Final Report

Analysis of Infrastructure Vulnerability to Climate Change

Wastewater Collection, Treatment and Disposal System

City of Limón

Costa Rica

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Without the hard and selfless work of all these professionals, it would not have been possible the successful completion of this important project.

Table of content

1. INTRODUCTION....7
1.1 Background information....7
1.2 Study details....7
1.2.1 Location of the study area....7
1.2.2 Purpose of the study....8
1.2.3 Study Scope....8
1.2.4 Awareness....10
2. PIEVC PROTOCOL AND ANALYSIS METHODOLOGY....11
2.1 Explanation of the PIEVC Protocol....11
2.1.1 Purpose of the Protocol....11
2.1.2 Description of the steps of the PIEVC Protocol....11
2.1.2.1 Step 1 – Project Definition....12
2.1.2.2Step 2 – Data gathering and sufficiency....12
2.1.2.3Step 3 – Risk Assessment....13
2.1.2.4 Step 4 – Engineering Analysis....14
2.1.2.5 Step 5 – Recommendations....15
2.2 Aplication of the Protocol....15
2.2.1 Summary of methodological adjustments....15
2.2.2 Explanation of methodological adjustments....16
2.2.2.1 Selection and classification of parameters....16
2.2.2.1.1 Selection criteria....16
2.2.2.1.2 Classification of events as per their occurrence....16
2.2.2.2 Analysis of the occurrence probability and severity....17
2.2.2.2.1 Probability analysis....17
2.2.2.2.2 Analysis and adjustment of event severity....18
2.2.2.3 Data Sufficiency....19
2.2.3 Risk assessment and tolerance thresholds....20
2.2.3.1 Risk Assessment....20
2.2.3.2 Tolerance Thresholds....21
2.3 Work Team and Plans....22
2.3.1 The Team....22
2.3.2 Work sessions....23
3. CLIMATE ANALYSIS AND PROJECTIONS....25
3.1 Purposes of climate analysis....25
3.1.1 Explanation of the purpose....25
3.1.2 Parameters selected....25
3.2 Data Methods and Sources....28
3.2.1 Historic information for climate parameters....28
3.2.2 Climate projections (future)....28
3.2.3 Time frame used for the assessment....28
3.2.3.1 Record interval....28
3.2.3.2 Projection term (future)....29
3.3 Climate Parameters....29
3.3.1 Recurrent Parameters....30
3.3.1.1. High temperature....30
3.3.1.1.1 Definition....30
3.3.1.1.2 Climate historic records....30

3.3.1.1.3 Probability Assessment 30
3.3.1.1.4 Trend 31
3.3.1.1.5 Climate projections 31
3.3.1.2 Sea waves 32
3.3.1.2.1. Definition 32
3.3.1.2.2 Climate History 34
3.3.1.2.3. Probability Analysis 35
3.3.1.2.4 Trend 36
3.3.1.2.5 Climate projections 36
3.3.1.3 Sea breeze 37
3.3.1.3.1 Definition 37
3.3.1.3.2 Climate History 38
3.3.1.3.3 Probability Analysis 39
3.3.1.3.4 Trend 39
3.3.1.3.5 Climate Projections 39
3.3.1.4 Atmospheric discharges (lightning) 40
3.3.1.4.1 Definition 40
3.3.1.4.2 Climate History 41
3.3.1.4.3 Probability Analysis 41
3.3.1.4.4 Trend 42
3.3.1.4. 5. Climate projections 42
3.3.2 Extreme parameters 42
3.3.2.1 Flooding rain 43
3.3.2.1.1 Definition 43
3.3.2.1.2 Climate History 43
3.3.2.1.3Probability Analysis 43
3.3.2.1.4Trend 44
3.3.2.1.5 Climate Projections 45
3.3.2.2 Overcharge Rain 46
3.3.2.2.1Definition 46
3.3.2.2.2 Climate History 47
3.3.2.2.3 Probability Analysis 47
3.3.2.2.4 Trends 47
3.3.2.2.5 Future projections 47
3.3.2.3 Hurricanes 48
3.3.2.3.1Definition 48
3.3.2.3.2Climate History 48
3.3.2.3.3 Probability analysis 50
3.3.2.3.4 Trend 51
3.3.2.3.5 Climate projections 51
3.3.2.4 Wind (speed and direction) 51
3.3.2.4.1 Definition 51
3.3.2.4.2. Climate background 52
3.3.2.4.3 Probability analysis 52
3.3.2.4.4 Trend 53
3.3.2.4.5 Climate projections 53
3.4 Summary of results 54
3.4.1 Frequency and current probability for recurrent parameters 54
3.4.2 Frequency and current probability for extreme parameters 54

3.4.3. Results summary table 54
4. INFRASTRUCTURE COMPONENTS 56
4.1 Sewage collection system 56
4.1.1. Connections with users 56
4.1.2. Waste Water Transport Elements 56
4.1.3. Inspection Elements (Manholes) 57
4.2 Pumping Stations 58
4.2.1 Coastal mini stations 60
4.2.2 Land mini-stations 61
4.2.3 Centrifugal stations 61
4.2.4 Submersible stations 63
4.3 Pre-conditioning stations (EPA) 65
4.3.1 Building 67
4.3.2. Ventilation system 68
4.3.3 Gates, grid, Parshall channel, interconnection channel 69
4.3.4 Milliscreens 70
4.3.5 Worm screw, baskets, hosting system, transport. 71
4.3.6 Tank 72
4.3.7 Pumps 72
4.3.8 Pumping line accessories 73
4.3.9 Overflowing structure 74
4.3.10 Control panel 75
4.3.11 Power plant 75
4.4. Underwater outfall 76
4.4.1 Pipes 76
4.4.2. Diffusers 76
4.4.3. Closing valve (flap) 77
4.4.4. Anchoring 77
4.5. Wave retaining wall 78
4.6. Personnel 80
4.6.1. At the wastewater collection system. 80
4.6.2. At EPA 81
4.6.3. At underwater outfall 82
4.7. Communication equipment 83
4.7.1. Telephones at EPA 83
4.7.2. Telemetry 83
4.7.3. Radio 84
4.7.4. Internet messages 84
5. ANALYSIS OF RESULTS 85
5.1 Risk Assessment 85
5.1.1 Performance Considerations 85
5.1.2 Risk Calculation 87
5.2. Engineering Analysis 90
5.2.1. Overcharge rain 91
5.2.2. Flooding Rain 95
5.2.3 Wind 100
5.2.3.1 Power failure 100
5.2.3.2 Decrease of treatment capacity 102
5.2.3.3 Personnel Security 105

5.2.4. Atmospheric Discharges 106
5.2.5. Sea Breeze 107
5.2.6. Wave 108
5.2.7. Hurricanes 109
5.2.8. High temperature 110
5.3 Summary of findings 112
6. LIMITATIONS 114
7. CONCLUSIONS AND RECOMMENDATIONS 115
7.1 Conclusions 115
7.2 Recommendations 116
8- BIBLIOGRAPHY 118

1. INTRODUCTION

1.1 Background information

According to world statistics, impact of disasters has considerably increased in the last decades. In less developed countries attention to disasters is focused on rebuilding damaged infrastructure and most of the time the new facilities are built on the same sites and under the same conditions existing prior to the disaster, thus giving place to reiterated cycles of damage to the same and this has been popularly called *reconstruction of vulnerability.*

Regarding climate change, from studies carried out by Ministerio de Ambiente, Energia y Telecomunicaciones (MINAET – Ministry of Environmental, Energy and Telecommunications) through the Instituto Meteorologico Nacional (IMN) in Costa Rica there is much work performed and broad information released on the effects resulting from global warming; however, it lacks approaches that may allow understanding the interaction mechanisms between climate changes and the possible damages to national infrastructure.

Developed countries have developed and applied mathematical and probabilistic models to anticipate knowledge on implications that might have several types of hydro climate, seismic, geological, and technological and other events, in order to take them into account when assessing the existing infrastructure or in future works.

PIEVC Protocol (Public Infrastructure Engineering Vulnerability Committee, www.pievc.ca) has been applied in several countries and the same has proved to be an appropriate instrument to have appropriate knowledge available on the implications of climate change on several types of public civil infrastructure; so that in this case it is a chance to progress in the potable water and sewerage sector. This is so without excluding the need to apply the same to other infrastructures of other sectors of the national economy.

This opportunity arises out of the initiative of Colegio Federado de Ingenieros de Costa Rica (Professional Association of Engineers of Costa Rica) who has become the partner of the project and Engineers Canada, whose undertakings are set forth in a memorandum of understanding. AyA is the owner of the infrastructure to be assessed and the study team was composed of officers from AyA, IMN and CFIA.

1.2 Study details

1.2.1 Location of the study area.

Figure 1-1 shows the project study area located in the Caribbean Coast of Costa Rica. The infrastructure that is the purpose of the study is the wastewater collection, treatment and disposal system of the city of Limon which is composed of the following: wastewater collection network and pumping stations, the pre-conditioning station (EPA) and the underwater outfall.

Figure 1.1 shows the project study area located in the Caribbean Coast of Costa Rica. The wastewater system in the city of Limon is the system purpose of the study.

Figure 1.1. Study area located in the Caribbean region of Costa Rica.

1.2.2 Purpose of the study

The main purpose of the case study is to identify the components of the sewage system of the city of Limon that are in increasing risk to collapse or be damaged, as well as the risk of operation effectiveness or life cycle reductions due to potential changes resulting from Climate Change, which determination is achieved through the use of the PIEVC Protocol.

1.2.3 Study Scope

During the initial phase of the study, the work team discussed and adopted a conceptual scheme in order to define the scope of the project and to start the different steps of the vulnerability study from a systemic approach.

This approach is that vulnerability is determined by the possible damage regarding the operation and stability due to the following:

a) Direct effects: potential effects caused by climate change which have impact on the infrastructure under study, called EPA and on the outfall.

b) Indirect effects: potential effects of climate change having direct impact on the other components of the system and which have effects on EPA and the outfall.

During this study, when applied to the Costa Rican situation, it was found that when there is an infrastructure (other related system) which operation interacts with the system under study or which failure would affect the main structure, this must be also assessed, thus highlighting the interactions and identifying the measures to be adopted in that system in order to secure the adaptive capacity to climate change of the main infrastructure under study. These relations are shown in Figure 1.2 that shows conceptualization, where the existence of interrelations is considered because the infrastructure is located under the influence of land and sea environments.

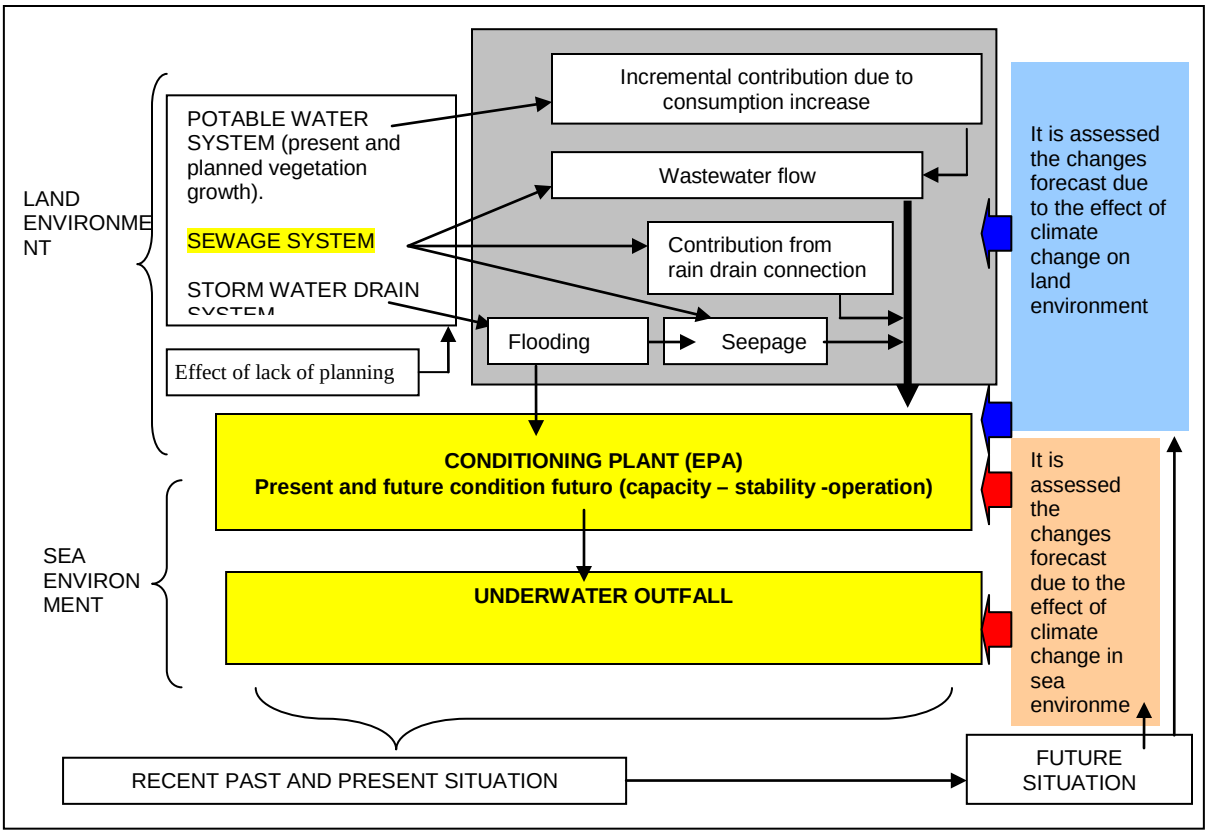


Figure 1.2. Conceptual scheme of the related systems in order to assess the vulnerability to climate change of the selected infrastructure

For the assessment it is required to break down each of the civil infrastructures into their components that are open to endure potential effects from Climate Change when conditions of known historical climate change, in a 30 year timeframe (from 2011 to 2040), term that was put forward by the AyA as owner of the infrastructure and which was later on approved by agreement of the work team.

In the land environment it was determined that there are three related systems (Fig. 1-2) that provide water to EPA and to the underwater outfall and that therefore said systems must be assessed in order to know the load on the components under study in this project, because they determine the operation shutdown of EPA and the damage to the infrastructure life cycle. The following are the systems:

- Potable water systems,
- Wastewater systems,
- Storm water drain systems.

However, only the two first systems are under the jurisdiction of AyA and the other one is under municipal management, thus limiting the scope of the study because of limited access to data. This involves limited access to hydrological and hydraulic data on urban basins that provide storm water to EPA, which was remedied through qualitative criteria,

when required. In any event having similar situations, whenever there are data gaps, it has been set forth the need to carry out subsequent studies if required.

1.2.4 Awareness

In order to give an idea to the owner of the infrastructure on the relevance of this type of analysis and following the format and approach of one of the studies checked (GENIVAR. 2010) it was considered of material importance to go over the awareness on the impacts on potable water and sewage systems caused by present climate and climate change. This was done because it is important to know how studies have been approached:

- In potable water and sewage systems in general (APS),
- In coast systems and underwater outfalls.

Besides, it is convenient to have data on how the analysis step was carried out and the way the adaptation measures will be implemented.

The bibliography includes the documents checked, however two studies were chosen as main reference.

These were the studies in downward importance:

- Vulnerability Assessment Undertaken for the Claireville and G. Ross Lord Dams and Reservoirs in accordance with the Public Infrastructure Engineering Vulnerability Committee (PIEVC). Draft report. 17 march 2010. Genivar.
- Metro Vulnerability of Vancouver Sewerage Area infrastructure to Climate Change, Metro Vancouver, British Columbia. Final report. March 2008. KERR WOOD LEIDAL – Associated Engineering.

2. PIEVC PROTOCOL AND ANALYSIS METHODOLOGY

2.1 Explanation of the PIEVC Protocol

2.1.1 Purpose of the Protocol

This section includes a revision of the PIEVC Protocol (Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment - April, 2009), hereinafter called the "Protocol".

The Protocol is a step by step process designed to conduct infrastructure vulnerability engineering assessment for evaluating impact of climate change on infrastructure; thus allowing the identification of the most relevant interactions between climate and infrastructure in the design, construction and the management of existing infrastructure, in order to take the necessary measures for adaptation to climate change.

Such aspect has bearing on investment scheduling and system operation.

In order to achieve such results, the assessing team must have sufficient and appropriate data to approach the analysis of:

- The infrastructure (main system) purpose of the study,
- The climate (recent, historic and projected) in the study area,.
- Historic and forecast responses of the infrastructure to climate change.

The Protocol has a 5-step process:

- Step 1 – Project definition,
- Step 2 – Data gathering and sufficiency
- Step 3 – Risk assessment
- Step 4 – Engineering Analysis
- Step 5 – Recommendations.

The PIEVC Protocol has been applied to:

1. Buildings,
2. Roads and associated structures (bridges, sewer, others),
3. Wastewater and storm water collection and treatment systems,
4. Water resources (potable water, flood controlling and regulating dams)
5. Other applications.

Below is a brief description of the contents of the PIEVC Protocol.

2.1.2 Description of the steps of the PIEVC Protocol

Below are the steps applied by the Protocol, transcribed from the document of Canadian Council of Professional Engineers, with some minor adjustments.

2.1.2.1 Step 1 – Project Definition

In step 1 the practitioner must describe, in a general way, the following:

- The infrastructure
- The location
- Historic climate
- The load on the infrastructure
- The age of the infrastructure
- Other relevant factors

In this step the professional defines the boundary conditions for the vulnerability assessment and must identify the main data sources. At the end of this step the data quality and quantity is reviewed starting from the assumptions adopted and their reasonability.

If it is defined that the boundary conditions of the systems under study were not appropriately defined or that data is not sufficient, the process must be redefined and improved and the missing data must be found and included.

If data cannot be developed, this shall be noted as a finding in Step 5 – Recommendations.

2.1.2.2Step 2 – Data gathering and sufficiency

During step 2 the professional must provide more information and additional detail regarding:

1. Which parts of the infrastructure will be assessed; and
2. The particular climate factors that will be considered

Step 2 is comprised of two key activities:

1. Identify the specific features of the infrastructure that will be considered in the assessment, considering the following:
   a) physical elements of the infrastructure,
   b) number of physical elements,
   c) location.

   Other important considerations of technical or engineering nature to be taken into consideration:

   - Material of construction
   - Age of the infrastructure
   - Importance within the region
   - Physical condition
   - Operation and maintenance practices
   - Infrastructure oepration and management
   - Insurance considerations
   - Policies
   - Guidelines
   - Regulations; and
   - Legal considerations

2. Identification of applicable climate information. Sources of climate information include, but are not limited to:
    - Construction codes of the country where the Protocol is applied.
    - Intensity – Duration – Frequency (IDF) curves
    - Mapping of the study area.
    - Regionally specific climatic modeling
    - Other sources, as appropriate

The practitioner must exercise professional judgment based on experience and training. Step 2 is an interdisciplinary process requiring engineering, climatological, operations, and maintenance and management expertise. The practitioner must ensure that the right combination of expertise is represented either on the assessment team or through consultations with other professionals during the execution of the assessment.

It is also during Step 2 that it must be determined if information is appropriate because if the data gathered is of poor quality, is highly uncertain or important data is missing, information will not be sufficient.

This step allows the practitioner to reassess the data sources, the methods to obtain information, get data missing and perform any and all activities that may be required to gather the information that is missing, if it is determined that there are data gaps or that data is insufficient. If data cannot be developed or obtained, this shall be entered in Step 5 – Recommendations as a finding.

2.1.2.3Step 3 – Risk Assessment

In Step 3 the practitioner must identify the interactions between the infrastructure, the climate and other factors that could lead to vulnerability. These include:

- Specific infrastructure components
- Specific climate change parameter values
- Specific performance goals

The Protocol requires the practitioner to identify which elements of the infrastructure are likely to be sensitive to changes in particular climate parameters. They will be required to evaluate this sensitivity in the context of the performance expectations and other demands that are placed on the infrastructure. Infrastructure performance may be influenced by a variety of factors and the Protocol directs the practitioner to consider the overall environment that encompasses the infrastructure.

At this point in the Protocol, in consultation with the project partner, the management, engineering and operation personnel, the practitioner will perform a risk assessment of the infrastructure's vulnerability to climate change. The interactions identified will be evaluated based on the professional judgment of the assessment team. The risk assessment will identify areas of key concern.

The practitioner will identify those interactions that need further quantitative evaluation. The assessment process does not require that all interactions be assessed quantitatively.

In fact, in most assessment processes most of the considered will ultimately be eliminated from further consideration. Some interactions may clearly present no, or negligible, vulnerability. Some interactions may clearly indicate high risk and the need for immediate action. Those interactions that do not yield a clear answer regarding vulnerability should be subject to a further engineering analysis as outlined in Section 8.4 of the Protocol document.

At this stage the practitioner must also assess data availability and quality. If professional judgment identifies a potential vulnerability that requires data that is not available to the assessment team, the Protocol requires that the practitioner revisit each step to acquire and refine the data to a level sufficient for risk assessment and/or engineering analysis.

The practitioner may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5 – Recommendation. This is a key decision point in the Protocol.

The practitioner is required to determine the following:

a) Which interactions require additional assessment
b) Where data refinement is required; and
c) Initial recommendations about:
    - New research
    - Immediate remedial actions; or
    - Non-vulnerable infrastructure

2.1.2.4 Step 4 – Engineering Analysis

In Step 4 the practitioner quantifies the vulnerability resulting from the interactions identified in Step 3 as requiring further assessment. It must be numerically assess the infrastructure vulnerability and capacity considering the projected loads resulting from climate change.

The Protocol sets out the equations that direct the practitioner to numerically assess:

a) The total load on the infrastructure, comprising:
    - The current load on the infrastructure
    - Climate change effects on the infrastructure;
    - Other change effects on the infrastructure.

b) The total capacity of the infrastructure, comprising:
    - The existing capacity,
    - The projected change in capacity arising from aging/use of the

infrastructure; and
- Other factors that may affect the capacity of the infrastructure.

Based on the numerical analysis, vulnerability exists when total projected load exceeds total projected capacity and adaptive capacity exists when the total projected load is less than the total projected capacity.

At this stage the practitioner must make one final assessment about data availability and quality. If, in the professional judgment the data quality or statistical error does not support clear conclusions from the Engineering Analysis, the Protocol directs the practitioner to revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for robust engineering analysis. The practitioner may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

Once the practitioner has established sufficient confidence in the results of the engineering analysis, the Protocol reaches another key decision point. The practitioner must decide to either:

- Make recommendations based on their analysis (Step 5); or
- Revisit the risk assessment process based on the new/defined data developed in the engineering analysis (Step 3).

2.1.2.5 Step 5 – Recommendations

In Step 5, the practitioner is directed to provide recommendations based on the work completed in Steps 1 through 4. Generally, the recommendations will fall into five major categories:

1. Remedial action is required to upgrade the infrastructure
2. Management action is required to account for changes in the infrastructure capacity
3. Continue to monitor performance of infrastructure and re-evaluate the same at a later time
4. There are gaps in data availability or data quality that require further work.
5. No further action is required

The practitioner may identify additional conclusions or recommendations regarding the veracity of the assessment, the need for further work or areas that were excluded from the current assessment.

2.2 Aplication of the Protocol

2.2.1 Summary of methodological adjustments

During the process developed it was fully applied the methodology under the PIEVC Protocol (Canadian Council of Professional Engineers – April 2009) but in the following aspects:

a) Differentiate the loads generated and which may have a negative effect and involve a risk for the infrastructure. In this case it is established the possibility of differentiating between events that occur in a given year and which effect depends more on the persistence of the same rather than on the occurrence of the event; and the events with a load generated on the infrastructure component by an extreme or special event in a given year. The above was adopted by the Costa Rica work team based on the study analysis performed by GENIVAR for the G. Ross and Clairvill reservoirs.
b) Initially the factors of the severity scale factors were taken from page 47 of 76 of PIEVC Protocol, however the work team found it difficult to apply because when referring to severity they also included aspects that are related to occurrence probability. Therefore the changes explained in the corresponding section were included.
c) The work team considered appropriate to establish information selection criteria in order to secure the quality of the risk assessment process, and for this purpose the categories, criteria and decisions discussed in this chapter were applied.

2.2.2 Explanation of methodological adjustments

2.2.2.1 Selection and classification of parameters

2.2.2.1.1 Selection criteria

In order to establish the definitions of the above mentioned parameters, the work team following the procedures used in the studies reviewed (GENIVAR. 2010; [1]) and upon several approaches, it established the following criteria:

a) The availability of data on events (load thresholds that occurred on dates recorded in logs) that damaged the components of the infrastructure subject matter of analysis,
b) Possibility of having data on the climate parameter relating the same with the events occurred, previously mentioned, for events under analysis of present climate.
c) Possibility of having data on the climate parameter relating it with events in analysis of future climate,
d) Possibility of the team to interact that data with an occurrence frequency and with a probability in accordance with pre-established scales.
e) As a result of this process experience it was found to be of material importance to have data on load thresholds and an appropriate preparation process of climatological data.

2.2.2.1.2 Classification of events as per their occurrence

From the parameters selected, it is considered convenient to classify the parameters depending on the nature of the same and to assess the loads generated and which have a negative effect on the infrastructure or are a risk for the same.

[1] GENIVAR. 2010. Flood control Dam Water Resources Infrastructure Assessment.

In the study of Genivar performed for G. Ross and Clairville reservoirs, when they designated class ¨Tier 1 and Tier 2¨ on page 3-2. (3.1.3) and on page 3-4 and 3-5 (3.1.6), it is established the possibility of differentiate between events that occur in a given year and which effect depends more on the persistence rather than on the occurrence of the same, from the events that depends on the load generated on the component of the infrastructure by an extreme or special event in a given year.

Such aspects are not under the PIEVC Protocol in the version used for the study performed in 2010-2011.

Considering the parameter separation above, calculation of probabilities for each parameter group will be made in a different way depending on the nature of the same and how they damage the infrastructure, provided the data on design loads of the infrastructure to be assessed is available.

The team separated the parameters having a high annual recurrence (**Recurrent**) from the extreme parameters **(Extreme).See Table 2-1**

Table 2-1 Classification of events according to occurrence.

Type of parameter	Description
Recurrent	In this case the effect of load on the components of the infrastructure under analysis depends more on the persistence of the event rather than on the occurrence of the same in a given year.
Extreme	In this case the effect of load on the components of the infrastructure under analysis depends on an extreme or special type event in a given year.

For the parameters of extreme type there is a wider return term and therefore they are more related to the design loads of the infrastructure to be assessed.

2.2.2.2 Analysis of the occurrence probability and severity

2.2.2.2.1 Probability analysis

The process to determine the occurrence probability of an event was carried out considering the historic occurrences and then calculating the probability. In order to calculate probabilities it was used the method developed in the Protocol and the GENIVAR study and some adjustments were made which are further explained herein.

Under the PIEVC Protocol, the probability scale factors are defined from 0 to 7. The practitioner is directed to express a professional opinion regarding the probability that a climate event will occur. This should not be confused with the consequences of that climate event. (CVIIP, 2009).
It is required a numeric relation to define the possibility of generating a climatic event as such in certain period of time, and for this purpose the discrimination process shall commence with the question, What is the probability that an event occurs in certain period of time? This period of time may be once a year.

In order to use methods B or C it is required historic data to be able to define the probability in a given year, because not all climate parameters have large historic records. For the purpose of selecting the probability for recurrent or extreme type parameters, it was used the criteria developed for this study (Bolaños, F; Rodríguez, A; Zamora, P; Villalobos, H. 2011) and which is included in **Annex 2** hereof.

Table 2-2 shows the ranges to define the value of the probability starting from the occurrence of the event whether it deals with the analysis of the present or future climate.

Table 2-2 Probability Scale Factors for recurrent and extreme events.

Probability scale	Descriptive terms	Recurrent events (1)	Extreme events (2)
0	Negligible or not applicable	<0.1	0
1	Improbable / highly unlikely	5%	>0 to 0.05
2	Remote	20%	0.05 to 0.1
3	Occasional	35%	0.1 to 0.25
4	Moderate/possible	50%	0.25 to 0.75
5	Often	65%	0.75 to 1.25
6	Probable	80%	1.25 to 2
7	Certain /highly probable	>95%	> 2

Source.
(1) Method B of Figure 8 of Pag 46 of PIEVC Protocol
(2) Table 3-1 of page 3-4 of the Genivar document for Claireville and G. Ross reservoir control.

Ranges above and terms used in Table 2-2 are from Table 3-1 of page 3-4 of the GENIVAR document for Claireville and G. Ross control reservoirs. For developing the same, the GENIVAR team took into consideration the number of occurrences per year, according to the ranges assigned completing several examples where probabilities were related to the descriptive terms.

2.2.2.2.2 Analysis and adjustment of event severity

As it is established in PIEVC Protocol (page 45 of 76), the professional team must develop a risk value for each climate-infrastructure interaction derived from the matrix 3 provided as part of the Protocol.
The gravity scale factors were taken from page 47 of 76 of the PIEVC Protocol, however the work team found it difficult to apply the same because they included aspects related to the occurrence probability. This is why the changes explained herein were made.

The group considered necessary to exclude from this table the terms that are simultaneously used: in the descriptive table of probabilities (Figure 8, for instance: probable, occasional) and in the figure of severity scale (Figure 9). It was also deemed necessary to exclude terms that are synonymous; for instance frequent that means often

and probably that means that it might happen (both terms used in Figure 9). It shall be noted here that figures mentioned are from the PIEVC Protocol.

The resulting table is shown in Table 2-3.

Table 2-3 Gravity Scale Factors.(Method E)

Scale	Severity of Consequences and Effects
0	Neglible or not applicable
1	Measurable change/ very low / rare
2	Change in serviceability low / seldom / marginal
3	Occasional loss of some capability
4	Moderate loss of some capacity
5	Loss of capacity and loss of some function
6	Major/critical loss of function
7	Extreme/continuous loss of asset

SOURCE: modified from PIEVC Protocol . Figure 9 of page 47 of 76.

2.2.2.3 Data Sufficiency

In the assessment process, it was considered convenient to establish criteria to determine the sufficiency of the climate type data:

a) Perform the analysis of any and all phenomena or parameters of climate type to know the prevailing conditions in the area.
b) Focus on the assessment of present and future climate in the area.
c) Guaranty that no redundancies are present caused by loads arising out of different parameters.
d) Classify the sufficiency of data on climate and load thresholds occurred, regarding the infrastructure components, in order to select the parameters used in the risk assessment stage.

From a first assessment by means of which conclusions were established regarding the effects expected from the historic trend and climate projections of IMN (Rojas, N. 2010) it was established the data selection criteria explained in **Annex 1** (Vargas, C; Rodríguez, A; Zamora, P; Villalobos, H; Araya, A. 2011).

In order to guaranty the quality of the risk assessment process, the categories, the criteria and the decisions set forth in Table 2.4 were applied.

Table 2-4 Definition of data sufficiency.

Category	Criteria	Decision
A	There is a threshold for the parameter analyzed –based on damage to the infrastructure subject of assessment. There is no redundancy between the parameter and other parameters included in the study regarding the load on the infrastructure. Meteorological data is available in comparable timeframes.	The parameter is used in the risk assessment (Matrix 3) for the assigning of probability and severity. The tolerance threshold analysis criterion is applied. The engineering analysis is carried out. Continue to Chapter 7 - Recommendations.
B	There is **NO** threshold for the parameter analyzed – based on damage to the infrastructure under assessment. There is redundancy between the parameter and others parameters in the analysis regarding the load on the infrastructure. Meteorological data is NOT processed in comparable timeframes.	The parameter analyzed is assessed from a climate point of view and is included in the report. The parameter is **NOT** used in the risk assessment (Matrix 3) for the assigning of probability and severity. It is **NOT** applied the analysis criterion of tolerance thresholds. It is **NOT** performed the engineering analysis. Continue to Chapter 7 - Recommendations.

For this analysis, regarding the concept of load: if two climate phenomena such as hurricanes and tropical waves induce an increase of rains (rain load in mm/day in that case), one of them is excluded, upon prior analysis of the other non-coinciding loads and of the importance of the resulting additional load (electric storm)

2.2.3 Risk assessment and tolerance thresholds

No adjustments were made to this part of the protocol it and the document was used as it is. However, it is clear for the work team that in the future some criteria more appropriate for Costa Rica would have to be developed, without excluding the validation of values and criteria used in this first analysis.

2.2.3.1 Risk Assessment

Following the procedure under the PIEVC Protocol, below are the stages for risk assessment where Matrix 3 of PIEVC Protocol:

a) The work team (see 2.3.1) chooses the components of the infrastructure under analysis.
b) It is analyzed, with professional judgement, the existence or not of interactions between the climate parameters and the loads generated on the infrastructure components, (see 2.3.1)
c) Write “yes” or “no” depending if there is or there isn’t interaction determining or not the need for an additional assessment.
d) The occurrence probability factor of the event is assigned (P) as per Table 2-2.
e) The severity factor (S) of the load for the parameter under analysis on the infrastructure component under analysis is assigned, as per Table 2-3.

f) Risk (R) is calculated using the following equation

$$R = P \times S$$

This process is performed for the following:

a) Conditions of historical and present climate (for P and S values chosen)
b) For future climate conditions (for P values for future climate conditions and the same S value chosen in the previous step)

2.2.3.2 Tolerance Thresholds

The work team went over the risk tolerance thresholds and the PIEVC Protocol (Figure 10 page 51 of PIEVC Protocol) risk tolerance thresholds were adopted. At this step it was discussed the possibility of modifying these thresholds but at the end the team decided to use the values and type of response included in the Protocol and which are shown in Table 2-5.

Table 2-5 Risk Tolerance Thresholds

Risk Range	Tolerance	Response
< 12	Low Risk	No immediate action necessary
12 – 36	Medium Risk	Action may be required Engineering analysis may be required
> 36	High Risk	Immediate action required

The following is how tolerance is explained:

Low risk: Low risk interactions represent no immediate vulnerability. In the professional judgment of the practitioner, there is very low potential climate change vulnerability associated with the infrastructure component. No further action is necessary.

Medium risk: Medium risk interactions represent a potential vulnerability. In the professional judgment of the practitioner, there is potential climate change vulnerability associated with the infrastructure component. Further Engineering Analysis may be necessary since the practitioner may not be able to provide a clear, unambiguous, determination of the vulnerability.

High risk: High risk interactions represent an identified vulnerability. In the professional judgment of the practitioner, there is identifiable climate change vulnerability associated with the infrastructure component. Immediate action may be required.

2.3 Work Team and Plans

2.3.1 The Team

An important aspect in the composition of the team that carried out the analysis is that it included the following:

a) The organization that owns the infrastructure,
b) The operator of the infrastructure under analysis
c) Organizations in charge of having and processing climate data,
d) A consulting firm,
e) An organization sponsoring the process,
f) And the organization who developed the PIEVC Protocol.

In order to carry out this analysis, we had the participation of the organizations above; it shall be noted here that no consulting firm was retained so that performance of the analysis was by officials of said institutions, who also have other tasks assigned in their own office and field work programs. This is why it was required to negotiate some time availability in order to comply with the tasks arising out of the protocol application.

Finally, even though there was some delay in the intermediate stages, the final due date was met.

The work team was composed of a team of engineers and other professionals with appropriate training and expertise in the following areas:

a) Operation of potable water, storm water and sewer systems.
b) Design and operation of potable water and sewage systems,
c) Experience in physical development,
d) Environmental management and risk management in case of disasters,
e) Waste water treatment

It shall be noted here that the personnel making up the team knows in detail the study area whether because they are people living there and who have operation and maintenance duties regarding the systems subject matter of the analysis or because they have performed studies for AyA in the area.

Among the positive aspects it shall be mentioned that AyA as organization owner of the infrastructure under assessment achieved the following:

a) An appropriate interaction with the PIEVC Protocol for the case under analysis as part of the learning and adoption process of the methodology.
b) It gave rise to the possibility of applying this protocol to other potable water and sewage infrastructures, provided data is available.
c) It is now clearer the data the owner of the infrastructure (AyA in this case) must gather in order to achieve an appropriate selection of critical thresholds for the components of the infrastructure under analysis. This is essential in order to be able to size and define the climate parameters to be analyzed.

In this step it is convenient to work together with the personnel of the organization owner of the infrastructure under analysis, with the personnel of the organization who made the climate study.

The work team was composed of the following:

AyA

Dr. Eng. Luis Carlos Vargas Fallas. Civil engineer with post-graduate degree in Management of Tropical Hydrographic Basins, Post-graduate degree in Natural Sciences for Development; more than 25 year experience in operation and maintenance of potable water and waste water system, environmental management, development and application of water flow mathematical models. He has been professor at Escuela de Salud Pública of UCR. Former Director de Environmental Management and present Director of UEN of Research and Development. Coordinator of the analysis on behalf of AyA.

Eng Alejandro Rodríguez Vindas; Civil Engineer with 8-year experience in operation and maintenance of potable water and sewage systems. Chief of Engineering of the Región Huetar Atlántica.

Eng Hernán Villalobos Slon Civil engineer with 3-year experience in application of mathematical models for water quality surveys in hydrographic basics, development of digital systems of meteorological and hydrological data. Member of the Steering Board of UEN Research and Development.

Eng Patricia Zamora Cordero, Civil engineer with 25 year experience in planning and physical development of potable water and sewage systems, development of master plans and system design. She works at UEN in Programming and Control.

M.Sc Eng. Alvaro Araya García. Civil engineer with post-graduate degree in sanitary engineering with over 10-year experience in assessments and designs, operation and maintenance of waste water systems, environmental impact assessments. Director of the UEN of Waste Water of the Assistant Manager's Office of Peripheral System Management.

IMN

M.Sc. Met. Roberto Villalobos Flores, Assistant Director of IMN, Meteorologist with post-graduate in Agricultural Meteorology; he has managed several analysis on climate change and water resources and regarding a climate and health change between 2003-2008 was the coordinator of the 2nd National Communication of the United National Convention on Climate Change.

Eng Nazareth Rojas Morales Agricultural Engineer, researcher of the Department of Climatologyand Applied Researches of the Instituto Meteorológico Nacional

CFIA

M.Sc. Eng. Freddy Bolaños Céspedez, Civil engineer with post-graduate degree in Sanitary Engineering. Professor of the School of Civil Engineer of UCR, Academic Coordinator of CFIA and link with Engineers Canada.

M.B.A Laura Solera Bonilla; Civil Engineer with Post-graduate degree in Business Administration. Link in the coordination with UPADI.

The advisory team was composed of the following engineers:

Eng. Jeff O´Driscoll
Eng. Guy Felio
Eng. Roger Rempel
Eng. Darrel Daniluk
Eng. Heather Auld
Eng. David Lapp

2.3.2 Work sessions

The main tasks set forth in Table 2-6 were carried out with the time and feature set forth below.

Table 2-6 Description of sessions held by the team

Type	Quantity of sessions (persons involved)	Total time assigned (8-hour day)	Description
Workshops on PIEVC Protocol.	3 (14)	42	Practical work with officials from Engineers Canada to get familiar with the PIEVC Protocol and its application.
Workshops on data analysis	14 (8)	112	Team work sessions to develop the analysis.
Field team work.	3 (12)	36	Work sessions to analyze the infrastructure subject matter of the survey, carried out in Limon
Individual field work	4 (1)	4	Verification of data gathered
Logistic support	13(5)	13	Support staff during visit to facilities under analysis, reproduction of data, gathering of documents and pictures.
Individual office work.	24 (8)	192	Gathering and analysis of documents, result calculation and analysis
Presentation of results	2 (8)	16	Presentation of results at Workshop held at CFIA and the city of Limon.
Bibliographic systematization	1 (2)	2	Revision and systematization of bibliographic documents
Drafting of final report	8 (5)	40	Work sessions of the writing and editing team of the final document

The total of 8-hour days assigned to this study was estimated based on the quantity of events occurred and the duration of the events and the quantity of persons involved.
It is estimated 457 days of 8 hours of domestic and international professionals involved and that includes 13 days of non-professional support staff.
The analysis began on August 16 2010 and the report was submitted on July 2011.

3. CLIMATE ANALYSIS AND PROJECTIONS

3.1 Purposes of climate analysis

3.1.1 Explanation of the purpose

The purpose of climate analysis and the projections in this type of analysis is to establish a set of climate parameters describing the climate and the meteorological events that characterize the geographical area where the project is. In this case of the Wastewater Treatment System of Limon (Costa Rica) composed of the sewer system, the Pre-Conditioning Station (EPA) and the underwater outfall, the analysis is specifically focused on direct and indirect effects on said infrastructure.

From this information and by means of the application of the PIEVC Protocol it will be carried out the assessment aimed at determining the general occurrence probability of each phenomenon measured by the chosen parameters, in a historic and future assessment. For the purposes of this analysis, “historic” shall include the present and recent past climate while “future” shall mean a fixed term in a prospective time horizon. This horizon has been established by the work team from criteria related to the number of years of the life cycle of the civil infrastructure.

This is the same period of time in which it shall be available data on climate changes expected as a consequence of the climate change. This information must be obtained from the atmospheric global circulation models (GCM) for scenarios of predefined emissions. The terms used were discussed by the work team and the criteria and conditions for data analysis are shown in 2.2.

3.1.2 Parameters selected

The work team held several sessions and field visits; then, from an initial list, it defined a list of chosen parameters. Subsequently, in order to guaranty the maximum consistency between the processes of necessary meteorological data gathering regarding the components of the infrastructure in process of assessment, the team developed and applied a matrix.

The matrix is shown in Table 3-1, which was discussed to determine the climate parameters that would be considered in the next phase. This Table shows three of the parameters that were discarded from the beginning of the process because they do not occur in the study area.

Other parameters were initially discussed and after discussion it was determined that both sun radiation and relative humidity are parameters that do not directly affect the infrastructure or the process in general, and on the other hand tornados, fog and hail were not considered because they are never present in the study area.

Table 3-1 Matrix of preliminary analysis for parameter selection

Parameter or climate event analyzed	Relevance of the event	Duplicity of the load effect ([2])	Occurrence possibility of the climate event in the site	Data availability	Discarded
High temperature	High	No	High	High	
Low temperature	Low	-	No	High	√
Oscillation of daily temperature	Low	-	No	Low	√
Heat waves	Medium	-	No	None	√
Cold front	High	Yes	Yes	High	
Sea breeze	High	No	Yes	Medium	
Overcharge rain	High	No	Yes	High	
Flooding rain in EPA	High	No	Yes	High	
Lightning	High	No	Yes	Medium	
Wind (speed and direction)	High	No	Yes	High	
Ocean currents (speed and direction)	High	No	Yes	Low	
Tropical waves	High	No	Yes	High	√
Sea waves	High	No	Yes	Low	
Drought	Medium	No	Yes	High	√
Flooding	Medium	Yes	Yes	Medium	√
Hurricanes	Medium	Yes	Yes	Medium	

Climate parameters chosen to begin the analysis are listed in Table 3-2, explaining the application of the parameter for vulnerability assessment purposes starting from the effects that the team deemed relevant.

[2] It refers if the load generated by this parameter (for instance rain, wind) is already considered in any of the other parameters included in the list

Table 3-2. Explanation of meteorological parameters chosen.

Parameter	Application in the analysis	Relevant effect on the infrastructure
High temperature	Determine variation in water consumption given that higher consumption involves higher returns.	Reduce the system treatment capacity upon early reaching the design value.
	Damage of operation conditions in the EPA.	Risks of accidents and operation shutdown of EPA.
Cold fronts	It may cause intense rain and flooding in the analysis area.	Operation shutdown of EPA and of the underwater outfall. Risk of damage to the equipment and operators.
Sea breeze	The breeze contains salinity that may damage the equipment and electric, telemetric, control and communication installations because breeze causes increased corrosion.	Failure of control system resulting in operation shutdown of EPA and of underwater outfall.
Overcharge rain	Intake flow to EPA increases due to storm drain connections.	Operation shutdown of EPA and of underwater outfall.
Flooding rain	Flooding of urban area upon exceeding hydraulic capacity of the storm drain system and damage caused from flooding of EPA.	Operation shutdown of the EPA and of the underwater outfall. Risk of damage to the equipment, infrastructure and operators.
Lightning.	Damage to electromechanical equipment and possible damage to personnel of EPA. Power supply failure at EPA and at the pumping stations.	Failure of the control system resulting from operation shutdown of EPA and of the underwater outfall.
Wind: Speed and direction	Wind speed and direction component determines the direction of ocean currents in the discharge area of the outfall diffusers.	They jointly determine the spreading of the outfall plume in accordance with the design, taking it far from the shore or towards the shoreline.
Ocean currents: speed and direction.	Direction and speed of ocean currents in the channel in the discharge area of the outfall diffusers.	
Tropical waves	They may cause intense rain and flooding in the analysis area.	Operation shutdown of the EPA and of the underwater outfall. Risk of damage to the equipment, infrastructure and operators.
Tides (waves)	Possibility of extreme hurricane winds and waves in the study area where the EPA and the underwater outfall are.	Operation shutdown caused by waves reaching the EPA level and flooding the operation area. Damage to the building infrastructure. Stability of the underwater outfall piping and anchoring.
Drought	Determine increase in water consumption and higher return.	Reduce treatment capacity of the system upon early reaching of the design value.
Flooding	Determine possible damage of infrastructure and overcharge– even though it depends on the hydraulic conditions of the drainage area.	Possible damage to the infrastructure in lower areas or in case of extreme exposure of pumping stations,
Hurricanes	Determine the possible infrastructure damage and overcharge– heavy rain and effect of wind and waves.	Possible damage to infrastructure under poor urban drainage conditions, height of stations and equipment considering the effects of loads.

3.2 Data Methods and Sources

3.2.1 Historic information for climate parameters

The climate analysis and description for the city of Limon was made taking into consideration data from different sources. Meteorological data as well as climate description was obtained from Instituto Meteorológico Nacional (IMN), both from the Database of the Station Limón 81-003, as well as from literature published by IMN.

The lightning data was obtained from Instituto Costarricense de Electricidad (ICE).
Flooding data was obtained from the database of Desinventar Project (Inventory System of Diaster Effects); for hurricanes it was used the data of ECAPRA (Evaluación Probabilística de Riesgo para América Central – Probabilistic Risk Assessment for Central America). Data on sea waves was obtained from simulations of the WAVEWATCH III model Version 2.22 of NOAA (National Oceanic and Atmospheric Administration of the United States of America)

3.2.2 Climate projections (future)

Future climate projections were assessed by means of the results of climate models made by dynamic downscaling, using the regional model PRECIS. This is a high resolution space and time model. It was developed by Centro Hadley of the Meteorology Office of the United Kingdom and is an updated version of the regional model. For results obtained space and time resolutions chosen were 50 km and yearly.

Results from the lower resolution atmospheric global model HadAM3H and anomalies of sea surface of the coupled model y HadCM3 were the input for the PRECIS model for Costa Rica. For climate simulation it was used the 1961-1990 timeframe which is considered the baseline of the IPCC. (IMN, 2008)

When no results of regional models were available, the global climate models generated by Environment Canada´s Canadian Climate Change Scenario Network (CCCSN) were checked, based on the results of the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), for A2 scenarios (scenario of high greenhouse gas emissions), run on the HADCM3 Model. Global models were used when the model was not available at regional scale. It shall be noted here that for some climate parameters there are no prediction models available and this is why the analysis was performed with historic data in order to determine the trend or the probability that this trend stays in the future, relating the same with the trend of other parameters.

3.2.3 Time frame used for the assessment

3.2.3.1 Record interval

Meteorological data was obtained from the records of the Limon Station 81-003, which has different assessment terms according to the parameter to be analyzed. Regarding precipitation data there are records available corresponding to the period of time from

1941 to 2009, temperature data is available from 1970 – 2009, to determine speed and direction arising out of sea breeze records data from 1970 to 1997 was used.

Regarding extreme rain events (cold front and tropical wave) the Instituto Meteorológico Nacional (IMN) has records from 1980 to 2006.

Data of sea waves was gathered from simulations made by NOAA for hurricane events in the north Atlantic affecting the Caribbean Sea due to groundswell. The records go from 2000 to 2010.

Historic data on the flooding frequency for the climate region of the Caribbean is documented by IMN for the 1949-1999 timeframe; flooding is more concentrated in the central and south central coast strip of the Caribbean region. The most damaged locations are Turrialba, Limón centro, Bananito and Valle de la Estrella. (IMN, 2008)

Regarding drought records for the area under assessment, the IMN has data of events that took place from 1960 to 2005.
For the assessment of lightning incidence on the assessment area, data from 2005 to 2009 was used.

As it follows from the above, historic timeframes for each parameter are different, however it was unanimously resolved to perform the assessment with the most quantity of data available per parameter.

3.2.3.2 Projection term (future)

As far as possible, the assessment term used for future projections is 30 years or from 2011 to 2040.

The AyA team established this term from the life cycle of the infrastructure per piece of equipment and subsequently this was analyzed by the Work Team of the Project. As a result of this, it was considered that this term exceeds the useful life of some components of the infrastructure which are usually replaced in short terms due to maintenance aspects.

For other infrastructure of larger size (buildings, piping and anchoring of the outfall) it can be expected that reconstruction or rehabilitation may be required in this period of time, even without the climate change effect.

3.3 Climate Parameters

For this chapter it was taken into consideration the feature of the parameters explained in 2.2.2.1.2, regarding the recurring or extreme nature of the event.
In February 2011 three workshops were held to discuss data gathered (see Annexes 1 and 2) and secure the highest consistency between climate aspects and the features of the infrastructure components to be assessed.
The purpose of the above is:
a) Have uniform frequency assessment units available,

b) Gain better understanding on possible damage caused by parameters to the components,
c) Select the parameters having quantitative value regarding their magnitude in order to carry out the engineering analysis.
d) Associate the dimension of climate parameter values with the design loads of the components under analysis.

Given that the classification divides parameters in recurrent and extreme, it was deemed convenient that climate data and its analysis be presented separately.

3.3.1 Recurrent Parameters

In this case the effect of load on the components of the infrastructure under analysis depends more on the persistence of the same rather than on the occurrence of the event in a given year.

The following are recurrent parameters:

- High temperature
- Sea waves
- Sea breeze
- Lightning

3.3.1.1. High temperature

3.3.1.1.1 Definition

For the purposes of this assessment, high temperature shall mean the number of days when temperature is equal to or higher than 30°C.

This threshold was determined based on the maximum temperature recorded at the Limon Station (81-003) in the 1970-2009 and it was 35°C; out of all the records there are two data with this value, one in June 1975 and the second one in May 1978. According to the average temperature records this value corresponds to a representative extreme high temperature event.

3.3.1.1.2 Climate historic records

In order to determine the temperature data for the area under assessment it was used the Limón Station (81-003). Table 3.1 shows the data of the monthly average maximum temperature for the 1970-2009 term.

Table 3.1. Monthly average values of maximum temperature (°C) Limón. 1970-2009

E	F	M	A	M	J	J	A	S	O	N	D
28,9	29,0	29,7	30,2	30,4	30,3	29,6	30,0	30,6	30,4	29,5	29,0

3.3.1.1.3 Probability Assessment

Based on historical data of Limón Station, it was obtained the number of records when daily maximum temperature between 1970 and October 2010 was equal to or higher than

30°C. It was obtained a total of 7935 data in 40 years of records; therefore, the frequency calculated was 198,38. The revised frequency is 54,3% (Annex 2) for a present probability of **4**, which is described as **moderate/possible**, using **Table 2-2** Probability Scale Factors for recurrent and non-extreme events of 2.2.2.2 hereof.

3.3.1.1.4 Trend

The monthly average temperature (1970-2009) at Limón shows little variation from month to month, but in any month there could be a considerable oscillation between the maximum and minimum temperature of the same day. In average, in March oscillation reaches its maximum with 8,4°C, while in July it reaches a minimum of 7,1°C. In average, annual oscillation is approximately 7,9°C. The hottest month is May and less hot month is January.

According to an assessment performed by IMN (2008) regarding variability and extreme events (dry and rainy) as per the baseline of IPCC (1961-1990), for the area under assessment, during an extreme rain event the maximum average temperature may decrease 1 °C, while during an extreme dry event these temperatures may increase up to 1 °C.

Figure 3.1 shows the comparison between the average values of maximum temperature and the average temperature for the sample of 1970-2009.

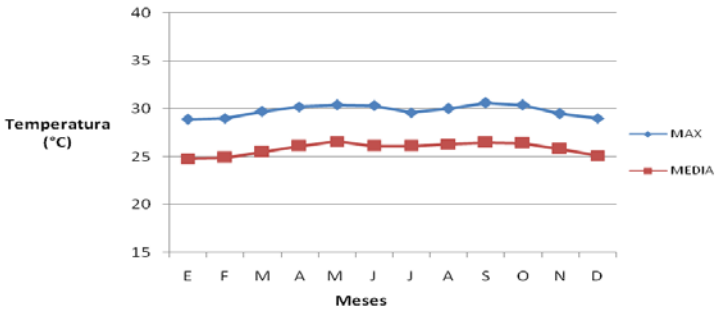


Figure 3.1 Monthly average values of maximum and average temperature (°C) Estación Limón, 1970-2009

3.3.1.1.5 Climate projections

In accordance with the results of the Regional Climate Model (Modelo Climático Regional - MCR) PRECIS scenario A2, for 2011-2040 term, the annual average temperature for the region where Limon city is will increased up to 1°C. If this increase is considered in the average maximum temperature it could be assumed that this increase would be enough to increase, to a certain percentage, temperatures higher than 30 °C.

Figure 3.2 shows the results of the MCR of the annual average temperature anomalies for Costa Rica.

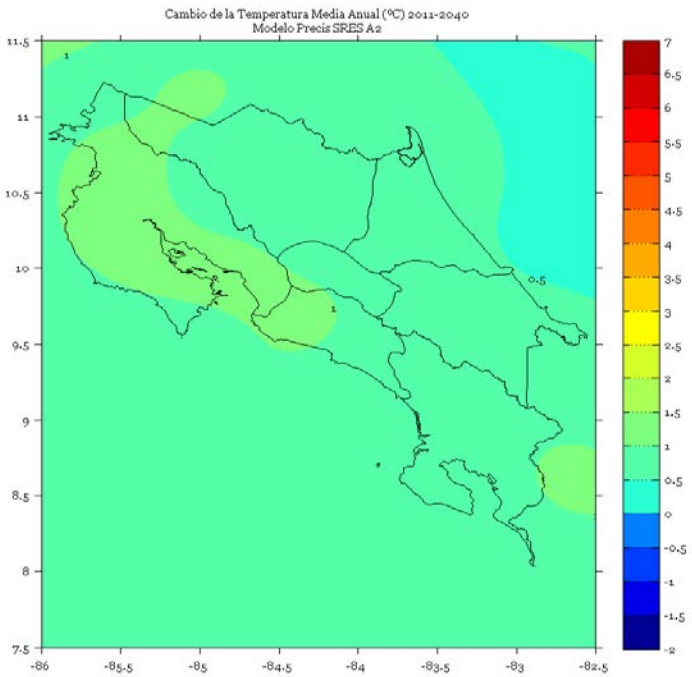


Figure 3.2. Results of MCR- PRECIS for annual average temperature. 2011-2040 term

Considering the increase above it is determined that the probability scale would increase one degree. Future probability increases one point being a probability of **5**; which is described as often, as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events, section 2.2.2.2 of this report.

3.3.1.2 Sea waves

3.3.1.2.1. Definition

For the purposes of this assessment, the sea wave parameter shall mean the number of days when waves reached from 2 to 3m high.

Waves or series of ripples on the water surface are the result of an interaction between the sea and the air. Formation and features of waves are influenced by several factors: the value and aeration of atmospheric pressure, configuration and depth of sea bottom, salinity and temperature of water and mainly the generating power of the wind; except for waves caused by volcano eruptions, crust breaks of the sea bottom (tsunamis) and waves resulting from tide effect.[3]

Hurricanes are meteorological phenomena that generate extreme wave conditions on the ocean surface. Under these conditions few instruments can be displayed in deep or shallow waters so that few real data on height and direction of these waves can be obtained. Therefore, wide information on the distribution of these parameters can be

[3]http://www.mailxmail.com/curso-meteorologia-general/mar-viento-fondo

obtained only by means of numerical models simulating the wave conditions during a hurricane. (Lizano, S.F)

A wave generating model must be coupled to a wind model that may provide a full description of the space variation of the wind field during a hurricane. (Lizano, S.F)

Regarding tides: The stations located from Puerto Limón in Costa Rica up to the station in Bahía de Caledonia in Panama show similar tide waves among them, being different only in the magnitude of the tide scope. Sometimes these stations show mixed tide and semi-diurnal tide. Around the moon quarters a mixed tide arises which daily inequality is hardly seen with a small rise or falling of tide. The days following full and new moon there is a tide that is rather pure semidiurnal tide. The form value to rate this tide places this station of Puerto Limón as predominantly diurnal mixed tide. (Lizano, 2006)
Considering that the information on tides is included in the results of the WAVEWATCH III Model for wave height, no specific analysis was performed for tides but it shall not be discarded the convenience of performing the assessment in the next phase of the analysis.

Regarding ocean currents: As it was already mentioned, in the analysis phase it was not possible to carry out an assessment of historic and future projections of ocean currents for the area where the diffusers of the underwater outfall are, in order to determine the future affectation of the plume diffusion and transportation with fecal contamination. There is only the result of the mathematical model of fecal contamination discharged into the marine environment through sewage outfall. (U. Cantabria, 2000).

This calculation was made using the AD2D contaminant transport model for 12 calculation situations resulting from the combination of a live astronomical tide (semidiurnal with 0.5 m stroke) and different situations of wind and ocean currents. This modeling was made in 4 time instants distributed all along 1 day simulation term.

From the results of this mathematical model it was determined that for an effluent concentration of 5.10^7 CF/100 ml, the conditions arising out of effluent transport towards the coast are associated to a 0.50m astronomical tide with a 0 m/s current south-east direction and calm wind, that is to say the sea waves as such will be in charge of this effluent transport. Another condition corresponds to the same height of tide, with 0 m/s current south-east direction and wind direction of 10 m/s north-east, in this case the transport speed is higher in a 24-hour term. Finally, if there is a 0.50m astronomical tide, current of 0 m/s south-east direction and 10 m/s wind predominantly east, there is also direct transport towards the coast.

If ocean currents higher than or equal to 0.25 m/s with south-east direction are kept, even if calm wind is kept, the effluent travels far from the coast with south-east direction even with predominant winds from north-east and east.

Figure 3-3 shows the map with the direction of ocean currents for the study area. We can see in the figure that the predominant direction is indeed south-east.

Fuente: http://www.hawksbillwwf.org/mapas_datos/mapas

Figure 3-3. Map of sea curr55ents in the analysis area

Tides produce currents by themselves; tides are produced by gravitational forces exerted by the Moon, Sun and the Earth, being the Moon the one that produces most force because it is closer. The larger the tide scopes the stronger the currents are (tide height difference between high tide and low tide). (Lizano, SF[2])

According to Lizano, S.F[2], there are several ocean currents that may be found near the coast. Among them we can mention the currents generated by the tide, currents generated by the wind, currents generated by density changes (salinity and/or temperature), currents generated by river discharges and currents generated by sea waves. Sea waves gives rise to several types of currents. When waves break they may generate currents all along the coast, currents towards the coast and return currents towards deep sea; the latter are known as backwash currents.

As it has been previously described, in order to determine the occurrence frequency of marine currents with 0 m/s speed and south-east predominating direction, it is required to perform an analysis by means of simulations based on waves, tides, salinity, sea temperature, among others. For this project there is no financing to carry out historical frequency surveys and the future projection analysis (year 2040) of marine currents in the area of interest.

Because of the above, the parameter of marine current will not be taken into consideration to define the vulnerability of the outfall infrastructure due to the inefficiency in the conveyance of effluent out of the coast line, as well as due to the blocking of the diffuser outlet as a result of sediment deposit near the anchorages and on the pipe itself.

3.3.1.2.2 Climate History

Climatological analysis of the wind in Costa Rica indicates that in the months of the so called dry season in Costa Rica (December to April), the wind speeds up in the Caribbean giving rise to strong energy waves in this area. [4]

[4] http://www.imn.ac.cr/educacion/oceanografia.PDF

The wind direction in the Caribbean is typical of trade winds, with north-east component (28,84°). The waves also go south-west thus reinforcing the local nature of the same. (Lizano, 2007)
According to Lizano, 2007, the historical series of waves and wind of the wave predictions of WAVEWATCH III Model of NCEP-NOAA for the 1997-2004 term were analyzed. The average of the wind speed was obtained by averaging every 3 hours the wind magnitude. The average of the wind direction was obtained averaging the respective zone and meridional components of these series.
Table 3-3 shows the general features of the data series.

Table 3-3 General features of the wind and wave series of NOAA-NCEP data

Parameter	Min	Med	Max
$H_{1/3}$ (m)	0,08	1,37	3,87
Tp (seg)	2,55	7,28	13,29
ϴH (°)	-	241,34	-
W (m/seg)	0,03	3,92	16,57
ϴW (°)	-	28,84	-

Source:Lizano,2007

Where;

H1/3: significative height of wave, defined as the average wave height of the highest one-third of waves in a wave record.
Tp: peak period of the wave.
ϴH: direction regarding the north of the wave, where they are heading (oceanographic convention).
W: magnitude of wind speed.
ϴW: direction of the wind with respect to the North (meteorological convention).

The average periods of Caribbean wave (7.38 sec) shows the local nature of these waves. In this region the maximum material height of wave can be reached and it can be up to 4 m.

When there is a material height, the maximum height of wave may be 1.5 x $H_{1/3}$, obtaining the probability of having in the Caribbean a 6m high wave. In this area there is only one type of wave which height grows lineally with the term. A small percentage of waves has a long period of time (12-13 sec.) (Lizano, 2007)

3.3.1.2.3. Probability Analysis

Among the documents to analyze the design of the underwater outfall there is a study performed by Universidad de Cantabria (Spain) for Instituto Costarricense de Acueductos y Alcantarillados through Universidad de Costa Rica, that is called: Summary of studies made on the Puerto Limon underwater outfall, and it was confirmed from an analysis of wave height frequency that there is little probability that height of the wave is higher than 6 m.
For the purposes of this study it was defined as extreme waves those that occurred on August 19 2007 when the height of waves exceeded the wall of the seafront promenade that protects EPA. It was determined from the research that waves generated on that date were from groundswell resulting from the path of the Dean Hurricane which caused casualties in Mexico during its passing.

In order to carry out the frequency analysis it was used the results of the wave height simulations performed by NOAA (National Oceanic and Atmospheric Administration of the United States of America)[5]. These simulations were made with the WAVEWATCH III Model Version 2.22, in 3 hour intervals of simulation.
This WAVEWATCH III model includes the refraction and effort of the wave field due to time and space variations of mean depth of water and of mean current (tides, tidal wave, etc.). Parameterization of physical processes include the growth of waves and the decadency due to action of the wind, the non-lineal interactions of resonance, dissipation, bottom friction and wave dispersion due to interactions in the lower part.

According to the results of this model, for August 19 2007 in the analysis area waves with a maximum height between 2 and 3m were simulated, and with this parameter it was counted the number of days when this condition was present. The analysis of the modeling was performed during the presence of hurricanes in the North Atlantic Ocean and those that affected the Caribbean from 2000 to September 2010.

In the above mentioned period of time it was counted a total of 132 days when wave height was from 2 to 3m in 9,75 years of records for a frequency of 13,54 and a revised frequency of 3,7% (Annex 2).

The probability is **1**, described as **Improbable / highly unlikely** as per **Table 2-2** Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 of this report.

3.3.1.2.4 Trend

During the year the Caribbean coast in Costa Rica keeps waves coming from north-east. During the last and first months of the year it has more energy, which is related to the intensification of trade winds during this time of the year. For May it decreases and for July it increases when trade winds speed up in this region. The minimum value is present in September and October when trade winds in this region are minimum.(Lizano,2007).

The monthly behaviour of wave height in the Caribbean is contrary to that on the Pacific Coast of Costa Rica because is higher during strong trade winds (December – April) and lower during weakening of the same (September - October).

3.3.1.2.5 Climate projections

As per the Synthesis Report (AR4) of 2007 of the IPCC, the average rate of increase of sea level is 4,2 mm/year between 2000 and 2080. For our case it is required the projection of the increase of sea level for year 2040; considering the reason above it was determined an increase of 0,13 m. It shall be noted here that this data corresponds to a global trend.

[5] http://polar.ncep.noaa.gov/waves/historical.html

On the other hand, high waves are generated by the wind on the sea surface; the cold fronts coming from the north of the Atlantic are also related to the generation of high energy waves. (Lizano, 2007). Considering the above, it was carried out an analysis of trade wind speed projections affecting the Caribbean coast of our country, as well as the future occurrence of cold fronts, analysis that was previously performed in this study.

Out of the results it was determined that the trend of trade winds for the last and first months of the year, according to the Global Model of CCCSN tends to **decrease** (period of cold fronts), there is an increase only in April through November and the maximum limits correspond to the months when the Caribbean coast of Costa Rica shows higher waves, and this is partially due to the generation of groundswell, because this is the season of hurricanes.

Even though it was assessed that there is a **downward** increase trend of Cold Fronts for the 2011-2040 period of time, there is an **upward** trend of trade winds during April through November, and in this period is the hurricane season of the North Atlantic and Caribbean. In the analysis carried out for hurricanes it was established that the trend until year 2040 is an increase in the generation of this type of events. Starting from these theories and from the analysis performed by the IPCC regarding the projected increase of the sea level it is clear that an increase of the average height of waves will take place.

The maximum wave height is in terms of the local wind speed when groundswell is generated and it is also in terms of the presence of hurricanes in the North Atlantic and the Caribbean and which cause the groundswell; another important factor to be considered is the tide, however to be able to analyze the effect of this parameter on wave height it is required simulations and numerical models which were not available at the time of carrying out the analysis.
It shall be noted here the need to perform studies on this aspect in future stages of this project.

Based on the above, it is considered that the Probability Scale Factor for the wave parameter will increase at a given point and therefore a probability value of 2 is projected which is described as **Remote** as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 of this report.

3.3.1.3 Sea breeze

3.3.1.3.1 Definition

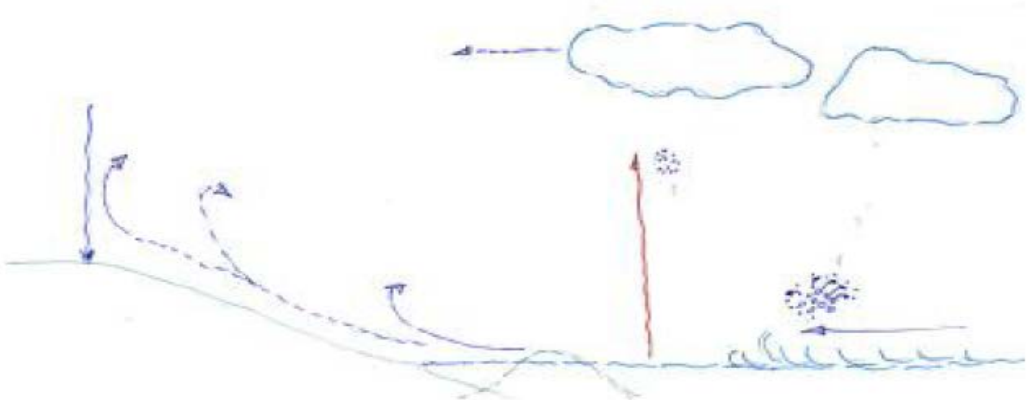
For the purposes of this assessment, sea breeze shall mean the quantity of days when winds are generated between 2 and 7 m/s with North-east and East directions, from the sea to the EPA.

Sea breeze are on the coasts and are produced by the effect of the differences of warming and cooling down experienced by the Earth and water bodies; sea breeze is responsible for the corrosion of metals and pieces of equipment of EPA when present in the place where said infrastructure is.

Marine regions are almost exclusively composed of sea salts and highly depend on wind speed. The following are the main components:- sea salt (most of it), - NSS: non sea - salt sulphate, - mineral powder, - nitrates.

The sea surface is considered an important source of these nuclei in the form of concentrated sea water drops formed from a spray generated once bubbles burst thus generating the wave (ocean-atmosphere interaction). One of the functions of the salt nucleus in the natural cycle is to absorb and convey water. The droplet is able to give place to vapour to liquid transformation phase thus releasing or storing latent enthalpy. It works in heat and mass transfers in preferential places: clouds and the space between the same where it goes through evaporation processes for instance. In the case of sea mist, the space in the vertical is filled by a droplet suspension generated by ocean evaporation, salt conveyance and hydration acute. This phenomenon is also observed in places near the coast at sunset time in sea breeze events where there are heat and mass exchanges.(Rivero, S.F.)

Figure 3-4 shows interactions between wind – sea and soil.



Fuente: Rivero, (S.F)

Figure 3-4. Wind – sea – soil interaction, formation and transport of sea spray

There is direct relation between wind force and bubble production; rain precipitation on the sea surface is another bubble producing phenomenon.
Making things a little more complicated, saline nuclei gain or loss water in relation to the relative humidity frame (HR) in which they move or are and this modifies the saline concentration of particles. Under balanced or saturated conditions the HR of deliquescence for each type of substance is specific and this means that if a particle travels in the air it is between the humidity attraction process and that of evaporation of the same. (Rivero, SF)

3.3.1.3.2 Climate History

In order to determine the frequency of winds with speed between 2 and 7m/s with prevailing North-east and east directions, we went over the records of Estación Limón 81-003 corresponding to years 1970-1997.

For the months between November and April, we found that the average speed value of wind is 2,13 m/s, while from May to October the same is an average of 2,00 m/s. Between June and August we find the lowest monthly average speeds: 1,94 m/s. Maximum average values recorded are in the range of 2,19 and 2,22 m/s during the rainy months.

3.3.1.3.3 Probability Analysis

In order to determine the probability frequency we obtained daily cases where wind was mainly North-east or east with speed between 2 and 7 m/s.

From the results we obtained a frequency of 13,3 % in the probability scale; this corresponds to a value of 2 that is described as **Remote** as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 of this report

3.3.1.3.4 Trend

The north fronts and the high pressure systems in the North Atlantic make that in this region trade winds blow intensively from November to April. On the Caribbean it is clear that all year round the wind has a North-east component.

In July the wind materially increases and coincides with the “veranillo de San Juan” (Saint Joseph’s little summer). Its minimum values are in September and October when the Equatorial wests are well established in Costa Rica. (Lizano, 2007)

3.3.1.3.5 Climate Projections

In order to determine the future projection of sea breeze it is required to carry out a thorough analysis of winds and precipitation because these are the parameters that are related to the salt nuclei transport.

Regarding the wind, according to the global models of CCCSN, it was determined that the annual mean speed of wind within the area under analysis tends to an increase of East winds up to 0.1 m/s.

This result is shown in Figure 3-5.

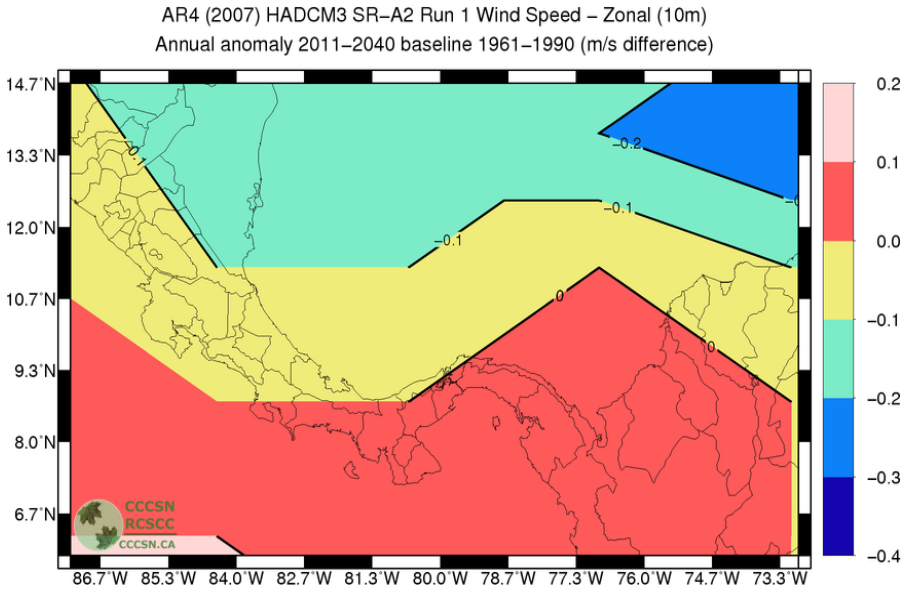


Figure 3-5. Global Model of anomalies in speed of annual wind. 2011-2040

On the other hand, according to the results of the precipitation analysis, it was determined that for 2011-2040, as per the regional climate models, the annual mean precipitation could show an increase of up to 25%.

Considering the average upward increase trend of East wind speed and of rainfall in the area under assessment, it is determined that the projection of sea breeze probability generating corrosion in the materials and equipment of EPA has an increasing trend.

Therefore, the probability scale factor would change in the future to 3 that is described as **Occasional** as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 of this report".

3.3.1.4 Atmospheric discharges (lightning)

3.3.1.4.1 Definition

The atmospheric discharge parameter is defined as the density of annual atmospheric discharges recorded in a 5 km radius around a point in the area of the underwater outfall, regarding the maximum density of mean annual discharges in the national territory.

Atmospheric discharge known as lightning is the sudden and extremely rapid equalization of electric charges which were formed between a cloud and the ground or between clouds. Lightning that is of interest for us because of their effect are those of cloud to ground and there 4 types: 2 that start in the clouds and 2 that start in the ground, because they can be positive or negative. The most common ones are from a negative cloud to ground and it accounts for 90% of lightning detected.

Atmospheric discharges may cause large differences of potential in electric systems distributed outside buildings or protected structures. This is why large currents may circulate in metal channels and among conductors connecting two isolated areas.

However, even without the discharge, an electrostatically charged cloud creates potential differences on the ground directly underneath. [6]

3.3.1.4.2 Climate History

It has been assessed the atmospheric discharge incidence in the area where the Underwater Outfall is; this report includes data on the density of atmospheric discharges from 2005 to July 2010. The assessment was made for a 5km radius having as epicenter the final section of the outfall piping.

Table 3-3 shows the quantity of atmospheric discharges the system detected in the study area during the assessment timeframe.

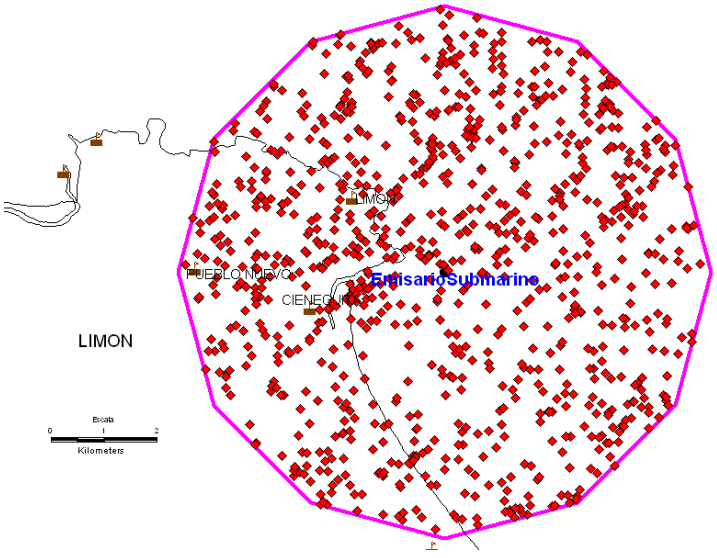
Tabla 3-3 Annual quantity of atmospheric discharges detected in a 5km radius around the place where the Underwater Outfall is.

Year	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010 (E-J)***
Quantity	114	5	0	144	46	311	358

3.3.1.4.3 Probability Analysis

According to data recorded (Table 3-3), the system has detected a total of 978 impacts on ground during the analysis timeframe; intensities recorded in negative polarity range from -3 kA to -142 kA and from 10 kA those of positive polarity. 99% of discharges are negative polarity and only 1% is positive polarity.

Figure 3-6 shows space distribution of atmospheric discharges in a 5km radius around the Zone of the Underwater Outfall for the term from January 2005 to November 2010.



[6] http://www.ruelsa.com/notas/tierras/pe50.html

Figure 3-6. Space distribution of atmospheric discharges in a 5km radius around the Zone of the Underwater Outfall. 2005-2010 . Source: records and report of ICE.

In order to calculate the occurrence frequency of atmospheric discharges in the assessment area, it was performed a comparison of density of the city of Limon with the maximum density of the country in order to obtain a percentage ratio that allows classifying the parameter as per the method selected of the protocol and at the same time to have the context of Limon situation reflected with respect to the country.

Frequency = Annual density Limón = 9.19 %
Maximum density - country

Annual density Limón = 978 lightning bolts / 78 km^2 / 6.5 years = 1.93 bolts/ km^2 / year
Maximum density country = 21 bolts/ km^2 / year

The results showed a frequency of 11,1 % in the probability scale which corresponds to a value of 2 described as **Remote** as per Table 2-2 Probability Scale Factors of Recurrent and Extreme Events of section 2.2.2.2 hereof.

3.3.1.4.4 Trend

It is not practical to analyze the punctual behaviour of discharges in such a reduced area as a 5km radius circle because there is a large variability of results; it is concluded that the Limon area has shown a relatively benign behaviour regarding discharges with an average of 5 discharges per km^2 per year (there are zones that have a density of more than 20 discharges /km^2 year).

Regarding monthly variation in the area where the underwater outfall is, according to the information supplied we can see that the months from November 2010 to July 2009 are the absolute and relative maximum values with more than 276 and 256 respectively. In the rest of months the maximum values are slightly more than 50 impacts per month and most of them do not exceed 30 atmospheric discharges during a month.

3.3.1.4. 5. Climate projections

No information was found that may relate the influence that climate change might have on atmospheric discharges, therefore we keep the probability obtained from historical data: a value of 2 that is described as **Remote** as per Table 2-2 Probability Scale Factors of Recurrent and Extreme Events of section 2.2.2.2 of this report

3.3.2 Extreme parameters

In this case the effect of the load on the components of the infrastructure is determined by the occurrence of extreme or special events in a given year. The following are the extreme parameters chosen:

- Flooding rain

- Overcharge rain
- Hurricane
- Wind (speed and direction)

For the extreme type parameters there is a wider return period of time and therefore they are more related to the design loads of the infrastructure to be assessed.

3.3.2.1 Flooding rain

3.3.2.1.1 Definition

The flooding rain parameter is defined as the occurrence of rain events in the assessment area and which value is higher than or equal to 213,6 mm in 24 hours.

This definition was taken from the accumulate rainfall on March 29 2006. This event caused flooding of EPA because the storm water drain system near this infrastructure collapsed and this is why water entered the preconditioning plant damaging the equipment and the process.

3.3.2.1.2 Climate History

According to IMN, 2008, extreme rainfall events recorded at Estación Limón (81-003) for the baseline 1961-1990 accounts for 49% of the increase in annual rainfall or the equivalent to 1.637 mm of this value.

In the assessment area, rainfall events may cause increases in rain precipitation mainly from November to February when the influence of cold fronts is a determining factor. During the month of May a new maximum of rainfall may occur. 93% of rainfall events have coincided with El Niño event. Table 3-4 shows the maximum and average values of monthly rainfall for 1941-2009.

3.3.2.1.3Probability Analysis

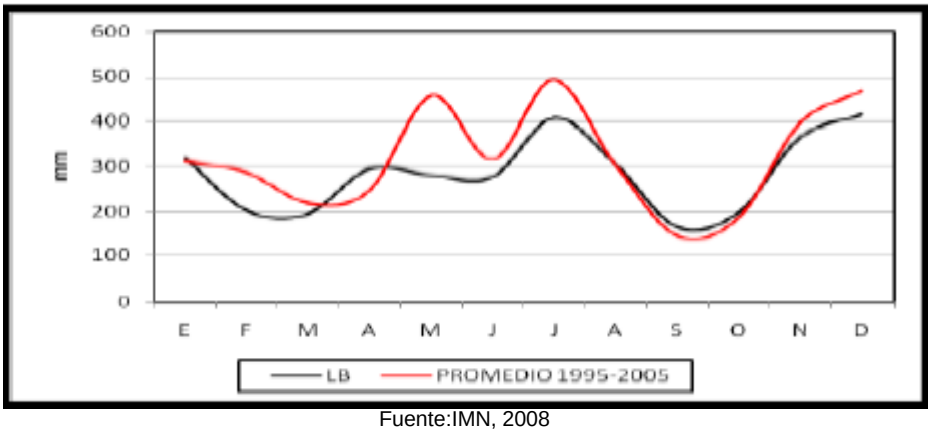
Based on historical records of Estación Limón, from the maximum daily rainfall values for 1941-2010 it was determined that the frequency of records higher than or equal to the threshold of 213.6 mm is 0,31; this value corresponds to a scale of 4, that is to say a "**Moderate/ Possible**" factor as per Table 2.2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 hereof

Table 3.4 Maximum and average values of monthly rain precipitation for 1941-2009.

Month Limón and max. historical values (1941-2009).MES	Average values (mm)	Maximum values (mm)
January	315,6	907,0 (2005)
February	233,8	796,1 (1997)
March	205,9	698,3 (2006)
April	267,2	925,1 (1970)
May	333,8	1055,9 (1997)
June	294,3	877,2 (1946)
July	432,2	1139,5 (1982)
August	311,6	691,5 (1990)
September	143,9	495,6 (1976)
October	208,9	1266,5 (1944)
November	380,3	1008,9 (1944)
December	446,3	1299,8 (1944)
Annual Average	**3.565,3**	

3.3.2.1.4Trend

The Instituto Meteorológico Nacional carried out an analysis of variations between 1961-1990 and 1991-2005 and it determined that for the Caribbean region monthly rainfall increases mainly in February, May and July. Annually the extreme rainy group disappears but rainfall becomes more frequent on the average.
Figure 3.7 shows the variations in monthly rainfall for the Caribbean region between 1961-1990 y 1991-2005.



Fuente:IMN, 2008

Figure 3.7. Variations in monthly rainfall between 1961-1990 (baseline) and 1991-2005

According to IPCC, in the results of the Work Team I of AR4 (Figure 39) (IPCC, 2008) it is established the trends in the extreme rain precipitation changes for the 1961-1990 term, and it is determined that for the Central America region there has been disproportionate

changes of intense and very intense rain precipitation regarding the change of annual and/or seasonal rain precipitation, that is to say there is an increasing trend of these facts. Figure 3.8 shows these results.

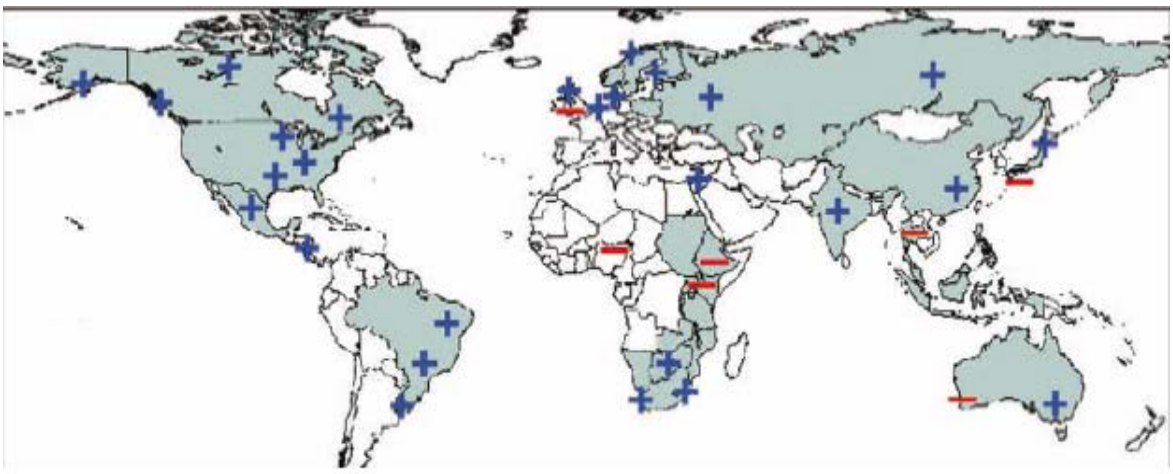


Figure 3.8 Disproportionate changes between intense and very intense rain precipitations compared to changes in annual rain precipitation
(1961-1990)

3.3.2.1.5 Climate Projections

According to the results of the PRECIS Regional Climate Model, scenario A2 it was determined for the 2011-2040 timeframe that for the zone under analysis it is projected an increase in annual rain precipitation of up to 25% in the assessment area.
Figure 3.9 shows the modeling results.

According to the results of the regional modeling, annual mean rain precipitation for 2040 could show an increase of up to 25%; on the other hand, according to IPCC (2008) based on global climate models, it has estimated that the extreme rain precipitation events will be more frequent, mainly in the tropical regions and high latitudes where an increase of mean rain precipitation is projected and it is even outlined that intense rain precipitations would increase more than the mean of rain precipitation. (WGI, AR4. 10.3.5, 10.3.6)

Based on the information above regarding climate projections, even though no increasing trends of intense rain precipitations are shown, some future projections suggest an increase in the frequency of this type of events.

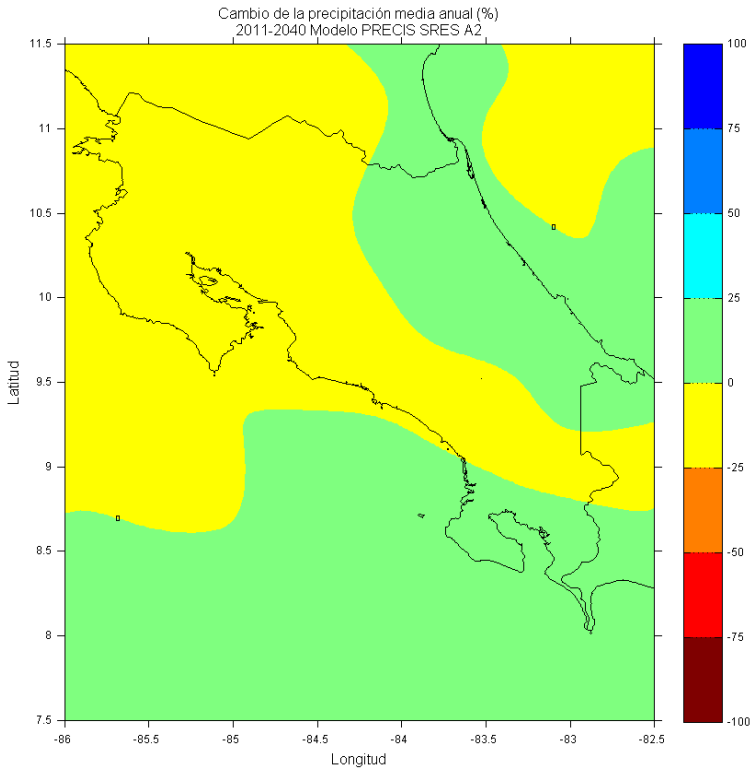


Figure 3.9 Results of MCR- PRECIS for annual mean rain precipitation. 2011-2040 term

Probability in the future was adjusted from the historical value of **4** to a value of **5, which is described as** "**Often**" as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 hereof

3.3.2.2 Overcharge Rain

3.3.2.2.1Definition

Overcharge rain shall mean the rain precipitation that reaches an intensity higher than or equal to 64,9 mm in 24 hours in the assessment area.

The occurrence probability of this parameter is calculated as the number of days of the record term on which rain precipitation reaches the intensity above, divided by the number of years of the record.

This is a parameter considered as extreme since it has been proved that it affects the functionality of the infrastructure because the storm water connections from houses which drain into the sanitary sewage when entering the EPA exceed the design flow for waste water when that intensity value is reached.

Therefore, the access gates must be activated and discharge direct water into the sea.

3.3.2.2.2 Climate History

Based on the IMN records of rain precipitation that include years 1941 to 2010, it was determined that there are 709 days on which rain precipitation reaches an intensity higher than or equal to 64,9 mm in 24 hours.

3.3.2.2.3 Probability Analysis

With the data above it was determined that the frequency of historical probability is 9,94 (number of events per year giving rise to damages in EPA in relation to the number of years of the analysis period of time) which corresponds to a value of **7** that is to say "**Certain /highly probable**" as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 hereof.

3.3.2.2.4 Trends

As it has been mentioned under 3.3.2.1.5 Climate Projections for the flooding rain parameter, according to IPCC in the results of the Work Team I of AR4 (Figure 39) (IPCC, 2008) it is established the trends in the changes of extreme rain precipitation for the 1961-1990 term and it is determined that for the Central America area there has been disproportionate changes of intense to very intense rain precipitation in relation to the change of annual and/or seasonal rain precipitation, that is to say that there is an increasing trend of these extreme events

3.3.2.2.5 Future projections

With the data above it was determined a probability factor of **7** that is to say "**Certain /highly probable**" as per Table 2-2 Probability Scale Factors for Recurrent and Extreme Events of section 2.2.2.2 hereof -

As it is set forth under 3.3.2.1.5 Climate Projections for the parameter flooding rain, the annual mean rain precipitation for year 2040 could show an increase of up to 25% and the events of extreme rain precipitation will be more frequent, mainly in the tropical regions where an increase of mean rain precipitation is projected, and it is even indicated that intense rain precipitation would increase more than the mean of rain precipitation.

In order to keep the purpose of the protocol and based on climate projections delivered by IMN which indicate that rain precipitation events will increase in the future due to a climate change, it was decided to assign a probability factor of **6** for the present scenario and **7** for the future scenario with climate change.

All the above is to reflect the effects that will occur with climate change and because the risks on the infrastructure components will increase if mitigation measures are not adopted.

3.3.2.3 Hurricanes

3.3.2.3.1Definition

The hurricane parameter is defined as the number of events which generated damage in the assessment area with respect to the number of years of the assessment period of time.

Hurricanes are a tropical depression that is considered a violent atmospheric anomaly that rotates as a cyclone and it is accompanied by strong winds and heavy rain. They take place in the Caribbean Sea and in the Tropical Pacific Ocean (Desinventar, 2009).

According to IMN (2008) the contribution of hurricanes to the total of annual rainfall is 1% for the Caribbean region.

Among the effects related to hurricanes are the increase in tidal waves, winds and rain.

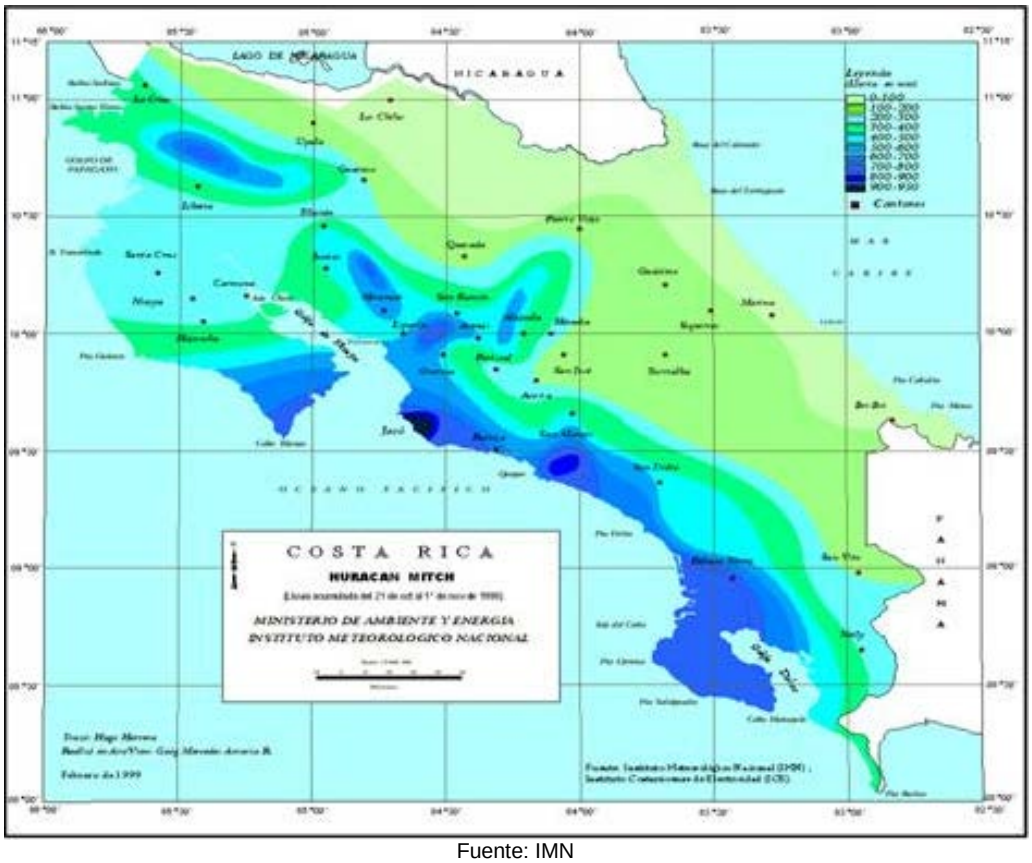
If the hurricane is in the Caribbean Sea, it will generate a tidal wave that will affect the surroundings of the hurricane, that is to say, it will affect mainly the condition of the sea (waves, rain, winds). In general terms Costa Rican coast is not damaged by tidal waves, however when a hurricane passes close to the Caribbean coasts of the country, northeast of Barra del Colorado, it affects said location. On the other hand, a hurricane generates from 150 to 300 mm of rainfall; winds related to a hurricane usually have devastating effects in large areas, mainly those directly affected by the phenomenon. [7]

3.3.2.3.2Climate History

Despite hurricanes are originated in the Caribbean Sea they also affect the Costa Rican Pacific Coast because of wind circulation and the movement of the Intertropical Convergence Zone towards the country.

In order to illustrate this effect we can take as example hurricane Mitch that affected our country from October 21 to November 01 1998 and which has been considered as the most devastating hurricane in the Central America history. Figure 3-10 shows that this event generated a material quantity of rainfall in the Pacific Basin, contrary to what happened on the Caribbean basin where rainfall was limited.

[7] http://www.imn.ac.cr/educacion/huracanes/huracan05.html



Fuente: IMN

Figure 3.10 Map of accumulated rainfall in Costa Rica related to the Hurricane Mitch from October 21 to November 1 1998.

Note in the map the maximum of rainfall in the Central Pacific area (Jacó, Quepos), approximately 900 mm. In the South Pacific area (Palmar Norte) rainfall accumulation is about 500 mm or more, as well as in Península de Nicoya, mainly in its southeast sector and north of Liberia, where material quantities of rainfall accumulated. In the plains of the North Zone the values reached 250 mm. On the contrary, in the mountain area rainfall accumulation ranged around 250 mm. The Caribbean basin was the driest region of the country with accumulated values of 100 mm or less. The quantity of rainfall accumulated by hurricane Mitch was higher than rainfall accumulated by the effect both of hurricane César (1996) and hurricane Joan (1988). [8]

According to the National Hurricane Center of the US agency NOAA, for the Atlantic Ocean the database shows 1377 tropical cyclones from year 1851 to 2007, while for the Pacific Ocean the database shows 833 tropical cyclones from year 1949 to 2007.

Figure 3-11 shows the path of tropical cyclones for the Atlantic and Pacific Oceans contained in the HURDAT database up to year 2007, while Figure 3-12 shows the events that have affected the national territory because at a given point of the path the hurricane

[8] http://www.imn.ac.cr/educacion/huracanes/huracan06.html

eye was less than 200 km from the Costa Rican coasts as well as events with a category ≥ (119 km/h) in the Saffir-Simpson (SS) scale.

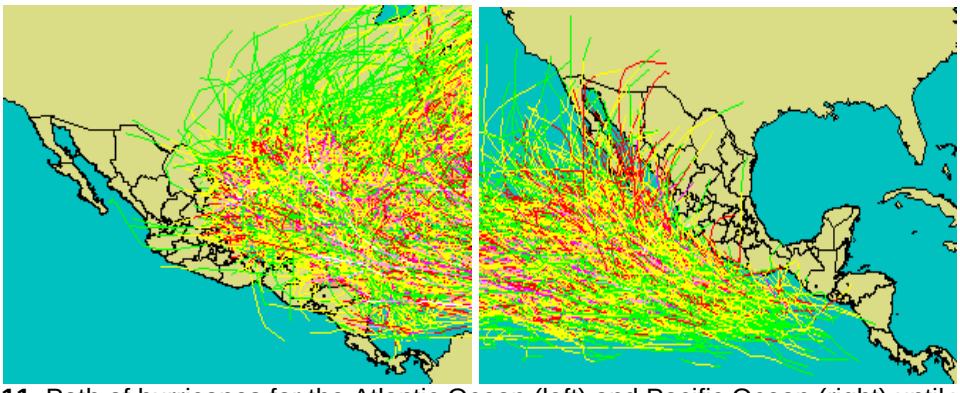


Figure 3-11. Path of hurricanes for the Atlantic Ocean (left) and Pacific Ocean (right) until year 2007. Source: HURDAT database of NOAA.

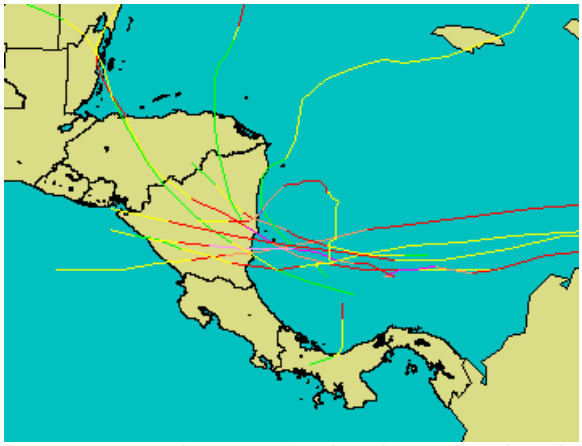


Figure 3-12. Hurricanes affecting the national territory

3.3.2.3.3 Probability analysis

In accordance with CAPRA (Central American Probabilistic Risk Assessment)[9] during the period 1970-2005, 15 hurricanes affected our country, out of them only 2 affected the area of assessment, including rainfall, floods and winds of great magnitude.

Based on the previous information, the frequency of probability is determined at 0.06 (number of events affecting the assessment area in relation with the number of years of the assessment period), in accordance with the established scale this corresponds to a value of **1** that is to say a probability of "**Improbable / highly unlikely**", as stated in Table 2-2 Probability Scale Factors for recurrent and extreme events 2.2.2.2 of this report.

[9] http://www.ecapra.org/capra_amenaza_por_huracanes_en_Costa_Rica

3.3.2.3.4 Trend

Hurricanes season goes from June to November every year, as it has been previously shown, most of them are originated in the Caribbean region, this affects due to the low pressure in the central region of the country and in regions of the Pacific coast.

It is very had to analyze changes in extreme climate events such as hurricanes, floods and draughts, as said events do not necessarily occur at the same time and in the same location, but the position of the IPCC has to be taken into consideration, which in its Fourth Executive Summary (2007) indicates that in accordance with a range of models, it is probable that in the future, tropical cyclones (typhoons and hurricanes) **will be more intense**, with maximums more emphasized on wind speed and more intense rainfall, all these linked to constant increase of tropical sea surface temperature. With lesser degree of confidence, projections indicate a global reduction in the number of tropical cyclones.

3.3.2.3.5 Climate projections

Most projections of general circulation models indicate relatively big anomalies in rainfall (positive and negative) for tropical zones in Latin America, besides it is also possible that in the future the frequency of extreme climate events will increase, mainly frequency and intensity of hurricanes in the Gulf of Mexico and Caribbean basins. [10]

Although hurricanes are associated to increases in sea temperature, winds, rainfall and even increase in sea level, it could be said that in accordance with climate projections there is an upward trend in the number and intensity of this type of extreme events (IPCC, 2007).

However, it cannot be defined with certainty if these type of events will be generated at less than 200 km from the Costa Rican Caribbean coast, in such a way that will directly affect the assessment area, since as it has previously been mentioned, the effects of hurricanes in the Caribbean are directly on the Pacific coast line and the central valley of our country.

Taking into consideration the upward trend of projections related to these type of events for the future, we increase the degree of probability related to this climate record by one, the value will increase to 2, that is to say a "**Remote**" probability, in accordance with Table 2-2 Probability Scale Factors for recurrent and extreme events, from section 2.2.2.2 of this report.

3.3.2.4 Wind (speed and direction)

3.3.2.4.1 Definition

For the purposes of this assessment, the wind parameter is defined as the number of days in which the speed is equal or exceeds 10 m/s and with northeast or east direction towards the site of this assessment, in relation to the number of years of the record.

[10] http://www.lariocc.net/riocc_principal/es/cc_iberoamerica/impactos_vulnerabilidad.htm

Wind is the air in movement, and as such has direction and speed. The direction is indicated from the point it comes from; the speed is the distance traveled by an air particle per unit of time (m/s; km/h; knot). Wind speed is measured by instruments called anemometers and the direction is observed with the help of a wind vane (Chacón, 1985).

For the purposes of this assessment, the wind parameter is defined based on the models performed by the Universidad de Cantabria in the study Summary of studies performed on Limon Underwater Outfall, Costa Rica; these are unfavourable wind conditions for the dilution of the contaminants plume dispersed by the underwater outfall. The outfall, as well as the infrastructure under assessment, is explained in detail in Chapter 4 of this document.

3.3.2.4.2. Climate background

In the area under assessment, the prevailing wind direction is southeast with an average intensity of 2.05 m/s measured at 5 m above the ground, for the period 1970 - 2009.

Figure 3-13 shows average monthly values of wind speed for the City of Limón.

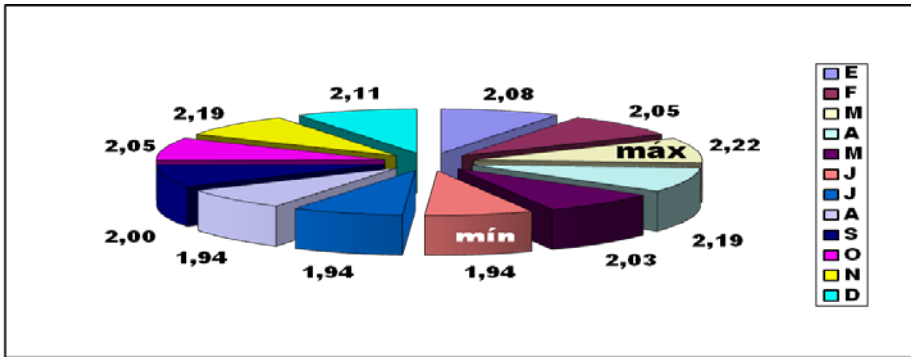


Figure 3.13. Monthly average values of wind speed (m/s),
Limón Station 81-003. Period 1970-2009.

From November to April, the average value of wind speed is 2,14 m/s, while from May to October the average is 2,00 m/s. The lowest average speeds are from June to August,: 1,94 m/s respectively. Maximum registered average values are 2,19 and 2,22 m/s during the less rainy months.

3.3.2.4.3 Probability analysis

In order to determine the probability of frequency, we obtained the number of events in which the meteorological station registered winds with speeds equal or above 10 m/s with northeast east directions. The analysis period is from 1970 to 1997.

Only in 4 cases the previous conditions were registered, from a total of 42.848 cases with northeast east wind. We took into consideration the number of cases because wind speed conditions can change during a day.

From the results we obtained a frequency of 0,15 (number of cases of the total sample in which the speed exceeded or was equal to 10 m/s with predominant directions northeast and east, divided by the total number of recorded years from 1970 to1997). This frequency value corresponds to 3 in the probability scale, this is "**Occasional**", from Table 2-2 Probability Scale Factors for recurrent and extreme events, section 2.2.2.2 of this report

3.3.2.4.4 Trend

The northern fronts and the high pressure systems from the North Atlantic cause intense trade winds in the region under assessment from November to April. It is clear that the wind has a northeast component the entire year for the Caribbean. The wind increases meaningfully in July coinciding with the "veranillo de San Juan" (Saint John's little summer). September and October represent the minimum values, when western equatorial winds are well established in Costa Rica. (Lizano, 2007)

3.3.2.4.5 Climate projections

In accordance with CCCSN global models, average wind speed, from November to April in the area of influence or affected area in the city of Limon, tends to decrease speed. The model results are for data above 10 m. of altitude, while data at Limon station are taken at 5 m. of altitude.

Taking into consideration the abovementioned, and considering that data used for the analysis are median values but at different altitude, we think that these results don't project the real trend of wind speed in the zone of interest, and thus we keep the value in the probability scale.

This frequency value corresponds to **3**, this is "**Occasional**", in accordance with Table 2-2 Probability Scale Factors for recurrent and extreme events, from section 2.2.2.2 of this report

*3.*4 Summary of results

3.4.1 Frequency and current probability for recurrent parameters

For these parameters we will use 2-2 Probability Scale Factors for recurrent and extreme events, from section 2.2.2.2 of this report that applies frequency calculus as percentages, which fits better to the reality of the parameter and its effects on the infrastructure. See table 3-5.

Table 3-5 Frequency and current probability for recurrent parameters

Parameter	Frequency	Current probability
High temperature	54,3%	4
Tides (waves)	3,7%	1
Sea breeze	13,3%	2
Lightning	9.2%	2

3.4.2 Frequency and current probability for extreme parameters

For these parameters we will use Table 2-2 Probability Scale Factors for recurrent and extreme events, from section 2.2.2.2 of this report. See Table 3-6.

Table 3-6 Frequency and current probability for extreme parameters

Parameter	**Frequency**	**Current probability**
Flooding rain	0,31	4
Overcharge rain	9,94	6
Hurricane	0,06	1
Wind	0,15	3

3.4.3. Results summary table

Table 3-7 shows a summary of data and the way probabilities were assigned for parameters under current and future climate conditions, in accordance with the risk analysis for climate change.

Once Step 2 has been concluded, this information is the foundation to proceed to Step 3 Risk Assessment. Step 2 focuses on obtaining enough data, in this stage the infrastructure under assessment is studied in detail.

Chapter 4 focuses on the components of the infrastructure under assessment.

Table 3-7(a) Summary of data from recurrent parameters for current and future climate

Parameter	Period	Threshold	Data A	Unit	Data B	Unit	Temporal unit	Frequency		Probability	
								Calculated	Percentage	Current	Future
High temperatures	1970-2010	≥30°C	7935	Day	40	Years	Days	198,38	54,3%	4	5
Tides (waves)	2000-Set 2010	2-3 m	132	Day	9,75	Years	Days	13,54	3,7%	1	2
Sea breeze	1970-1997	2-7 m/s NE-E	31501	Day	27	Years	Days	1166,70	13,3%	2	3
Atmospheric discharge	2005-Jul 2010		978	Discharge	6,5	Years	Discharge	1.93	9.2%	2	2

Table 3-7(b) Summary of date from extreme parameters for current and future climate

Parameter	Period	Threshold	Data A	Unit	Data B	Unit	Temporal unit	Frequency	Probability	
									Current	Future
Flooding rain	1941-2009	≥ 213,6 mm en 24 hours	21	days	68	years	days	0,31	4	5
Overcharge rain	1941-2009	≥ 64,9 mm en 24 hours	676	Days	68	years	Days	9,94	6	7
Hurricane	1970-2005		2	event	35	years	events	0,06	1	2
Wind	1970-1997	10 m/s NE-E	4	days	27	years	days	0,15	3	3

4. INFRASTRUCTURE COMPONENTS

In this section we present the infrastructure components to be assessed under the PIEVC Protocol.

4.1 Sewage collection system

4.1.1. Connections with users

The sewage collection system in the city of Limon covers 7.164, of the 17.101 drinking water services that the aqueduct currently has, accounting for 42% of total coverage.

The following are the specific elements that can be affected by climatic events:

- Connections
- Syphons

These two elements are considered as one in the analysis made under the guidance of the Protocol.

It is worth mentioning that the sewage system that counts with waste water treatment is 40%, as there are 275 services in the communities of Los Almendros, Decar and Cangrejos that outfall water without treatment.

We attach Table 4.1, in order to indicate sectors and identify communities with sewage system and the amount of services delivered, in accordance with the Commercial system of AyA, the table shows the sectors by the AyA commercial system and communities that have sewage service.

In the City of Limon, the sewage was built in 1976, new asbestos cement collectors were installed ranging from 200 mm to 400 mm of diameter, the rest of the existing network were glazed clay pipes of 150 mm diameter, this system only covered the central quarter of the city, and some nearby neighbourhoods, however this sewage system collapsed as consequence of the earthquake that affected the city of Limon on April 22nd, 1991, and thus it had to be rebuilt again.

4.1.2. Waste Water Transport Elements

The specific elements of the infrastructure in the waste water collection system that can be affected by climate events are the following:

- Networks
- Sub sewers
- Sewers

These three elements are grouped as one in the analysis made under the guidance of the Protocol.

The sewage network is 67,15 km long and the collection area is 290 hectares, as it is shown in Figure 4.1.

Table 4.1. Sectors in accordance with AyA commercial system and communities that have sewage service.

Sector	Neighborhood	Amount of Services
1	Limón Center	653
2	Limón Center	653
3	B° Rooselvelth	623
4	Cangrejos (without treatment)	127
5	Bella Vista, Triunfo and Laureles	508
6	Margarita Garrón, Urb. Lomas, Siglo XXI, Coopeutba San Juan	1172
7	Corales 1 (Some Sectors) Corales 2 and Corales 3	792
13	Cristóbal Colón	535
14	Cristóbal Colón	283
18	Pacuare	1629
21-22	Urb. Los Almendros and Coopedecar (without treatment)	146
23	Siglo XXI II and IV Etapa	43
	TOTAL	**7164**

Figure 4.1. Coverage of Sewage Network with treatment in the City of Limón**.**

4.1.3. Inspection Elements (Manholes)

The main operation and maintenance activities in wastewater systems are removal of obstacles from networks, sub sewer and sewer; access in order to perform this work is through manholes, which are analyzed as a component of the infrastructure under the protocol.

Networks don't have a cleaning program, because the Region doesn't have equipment for this activity (Hydro vacuum). This is an important activity for the city, due to low slopes in most part of the network and sewers that favour sedimentation, reducing pipes capacity.

4.2 Pumping Stations

Waste water collection system works in such a way that waste water from different basins flow towards the Underwater Outfall Pre-conditioning Station (Estación de Preacondicionamiento del Emisario Submarino) (EPA), which are re-directed from micro basins that pour into the different pumping stations.

Every four or three months, periodically revisions of pumping stations are carried out, where different hydraulic and electric variables are measured, in order to preventively detect possible damages. These revisions have been recorded for more than 10 years.

Additionally, a record of all preventive and corrective maintenance work performed by each pumping team is kept, as well as a control of electricity consumption at each station, in order to identify consumption patterns, inefficiencies in the systems, among others.

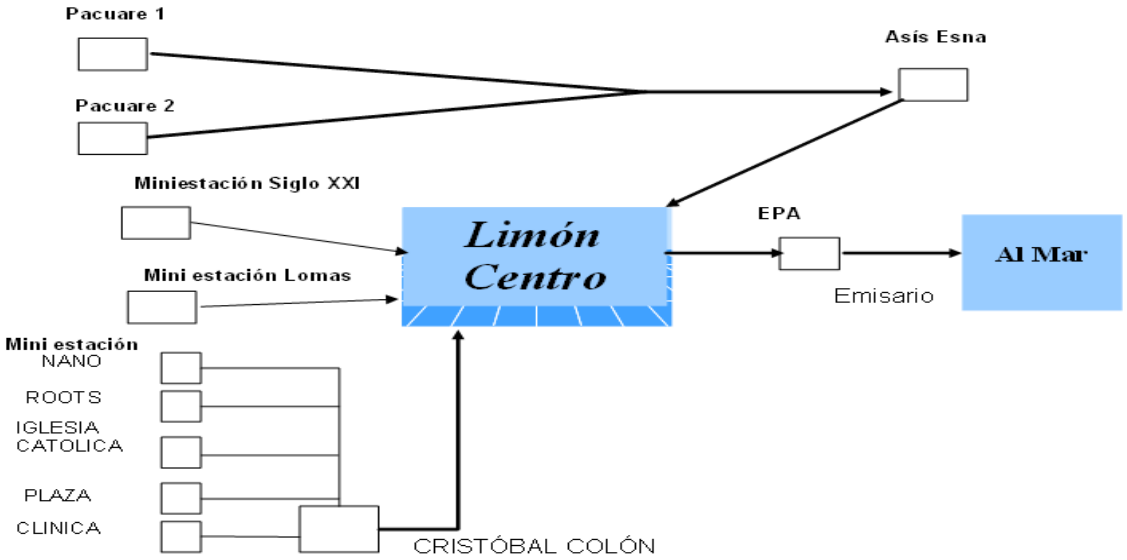
Table 4.2 is attached to summarize characteristics and state of Pumping Stations.

Table 4.2. Shows characteristics of Waste Water Pumping Stations in the City of Limon.

Pumping Station	Amount of Equipment	Power of each equipment (Hp)	Generator set	State of the station
Asis Esna	3 (Horizontal axis centrifuge)	40	YesI	Working
Cristóbal Colón	3 (Horizontal axis centrifuge)	20	Yes	Working
Pacuare 1	1 (submersible)	30	NO	Working
Pacuare 2	1 (submersible)	30	NO	Out of service
Miniestaciónes (7)	1(submersible)	1,5	NO	Working

Figure 4.2 is attached to show how the different pumping stations and micro basins pour towards the Underwater Outfall Pre-conditioning Station.

Figure 4.2 Pumping scheme of waste water collection system



Figures 4.3 and 4.4 show the location of the different pumping stations.

Figure 4.3. Location of Pumping Stations in Limon Northern zone.

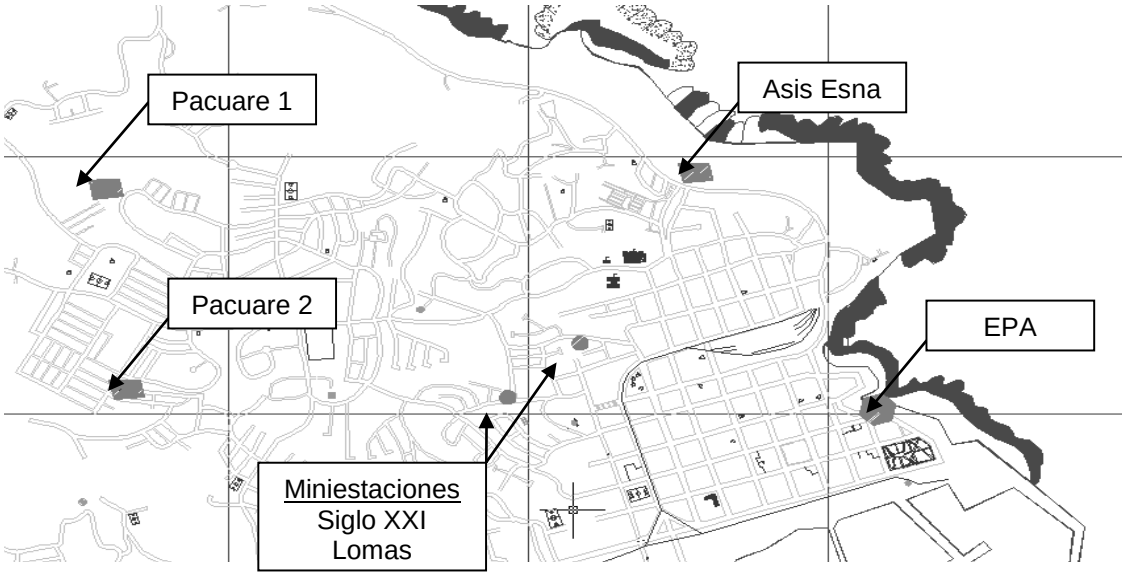
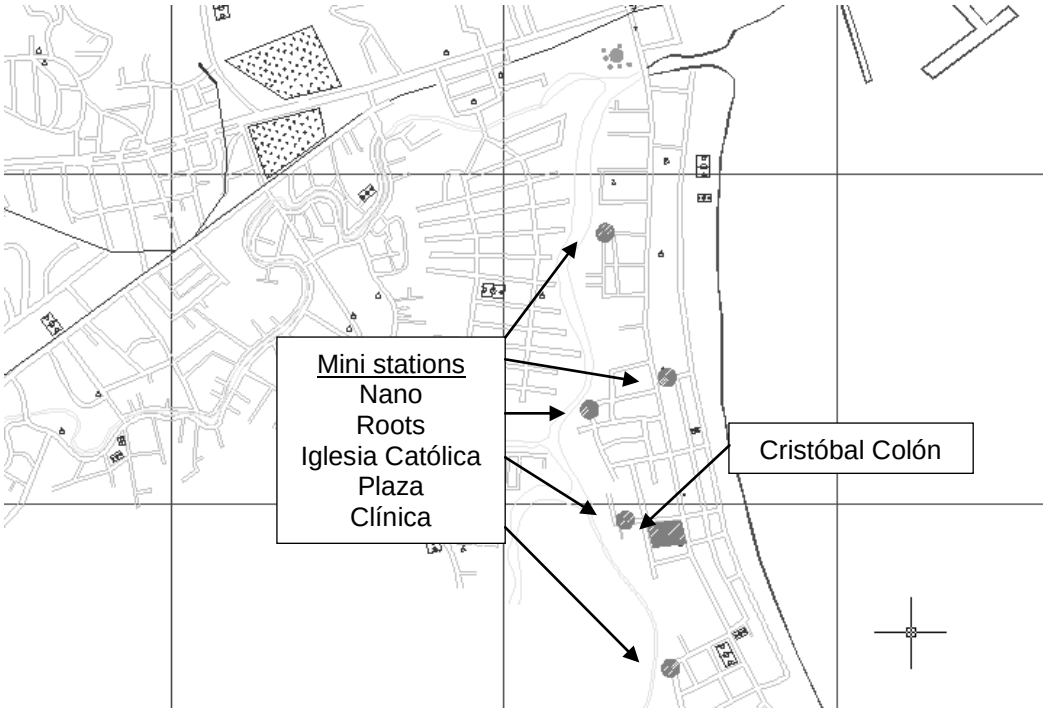


Figure 4.4. Location of five mini-stations of Cieneguita, which pump to a sewer that discharges into the Cristobal Colón Pumping Station.



We define the following group of stations in order to classify pumping stations in accordance with similar characteristics such as: closeness, altitude, type of equipment used, closeness to the coast, etc and, in this way, try to group pumping stations that could have the same behaviour facing a climate event.

4.2.1 Coastal mini stations

Cristóbal Colón or Cieneguita mini stations pump towards the sewer, in its turn the sewer by gravity deposits the waters at Cristóbal Colón.

i. Nano
ii. Roots
iii. Iglesia católica
iv. Plaza
v. Clínica

At these stations the inflow of rainwater from waste water collection systems represents a small problem, as houses are separated, there are empty spaces and many do not have canoes, and thus rainwater isn't discharged into the streets; on the contrary this water infiltrate the land. (See Photograph 4.1).

In this specific case, water drains into Cieneguita lake, for this reason it doesn't cause flooding in the zone where the pumping facilities are located; except at extreme events, when great part of Cieneguita is affected by flooding.

Photograph 4.1. Houses near coastal mini stations

4.2.2 Land mini-stations

Siglo XXI and Lomas de Chita mini pumping stations pump wastewater towards the sewage collection network of Limon center and from there by gravity towards EPA.

i. Lomas
ii. Siglo XXI

The difference from coastal stations is that they are located at higher altitude over sea level, near ravines and the effect of rainwater is greater as they are located in zones that have rainwater collection systems, increasing the possibilities of interconnections (rainwater flows) to the sewer system.

4.2.3 Centrifugal stations

i. Asis Esna

It directly receives wastewater from nearby sewage networks, and also receives water pumped from submersible stations Pacuare 1 and 2.
It pumps wastewater towards the sewage collection networks of the Center of Limón that discharges its wastewater into EPA.

It is located in the coast and thus is prone to negative effects of climate events.

Photograph 4.2. Building, control panels, Pumps and impulsion pipes at Asis Esna Wastewater Station.

Photograph 4.3. Shows Asis Esna Waste Water Station in the coast.

ii. Cristobal Colón

It receives wastewater pumped from mini coastal stations and pumps towards the sewage collection network of Limon Center and from there wastewater flows by gravity to EPA.

There is no risk of flooding at the plant. There are no problems of overcharge or obstructions; the low density at the urban zone explains this (it is assumed that there is a lower amount of interconnections).

Overflowing that takes place at mini-stations during heavy rainfall limits flows arriving to Cristóbal Colón station due to the design of tributary stations. It was also mentioned, the effect of reduction of obstructions induced by the previous removal of big objects at each subsidiary station. This involves greater durability of the equipment at Cristóbal Colón station.

Photograph 4.4. Cristóbal Colón Wastewater Station.

4.2.4 Submersible stations

Pacuare 1 and 2 pumping stations pump towards the sewage collection network tributary of Asis Esna Station.

i. Pacuare 1

At this station, a relevant contribution of rainwater into the sewage system has been identified, maybe because it is located in an area of high population density with water proofing soil. Houses are one next to the other and roofs have gradient towards the back of the properties, in such a way that it is possible that rainwater directly discharges into the sewer system.
There are no records of flooding in the premises, maybe because there is an adjacent coated channel in the adjoining area.

It is important to mention that the station is prone to vandalism-related issues, and this is why the station has been shut down.

Photograph 4.5. Pacuare 1 Station.

ii. Pacuare 2

This station has been out of service for more than 8 years, as a consequence of a flood in the premises, due to deficiencies in the storm water drain system that was clogged mainly by waste; we observed this at the site (See Photograph 4.6).

The urban drainage area is similar to Pacuare 1 (housing type and density), and thus a relevant contribution of rainwater into the sewage system is expected.

In order to reduce the vulnerability of the station to extreme rainfall events, a control cabin was built in a nearby plot that does not present flooding risk floods, as shown in Photograph 4.6.

Photograph 4.6. Pacuare 2 Station and waste clogging the storm water collection system

4.3 Pre-conditioning stations (EPA)

The earthquake of 1991 seriously affected the sewage collection system in the City of Limón. Subsequently, AyA developed studies and designs required to rehabilitate sewage system, the rainwater collection system and the supply of drinking water, and also needed to supply preliminary treatment to wastewater through a Pre-conditioning Station (EPA) and an underwater outfall. Both the EPA as well as the outfall correspond to the Final Stage of the reconstruction of the sewage system in the City of Limón.

The EPA is located next to Park Hotel, as it is shown in Figure 4.5, between the coordinates Lambert Costa Rica 643777 North and 219558 East and 644359 North 219693 East.

Figure 4.5. Shows the location of the EPA plant and the underwater outfall.

We attach Figure 4.6, in order to define each of the parts that comprise the EPA, indicating the different components of the station. We also attach two sections in Figures 4.7. and 4.8, which were made by drawing vertical and horizontal central lines in Figure 4.6.

Figure 4.6. Shows EPA plant, with the name of the elements that comprises it.

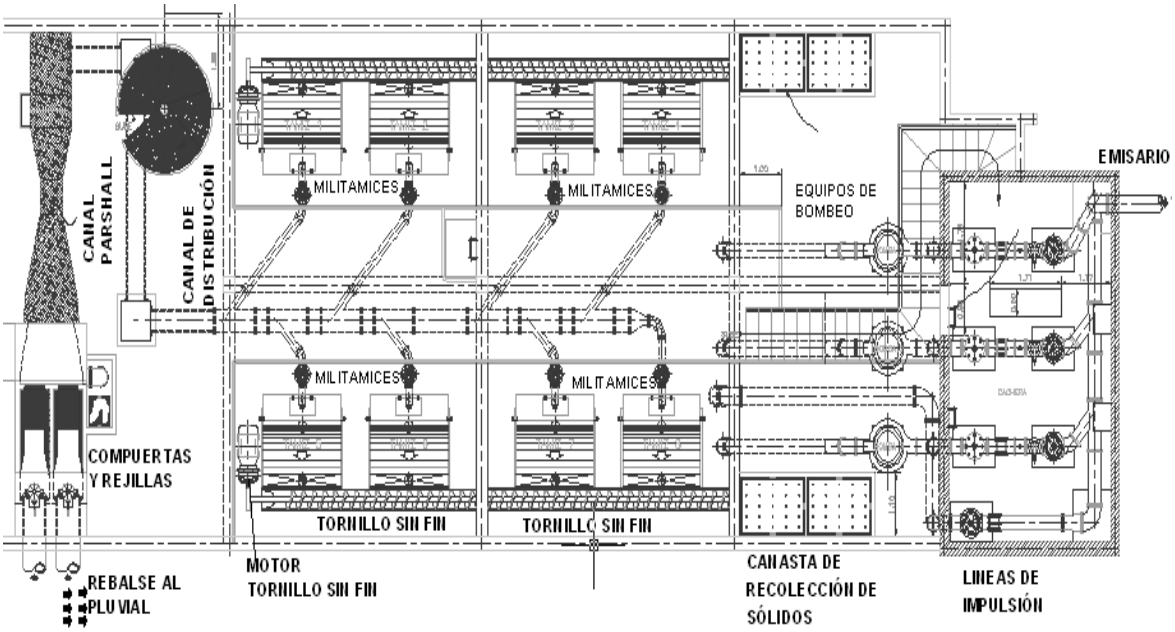


Figure 4.7. Shows central horizontal section of Figure 4.6.

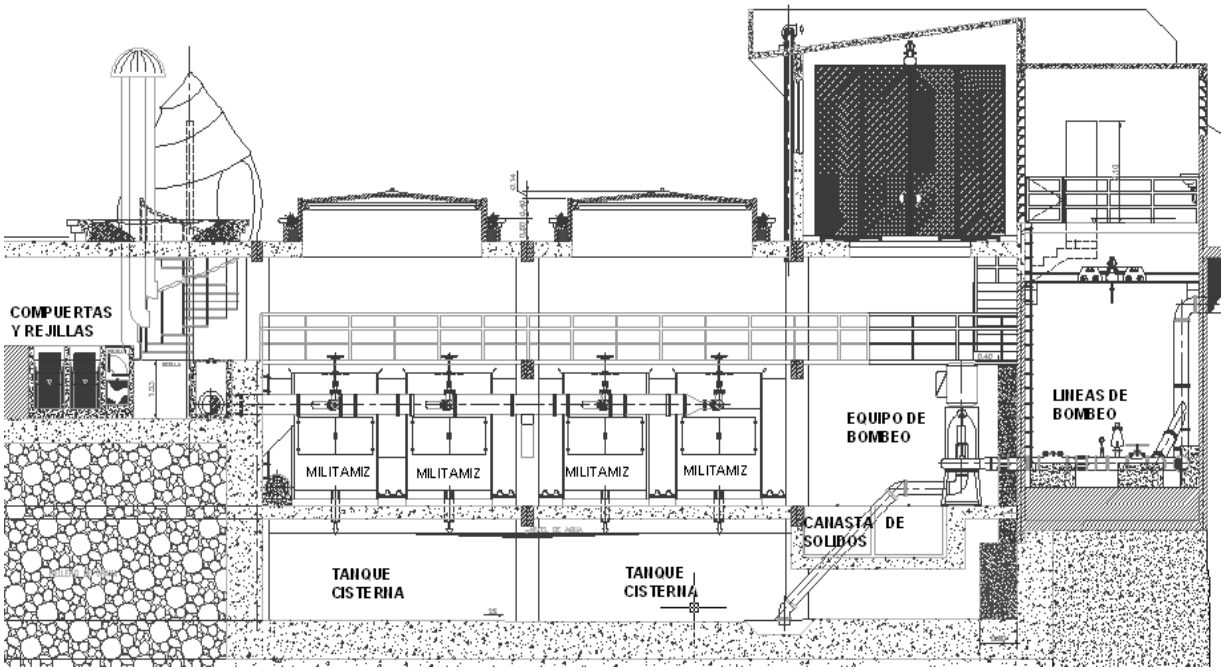
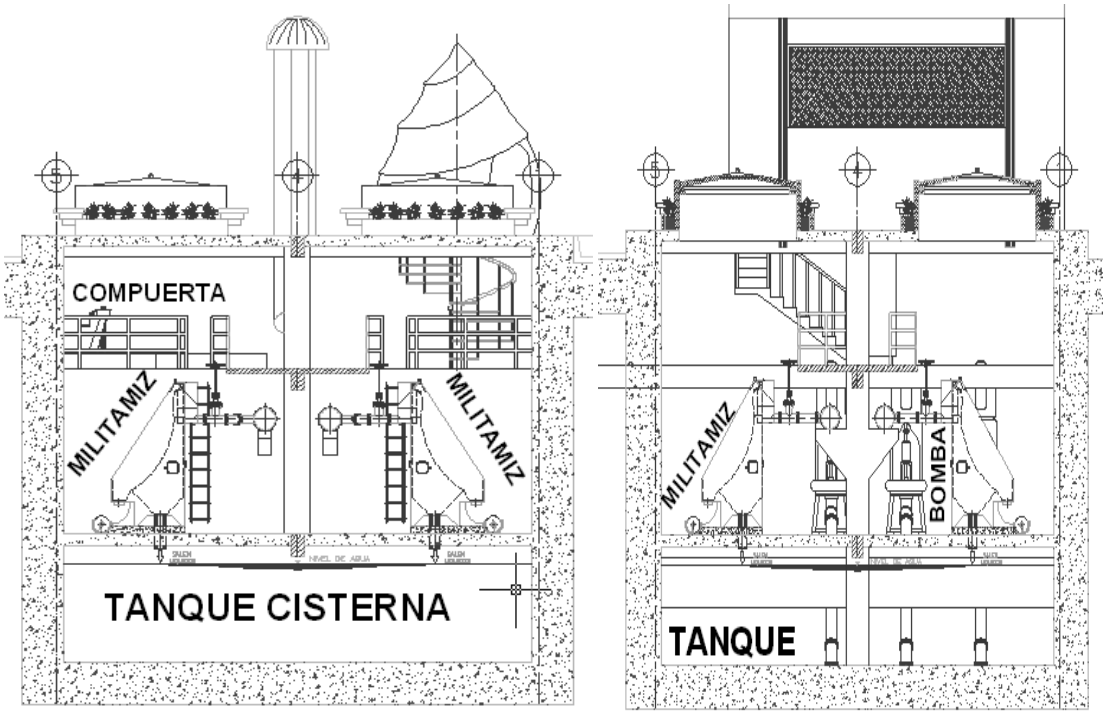


Figure 4.8. Shows central vertical section at both sides of Figure 4.6.



Once all the different components have been identified, we detail each of them.

4.3.1 Building

EPA is located in a concrete structure with metal gates and windows. This building contains the following: control panels, charge and solid transport system, communication equipment and a desk for the plant operator.

Metal elements enclosing the building are deteriorated due to abrasion from marine environment, as well as consequence of internal gases released by wastewater.

Some structures inside the station show corrosion that has exposed the iron of reinforced concrete, as well as from tie beams and slabs for the milliscreens. (See Photograph 4.7)

Photograph 4.7 EPA's building.

4.3.2. Ventilation system

This system has two mechanical exhaust fans located in the second floor of the station and one air entrance with outside connection, there is no mechanic equipment to guarantee flow of fresh air into the station.

There is no ventilation system inside EPA for a proper air circulation, as the highest concentration of gases is in the ground floor (at the level of the tank) and the current system's air extractor cannot circulate or evacuate the gases.

In general, the ventilation system is deficient, it has to be re-designed and re-build. A proposed solution should solve the proper circulation of gases inside the station, entrance of fresh air, and won't affect nearby commercial facilities and will keep concentration below standards.

Photograph 4.8 Ventilation system
On the left, air intake and on the right an exhaust fan

4.3.3 Gates, grid, Parshall channel, interconnection channel

As it can be seen in Figure 4.9 and 4.10, wastewater flow coming from the sewage system enter into the EPA through two casted iron 500 mm pipes, at the end of each of these pipes, there are stainless steel gates (See Figure 4.10), which regulate water entering into EPA, the maximum capacity of each of the gates is 350 l/s for a maximum speed of 2 m/s.

It is important to emphasize that EPA's level is 3,9 meters below sea level, for this reason the incoming flow should not exceed the design flow, controlling it with the gates; otherwise the facility will be flooded.

Figure 4.9. Entrance gates, EPA entrance grid system, location of Parshall channel and interconnection channel that distributes the flow into the milliscreen.

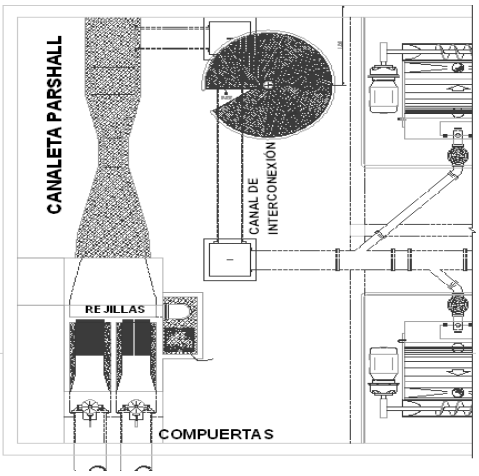
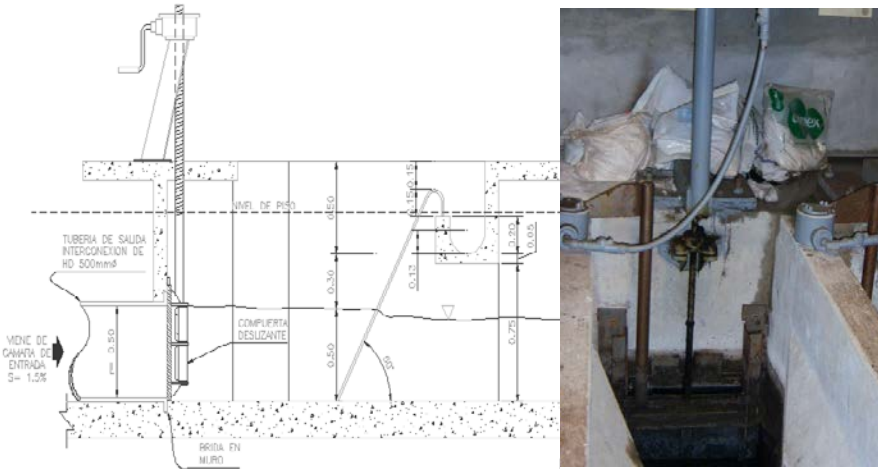
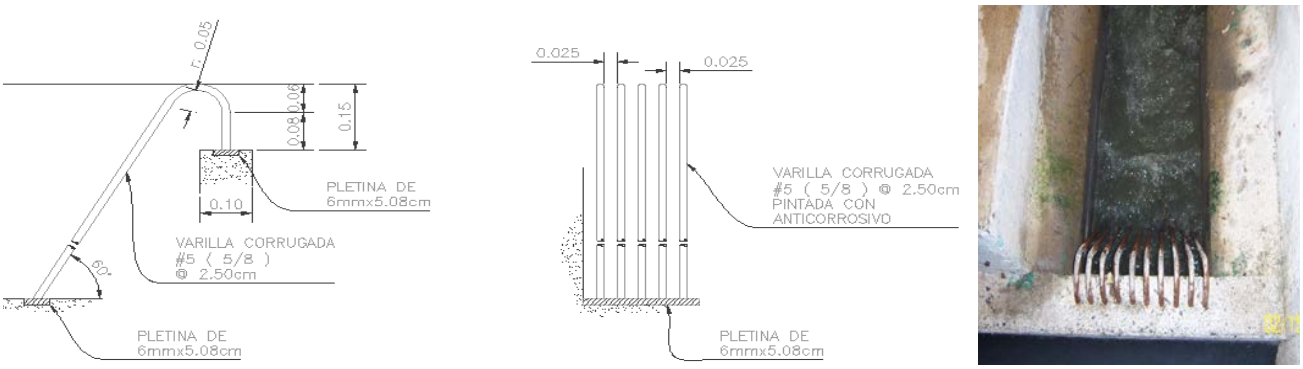


Figure 4.10. Entrance gates and grids system to enter EPA.



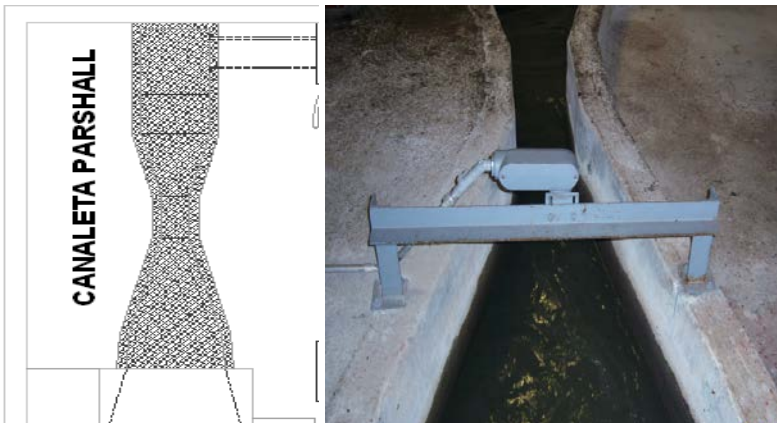
Later, the flow goes through the grids with a gradient of 60 degrees in relation to the horizontal, with 25 mm of separation (See Figure 4.11).

Figure 4.11. Grids to enter EPA,
with 60º inclination and 25 mm separation



Then, the flow from both grids joins together into the Parshall channel (See Figure 4.12), where the flow is measured, finally, it goes through an interconnection channel to be distributes into two sets of milliscreens.

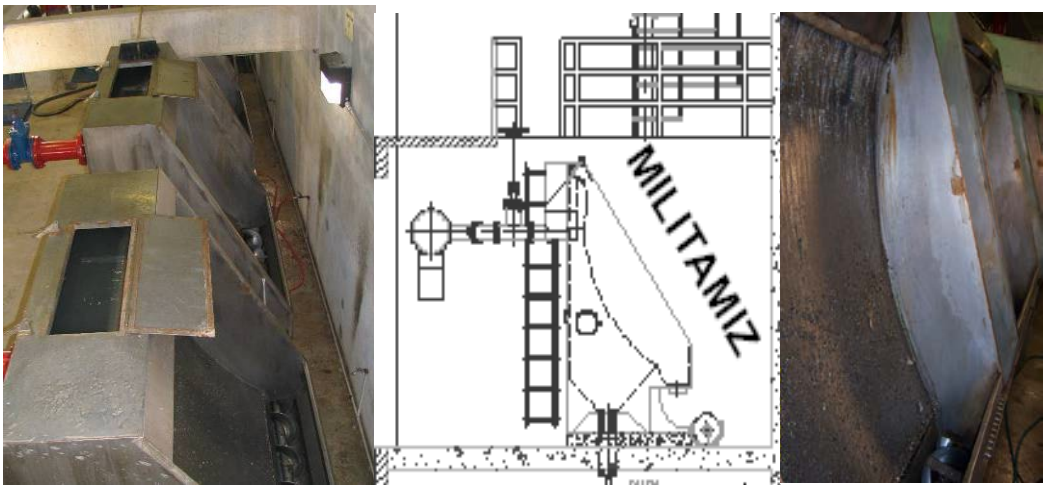
Figure 4.12. Parshall Channel and flow gauge.



4.3.4 Milliscreens

As it has been shown in Figures 4.6, 4.7 and 4.8, there are two sets of four static Milliscreen each. They are made of stainless steel (Johnson, 2004), each one has a capacity of 70 l/s with an opening of 0,5 mm, as it is shown in Figure 4.13. Solids over 0.5 mm are separated at the worm screw and the liquid is stored in the tank to be pumped to the underwater outfall.

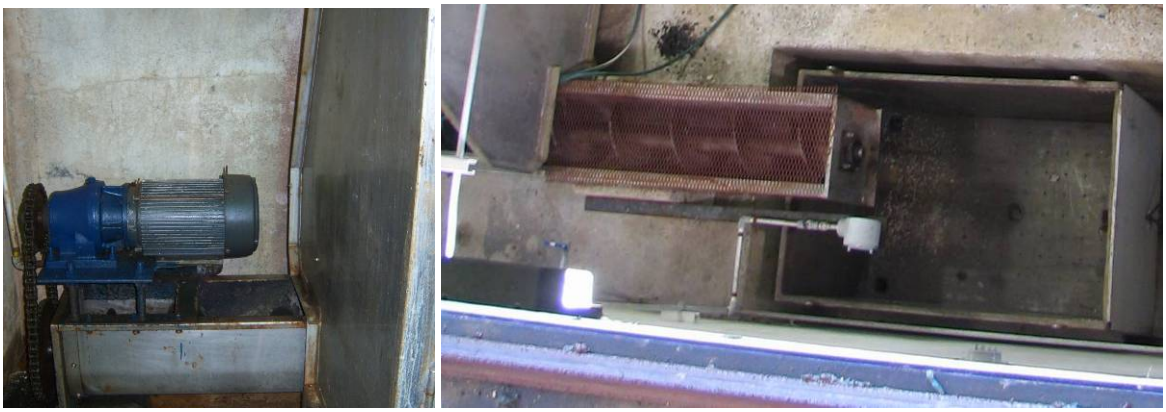
Figure 4.13. Miliscreen working, maximum capacity 70 l/s and 0,5 mm opening.



4.3.5 Worm screw, baskets, hosting system, transport.

As it has been mentioned, the solid separated through the milliscreens, passes through the worm screw (See Photograph 4.9), whose operation can be alternated redirecting the flow to one set of milliscreens or to the other.

Photograph 4.9 Worm screw and solid baskets



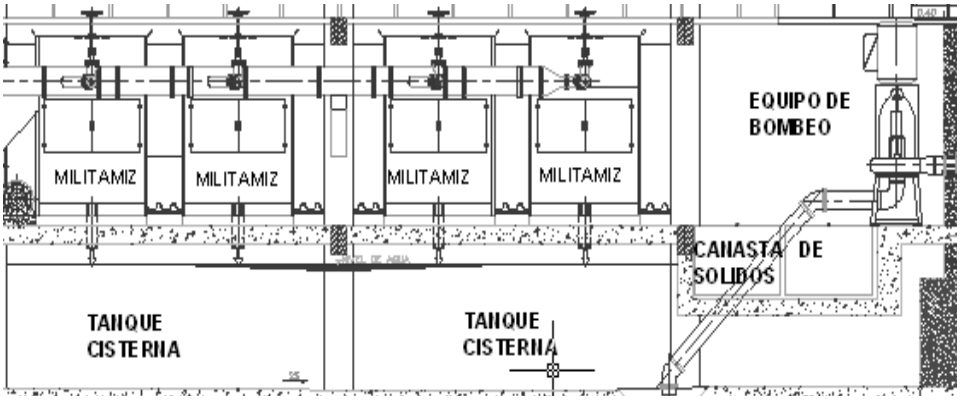
Solid is conveyed to storage baskets, once baskets are full, they are replaced by others and are left to dry for a day, then they are hosted (See Photograph 4.10) and transported to a sanitary landfill. There are four baskets, each with 1 Ton capacity. Average solid volume generated per month is 6 Ton.

Photograph 4.10 Solid basket and hosting system

4.3.6 Tank

As it has been alrady mentioned, screened wastewater is stored in a tank before being pumped (See Figure 4.13), the capacity of this tank is 150 m3, and it has the following dimensions: 16.7 m long, 9.0 m width, 1.0 m height.

Figure 4.13 Tank



4.3.7 Pumps

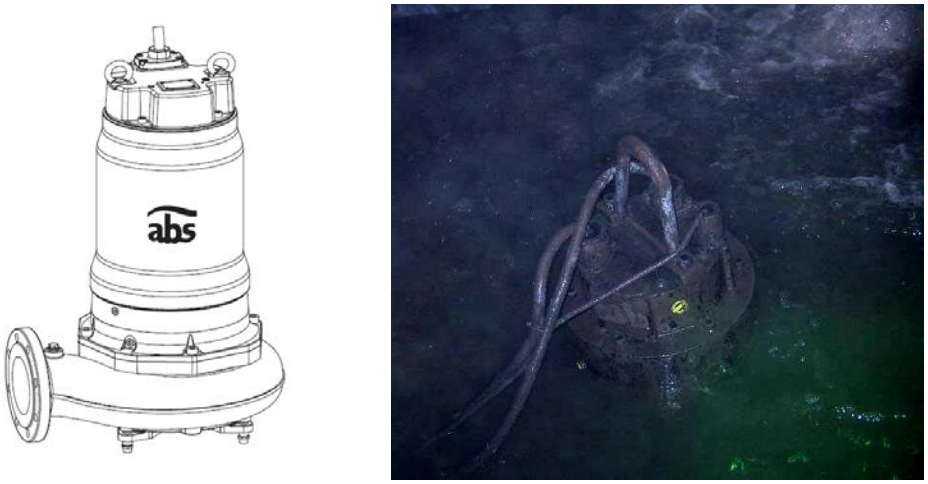
Water stored in the tank is pumped to the underwater outfall.

In the original design there were three pumping pieces of equipment, with centrifugal pumps with vertical axis and exposed motor, the capacity of each pump was 100HP, Weinman model 7198-8185 (See Photograph 4.10).

Photograph 4.10 Old centrifugal pumps

Due to the need of reducing the flooding vulnerability of the station and in order to improve the operation of this system, the centrifugal pumps were replaced by three submersible pumps, each of 75HP, ABS Pumps, model A2JL7TBD48LMIA4 (currently two are installed). These pumps have been in operation since October, 2007. (See Figure 4.10).

Figure 4.14 Current submersible pumps



4.3.8 Pumping line accessories

There are three pumping lines of 250mm diameter, each with a check valve of 250mm and an air admission-exhaustion valve with an opening of 50mm, (See Photograph 4.11). A line has been considered for a fourth pumping equipment. These pipes join into one to connect into the underwater outfall; this pipe has two additional air valves.

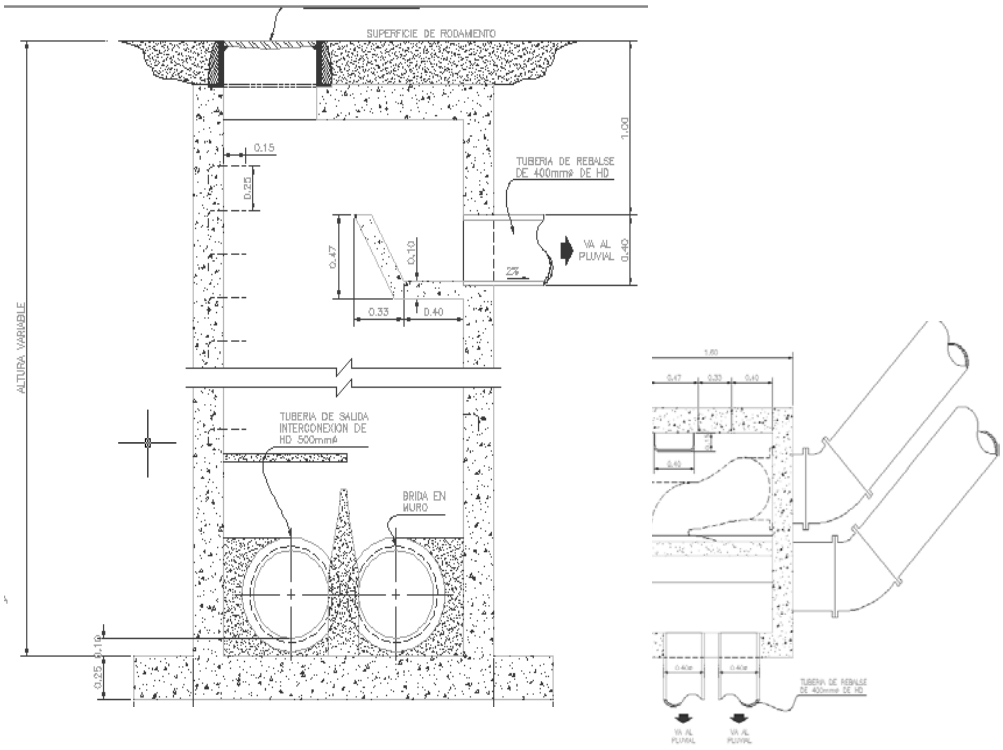
Photograph 4.11 Accessories of the pumping line

4.3.9 Overflowing structure

When, due to rainfall or when EPA has to be out of operation due to any mayor issue, the incoming flow exceeds the design flow, there is an overflow at EPA' entrance, at that moment the EPA entrance gates are closed and the overflows goes into the storm water drain system, as it is shown in Figure 4.14.

As it can be seen in Figure 4.14, it enters into the main 800 mm collector at the end of the sewage, from there two 500 mm pipes go to EPA and at a higher level two 400 mm pipes are connected to the storm water drain system.

Figure 4.14. EPA overflow



4.3.10 Control panel

There are four cabinets to control the three pumping pieces of equipment, the frequence variator, the electric generator set, the worm screw and the gates. The exhaust fans aren't connected to these cabinets. (See Photograph 4.12)

Photograph 4.12 EPA Control Panel

4.3.11 Power plant

It is a diesel power plant, GENERAC, with enough power to operate all the equipment at the station; since 2004 is out of operation, after operating for 5 years. It is entirely corroded by marine breeze.

Photograph 4.13 EPA power plant

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4.4. Underwater outfall

4.4.1 Pipes

The outfall has 1.8 km of high density polyethylene pipes, 60 cm diameter, installed at the seabed. Each pipe follows the trajectory showed in Figure 4.15 and transport the effluent from EPA to a point in the sea, where concentrations will not affect or generate conflicts with uses at nearby beaches. It can also be seen how the marine environment is colonizing the exterior part of the outfall pipe.

Photograph 4.14 shows the launching of the underwater outfall pipe.

Figure 4.15. Outfall pipe at seabed and its trajectory

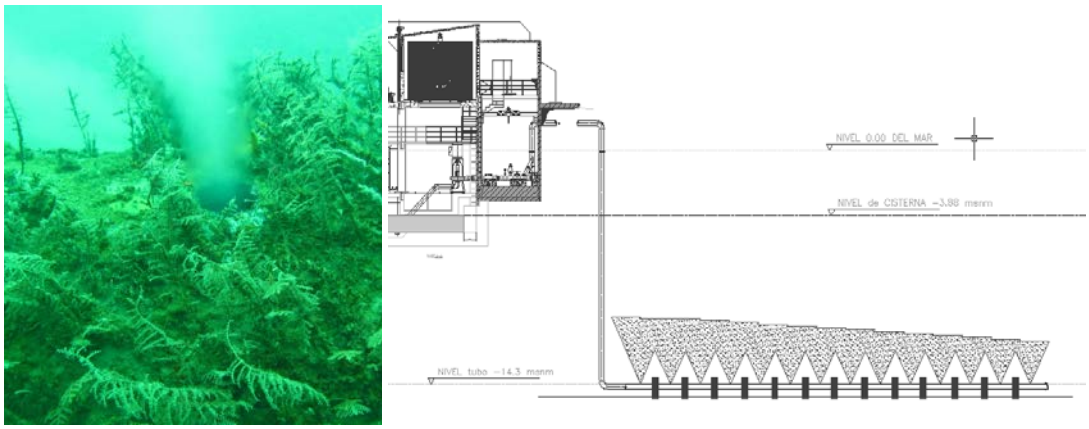
Photograph 4.14 Underwater outfall pipe installation phase

4.4.2. Diffusers

At the end of the outfall there are 60 m long diffusers; specifically, there are 14 diffusers consisting in 75mm diameter holes, located every 4 m. They distribute the effluent from the plant and through a dilution process and dispersion of the far field, they reduce

pollutant charges below 240 CF/100ml, so that it can be considered as waters fit for swimming and recreational purposes.

Figure 4.16. Diffusers in operation and scheme of diffusers operation



4.4.3. Closing valve (flap)

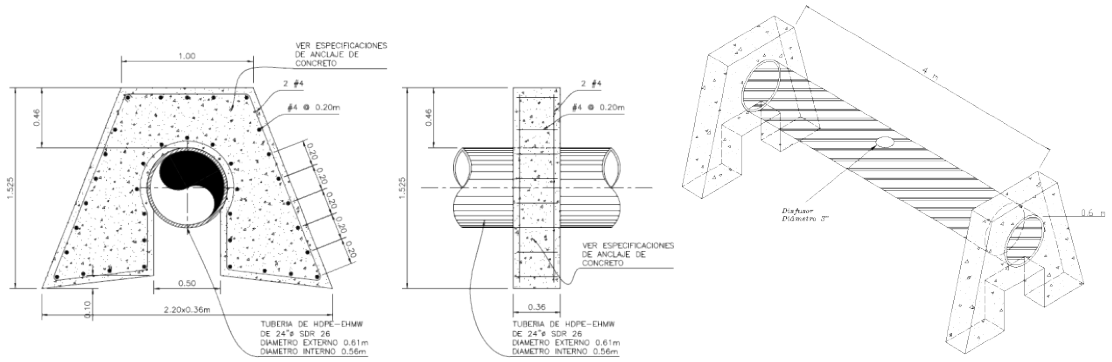
At the final section the outfall has a closing valve or flap valve, for internal cleaning, most of the time it is closed to ensure proper work of the outfall plume, generated at the diffusers length.

Photograph 4.15. Closing valve with anchoring device

4.4.4. Anchoring

These are A shaped concrete blocks separated every 4.0m, average anchoring weight is 400kg. These anchors keep the high density polyethylene pipes at the bottom, as the density of these pipes is lower than sea water density. Anchoring also stabilizes the pipe on the seabed, protecting it from waves and marine currents.

Figure 4.17. Scheme of anchoring installment.

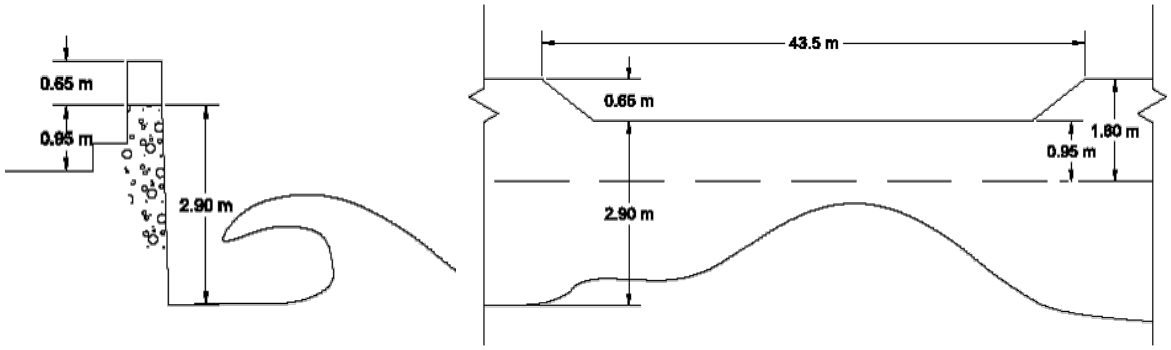


4.5. Wave retaining wall

The wall is a massive structure, built of boulder conglomerate, with a 2 to 3 cm mortared. It shows several reparations and additions, cracks and wears due to wave's effect. There are no drawings of it and is a very old structure.

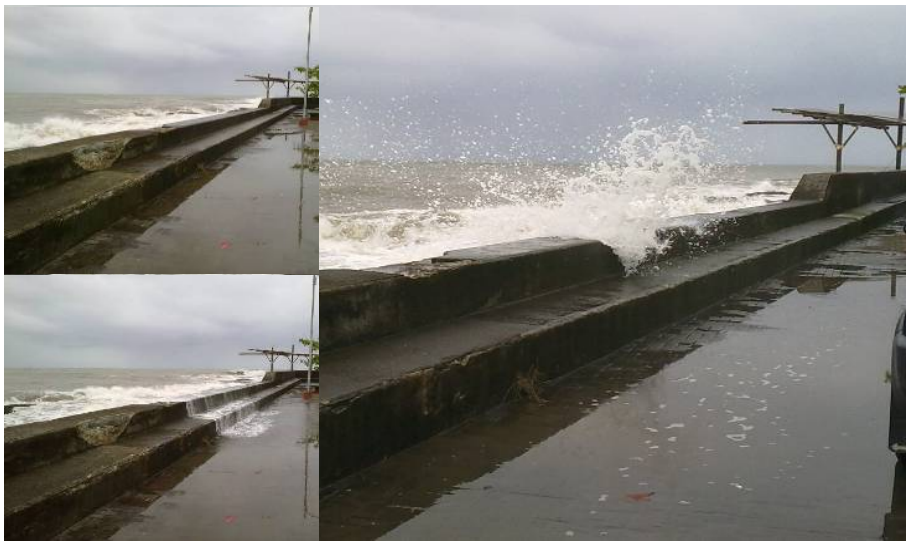
Wall dimensions from the center facing EPA are the following: 2,9 m height at the crest of the wall, 43,5 m long, the rest of the wall is 3,55m height, see Figure 4.18.

Figure 4.18. Scheme of wave retaining wall.



In several occasions, waves have exceeded the level of the crest of the wall (at the lowest part of the wall) confirming that there is not enough protection for EPA, see Photograph 4.16.

Photograph 4.16. wave retaining wall



Photograph 4.17 clearly shows the “opening” in the wall in front of EPA, as this area is used by the citizens as a sea view recreational park.

Photograph.17. View from the sea of the wave retention wall

In 2004, during the construction of EPA, a protection screen was placed at the base of the Wall, indirectly strengthening its stability. See Photograph 4.18.

Photograph 4.18. Protection screen in front of EPA

4.6. Personnel

4.6.1. At the wastewater collection system.

There are several resources for unclogging works, among them two squads, and also in Las Pilas facility, where there is a warehouse for tools and for the equipment used by the squad; there are also toilets.

Photograph 4.19. Personnel at the wastewater collection system

Squads for unclogging the wastewater collection system are composed of the following:

Squad 1:
1 foreman,
3 uncloggers,
2 sewage asistants,
1 worker,
1 vehicle
1 small pump to pump water from holes and manholes and
1 minimum tool kit.

Squad 2:
1 foreman,
1 uncloggers,
2 sewage assistant,
1 vehicle.
1 tool kit

There are two vehicles per squad in order to perform operation and maintenance in the sewage collection network.

Squad 1:

Vehicle plate 102-1076,
Dyna double cab,
Pick up,
Model 2003.

Squad 2:

Vehicle plates 102-1190,
Chevrolet single cab
Truck no cab.
Model 2006,

Summarizing, we have the following personnel: 11 individuals for 7.164 services, this means 1,5 persons for each 1000 services.
To have an idea of the magnitude of unclogging work, we attach Table 4.3 that summarizes monthly unclogging data from 2008 to October, 2010.

Table 4.3.Monthly unclogging work from 2008 to October, 2010 in Sewage Collection System of Limón.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Set	Oct	Nov	Dec
2008	52	41	39	42	49	52	46	54	45	42	52	56
2009	33	40	67	49	63	49	60	69	57	50	36	48
2010	46	56	57	34	38	41	47	44	45	30		

The Table shows the following average unclogging per year: 2008: 47,5 clog. / month, 2009: 51,75 clog/ month and October 2010: 45,3 clog/ months.

The following are the main current problems in the networks: presence of fat in networks and collectors, low gradients with generation of sediments that reduce pipes capacity and illicit connections from the storm water drain system to the sewage and vice versa.

4.6.2. At EPA

In order to perform operation and maintenance at EPA, there are personnel 24 hours a day, composed by 4 operators and one plant chief. The most important activities are the following: manual collection of solid waste and fat over 2.54 cm (See Photograph 4-20, operation of mechanic and electro-mechanic equipment, as worm screw, pumps, baskets, hosting system, among others). As well as cleaning milliscreens, several times a day, and maintenance to metal structures (such as paint and cleaning).

Photograph 4.20 Personnel at EPA removing great amount of fat

In order to avoid excessive entrance of fat and solid waste into EPA, there is a monthly control of clogging, trying to reduce it and detecting causes in order to implement corrective measures; such as the construction of fat and solid tramps before discharge into the sewage.

Photograph 4.21 Personnel at EPA

4.6.3. At underwater outfall

Personnel at the underwater outfall is composed of a highly trained team of divers from AyA. Currently there are 5 persons in the team; they are in charge of inspecting the outfall components, at least once a year, for good performance, detection of possible damages due to the interaction with the marine environment.

Photograph 4.22 Personnel working at seabed, Underwater Outfall

Photograph 4.23 AyA divers team, trained to work at the Underwater Outfall

4.7. Communication equipment

4.7.1. Telephones at EPA

Communication with the personnel is through telephones and operators have cellular phones in case of failure of the telephone system.

4.7.2. Telemetry

Originally the Project had a telemetry system to control, electro mechanic components, such as: gates, worm screw, pumping equipment, among others. It was expected that

most of the system will be automatic; but in practice, it has not been possible to implement the use of the system.

4.7.3. Radio

There is a “walkie-talkie” type of radio to communicate with the personnel, but is has been damaged. Currently, its use is not necessary as there are other means of communication.

4.7.4. Internet messages

There is computer equipment to keep reports of pumping equipment and movement of basket with solids. This equipment has e-mail and communication through internet messages.

5. ANALYSIS OF RESULTS

5.1 Risk Assessment

5.1.1 Performance Considerations

Performance considerations are defined, in order to assess risk. 10 groups of main performance considerations were identified, as shown in Table 5.1.

Table 5.1 Interaction of performance considerations with infrastructure components

Performance Considerations	Interacciones
Structural design	19
Functionality	94
Basin	59
Operation, Maintenance and Materials Performance	64
Intervention in case of Emergency	49
Considerations related to insurances	16
Considerations related to politics	24
Social effects	30
Public Health and Safety	19
Environmental Effect	19
TOTAL	**393**

These ten groups are divided into other more specific performance considerations in order to have a total of 41 performance considerations that are contrasted with 32 infrastructure components, in order to assess possible effects of charges generated by climate parameters on components.

There are 393 interactions between performance considerations and the 32 infrastructure components, the interactions are shown in Table 5.2. All the interactions are shown in Annex 3.

Table 5.2 Amount of interactions of infrastructure components with performance considerations

1	**SEWAGE COLLECTION SYSTEM**	**Interactions**
1.1	Syphones, Connections	9
1.2	Networks, Subcollectors, Collectors	23
1.3	Manholes.	6
2	**PUMPING STATIONS**	
2.1	**Coastal mini stations**	
	Clínica, Plaza, Iglesia, Católica, Nano, Roots.	14
2.2	**Land mini stations**	
	Lomas, Siglo XXI	14
2.3	**Centrifugal stations**	
2.3.1	Asis Esna,	20
2.3.2	Cristobal Colón.	8
2.4	**Submersible stations**	
2.4.1	Pacuare 1	18
2.4.2	Pacuare 2	19
3	**Pre-conditioning station (EPA)**	
3.1	Building	5
3.2	Ventilation system	14
3.3	Gates, Grids, Parshall Channel, Interconnection Channel	13
3.4	Milliscreens,	12
3.5	Worm screw, baskets, hosting system, transport.	20
3.6	Water tank	4
3.7	Pumps	7
3.8	Accessories in pumping line	8
3.9	Overflowing structure	7
3.10	Control panel	2
3.11	Electrical plant	11
4	**UNDERWATER OUTFALL**	
4.1	Piping	16
4.2	Diffusers	14
4.3	Closing valve	10
4.4	Anchoring	13
5	**WAVE RETAINING WALL**	
5.1	Wall	16
6	**PERSONNEL**	
6.1	At wastewater collection system.	16
6.2	At EPA	15
6.3	At underwater outfall	17
7	**COMMUNICATION EQUIPMENT**	
7.1	Telephones at EPA.	6
7.2	Telemetry	17
7.3	Radio	10
7.4	Internet text messages	9
	TOTAL	**393**

5.1.2 Risk Calculation

Taking into consideration information provided about climate parameters (Chapter 3) and infrastructure components (Chapter 4), we apply:

$$R = P \times S$$

Where:

R = Risk
P = Probability
S = Severity

Likewise, a matrix or heat map is used (Figure 5.1) assigning colors to the value of "R" in relation to risk ranges and tolerances that have been indicated in Table 2.5 of this report.

Figure 5.1 Heat map of possible risk values

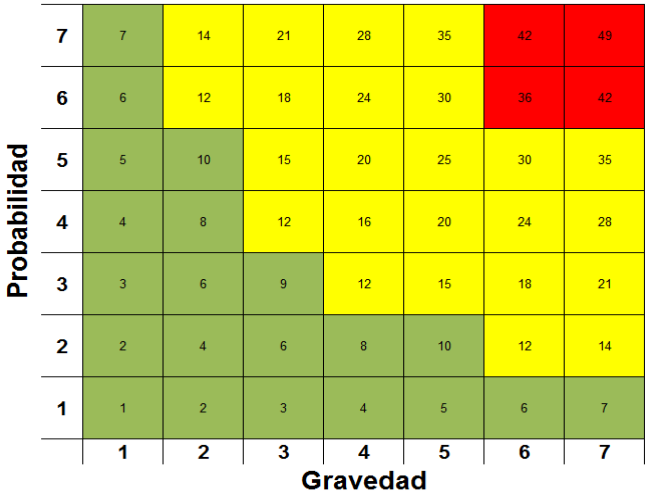


Figure 5.2 shows an example of matrix used to assign risk values, both for current as well as for future scenarios.

Figure 5.2 Example of risk calculation for each component

	Componentes de Infraestructura	Lluvia de sobrecarga			
		S/N	P	G	R
2.3	**Estaciones centrífugas**				
2.3.1	Asis Esna,	S	6	5	30
2.3.2	Cristobal Colón.	S	6	2	12
2.4	**Estaciones Sumergibles**				
2.4.1	Pacuare 1	S	6	4	24
2.4.2	Pacuare 2	S	6	4	24
3	**(EPA) ESTACION DE PREACONDICIONAMIENTO**	S/N	P	G	R
3.1	Edificio	N	6		
3.2	Sistema ventilación	N	6		
3.3	Compuertas, Rejillas, Canal Parshall, Canal Interconexión	S	6	5	30

After contrasting each infrastructure component with climate parameters and assessing risk values, the results of both current scenarios as well as future scenarios with climate change are shown in Table 5.3 (See 2.2.3.2 to tolerance to risk thresholds)-

Table 5.3 Defined risk thresholds

Risk Thresholds			Current	Future
< 12	**Low Risk**	Excluded for further analysis	97	84
12 - 35	**Medium Risk**	Kept for further analysis	41	54
> 36	**High Risk**	Go directly to recommendations	0	0
		Total	138	

In total, there were 138 interactions between infrastructure components and climate parameters.

For the current scenario there are 97 (70.3%) interactions with low risk and 41 (29.7%) with medium risk.

For the future scenario, with climate change, interactions with low risk decrease, as 13 of them move to medium risk; interactions with medium risk increase to 54 for the future scenario.

Figure 5.3 Risks obtained for current and future scenarios.

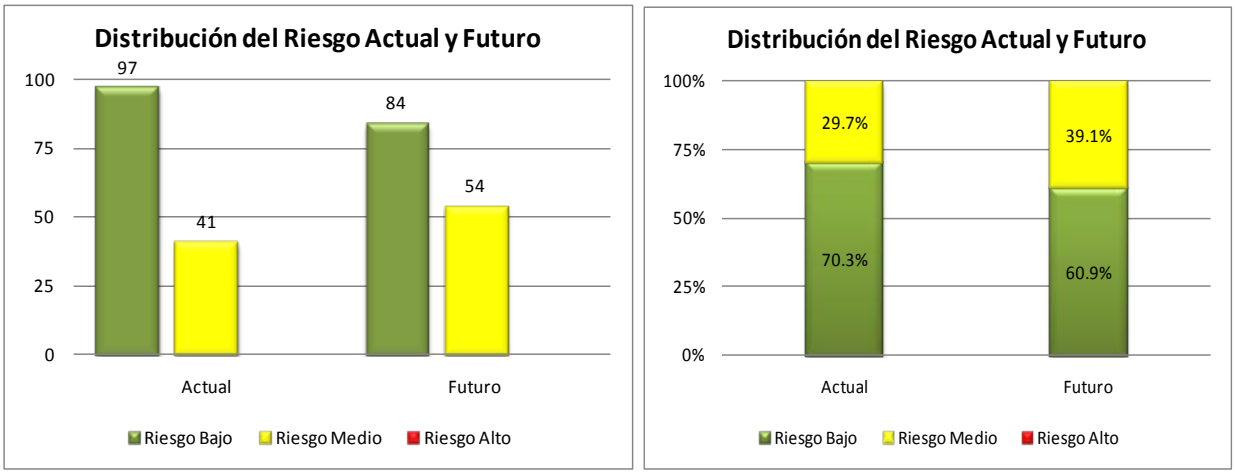


Figure 5.4 shows distribution of risk values in heat maps for analysis scenarios, it can be observed that due to the effect of climate change, risks in infrastructure components change.

Figure 5.4 Heat maps with values of Current and Future Risks

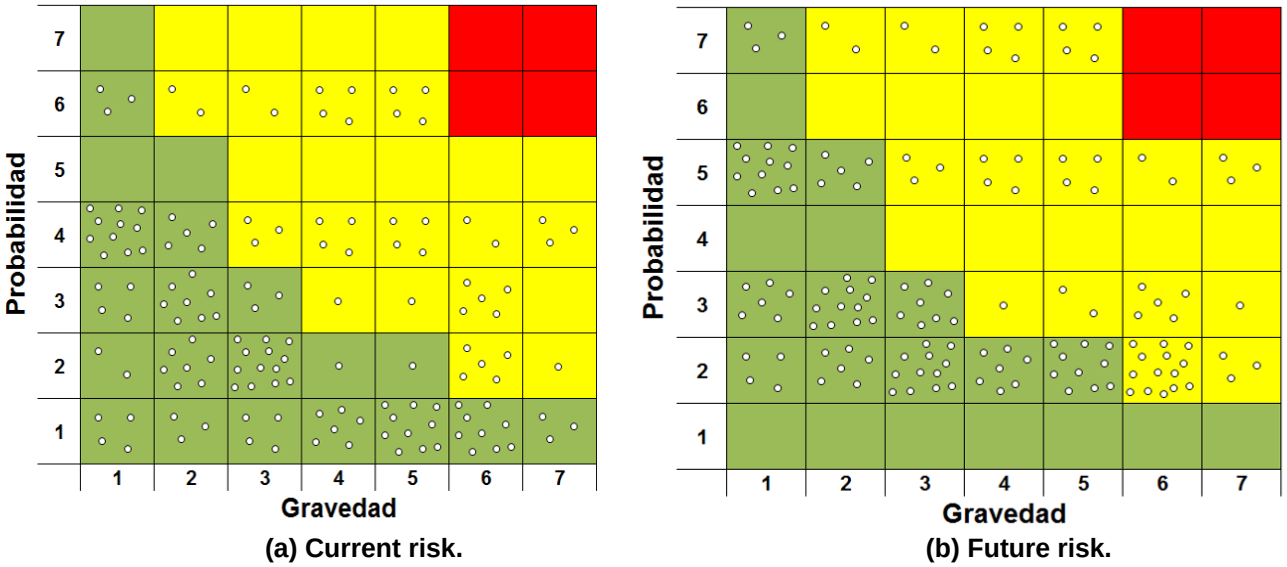
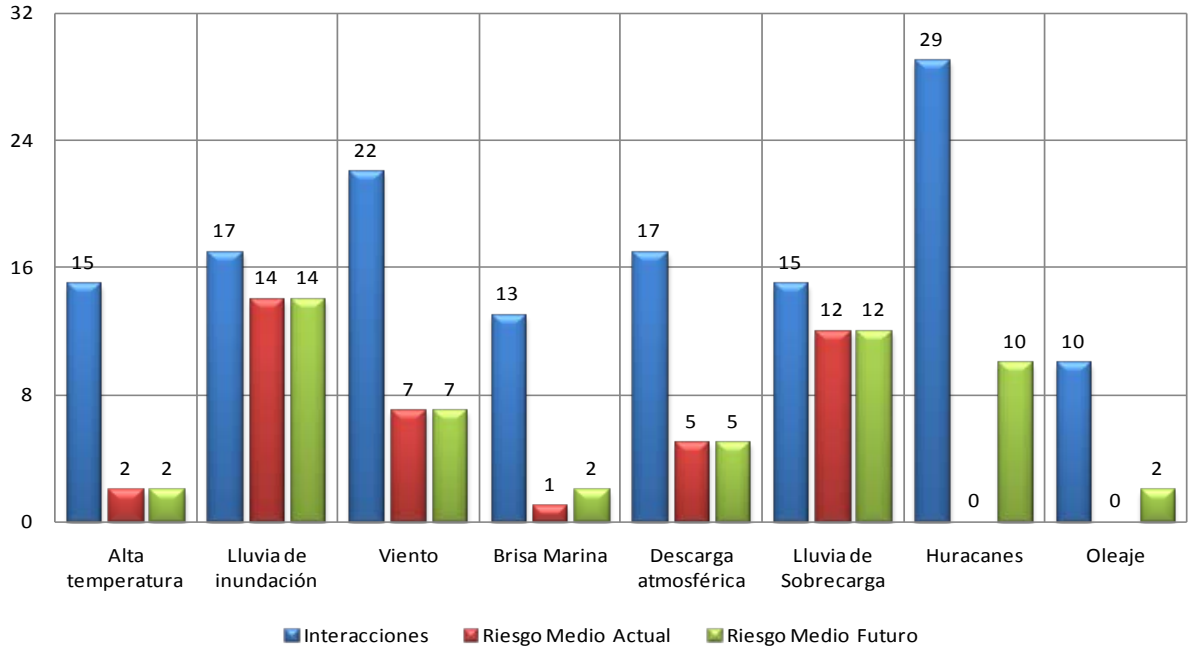


Figure 5.5 shows interactions of infrastructure components (blue) per climate parameter, it is also shown how many of these interactions are valued as medium risk, both for current scenario (red), as for future scenario with climate change (green).

Figure 5.5 Interactions with medium risk value per climate parameters



The analysis will be done per parameter, analyzing the way to mitigate or eliminate charges generated by climate parameters.

Table 5.4 shows components that obtained higher risk values and in this Table it is observed that climate parameters that generate higher risk are flooding rain and overcharge rain. It has to be taken into consideration that these two climate parameters should not generate charges to the systems due to its nature (sewage).

Table 5.4 Components of High Risk

Componente de Infraestructura	Parámetro Climático	PA	PF	G	RA	RF
Asis Esna,	Lluvia de inundación	4	5	7	28	35
Pacuare 2		4	5	7	28	35
Compuertas, Rejillas, Canal Parshall, Canal Interconexión		4	5	7	28	35
Redes, Subcolectores, Colectores	Lluvia de sobrecarga	6	7	5	30	35
Mini estaciones terrestres		6	7	5	30	35
Asis Esna,		6	7	5	30	35
Compuertas, Rejillas, Canal Parshall, Canal Interconexión		6	7	5	30	35
Redes, Subcolectores, Colectores	Lluvia de inundación	4	5	6	24	30
Mini estaciones costeras		4	5	6	24	30
Mini estaciones costeras	Lluvia de sobrecarga	6	7	4	24	28
Pacuare 1		6	7	4	24	28
Pacuare 2		6	7	4	24	28
Tanque cisterna		6	7	4	24	28
Mini estaciones terrestres	Lluvia de inundación	4	5	5	20	25
Pacuare 1		4	5	5	20	25
Tanque cisterna		4	5	5	20	25
Estructura de Rebalse		4	5	5	20	25
Planta eléctrica	Brisa Marina	3	3	7	21	21
Bombas	Lluvia de sobrecarga	6	7	3	18	21
Estructura de Rebalse		6	7	3	18	21
En la EPA	Alta temperatura	4	5	4	16	20

5.2. Engineering Analysis

An engineering analysis per climate parameter is performed and charges generated by them into the infrastructure are estimated.

Due to the nature of the infrastructure to be assessed, the engineering analysis focus in performing an analysis per climate parameter, as for each one, actions to be performed in order to reduce vulnerability will have to be determined.

5.2.1. Overcharge rain

This climate parameter (overcharge rain) has 15 interactions with infrastructure components and generate medium risks in 12 of them, both for current as well as for future scenarios with climate change (See Table 5.5), for them there is an engineering analysis focused on eliminating the charge and not in increasing the capacity of the component, due to the nature of both of them, as it is explained later.

This climate parameter was conceptualized in order to reflect the increase in the incoming flow to EPA at the moment of rainfall and the need to correlate the increase in incoming flow with relation to the intensity of the registered rainfall. For this purpose based on EPA operation log and IMN records, a representative intensity of **64mm/day** was defined, which causes excessive and real increase in incoming flow to the system.

Table 5.5 Medium risk generated by the parameter overcharge rain

Infrastructure component	P_A	P_F	G	R_A	R_F
Syphones, connections	6	7	2	12	14
Networks, Subcollectors, Collectors	6	7	5	30	35
Coastal mini stations	6	7	4	24	28
Land mini stations	6	7	5	30	35
Asis Esna,	6	7	5	30	35
Cristobal Colón.	6	7	2	12	14
Pacuare 1	6	7	4	24	28
Pacuare 2	6	7	4	24	28
Gates, grids, Parshall channel, interconnection channel	6	7	5	30	35
Water tank	6	7	4	24	28
Pumps	6	7	3	18	21
Overflowing structure	6	7	3	18	21

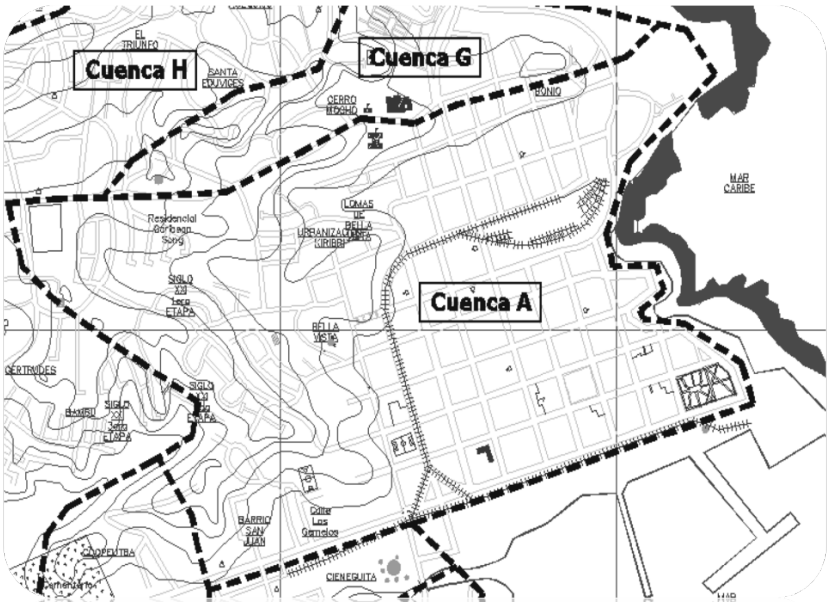
From the meteorological information it follows that this event occurs in average 10 times per year and that it is expected that with climate change, it will increase its frequency, and thus is the main risk for the functionality of the system. In this way, this phenomenon is going to be studied and quantified in order to take the required corrective measures to guarantee the system functionality.

As the intensity of 64mm/day corresponds to accrue daily rainfall, it is considered that this rainfall will have a temporal distribution of 4 hours, based in the experience of people living in the area, and thus the intensity will be **16mm/hr**.

Total Charge (L_T)

In order to estimate charges with incidence in the infrastructure components due to overcharge rain, we take as example the basin that flows towards EPA (Basin A, see Figure 5.6) the area of this basin is 137.4 ha.

Figure 5.6 Urban basins in the city of Limón



There are 3351 sewage services in this basin and it is considered that the contribution from roof area accounts for 40% of the total area, and thus roof area is 164 m^2 / service. Runoffs coefficient for roofs is 0.90, both based on aerial photography (see Photograph 5.1).

Photograph 5.1. Aerial view of Basin A, City of Limón

Based on the information above, total load of overcharge rain on the sewage system components can be estimated (rational equation). To obtain an order of magnitude, it is calculated as if all roofs were connected to the sewage.

$$L_T = C \cdot I \cdot A = 0.90 \cdot 16 \text{ mm/hr} \cdot (130 \text{ ha} \cdot 40\%) = 2080 \text{ l/s}$$

Total Capacity (C_T)

To quantify the sewage total capacity (C_T), the maximum design flow of 91.1 l/s is used, calculated by Tecnosan for basin A of the sewage system of the City of Limón.

$$C_T = 91{,}1 \text{ l/s}$$

Vulnerability Ratio (V_R)

Vulnerability ratio (V_R) for components affected by overcharge rain is more than one (22.8), as collection system and treatment of sewage must not be designed to transport or treat storm water.

$$V_R = L_T / C_T = 2082 / 91.1 = 22.8$$

Under the protocol, as the vulnerability ratio is greater than one, we should proceed with recommendations and corrective measures.

Capacity Deficit (C_D)

Collection system and wastewater treatment and storm water drain system are designed as separate systems and not as combined systems; the capacity of the sewage system is not designed for and should not transport water from roofs. And it is so due to environmental, technical, legal and economic considerations and implications.

At most, it should be taken into consideration flow contributed by infiltration into the collectors, which was considered for this basin, and is equivalent to 0.60 l/s/km, for a total of 16 l/s in basin A.

Based on the above mentioned, there should be no charges generated by rainfall (collected from roofs) entering directly into the sewage system neither a Capacity Deficit (C_D) from the sewage system under analysis. This involves that an increase in the capacity of the system should not be considered in order to support these types of charges, but a way to eliminate said loads.

In order to dimension the corrective measures to eliminate said loads in the system, we estimate how many houses or services -which have their roofs connected to the sewage-, will cause the collapse of the system. This means that every wastewater design flow is being substituted by rainfall collected by the roofs. The abovementioned applies for rainfall that currently occurs once a month and no for extreme events.

The previously estimated total charge (L_T= 2080 l/s) is divided by the number of services (3351) in order to obtain the contribution for each service, which will generate a flow of 0.62 l/s/service.

$$L_{T\,/serv} = L_T / \text{No. Services} = 2080 \text{ l/s} / 3351 \text{ services} = 0.62 \text{ l/s/service}$$

Dividing the total capacity by the total charge per service, the number of services that can make collapse the system capacity can be obtained.

No. Services that collapses the system = C_T / $L_{T\ /serv}$ = 91.1 l/s 0.62 l/s/service = 139 services

The abovementioned reflects that with the indicated intensity (16 mm/hr) with 4% of interconnected services (139 to 3351), the system collapses, and thus measures to be taken to eliminate these charges must involve this level of detail.

Currently, in the City of Limón, it has been found that 5% of services connect their roof waters to the sewage system, showing the need of making a program –house by house- to identify and reduce service interconnections with the support of the Ministry of Health and the Municipality of Limón.

Due to this reality (more than 4% of services interconnected) and in order to protect public health, there are interconnections between the sewage system and the rainfall collection system, as it is shown in photograph 5.2. The function of these interconnections is to avoid storm water to overflow wastewater at populated centers, and thus eliminating them will involve a public health issue in the center of the city, if the problems of interconnected systems are not solved.

Photograph 5.2 Interconnection between sewage systems and rainwater collection system

In order to quantify reductions of interconnections contributions after the inter-institutional program, AyA has foreseen installing a meteorological station in the zone that will allow quantifying results from the program.

5.2.2. Flooding Rain

This climate parameter (flooding rain) has 17 interactions with the infrastructure components and out of them it generates medium risk in 14 interactions, both under the present scenario and for climate change (See Table 5.6). The engineering analysis is made focused on what the storm drain system capacity is and not on the capacity of the sewage system because of the nature of both as it will be explained below.

Table 5.6 Average risks arising out of the flooding rain parameter

Infrastructure component	P_A	P_F	G	R_A	R_F
Syphons, connections	4	5	4	16	20
Networkds, sub sewers, sewers	4	5	6	24	30
Manholes	4	5	3	12	15
Coastal mini-stations	4	5	6	24	30
Land mini-stations	4	5	5	20	25
Asis Esna,	4	5	7	28	35
Cristobal Colón.	4	5	4	16	20
Pacuare 1	4	5	5	20	25
Pacuare 2	4	5	7	28	35
Gates, grids, Parschall channel, interconnection channel	4	5	7	28	35
Worm screw, baskets, hosting system, transportation.	4	5	4	16	20
Water tank	4	5	5	20	25
Pumps	4	5	3	12	15
Overflowing structure	4	5	5	20	25

This climate parameter is defined based on the event of March 29 2006 when storm water flooded the surroundings of the EPA; even though the sewage system access gates were closed, water entered by the EPA gate giving rise to flooding risk and damage to the equipment in the facilities.

The lower level of the EPA building is some 9m below the street level and almost 4m below the sea level thus making disposal by gravity impossible.
In order to solve the flooding problem it was decided to open one of the storm drain system manholes and thus flooding was released. This fact caused the revision of the real capacity of the storm drain system because its bad operation gives rise to a risk for the components of the sewage system components under analysis.

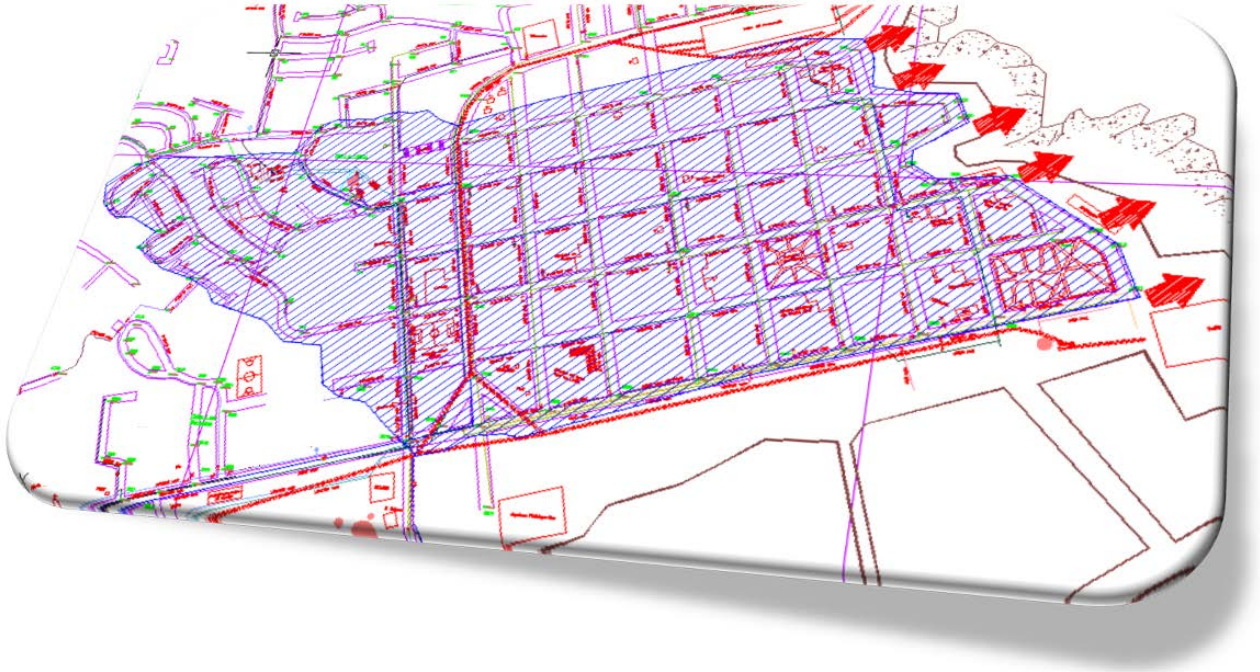
According to IMN data on that date it rained 213.6 mm/day, and using this value the frequency of the phenomenon was obtained, which has a return period of approximately 3 years.

In order to carry out the engineering analysis and obtain the loads on the infrastructure components, it was requested the temporary distribution of rainfall during that day and the result was a maximum intensity value of 106 mm/hr.
This phenomenon will be more recurrent with climate change so that its return period will be less.

Based on these climate data it was assessed the capacity of the storm drain system downtown the city of Limón. This analysis is focused on this zone because most of the infrastructure of the sewage system affected with this parameter is located there.

Total Load (L_T)
In order to calculate the total loads on the infrastructure components from flooding rain it is chosen as example the basin shown in Figure 5.7. The area of this basin is 71.4 ha and it is assumed a runoff coefficient (conservative) of 0.75 for the urban area downtown the city of Limón.

Figure 5.7. Urban storm basin of downtown Limon



Based on the previous data it can be estimated (by rational equation) the total load exerted by flooding rain on the storm drain system and how this load may have an indirect influence on the components of the sewage system.

$$L_T = C \cdot I \cdot A = 0.75 \cdot 106 \text{ mm/hr} \cdot (71.4 \text{ ha}) = 15.7 \text{ m}^3/\text{s}$$

Total Capacity (C_T)

In order to quantify the total capacity (C_T) of the storm drain system it is calculated the installed capacity of the outlets discharging into the sea as the one shown in Photo 5.3.

Photo 5.3 Outlet discharging into the sea of the storm drain system

It was performed an analysis of the last 250 m of the storm drain system that discharge into the sea, because there is an important slope change in the downtown area, it goes from slope values of more than 1.4% up to 0.1% (10 cm in 100 m) which determines that this is the zone of less discharge capacity.

Quantification of capacity involves adding up the discharge capacity of the six outlets (one per avenue) of the storm drain system (see Figure 5.7). Table 5.1 shows the features of the outlets per avenue and also the outlet capacities and the minimum capacity in the last 250 m.

Table 5.1. Characteristics of the outlets, discharge and minimum capacities per avenue

Avenue	Section	Size (m)	Slope (%)		Capacity (m^3/s)	
			Lower	Outlet	Lowest slope section	Outlet
1	Canaleta	1.1x0.85	0.1	0.2	1.094	1.548
2	Circular	1.2	0.1	0.2	1.700	2.070
3	Circular	1.1	0.2	0.4	1.925	2.300
4	Circular	1	0.3	0.3	1.825	1.825
5	Canaleta	2.0x1.0	0.2	0.4	4.334	6.129
6	Circular	1	0.7	0.7	2.800	2.800
				C_T =	**13.678**	**16.672**

Out of the values of Table 5.1, the total capacity at the system outlet is obtained.

$$C_T = C_{A1} + C_{A2} + C_{A3} + C_{A4} + C_{A5} + C_{A6} = 16.67 \text{ m}^3/\text{s}$$

Vulnerability Ratio (V_R)

The vulnerability ratio (V_R) of the storm drain system for the 106 mm/hr intensity is lower than but very close to the unit (0.95) which means that for that intensity the system capacity has been almost reached.

$$V_R = L_T / C_T = 15.7 / 16.67 = 0.95$$

The above shows that the system is quite vulnerable to such intensities which occur in a 3-year return period and that with the climate change will occur more frequently. This is why present and future vulnerability of the sewage system shall be assessed because the vulnerability ratio will increase as a consequence of the climate change.

Capacity Deficit (C_D)

It is clear that the system has the rated and theoretical hydraulic capacity at the outlet to release the event of March 29 2006 and this was proved with the calculations and in person when the cover of the storm drain system was opened to drain off the flooded area.

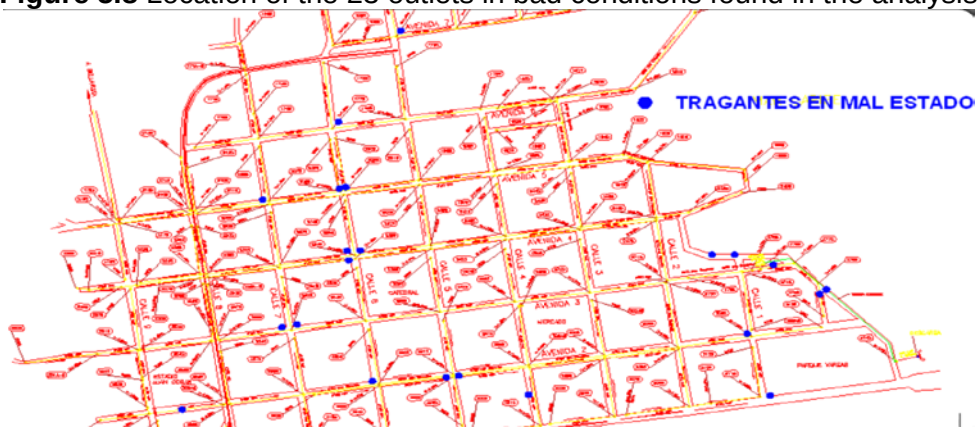
$$C_D = L_T – C_T = 15.7 - 16.67 = - 0.97 \ m^3/s$$

The negative capacity deficit value means that there is no such rated deficit for this event.

It shall be assessed why at said event it was not possible to discharge the load generated by the flooding rain if the storm drain system had enough hydraulic capacity. We might think that there are conditions that limit the system capacity such as clogs or outlets in bad conditions.

In order to quantify the quantity of outlets in bad conditions a diagnosis of the quantity (23) and location of the same was made, as it is shown in Figure 5.8. In this analysis “outlets in bad condition” shall mean the one that limits the system capacity for reasons such as clogging with garbage, they lack grid or they are flooded.

Figure 5.8 Location of the 23 outlets in bad conditions found in the analysis



As a consequence of this fact storm water runs on the streets towards the lowest section of the basin corresponding to the EPA, thus flooding the city even with lower intensities than the one analyzed.

Another problem encountered and that limits the capacity of the storm drain system is the bad management of solid wastes experienced and seen in several places of the city as shown in Photo 5.4 where we can see garbage on the storm drain systems including channels, brooks and grids.

Photo 5.4 Example of bad management of solid waste

It follows from this analysis that at present there is hydraulic capacity to drain off the climate event analyzed but there are some determining factors that do not allow the storm drain system to reach its full capacity.

On the other hand, upon analyzing the future situation with climate change the loads on the system will increase and this is why the load deficit will increase and it might be that the storm drain system capacity be exceeded.

However, given the abrupt slope change in the area near the sea there might be a remaining capacity resulting from the pressurization of both sections which may allow draining off a larger flow. This requires a detailed study of the whole storm drain system in order to estimate the real capacity of the same.

It follows from the present analysis that cleaning of the whole storm drain system must be carried out; upon cleaning and in order to achieve measuring of real capacity of the same it must be correlated the performance of the sewage system for different precipitation intensities which must be recorded by establishing a meteorological station within the basin (in the EPA).

Regarding the future analysis it shall be noted that there is no tool to estimate the values of design intensity for the climate change scenario but it is clear that intensities will increased for the same return periods so that it is recommended to perform a thorough and detailed analysis of real hydraulic capacity of the whole storm drain system and asses the need to extend the capacity of the same depending of the results obtained.

5.2.3 Wind

This climate parameter (wind) has 22 interactions with the infrastructure components and generates mean risk in 7 of them both for the present scenario and for climate change (See Table 5.7).

For this parameter, three possible effects on the different infrastructure components are assessed: power failure, decrease of treatment capacity and personnel security.

Table 5.7 Meam risks generated by the wind parameter

Infrastructure Component	P_A	P_F	G	R_A	R_F	Risk genereated
Vent system	3	3	6	18	18	Power failure
Gates, grids, Parshall channel, interconnection channel	3	3	6	18	18	Powe failure
Worm screw, baskets, hosting system, transportation.	3	3	6	18	18	Power failure
Pumps	3	3	6	18	18	Power failure
Control board	3	3	6	18	18	Power failure
Difussers	3	3	4	12	12	Decrease of treatment capacity
Personnel at the underwater outfall	3	3	5	15	15	Personnel safety

5.2.3.1 Power failure

There is a premise that strong wind affects power networks and therefore power supply to the different electromechanical equipment is interrupted thus giving rise to a temporary loss of functionality of collection, treatment and disposal of the sewage system.

In order to validate this premise it was obtained from the operation record log of EPA a series of days when power supply was interrupted, assuming the shutdown was due to adverse environmental conditions (See Table 5.8).

Table 5.8 Days on which power was interrupted in EPA

Day	Time	
	start	end
October 2 2008	15:10	17:11
October 7 2008	16:41	17:26
November 18 2008	00:00	24:00
March 29 2009	7:10	7:54
May 16 2010	6:20	9:10
May 23 2010	5:50	6:30
July 21 2010	17:15	19:20
August 8 2010	5:45	16:45

We couldn`t correlate the power failure with the wind recorded at the meteorological station of IMN that is at the Airport of the city of Limon.

Total Load (L_T)
Since the premise could not be validated with the days surveyed it was not possible to establish a threshold or a direct relation between the wind and the power failure. Likewise, in order to estimate the loads generated by the wind on the power supply system it must be carried out a detailed study allowing the identification of the relation mentioned in the premise.

Total Capacity (C_T)
Even though it was not proved a direct relation in the premise, it may be stated that there must be a total installed capacity to supply the lack of power whenever it fails.

This capacity must be supplied by a fuel driven power generating set with capacity to supply power for not less than 4 hours to all the electromechanical pieces of equipment of the sewage system.

At present the installed capacity of alternate systems has been decreased as a result of the damage of existing generating sets, mainly due to corrosive effects of the environment which will be discussed later on. However, it shall be considered the infrastructure existing at the different elements of the system because in some of them there is not enough room to install this type of equipment.

Vulnerability ratio (V_R)
The vulnerability ratio (V_R) is higher than one because at present most elements do not have alternate power supply systems in good operating conditions.

$$V_R = L_T / C_T > 1$$

Capacity Deficit (C_D)
It has been determined that there is a capacity deficit ($C_D > 0$) in the electromechanical systems because as it has been already mentioned loads generated by power failures are larger than the installed capacity to supply the same.

$$C_D = L_T – C_T > 0$$

In order to extend the response capacity of the infrastructure to failures in the power system, it shall be verified each electromechanical component in order to estimate which of these have power supply equipment in good operating conditions; it shall be also estimated the space availability to place the sources.

On the other side, the design and supply of the alternate power supply system must provide for the use of equipment with materials of longer useful life and which can stand adverse environments as the saline one and waste water systems. These pieces of equipment must guarantee continuous maintenance of the same by means of the timely supply of spare parts and personnel duly trained.

5.2.3.2 Decrease of treatment capacity

At present the sewage system treats waste water by means of the separation of solids that are larger than 1mm in the EPA, dilution in 100% or more that is obtained upon discharging waste water in the diffuser area and finally the behaviour of the marine environment which allows with time degradation of bacteriological load to values lower than standardized parameters.

Based on the above, the degradation mechanisms of the bacteriological load are related to the marine environment conditions which depend in certain degree on climate parameters such as wind, tide, waves, current, sun radiation among others.

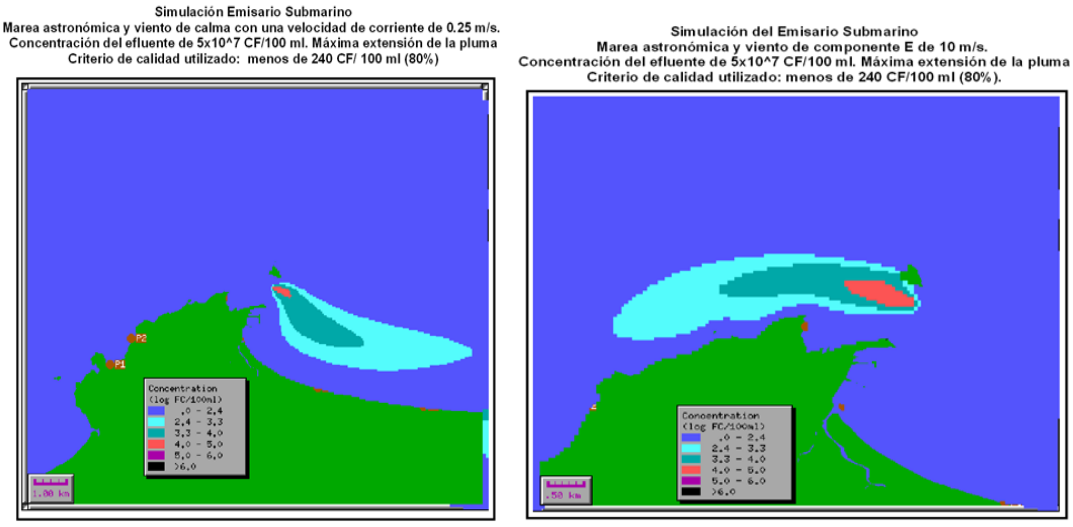
Given the complexity to measure the sea depuration capacity where the outfall was placed, AyA carried out with Universidad de Cantabria a modeling which may allow determining the outfall depuration capacity when facing the effects of climate parameters such as tides, currents and winds (See Table 5.9).

Table 5.9 Conditions projected by Universidad de Cantabria

Calculation situation	Tide (Stroke=0,5m)	Currents Direction SE (m/s)			Wind situation (10 m/s)		
		0,25	***0,45***	***0,6***	***Calm***	***NE***	***E***
1	x				x		
2	x					x	
3	x						x
4	x	x			x		
5	x		x		x		
6	x			x	x		
7	x	x				x	
8	x		x			x	
9	x			x		x	
10	x	x					x
11	x		x				x
12	x			x			x

From the 12 different modelling it was determined that current conditions in the outlet favour the purification process because it moves the contamination plume away from the center of Limon. In order to have a visual effect we can see the left image of Figure 5.9 (modeling 1). It shall be mentioned here that this current has a south component almost all year round and obeys to the transportation of sediments of rivers of the North Atlantic basin towards the South (Ríos Matina, Moín and Chirripó), which increases its speed in the discharge point of the outfall due to the narrowing caused by Uvita Island and Muelle Aleman (dock).

Figure 5.9 Results of projected conditions



Modeling 1 **Modeling 3**

It follows from the above that the critical condition of the contaminant plume behaviour in relation to the current takes place when the same is zero or when a change of direction takes place as a consequence of the wind, in NE and E direction, and therefore the contaminant plume gets closer to the coast of the city (see right image of Figure 5.9, modeling 3).

Therefore, the wind with coast direction of more than 10 m/s and in low current conditions becomes the critical climatological condition in the behaviour of the contamination plume, thus giving rise to the possibility of showing bacteriological contamination issues (>240 CF/100ml). Based on the above, what shall be assessed regarding the wind is the possibility of having winds towards the coast of more than 10m/s and under calm conditions.

From the meteorological data it was obtained values of 10m/s in the above mentioned directions, approximately once every 7 years. These events coincide with atmosphere changes in the Caribbean which generate material ocean activity (tides, waves and currents) so that it may be discarded the simultaneous occurrence of winds of more than 10m/s and low current conditions.

Total Load (L_T)

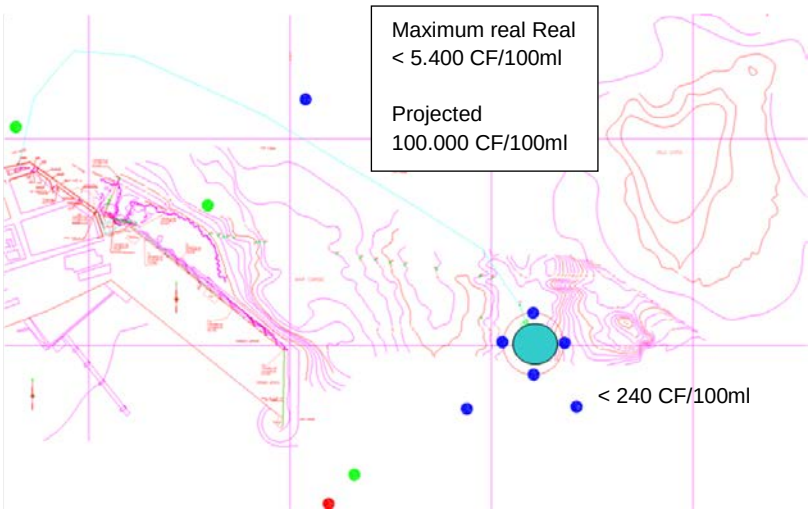
As per the above, the load generated by the wind regarding a decrease of treatment capacity is almost none because this projected event will not happen.

$$L_T \approx 0$$

Total Capacity (C_T)
Besides the fact that it is practically improbable the occurrence of this event, modelling indicates that in the outfall outlet fecal coliform concentrations of approximately 100.000 CF/100ml will be present. In the samplings of Laboratorio Nacional de Aguas (LNA) from 2005 on, we find concentrations of less than 5.400 CF/100ml, approximately 18 times less the projected event thus evidencing a real treatment capacity higher than the one initially assumed (See Figure 5.10).

$$C_T >> \text{Projected capacity}$$

Figure 5.10 Real Treatment Behaviour of Outfalls



Vulnerability Ratio (V_R)
The vulnerability ratio (V_R<<1) is less than one, almost zero, because the loads generated by the wind are almost null and the outfall has proved to have a very high treatment capacity.

$$V_R = L_T / C_T \approx 0 << 1$$

Capacity Deficit (C_D)
It was determined that there is no capacity deficit ($C_D < 0$) in the treatment capacity because it has been proved the high treatment capacity of the outfall.

$$C_D = L_T - C_T < 0$$

It is recommended to continue with the monitoring campaigns by LNA-AyA in the discharge area in order to identify any change in the results obtained.

It shall be included to the present treatment system the areas that do not have sewage, for instance the Proyecto Limón Ciudad Puerto in order to improve the quality of bodies of water and recover Playa de Cieneguita and the basin of Río Limoncito.

Place a meteorological station to monitor the wind pattern that may change the behaviour of the contaminant plume and include this in the information from the sampling carried out by LNA.

Using all the information available (technical and scientific) it was considered that treatment capacity of the underwater outfall is not in risk from the effect of climate change.

5.2.3.3 Personnel Security

As it has been already mentioned, strong winds are related to atmospheric alterations in the Caribbean which give rise to large ocean activity (tides, waves and currents) keeping the personnel from performing the regular activities in the underwater outfall and this is why no diving shall be scheduled or made whenever atmospheric perturbations coming to the coast are forecast.

Total Load (L_T)

The strong wind conditions give rise to conditions not suitable for diving because of less visibility, instability of the boat and more currents.

Total Capacity (C_T)

Capacity of personnel carrying out inspection works at the underwater outfall (diving team of AyA) is high and at present all the members of the team have passed advanced diving courses.

Besides, the diving team shall be increased to be able to work in pairs (at present there are 5). This team must be completed with people who is familiar with the project and having present diving license.

Vulnerability Ratio (V_R)

In case of strong winds the vulnerability ratio (V_R) is more than one because sea conditions in case of strong winds are not optimal to carry out inspections.

$$V_R = L_T / C_T > 1$$

Capacity Deficit (C_D)

It has been determined that there is capacity deficit ($C_D > 0$) because in case of adverse conditions no diving shall take place.

$$C_D = L_T – C_T > 0$$

In order to avoid scheduling failed tours, constant monitoring of sea conditions shall be made on the dates close to the diving and select the time of the year when favourable climate conditions are expected.

5.2.4. Atmospheric Discharges

This climate parameter (atmospheric discharges) has 17 interactions with the infrastructure components and gives rise to average risk in 5 of them, both for the present scenario and for that of climate change (See Table 5.10).

Table 5.10 Average risks generated by the atmospheric discharge parameter

Infrastructure Component	P_A	P_F	G	R_A	R_F
Ventilation system	2	2	6	12	12
Gates, Grids, Parshall Channel, Interconnection channel	2	2	6	12	12
Worm scree, baskets, hosting system, transportation.	2	2	6	12	12
Pumps	2	2	6	12	12
Control Board	2	2	6	12	12

Total Load (L_T)

In order to be able to estimate the loads generated by lightning (atmospheric discharges) on the electromechanical equipment the following shall be taken into consideration: current peaks, irregularities in quality of power and outlets of power supply caused by atmospheric discharges. For this purpose, a more detailed study must be carried out focused on the protection of electromechanical equipment.

Total Capacity (C_T)

Total capacity is considered as the protection the electromechanical equipment must have in order to continue in operation in front of the charges generated by lightning on the equipment.

This capacity must be given by the following:

- Protection of the equipment in case of irregularities in electrical power quality, such as peaks.
- Landing system for atmospheric discharges.
- A fuel power generator set with capacity to supply power for not less than 4 hours to the electromechanical equipment.

As we have previously stated, at present the installed capacity in alternate systems has been decreased as a consequence of the progressive deterioration of the existing generator sets and it is required to go over the existing protections to mitigate any discharge.

Vulnerability Ratio (V_R)

It is estimated that the vulnerability ratio (V_R) must be close to one because there are no records of damage to the equipment as a consequence of a discharge.

$$V_R = L_T / C_T \leq 1$$

However, an analysis of the protection elements placed shall be made in order to establish the need to improve them or adjust the same.

Capacity Deficit (C_D)
It is estimated that the capacity deficit ($C_D \leq 0$) shall be less than or equal to zero because there is evidence of discharges close to the EPA and it has not been reported damage or shutdown of the electromechanical components.

$$C_D = L_T - C_T \leq 0$$

However it must be checked that every electromechanical component has the appropriate protections for the effects caused by the atmospheric discharges since there is no total protection of components.

5.2.5. Sea Breeze

This climate parameter (sea breeze) has 13 interactions with the infrastructure components and generates mean risk in 2 both for the present scenario and for climate change scenario (See Table 5.11).

Table 5.11 Mean risks generated by the sea breeze parameter

Infrastructure component	P_A	P_F	G	R_A	R_F
Building	2	3	5	10	15
Power plant	2	3	7	14	21

Total Charge (L_T)
Total charge for this climate parameter is the abrasive action of the saline medium to which the structures are exposed together with the abrasive action of gases generated in the sanitary system.

Total Capacity (C_T)
Experience shows that pieces of equipment installed are not made of appropriate materials or they are not designed to stand the abrasive conditions generated by sea breeze because components show damage due to corrosion.

Vulnerability Ratio (V_R)
For components under analysis the vulnerability ratio (V_R) is more than one because at present there are pieces of equipment that do not stand corrosive charges.

$$V_R = L_T / C_T > 1$$

This vulnerability is materialized with the shutdown of the generating plant which is completely corroded and the required change made to metal enclosures (doors, windows, gates) of the EPA building.

Capacity Deficit (C_D)
It has been determined that there is a capacity deficit ($C_D > 0$) as per the above.

$$C_D = L_T - C_T > 0$$

In order to reduce the effects of sea breeze it is recommended to change the elements of the enclosures (windows, doors, covers, gates) with non-corrosive materials such as wood, stainless steel, fiberglass, among others.

In the case of the structural elements we can see damage of the reinforcement steel in places where the coating was not the appropriate one, so that it is recommended to protect these elements using special additives.

In the case of the generator set, this must be designed to stand this type of abrasive conditions. These activities must be intensified in the future since with climate change the incidence will increase.

5.2.6. Wave

This climate parameter (wave) has 10 interactions with the infrastructure components and does not give rise to mean risk for the present scenario but it does generate 2 mean risks for the climate change scenario (See Table 5.12).

Table 5.12 Mean risks generated by the parameter waves

Infrastructure Component	P_A	P_F	G	R_A	R_F
Asis Esna	1	2	6	6	12
Wall	1	2	6	6	12

Total Load (L_T)
Load is considered as the height of the wave used to estimate the frequency of the climate parameter, 3m.

$$L_T = 3.0 \text{ m}$$

This value was estimated based on an event when waves hit the doors of EPA.

Total Capacity (C_T)
Capacity is given by the level above sea level at which the components are.

Asís Esna	C_T = 3.2 m
Wall	C_T = 2.9 m

Vulnerability Ratio (V_R)
Based on the above, vulnerability ratios (V_R) are calculated for each component

Asís Esna	$V_R = L_T / C_T = 3.0 / 3.2 = 0.94$	< 1	=>Non vulnerable
Wall	$V_R = L_T / C_T = 3.0 / 2.9 = 1.03$	> 1	=> Vulnerable

Capacity Deficit (C_D)
Capacity deficit is calculated per component (C_D).

Asís Esna	$C_D = L_T – C_T = 3.0 – 3.2 = - 0.2$	=> without deficit
Wall	$C_D = L_T – C_T = 3.0 – 2.9 = 0.1$	=> With deficit

Asís Esna

For this component there is no capacity deficit because the component is higher than the wave under analysis. Furthermore, this infrastructure is naturally protected by the coral reef that in this area has 150 m of exposed coral. For a future scenario a deeper analysis must be made on the affectation of this infrastructure.

Wall

It has been shown that for the future scenario with climate change a wall must be built to protect EPA against waves. Extension of this height shall take into consideration that this point is used as observation point and therefore the extension of the same must consider the improvement and respect of this recreation space.

5.2.7. Hurricanes

This climate parameter (hurricanes) has 29 interactions with the infrastructure components and does not generate mean risk for the present scenario but it does generate 10 mean risks for the climate change scenario (See Table 5.13).

Based on the climate history of the country this phenomenon involves no risk for the present scenario because the hurricane paths did not have direct impact on the country giving rise to changes in the Atlantic area.

Table 5.13 Mean risks generated by the hurricane parameter

Infrastructure Component	P_A	P_F	G	R_A	R_F
Networks, sub sewers sewers	1	2	6	6	12
Coastal mini-stations	1	2	6	6	12
Asis Esna,	1	2	7	7	14
Pacuare 2	1	2	7	7	14
Ventilation system	1	2	6	6	12
Gates, grid, Parshall channel, interconnection channel	1	2	7	7	14
Worm screw, baskets, hosting system, transportation.	1	2	6	6	12
Pumps	1	2	6	6	12
Control board	1	2	6	6	12
Wall	1	2	6	6	12

For the climate change scenario it shall be carefully and thoroughly analyzed the possibility of direct incidence of hurricanes and the possible effects of the same on the territory. Besides, special emphasis should be placed on the infrastructure placed in the sea with anchors and pipes. This analysis must be complemented with oceanographic information which we did not have available for this study.

Initially the effects of this climate parameter were defined as an added effect of flooding rain, waves and wind; so that for this parameter no charges and capacities were assessed for the components due to a lack of threshold that may allow carry out this analysis.

The magnitude of hurricanes was discussed once the risk matrix was made so that the same does not reflect the severity on the components of the infrastructures assessed.

5.2.8. High temperature

This climate parameter (high temperature) has 15 interactions with the infrastructure components and generates mean risk in 2 both for the present scenario and for the climate change scenario (See Table 5.14),

Table 5.14 Mean risks generated by high temperature.

Infrastructure Component	P_A	P_F	G	R_A	R_F
Building	4	5	3	12	15
Personnel in EPA	4	5	4	16	20

Total Charge (L_T)
Total charge for this climate parameter is obtained from the threshold defined for the analysis which was defined in 30ºC.

$$L_T = 30ºC$$

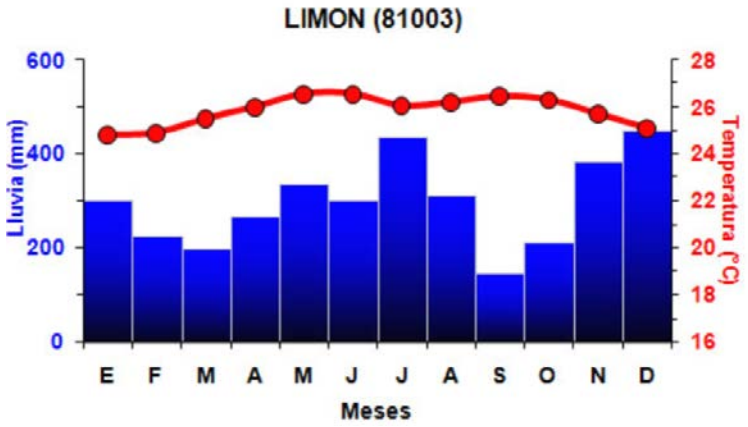
This threshold was defined in this value because at this temperature there are unfavourable conditions for works to be carried out at EPA and because when temperature increases concentration of gases coming from waste water increases thus directly affecting the personnel and the building wwhere the EPA is, since these gases are abrasive.

Total Capacity (C_T)
Total capacity for this study was defined as the average temperature recorded in the cit of Limón, 26ºC (See Figure 5.11)

$$C_T = 26ºC$$

This value was defined as the capacity since it is the temperature at which workers are used and at which the waste water gas generation processes do not increase because they are under average conditions.

Figure 5.11 Average temperature in Limon city



Source: IMN

Vulnerability Ratio (V_R)
For the components under analysis the vulnerability ratio (V_R) is more than one because the load assumed for this analysis is 15% higher than the projected capacity.

$$V_R = L_T / C_T = 30 / 26 = 1.15$$

In order to decrease vulnerability, it must be designed a ventilation system guarantying in the work place a temperature equal to or lower than the one defined as the capacity for this analysis.

Capacity Deficit (C_D)
For the components under analysis it is calculated a capacity deficit (C_D) which shows that for the threshold established there is a deficit of 4ºC

$$C_D = L_T – C_T = 30 – 26 = 4ºC$$

In order to compensate this capacity deficit it must be designed a ventilation system that keeps temperatures in at least 26ºC in order to guarantee favourable working conditions for the personnel who is in charge of EPA operation and maintenance.

Besides keeping temperatures below the defined capacity, the system must guarantee that there is good circulation of fresh air, with fresh air entering the working places and exhausting the waste water gases without affecting the surrounding buildings.

5.3 Summary of findings

Below is a summary of findings for recurrent and extreme events:

Table 5.15 Findings for recurrent type parameters

Parameter	Summary
High temperature	It must be redesigned the ventilation system of EPA and guarantee optimal working conditions in case of increase of temperature and decrease the gas concentration from waste water.
Waves	*Asís Esna:* For a future scenario a deeper analysis must be carried out regarding the affectation of this infrastructure. *Wall:* this must be built to protect the EPA from waves in the future scenario with climate change, taking into consideration its recreation purpose.
Sea breeze	Decrease the effects on the enclosure elements by changing them to non-corrosive materials. Revise and protect the structural elements on the spots where the reinforced steel is damaged. Solve the issue of the power generating set
Lightning	Verify that each electromechanical component has the appropriate protections for the effects generated by the atmospheric discharges.

Table 5-16 Findings for extreme parameters

Parameter	Summary
Flooding rain	Analyze present and future vulnerability of the sewer system since the vulnerability ratio will increase as a consequence of climate change. The whole storm drain system must be cleaned up; after cleaning (and possible reconstruction of outlets) and in order to measure the real capacity of the same, correlation of the sewer performance with different precipitation intensities must be made and record the same through the meteorological station that will be placed at EPA. There is no tool available to estimate the design intensity values for the climate change scenario (intensities will increase for the same return timeframes) and a thorough analysis must be made of the real hydraulic capacity of the whole storm drain system and assess the need to extend its capacity according to the results obtained.
Overcharge rain	Interconnections (sewer-storm drain system) must not be removed in the city as long as the issues of the interconnected services are not settled upon carrying on the inter-institutional program, Install a meteorological station in the zone which may allow quantifying the results obtained with this measure.
Hurricanes	For the climate change scenario it must be carefully analyzed the possibility of direct incidence of hurricanes and their possible effects. Place emphasis on the infrastructure placed in the sea such as anchoring and pipes starting from new oceanographic information.
Wind	Continue with the campaigns of the LNA-AyA in the outfall discharge zone in order to identify some change in the results obtained. Include the zones that do not have sewerage to the present treatment system - Install a meteorological station to monitor the wind pattern which may modify the behaviour of the contaminant plume and include it in the information of the samplings carried out by LNA. Keep the underwater outfall inspection program and increase the number of members of the diving team with people who is familiar with the project and who have diving permits.

6. LIMITATIONS

We had some data sufficiency issues during Step 2 of PIEVC Protocol mainly regarding data required for gathering the climate parameters that were established to carry out the Step 3 - Risk Assessment. Due to the lack of historical data and the lack of climate projection models some considerations were established based on professional judgement and going over scientific articles and some websites and literature.

On the other hand, it shall be noted that historical data of climate parameters is not recorded for a same period of time because there is data with hour, day, month and even year records.

Another important aspect here is the lack of climate projections based on regional circulation models thus contributing to uncertainty in the assessment of the probability ad magnitude of climate change at local level, because the global analysis is too general and gives errors related to the discussion on the interaction and affectation of the infrastructure due to climate change.

It shall be noted here that some climate projections are based on the expert judgement and the respective explanation is grounded on the relation with other climate parameters as well as on the consultation of the results of other research works. However, in some cases it was not possible to carry out the analysis of future projections because of the lack of data and it was not deemed accurate to make an estimate.

This data insufficiency limits the ability of the work team to make quantitative estimates of the effects of climate change on the infrastructure of the waste water treatment system of Limon city.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- The application of PIEVC Protocol to the Sewer System of Limon city has allowed approaching the climate change issue in a systematized way starting from a wide climate analysis.
- The best results of applying the Protocol were obtained for those parameters we had load thresholds based on the corroboration of the occurrence of events (recorded in operation logs) with the climate records.
- For those thresholds it was identified the infrastructure that at present is affected regarding capacity loss or operation shutdown.
- It was identified the adaptation measures requiring immediate action, even if there are no extreme conditions ascribable to climate change effects.
- It has been also identified the aspects requiring more detailed studies, improvement of equipment and better data recording.
- Considering that 4% of services collapse the system (due to overcharge rain) it must be carried out an identification and reduction program of service interconnections with the support from MINSA and the Municipality of Limón.
- The storm drain system has capacity to evacuate the flooding rain defined for this analysis. However, a detailed and thorough analysis must be made of the real hydraulic capacity of the whole storm drain system and assess the need to extend its capacity based on the results obtained. Furthermore, in the present scenario, a cleaning program and replacement of outlets and main pipes must be carried out.
- Modelled conditions of the contaminant plume used extreme conditions which probabilities of occurrence are low. Furthermore, the real conditions assessed reflect a larger depuration capacity of the outfall than what was originally expected. In conclusion, there is no contamination risk of the Limon coastal areas, neither at present nor in the future due to climate change.

The application of the PIEVC Engineering Protocol

In this process the general purposes established in the original proposal were achieved:

- Determine the vulnerability to climate change of the waste water collection, treatment and disposal system of the city of Limón.
- Better understanding on the need of climatological data, the way said data must be requested to the respective institutions and the way the data must be presented to the technical team.
- Expertise on the use and applicability of the PIEVC analysis process was achieved.

- Establishment of the direct or indirect relation of climate changes with the infrastructure under analysis through the definition of interrelations between the infrastructure components and the climate factors.
- Identification of priority actions in order to adapt the existing infrastructure to present and future climate events.
- Identification of climate data gaps that must be filled in the future in order to carry out a second engineering analysis cycle of this project.
- Establishment of an operation structure integrating all the parties involved (system operator, owner of the system, meteorological specialist, project manager, among others) and that we expect will be applicable to other projects.

As general conclusion regarding the vulnerability of the system under analysis to climate change we can conclude that this system has enough capacity to stand the projected climate change effects for a 30 year analysis timeframe. The above is possible if the recommendations hereof are implemented. Besides, some other issues that were not discussed in this analysis must be explored by means of future investigations and we deem essential to solve the limitation issue mentioned regarding the quality of information and to improve the PIEVC Protocol application process as it has been mentioned in this analysis.

7.2 Recommendations

- For future applications of PIEVC Protocol in national infrastructures, institutions must secure the participation of officials according to the work load arising out of the protocol application, in order to secure and appropriate process and optimum transfer of knowledge.
- For the right implementation of the Protocol in future projects, it is of material importance that the person defining and following up the work schedule (coordinator) knows the real time the practitioners can dedicate to the project and even more important, the coordinator must monitor the time assigned to each task during the project because even though the initial steps are important for the project, these are not the ones that must consume most of the time of the work team; steps 3 (Risk Assessment) and 4 (Engineering Analysis) are the steps the work team must dedicate most of the time since they are the core of the analysis. If the work schedule is well defined from the beginning (with the required personnel) and if progress is monitored thus guarantying the assignment of enough time to main activities, future projects will be successfully implemented.
- The existing alternative, retaining consulting firms (study case of the Claireville and G. Ross Lord Dams and Metro Vancouver Sewerage) may save time but it is recommended the application of the Protocol by the domestic institutions in order to secure an appropriate knowledge transfer.

- The Risk Management issue must reach a nationwide level to secure leadership and joint participation of the institutions responsible for the infrastructure and mainly of those that generate climatological type data.
- It is not recommended to close the interconnections between the systems (waste water – storm water) until obtaining some results from a program to reduce the contribution of storm water from the house roofs into the sewer system, with the support of MINSA and the Municipality of Limón.
- It is recommended to continue with the monitoring campaigns by Laboratorio Nacional de Aguas - AyA in the discharge area, with inspection immersions of the outfall and its components and increase the number of members of the diving team of AyA.
- In the future scenario it is recommended to install a meteorological station in the area in order to quantify the decrease of interconnection contributions upon implementing the program and to be able to quantify the storm drain system performance.

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