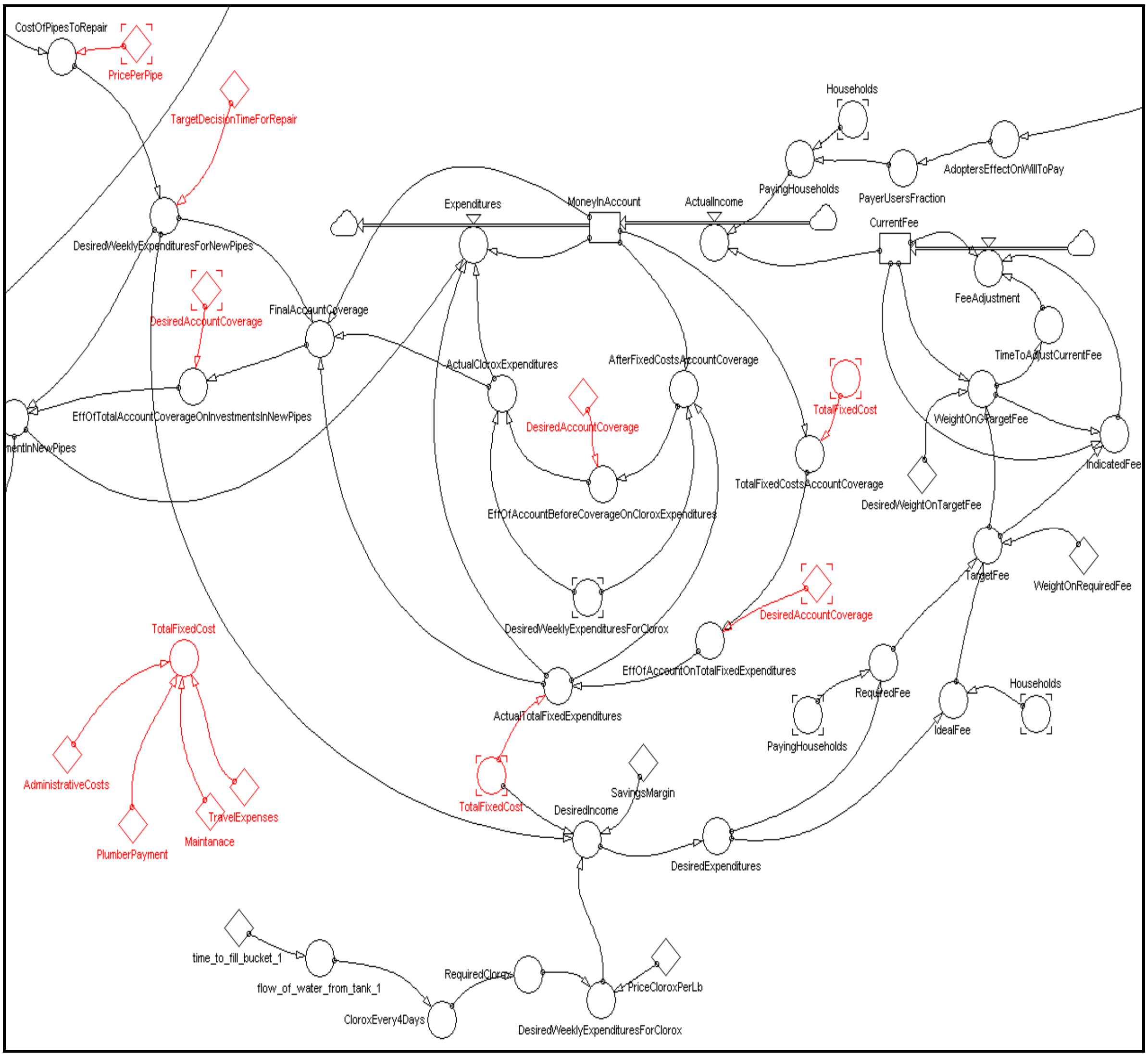

Figure 25 Structure Expenditure Sector

The Expenditure sector with its different feedbacks is shown in the causal loop diagram in figure 26 The first expense the water board wants to cover is the *TotalFixedCosts*. The board then evaluates if there is enough coverage for the Clorox expenses. After fixed costs and Clorox expenses have been covered, the board evaluates if there is enough coverage to investment in new pipes. The *ActualIncome* to cover these expenses comes from the *CurrentFee* and the *PayingHouseholds*.

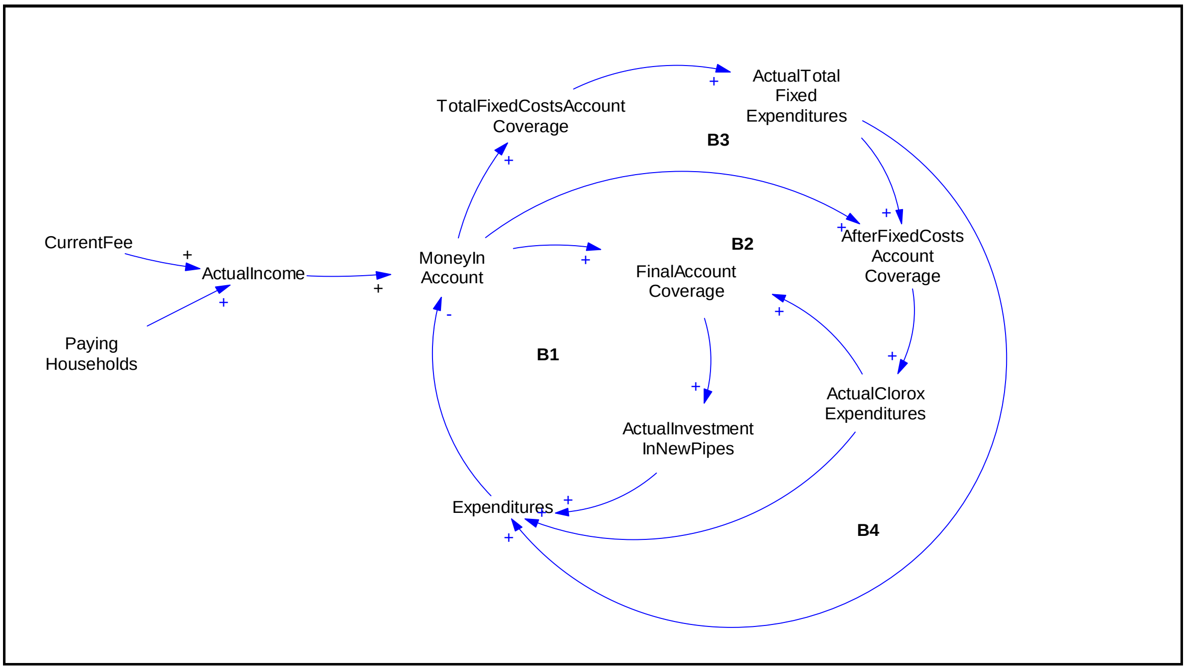

Figure 26 Income and Expenditure Sector Causal Loop Diagram

7. Analysis

This section intends to test the different hypothesis that have been proposed, modeled and explained in the previous section. The hypotheses will be tested through different methods to see if they can recreate the problematic behavior. The problematic behavior, the hypothesis and the model built has been described already. It is now possible to test the hypotheses and the model as well.

7.1 Testing the Dynamic Hypotheses

The dynamic hypotheses described in this section seek to explain the causes for the behavior of sick children with diarrhea in the community of Casco Urbano. To test these hypotheses, different runs in the simulation must be made to explore the effects of each of the hypothesis in the number of children getting sick each week.

A base run was first made. This base run does not include any of the hypotheses that have been presented in this paper. The base run has been set under the following assumptions:

- The *InfectionRate* is equal to the *Reference_Illness_Probability* keeping the *InfectionRate* constant.

- Simulation time is 104 weeks or 2 years

Figure 26 shows the simulation results of the base run.

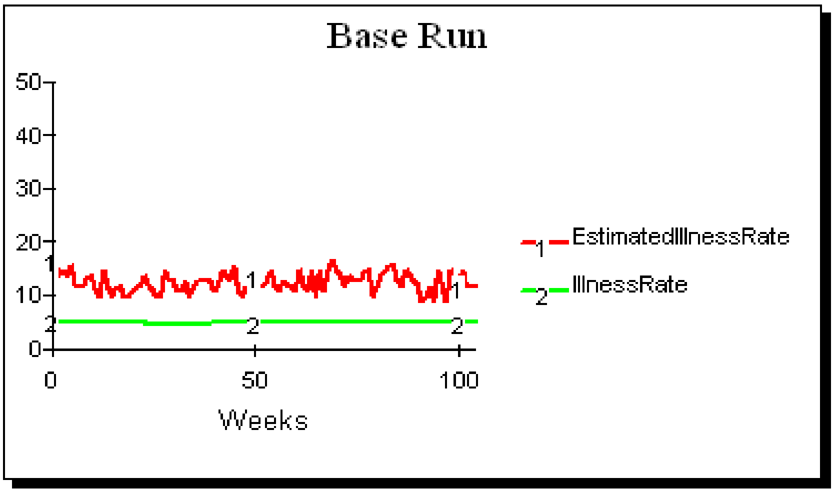

Figure 27 Hypothesis Base Run

The result represented in the Base Run on figure 27 is comparing the reference mode represented by the *EstimatedIllnessRate* and the *IllnessRate* from the simulation. As can be seen, the constant value of the *Reference_Illness_Probability* does not replicate the problem in hand. To try to replicate the *EstimatedIllnessRate*, the different hypothesis will be tested.

7.2 Testing H1: The prevalence of the illness increases the infection rate.

The *Prevalence* as explained before is the proportion of the children population that have diarrhea. The *Prevalence* in the model is assumed to have different effects on different variables, affecting directly and indirectly the illness rate. Figure 28 demonstrates the causal loop diagram for the *Prevalence*. For this hypothesis loop R1 is being analyzed. The other two hypotheses that are being assumed are cut off and not considered in testing the first hypothesis.

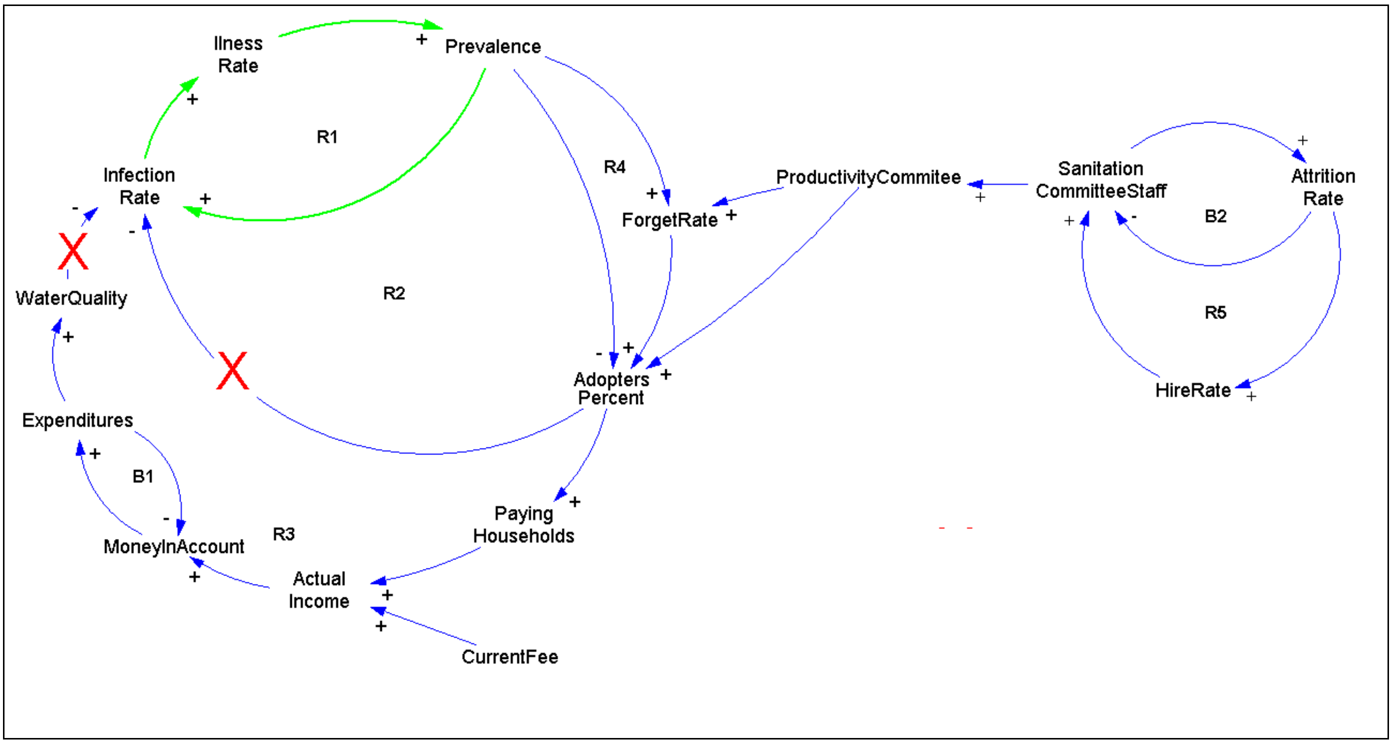

Figure 28 Causal Loop Diagram Prevalence Effects

The *Prevalence* has an instant effect on the *InfectionRate.* The more children are sick; the more chances of other children to become infected. The effect on the *InfectionRate* is created through a nonlinear function that states that as the *Prevalence* increases, the effect on the *InfectionRate* increases. Figure 29 demonstrates the effect on the IllnessRate.

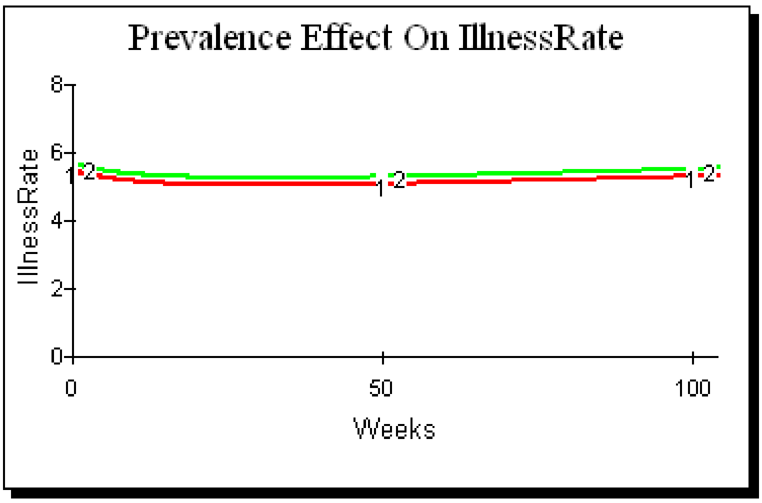

Figure 29 Prevalence Effect on IllnessRate

The first run represented by the red line is the *IllnessRate* with no effect from the *Prevalence*, affected only by the *Reference_Illness_Probability*. The second run represented by the green line is the *IllnessRate* with the effect of the *Prevalence*. There is barely any effect on the *IllnessRate*. This is because the *Reference_Illness_Probability* is very small, making the *InfectionRate* small as well, producing a small *Prevalence* therefore it has no real effect.

If the *Reference_Illness_Probability* was put through an extreme condition, increasing the value from 0.01 to 0.1, there should be a higher effect.

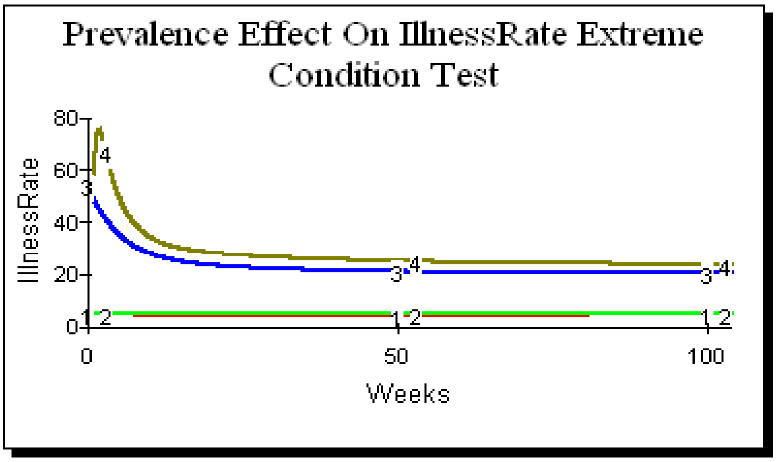

Figure 30 Prevalence Effect on IllnessRate Extreme Condition Testing

The first hypothesis is tested in extreme conditions by raising the *Reference_Illness_Probability* to 10%. The effect of the Prevalence in the *IllnessRate* can be observed in figure 30.This shows that the Prevalence has an effect on the *IllnessRate* as it increases. When the Prevalence is very small, there is little effect on the *IllnessRate*. In run 1 and 2 there is little change in the Prevalence. The third run considers the *Reference_Illness_Probability* to be10% considering no feedback from the *Prevalence.* The 4th run is the highest when there is feedback from the Prevalence to the *InfectionRate*. The results for the *Prevalence* are shown in figure 3. The Prevalence in the third run is the extreme condition with no feedback from the Prevalence. The fourth run is the extreme condition with feedback from the Prevalence. The IllnessRate was the highest in the fourth run because the Prevalence was higher. This can be observed in figure 29. Figure 31 illustrates the behavior of the Prevalence in the extreme conditions test.

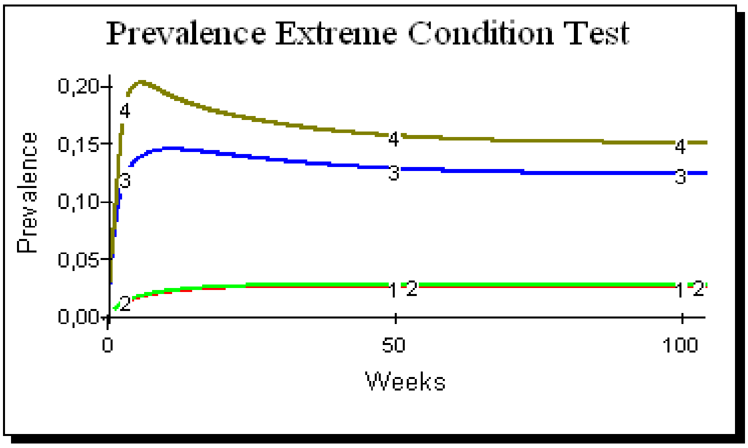

Figure 31 Prevalence results testing H1

7.3 Testing H2: The lack of adoption of hygienic and sanitation habits increases the infection rate.

There are many researches made that indicate that sanitation and hygiene in a child's life has a big impact on the probability of diarrhea infection. H2 suggests that the deficiency in the practice of hygienic and sanitation habits increase infection rate. As explained in the model description, the sanitation committee is in charge of visiting homes to remind them of the different hygienic and sanitation habits that should be implemented not just at home but anywhere they are. The committee then has an effect on the adult potential adopters who then become adopters of these habits. They then forget and become potential adopters again.

For people to be reminded about the information the sanitation committee teaches, the sanitation committee has initially 5 staff members and they only replace those who want to quit. The sanitation committee has set goals for the number of homes to visit each week and how many times each home should be visited per year has been explained before. However, the sanitation committee does not consider that the population is growing; therefore their productivity can decrease if they do have enough staff. If their productivity decreases then it takes more time for people to become adopters. This delay increases the probabilities of infection rate in children because the sanitation and hygienic habits required to prevent the sickness are not being implemented at home, discouraging children to do so at school as well. Even with 5 people the sanitation committee falls short in fulfilling their goals of 10 visits per home per year. In the causal loop diagram on figure 32 one can see that the loop being tested for this hypothesis is R2. R1 and R3 which are the other hypotheses assumed have been cut off so they will not be tested in this hypothesis.

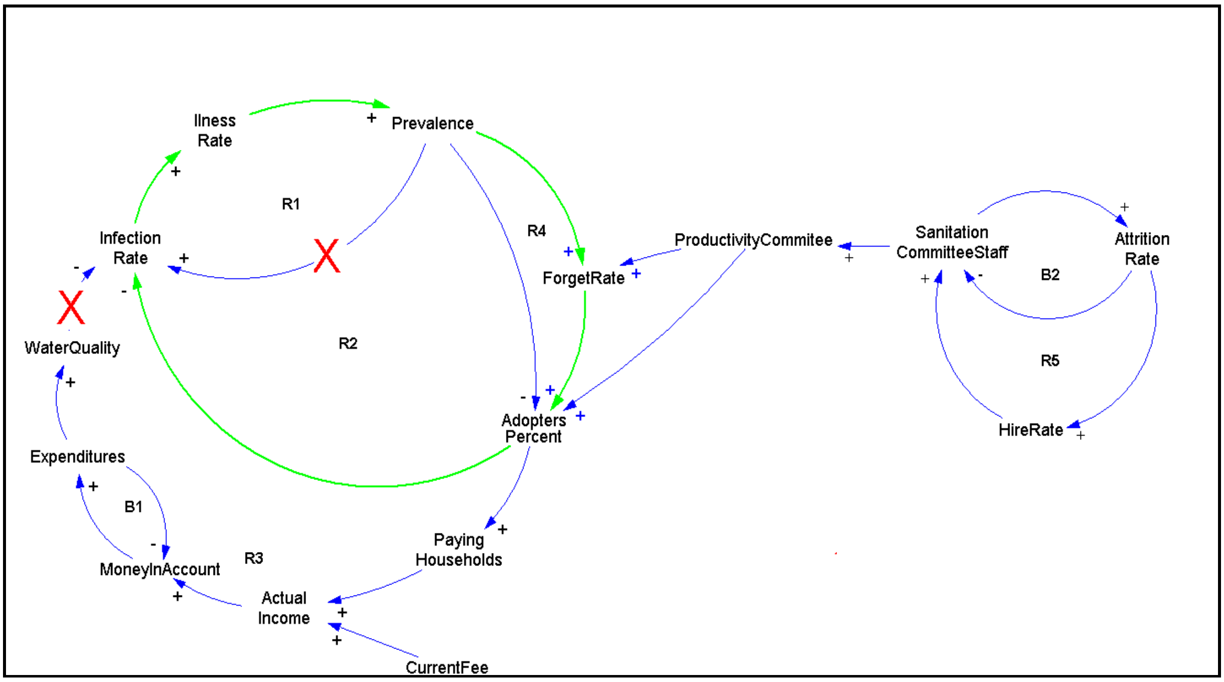

Figure 32 Hypothesis 2 Causal Loop Diagram

The *ForgetRate* is another factor that reduces the number of *Adopters*. The faster people forget, the less adopter there are. The *ForgetRate* is affected by the *Prevalence* and the *ProductivityCommittee*. If the *Prevalence* increases then the *ForgetRate* increases, reducing the number of *Adopters*. When the *ProductivityCommittee* decreases, the *ForgetRate* increases which also reduces the *Adopters.* When there are more *Adopters* than *Potential_Adopters* the *AdoptersPercent* reduces, increasing the *InfectionRate*. The causal loop diagram in figure 33 represents the effects from the *ProductivityCommittee* to the effect on the *Adopters* to the effect in the *InfectionRate*. Figure 32 demonstrates the effects of the Adoption on the *IllnessRate*.

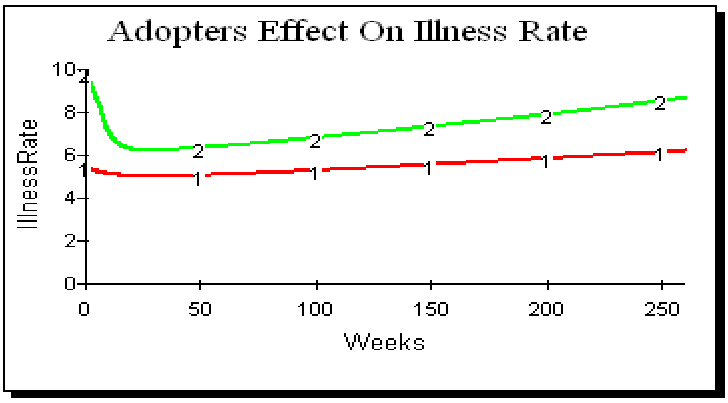

Figure 33 Adopters' effect on IllnessRate

The red line represents the first run with no effect from the Adopters. The *Reference_Illness_Probability* is taken as the *InfectionRate*. The second run the effect of the *AdoptersPercent* was taken into account.

A sensitivity test was done on to test the IllnessRate. To test this sensitivity three runs were made. Figure 34 shows the *ProductivityCommittee* results from the sensitivity test. The first run represented by the red line in figure 33 is the base run done like in hypothesis 1. The second run is the *IllnessRate* with the effect of the *AdoptersPercent* with no adjustment in the *SanitationCommitteeStaff*. In the third run represented by the blue line there was an immediate adjustment of 10 people in the *SanitationCommitteeStaff*.. When the *ProductivityCommitee* is up to 100% then the IllnessRate will be the minimum InfectionRate of 1%.

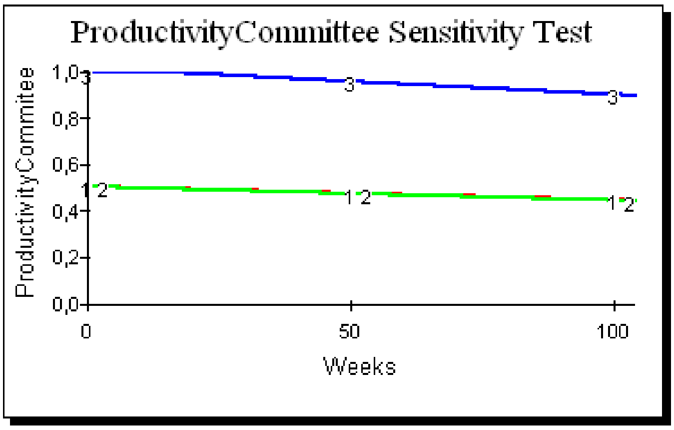

Figure 34 Productivity of Committee

With the present staff, the *ProductivityCommittee* is about less than 50%. This means that only 50% of the homes are being visited each year. This poor productivity from the sanitation staff is increasing the *InfectionRate*, increasing the *IllnessRate.*

Figure 35 shows how the IllnessRate reacted to this sensitivity test. The base run is the same being used before. In the second run when there is no adjustment to the *SanitationStaffCommitee* the *IllnessRate* was somewhat higher than the base run. In the third run with the adjustment of staff, the IllnessRate is as high as the second run but then decreases until it is the same as the base run, considering it is the minimum of cases per week.

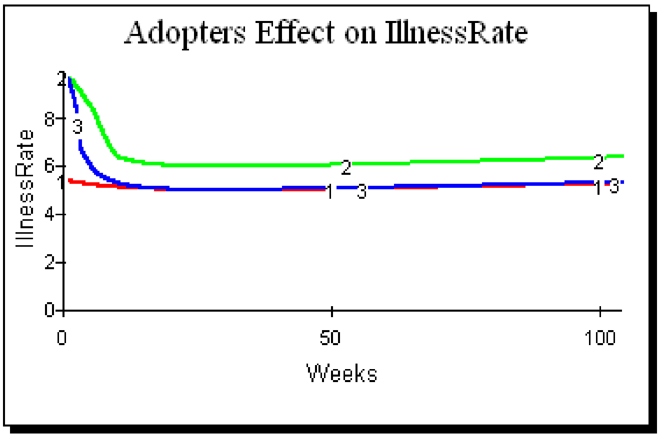

Figure 35 Sensitivity Testing on Adopters effect on IllnessRate

7.4 Testing H3 Infection rate for diarrhea increases when the drinking water is contaminated.

The *WaterQuality* depends on numerous factors in the system. It depends on the *EfficientFuctionalPipes*, *ClorationEfficiency* and *ActualTotalFixedExpenditures*. These are the expenditures that are required to be covered in order to have an adequate water quality. To cover for these expenditures the people from the community pay a water fee referred to as *CurrentFee.* The *CurrentFee* must be sufficient so that the water board has enough money for the *Expenditures*. Another factor that influences the income is the *PayingHouseholds*. The *PayingHouseholds* are the homes that are actually paying their water fee. It is assumed that the *AdoptersPercent* has an effect on the *PayingHouseholds*. This is assumed because part of the reinforcement of the committee in the homes is to explain and remind to people the importance of paying an adequate fee. It can become very easy for people to lose will to pay if they are not constantly reminded. The causal loop diagram in figure 36 shows that loop R3 is being tested for this hypothesis. R1 and R2 are not being included in the testing of this hypothesis.

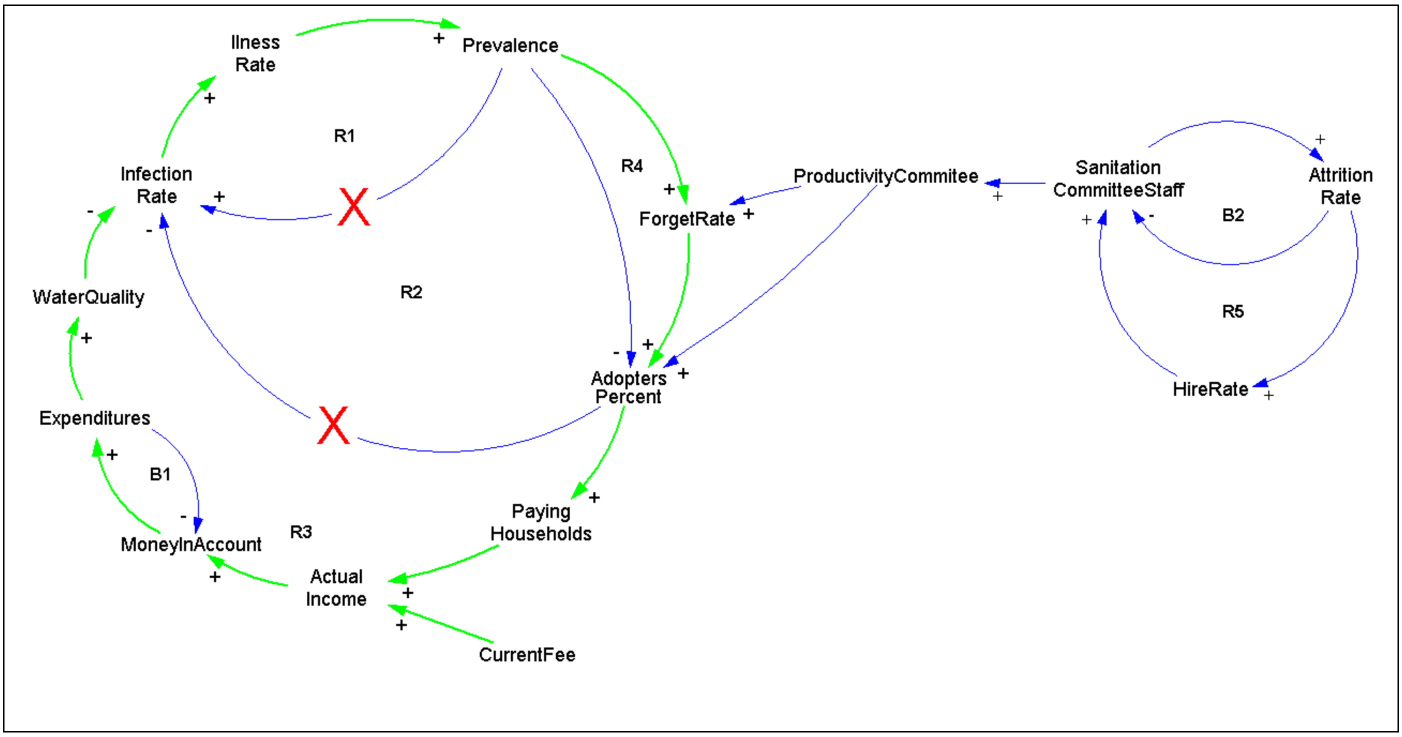

Figure 36 Hypothesis 3 Causal Loop Diagram

When the ActualIncome becomes insufficient to cover for the expenses required, then the water board cannot repair pipes, the water is not properly disinfecting the water with clorox and the other expenses are not covered. This hypothesis will be tested with the best and worst case sensitivity analysis. A base run was done with only the *Reference_Illness_Probability* affecting the IllnessRate. The second run was the worst case scenario, in this case, hypothesized to be the current situation with 500 Lempiras in the *MoneyInAccount* and 10 Lempiras as a *CurrentFee*. A third run was testing the best case scenario of having enough money. The *MoneyInAccount* was set with an initial value of 10000 Lempiras which covers for all Expenditures and a *CurrentFee* of 32 Lempiras, which equals to the IdealFee. Figure 36 demonstrates the results for this test.

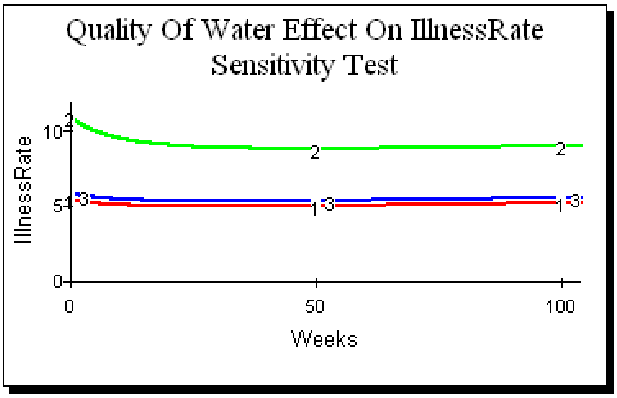

Figure 37 Sensitivity Testing of WaterQuality effect on IllnessRate.

In the first run the InfectionRate was equal to the *Reference_Illness_Probability* which is 1%. In the second run set as the worst case scenario, the *IllnessRate* doubled showing that the *WaterQuality* was poor due to the lack of coverage to the *Expenditures*. In the third run set as the best situation where everyone is paying the *CurrentFee*, the *CurrentFee* is the *IdealFee*, and there was enough *MoneyInAccount* to cover for the Expenditures. The *IllnessRate* was almost the same as the base run. This is because all Expenditures were covered improving the *WaterQuality*.

7.5 Reference Mode Replication

After testing all three hypotheses individually, it is now possible to simulate with all three hypotheses and identify if these hypotheses can replicate the reference mode. Figure 38 represents the simulation results of the different hypotheses in the same simulation. As can be observed the replication of the *EstimatedIllnessRate* or the reference mode, can be considered a fair replication of the actual behavior.

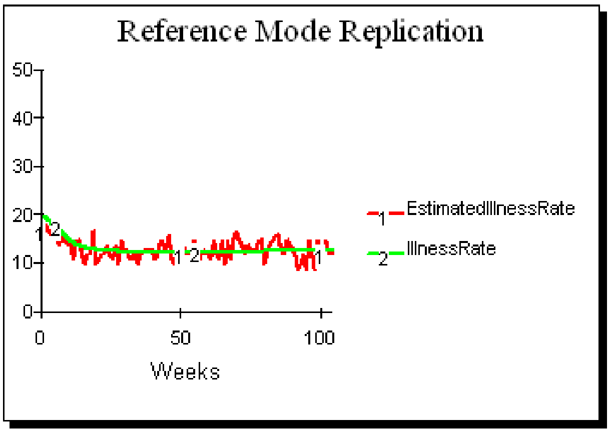

Figure 38 Reference Mode Replication

The hypotheses that have been assumed in this paper succeed in replicating a similar behavior to what is happening in real life concerning the Illness Rate in the community of Casco Urbano. Figure 39 illustrates the three hypotheses tested working together in the system which is doing a fair reproduction of the reference mode.

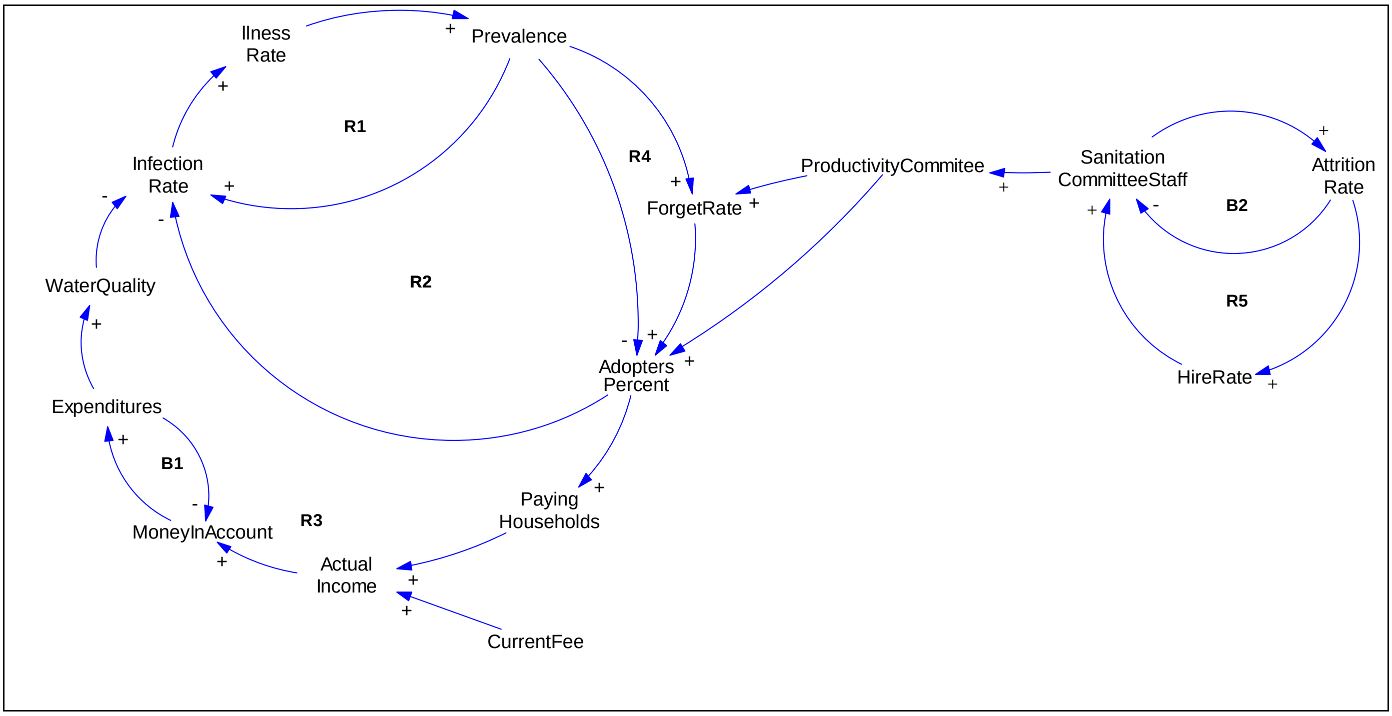

Figure 39 Causal Loop Diagram H1,H2 and H3

7.6 Summary

This chapter reviewed the analysis of the hypotheses suggested. The problematic behavior of the number of children getting sick from diarrhea was shown. The dynamic hypotheses assumed were tested separately to find how each one affected the *IllnessRate* of children. Then the hypotheses were tested together with the purpose of recreating the problematic behavior.

The model was put through different tests to make sure that it was robust and recreating a behavior that could be seen in real life. The model has proven to not be right, but useful. For that reason, it is possible to continue using the model in search of policies that could help improve the problematic behavior the model is reproducing.

8. Policy Analysis

The model has been tested and has proven to being robust and useful enough to use for policy analysis. The purpose of this section is to find policies that can positively influence the problem of diarrhea cases in Casco Urbano. There are 3 policies hypothesized to help improve the illness rate in children. Each policy will be explained individually. They will then be tested together to observe how the illness rate is affected by them. The additional policy structure added to the model can be found in Appendix B.

8.1 Problem

The problem the community of Casco Urbano has is the numbers of cases of diarrhea per week in children are very high considering the small population of the community. The model built and analyzed in this paper shows how the infection rate of diarrhea is being affected by the different situation the community faces.

To approach these situation this paper suggests a number of policies that aim to help get a perspective on how to approach these problems. They can be useful for the Water Board to take perspective on what parameters are manageable by them and how they can modify them to improve the situation of the number of diarrhea cases in children in the community.

The causal loop diagram in figure 39 presented the different causes for the high diarrhea illness rate. In this section, policies are proposed to address the problematic behavior in hand.

8.2 Policy Assumptions

The time horizon for the simulation in the policy testing is 260 weeks or 5 years. The policies are active after the second year or after 104 weeks.

The policies suggested are explained and tested separately and together to show the full effect on the diarrhea infection rate.

The base run in all three policy testing represented by the red line in all cases is the simulation resulting from the replication of the reference mode.

8.3 Policy 1 Additional Sanitation Committee Staff

The sanitation committee is an important factor to the improvement of the diarrhea illness rate in Casco Urbano. They are in charge of visiting homes to reinforce the information on the proper practice of hygienic and sanitation habits at home. At the same time, they encourage people to pay their water fee highlighting the importance of that income for each home and the community. The sanitation committee as discussed before is people from the same community, volunteering to perform this kind of work. At the moment, the sanitation committee has 5 people. The workload per staff member is to visit 5 homes per week. This workload is difficult to alter or increase considering that the sanitation committee does this work in their free time. As the number of homes increase, the time between visits each home is greater. If people are not reminded often about the importance of paying their water fee and implementing hygienic and sanitation habits, people tend to forget, decreasing the number of adopters. The first policy suggested is to have additional staff added to the sanitation committee. The committee at the moment only replaces people who do not want to be part of the sanitation committee. This kind of attrition is estimated to happen every 1.5 years or 78 weeks. The proposed policy is to have an additional staff added to the committee. The desired household visits per week is known or the *DesHouseholdVisitedPerWeek.* To find the *DesiredStaff* the *DesHouseholdVisitedPerWeek* is divided by the *ProductivityPerStaffMemeberPerWeek* of 5 homes per staff member per week. To determine the number of *AditionalStaff* the *SanitationCommitteeStaff* is subtracted from the *DesiredStaff.* The *AdditionalStaff* is then adjusted by the *AverageAdjustmentTimeStaff* and added in the *HireRate*. Figure 40 shows the additional structure added to the Sanitation Committee Sector to implement policy 1. The additional structure is shown in blue.

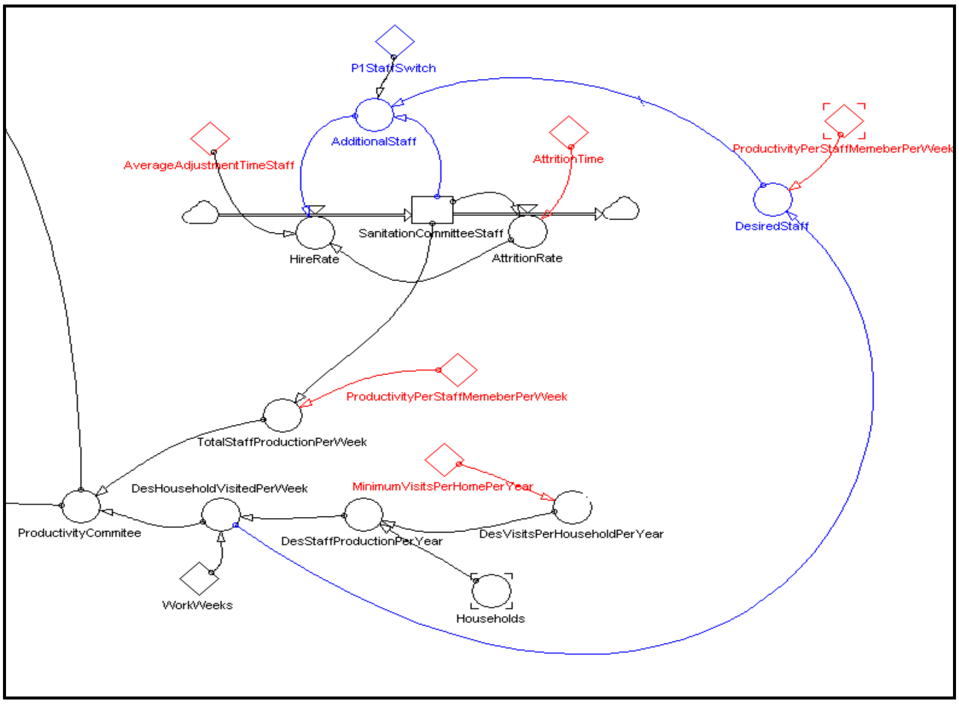

Figure 40 Policy 1 Structure

The causal loop diagram on figure 41 illustrates the feedback behind Policy 1. B2 represents the balancing loop that accounts for the *AdditionalStaff*. There is a number of *DesiredStaff* that comes from the *DesHouseholdVisitedPerWeek.* The *AdditionalStaff* is then the DesiredStaff minus the *SanitationCommitteeStaff*. The AdditionalStaff would increase the *HireRate*, increasing the *SanitationCommitteeStaff*. If there is enough staff the *TotalStaffProductionPerWeek* will increase, improving the *ProductivityCommittee*. As it has been explained before, this would increase the *AdoptersPercent* which would help decrease the *InfectionRate* decreasing the *IllnessRate*.

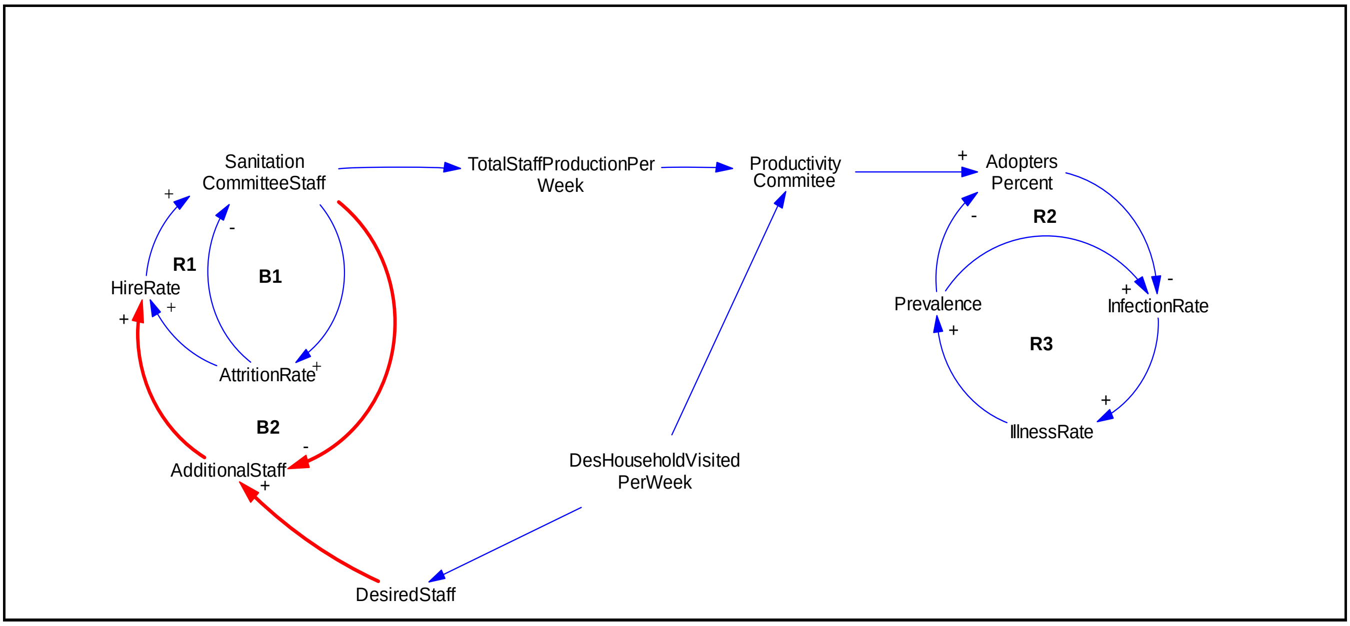

Figure 41 Policy 1 Causal Loop Diagram

Figure 42 shows the simulation results for the *ProductivityCommittee*. Policy 1 has been put in place after week 104. Before week 104 the *ProductivityCommittee* is on a declining trend. This is because the population of the community is growing increasing the workload for the committee. At the same time, the committee has decided to maintain only 5 staff memebers making it more difficult to be more productive. When the policy is implemented *the ProductivityCommittee* quickly increases.

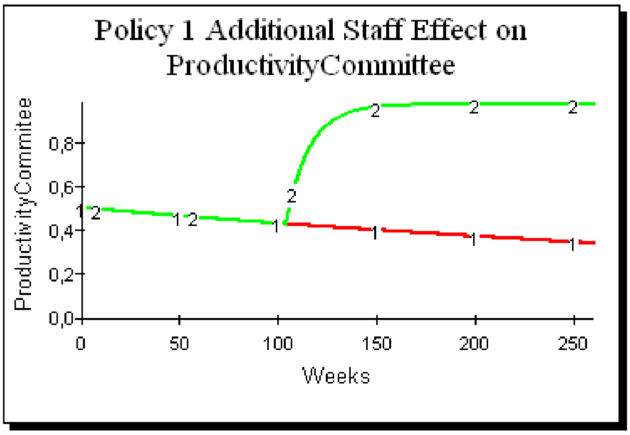

Figure 42 Policy 1 Productivity Committee

When the sanitation committee improves their ProductivityCommittee the number of Adopters increases, reducing the *IllnessRate*. The simulation results for Policy 1 for the *IllnessRate* are presented in figure 43. The problematic behavior is represented by the red line. The green line is the second run when the policy is implemented after 2 years or 104 weeks. Due to the improvement on the *ProductivyCommittee*, the *IllnessRate* has decreased significantly. This confirms that the work of the sanitation committee is very important and additional staff in the committee would only help improve the situation of diarrhea in children.

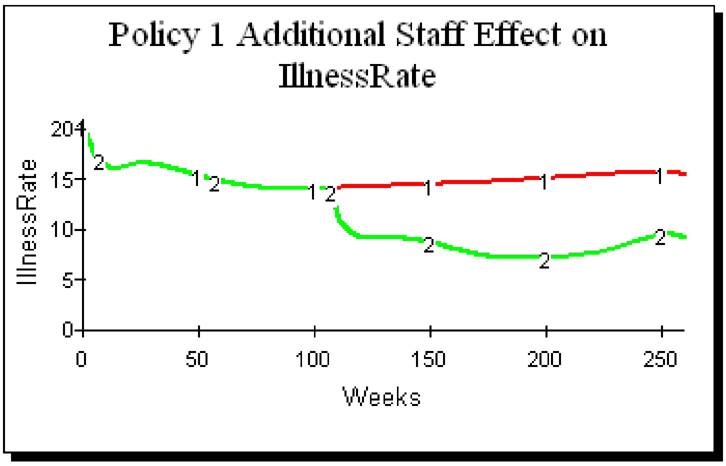

Figure 43 Policy 1 IllnessRate

8.4 Policy 2 Increase Number Of Visits Per Home Per Year

Currently, the committee has set a goal of visiting each home 10 times during the year. The second policy suggests that if the *Prevalence* of the diarrhea in children increases the *DesVisitsPerHouseholdPerYear* increases. The *EffectPrevalenceOnAditionalVisitsPerHomePerYear* is nonlinear graphical function which has an increasing effect on the *DesVisitsPerHouseholdPerYear* as the *Prevalence* increases. Figure 44 shows the additional structure added to the Sanitation Committee Sector in order to implement Policy 2. The structure in blue represents the additional structure for Policy 2.

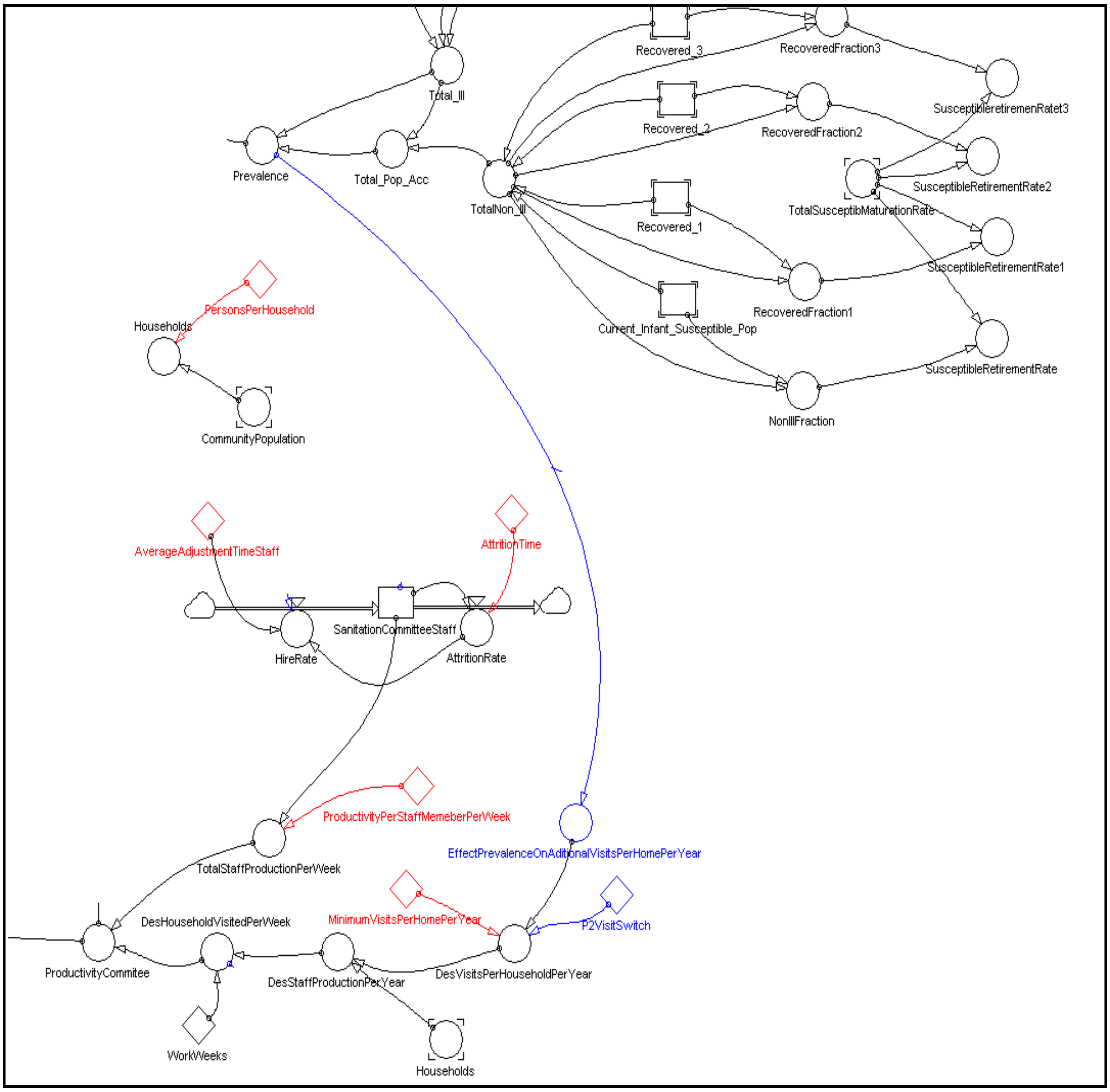

Figure 44 Structure Policy 2

The causal loop diagram in figure 45 represents Policy 2. R4 is the new feedback that has been created from Policy 2. As can be observed the policy suggests that if the *Prevalence* increases, the *DesVisitsPerHouseholdPerYear* increases. The *DesVisitsPerHouseholdPerYear* would increase the DesHouseholdVisitedPerWeek.

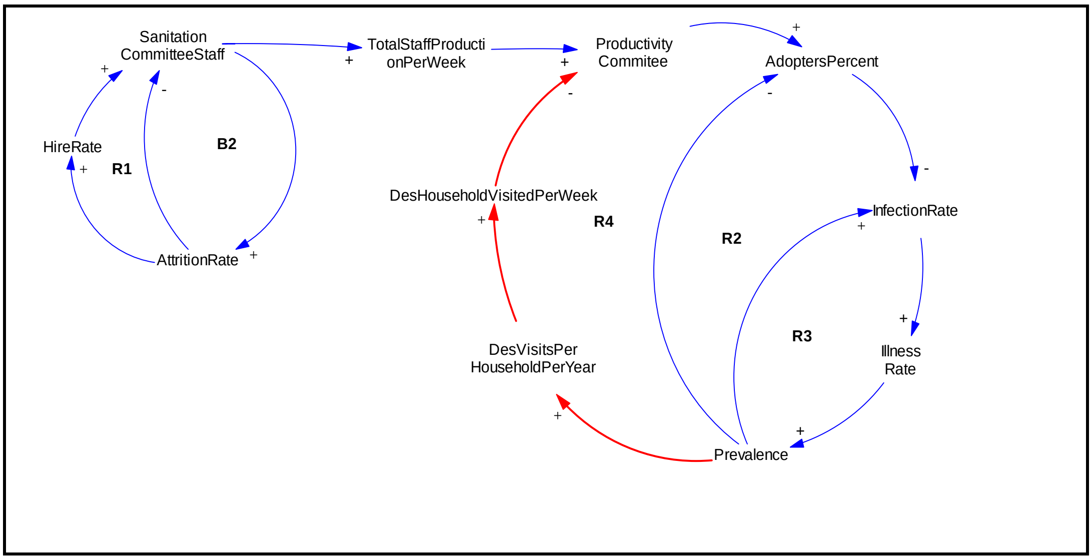

Figure 45 Policy 2 Causal loop diagram

Additional visits however, would mean more workload for the *SanitationCommitteeStaff.* The DesHouseholdVisitedPerWeek has a decreasing effect on the ProductivyCommittee, If there is more work and no extra staff helping, the *ProductivityCommittee* will simply decrease even more. When the *ProductivityCommittee* decreases it will eventually increase the *IllnessRate*. Figure 46 shows the comparison of the problematic behavior and the implementation of policy 2 to the *ProductivityCommittee.*

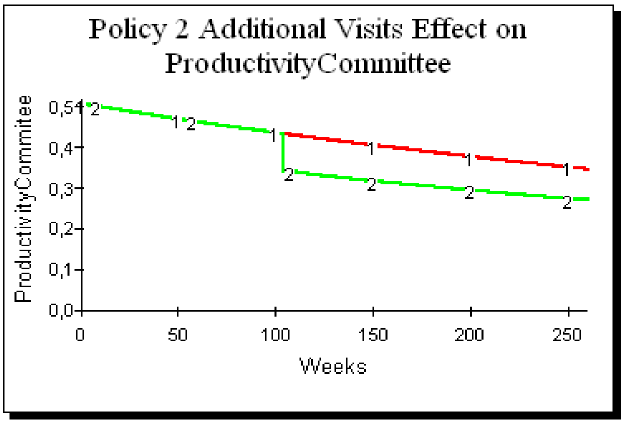

Figure 46 ProductivityCommittee Policy 2

The red line represents the *ProductivityCommittee* from the base run. When the policy is introduced after week 104 the *ProductivityCommittee* decreases even more. This is due to the additional workload the committee will have. Increasing the number of visits would only mean more work for the committee. Their productivity will be even less than when policy 2 was not implemented.

The *Prevalence* also increases when the policy is implemented. Figure 47 shows the results from the simulation comparing the *Prevalence* without the policy and with it.

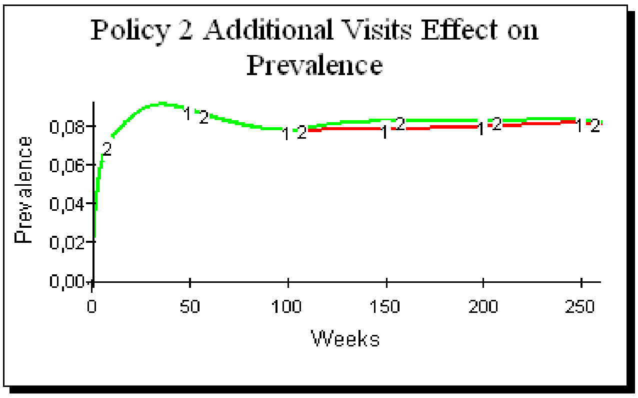

Figure 47 Prevalence Policy 2

The *ProductivityCommittee* has decreased more when the policy was implementing and the *Prevalence* was increased slightly. This is because the *ProductivityCommittee* went down, reducing the number of Adopters, reducing the *AdoptersPercen*t, increasing the *InfectionRate*. As seen before the *IllnessRate* which is changed by *the InfectionRate*, affects the *Prevalence* of sick children.

All the effects from these changes will then increase somewhat the *IllnessRate*. Figure 48 shows the simulation results of the effects of the policy on the *IllnessRate*. The *IllnessRate* slightly increases when Policy 2 is implemented.

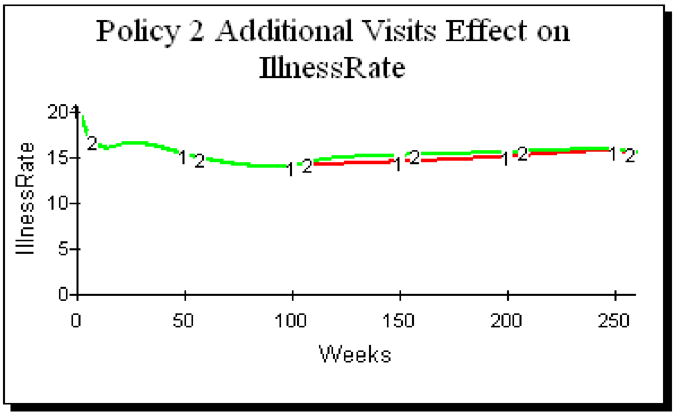

Figure 48 IllnessRate Policy 2

The purpose of a policy is to improve the current situation. However, the policy of increasing the *DesVisitsPerHouseholdPerYear* is a policy that cannot work on its own. If the workload is increased, the workforce must be increased as well. Policy 2 is only efficient when Policy 1 is implemented as well. If the sanitation committee decided to add more workload, they must decide to hire and train more people as well to be as efficient as possible. The causal loop diagram in figure 49 shows the feedback from both policies. B3 is the balancing loop representing Policy 1 where additional staff is added to the sanitation committee. The AdditionalStaff would increase the number of SanitationCommitteestaff improving the ProductivityCommittee. R4 is the reinforcing loop that represents Policy 2. This reinforcing loop would only increase workload which would decrease the *ProductivityCommittee*. However, when both policies are working together B4 is created. This negative feedback is the result of adding additional staff as the workload increases increasing the productivity of the committee, increasing the *AdoptersPercent* which will decrease the *IllnessRate*. The more visits are required because of increase of *Prevalence*, the more *AdditionalStaff* the committee will hire improving the *ProductivityCommittee* instead of decreasing it.

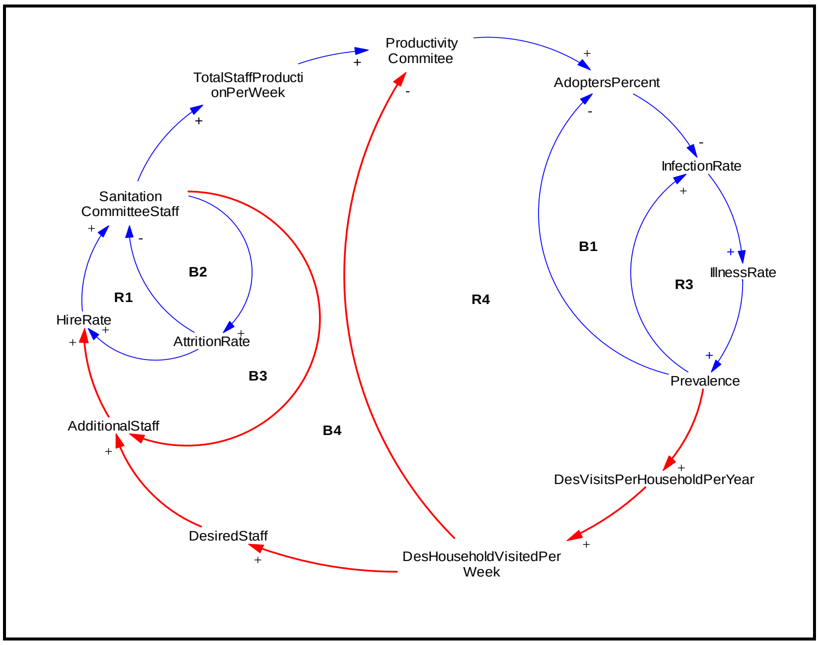

Figure 49 Causal Loop diagram Policy 1 and Policy 2

The simulation results for the *ProductivityCommittee* are shown in figure 50. The third run represents the result of when both policies are working together. The *ProductivityCommittee* improves significantly. This shows that as the workload increases, so does the staff in order to complete the goal set for the number of visits.

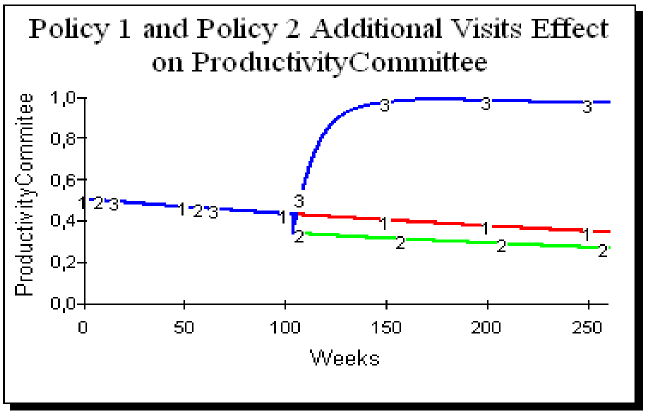

Figure 50 Policy 1 and Policy 2 ProductivityCommittee

The Prevalence was also expected to decrease. The graph in figure 51 demonstrates how the two policies decreased the *Prevalence*. When Policy 2 was put in place it had made the *Prevalence* increase slightly. When Policy 1 and 2 work together, the *Prevalence* decreased significantly.

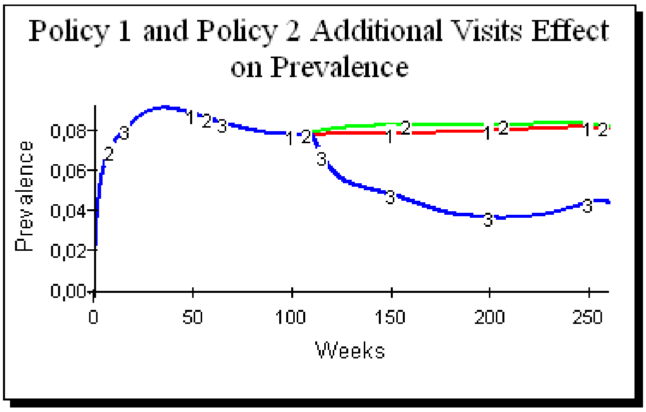

Figure 51 Policy 1 and Policy 2 Prevalence

The policies have managed to increase the *ProductivityCommittee* and decrease the *Prevalence* of sick children. The *IllnesRate* is then expected to decrease significantly as well. The blue line in figure 52 is the *IllnessRate* when both policies are working together. As discussed in the policy 1 testing, the *AdditionalStaff* has a positive effect on the *IllnessRate* by itself. Policy 2 has shown that it can create a bigger problem than the one presently if not hired additional staff to take over the workload.

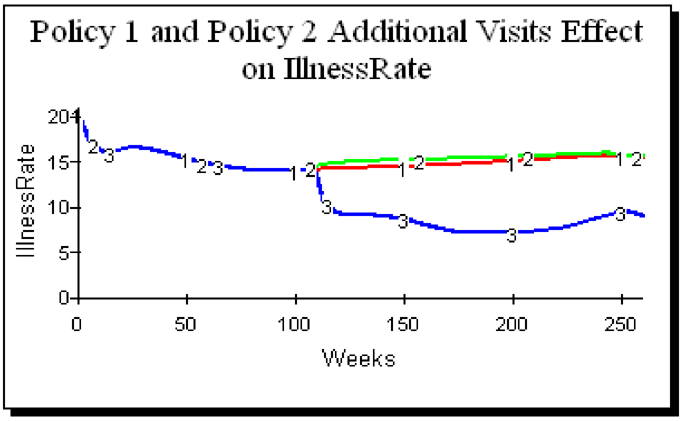

Figure 52 Policy 1 and Policy 2 IllnessRate

8.5 Policy 3 Adjustment of Water Fee

The third policy suggested in this paper is to improve the *CurrentFee* the community pays for the service of water distribution. The people in this community do not pay for the amount of water that each consumes. They pay a fixed fee that the water board is in charge of calculating in order to cover for the expenses required for the proper management of the water infrastructure assuring that the quality of the water is adequate for drinking. Figure 53 shows the causal loop diagram for Policy 3.

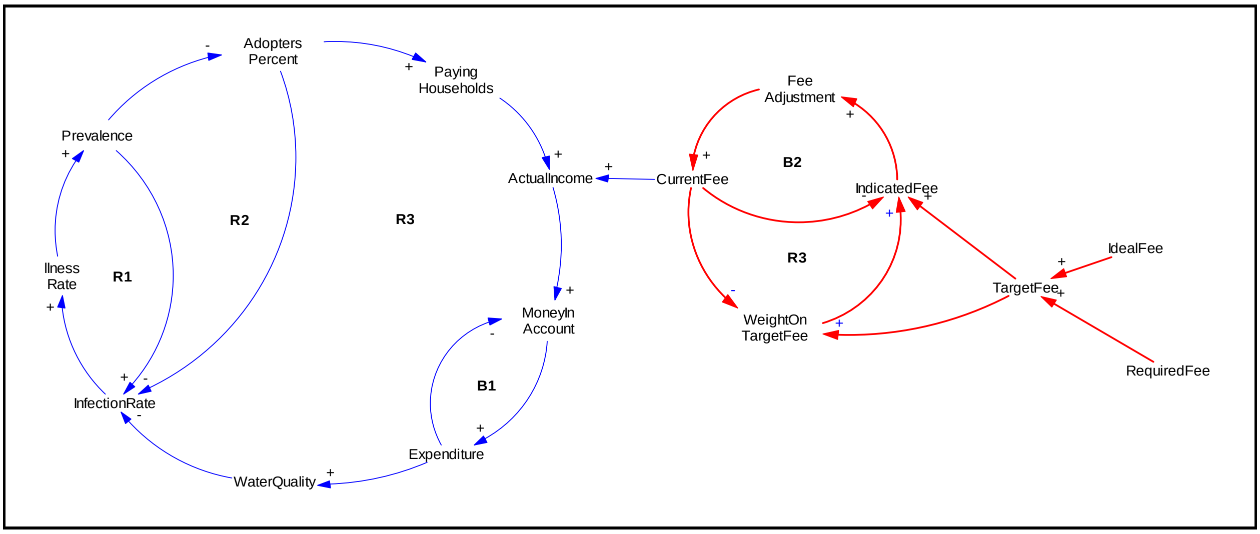

Figure 53 Policy 3 Causal Loop Diagram

Policy 3 of adjusting the *CurrentFee* consists of setting a goal for the fee and actually using it. What this policy suggests is that the water board finds an *IdealFee* and a *RequiredFee*. The *IdealFee* is the water fee that covers for the *DesiredExpenditures* assuming that all the Households are paying. The *DesiredExpenditures* are all the expenses that need to be covered fully. The *RequiredFee* is the water fee calculated from the *DesiredExpenditures* and considering only the *PayingHouseholds.* The

RequiredFee and the *IdealFee* will only be equal if all the Households becom *PayingHouseholds*. The WeightOnRequiredFee is the weight wanted on the *RequiredFee* and *IdealFee*. The *TargetFee* is then the *WeightOnRequiredFee* multiplies to the *RequiredFee* plus 1- *WeightOnRequiredFee* multiplied by the *IdealFee.* At this point the goal has been set, which is *the TargetFee*, but has not been used yet.

The *WeightOnTargetFee* is the weight that is given to the *TargetFee* if it greater than the *CurrentFe*e. The *IndicatedFee* is then the *TargetFee* multiplied by the *WeightOnTargetFee* plus 1- *WeightOnTargetFee* multiplied by the *CurrentFee*. The *IndicatedFee* represents the using of the goal. The *IndicatedFee* is then adjusted becoming the *CurrentFee*.

In the present situation, there is a very small weight on the *TargetFee*. The goal for the *TargetFee* is set, but the weight is so small that the goal is not being used. The small *WeightOnTargetFee* creates little change on the *IndicatedFee*, having a very insignificant increase in the *CurrentFee*. The graph on figure 54 shows how the IllnessRate decreased when the third policy was put in place.

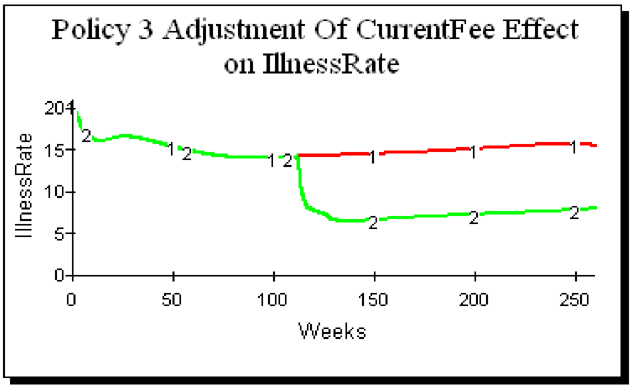

Figure 54 Policy 3 Illness Rate

8.6 Policy 1, Policy 2 and Policy 3

Each policy suggested in this paper was explained and tested separately. If all the policies were applied at once, then there would be a significant change in the *IllnessRate*. There would be more staff working due to policy 1. People would be visited more often by the sanitation committee because of policy 2. The water people would be receiving would be disinfected because people would pay the adequate fee required to have a proper functioning system because of policy 3. The causal loop diagram in figure 55 illustrates the three policies suggested working together. Policy 1 is represented by B3. Policy 2 is represented by the reinforcing loop R3. Policy 3 is represented by B6 and R4. These feedbacks suggest that if the number of visits per home were increased if the *Prevalence* increased, the number of staff was increased according to the additional workload and an adequate water fee was paid then the *IllnessRate* would decrease significantly.

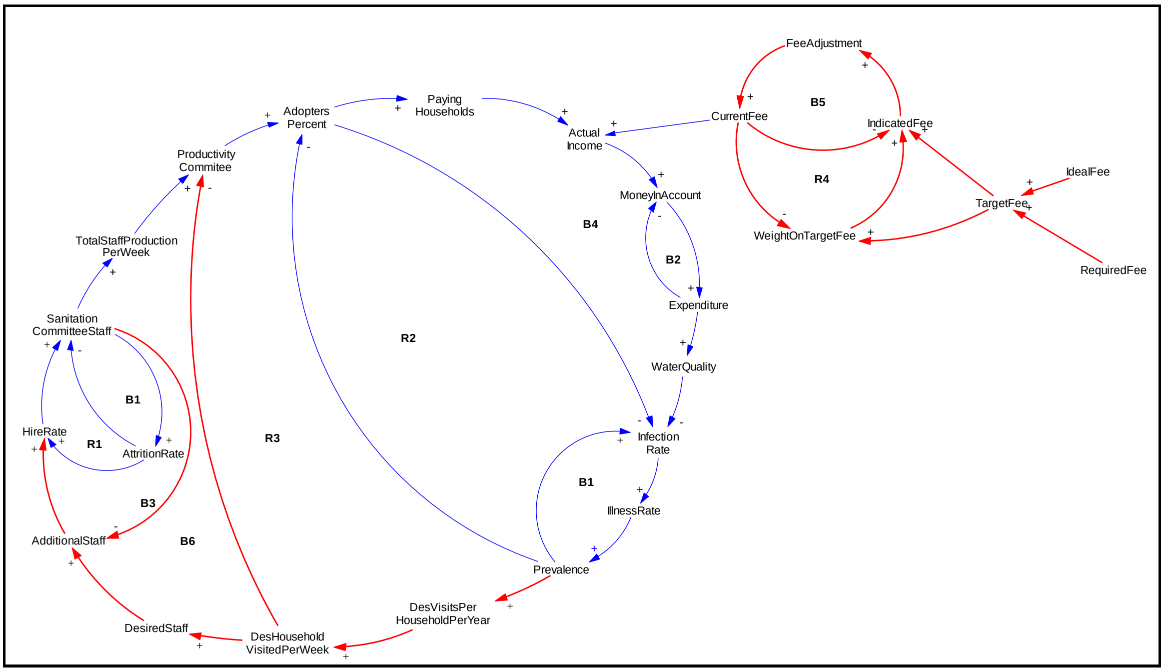

Figure 55 P1, P2, and P3 Causal Loop Diagram

The problem until week 104 is that there is no improvement in the *IllnessRate*. After week 104 the three policies were put in place. Since the Prevalence was slowly increasing with no policy. The *ProductivityCommitee* was on a decreasing trend because the adult population was increasing, and the number of staff to visit the homes was the same. When the three policies are put to place the number of visits per home per year increases which increasing the workload for the committee. At the same time, the sanitation committee would adjust their staff in order to fulfill the workload given by the growing population and the additional visits. The water board would also adjust the water fee that people pay in order to cover for the expenses required to provide clean drinking water. Due to all the changes the IllnessRate is expected to decrease considerably. Figure 56 shows the graph of how the *IllnessRate* reacts to the implementation of the three policies.

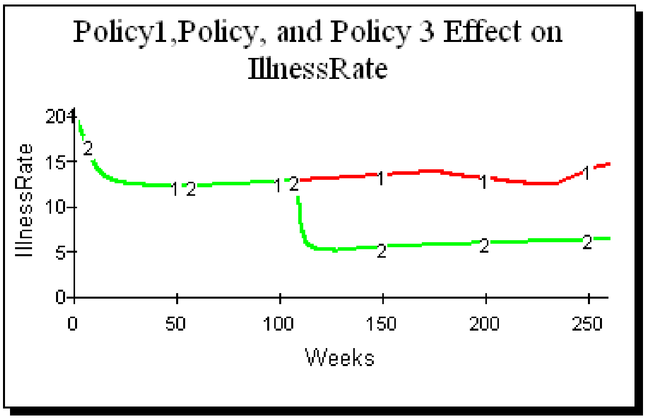

Figure 56 IllnessRate with P1,P2 and P3

8.7 Testing Policies 1,2, and 3

To test all three policies in extreme conditions, the *FractionOfFunctionalPipesDamaged* will be changed for 30 weeks. The present value is 0.001. The extreme condition would be that 10% of the pipes in the system would break down from week 150 to 180.

The adjustment of the *CurrentFee* is presented in the graph in figure 57. The fourth run is how the fee was adjusted in response to the shock in the system with the damaged pipes. For a period of time people pay a fee of about 50 Lempiras. This is the highest fee in the simulation, which happens when the accident is taking place. The *CurrentFee i*s then reduced and even decreases because the pipes have been replaced and the fee is adjusted to the financial needs of the system.

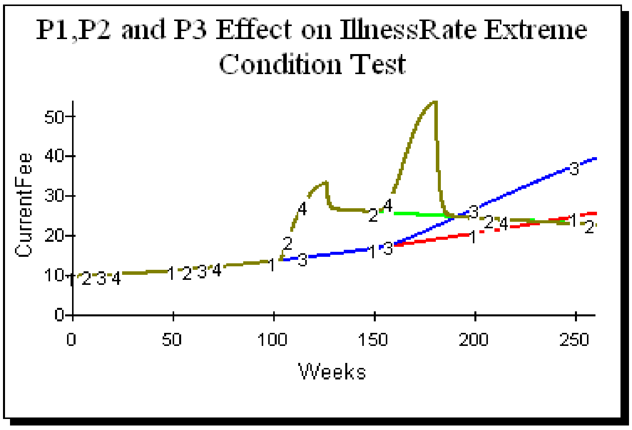

Figure 57 Current Fee Extreme Conditions Test P1,P2 and P3

The graph in figure 58 shows the results of the effect of the policies in the *IllnessRate* in extreme conditions. The second run shows the system after the policy has been put into place. The fourth run shows the system when there is a shock of 10% of *FractionOfFunctionalPipesDamaged* for 30 weeks. The *IllnessRate* increased for some time but decreased again. The *IllnessRate* increased because it would take time to adjust the *CurrentFee* to cover for the purchase and replacement of the pipes that are being damaged. It would also take time to adjust the *SanitationCommitteeStaff* if it was necessary.

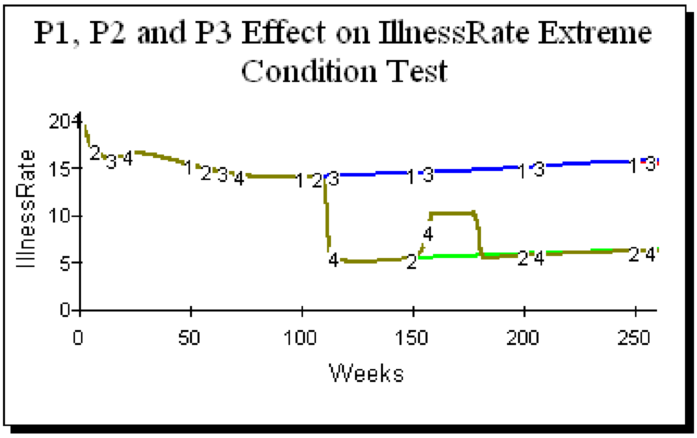

Figure 58 IllnessRate Extreme Conditions Test P1, P2 and P3

8.8 Summary

This section presented the different policies that have been hypothesized to help improve the high *IllnessRate* of diarrhea cases in children in the community of Chinda. The additional structures for the policies were first explained individually, explaining the behavior of the *IllnessRate* in response to each one. They show to be robust under the different scenarios and tests done. The policies presented in this paper do not intend to fully solve the problem in hand, but it can be a good starting point.

9. Implementation

In this section the implementation of the policies suggested is discussed. The policies discussed have been previously tested to make sure that they are realistic approaches to the problem the model recreates. The socio- cultural aspects of implementing these policies have also been thought of. They are decisions and scenarios that would not have a cultural impediment when it comes to implement them.

9.1 Implementing Policy 1 Additional Sanitation Committee Staff

Policy 1 suggested that the sanitation committee increase their number of staff according to the workload and their goals of visiting homes 10 times a year. A way to implement this policy is to ask for more volunteers to participate in the sanitation committee. This could be done in town meetings or while visiting the homes. They could encourage people to join the committee. They could evaluate people that seem to be capable to join the committee and persuade them. Being in the committee could be projected as a prestigious work, stressing the important task they have. The committee members are possibly seen as important leader figures by others and this could become a motivation for people to volunteer.

9.2 Implementing Policy 2 Additional Visits

Policy 2 recommends that there are additional visits per home per year if there was an increase in the Prevalence. It was also recommended that if this policy were to be implemented the sanitation committee should also apply the first policy of adjusting their staff.

The implementation for this policy would be partly implemented like the first policy. If they decide to increase the number of visits, they could encourage people to join the committee. They would have to explain the problem of the increase in the number of children getting sick and how it is important for the committee to reach all homes as many times as possible to promote good hygienic habits.

To implement this policy the water board must be aware of the Prevalence of the disease in the community. In order to do this they must keep record of the diarrhea cases in children. This could be done in the visits to each home. They could keep track of how many cases are happening each week from the number of homes they visit. They can also promote to the community members to report if they sick children with diarrhea to their visitor even if they are not being visited that week. Keeping track of the number of cases is crucial to the implementation of this policy because it would become difficult for the committee to know if they should add more visits if they do not know how the diarrhea cases are developing.

9.3 Implementing Policy 3 Adjustment of Current Fee

The third policy suggests that the CurrentFee be adjusted in order to cover for the expenses need in order to receive clean water. If there was an accident as seen in the extreme conditions tested in the policies, there would need a quick adjustment of the CurrentFee to ensure that the quality of the water will not decrease. Once the situation is under control, the fee can be adjusted again but this time to reduce it. The Water Board has to take much of the responsibility to make people in the community understand when and why the fee will be adjusted. If people are not explained properly, much speculation of the water board and sanitation committee intentions could be questioned losing credibility. However, if done right, people would be willing to accept any change in the fee if justified right.

10. Conclusions

This paper presented a problem of diarrhea cases in children in the rural community of Casco Urbano located in Santa Barbara Honduras. There have been different studies done to pinpoint the main causes of diarrhea in children. The model built and presented in this paper intended to represent the structure of the hypotheses thought to explain the problem. The model intended to reproduce the problematic behavior happening in real life as well. As the model was found to be useful, policies were suggested to find possible solutions to control the problem. The policies resulted to be useful as well.

The use of System Dynamics helped explore the many causes for diarrhea. It has been showed there are three important factors that influence the infection rate of diarrhea:

- Education
- Sanitation and Hygiene
- Quality of Water
- Prevalence

In order for people to know about diarrhea, its causes, effects and how to prevent it , they must be told about it. Educating people on the illness is an important way to prevent it. Sanitation and hygienic habits must also be taught to people. When the proper sanitation and hygienic habits are practiced on a daily basis it decreases the probability of getting sick from diarrhea decrease. Investment in the water infrastructure is important. The investments on the infrastructure and maintenance will determine the quality of the water that is being distributed. Finally, the prevalence also increases the infection rate.

I consider that this paper has illustrates important feedbacks in the system that are possible not being considered. Again, this paper does not intend to solve the problem, but it is definitely a step start to modifying the system in order to improve the problem of diarrhea in children.

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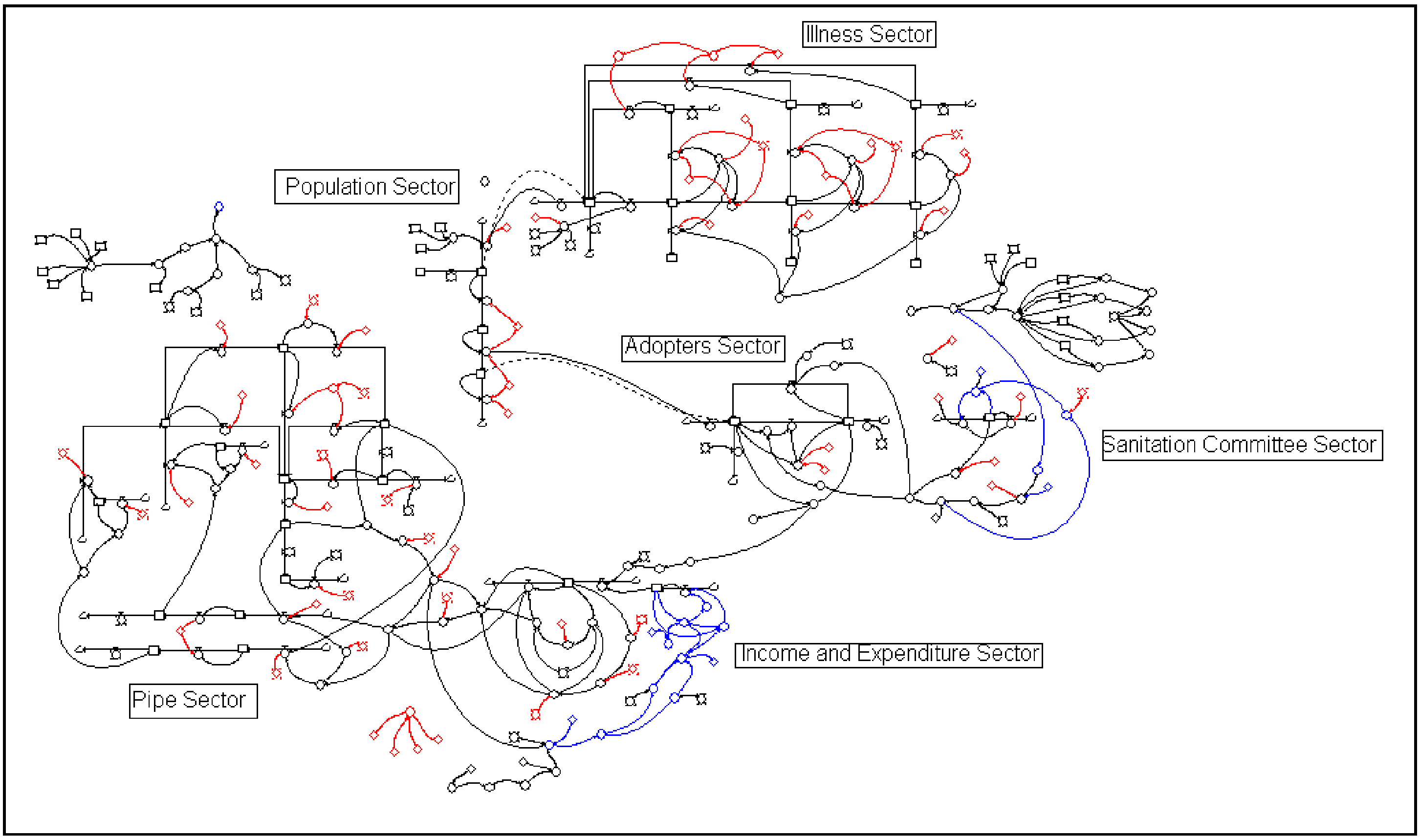
12. Appendix

The appendix contains material that has not been included in the main report. However, they are important to the understanding of the material presented in this paper. This appendix will first present the overview of the model as well the policy structure added to it. It will also present the equations of such and pictures from the field research done for this paper.

12.1 Appendix A

Appendix A presents a full picture of the model discussed in this paper.



12.2 Appendix B

Appendix C presents the equations for the model subdivided into the six sectors that have been discussed and described previously. The variables have been identified according to the type of variable and their respective units. The following list elaborates the meaning of the abbreviations used in this section:

- Aux: auxiliary variable
- Const: constant variable
- Flow: inflows and outflows changing the stock variable
- Init: variable's initial value
- Unit: variable unit
- Variables in color blue are policy variables
    - Lmps: Lempiras (Honduran Currency)

12.2.1 Population Sector

aux AdultDeathRate = AdultPopulationInNewHouseholds/(Life_Time-AgeOfMarrying)

unit AdultDeathRate = people/week

init AdultPopulationInNewHouseholds = 400

flow AdultPopulationInNewHouseholds = dt*AdultDeathRate+
dt*PopulationEnteringNewHouseholds

unit AdultPopulationInNewHouseholds = people

const AgeOfMarrying = 25*52

unit AgeOfMarrying = weeks

const AgeOfNon_Susceptible = 15*52

unit AgeOfNon_Susceptible = weeks

aux Births = CommunityPopulation*BirthRate

unit Births = people/week

const BirthRate = 0.06/52

unit BirthRate = 1/week

aux CommunityPopulation = AdultPopulationInNewHouseholds+PopulationInFormerHouseholds+TotalInfantPopulation

unit CommunityPopulation = people

init CumDead = 0

flow CumDead = -dt*Tot_Infant_Mortality_Rate

unit CumDead = people

const Life_Time = 70*52

unit Life_Time = weeks

init PopulationInFormerHouseholds = 370

flow PopulationInFormerHouseholds = -dt*PopulationEnteringNewHouseholds

+dt*TotalSusceptibMaturationRate

unit PopulationInFormerHouseholds = people

aux PopulationEnteringNewHouseholds = PopulationInFormerHouseholds/(AgeOfMarrying-AgeOfNon_Susceptible)

unit PopulationEnteringNewHouseholds = people/week

init TotalInfantPopulation = 550

flow TotalInfantPopulation = +dt*Births

+dt*Tot_Infant_Mortality_Rate

-dt*TotalSusceptibMaturationRate

unit TotalInfantPopulation = people

12.2.2 Illness Sector

init Current_Infant_Susceptible_Pop = TotalInfantPopulation

flow Current_Infant_Susceptible_Pop = -dt*SusceptibleRetirementRate

+dt*SusceptibleRate

+dt*ImmunityLossRate3

+dt*ImmunityLossRate2

-dt*IllnessRate

+dt*ImmunityLossRate1

unit Current_Infant_Susceptible_Pop = people

aux EffOfPrevalenceOnProbOfInfection = GRAPH(Prevalence,0,0.02,[1.04,1.04,1.06,1.11,1.21,1.49,1.69,1.79,1.85,1.86,1.86"Min:1;Max:2;Zoom"])

aux IllnessRate = Current_Infant_Susceptible_Pop*InfectionRate

unit IllnessRate = people/week

aux InfectionRate = EffAdoptionOnProbToGetInfected*EffOfPrevalenceOnProbOfInfection*WaterQualityEffectOnInfectionRate*Reference_Illness_Probability*0+Reference_Illness_Probability*0+Reference_Illness_Probability

unit InfectionRate = 1/week

aux ImmunityLossRate1 = Recovered_1/TimeToLose_Imm_1

unit ImmunityLossRate1 = people/week

aux ImmunityLossRate2 = Recovered_2/TimeToLose_Imm_2

unit ImmunityLossRate2 = people/week

```
aux     ImmunityLossRate3 = Recovered_3/TimeToLose_Imm_3
unit    ImmunityLossRate3 = people/week

aux     NonIllFraction = Current_Infant_Susceptible_Pop/TotalNon_Ill
const   Max_DurationOfDisease_1 = 1
unit    Max_DurationOfDisease_1 = weeks

const   Max_DurationOfDisease_2 = 2.5
unit    Max_DurationOfDisease_2 = weeks
const   Max_DurationOfDisease_3 = 10
unit    Max_DurationOfDisease_3 = weeks

const   Mortality_1 = .02
unit    Mortality_1 = 1/week

const   Mortality_2 = 0.04
unit    Mortality_2 = 1/week

const   Mortality_3 = 0.1
unit    Mortality_3 = 1/week

aux     Mortality_Rate_1 = Pop_Transf_From_1*Mortality_1
unit    Mortality_Rate_1 = people/week

aux     Mortality_Rate_2 = Pop_Transf_From_2*Mortality_2
unit    Mortality_Rate_2 = people/week

aux     Mortality_Rate_3 = Pop_Transf_From_3*Mortality_3
unit    Mortality_Rate_3 = people/week
```

init Mortality_Pop1 = 0

flow Mortality_Pop1 = +dt*Mortality_Rate_1

unit Mortality_Pop1 = people

init Mortality_Pop2 = 0

flow Mortality_Pop2 = +dt*Mortality_Rate_2

unit Mortality_Pop2 = people

init Mortality_Pop3 = 0

flow Mortality_Pop3 = +dt*Mortality_Rate_3

unit Mortality_Pop3 = people

aux Pop_Transf_From_1 = Stage1_IllPopulation/(Max_DurationOfDisease_1)

unit Pop_Transf_From_1 = people

aux Pop_Transf_From_2 = Stage2_IllPopulation/(Max_DurationOfDisease_2)

unit Pop_Transf_From_2 = people

aux Pop_Transf_From_3 = Stage3_IllPopulation/(Max_DurationOfDisease_3)

unit Pop_Transf_From_3 = people

aux Prevalence = Total_Ill/Total_Pop_Acc

aux PrevalenceEffOnForgetRate =
GRAPH(Prevalence,0,0.02,[0.14,0.14,0.14,0.19,0.26,0.38,0.51,0.7,0.83,0.9,0.9"Min:0;Max:1"])

const Prob_Recovery_1 = 0.7

const Prob_Recovery_2 = 0.5

init Recovered_1 = 0

flow Recovered_1 = -dt*SusceptibleRetirementRate1
-dt*ImmunityLossRate1
+dt*RecoveryRate_1
unit Recovered_1 = people

init Recovered_2 = 0
flow Recovered_2 = -dt*ImmunityLossRate2
-dt*SusceptibleRetirementRate2
+dt*RecoveryRate_2
unit Recovered_2 = people

init Recovered_3 = 0
flow Recovered_3 = -dt*ImmunityLossRate3
-dt*SusceptibleretiremenRatet3
+dt*RecoveryRate_3

unit Recovered_3 = people

aux RecoveredFraction1 = Recovered_1/TotalNon_Ill

aux RecoveredFraction2 = Recovered_2/TotalNon_Ill

aux RecoveredFraction3 = Recovered_3/TotalNon_Ill

aux RecoveryRate_1 = Pop_Transf_From_1*(1-Mortality_1)*Prob_Recovery_1
unit RecoveryRate_1 = people/week

aux RecoveryRate_2 = Pop_Transf_From_2*(1-Mortality_2)*Prob_Recovery_2
unit RecoveryRate_2 = people/week

```
aux    RecoveryRate_3 = Pop_Transf_From_3*(1-Mortality_3)
unit   RecoveryRate_3 = people/week

const  Reference_Illness_Probability = .01
unit   Reference_Illness_Probability = 1/week

init   Stage1_IllPopulation = 0
flow   Stage1_IllPopulation = -dt*TransferStage1_2
       +dt*IllnessRate
       -dt*Mortality_Rate_1
       -dt*RecoveryRate_1
unit   Stage1_IllPopulation = people

init   Stage2_IllPopulation = 0
flow   Stage2_IllPopulation = +dt*TransferStage1_2
       -dt*Mortality_Rate_2
       -dt*TransferStage2_3
       -dt*RecoveryRate_2
unit   Stage2_IllPopulation = people

init   Stage3_IllPopulation = 0
flow   Stage3_IllPopulation = +dt*TransferStage2_3
       -dt*Mortality_Rate_3
       -dt*RecoveryRate_3
unit   Stage3_IllPopulation = people

aux    SusceptibleRate = Births
unit   SusceptibleRate = people/week
```

aux SusceptibleretiremenRatet3 = TotalSusceptibMaturationRate*RecoveredFraction3

unit SusceptibleretiremenRatet3 = people/week

aux SusceptibleRetirementRate = TotalSusceptibMaturationRate*NonIllFraction

unit SusceptibleRetirementRate = people/week

aux SusceptibleRetirementRate1 = TotalSusceptibMaturationRate*RecoveredFraction1

unit SusceptibleRetirementRate1 = people/week

aux SusceptibleRetirementRate2 = TotalSusceptibMaturationRate*RecoveredFraction2

unit SusceptibleRetirementRate2 = people/week

aux TimeToLose_Imm_1 = TimeToLose_Imm_2/2

unit TimeToLose_Imm_1 = weeks

aux TimeToLose_Imm_2 = TimeToLose_Imm_3/2

unit TimeToLose_Imm_2 = weeks

const TimeToLose_Imm_3 = 34

unit TimeToLose_Imm_3 = weeks

aux Total_Ill = Stage1_IllPopulation+Stage2_IllPopulation+Stage3_IllPopulation

unit Total_Ill = people

aux Tot_Infant_Mortality_Rate = Mortality_Rate_1+Mortality_Rate_2+Mortality_Rate_3

unit Tot_Infant_Mortality_Rate = people/week

aux TotalNon_Ill = Recovered_1+Recovered_2+Recovered_3+Current_Infant_Susceptible_Pop unit   TotalNon_Ill = people

aux   Total_Pop_Acc = Total_Ill+TotalNon_Ill

unit   Total_Pop_Acc = people

aux   TotalSusceptibMaturationRate = TotalInfantPopulation/AgeOfNon_Susceptible

unit   TotalSusceptibMaturationRate = people/week

aux   TransferStage1_2 = Pop_Transf_From_1*(1-Mortality_1)*(1-Prob_Recovery_1)

unit   TransferStage1_2 = children/week

aux   TransferStage2_3 = Pop_Transf_From_2*(1-Mortality_2)*(1-Prob_Recovery_2)

unit   TransferStage2_3 = people/week

aux   WaterQualityEffectOnInfectionRate =
GRAPH(WaterQuality,0,0.1,[2,2,2,2,1.83,1.45,1.31,1.2,1.15,1.08,1.08"Min:1;Max:2"])

12.2.3 Sanitation Committee Sector

aux   AditionalStaff = IF(TIME>104,IF(P1StaffSwitch=1,(DesiredStaff-SanitationCommitteeStaff),0),0)

unit   AditionalStaff = staff

aux   AttritionRate = SanitationCommitteeStaff/AttritionTime

unit   AttritionRate = staff/week

const   AttritionTime = 52*1.5

unit   AttritionTime = weeks

const   AverageAdjustmentTimeStaff = 12 unit AverageAdjustmentTimeStaff = weeks

aux DesHouseholdVisitedPerWeek = DesStaffProductionPerYear/WorkWeeks

unit DesHouseholdVisitedPerWeek = visits/week

aux DesiredStaff = DesHouseholdVisitedPerWeek/ProductivityPerStaffMemeberPerWeek

unit DesiredStaff = staff

aux DesStaffProductionPerYear = DesVisitsPerHouseholdPerYear*Households

unit DesStaffProductionPerYear = visits/year

aux DesVisitsPerHouseholdPerYear = IF(TIME>104,IF(P2VisitSwitch=1,EffectPrevalenceOnAditionalVisitsPerHomePerYear*MinimumVisitsPerHomePerYear*P2VisitSwitch,MinimumVisitsPerHomePerYear),MinimumVisitsPerHomePerYear)

unit DesVisitsPerHouseholdPerYear = visits/home/year

aux EffectPrevalenceOnAditionalVisitsPerHomePerYear = GRAPH(Prevalence,0,0.05,[1,1.18,1.32,1.44,1.48,1.5,1.5,1.54,1.61,1.73,1.96"Min:1;Max:2"])

aux HireRate = AttritionRate+(AditionalStaff/AverageAdjustmentTimeStaff)

unit HireRate = staff/week

aux Households = CommunityPopulation/PersonsPerHousehold

unit Households = homes

aux LearningRate = (AdoptionFromCommitee+AdoptionFrom_W_of_M)

unit LearningRate = people/week

const MinimumVisitsPerHomePerYear = 10

unit MinimumVisitsPerHomePerYear = visits/home/year const P1StaffSwitch = 0

const P2VisitSwitch = 0

const PersonsPerHousehold = 6

unit PersonsPerHousehold = people/home

aux ProductivityCommitee = MIN(1,TotalStaffProductionPerWeek/DesHouseholdVisitedPerWeek

const ProductivityPerStaffMemeberPerWeek = 5

unit ProductivityPerStaffMemeberPerWeek = visits/staff/week

aux TotalStaffProductionPerWeek =
SanitationCommitteeStaff*ProductivityPerStaffMemeberPerWeek

unit TotalStaffProductionPerWeek = visits/week

init SanitationCommitteeStaff = 5

flow SanitationCommitteeStaff = -dt*AttritionRate

+dt*HireRate

unit SanitationCommitteeStaff = staff

const WorkWeeks = 45

unit WorkWeeks = weeks

12.2.4 Adopters Sector

init Adopters = 0

flow Adopters = -dt*AdoptersDeathRate+dt*LearningRate-dt*ForgetRate

unit Adopters = people

init Potential_Adopters = AdultPopulationInNewHouseholds flow Potential_Adopters = -dt*PotentialAdoptersDeathRate

+dt*NewAdoptersRate

+dt*ForgetRate

-dt*LearningRate

unit Potential_Adopters = people

aux AdoptersDeathRate = AdultDeathRate*0.1

unit AdoptersDeathRate = people/week

aux AdoptionFrom_W_of_M =
ContactRate*AdoptionRate*Potential_Adopters*Adopters/Potential_Adopters

unit AdoptionFrom_W_of_M = people/week

aux AdoptionFromCommitee = CommitteeEffect*Potential_Adopters

unit AdoptionFromCommitee = people/week

aux AdoptersPercent = Adopters/(Adopters+Potential_Adopters)

const AdoptionRate = 0.01

aux CommitteeEffect =
GRAPH(ProductivityCommitee,0,0.2,[0,0.04,0.09,0.13,0.19,0.21"Min:0;Max:1"])

const ContactRate = 3

aux EffAdoptionOnProbToGetInfected =
GRAPH(AdoptersPercent,0,0.1,[1.8,1.8,1.8,1.75,1.65,1.3,1.21,1.12,1.06,1,1"Min:1;Max:2;Zoom"])

aux ForgetRate = Adopters*ProductivityCommiteEffonForgetRate*PrevalenceEffOnForgetRate

unit ForgetRate = people/week

aux NewAdoptersRate = PopulationEnteringNewHouseholds

unit NewAdoptersRate = people/week

aux PotentialAdoptersDeathRate = AdultDeathRate*0.9

unit PotentialAdoptersDeathRate = people/week

aux ProductivityCommiteEffonForgetRate =
GRAPH(ProductivityCommitee,0,0.1,[0.8,0.8,0.8,0.8,0.8,0.79,0.64,0.49,0.42,0.4,0.4"Min:0;Max:1"])

12.2.5 Income and Expenditure Sector

aux ActualIncome = PayingHouseholds*CurrentFee

unit ActualIncome = lmps/week

aux ActualCloroxExpenditures =
DesiredWeeklyExpendituresForClorox*EffOfAccountBeforeCoverageOnCloroxExpenditures

unit ActualCloroxExpenditures = lmps

aux ActualInvestmentInNewPipes =
DesiredWeeklyExpendituresForNewPipes*EffOfTotalAccountCoverageOnInvestmentsInNewPipes

unit ActualInvestmentInNewPipes = lmps

aux ActualTotalFixedExpenditures = TotalFixedCost*EffOfAccountOnTotalFixedExpenditures

unit ActualTotalFixedExpenditures = lmps

aux AdoptersEffectOnWillToPay =
GRAPH(AdoptersPercent,0,0.1,[0.61,0.61,0.61,0.61,0.66,0.83,0.96,1,1,1,1"Min:0;Max:1"])

aux AfterFixedCostsAccountCoverage = (MoneyInAccount-
1*ActualTotalFixedExpenditures)/DesiredWeeklyExpendituresForClorox

unit AfterFixedCostsAccountCoverage = lmps aux ClorationEfficiency = ActualCloroxExpenditures/DesiredWeeklyExpendituresForClorox

aux CloroxEffectOnWaterQuality = GRAPH(ClorationEfficiency,0,0.2,[0.03,0.06,0.15,0.59,0.93,0.99"Min:0;Max:1"])

aux CloroxEvery4Days = GRAPH(flow_of_water_from_tank_1,10,30,[1,6,8,15,17,24,27,32,35,42,48"Min:0;Max:50"])

unit CloroxEvery4Days = lbs

init CurrentFee = 10

flow CurrentFee = +dt*FeeAdjustment

unit CurrentFee = lmps/home

const DesiredAccountCoverage = 1

unit DesiredAccountCoverage = weeks

aux DesiredExpenditures = DesiredIncome

unit DesiredExpenditures = lmps

aux DesiredIncome = (DesiredWeeklyExpendituresForClorox+DesiredWeeklyExpendituresForNewPipes+TotalFixedCost)*SavingsMargin

unit DesiredIncome = lmps

aux DesiredWeeklyExpendituresForClorox = RequiredClorox*PriceCloroxPerLb

unit DesiredWeeklyExpendituresForClorox = lmps

aux DesiredWeeklyExpendituresForNewPipes = (CostOfPipesToRepair)/TargetDecisionTimeForRepair

unit DesiredWeeklyExpendituresForNewPipes = lmps aux DesiredWeightOnTargetFee = IF(P3SwitchFee=1,IF(TIME>104,0.5,0.02),0.02)

doc DesiredWeightOnTargetFee = IF(TIME>104,0.5,0.02)

aux EffOfTotalAccountCoverageOnInvestmentsInNewPipes = MIN(FinalAccountCoverage/DesiredAccountCoverage,1)

doc EffOfTotalAccountCoverageOnInvestmentsInNewPipes = GRAPH(FinalAccountCoverage/DesiredAccountCoverage,0,0.2,[0.54,0.74,0.89,0.98,1,1,1,1,1,1,1"Min:0;Max:1;Zoom"])

aux EffOfAccountBeforeCoverageOnCloroxExpenditures = MIN(AfterFixedCostsAccountCoverage/DesiredAccountCoverage,1)

aux EffOfAccountOnTotalFixedExpenditures = MIN(TotalFixedCostsAccountCoverage/DesiredAccountCoverage,1)

doc EffOfAccountOnTotalFixedExpenditures = GRAPH(TotalFixedCostsAccountCoverage/DesiredAccountCoverage,0,0.2,[0,0.05,0.5,0.86,0.97,1,1,1,1,1,1"Min:0;Max:1;Zoom"])

aux Expenditures = MIN(ActualTotalFixedExpenditures+ActualCloroxExpenditures+ActualInvestmentInNewPipes,MoneyInAccount/TIMESTEP)

unit Expenditures = Imps/week

aux FeeAdjustment = (IndicatedFee-CurrentFee)/TimeToAdjustCurrentFee

unit FeeAdjustment = Imps/week/home

aux FinalAccountCoverage = MAX(0,(MoneyInAccount-ActualTotalFixedExpenditures-ActualCloroxExpenditures)/(DesiredWeeklyExpendituresForNewPipes+0.000000000000000001))

unit FinalAccountCoverage = Imps

aux FixedCostEffWaterQuality = GRAPH(ActualTotalFixedExpenditures/TotalFixedCost,0,0.1,[0,0,0,0.03,0.16,0.49,0.74,1,1,1,1"Min:0;Max:1"])

```
aux    flow_of_water_from_tank_1 =
GRAPH(time_to_fill_bucket_1,1,0.5,[300,200,150,120,100,85.7,75,66.7,60,54.5,50,46.2,42.9,40,37.5,
35.3,33.3,31.6,30,28.6,27.3,26.1,25,24,23.1,22.2,21.4,20.7,20,19.4,18.8,18.2,17.6,17.1,16.7,16.2,15.
8,15.4,15,14.6,14.3,14,13.5,13.3,13,12.8,12.5,12.2,12,11.8,11.5,22.3,11.1,10.9,10.7,10.5,10.3,10.2,1
0"Min:0;Max:300"])

aux    IdealFee = DesiredExpenditures/Households
unit   IdealFee = Imps/home

aux    IndicatedFee = WeightOnTargetFee*TargetFee+(1-WeightOnTargetFee)*CurrentFee
unit   IndicatedFee = Imps/home

const  Maintanace = 600
unit   Maintanace = Imps

init   MoneyInAccount = 500
flow   MoneyInAccount = +dt*ActualIncome
       -dt*Expenditures
unit   MoneyInAccount = Imps

const  P3SwitchFee = 0

aux    PayerUsersFraction = AdoptersEffectOnWillToPay
unit   PayerUsersFraction = 1/week

aux    PayingHouseholds = Households*PayerUsersFraction
unit   PayingHouseholds = homes/week

const  PriceCloroxPerLb = 40
unit   PriceCloroxPerLb = Imps
```

```
const  PricePerPipe = 1000
unit   PricePerPipe = Imps

const  PlumberPayment = 600
unit   PlumberPayment = Imps

aux    RequiredClorox = CloroxEvery4Days*7.5
unit   RequiredClorox = lbs

aux    RequiredFee = DesiredExpenditures/PayingHouseholds
unit   RequiredFee = Imps

const  SavingsMargin = 1.10

aux    TargetFee = WeightOnRequiredFee*RequiredFee+(1-WeightOnRequiredFee)*IdealFee
unit   TargetFee = Imps/home

aux    TimeToAdjustCurrentFee = IF(WeightOnTargetFee<1, 52, TIMESTEP)
unit   TimeToAdjustCurrentFee = weeks

const  time_to_fill_bucket_1 = 3
unit   time_to_fill_bucket_1 = sec

aux    TotalFixedCost = (AdministrativeCosts+Maintanace+TravelExpenses+PlumberPayment)
unit   TotalFixedCost = Imps

aux    TotalFixedCostsAccountCoverage = MoneyInAccount/TotalFixedCost

const  TravelExpenses = 300
```

unit TravelExpenses = Imps/week

const WeightOnRequiredFee = 1

aux WeightOnTargetFee = IF(TargetFee<=CurrentFee,1,DesiredWeightOnTargetFee)

const AdministrativeCosts = 300

unit AdministrativeCosts = Imps

12.2.6 Pipe Sector

aux AdjustmentForCapacityDP = DesiredReplacementCapacityDP-ReplacementCapacityDP

unit AdjustmentForCapacityDP = pipes

aux AdjustmentForCapacityOP = DesiredReplacementCapacityOP-ReplacementCapacityOP

unit AdjustmentForCapacityOP = pipes

const AvgLifetimePipe = 20*52

unit AvgLifetimePipe = weeks

const CapacityAdjustmentTime = 2

unit CapacityAdjustmentTime = pipes/week

aux CostOfPipesToRepair = IF(TotalPipesToFix>0,TotalPipesToFix*PricePerPipe,0)

unit CostOfPipesToRepair = Imps

aux DamagedOrderedObsoletePipesToRemovRate = OrderedObsoletePipesToRemove*FractionOfObsoletePipesDamaged

unit DamagedOrderedObsoletePipesToRemovRate = pipes/week

```
const  DeliveryTime = 1
unit   DeliveryTime = week

aux    DesiredReplacementCapacityDP = ReplacementDamagedPipeOrdersToBeSatisfied
unit   DesiredReplacementCapacityDP = pipes

aux    DesiredReplacementCapacityOP = ReplacementObsoletePipeOrdersToBeSatisfied
unit   DesiredReplacementCapacityOP = pipes

aux    EfficientFuctionalPipes = 1-NonFunctionalPipes/FunctionalPipes
unit   EfficientFuctionalPipes = pipes

const  FractionOfFunctionalPipesDamaged = 0.001
doc    FractionOfFunctionalPipesDamaged = IF(TIME>150 AND (TIME<180),0.1,0.001)
unit   FractionOfFunctionalPipesDamaged = 1/week

aux    FractionOfObsoletePipesDamaged = FractionOfFunctionalPipesDamaged*10
unit   FractionOfObsoletePipesDamaged = 1/week

init   FunctionalPipes = 100
flow   FunctionalPipes = +dt*ReplacementDamagedPipeOrdersSatisfied
       +dt*ReplacementObsoletePipeOrdersSatisfied
       -dt*FunctionalPipesDamageRate
       -dt*Pipe_Depreciation_Rate
unit   FunctionalPipes = pipes

aux    FunctionalPipesDamageRate = FunctionalPipes*FractionOfFunctionalPipesDamaged
unit   FunctionalPipesDamageRate = pipes/week
```

const IndReplacementTime = 1

unit IndReplacementTime = week

aux IndReportedObsoleteDamagedPipesRate = ObsoletePipes/IndReplacementTime

unit IndReportedObsoleteDamagedPipesRate = pipes/week

aux InvestmentDamagedPipes = OrderRateDamagedPipes*PricePerPipe

unit InvestmentDamagedPipes = lmps/week

aux InvestmentInNewPipesOP = ActualInvestmentInNewPipes-InvestmentDamagedPipes

unit InvestmentInNewPipesOP = lmps/week

aux NonFunctionalPipes =
OrderedDamagedPipesToRemove+OrderedObsoletePipesToRemove+ObsoletePipes+ReportedDamagedPipesToBeReplaced+ReportedObsoletePipesToBeReplaced+UnreportedsDamagedPipes

init ObsoletePipes = 0

flow ObsoletePipes = -dt* ReportedObsoleteDamagedPipesRate

-dt*ObsoletePipesDamageRate

+dt*Pipe_Depreciation_Rate

unit ObsoletePipes = pipes

aux ObsoletePipesDamageRate = ObsoletePipes*FractionOfObsoletePipesDamaged

unit ObsoletePipesDamageRate = pipes/week

init OrderedDamagedPipesToRemove = 0

flow OrderedDamagedPipesToRemove = +dt*OrderRateDamagedPipes

-dt*RemovalOfDamagedPipeRate

unit OrderedDamagedPipesToRemove = pipes init OrderedObsoletePipesToRemove = 0

flow OrderedObsoletePipesToRemove = -dt*RemovalOfObsoletePipeRate

-dt*DamagedOrderedObsoletePipesToRemovRate

+dt*OrderRateObsoletePipes

unit OrderedObsoletePipesToRemove = pipes

aux OrderRateDamagedPipes = MIN(ActualInvestmentInNewPipes/PricePerPipe,ReportedDamagedPipesToBeReplaced/TIMESTEP)

unit OrderRateDamagedPipes = pipes/week

aux OrderRateObsoletePipes = MIN(InvestmentInNewPipesOP/PricePerPipe,ReportedObsoletePipesToBeReplaced/TIMESTEP)

unit OrderRateObsoletePipes = pipes/week

aux Pipe_Depreciation_Rate = FunctionalPipes/AvgLifetimePipe

unit Pipe_Depreciation_Rate = pipes/week

aux PipeEfficiencyEffectonWaterQuality = GRAPH(EfficientFuctionalPipes,0,0.1,[0.01,0.11,0.23,0.36,0.46,0.59,0.71,0.79,0.9,0.97,1"Min:0;Max:1"])

aux RemovalOfDamagedPipeRate = MIN(ReplacementDamagedPipeOrdersSatisfied,OrderedDamagedPipesToRemove/IndReplacementTime)

unit RemovalOfDamagedPipeRate = pipes/week

aux RemovalOfObsoletePipeRate = MIN(ReplacementObsoletePipeOrdersSatisfied,OrderedObsoletePipesToRemove/IndReplacementTime)

unit RemovalOfObsoletePipeRate = pipes/week

aux ReplacementCapacityRateDP = MAX(0,AdjustmentForCapacityDP/CapacityAdjustmentTime) unit ReplacementCapacityRateDP = pipes/week

aux ReplacementCapacityRateOP = MAX(0,AdjustmentForCapacityOP/CapacityAdjustmentTime)

unit ReplacementCapacityRateOP = pipes/week

aux ReplacementDamagedPipeOrdersExecuted = ReplacementDamagedPipeOrdersPlaced/DeliveryTime

unit ReplacementDamagedPipeOrdersExecuted = pipes/week

aux ReplacementDamagedPipeOrdersSatisfied = MIN(DesiredReplacementCapacityDP/IndReplacementTime,ReplacementCapacityDP/IndReplacementTime)

unit ReplacementDamagedPipeOrdersSatisfied = pipes/week

aux ReplacementObsoletePipeOrdersExecuted = ReplacementObsoletePipeOrdersPlaced/DeliveryTime

unit ReplacementObsoletePipeOrdersExecuted = pipes/week

aux ReplacementObsoletePipeOrdersSatisfied = MIN(DesiredReplacementCapacityOP/IndReplacementTime,ReplacementCapacityOP/IndReplacementTime)

unit ReplacementObsoletePipeOrdersSatisfied = pipes/week

aux ReportedObsoleteDamagedPipesRate = DELAYMTR(IndReportedObsoleteDamagedPipesRate,TimeToReportObsoletePipes)

unit ReportedObsoleteDamagedPipesRate = people/week

aux ReportedObsoletePipesDamageRate = ReportedObsoletePipesToBeReplaced*FractionOfObsoletePipesDamaged

unit ReportedObsoletePipesDamageRate = pipes/week

aux ReportedPipesRate = UnreportedsDamagedPipes/TimeToReportFunctionalPipesDamaged unit ReportedPipesRate = pipes/week

init ReplacementCapacityDP = 0

flow ReplacementCapacityDP = +dt*ReplacementCapacityRateDP

unit ReplacementCapacityDP = pipes

init ReplacementCapacityOP = 0

flow ReplacementCapacityOP = +dt*ReplacementCapacityRateOP

unit ReplacementCapacityOP = pipes/week

init ReplacementDamagedPipeOrdersPlaced = 0

flow ReplacementDamagedPipeOrdersPlaced = -dt*ReplacementDamagedPipeOrdersExecuted

+dt*OrderRateDamagedPipes

unit ReplacementDamagedPipeOrdersPlaced = pipes

init ReplacementDamagedPipeOrdersToBeSatisfied = 0

flow ReplacementDamagedPipeOrdersToBeSatisfied = -dt*ReplacementDamagedPipeOrdersSatisfied

+dt*ReplacementDamagedPipeOrdersExecuted

unit ReplacementDamagedPipeOrdersToBeSatisfied = pipes

init ReplacementObsoletePipeOrdersPlaced = 0

flow ReplacementObsoletePipeOrdersPlaced = +dt*OrderRateObsoletePipes

-dt*ReplacementObsoletePipeOrdersExecuted

unit ReplacementObsoletePipeOrdersPlaced = pipes

init ReplacementObsoletePipeOrdersToBeSatisfied = 0

flow ReplacementObsoletePipeOrdersToBeSatisfied = +dt*ReplacementObsoletePipeOrdersExecuted

-dt*ReplacementObsoletePipeOrdersSatisfied

```
unit    ReplacementObsoletePipeOrdersToBeSatisfied = pipes

init    ReportedDamagedPipesToBeReplaced = 0
flow    ReportedDamagedPipesToBeReplaced = -dt*OrderRateDamagedPipes
        +dt*ReportedPipesRate
unit    ReportedDamagedPipesToBeReplaced = pipes

init    ReportedObsoletePipesToBeReplaced = 0
flow    ReportedObsoletePipesToBeReplaced = -dt*ReportedObsoletePipesDamageRate
        -dt*OrderRateObsoletePipes
        +dt* ReportedObsoleteDamagedPipesRate
unit    ReportedObsoletePipesToBeReplaced = pipes

const   TargetDecisionTimeForRepair = 1
unit    TargetDecisionTimeForRepair = weeks

const   TimeToReportFunctionalPipesDamaged = 1.5

const   TimeToReportObsoletePipes = 4
unit    TimeToReportObsoletePipes = weeks

aux     TotalPipesToFix =
ReportedDamagedPipesToBeReplaced+ReportedObsoletePipesToBeReplaced
unit    TotalPipesToFix = pipes

init    UnreportedsDamagedPipes = 0
flow    UnreportedsDamagedPipes = +dt*DamagedOrderedObsoletePipesToRemovRate
        +dt*ObsoletePipesDamageRate
        +dt*ReportedObsoletePipesDamageRate
```

-dt*ReportedPipesRate

+dt*FunctionalPipesDamageRate

unit UnreportedsDamagedPipes = pipes

aux WaterQuality =
CloroxEffectOnWaterQuality*PipeEfficiencyEffectonWaterQuality*FixedCostEffWaterQuality

12.3 Appendix C

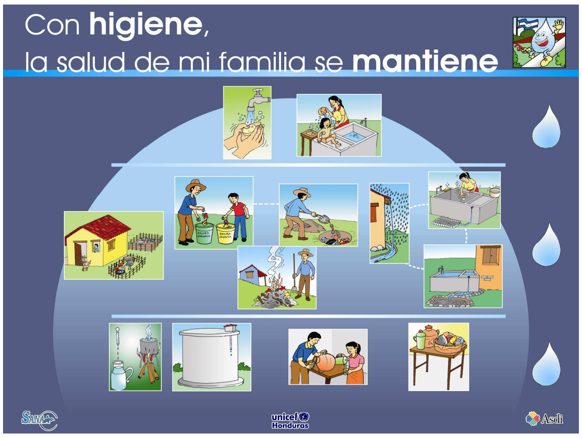
Appendix C illustrates pictures from the field research done in Chinda.

This picture was taken in one of the communities of Chinda, where pipes where new pipes were being installed. The members of the community are responsible for the work involving the installation of pipes.

This is the Health Center of Chinda. This Health Center is in charge of all the communities of the municipality of Chinda.

The Importance of the sanitation committee in the community has been emphasized throughout this paper. These pictures illustrate the different ways the committees prepare for the home visits they do every week.

The improvement in some of the communities has become very obvious. The pictures above show the great progress in the restrooms of one of the schools from these communities.



This is some of the didactic material that has been provided to the water boards and sanitation committees to promote hygienic and sanitation habits. This material has been donated by Unicef through Water For People.