018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

D5.3.2: Workshop report on the use of natural systems in the urban water cycle
D5.3.11: Workshop reports and plan on how to maximise the use of natural systems in the urban water cycle in demo-cities

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

SWITCH WP 5.3 - Maximizing the use of natural systems in urban water management

D5.3.2: Workshop report on the use of natural systems in the urban water cycle
D5.3.11: Workshop reports and plan on how to maximise the use of natural systems in the urban water cycle in demo-cities

The hydrological water cycle runs via a wide variety of ecosystems, and is aided by bio-geo-chemical activities in these natural systems. The processes in natural systems relating to water purification and remediation can be employed for effective urban water management in two ways: a) by applying the processes of natural systems in ‘eco-technologies’ (e.g. AWWT, constructed wetlands, stabilization ponds), or, b) by employing full scale natural systems (e.g. river bank filtration, natural wetlands, phyto-technology, eco-hydrology).

Tasks 1b and 5a within workpackage 5.3 were partly overlapping, and were aimed at organising workshops to (1) discuss and analyse the use of natural systems in the urban water cycle, and (2) to produce a (preliminary) plan on how to maximise their use in demo-cities

Activities took place in three demo cities: Accra (Ghana), Lodz (Poland) and Cali (Colombia).

1. <u>Accra (Ghana), 4 April 2007</u>

As part of SWITCH activities in Accra, a workshop on the use of Natural Systems for the treatment of wastewater was held on the 4th of April at Alisa Hotel in Accra. The objective of the workshop was to introduce participants to the concept of integrated urban water management as well as the use of natural systems for wastewater treatment and come up with sustainable technologies for urban waste water management in Accra.

The workshop was made up of presentations and discussion sessions and well as a working session. The presentations focused on Integrated Urban Water Management, Toilet Technologies in Ghana and the Use of Natural Systems in Waste water treatment. There were discussion sessions

after each presentation and a group work on prioritizing the research needs for Accra in the area of wastewater treatment.

At the end of the workshop participants concluded that Workpackage 5.3 could respond to the waste water treatment problem in Accra by helping to find a sustainable technology for wastewater treatment. The main action points that were agreed on are as follows:

- Piloting a demonstration of the use of natural systems using the Kpeshie Lagoon Area.
- A Documentation Centre to put together literature which will be useful not only to WP 5.3 but also to the main Learning Alliance and other workpackages.
- Students to do Research

The detailed workshop report can be found in the Annex.

Results from the follow-up studies can be found in Deliverable 5.3.12:

- MSc thesis A. Muzola on Grey water treatment using natural wetlands
- MSc thesis P. Niyonzima on Grey water treatment using constructed wetland at KNUST in Kumasi
- MSc thesis M. Ansah on The use of natural systems for the treatment of greywater: A case study of Kpeshie lagoon
- MSc thesis of P. Antwi-Agyei on Faecal sludge management: the case of Madina

2. Lodz (Poland), 16 December 2008

The objective of the meeting was to present available know-how concerning possibilities of application of natural systems in water resources management in urban areas, including alternative solutions for rainwater management. The following were proposed: a review of BMPs, possibilities of their application, examples of successful applications which launch new trends in the field of sustainable development sector, presentation of financial issues in the field of charges for rainwater, development of integration of the measures, including the context of institutional aspects' impact on the decision-making process, and presentation of examples of natural systems applications.

During the workshop, the LA agreed that there was a need for development of a plan and implementation of the sustainable solutions presented during the workshop. Both the BMPs in

stormwater management and the Natural Systems met a great interest. There is a need to work further on capacity building and integration of efforts within the stakeholders group to assure success of the activities undertaken towards these goals. There is also a need to make sure that there is enough of research evidence for the alternative solutions are in accordance with the health standards, and recognized the possibilities of introducing of the alternative solutions into the local/national legislation. Steps need to be taken towards building awareness and policy adjustment.

The detailed workshop report can be found in the Annex.

One of the outcomes of this workshop is the production of the Movie and Training Package on Natural Treatment Systems (see SWITCH training package). Persons from several demonstration cities came to The Netherlands to visit the systems that were discussed during the workshop in Lodz and were interviewed about their impressions and potential applicability.

3. **<u>Use of natural systems in Cali</u>**

The city of Cali in Colombia was "upgraded" during the project from a Pilot Site to a Demonstration City with a full-fledged Learning Alliance (LA). Regular LA meetings started in 2007 and were structured based on the SWITCH strategic planning approach, starting with baseline data collection and problem identification, visioning, scenario's and finally a plan for improved (waste) water management in Cali (see Deliverable 5.3.6). During several of those meetings attention has been paid to Natural Treatment Systems. The meeting rapports are not given as annexes to this deliverable, but appear under work package 6.2 "Learning Alliances".

However, as a concrete output of those meetings, a plan has been produced for the Application of natural systems for wastewater pollution control in the expansion area of Cali. This report is can be found in the Annex and is based on the internship of Mr. Andrea Gaviano during his stay at CINARA Institute of Universidad del Valle, Cali, Colombia. The internship, that lasted 4 months, was about the application of natural systems on wastewater pollution control in the expansion area of Cali.

Activities consisted in performing an area visit, the review of the natural system technological options and investigate their application in the study area, the preliminary analysis of the strategies

for the pollution control in the expansion area. In parallel with these activities other specific activities have been carried out as: meetings with SWITCH and Univalle work groups; meetings with institutions and members of the learning alliance; field activity in the water quality monitoring plan of Río Cauca; visit the water infrastructure of the city of Cali.

The report has been discussed with the Learning Alliance and has also been presented to a wider audience during the Agua 2009 conference in Cali:

> GAVIANO A., D.A. ZAMBRANO, A. GALVIS and D.P.L. ROUSSEAU (2009). Application of natural treatment systems for wastewater pollution control in the expansion area of Cali. Oral presentation at Agua2009 - Seminar on 'Los humedales como Tecnologia Sostenible para el manejo del agua y la mitigacion del cambio climatico', 9-13 November 2009, Cali, Colombia.

Annex A

Report of the SWITCH Workshop on the use of natural systems for wastewater treatment, April 2007, Accra, Ghana

WORKSHOP REPORT

SWITCH WORKPACKAGE 5.3 WORKSHOP ON THE USE ON NATURAL SYSTEMS FOR WASTE WATER TREATMENT

WEDNESDAY, 4TH APRIL2007
ALISA HOTEL, NORTH RIDGE.

SWITCH ACCRA, SECRETARIAT

APRIL 2007

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Summary

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The workshop was made up of presentations and discussion sessions and well as a working session. The presentations focused on Integrated Urban Water Management, Toilet Technologies in Ghana and the Use of Natural Systems in Waste water treatment. There were discussion sessions after each presentation and a group work on prioritizing the research needs for Accra in the area of wastewater treatment.

At the end of the workshop participants concluded that Workpackage 5.3 could respond to the waste water treatment problem in Accra by helping to find a sustainable technology for wasterwater treatment. The main action points that were agreed on are as follows:
Piloting a demonstration of the use of natural systems using the Kpeshie Lagoon Area. A Documentation Centre to put together literature which will be useful not only to WP 5.3 but also to the main Learning Alliance and other workpackages. Students to do Research.

1 Introduction

1.1 SWITCH Project

SWITCH is an acronym for **S**ustainable **W**ater management **I**mproves **T**omorrow's **C**ities' **H**ealth. The main aim of SWTICH is to achieve a paradigm shift in the management of urban water resources. SWITCH is an international consortium made up of 32 partners and looks at a strategic approach to urban water management which cuts across all aspects of the urban water cycle from storm water management, efficient water supply to all, water use, sanitation and waste management, planning of urban water environment and governance and institutional change to urban water management. These are captured under 6 main themes and various sub-themes known as workpackages.

SWITCH will undertake research, training and demonstration to find scientific, technological and socio-economic solutions for sustainable urban water environment. This will be done through Learning Alliances (multi-stakeholder platforms) which help the exchange of knowledge and experiences between government, private sector, civil society stakeholders and consumer groups.

Accra is one of the cities where SWITCH demonstrations will be carried out. Accra is growing rapidly, especially on its fringes. Slum areas have developed and are increasingly growing in number and density. This is a major challenge to sustainable urban water management. Major problems are poor access to proper water supply and sanitation by the urban poor, high losses in the distribution network, polluted water resources, low cost recovery for water supply services and poor sanitation in slum areas. SWITCH in Accra will respond to these problems by carrying out research and demonstration activities in the areas of

- Use of urban water (fresh and waste water) for urban agriculture and other livelihood opportunities
- Maximizing the use of natural systems in all aspects of the municipal water cycle
- Governance for integrated urban water management
- Other Areas identified by the Accra Learning Alliance

The Accra Learning Alliance was formally launched on 14th March, 2007 and is made up of a series of platforms including the ones that deal with social inclusion, urban agriculture and the use of natural systems for wastewater treatment.

1.2 Workpackage 5.3

SWITCH theme 5 deals with urban water environments and planning. In Accra one of the problems is the treatment of wastewater. Workpackage 5.3 looks at the use of natural systems for wastewater treatment and is expected to respond to the problems in Accra through research and demonstration.

As part of the activities for workpacke 5.3 this workshop on the use of natural systems was orginasied at Alisa Hotel in Accra on Wednesday, April 4, 2007.

1.3 Objectives of Workshop

The main aim of the workshop was to introduce the concept of integrated urban water management and the use of natural systems for waste water treatment as well as come up with an Action plan for WP 5.3 in accra to follow. The specific objectives to help achieve the aim were

(a) To introduce Natural systems and how it could be used in Accra
(b) Introduce Various Toilet technologies and select an appropriate one for Accra
(c) Prioritize Research needs
(d) Identify training needs
(e) Draw up an action plan for implementation in Accra

1.4 Expected Outcome from Workshop

At the end of the meeting, it was expected that

- participants would know more about the use of natural systems and different types of toilet technologies in Accra
- appropriate toilet technologies will be selected for different areas in Accra
- the group will decide on priority areas for which WP 5.3 could respond to.
- An action plan for implementation will be drawn

2 Summary of Workshop Presentations and Discussions

The meeting started with self introduction of the participants. Prof. Mrs. Esi Awuah gave an overview of the workshop objectives and expected outcome. There were presentations followed by discussion sessions and a group work using problem tree analysis

2.1 1st Presentation by Peter van der Steen (PhD)

The first presentation was on Integrated Urban Water Management (IUWM) and it was delivered by Peter Vander Steen. He explained the concept of IUWM in considering all parts of the water cycle, natural and constructed, surface and sub-surface, recognizing them as an integrated system. He gave a diagrammatic presentation of IUWM.

He also looked at the role of various institutions and how they can come together in the development of IUWM. He said IUWM depended on the optimisation of the entire system rather than optimisation of elements. It is very important that all stakeholders are involved.

For the Improved sustainability of Urban Water Management there should be a balance in the following areas.

- Environmental
- Economic
- Social
- Engineering
- Health

He went on to give an example of the strategic plan and vision for the Yarra Valley system in Melbourne, Australia. He drew a parallel with Accra and the possible vision Accra could have for the future

Possible sustainability objectives for Accra by 20xx:

- all citizens of Accra served
- no negative health effects from water system
- no flooding events
- sustainable infrastructure (UASB)
- at lowest possible cost
- healthy lagoon and marine environment

There should be a balance between economy, society and environment. He also discussed the indicators for monitoring the progress of the attainment of objectives.

He concluded with the elements of SWITCH expected to be undertaken in each city.

1. Vision

2. Scenarios and strategies
3. Decision Support systems
4. Detailed Options analysis
5. SWITCH City Strategy

2.2 Discussion on 1st Presentation

After the presentation, there was a short discussion. The following are some highlights of the discussion.
Comment: Feasible objectives should be set for the city. eg. We cannot prevent flooding but the objective could be flooding control.

Question: Should there be an objective which captures awareness of the issues in IUWM by the citizens?

Response: Learning Alliance needs to draft the objectives and the objectives on awareness could be included. Eg. Having an objective that is aimed at giving citizens a basic understanding of the issues in IUWM

Question: Should there be an objective which considers how institutions will work together to ensure IUWM?

Comment from Prof Mrs Awuah: the Ministers have already shown their commitment from the first learning alliance meeting that was held in March.

Question: At what point do we say we have included all stakeholders in the process; how do we ensure this; what is the optimum size of stakeholders to be involved in SWITCH?

Comment from Prof: Mrs. Awuah: There are different classes of stakeholders and they are invited according to the objectives of the workshop.

2.3 2nd Presentation by Prof. Mrs. Awuah

The presentation was on toilet technologies in Ghana. The presentation was given under the following topics

- Composition of Human Waste

- Pathogens
- Qualities of an Ideal Toilet
- Types of Toilet Technologies (Water Dependent and Independent)
- Operations of VIP latrines
- Treatment of Human Excreta
- Selection Criteria for Selecting Appropriate Technologies.
    1. Examine the reason for the proposed technology
    2. Describe the technology
    3. Consider alternatives
    4. Examine future trends and events
    5. Identify and evaluate potential impacts
    6. Identify affected stake holders
    7. Identify the key decision makers
    8. Identify action options for the framework that supports decision making
    9. Draw conclusions
    10. Make recommendations

- What Stakeholders can do?
    - Modify the project to reduce disadvantages
    - Identify regulatory or other control needs
    - Define surveillance program for the technology as it becomes operational
    - Stimulate research and development to define risks more reliably, forestall anticipated negative effects, identify alternative methods for achieving goals, identify corrective measures for reducing or eliminating negative effects.

Making a comment on the UASB reactor which is currently not in use, she mentioned that Ghana Water and Sewerage was in charge of sewage around the time that the construction began and as such AMA staff were not trained during construction so when they had to take over the management it became difficult for them. There was also no budget for operation and maintenance and flood Levels were also not taken into consideration

Recommendations

- Identify experiments in order to clarify uncertainties
- Identify needed institutional changes
- Identify new benefits
- Delay project
- Identify partial or incremental implementation strategies
- Prevent the technology from developing or being used

2.4 Discussion on 2nd Presentation

A discussion session followed the presentation.

There was a clarification question on the definition of ecosan toilets.

Ecosan toilets are different from the "Dry Sanitation Systems" as indicated in the presentation. Ecosan toilets are "urine diversion" (UD) toilets, thus the urine is separated from the faecal matter; the faecal matter is sanitized and reused. However, the dry sanitation systems indicated in the presentation collect the urine and faeces together. Ecosan toilets are strictly UD toilets and then sensitizing the urine and toilets for re-use.

Question: Does the AMA have a policy on toilet technologies and who ensures its implementation?

Response (Maj. Awuah): There is no law but the AMA is evolving according the evolution of technologies. AMA has gotten to an age where various technologies are being managed. Pan latrines to be abolished by 2010. (Local Government Policy)AMA is supporting people to have KVIPs (and now some are being helped with Water closets in their homes)

Comment: Development is moving far ahead of planning. Monitoring is low in the peripheries. People have pit latrines in their homes.

Question: What is the ideal toilet technology to adopt? Is it possible to have a simple matrix of the "Qualities of an ideal toilet" as against the "types of toilet technologies in Ghana"

Comment for the selection criteria, Additional criteria, e.g. Socio-cultural practises of the people.

Comment: Discussions should be narrowed to the appropriate technology in Accra and hence come out to a communiqué that shall be the basis for formulation of a policy on toilets in Accra.

Question: How will AMA ensure toilet facilities for all the residents?

2.5 3rd Presentation by Peter Vander Steen (PhD)

The presentation was on the use of Natural systems in Waste water treatment. He started by first giving on overview of the research options through which SWITCH hopes to address IUWM issues in the various cities.

- Methods for IUWM
- Stormwater infiltration / retention
- Wastewater treatment and reuse (SAT/bank filtration)
- Ecosan
- Urban agriculture
- WDM
- Water Sensitive Urban Design
- Natural Systems
- Methods for social inclusion
- New financial/institutional setups

He then gave an overview of Methods of IUWM using a research undertaken by his MSc. Student from IHE (Isabella Lunani) on the Microbial Risk Asessment for Accra's Urban Water System.

He then went on to discuss the following topics:

- Types of Treatment systems
- Types of Natural Systems
- Advantages of Natural Systems
- Disadvantages of Natural Systems
    - Large land area required
    - Odour and mosquito problems (can be overcome by proper design and management)

- Concept of using natural treatment systems for domestic purposes: Treatment

- Lessons Learnt from the UASB Reactor in Accra

He ended the presentation by discussing the vision for IUWM in Accra.

2.6 Discussion on 3rd Presentation

Question: What to do with mosquitoes (How to deal with mosquitoes)?
Response: Mosquito eating fish could be bred in the water or the areas could be sprayed regularly.

Comment: in dealing with mosquitoes, some work has been done by IWMI on urban agriculture and could serve as reference.

Question: what can be done about the ownership of land since large areas are needed.
Response: Decentralisation of treatment plants. Made example of Dutch Hotel

Question: (relating to the Management of Stormwater) How can we incorporate storm water retention and infiltration into our building codes? E.g. Cameroun has a building code that says that buildings should have greens areas around them.

Response: The building codes exist. People bring plans and when they finish building, it is different from what is done. There are not enough building inspectors and this hinders programmes which are required to check and inspect buildings. The Building Code is not very clear on greening concepts. Trees which are safe for residential areas should be identified. These should be well laid out in our building codes which would ensure that . For new areas there should be a task force that will insist on following regulations for building and pavements.

Question: Whether Isabella(IHE Student)'s research on Microbial Risk Assessment for Accra was geo-referenced. i.e. data spatially representative (GIS)

Question: How will the uncertainties in the project be resolved?

Response: The project has not been geo-referenced yet. Uncertainties that are in the project will be filled in by having some students continue the research to fill in the gaps. In this direction, some students are going to be sent to do further studies in the area.

Accra has a greater part already constructed. Natural systems will relate to Lagoons that already exist. But for new areas the ideas of retention ponds can be introduced. Research can consider how the use of retention could be applied in these areas.

Comment from Prof. Mrs. Awuah: Lagoons could be used to treat grey water

Question: has there been research to confirm the pollution of rainfall from Zinc roofing sheets; why have they been allowed if there is pollution?

Response: Previously in Netherlands, there were no building codes for the types of roof materials to be used.

Question: What is being done about the water heaters with Copper?

Response: Some Pipelines have been changed and others are being changed to PVC pipes

Comments: Septic tanks are not being constructed the way they are supposed to be constructed. The first and 2nd chambers are the same size. The chambers are connected and they are at the same level.

Response: Old practises should not be continued. Communiqué should include something on the design of septic tanks. Workshop should be organised for architects and artisans.

We could start in our own small way to correct the construction of septic tanks and move on to our neighbours.

Question: What could be done about refuse in open drains and streams?

Comment: Bins are not available and where they are you would have to walk over a very long distance to get to use them.

Comment: these happen because Laws are not enforced.

2.7 Group Work

The Afternoon session looked into detail at the problems in Accra that we would like to solve and how WP 5.3 can respond to those problems. There was sharing of ideas on the selection of sustainable technologies for waste water treatment. Questions were posed to participants for their responses (shown in Appendix 1). After this, there was a group work using problem tree analysis. This began with defining the problem. It was agreed that the problem to be tackled is Poor Sanitation. The root causes of this problem were examined and are given in figure 1.

The solution tree is given in figure 2. The suggested ways of achieving the proposed solutions for dealing with the problem of poor sanitation are given as follows:

- Adoption of sustainable technologies
- Application of "Polluter Pays Principle" (PPP)
- Enforcement of payment for public sanitation services (with available funds)
- Proper planning
- To address poor planning
    - Regular working meetings AMA-GWCL-EPA
    - Systematic data collection (census, maps/GIS, etc)
- National consideration for waste management as a serious business and allocation of adequate funds towards it.
- Investing money into sanitation and raise money internally
- Creation of public awareness on waste management
- Regular education on good practices

Linkages between the solutions and WP5.3 were drawn. Workpackage 5.3 which is the use of Natural Systems for waste water treatment could respond to the first, which is, finding an appropriate and sustainable technology for waste water treatment in Accra. There will be some MSc students to do some research in this Accra. The LA will link up with the other workpackages to see how they can help to respond to the other issues raised.

Figure 1 Root Causes of Poor Sanitation

Figure 2 Suggested Solutions to Poor Sanitation

Based on the discussions and suggestions for research and demonstration, an action plan was drawn for Accra.

The main action points that were agreed on are as follows:

1. Piloting a demonstration of the use of natural systems using the Kpeshie Lagoon Area. (this will be handled by the SWITCH secretariat with major input from Major Awuah.
2. Documentation Centre to put together literature which will be useful not only to WP 5.3 but also to the main Learning Alliance and other workpackages. (to be handled by the SWITCH Secretariat)
3. Students to do Research. (Already City Co-ordinator is supervising some students in this area. Peter Van der Steen is also expected to bring in 2 MSc. Students and possibly a PhD student to work on this)

3 Evaluation of workshop

At the end of the day, an evaluation was done to find out from participants what they liked or disliked and the key things that they had learnt.

Likes	**Dislikes**
Liked the lively discussions	I disliked the fact that the timing of the programme was not followed at all
The resourcefulness of the process and its interactive nature	The presentations on the white board were not readable
Liked the participatory discussion	The time was short to make a more detailed action plan
SWITCH is making some positive impact	Service at the restaurant inadequate
Good Discussions Information was shared that previously was unknown, even to institutions from Accra/ Ghana	Late start of the programme
The handouts contained	Limited publicity by media on UWM
Open and frank discussions	Too much to do in one day (rushed programme)
Knowledge sharing	Discussion was not adequately focused
Conference spacious	Bad time keeping
Impressed about knowledge on varying toilet technologies	
I have learnt a lot through the exchange and sharing of ideas	

3.1 Lessons Learnt

At the end of the day the participants felt they gained more knowledge in the following areas

- Different toilet technologies
- Participating in discussions
- Water related projects going on in Accra
- The importance of waste water management and its effects on society
- A wider perspective of interventions

4 Conclusion:

At the end of the meeting, it was agreed that there should be a communiqué with the issues raised at the meeting. The issues concerning poor sanitation in Accra were prioritized. The areas which when addressed will lead to an improvement in the sanitation situation in Accra are:

- Finding sustainable technologies for waste water treatment
- Helping to change behavioural attitudes
- Provision of adequate infrastructure for management of sanitation
- enforcement of policy and regulation
- improvement in the service delivery for sanitation

It was agreed that Work Package 5.3 could respond to the problem of poor sanitation in Accra through the selection of appropriate sustainable technologies. It was agreed that there should be a Pilot project using the Kpeshie Lagoon and the Burma camp area for the demonstration of the use of treatment of wastewater using natural systems. It was agreed that there is the need to build the capacity of artisans who construct septic tanks. In this direction, it was suggested that SWITCH WP 5.3 should organise a training programme for artisans in Accra.

Appendix 1:

Questions for review

1. How should we prevent construction of unsustainable technologies?
2. What new sustainable technologies can be incorporated?
3. What strategies should be adopted for the implementation of these sustainable technologies?

Responses to question 1

1. a. To apply a very careful process of technology selection weighing ALL advantages and disadvantages.
   b. Identify risk factors and actions to reduce risks
2. a. By having clear cut policies in place
   b. Extensive education on available technologies stating the advantages and disadvantages
   c. Regular monitoring by the district assemblies and other relevant stakeholders who have the mandate to stop the operation of these technologies.
3. Involve stakeholders in the planning and implementation of the technologies.
4. a. Provide rules and regulations on technologies that are acceptable in any geographical area.
   b. Sanctions on unapproved technologies.
5. a. Providing Insight/knowledge to the authorities that are involved on urban water.
   b. Stimulate propaganda for sustainable technologies.
6. a. Pass a law that makes the construction of the unsustainable technologies illegal.
   b. Educate the public on the unsustainability of the technology in question.
   c. Involve all stakeholders in the campaign against the technology.
   d. Introduce a sustainable alternative
7. a. We need to define unsustainable technologies constitute and define policies to guide the selection of alternatives.
   b. Sustainable technologies should then be readily available, convenient, affordable and socially acceptable.
8. a. Development and enforcement of policies and legislation.
   b. Research and provision of innovations.
9. a. By putting in place a policy that requires house owners institutions and organizations to meet certain specified requirements before they get permit to build.
   b. Monitoring evaluation and stiff sanctions for violators
10. By education and involvement of the people in selecting the appropriate technology.
11. Education, planning, prioritization pf the technology. Involvement of key stakeholders

Responses to question 2

1. a. Advanced and convenient toilet technologies that use no or small amounts of water.
   b. Water and sludge treatment and reuse in urban agriculture. Ecosan 'Urine diversion' toilets for selected areas.
   c. Biogas
2. a. Less water-dependent innovations.
   f. Adapt technologies to locations for use.
3. Adopt new technologies that are: energy saving; less costly to maintain; uses less water; socially/culturally acceptable; easily replaceable and can be transferred easily; integrated system.
4. Adopt technologies that are environmental, sociological and economically accepted. Eg. KVIP at areas where there is no water supply and have a low water table.

5. The new technology which should be adopted is the dry sanitation systems which uses very little water (ecosan).
6. The new sustainable technology can only be done by educating people either man to man which is one on one. Publication of concept in News papers, on Radio and TV stations.
7. a. Technologies using 25% of water used by current systems.
    f. Dry toilet technologies
    g. Technologies which can be lead to composting of toilet for agriculture.
8. Extension of wastewater irrigated areas in Accra together with good knowledge transfer to farmers
9. The new sustainable technology can be dry sanitation systems or ecosan.

Responses to question 3

1. Small scale demonstration projects, followed by scaling it up via the learning alliances.
2. a. Educate the masses
   b. Research into the use
3. a. Formulate appropriate policies and regulations.
   b. Provide guidelines and standards on usage of operation.
   c. Create public awareness
   d. Undertake pilot projects to market technology.
   e. Involve all stakeholders in the process.
    f. Research on specific problem areas.
4. a. Pass legislation on appropriate technologies
   b. Define policies and guidelines on its adoption
   c. Empower regulatory and monitoring institutions through capacity building.
   d. Create public awareness.
   e. Make technology affordable.
5. a. Have a policy in place.
   b. Set up pilot/demonstration projects (to be done by the District Assemblies)
   c. Extensive education on technologies.
6. a. Adoption in policy at city and country level
   b. Adoption in institutional policy.
7. a. Public awareness
   b. Demonstration
   8.
    a. Consultation with the community
    b. Selection of site
    c. Education of community
    d. Stimulate research
    e. Impact assessment

Problem tree: Problem: Poor sanitation

Table 1: Root Causes of Poor Sanitation

Resources	**Sustainable Technology**		**Law enforcement**	**Planning**	**Institutional framework**	**Behavioral Attitudes**
Financial constraints (institutional)	Poor waste management	Lack of disposal sites	Inability of AMA to prosecute people	Shortsightedness on the part of authorities	Inadequate waste management services	Poverty levels preventing people from attaining hygienic environment
Inadequate facilities	Lack of simple waste management technologies		Inability of relevant institutions to enforce regulations	Poor collaboration between institutions in the sector	Poor institutional frame work	Poor hygienic practices
Insufficient institutional capacity			Lack of policy enforcement			Changing patterns of production and consumption (changing lifestyles)
Lack of logistics and incentives for staff						Negative public attitude
Inadequate sanitation infrastructure						Lackadaisical attitude towards sanitation
Lack of funds to improve the sanitation infrastructure						Level of illiteracy
						Poor attitude of the populace
						Low sense of patriotism

APPENDIX 3: PROGRAMME OUTLINE

Programme Outline for One-day Workshop (SWITCH Workpackage 5.3) at Alisa Hotel, Accra.

Date: Friday, 4th April, 2007

Time	Session	Topic / Details	Facilitator/ Resource persons
9:00-10:00	**Registration**	Registration of participants	
10:00-10:15	**Welcome Event**	Introduction of Participants	
10:15 – 10:30	**Introduction**	Overview of Workshop	Prof. Mrs Esi Awuah
10:30-10:45	**Presentation**	Integrated Urban Water Management	Peter
10:45-11:15	**Discussion**	Sustainable Technologies in Integrated Urban Water Management	*Mrs. Sarah Fanny H. Duncan*
11:15-11:30	BREAK with coffee/ tea		
11:30-11:45	**Presentation**	Sanitation Technologies	Prof. Mrs. Esi Awuah
11:45 - 12:15	**Discussion**	Appropriate Technologies for different Suburbs in Accra	*Mrs. Sarah Fanny H. Duncan*
12:15-13:00	**Group Work**	Prioritizing Sanitation Problems in Accra Selecting Sustainable Technologies for Wastewater Treatment	Bertha Darteh (Problem Tree)
13:00 – 13:45	LUNCH		
13:45-14:30	**Group Work**	Reporting Back 1. List of Priority Areas in Sanitation 2. List of Identified Appropriate Sanitation Technologies for Accra	Group Rapporteurs
14:30-14:45	**Reflection/ Closing**		Mrs. Sarah Fanny H. Duncan
14:45 - 15:00	Tea/ coffee		

APPENDIX 4: LIST OF PARTICIPANTS

	Title	NAME	ORGANISATION	POSITION
1	Prof	(Mrs) Esi Awuah	KNUST	Head, Dept. of Civil Eng/ City Coordinator-SWITCH
2	Mr.	Kwasi Attafua	KNUST	NSP
3	Ms	Bertha Darteh	KNUST-SWITCH	Facilitator
4	Dr	Olufunke Cofie	IWMI	
5	Mr	T. O Larbi	IWMI	Senior Resource Officer
6	Mr	Daan Van Rooijen	IWMI	Scientist
7	Mr	Ernest M. Abraham	IWMI	Researcher
8	Mr	Ekow Moses	Channel R	Reporter
9	Ms	Florence Agyei	EPA	Deputy Director
10	Mr	Frank Chinbuah	AMA	Principal Env. Health Tech.
11	Dr	Nelson Obirih - Opareh	STEPRI	Economist/Researcher
12	Mr	S. K. Kpodo		
13	Mr	Samuel Anku	EPA	Director
14	Mrs	Sarah Fanny Hackman Duncan	Accra Polytechnic	Lecturer- Building & Civil eng. Dept.
15	Major	T.N. K Awuah (RTD)	AMA	Head, AMA serage Unit, Project MGR - ASIP
16	Ms	Aisha idetus	Enquirer	
17	Ms	Harijatu Yabah	Top Radio	
18	Ms	Jamilatu Wahab	The Ghanaian voice	

Annex B

Report of the SWITCH Workshop "Natural systems and sustainable stormwater management", December 2008, Lodz, Poland

Report from the SWITCH Workshop

"Natural Systems and Sustainable Stormwater Management"

Participated by presenters and trainers from Poland, Germany, the United Kingdom and the Netherlands

16 December 2008

Educational and Conference Centre of the European Institute, 258/260Piotrkowska Street, Room C 101

The Objective of the Meeting

The objective of the meeting was to present available know-how concerning possibilities of application of natural systems in water resources management in urban areas, including alternative solutions for rainwater management. The following were proposed: a review of BMPs, possibilities of their application, examples of successful applications which launch new trends in the field of sustainable development sector, presentation of financial issues in the field of charges for rainwater, development of integration of the measures, including the context of institutional aspects' impact on the decision-making process, and presentation of examples of natural systems applications.

Opening of the Meeting

The meeting was opened by **Professor Maciej Zalewski** – the Director of the International Institute of the Polish Academy of Sciences – European Regional Centre for Ecohydrology under the auspices of UNESCO and Faculty of Applied Ecology of the University of Łódź Professor delivered a brief presentation entitled "Solutions for Rainwater in the Case of the Sokółowka River Restoration under the SWITCH Project in Łódź".

Włodzimierz Tomaszewski, the Vice-Mayor, who represented the Łódź City Office – a key partner of the University of Łódź under the SWITCH Project – emphasised an urgent need of joint elaboration of methods of rainwater management in Łódź.

Tomasz Kacprzak – Chairman of the Łódź City Council emphasised an important role of the water and environmental aspects in management of Łódź, especially that our city was founded and developed its economic capacity on the basis of the water and environmental resources. The Chairman emphasised the interest of the City Council in the progress achieved in implementation of the SWITCH Project by referring to the presentation by Dr Iwona Wagner during the Council Session in November 2008. He also ensured that the Council supported and declared its broad support to the projects that contributed to sustainable

development of Łódź. He also emphasised the interest in the progress of the SWITCH project expressed by media during the City Council meeting in November.

The Coordinator of the Łódź SWITCH Learning Alliance Group ensured the Chairman that the City Council should be notified of the results of the workshop held on 16 December and invited to closer cooperation under the Learning Alliance Group in order to improve intensity and efficiency of the processes aiming at integrated water and environmental resources management in Łódź, and at development of a strategic integrated water resources management plan for the City. The Plan should ensure implementation of the „Vision 2038 – Łódź Uses Its Water Wisely", which has been identified during a workshop held by the Learning Alliance Group in January 2008. Moreover, on 15 January 2009 a working meeting of the Coordinator of the Learning Alliance Group and the Chairman was held. During that meeting the Chairman indicated the Committee for Environmental Protection and Management and the Committee for the Spatial Planning, Construction, Urban Management and Architecture were competent bodies to participate in direct measures of the Learning Alliance Group. On 22 January 2009, Dr Iwona Wagner and Monika Dzięgielewska-Geitz had a working meeting with Anna Lucińska, the Chairman of the Committee for Environmental Protection and Management who is also a member of the Committee for the Spatial Planning, Construction, Urban Management and Architecture. During the meeting they agreed that as soon as possible, the SWITCH Coordinators in Łódź would have meetings with these Committees in order to develop a method of harmonising all the measures implemented in the field of water and environmental resources, and rainwater and natural systems issues in particular. The SWITCH Coordinators also desire to provide these Committees and Councillors with detailed presentations of alternative solutions aiming at sustainable development, and to inspire them to participate in the next round of training in the field of rainwater, natural systems and strategic planning to be held in 2009.

Presentations about Łódź

The following persons presented directions of the measures related with storm water management delivered in Łódź during the Presentation Part of the meeting:

1) Teresa Woźniak - President of the Łódź Infrastructural Company delivered a presentation entitled: "Technical, Infrastructural and Legal Perspectives for Implementation of Innovative Solutions for Sustainable Rainwater Management in Łódź – the City of Future".

2) Anna Wosik – of the Strategy and Analysis Division of the Łódź City Office "Integrated Water Resources Management in Łódź in the Context of the Łódź Development Plan 2009 – 2015".

Presentations from Germany, the United Kingdom and the Netherlands

Dr Heiko Sieker
1) Emschergenossenschaft: The Emscher River Valley (Germany): "Case Study of the Sustainable Rainwater Management in Emscher Region";
2) "Financial Tools and Mechanisms for Sustainable Rainwater Management".

In his first presentation on the Emscher River Valley Region in Germany (the so-called

„Rainwater Route”), where innovative solutions for rainwater management are implemented, **Dr Heiko Sieker** emphasised that resistance to changes faced on every-day basis was one of a key factors to be considered in the process of innovative solutions' implementation. BMPs are successfully implemented in new investments, however they are difficult to apply in the existing and older structures. Dr Sieker shared a reflection that according to his experience implementation of pilot measures was not enough – implementations should be introduced throughout the catchment area. A potential of disconnection from the rainwater discharge system should be evaluated. A 15/15 Project is implemented in the Emscher River Valley Region, whose objective is to reach the level of 15% disconnections from the rainwater discharge system within the deadline of 15 years.

In his second presentation on financial tools and mechanisms for sustainable management of rainwater, Dr Heiko Sieker re-emphasised that counteracting resistance to a change from a routine and traditional approach to problem solving to an approach favourable for sustainable development was one of the most difficult issues when introducing innovative solutions. Dr Sieker compared BMPs to traditional restoration-related solutions referred to as the „end-of-pipe treatment". Application of the Sustainable Drainage Systems – SUDs is delivered through such measures as drainage by green roofs, infiltration, local retention, collection and re-use of rainwater. In order to identify the optimum solution for the city, Dr Sieker proposed a „decision matrix", which facilitates comparison of the approaches to select the most appropriate and compatible one with the sustainable development principles, and feasible for maintenance of a site, city, etc. The Decision Matrices are widely used by such institutions as German consumers magazines in order to carry out economic and quality-based comparisons of products and solutions in the context of the existing and envisaged needs and opportunities. Dr Sieker presented examples of support tools, such as „sustainability indicators" and the „STORM" model, which is a hydrological rainfall-runoff model, and which allows to model storm events in municipal catchments. STORM model is available free of charge. Dr Sieker emphasised that the Ecological Rainwater Management in Emscher Region is a „Net Present Value" approach.

3) Professor Mike Revitt, University of Middlesex (the United Kingdom): "BMPs – Examples of Best Implementations for Sustainable Rainwater Management in the Context of Possibilities of Their Application in Łódź."

Professor Mike Revitt of the University of Middlesex presented various examples of the BPMs' applications and interactive SWITCH tools SW BMP DSS, BMP Assessment Component – Multi-Criteria Comparator, Potential Areas Tool and Site-by-site Assessment Tool. The BMPs' application should be included in spatial and economic planning. Legal and social aspects of the urban management directions, and technical, operational and maintenance aspects should also be considered.

In his presentation Professor Revitt emphasised the difference in the following approaches to rainwater management:

a. traditional – focused on flood control and risks to human life,
b. innovative – focused on sustainable development, which includes climate changes, rapid urban development processes, infiltration, water retention in the ecosystem, SUDs and the so called water-sensitive urban design.

In his presentation, Professor demonstrated numerous examples of structural and non-structural BMPs applications. He recommended the participants to visit the following site http://daywater.in2p3.fr/EN/, which includes BMP-related information.

4) Jochen Eckhart – SWITCH Hamburg (Germany): "Planning Solutions for Rainwater in Urban Space and Presentation of the Design Guide, Including the Solutions for Water Management"

Jochen Eckhart of Hafen Universitaet in Hamburg is a SWITCH Learning Alliance Group Coordinator in Hamburg, and he presented an approach to spatial planning, including water as a predominant factor. Spatial planning, including this component, is also a process based on a broad interdisciplinary cooperation. The local water balance has become a catalyst for interdisciplinary communication. An issue of achieving a maximum retention of rainwater retention and management of heavy rainfall will potentially become a new platform for exchanging opinions and ideas concerning urban development. Water-related „problems" are likely to become development „opportunities". Solutions developed by designers should be as simple, economical and environment friendly as possible. H+N+S Landschaftsarchitekten in Hamburg is an example of an architectural design office, which applies environmental and social synergies, multi-purpose use of sites, and solutions for rainwater control and tools. Integrated approach to environment – geology, topography, surface water, landscape and architecture – all these elements are considered by landscape architects with an aim of achieving the best aesthetic and environmental effect – attractive spatial structures, optimized correlations of the elements of the rainwater management, cooperation, environmental changes, topography – reduction of tectonic movements to minimum, overcoming such barriers as streets, elevations, altitude differences: all the factors should be considered in an integrated manner in order to deploy as low effort as possible while achieving as beneficial results as possible. Use of energy, building materials, space, substances that pollute environment and „nutrients" should be also taken into consideration. Various spatial platforms – planning for the city as a whole, planning of selected sites and „single measures".

5) Hans van Bruggen – UNESCO-IHE (Delft, the Netherlands): "Summary: Perspective of Application of Natural Systems in Water Management in Łódź"

Following the presentations on the rainwater, **Hans van Bruggen** of UNESCO-IHE presented an overview of the perspectives of benefitting from the natural systems in water resources management, including the case studies of the residential districts of „Drielanden", „Sneek" and „Culemborg Lanxmeer in the Netherlands. The residents segregate communal waste water, the so-called „black water" and „grey water". The grey water is re-used for such purpose as toilet flushing or garden watering. Services for the „Sneek" residential district are rendered with an aid of a decentralised water system, to which 35 households are connected. They use local UASB purification systems, which are kept in garages and are equipped with vacuum toilet with 1 litre flushing capacity. Nitrogen and phosphorus are re-used in the system. Currently a project of connecting 200 households is implemented, which is economically profitable. The „Culemborg Lanxmeer" residential district has functioned for 10 years and is an example of a community which functions in accordance with the principles of sustainable development in the context of construction („green buildings" with closed cycles of matter and energy circulation) and the community living formula. The basic principles of construction used in this district benefit from the natural conditions of the site, an optimum connection between the elements of landscape and architecture, integration of integrated water resources management and energy supply, design of green zones and creating conditions for the residents to undertake their own initiatives and participate in the process of design and management. The district covers the area of 24 hectares. It holds 250 houses and apartments, and partly a small industrial area. 42,000 m2 are occupied by offices, which combine business and housing functions, there are also community farms for elderly farmers,

a municipal organic farm which produces organic food, hotel, water supply area and archaeological research site. The energy-saving solutions applied in the design of the district assume: the maximum energy use of up to 40 GJ per house (15 GJ for heating and hot water and 25 GJ for electricity), no mechanical cooling, use of the water from the household as a heating and cooling source, sound use of energy, use of sustainable/renewable energy sources (such as wind and solar power) and sound use of these energy sources. As regards water solutions – water obtained from green roofs is collected in 5 retention reservoirs; the green roofs reduce rainwater supply for retention reservoirs, and rainwater from the streets is disposed of to specifically constructed landscape elements (the so-called wadis) and infiltrates in the ground waters. Sewage is segregated into grey water, black water and water from the household. Grey water from the laundry, bathroom and kitchen is disposed in a specifically constructed „wetland". One wetland is next to school for educational purposes.
Each house has two systems which supply drinking water and household water, and three systems which carry off rainwater, and grey and black water. 4-litre water saving toilets are used. They are equipped with a „booster" with a water-saving shower head, which services several houses. Sewage from toilets will soon be used for installations. Currently it is disposed of to sewage treatment and purification system. Biogas reactor will be powered by organic waste (vegetables, fruit and waste from the gardens). The houses in the district presented are mainly made of timber. The area is characterised by hard surface that has been reduced to minimum, pvc re-cycled piping. The street lighting has been reduced to orientation lighting and energy-saving lights. The fence is made of natural materials.

Conclusions:

The following issues – in general - were raised in the discussion relating the presented material and prospects for application to the context of Łódź:

1) The mindset of the city's stakeholders, with the focus on the decision-makers and the inhabitants, for the application of policy such as the one used in the Emscher region, the BMPs in stormwater management, and the Natura System seolutions in Integrated Urban Water Management.

The LA agreed that there is a need for development a plan and implementation of the sustainable solutions presented on the workshops in Lodz. Both the BMPs in stormwater management and the Natural Systems met a great interest. There is a need to work further on capacity building and integration of efforts within the stakeholders group to assure success of the activities undertaken towards these goals. There is also a need to make sure that there is enough of research evidence for the alternative solutions are in accordance with the health standards, and recognized the possibilities of introducing of the the alternative solutions into the local/national legislation. Steps need to be taken towards building awareness and policy adjustment.

2) Availability of data for the application of the "decision matrix" that to support the application of BMPs;

The problem of data availability has been arising several times, since the beginning of the SWITCH project implementation. The access to some of the crucial information (GIS, maps, aerial photos) seems to be still difficult, the SWITCH Lodz co-coordinators declared to took additional actions to assure the access, including rising additional funds, if necessary.

3) Possibilities of the merging the alternative technologies and tools with the traditional ones for the "inclusive" and step-by-step shift, which would support current technologies providers with the change of their products.
The undertaken actions need to take into account financial aspects, long time of replacement of the existing (in particular new) infrastructure, and implementation of the new adaptations. There is a need to make sure, that all the decision makers are aware of the alternatives and are working together towards implementation of the common vision, to assure complementarities of undertaken actions (e.g., road infrastructure and stormwater management; sewage system development and Natural System technologies for decentralised water treatment; possibilities of introducing water harvesting and augmentation in new developments and introducing them within a local legislation).

The participants expressed interest in taking part with the follow-up training workshops, to be organized separately for the:

1) stormwater management, including executive training for specialists on use of software and tools on design, financial aspects and decision making. A one-day workshop – led by Heiko Sieker, is planned to be held on 26th March 2009
2) Natural systems – a two day workshop and a day od site visit to be led by Hans van Bruggen (mid 2009).

Draft Plan of action for Natural Systems implementation

The following actions are to be undertaken to assure capacity building and integration of actions towards implementation of the Natural Systems solutions in Lodz:

1) Integration of the Natural System solutions within existing and developed plans for the water management in Lodz (e.g., materplan for the city water resources; Strategic Planning for the City of Lodz);
2) Inform the City Council and the President of the City about the outcome of the Workshop; presentation of the workshop materials (presentation and report) on the CC

meeting; Identification of the commissions of the CC, representatives o the Departments of the City of Lodz Office and scientists to be involved in the brainstorming meeting on further implementation;

3) Get information from the LA members about how to improve the decision making process in the City, including development of appropriate legislation;
4) Organize a brainstorming meetings on the Natural Systems implementation (including rivers restoration and stormwater) in the context of the Vision Lodz 2028, developed by the LA within the SWITCH project;
5) Preparation of informative booklets on BMPs in stormwater and Natural Systems to be distributed in District City of Lodz Offices;

Annex 1: List of the Workshop Participants
Annex 2: List of Participants interested in the follow-up Stormwater Training planned for 26th March 2009

Report from the SWITCH Workshop Annex 1
”Natural Systems and Sustainable Stormwater Management”

Participated by presenters and trainers from Poland, Germany, the United Kingdom and the Netherlands

16 December 2008

Educational and Conference Centre of the European Institute, 258/260Piotrkowska Street, Room C 101

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Report from the SWITCH Workshop Annex 2
"Natural Systems and Sustainable Stormwater Management"

Participated by presenters and trainers from Poland, Germany, the United Kingdom and the Netherlands

16 December 2008

Educational and Conference Centre of the European Institute, 258/260Piotrkowska Street, Room C 101

Participants Interested in Taking Part in the Follow-up Stormwater Training (26th March 2009)

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Annex C

Report on the "Application of natural systems for wastewater pollution control in the expansion area of Cali"

Table of content

INTRODUCTION

This report is based on the internship of Mr. Andrea Gaviano during his stay at CINARA Institute of Universidad del Valle, Cali, Colombia.

The internship, that lasted 4 months, was about the application of natural systems on wastewater pollution control in the expansion area of Cali.

Mr. Gaviano has been involved into the SWITCH project (Sustainable Water Management Improves Tomorrow's Cities Health) financed by the European Union, in which Cali is a Demonstration City.

Into the SWITCH, CINARA and UNESCO-IHE Institute for Water Education of Delft, The Netherlands, cooperate intensely. Mr. Gaviano started his internship at UNESCO-IHE working on modeling of constructed wetlands and carrying out a lab work on heavy metal removal with duckweed plants.

The purpose of the internship at CINARA is to continue his work on natural system treatments, investigating the possibility to apply them in the expansion area of the city of Cali. To do this has been necessary to perform before the area recognition, the review of the natural system technological options and investigate their application in the study area, the preliminary analysis of the strategies for the pollution control in the expansion area.

In parallel with these activities other specific activities have been carried out as: meetings with SWITCH and Univalle work groups; meetings with institutions and members of the learning alliance; field activity in the water quality monitoring plan of Río Cauca; visit the water infrastructure of the city of Cali.

CHAPTER 1

SWITCH Project documentation review

PROJECT DESCRIPTION

Project description

SWICHT project is an EU-FP6 project financed by the European Union and it is focused on the change of the paradigm in water management in a sustainable development view. SWITCH project works in urban areas using the concept of the “city of the future”, in this view the project includes 13 Demonstration City in all the world where the different stakeholders participate in Learning Alliances.

The project is coordinated by UNESCO-IHE of Delft, The Netherlands; 33 institutions of Europe, Africa, Asia and Latin America are involved into the project.

Paradigm shift

The objective of SWITCH project is the paradigm shift in water management in urban areas. Sustainability and efficiency are the main concepts at the base of the integrated vision of SWITCH.

Several strategies are defined for pollution control in the urban water cycle, concerning: housing, industry, supply system, collection and transportation of wastewater, solid waste management and water basin.

The first strategy that can be used is the efficient water use; for instance with low consumption devices, using grey water and rain water. At industrial level, cleaner production, technological restructuring, process optimization, recycling and water re-circulation play an important role in the paradigm shift. At household and industry level, alternative sources of water supply like storm water, minimize the water demand and decrease the rainfall water disposal.

Strategies proposed by SWITCH project bring to the shift from the city of today to the city of tomorrow. This shift covers all fields of water management: organizational structure, drinking water, wastewater, rainwater.

Several entities for different types of water become, in the city of tomorrow, one entity for *water* in all the urban area. In this vision is taken into account that different types of water are part of the same cycle.

In the city of tomorrow water has different quality depending on the use, specially one quality for drinking and second quality for other uses.

About wastewater the trend in the city of tomorrow is to accept clean wastewater and to treat them with a reuse/recovery point of view.
In the rainfall approach the main idea is to use as good as possible this resource, opposite to the current tendency to remove as quickly as possible rain water.

THE CITY OF SANTIAGO DE CALI

Municipality

The city of Cali is located in the south-west of Colombia in a region named Valle del Cauca, a valley in the Andes (see Figure 1.1). Cali is the 3rd city of Colombia with 2,075,380 inhabitants and 560.3 km^2 of municipal area. The urban area has elevations above the sea level between 958 m and 1200 m, temperatures between 20 °C and 30 °C, precipitations are around 1000 mm/year. In the mountainous area elevation are between 2800 – 4000 m, temperatures 10 – 16 °C and precipitations 1300 – 3000 mm/year. Between the urban area and the mountainous one there are also a rural area and a protected green area.
Cali has seven rivers in its municipality area: Cauca River, Pance, Melénedz, Lili, Cañaveralejo, Cali, Aguacatal.

Figure 1.1 (a) Cali localization

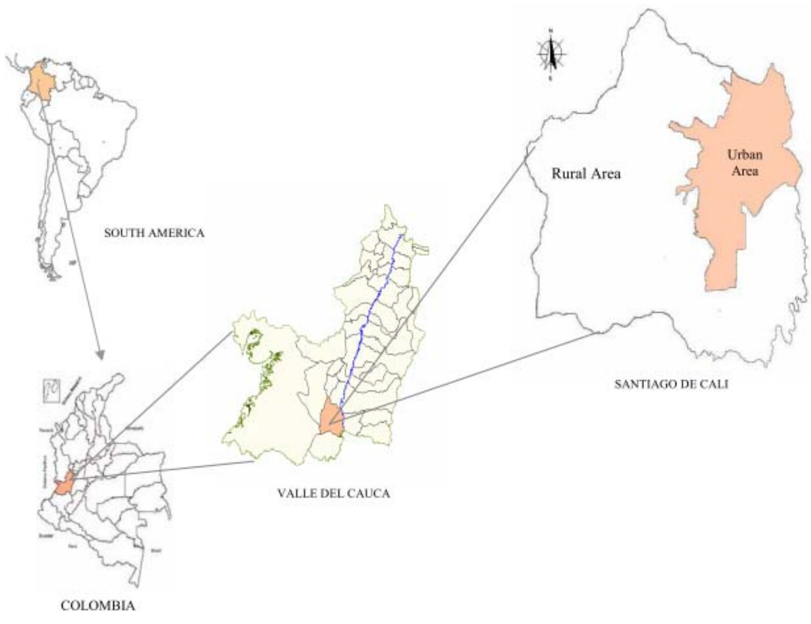
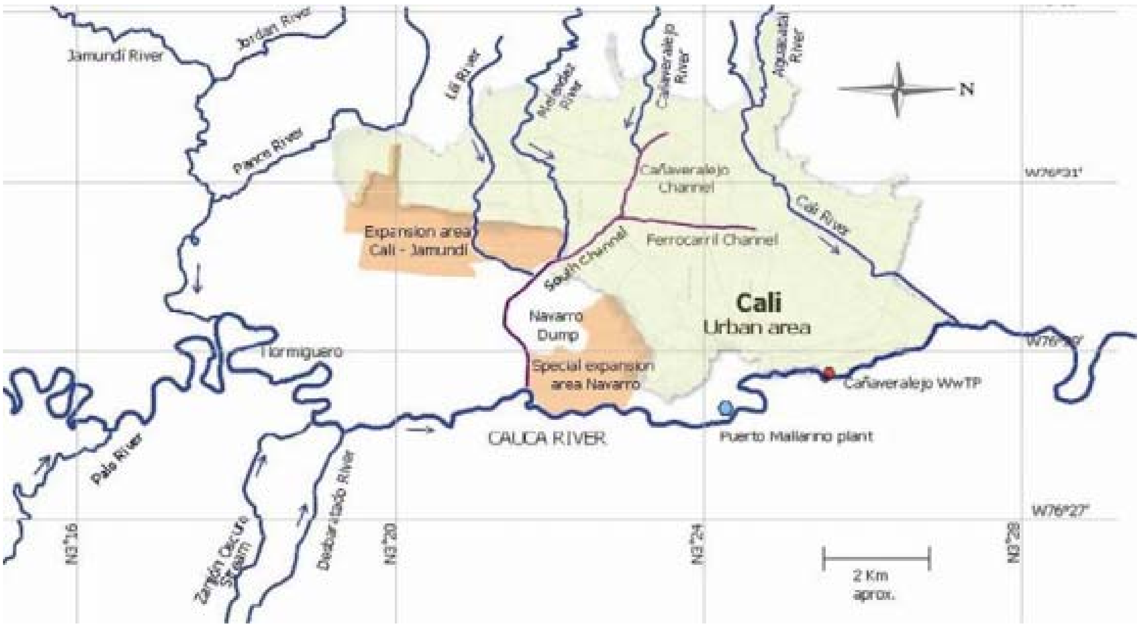


Figure 1.1 (b) Cali localization



Sewage system

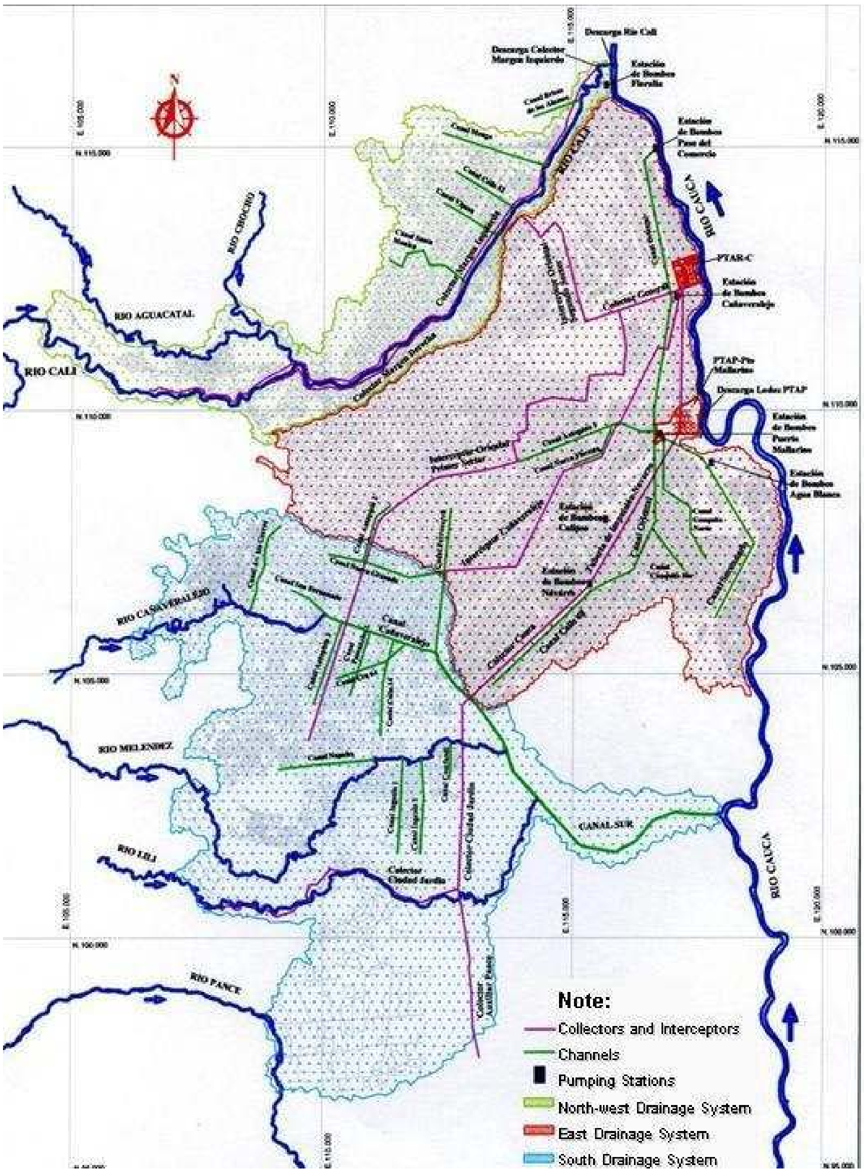
The sewage system in Cali is formed by: sanitary and combined sewers (2099 km combined network and 733 km sanitary network), storm water sewers (8872 km), regulation system (2 lagoons and the Cañaveralejo dam), drainage systems (South Drainage System, North-West Drainage System, Eastern Drainage System).

The sewage system is controlled by EMCALI that is the company responsible for the delivery of water supply, sewage and energy services in the municipality of Cali.

All the drainage systems have similar environmental problems, like the presence of wastewater in storm water channels, clogging of channels due to an inadequate disposal of solid waste, excessive sediments in the channels, presence of toxic substance due to industrial wastewater that is discharged directly in the sewage system of the city.

Is possible to divide the city in three sectors: Sector 1 (the Eastern and North-Western drainage systems) in which wastewater are drained towards the WwTP-C; Sector 2 (South-Western drainage system) in which wastewater and storm water are drained to the Cauca River; Sector 3 (expansion zone south) in which is possible to implement the new concepts of sustainable use of water of the SWITCH philosophy.

Figure 1.2 Drainage system of Cali



Wastewater Treatment Plant

The plant of Cañaveralejo (WwTP-C) is the only one in the city and is designed to treat the 80% of the wastewater flood with a projection until year 2015. WwTP-C can work as conventional primary treatment with a simple sedimentation or as advanced primary treatment (TPA), adding ferric chloride as a coagulant and organic polymer to enhance flocculation.

Has been possible to visit the plant with a field trip. In succession there is a description of the plant from the field trip.

The plant of Cañaveralejo starts the activities in December 2001 and is the biggest of the three wastewater treatment plant in Colombia. Currently the plant is receiving the 85% of the wastewater of the city of Cali. The plant is planned for an influent flow of 7.6 m^3/s for the year 2015.
In 2006 the annual average flow influent was 3.82 m^3/s with a concentration of 195.8 mgTTS/l and 228 mgBOD/l in the influent and of 65.5 mgTSS/l and 144.4 mgBOD/l in the effluent. So removal percentages were: 66.5% for TTS and 36.6% for BOD (EMCALI, 2006).

The sewer entering in the plant is a combined sewer with a diameter of 2 m. Ahead to the plant is present a pumping station to allow the functioning for gravity inside the plant.
The plant is form by the pre-treatment section, primary treatment section, sludge treatment section, power station and gas treatment section.

The pre-treatment section is form by two sub-sections: riddling and de-sanding. In the riddling the distance between the bars is of 2 cm, but is planned to reduce at 10 mm. The desanding process happen with aeration in order to create helicoidal trajectory of the particles to improve the removal efficiency. Moreover the aerated desanding channels are also utilized to mix chemicals reagent used in the primary treatment.
In this part of the plant there is the maximum production of H_2S because of the anaerobic conditions in the sewage system; this is caused by the long time that wastewater need to arrive to the treatment plant due to the plan topography of the city. H_2S is evacuated by extractors to the gas treatment section.

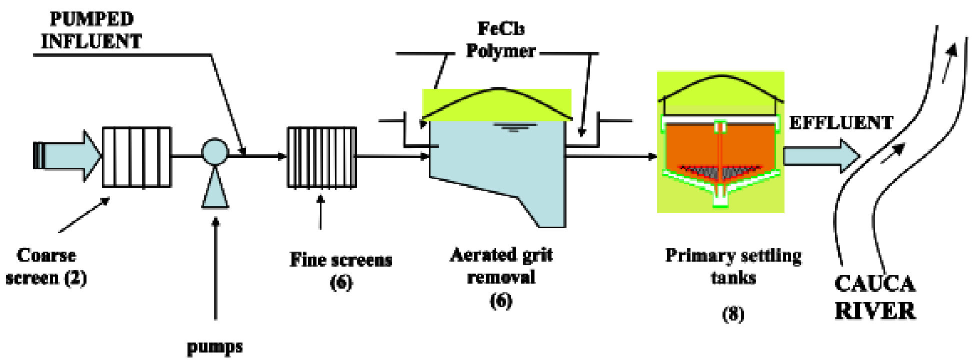
The primary treatment can work in two ways: as a conventional sedimentation or as an advanced sedimentation by adding $FeCl_3$ and polymers with coagulant and coadjutant effects respectively. The discriminate factor to use the two approaches is the dilution of the wastewater. In fact when there is a big precipitation arrive to the plant a dilute wastewater and the effect of reagents is smallest.
The HRT in the primary treatment is of 1.5 – 2 hours.
Removals of BOD and TSS with the conventional sedimentation are respectively 25-30% and 50%; adding chemicals reagent removals increase: BOD 42-45% and TSS 63-65%.
Moreover $FeCl_3$ help to control Phosphorus in wastewater.

In the primary treatment there is the production of a sludge that is treated in the sludge treatment section.

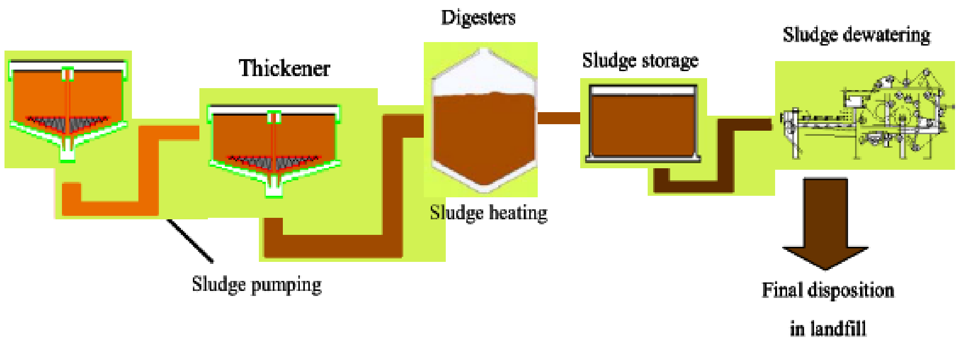
Sludge treatment section is form by anaerobic digesters and sludge thickeners, see Figure 1.3b.

Figure 1.3

(a) Water line scheme



(b) Sludge line scheme



Digestion of the sludge happened in mesophilic condition at a temperature of about 35°C. Cooling water is used to heat the digesters. Stabilization of the sludge needs 20 days. The production of sludge is of 120 Ton/d with humidity of 70%.

In the sludge thickeners is used a polymer for the coagulation of the particles and a porous cell to produce the filter-cake. There is also an alkaline treatment of the filter cake to increase the pH in order to reduce the pathogens.

The sludge produced by the plant is classified as a Class B by the EPA regulation, so it can be used in farming with some restriction.

During the digestion is produced a big quantity of bio-gas with 70% of methane. Biogas is used to produce energy in the power station. The production of energy is of 700-800 kW*h that cover the energy demand of the plant.

All the plant is automatically controlled by 5 Programmable Logic Controllers (PLC) for each section of the plant. From a control room is possible to control the state of all the plant.

To treat the H_2S a soil bed filter is used. It is constituted by a bed of stones, gravel, sand and humus; the last one is the substrate for the microorganisms that remove the H_2S.

In the plant is present an experimental plant to test a secondary treatment. The investigation is about a scheme of treatment with a pre-treatment of the wastewater and an activated sludge section, this experimental scheme excludes the primary sedimentation.

Proposal of wastewater pollution control strategies by institutions

Each of the three sectors of the city of Cali has proposals for wastewater management proposed by institution as EMCALI and Hidroccidente S.A.

In the Sector 1 is proposed the implementation of the WwTP-C. The study is oriented on conventional solutions as activated sludge system (suspended and attached growth solutions) and reuse of the effluent for agricultural purposes. The proposal are based on lab-scale studies.

In the Sector 2 the proposal is about the drainage system of the South channel, anaerobic pond, constructed wetlands, polishing ponds, irrigations of crops.

In the Sector 3, expansion area of Cali-Jamundí and of Navarro, there are several proposals about drinking water supply, the sewerage system, wastewater treatment. They include different sceneries about the water management that will be deepening in the next part of the report.

DEVELOPED STUDIES

Public services proposals in the South expansion zone

The alternative proposals for delivery of water supply, sewage system and water treatment in the expansion zone of Cali-Jamundí, proposed by institutions outside the SWITCH project, will be now discussed.

The expansion area has a surface of 1652.85 ha. The zone is now used primarily with agricultural purpose and moreover educational, commercial, recreational, residential activities are present. Where are present these activities, exist already sewage and water supply systems.

Are present 15 partial plans about the urbanization of the expansion zone, but only 3 have been approved by the municipality.

As in the rest of the city, the urbanization in the expansion area follows the rules of social stratification. So is planed to receive in the area social strata 3, 4, 5 and 6 (strata are increasing with the well-being, so stratum 6 is the richest).

Social strata have different water demand, so water supply for the different strata respectively is: 200, 220, 250 and 340 l/inh*d.

Also the planned population density varies with the stratum, in this case is decreasing with the increasing of the stratum, respectively: 390, 310, 250 and 150 inh/ha. These values are the gross values and don't consider losing of water in pipes.

In the follow table data about EMCALI estimation are resumed.

Table 1.1 Resume of the planned situation in the expansion area Cali-Jamundí

Stratum	Density Inh/Ha	Water Supply l/inh*d	Area Ha	Water demand l/s
3	390	200	305	275
4	310	220	528	417
5	250	250	490	354
6	150	340	35	21
TOTAL				**1067**

Source EMCALI, 2006

The proposals for the water management in the expansion area concern water supply systems, sewage system and wastewater treatment.

Densities estimated by EMCALI produce a total population in year 2030 of 450.880 inhabitants.

Anyway estimation about population density is not correspondig to the actual trend. In chapter 3 is presented the evaluation of the population used for the natural system design.

Water supply alternatives

The total water demand is of 1067 l/s. There are 5 alternatives to distribute this flow in the expansion area.

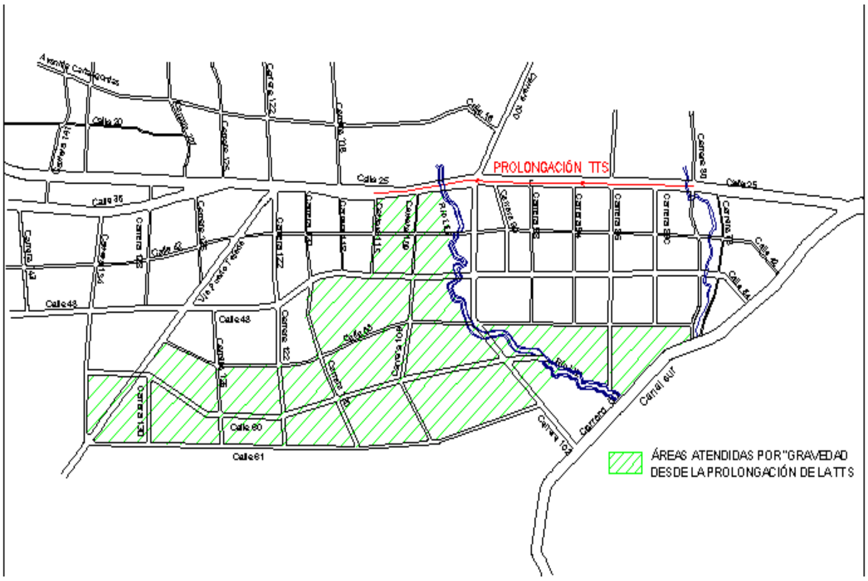
Alternative 1

The first alternative is about the prolongation of the Oriental transmission pipe TTO to supply 510 l/s and a new transmission pipe TTNV until Navarro area to supply the resting 557 l/s.

Advantages: immediate possibility to supply water in the zone of expansion area with more urgency.

Disadvantages: is not considered a big zone of the expansion area in water supply, the new transmission pipe is expensive and requires a long time to be constructed.

Figure 1.4 Scheme of the water supply alternative 1



<u>Alternative 2</u>

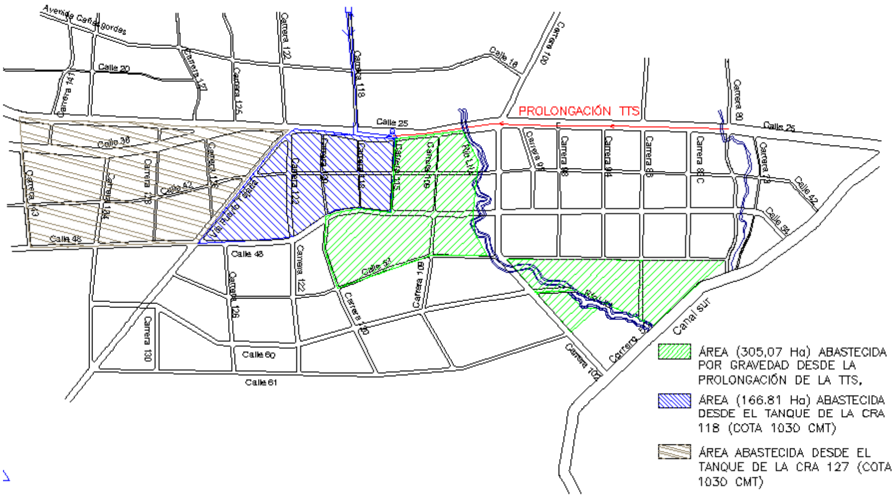
There is the prolongation of the TTO but with a lower flow (207 l/s); the resting flow of 303 l/s is supply by two tanks, pumping water from a new pumping station in order to cover a bigger zone.

The new transmission pipe TTNV with 557 l/s is however necessary to supply the total demand of 1067 l/s.

Advantages: immediate possibility to supply water in the zone of expansion area with more urgency; with the pumping is possible to supply water to the zone of stratus 5 that has more expectation of urbanization.

Disadvantages: construction of the pumping station and tanks can be quite long and can be limit the service in Pance; the new transmission pipe is expensive and requires a long time to be constructed.

Figure 1.5 Scheme of the water supply alternative 2

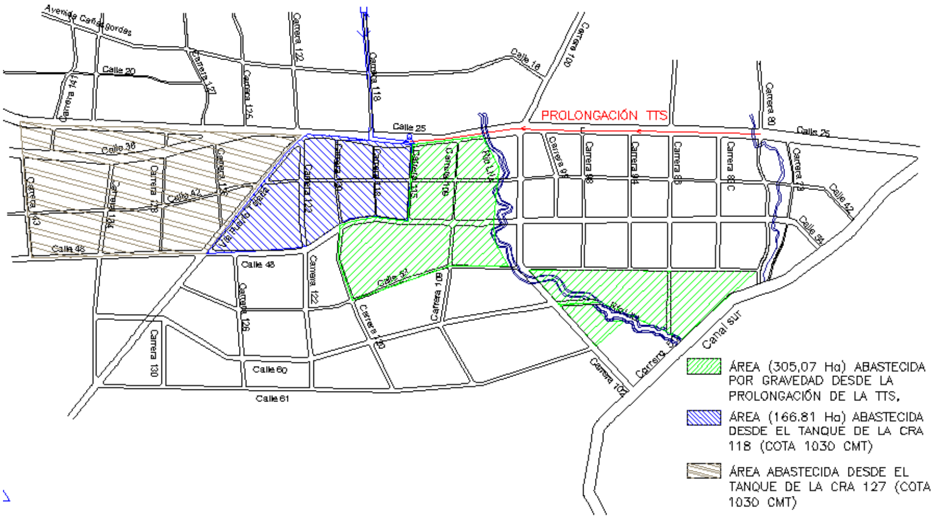


Alternative 3

The third alternative is very similar to the second one, with the difference that the new transportation pipe arrive until Pance (TTP)

Advantage end *Disadvantages* are similar to Alternative 2.

Figure 1.6 Scheme of the water supply alternative 3



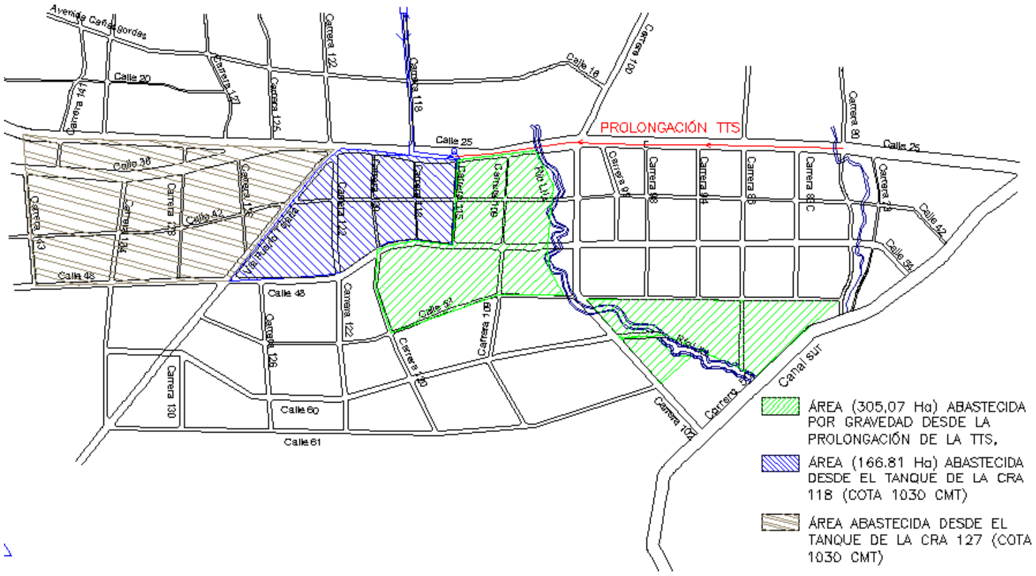
Alternative 4

In this alternative the difference with the second one is that the resting 557 l/s are coming by gravity from a new drinking water plant in the zone of Pance Alto.

Advantage: is supplied the more important zone of the expansion area; half part of the zone is supplied by gravity, future feed of the new drinking water plant with other connections, decreasing of pumping costs.

Disadvantages: planning and construction can last 5 -7 years.

Figure 1.7 Scheme of the water supply alternative 4



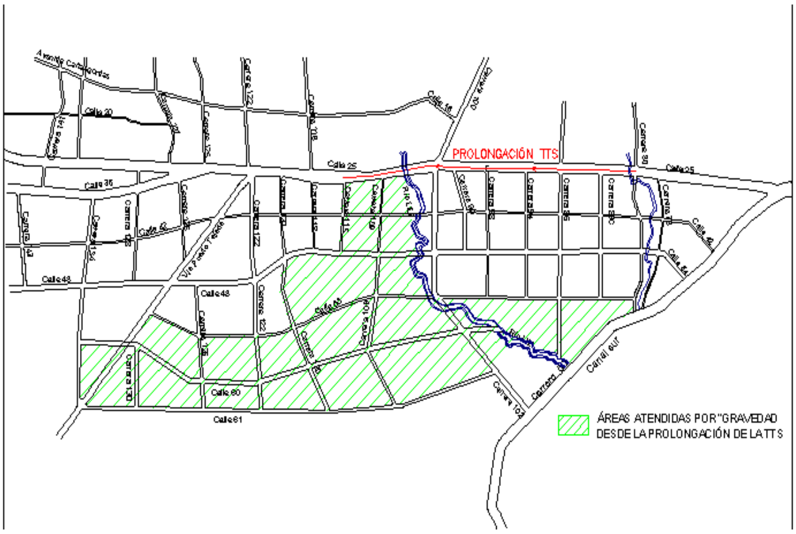
<u>Alternative 5</u>

Supply half part of the expansion area with the pipe TTO or TTS and he resting amount from La Reforma plant after the construction of a regulating reservoir in the Río Cali.

Advantage: is supplied the more important zone of the expansion area, supply all the area by gravity, operational and maintenance costs are lower than pumping costs.

Disadvantages: long time to construct and elevate initial costs.

Figure 1.8 Scheme of the water supply alternative 5



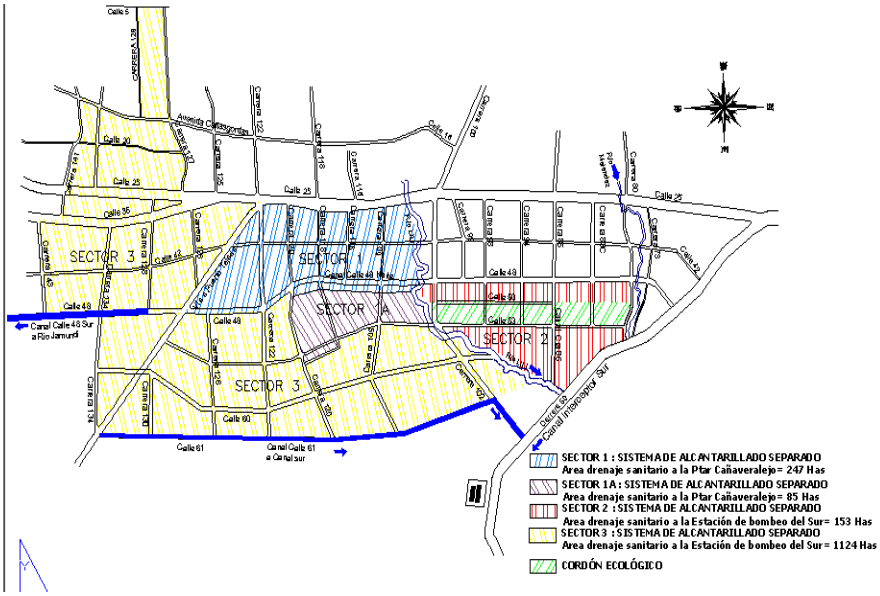
Sewage system

<u>Alternative 1</u>

The first alternative concerns the implementation of a separate sewage system in the entire expansion zone.

With this alternative there is a big accumulation of storm water with consequent big diameters of the sewer and in depth.

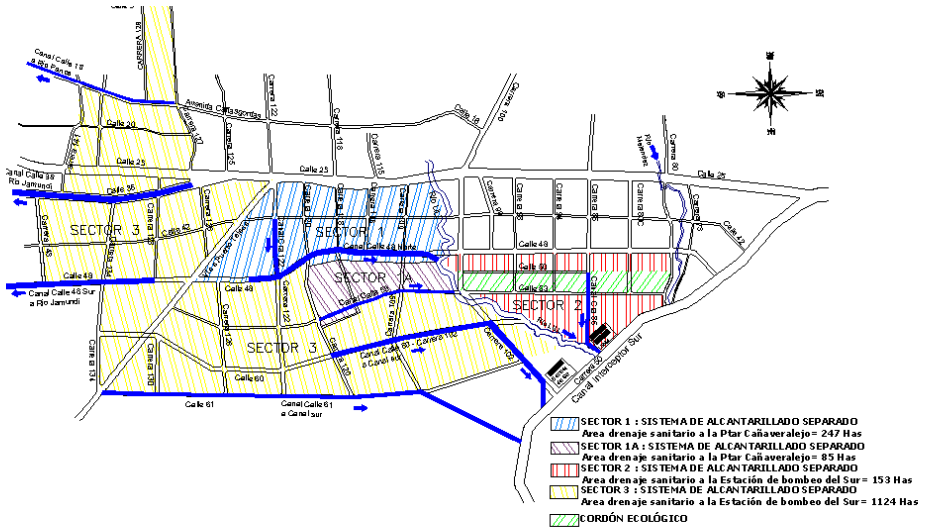
Figure 1.9 Scheme of the sewer system alternative 1



<u>Alternative 2</u>

Also in this alternative is adopted a separate sewage system, but the removing of storm water happened with a more dense sewage system.

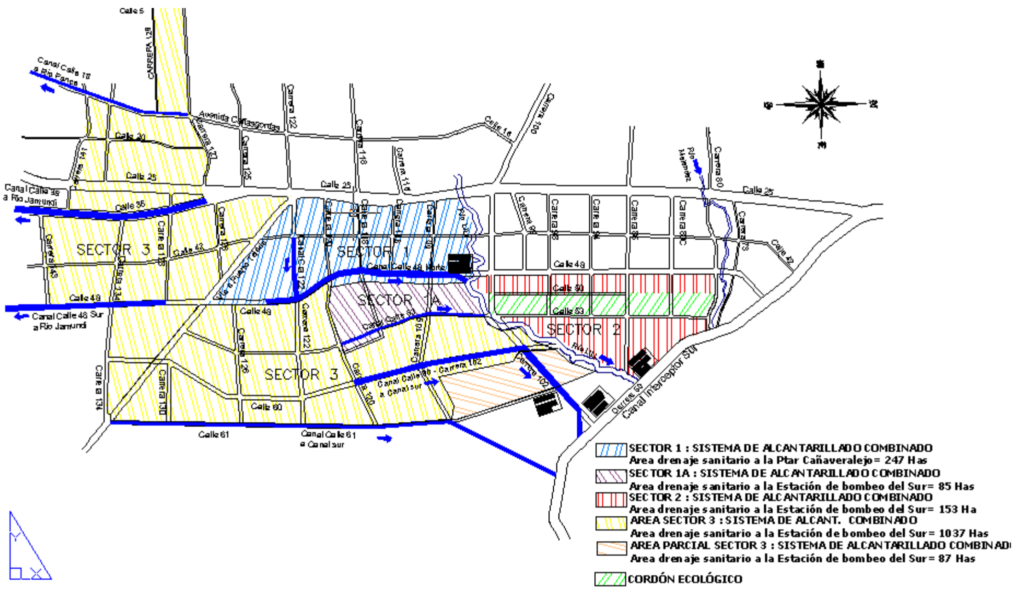
Figure 1.10 Scheme of the sewer system alternative 2



Alternative 3

In the third alternative is presented a combined sewage system; this system has the same conception of the second alternative

Figure 1.11 Scheme of the sewer system alternative 3



Alternative 4 - 5

This alternative takes into account the possibility to combine the solutions with combined and separate sewers.

Figure 1.12 Scheme of the sewer system alternative 4

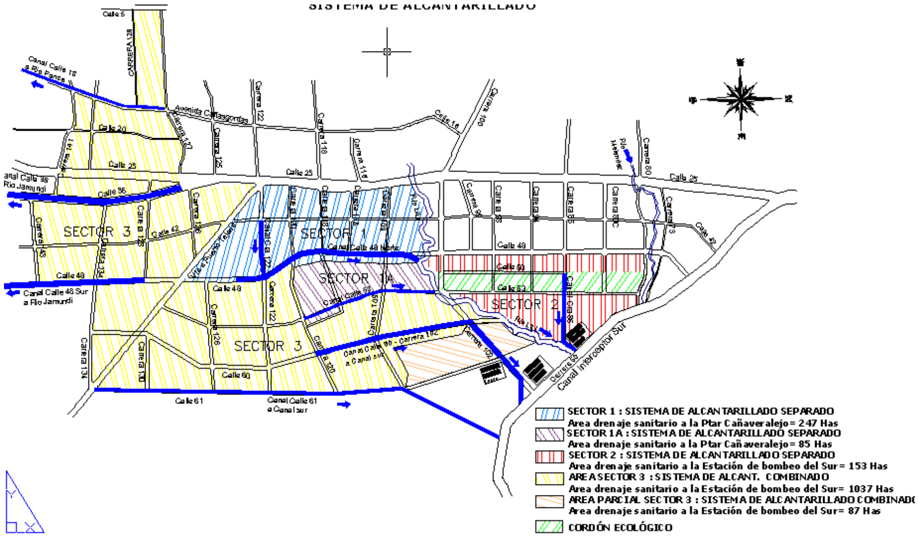
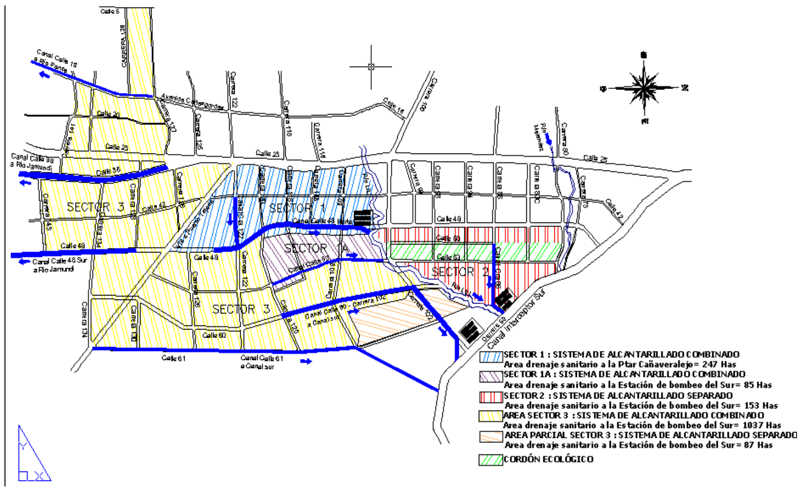


Figure 1.13 Scheme of the sewer system alternative 5



Wastewater treatment

Four alternatives have been proposed for wastewater of the expansion zone of Cali-Jamundí.

Alternative 1

In this alternative is proposed to pump all the wastewater of the expansion area to the existing treatment plant of Cañaveralejo. This alternative takes into account to use at the most the existing infrastructure, as the Cauca sewer, the pumping station of Navarro (that pump wastewater to the wastewater treatment lant of Cañaveralejo) y the WwTP – C. A new pumping station to pump wastewater until the pumping station of Navarro is necessary.

Alternative 2

The second alternative takes into account the construction of a new wastewater treatment plant operating with activated sludge.

Alternative 3 - 4

These are two proposals about a UASB process plus activated sludge (in the third alternative) and plus aerated ponds.

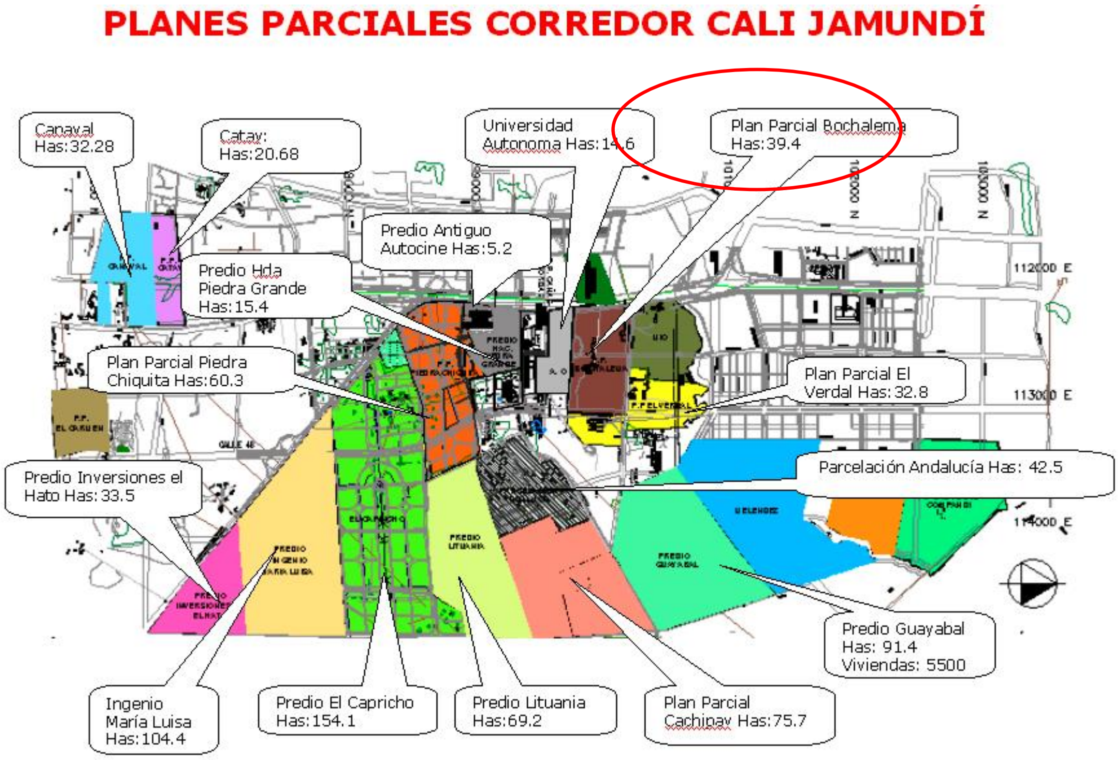
These two alternatives are not token into consideration by EMCALI for the reason that are not sufficiently tested technologies.

PARTIAL PLANES IN THE EXPANSION AREA

Bochalema partial plan

This is a plan produced by San Buenaventura University of Cali. Bochalema is ubicated in the West part of the expansion zone, as showed in Figure 1.14.

Figure 1.14 Partial plans in the expansion area of Cali-Jamundí



The main objective of the partial plan of Bochalema is oriented to the solution of household for strata 4 and 5, with a maximum projection of 4230 households; moreover commercial activities are planned to improve this proposal. The zone has been divided in sub-areas each one with particular uses (areas for complementary mixed activity, household, public spaces).

Bochalema is planned to be complementary in the tertiary contest of the city of Cali, the South Sector and near municipalities. The purpose is to develop an urban design integrated in the context around. However the objective is to integrate the town planning in the environmental conditions of the zone and to produce a partial plan in harmony with the developing of the urbanization of the area.

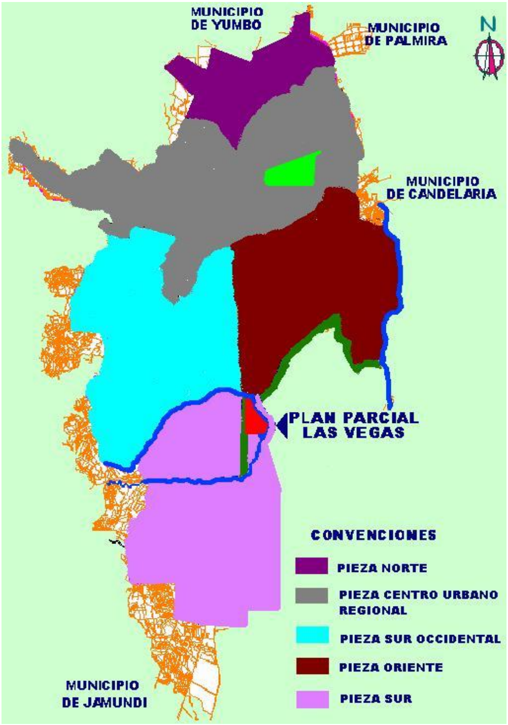
Las Vegas partial plan

Las Vegas is located in the north of the expansion area of Cali-Jamundí and has an area of 62.72 Ha (see Figure 1.15). The purpose of this partial plan is to create a solution of "vivienda" (household) and human settlement. The main idea is to contain the quantitative develop and increase the qualitative one. Moreover is considers to stop the illegal occupation of areas and to build in protected zones and in zones with risk of flood.

The zone of Las Vegas includes, in the view of the partial plan, public spaces as the protected belts of Río Cali and of the South Channel.

The partial plan counts 3450 households with a population of 15000 inhabitants.

Figure 1.15 Las Vegas

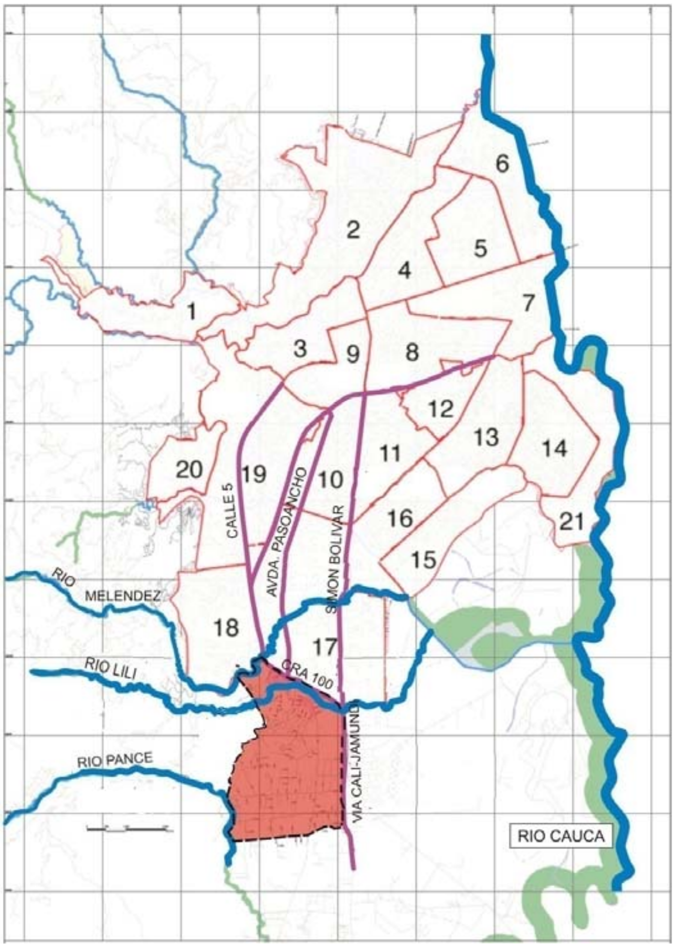


Flood control proposal in Comuna 22

Comuna 22 is located in the extreme South of the city and this is the newest, it is born in August 2004. Here live 8943 inhabitants in an area of 1062 ha.

This is the zone with the major potential for the urban expansion, due to green areas and wetlands that establish an important environmental offer for the community. Moreover are present educational and recreational activities that promote the area.

Figura 1.16 Comuna 22



The proposal for Comuna 22, developed by Eng. Hugo Salazar Jaramillo, is about food control using wetlands present in the area.

The absence of an adequate sewage system in the zone is causing damages to the infrastructures present in the area when happen a big precipitation. There are some alternative to solve this problem but all of them need a lot of money and time to be realized.

The alternative to use ecological corridors and wetlands to contrast flood events, has moreover benefits as increasing public spaces and biodiversity. 16 wetlands are present in the zone.

The proposals might be applied with the comprehensive management of wetlands present in the zone, stream control, water storage, pollution control. Using the existing wetlands, however is necessary to improve them, for instance increasing volumes, impermeabilization, build dikes, etc. Moreover is necessary a pre-treatment of storm water in order to avoid the clogging of wetlands.

This alternative for sure is cheaper than the conventional ones proposed and it can build in the short and medium period.

In succession are showed some photos of the wetlands present in the area.

Figura 1.17 Wetlands in Comuna 22

(a) wetland Lili 1E

(b) wetland Cañas Gordas 2-E


Image © 2008 DigitalGlobe
©2008 Google
3°21'06.38" N 76°32'04.89" O
elev. 1009 m
Jul. 2007
Alt. ojo 1.38 km

(c) Wetland La María - N

CONCLUSIONS

From the literature review of the SWITCH documents and documentation of other studies developed in the area, is possible to have a global idea of the contest that include the expansion area.

SWITCH documentation gives the guideline with which is possible to plan a sustainable alternative for the wastewater pollution control of the expansion area of Cali-Jamundí, which is the object of the internship. The solution that will be planned has to be connected with the paradigm shift following SWITCH project philosophy.

From the SWITCH documents is possible to have a global idea of the environmental situation in Cali. Talking about the water management with particular reference to the wastewater management, the current situation of the city of Cali is critical, referring for instance to the amount of water not treated and discharged directly in Cauca River and to the illegal discharge in storm water channel. All this problems are linked obviously with the fragmentation of the organism that oversee the water management and with the absence of a defined water law in Colombia.

The approach of SWITCH project to solve the current situation in Cali, and to put in practice the formulated strategies, is oriented to pollution prevention and waste minimization, treatment for reuse, stimulate natural self purification.

Moreover analyzing the documentation of other studies developed in the area is possible to have a particular view of the city. The solutions proposed by the local institutions to solve the environmental problem linked to the water management follow conventional guidelines, looking for instance at the wastewater schemes proposed.

From the partial planes of the expansion area is possible to see the wish to integrate urbanization and environment looking at the preservation of the public green spaces and ecological corridor.

The proposal of the Comuna 22, about the flood control through wetlands, enters in a SWITCH view. Moreover can be considered the possibility of use the wetlands also to treat the wastewater on that area. Working in the expansion area gives the best possibility to implement the SWITCH guidelines because of all scenarios are still possible, thing that is more difficult in the other parts of the city in which is necessary to take into account the present urbanization.

So the expansion area of Cali-Jamundí is the best part of the urban area of Cali planning the alternative of natural systems for the wastewater following the SWITCH guidelines.

CHAPTER 2

Natural systems literature review

Introduction

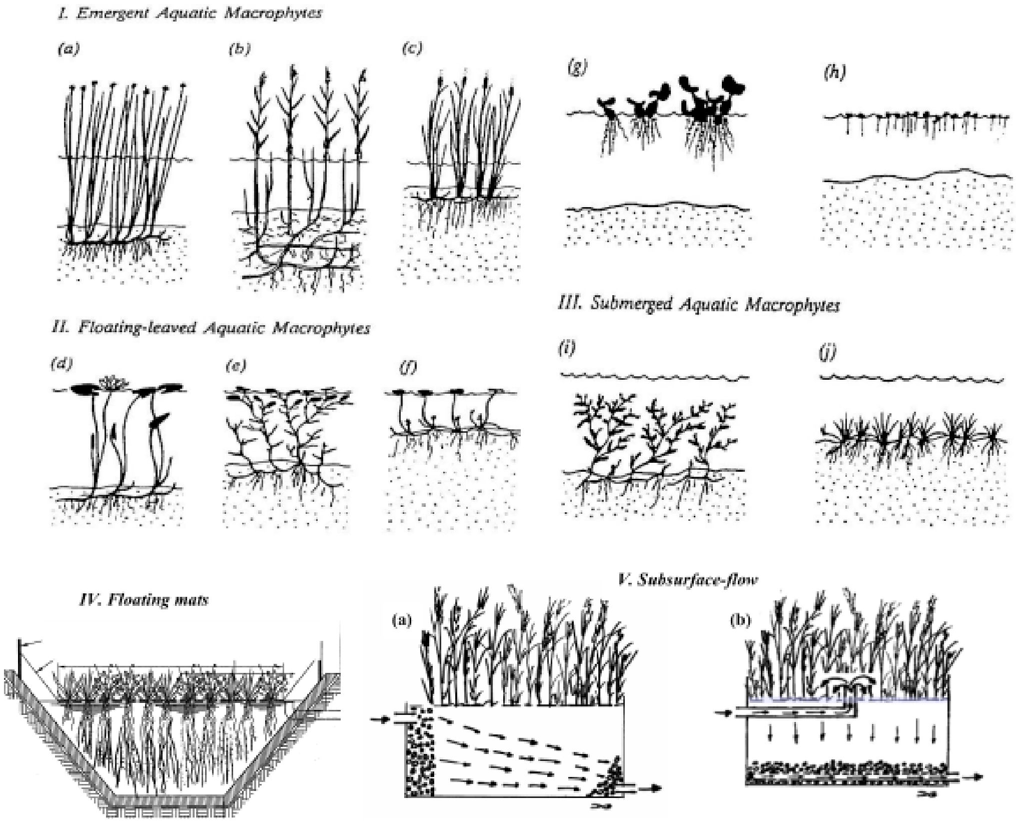
First studies on natural systems for wastewater treatment start from fifties and sixties of the XX century when purification capacities of wetlands have been discovered (SWITCH Project, 2006).
Natural systems are characterized to use natural energies to treat wastewater as solar and wind energies instead of using non-renewable energies as in the conventional treatment. Moreover in natural systems for wastewater treatment, there isn't adding of chemicals and the actors in the bio-chemical processes are microorganisms, algae and plants.
Natural systems are low-cost and easily operated and maintained technologies therefore have a strong potential for application in developing countries, in which implementation of conventional wastewater treatment is difficult due to the high costs necessary.
Using natural systems, nutrients are converted into usable biomass, instead of converting them in unusable forms with expensive ways as happen in conventional treatment. Moreover the aspect of reuse of the effluent is important, for instance in agriculture.
It is possible to classify natural treatments in macrophyte and microphyte systems. The first ones take the name of constructed wetlands and the second ones of stabilization ponds.

Constructed Wetlands

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters (Vymazal, 2005).
Natural wetlands are defined as transitional areas between land and water and are distinguished by wet soil, plants and a water table that maintain these characteristics.
Wetlands are characterized by high organic matter accumulation due to high grow rate and low rate of decomposition due to anaerobic conditions.
In Constructed Wetlands (CWs) the purpose is to use natural processes with engineered wetlands that are designed and constructed to simulate and improve natural wetlands (EPA, 2000).
CWs utilize plants, soil and associated microorganisms to purify a wastewater. In developed countries CWs are used for treating domestic wastewater, acid mine drainage, agricultural wastewater, landfill leachate, urban storm-water (Kivaisi, 2001).

CWs are widely used in treatment of organic discharges so they are used normally as biologic treatment. Two kinds of CWs are usually used: Surface-flows and Subsurface-flow, the second one is once more subdivided in Horizontal-flow and Vertical-flow (Langergraber, 2008).
Surface-Flow CWs can be classified depending by the kind of plant used: emergent macrophytes, bottom-rooted macrophytes, free-floating macrophytes, submersed macrophytes, floating mats.
Subsurface-flow CWs are planted with emergent macrophytes.

Figure 2.1 Macrophytes used in Constructed Wetlands



Treatment systems with water hyacinth are sufficiently developed to be successfully applied in the tropics and sub-tropic where climatic conditions favor luxuriant and continuous growth of the macrophyte for the whole year (Kivaisi, 2001). This kind of plants has its optimum growing temperature range between 20 and 30°C, for this reason is indicate for the tropical environment.
Water hyacinth has a rapid growth rate that causes a big amount of excess of biomass, so is necessary a frequent harvesting with increasing of costs. Anyway biomass can be reused, for instance, in anaerobic digestion systems to produce biogas (60% methane) and consequently electricity.
Water hyacinth has a large surface area for attached microorganisms due to the extensive root system. The main process for nutrient removal is plant uptake and consequent harvesting.

Advantages and disadvantages

All CWs technologies (free-water-surface constructed wetlands, horizontal subsurface flow constructed wetlands, vertical subsurface-flow constructed wetlands, floating mats, duckweed ponds, water hyacinth ponds) are easy to build, low operational costs, low energy requirements, resistance to shock loading, no energy needed. But to the other side require a high area, removal efficiency are seasonally dependent and have relatively long start-up period.

Systems with plant cover reduce mosquito proliferation, as duckweeds pond. Also in subsurface flow constructed wetlands there isn't the problem of mosquito proliferation but are sensitive to clogging.

Determining the best available technology in developing countries

Choosing the best constructed wetland system, several factors have to be taken into account.

First of all economical factors as the availability of suitable free-land, presence of flat topography to minimize the construction costs, presence of relatively impermeable soils to protect groundwater, considering operating and maintenance costs including harvesting of vegetation and nuisance control.

Type of wastewater and the target quality have big importance. In fact in many developing countries municipal sewerage systems carry mixed wastewater rich in inorganic and organic toxic pollutants which may inhibit microbial processes. The main wastewater treatment goal in developing countries is protection of public health through control of pathogens, particularly if the water is to be reused.

Designing the system, selection and management of suitable macrophyte species have to be carefully taken into account, given that the high grow rates, due to the favourable temperatures in a tropic environment, require frequently harvesting increasing maintenance costs.

Choosing the system typology is necessary minimizing the proliferation of mosquitoes that are vectors disease as malaria, yellow fever, filariasis and encephalitis.

Reuse

An important aspect with constructed wetlands, and natural treatments in general, is the possibility to reuse the effluent, that this an excellent aim specially in developing countries.

Influent of CWs can be used for irrigation of agricultural crops, watering of gardens, golf courses, public parks, flushing toilets, cleaning purposes, cooling water, water supply for natural wetlands and nature reserve areas. CWs can also be used as infiltration areas for groundwater replenishment (Rousseau el al., 2008).

Apart from water reuse is possible also to reuse harvested plants. Plants of CWs can be used as ornamental plants or harvested plants can be used with other purposed, as soil additives, fibres production, silaging to produce fodder. Another use is producing power by combustion of plants.
With these alternatives to reuse harvested plant biomass, it is possible to create an extra income.

Wastewater Stabilization Ponds

Wastewater stabilization ponds (WSPs) are a simple, low-cost, low-maintenance process for treating wastewater.
Usually WSPs are formed by several constructed ponds operating in series. Purification of wastewater happens by sedimentation and biochemical reactions. In the bottom of the ponds there is the formation of a sludge layer due to the sedimentation of influent suspended solids as well as algae and bacteria that grow in the pond. A periodic sludge removal is usually required (Nelson et al., 2004).
It is possible to classify WSPs in: anaerobic ponds, facultative ponds and maturation ponds (SWITCH project 2006).

Anaerobic ponds

Anaerobic ponds have a depth between 2 and 5 m and work with a high organic load (bigger than 3000 kgBOD/ha*d) and operate with a minimum HRT of 1 day. Phytoplankton is not present (apart of *Chlamydomonas*) because of toxicity of undissociated ammonia and high sulphide concentrations. Since the absence of phytoplankton, oxygen it is absent at all levels.
Purification of water occurs by sedimentation and degradation by anaerobic bacteria with the formation of carbon dioxide and methane formation. Temperature is important for biologic activity; for optimal operation temperature should be over 15°C, under 10°C only sedimentation effect is present.

Facultative ponds

Facultative ponds have a depth of 1-2 m and are classified in primary facultative ponds (that receive directly raw wastewater) and secondary facultative ponds (they are located in series after an anaerobic pond). Organic load is low: 100-300 kgBOD/ha*d.
It is present phytoplankton that produces oxygen by photosynthesis, BOD removal is supported by aerobic and anaerobic metabolism. Anaerobic conditions increase with increasing of depth of the pond. In the lower layer anaerobic fermentation occurs and in the higher one there is the aerobic stabilization.

Presence of algae is necessary for oxygen production but makes worse the effluent.

Maturation ponds

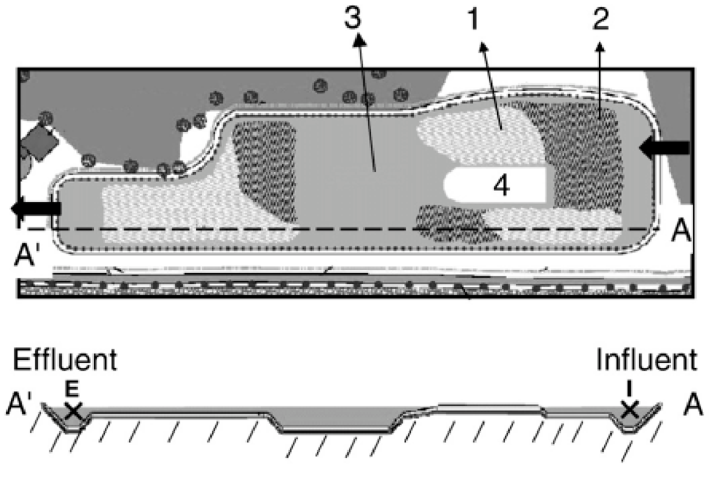
Maturation ponds have a depth of 1-1.5 m and receive the effluent of a facultative pond. The main objective of maturation ponds is removal of pathogens by solar irradiance, temperature, high pH and DO due to activity of phytoplankton. In maturation pond removal of BOD is small (contrary to anaerobic and facultative ponds) but removal of nutrients can be important.
Eggs of helminths and protozoan cysts are removed by sedimentation, viruses are removed by adsorption and sedimentation and bacteria are removed by sunlight effect, alkaline pH and temperature conditions (increasing of the mortality rates of bacteria)

Study cases of natural Systems for wastewater treatment

Granollers, Spain

The surface flow constructed wetland in Can Cabanyes (Granollers, Catalonia, northeastern Spain) is fed with a small part of the secondary effluent, which is not completely nitrified, from an urban wastewater treatment plant.
The surface area is of 1 ha and is planted with 2250 transplant units of Phragmites australis and Typha latifolia (Llorens et al., 2009). These different zones are planted shallow zones (water depth between 0.3 and 0.4 m), unplanted deep zones (water depth of 1.5 m) and a small island (surface area of 550 m^2), see Figure 2.2.

Figure 2.2 Scheme of the constructed wetlands plant of Granollers, Spain



(1) Zone planted with Phragmites australis; (2) zone planted with Typha latifolia; (3) deep zone free of macrophytes; (4) island.

The CW of Granollers serves 3 main purposes: effluent polishing before discharge with particular attention to NH_4 (reducing from 31 to 4.5 mgN/l) and pathogens (faecal coliform lower than 2400 / 100 mL in the effluent); landscape restoration; habitat function (SWITCH project, 2006). Moreover is planned to reuse the effluent in the future.

Construction costs were 72000 € and maintenance costs (for vegetation control, sludge removal, pump maintenance and water quality monitoring) are 12000 € per year.

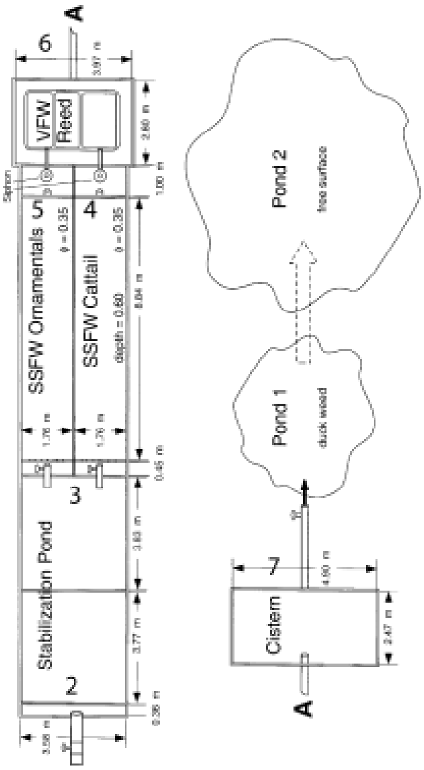
Texcoco River, Central Mexico

Pilot-scale treatment wetland in the small community of Santa María Nativitas (1881 inhabitants in year 1995) in the Rio Texcoco watershed (Central Mexico) is formed by sedimentation terraces, stabilization pond, subsurface flow wetland SSFW and vertical flow wetland VFW (Belmont et al., 2004). See Figure 2.3.

Figure 2.3

(a) Localization Texcoco River

(b) Scheme of the plant in Texcoco river



VFW was located after the SSFW in the treatment system because the objective was to transform organic nitrogen into NH4 and NO3 for crop fertilization as the reclaimed water is used for irrigation.

The two subsurface horizontal flow wetlands are connected in parallel and ornamental plants (calla lily and canna lily) and cattail plants respectively are planted in a subtrate of coarse gravel of 3–5 cm in diameter. The SSFW are 0.6 m in depth.

Vertical flow wetland is planted with the common reed Phragmites communis in a substrate of coarse sand.

In one of the two ponds there are duckweeds plants (*Lemna*) with a surface area of 30 m^2, the second one has a free surface with an area of 100 m^2. Infiltration occurs from the ponds, which contributes to recharge of groundwater. Stabilization ponds have an average depth of 1.7 m.

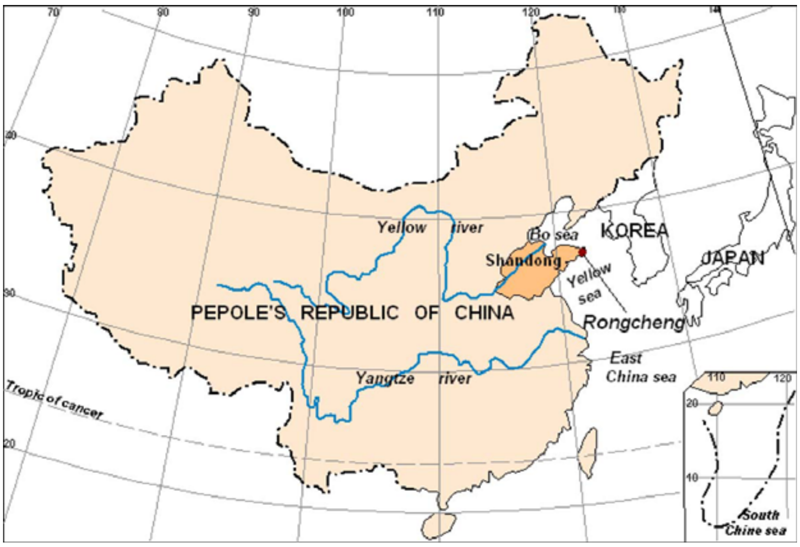
The purpose of the pilot scale treatment system was to produce reclaimed water useful for agriculture and to facilitate the calculation of the removal rate constants.

Rongcheng, China

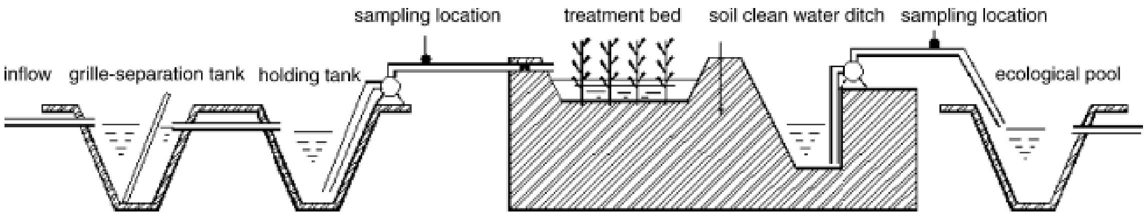
A 80 ha constructed wetland was constructed in year 1998 in Rongcheng, Shandong Province, China, with a treatment capability of 20.000 m^3/d of domestic wastewater with a small quantity of industrial wastewater, serving 120.000 inhabitants (Song et. Al, 2006). Vertical flow and surface flooding CWs are used with pulse or intermittent hydraulic loading. A grill-separation tank and a holding bank are present. See Figure 2.4 for the localization and the system scheme.

Figure 2.4

(a) Localization of Rongcheng



(b) Schematic diagram of the Rongcheng constructed wetland system



Plants used are common reed (Phragmites australis) and a few naturally germinated wetland plants (Typha orientalis; Scirpus validus; Lemna minor, etc.).

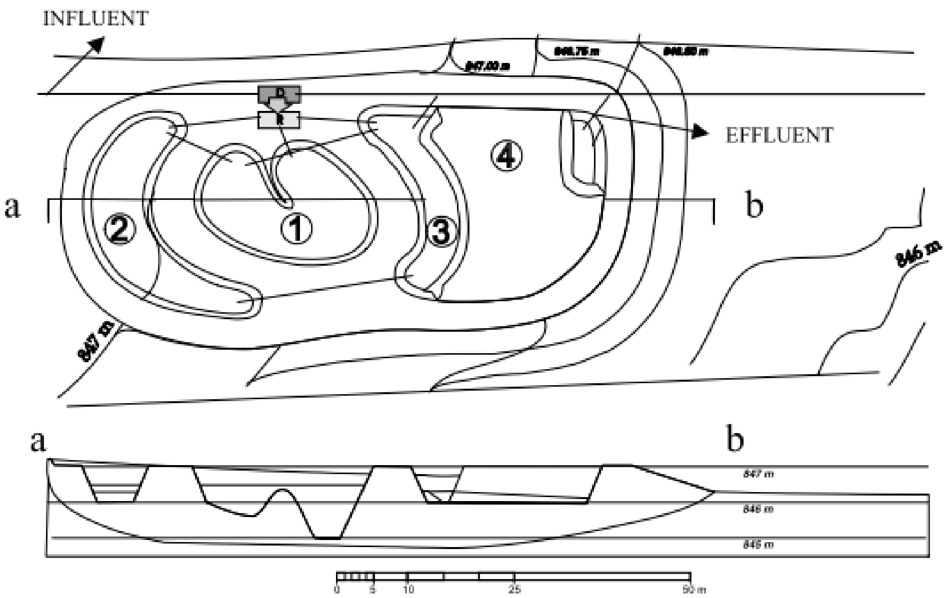
From analysis during 10 years is observed that constructed wetland system could effectively reduce the output of SS (71.8 ± 8.4%), BOD5 (70.4 ± 9.6%), COD (62.2 ± 10.1%), total coliform (99.7%) and fecal coliform (99.6%). The removals of nutrients, however, were not as good as those of SS, BOD5, and COD. After treatment the averaged effluent concentrations in ammonia nitrogen and total phosphorus were 11.3 ± 2.6 and 2.00 ± 0.28 m/l, giving reduction efficiencies of 40.6 ± 15.3% for ammonia nitrogen and 29.6 ± 12.8% for total phosphorus.

Bustillo de Cea, Leon, northwest of Spain

The Hierarchical Mosaic of Aquatic Ecosystems (HMAE®), originally developed in Belgium, was built in Bustillo de Cea, Leon, northwest of Spain, that has 250 inhabitants in the winter, increasing to 400 in full summer.

The full–scale pilot plant with constructed wetlands for municipal wastewaters treatment consist in a stabilization pond (stage I) followed by a semi-aquatic ecosystem planted with helophytes (stage II) and by a terrestrial ecosystem (stage III) where ligneous species are planted. See Figure 2.5 for the pilot full-scale treatment plant scheme.

Figure 2.5 Pilot full-scale treatment plant scheme



D and R pre-treatments; (1) Waste Stabilization Pond basin, (2) FWS with Typha, (3) FWS with Iris; and (4) SSF with gravel

The average performance of integral treatment of the full scale HMAE® system exceeds a 60% reduction in organic matter, a 30% reduction in nutrients and a 90% removal of faecal pollution (Ansola et al., 2003).

Conclusions

From the literature review is reasonable to conclude that natural systems are efficiently applied for domestic wastewater.

The majority of full-scale plants are located in temperate zones of Europe, United States and Australia and only a limited amount are located in the Tropic. Anyway several studies suggest that in the Tropic these technologies can be successfully applied because of the difference between temperate and tropical climate. In fact in the tropic there is a higher humidity and the temperature are commonly between 20 and 30 °C due to the presence of only a wet and dry seasons or only wet season close to the equator. In particular wetlands can find in the Tropic an optimal environment to be applied.

Moreover as seen in the studies cases analysis, there are a lot of experiences with natural systems for wastewater systems in small communities. So the expansion area of Cali-Jamundí, object of this work, is an ideal zone in which apply natural systems.

During the design part of the research it will be analyzed the best solution for the Cali context, taking in account the state of the art and the study cases that can be found in technical literature, with particular reference to advantages and disadvantages of each natural treatment system.

CHAPTER 3

Analysis of the possibility to include natural systems in the expansion area of Cali-Jamundí

Introduction

The future expansion area of Cali-Jamundí offers the opportunity to implement a wide range of suggested alternatives and new concepts oriented towards sustainable wastewater management.
Designing the alternatives for wastewater treatment, scenarios with and without the application of strategies to prevent and minimize production of municipal sewage have been analyzed.
Tropical climate and the availability of land at low-cost, that characterize the area of Cali, provide an ideal zone where apply natural systems.
Moreover in the expansion area is still possible to implement efficiently the SWITCH guidelines about paradigm shift for water management; which is more difficult in other parts of the city because of the already existing urbanization.

Comparison between natural systems and conventional technologies for wastewater treatment

Natural treatment systems are largely studied as sustainable and low-maintenance technologies compared with conventional technologies.
Detailed studies in five Czech HSF CWs revealed that the retention of coliforms and fecal coliform bacteria is very high (>95%) and exceeds common retention values for conventional systems (Ottova et al., 1997).
Well-designed and well-operated stabilization ponds can achieve almost total removal of helminthes (99.99%), enteric bacteria and viruses (99%).
CWs with horizontal subsurface flow usually provide high treatment effect in terms of removal of organics (BOD_5, COD) and suspended solids (SS).
The removal of nitrogen and phosphorus is lower but comparable with conventional treatment technologies which do not include special nutrient removal step (Cooper et al., 1996; Vymazal et al., 1998b).
In table 3.1 some data about BOD and COD with horizontal subsurface flow CWs in Europe are showed.

Table 3.1. Average influent (In) and effluent (Out) concentration (mg/1) and removal efficiencies (Eff, %) of organics in vegetated beds of HSF CWs (Vymazal, 2002)

BOD_5	In	SD	Out	SD	Eff	*n*
Czech Republic	87.2	63.1	10.5	9.9	88.0	55
Denmark and UK[a]	97.0	81.0	13.1	12.6	86.5	80
North America[b]	27.5		8.6		68.5	34
Germany-L. Saxony[c,d]	248	233	42.0		83.0	39
Germany-Bavaria[c]	106	62.1	21.6	16.4	79.6	7
Poland[e]	110	87.8	18.1	14.3	83.5	6
Slovenia[f]	107	30.2	11.3	2.5	89.0	3
Sweden[g]	80.5	55.0	5.9	4.5	92.7	3
COD						
Czech Republic	211	160	53.0	48.3	75.0	53
Denmark[a]	264	192	64.7	27.9	75.0	59
Germany-L.Saxony[c,d]	430	348	133		69.0	47
Germany-Bavaria[c]	234	124	69.4	39.1	70.3	7
Poland[e]	283	170	101	23.6	64.3	6
Slovenia[f]	200	41.5	35.7	3.1	82.0	3

At loading rates of 445÷1235 kgBOD/ha/day in the tropics, removal efficiencies of BOD, nitrogen, phosphorus and indicator bacteria have been reported to be 75÷90; 30÷50; 20÷60 and 60÷99%, respectively (Kivaisi, 2001).

At present, the capital cost of a CW, including pre-treatment facilities and without sewerage, approximately equals the capital cost of an equivalent conventional treatment system without advanced nutrient removal (Vymazal, 1998a).

The major part of the capital cost relates to filtration material (ca. 40% including transportation) and excavation (ca. 30%), liner (ca. 15%) and plants (ca. 5%). The operation and maintenance costs are much lower than those for conventional treatment systems due to the fact that CWs do not use electric power.

The construction cost equals that for conventional treatment systems but the operation and maintenance costs are much lower.

Table 3.2. Typical characteristics of the main wastewater treatment systems in developing countries (Von Sperling, 1996)

Treatment systems	Removal Efficiencies (%)				Requirements		Construction cost (US $ /Inhabitant.)	Total HRT (Days)	Quantity of sludge to be removed ($m^3 Inhab^{-1} yr^{-2}$)
	BOD	N	P	Coliforms	Land (m^2/Inhab.)	Power (W/Inhab.)			
Preliminary treatment	0–5	~0	~0	~0	<0.001	~0	2–8	–	–
Primary treatment	35–40	10–25	10–20	30–40	0.03–0.05	~0	20–30	0.1–0.5	0.6–1.3
Facultative pond	75–85	30–50	20–60	60–99	2.0–5.0	~0	10–30	15–30	–
Anaerobic pond/Facultative pond	75–90	30–50	20–60	60–99.9	13–3.5	~0	10–25	12–24	–
Facultative aerated lagoon	75–90	30–50	20–60	60–96	0.25–0.5	1.0–1.7	10–25	3–9	–
Completely mixed Aerated sediment pond	75–90	30–50	20–60	60–99	0.2–0.5	1.0–1.7	10–25	4–9	–
Conventional activated Sludge	85–93	30–40	30–45	60–90	0.2–0.3	13–2.8	60–120	0.4–0.6	1.1–1.5
Extended aeration (continuous flow)	93–98	15–30	10–20	65–90	0.25–0.35	23–4.0	40–80	0.8–1.2	0.7–1.2
Sequence batch reactor	85–95	30–40	30–45	60–90	0.2–0.3	1.5–1.0	50–80	0.4–1.2	0.7–1.5
Low rate trickling filter	85–93	30–40	30–45	60–90	0.5–0.7	0.2–0.6	50–90	NA[a]	0.4–0.6
High rate trickling filter	80–90	30–40	30–45	60–90	0.3–0.45	0.5–1.0	40–70	NA	1.1–1.5
Upflow anaerobic sludge Blanket reactor	60–80	10–25	10–20	60–90	0.05–0.10	~0	20–40	0.3–0.5	0.07–0.1
Septic tank-anaerobic filter	70–90	10–25	10–20	60–90	0.2–0.4	~0	30–80	1.0–2.0	0.07–0.1
Slow rate infiltration	94–99	65–95	75–99	>99	10–50	~0	10–20	NA	
Rapid infiltration	86–98	10–80	30-99	>99	1–6	~0	5–15	NA	
Subsurface infiltration	90–98	10–40	85–95	>99	1–5	~0	5–15	NA	
Overland flow	85–95	10–80	20–50	90– >99	1–6	~0	5–15	NA	

[a] NA, not applicable.

Experiences with natural treatment systems already present in the zone

Experiences with natural systems already exist in the Cauca Valley region, such as the anaerobic and facultative ponds in the Cauca Valley municipalities of Guacari, La Union, Roldanillo and Toro, with BOD_5 removals between 80 and 85%.

Some data about these systems are showed in succession (Corrales et al., 2000).

Table 3.3. Stabilization ponds in Cauca Valley

Municipality	Flow l/s	Temperature °C	pH	Operation cost COP/year	Operation cost €/year
Guacarí	41,7	24,1	6,8	7.130.000	2.377
Roldanillo	32,96	24,8	6,9	6.450.000	2.150
La Unión	19,89	24,7	7	6.450.000	2.150
Toro	21,48	25,1	7,3	6.450.000	2.150

Other experiences with natural treatment already developed in the area are the full-scale study case in the municipality of Cali (in the rural community of La Voragine) and the pilot-scale case in the municipality of Ginebra.

These plants are formed by a septic tank with an anaerobic filter and a subsurface-flow horizontal constructed wetland working with *Scirpus, sp.*; results show an excellent organic matter removal; nutrient and pathogen removal were found to depend on hydraulic retention times (Madera et al., 2003).

Table 3.4. Characteristics of pilot-scale system of Ginebra and full-scale system of La Voragine

	System	**Flow** m3/d	**HRT** d	**Width** m	**Length** m	**Depth** m	**Macrophyte**	**Drain medium** m
Ginebra	Septic Tank	1,36	0,5		1,5	1,2		
	Anaerobic filter	1,36	0,5		1,5	1,6		0,07
	SF CWs	1,36	0,5	2,25	0,7	0,6	*Scirpus*	0,07-0,10
La Voragine	Septic Tank	104	1	10	5	2		
	Anaerobic filter	104	0,4	10	5	1,8		0,04-0,07
	SF CWs	104	0,13	23	1,6	0,7	*Scirpus*	0,04-0,08

In Ginebra is also present a full-scale stabilization pond that consists in an anaerobic pond followed by a secondary facultative pond that receives wastewater from Ginebra (population equivalent of 9000 inhabitants) after a preliminary treatment (Peña, 2002).

Table 3.5. Removal in the anaerobic and facultative ponds of Ginebra

Parameter	Influent	Effluent	% Removal
COD (mg/l)	439,5	67	85
SS (mg/l)	276,6	48,1	83
Fecal coliforms (UFC/100ml)	1x10^9	1x10^7	99
Helmints edgs (n.edges/l)	21	0	100

Application of the paradigm shift concept in the expansion area

Three different strategies have been proposed to prevent and minimize production of municipal sewage in the expansion area of Cali-Jamundí taking into account the SWITCH Project guidelines (SWITCH, 2008). Each one has an increasing level of innovation.

Implementing the natural system for wastewater treatment, effect of reduction wastewater production at household level is taken into account.

In the first alternative are present the basic strategies for prevention and minimization that are present also in the other two strategies. These action mainly concern:

- water loss control in the housing., installation of low water consumption devices;
- participation in training programs about the efficient use of water and the use of new technologies;
- education campaigns and socialization programs about dry sanitation systems;
- inter-institutional participation in household planning;
- education campaigns and socialization programs about dry sanitation systems;
- economic incentives for encourage water consumption reduction;
- study and adjustment of the water tariff.

In the second alternative are additionally considered:

- rainwater use;
- evaluation and internalization of externalities;
- technical standards for the construction of households using new water management trends.

The third alternative also considers:

- implementation of grey-water recirculation systems;
- water use environmental education;
- soft credits for the implementation of dry sanitation technologies.

Appling prevention and minimization strategies, is possible to reduce the production of wastewater. In particular implementing the following strategies is possible to estimate a wastewater reduction of the 50%.

- water loss control in the housing., installation of low water consumption devices;
- participation in training programs about the efficient use of water and the use of new technologies;
- economic incentives for encourage water consumption reduction;
- rainwater use;
- implementation of grey-water recirculation systems;

Application of natural systems in the expansion area

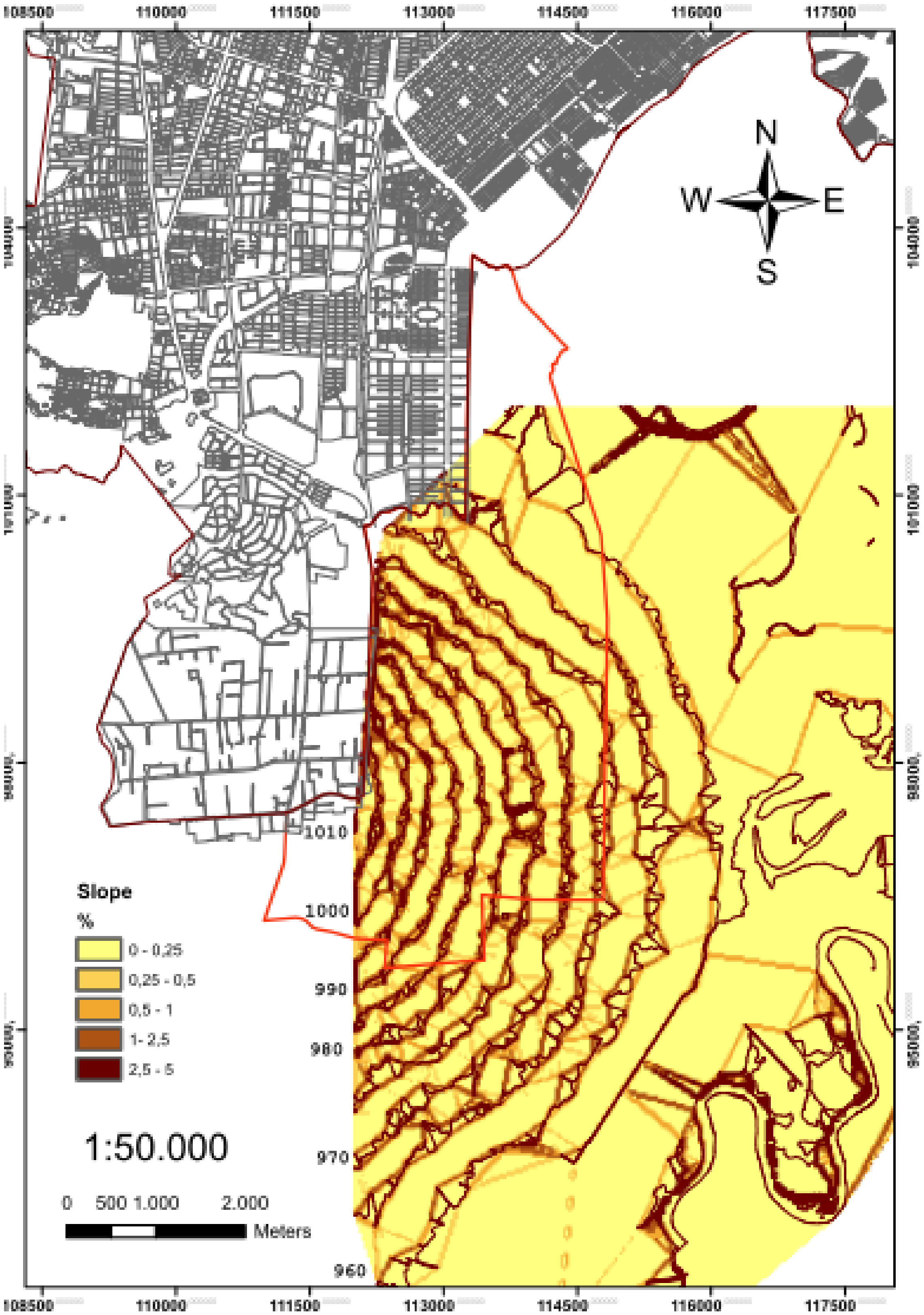
- *Area Description*

The future urban expansion area defined in the POT (Land Ordering Plan) as "Cali-Jamundí" is located in the south of the city and has a surface area of 1652.85 hectares.

Altitude of the area is between 1030 and 955 meters above the sea level.

Its topography is uniform with a slight descending slope towards the Cauca River. In Figure 3.1 contour lines and slopes are presented. Analysis about slope has been performed by the Digital Terrain Model of the zone.

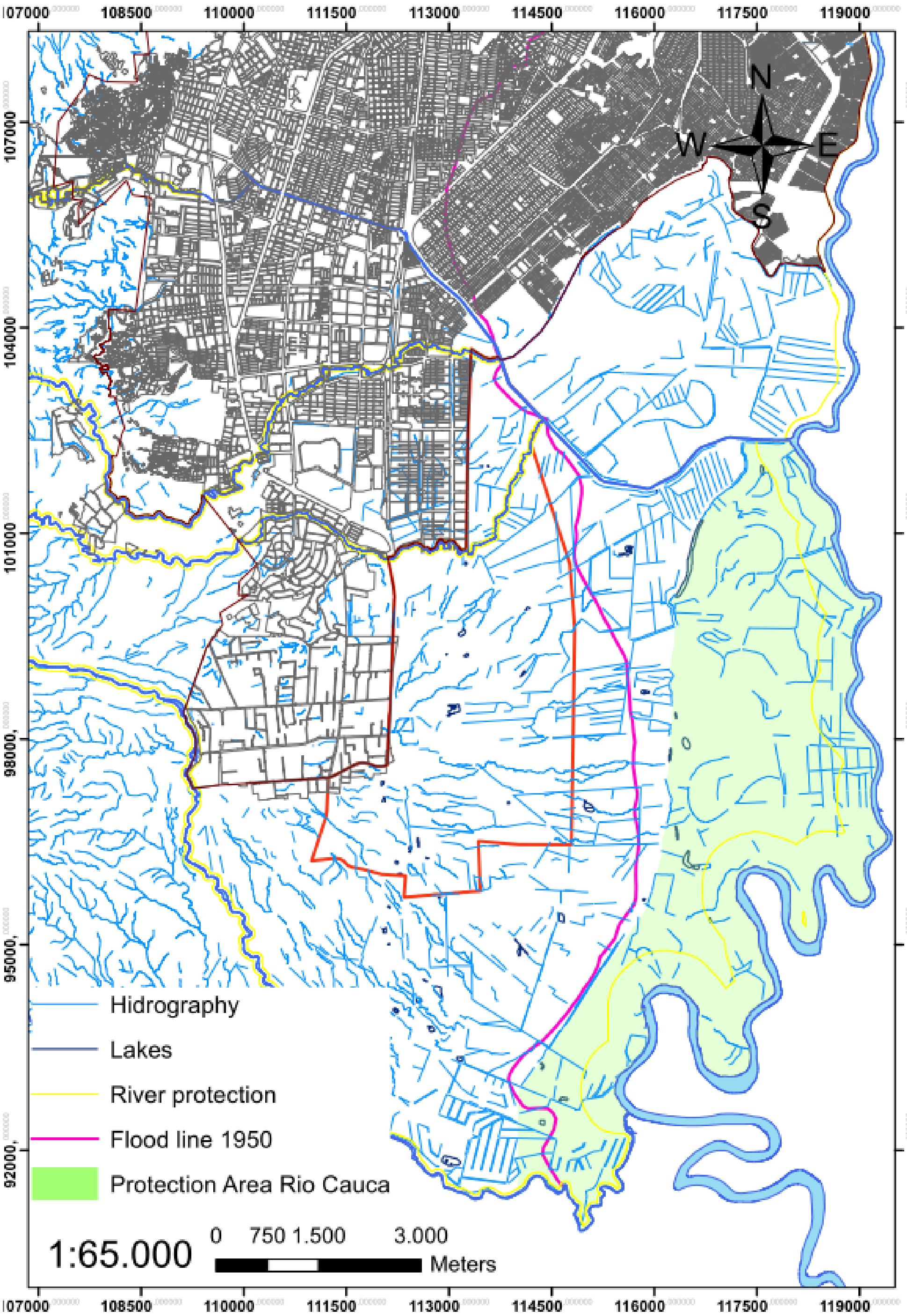
Figure 3.1. Topography expansion area



The area is characterized by a dense hydrography and is located upstream the line of the maximum flood event registered in 1950.

In Figure 3.2 is presented the hydrography in the expansion area.

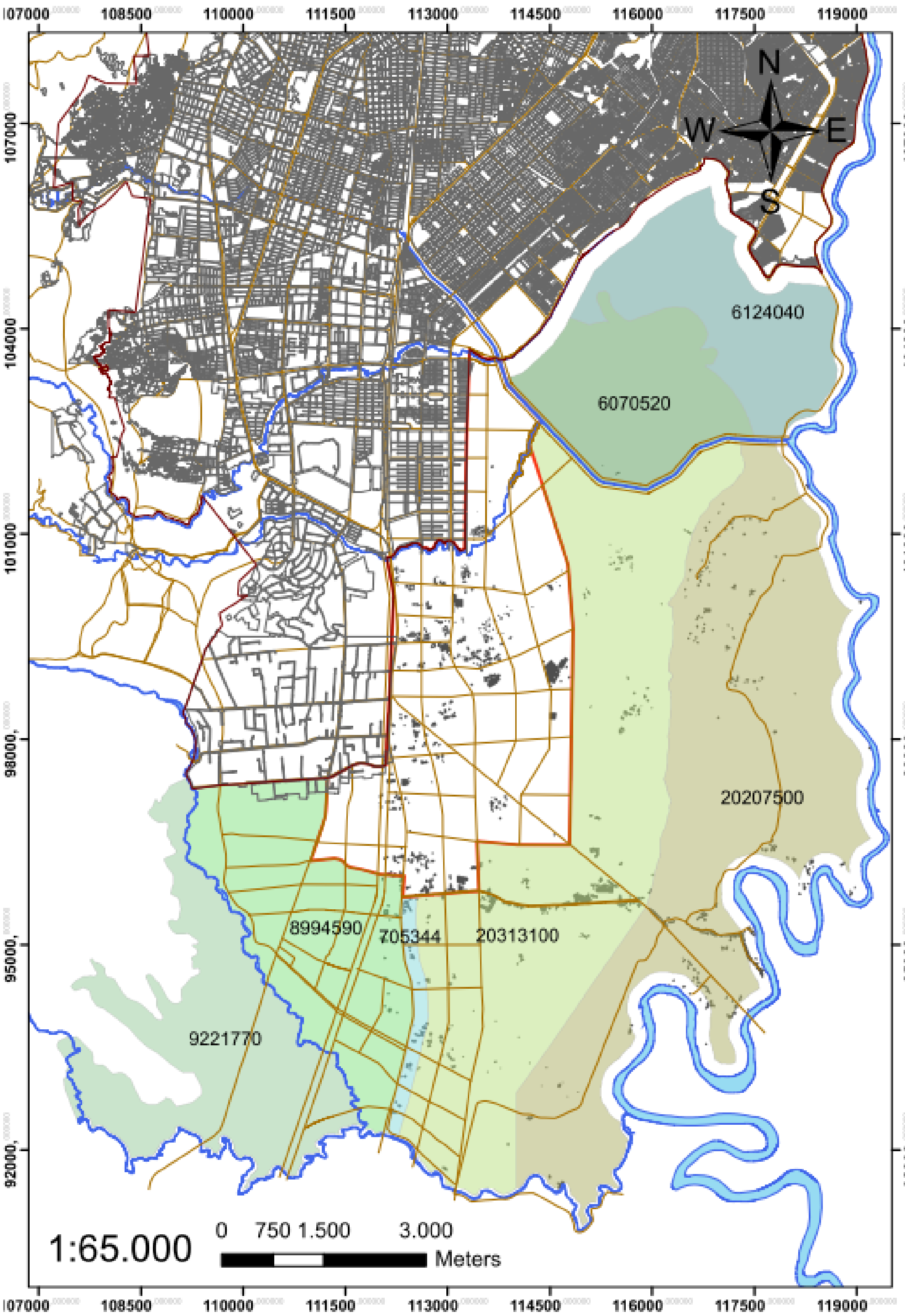
Figure 3.2. Hydrography in the expansion area



Currently, this area is mostly used for agricultural purposes.

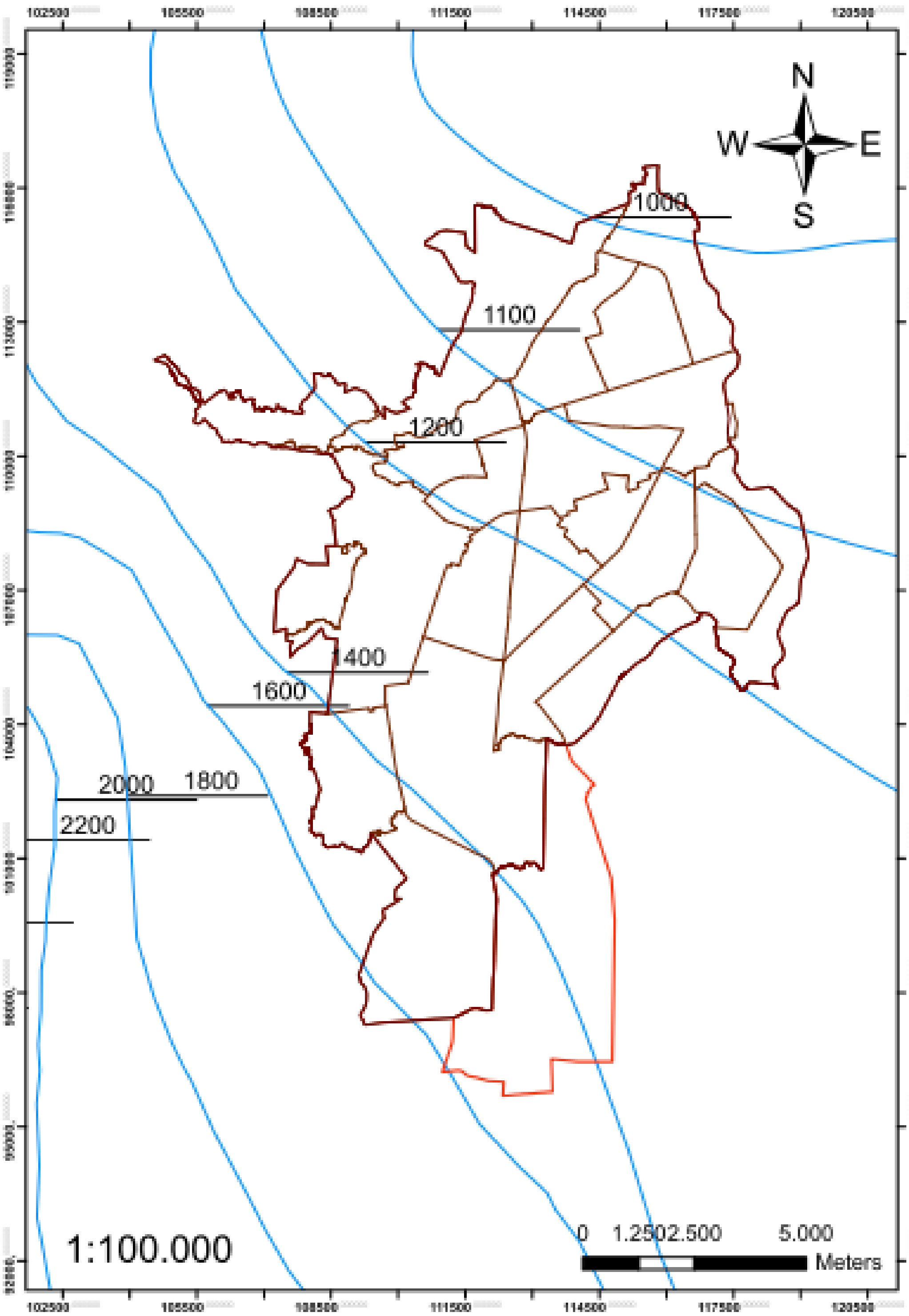
Around the area are already present agricultural zones for sugar cane culture. In Figure 3.3 these areas are showed with the value of surface area in m^2.

Figure 3.3. Agricultural zones present around the expansion area



Precipitations in expansion area are between 1300 and 1600 mm/year, in Figure 3.4 precipitations in the municipality of Cali are showed.

Figure 3.4. Precipitation in the municipality of Cali.



- *Estimation of wastewater production*

Expansion area will be developed according to the economical status of its inhabitants using the figure of social stratum. The inhabitants of the area belong to strata 3, 4, 5 and 6 that correspond to the upper middle economical classes.

For the estimation of population of the expansion area, density data of Cali from year 1999 and 2007 are considered; increasing of population density is not found.

Population density of the expansion area has been estimated with the average values of other "comunas" of Cali considering the population distribution in strata.

Estimation of population in the expansion area is showed in succession.

Table 3.6. Estimation of the population in the expansion area

Population expansion area			
Stratum	Density	Area	Population
	inh/ha	ha	inh
3	200,48	305	61.146
4		528	105.853
5	90,46	490	44.325
6		305	27.590
TOTAL			**238.916**

(Source EMCALI)

Data of consumption of drinking water for the city of Cali are showed in table 3.7.

Table 3.7. Residential drinking water consumption for the city of Cali in year 2007

2007	
Residential drinking water consuption	105.087.000 m3/year
Households	447.945

(Source EMCALI)

Considering an average value of 4.5 persons/household, the average value of residential drinking water supply is of **142.8 l/ihn/d**.

Considering a return coefficient of 0.8 and estimating infiltration in wastewater pipes with a percentage of 10%, the production of wastewater for the expansion area of Cali-Jamundí can be estimated in a value of **30.000 m^3/d**. This is the design flow consider during the design phase.

Wastewater concentrations for the city of Cali can be estimated as showed following.

Table 3.8. Typical domestic wastewater concentrations in Cali

Typical domestic wastewater concentrations in Cali	
BOD_5	200 mg/l
TSS	188 mg/l

(from measurements in year 2006)

The value of 200 mg/l of BOD_5 and 188 mg/l of TSS in the influent are taken from measurements of the raw wastewater influent to the WwTP "El Caney" in Cali in May 2006. Measurements have been performed every 30 minutes for a 24-hours period.

In the WwTP of "El Caney" arrives the wastewater of a residential *comuna* with similar characteristics to the expansion area of Cali-Jamundí. Wastewater pipes are new in the served zone and are not affected by storwater infiltration, so measured values are realistic (thing that doesn't happened for instance in the WwTP of Cañaveralejo).

- *Area requirement for natural treatment*

Functioning of natural systems is affected a lot by the climate. In Cali the average temperature is of 24 °C and evaporation can be estimate in the value of 4.8 mm/d.

In table 3.9 estimations of area requirement are showed, these values are taken from a study about technology selection for domestic wastewater treatment with natural systems with focus in several Colombian regions (Bernal and Cardona, 2003).

The water supply considered for this study is of 120 l/inh/day. BOD concentration considered in the influent is of 220 mg/l and, BOD removal is planned of 80% as imposed by the Colombian Decree 1594 of year 1984, with consequently BOD concentration in the effluent of 44 mg/l.

Table 3.9. Area requirements for Cali climate

Natural system	**Surface area required** m^2/inh
Facultative Pond	0,6
Anaerobic pond	0,017
Slow infiltration systems	5,5 - 66
Quick infiltration systems	0,26 - 5,5
Superficial flow systems	1,6 - 11
Duckweed pond	1,13 - 1,5
Hyacinth pond	1,8 - 4,05
Surface flow Constructed Wetland	0,6
Sub-surface flow Constructed Wetland	0,5

These values give a first idea for the application of natural systems in the expansion area of Cali, before to start with the design methodology.

Stabilization ponds and constructed wetlands are investigated for application of natural treatment systems due to the smaller surface area required.

Alternatives considered in the design phase concern different options: a primary facultative pond, an anaerobic pond with secondary facultative ponds and sub-surface horizontal-flow constructed wetlands in series; implementation of maturation ponds and rock filters in order to reach the standards for the reuse of the effluent.

Scenarios with and without prevention and minimization strategies are considered.

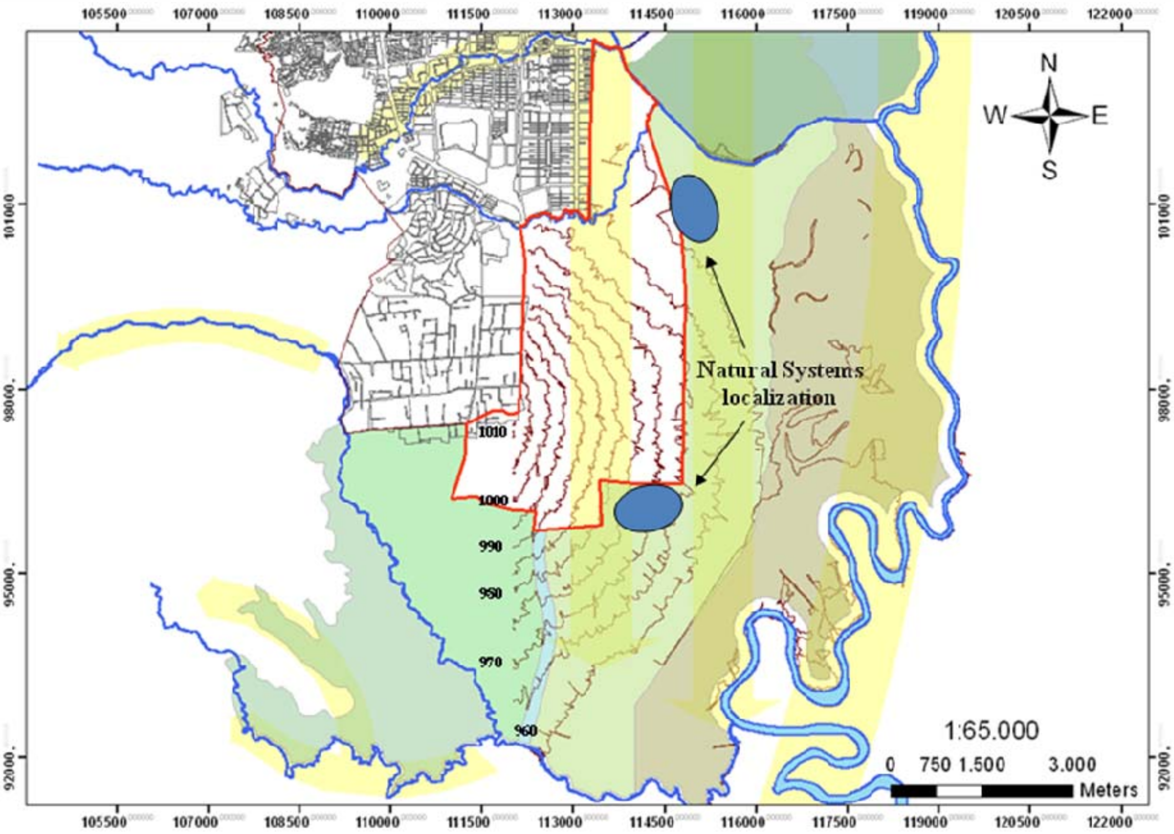
Moreover taking into account the presence of 2000 ha of sugar cane cultures in the east part of the expansion area, scenarios with and without the possibility of reuse the effluent are considered.

Considering that sugar cane culture needs approximately 1200÷1500 mm/year of water, the water demand for 2000 ha of culture is about 65.000÷82.000 m^3/d. Anyway further analyses about demand of water for sugar cane culture are necessary, in particular about demand of water in wet and dry seasons.

The natural treatment system can be planned to be divided in two plants localized in the east part of the expansion area (see Figure 3.5), taking into account the terrain slope towards east.

Technical aspects about natural system design will be showed in the next chapter.

Figure 3.5 Possibly natural systems localization



Natural Systems localization
1:65.000
0 750 1.500 3.000 Meters
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1000
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970
960
105500
107000
108500
110000
111500
113000
114500
116000
117500
119000
120500
122000
101000.
98000.
95000.
92000.

CHAPTER 4

Natural System Design

Introduction

Design of different solutions for wastewater treatment in the expansion area of Cali-Jamundì is presented in this report.

Several alternatives are considered, taking into account implementation of anaerobic ponds, facultative ponds, maturation ponds, rock filters, sub-surface horizontal-flow constructed wetlands, and fishponds.

Scenarios concerning prevention and minimization of wastewater production and reuse of the effluent have also been considered.

CONVENTIONAL ANAEROBIC POND

- ***Area requirement***

Anaerobic ponds can be satisfactorily designed, without the risk of odour release, on the basis of volumetric BOD loading:

$$\lambda_v = \frac{L_i \cdot Q}{V_a}$$

λ_v = volumetric BOD loading [g/m^3/d];
L_i = BOD influent [g/m^3];
Q = flow [m^3/d];
V_a = anaerobic pond volume [m^3].

The volumetric BOD loading increases with the temperature as showed in Table 4.1.

Table 4.1. Variation of volumetric BOD loading with the temperature (Mara, 2003).

T	λv	BOD Removal
°C	*g/m3/d*	*%*
< 10	100	40
10 ÷ 20	20T - 100	2T + 20
20 ÷ 25	10T + 100	2T + 20
> 25	350	70

λv should be between 100-400 g/m^3/d; considering a maximum value of 350 g/m^3/d it gives an adequate margin of safety with respect to odour.

Considering the average temperature of Cali of 24 °C the volumetric BOD loading is:

$$\lambda_v = 340 \text{ g/m}^3\text{/d}$$

24 °C ⟶

BOD removal = 68 %

The total wastewater flow can be estimated considering:

- population of the expansion area of 238.916 inhabitants;
- water supply of 142.8 l/inh/d;
- return coefficient of 0.8;
- infiltration of 10%.

Moreover considering 2 different treatment plants, the wastewater flow influent can be estimated in a value of 15.000 m^3/d for each plant.

Assuming the depth of the anaerobic pond of 3 meters, the area of the anaerobic pond can be estimated as:

$$A_a = \frac{L_i \cdot Q}{\lambda_v \cdot D_a} = 2941 \text{ m}^2$$

L_i = 200 mgBOD$_5$/l [*];
Q = 15.000 m^3/d;
λ_v = 340 g/m^3/d;
D_a = 3 m.

The hydraulic retention time of the anaerobic pond is given from:

$$\theta_a = \frac{V_a}{Q} = \frac{A_a \cdot D_a}{Q} = 0.59 \text{ d}$$

V_a = 2941 m^3;
D_a = 3 m;
Q = 15.000 m^3/d;

The value of the hydraulic retention time is too small. The minimum retention time in anaerobic ponds is 1 day.

Considering a value of 1 d for the HRT, the area of the anaerobic pond can be recalculated as:

$$A_a = \frac{Q \cdot \theta_a}{D_a}$$

[*] The value of 200 mg/l of BOD$_5$ influent is taken from measurements of the raw wastewater influent to the WwTP "El Caney" in Cali in May 2006. Measurements have been performed every 30 minutes for a 24-hours period.
In the WwTP of "El Caney" arrives the wastewater of a residential *comuna* with similar characteristics to the expansion area of Cali-Jamundí. Wastewater pipes are new in the served zone and are not affected by storwater infiltration, so measured values are realistic (thing that doesn't happened for instance in the WwTP of Cañaveralejo).

$= 5000\ m^2 = 0.5$ ha

Q = 15.000 m^3/d;
$\theta_a = 1$ d;
$D_a = 3$ m.

- ***BOD removal***

According with the values in Table 4.1, the BOD removal of the anaerobic pond for the temperature of 24 °C is 68%. The concentration of BOD in the effluent of the anaerobic pond, considering the BOD in the influent 200 mg/l, is:

$$L_e = L_i \cdot \left(1 - \frac{BODremoval}{100}\right) = 64.0\ mg_{BOD5}/l$$

- ***TSS removal***

A value of 188 mg/l of TSS, taken from the measurements in the WwTP of “El Caney” described previously, is considered.
Considering a percentage of TSS removal in anaerobic ponds of 65 %, the concentration in the effluent of the anaerobic pond is:

$$TSS_e = TSS_i \cdot (1 - TSSremoval) = 188 \cdot (1 - 0.65) = 65.8\ mg/l$$

- ***Human intestinal nematode eggs removal***

Removal of human intestinal nematode eggs is given by:

$$R = 100 \cdot \left(1 - 0.41 \cdot e^{-0.49 \cdot \theta + 0.0085 \cdot \theta^2}\right)$$

R = 74.7 %

Considering a value of 100 human intestinal nematode eggs/l, in the effluent will be 25.3 eggs/l.

- ***Fecal Coliforms removal***

Fecal Coliforms in the effluent is given by:

$$FC_e = \frac{FC_i}{1 + k_b \cdot \theta_a} \qquad k_b = 2.6 \cdot (1.19)^{T-20}$$

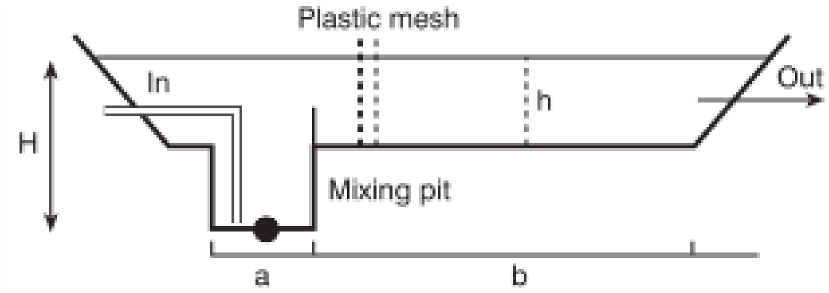
Considering Fecal Coliforms in the influent with a value of: 5,00E+07 Escherichia Coli/100ml,

FC_e = 8,05E+06 Escherichia Coli/100ml.

HIGHT RATE ANAEROBIC POND

A high rate anaerobic pond can be design to decrease the area requirement and to optimize the biogas production.

Figure 4.1. High rate anaerobic pond scheme



The first zone is completely mixed and has a depth of 4 m, it has a lenght of 1/3 of the total. The second part of the pond need for the sedimentation and has a depth of 2 m.

The HRT is 0.75 days in total that can be divided in 9 hours for each part of the pond.

The completely mixed part with 4 m depth is designed for an organic load of 700 $g/m^3/d$ finding an area of 1406 m^2 (L = W = 37.5 m). To respect the ratio L:W = 3:1 the second part of the pond has a width of 75 m.

The total area of the high rate anaerobic pond is 4219 m^2 with a total HRT of 0.75 d.

Pollutant removals can be calculated has shown previously for the conventional anaerobic pond.

Biogas production can be estimated by the following equation (Peña, 2003):

$$Q = 0.25 \cdot \frac{k \cdot VSS \cdot CODeffl}{Ks + VSS} \cdot V$$

0.25 [g/CH_4/gCODremoved]

k [gCOD/gVSS/d] = 13

Ks [g/l] = 0.03

VSS [g/l] = 0.053

CODeffl [g/l] = 0.096

V [m^3] = 5625

CH_4 production is 733,200 gCH_4/d; considering the CH4 molecular weigh of 16,043 g/mol, the volume occupied by a mole of ideal gas of 22.4 l and the percentage of methane in biogas of 60%, production of biogas is estimated in a value of 1706 m^3/d.

FACULTATIVE POND

- ***Area requirement***

Two types of facultative ponds are normally considered: primary facultative ponds that receive the raw wastewater after a pre-treatment, and secondary facultative ponds that receive the effluent of anaerobic ponds.

The two types of facultative ponds are now compared in terms of area requirement.

Design of facultative pond is based on the basis of the surface BOD loading:

$$\lambda_s = \frac{10 \cdot L_{i.} \cdot Q}{A_f}$$

λ_s = surface BOD loading [kg/ha/d];
L_i = BOD influent [g/m^3];
Q = flow [m^3/d];
A_f = area facultative pond [m^2];
10 = conversion factor = $\frac{1[kg]}{1000[g]} \cdot \frac{10000[m^2]}{1[ha]}$

They are usually designed for BOD loading between 100-400 kg/ha/d to permit the development of a healthy algal population (oxygen for BOD removal by the pond bacteria is mostly generated by algal photosynthesis).

The permissible design value of λs increases with temperature as described by the following equation (Mara, 1987):

$$\lambda_s = 350 \cdot (1.107 - 0.002 \cdot T)^{T-25}$$

This equation is based on a loading of 80 kg/ha day at ≤ 8 °C in European winters, a loading of 350 kg/ha day at 25 °C in northeast Brazil, and an arbitrary loading of 500 kg/ha day at 35 °C.

Considering a temperature of 24 °C the permissible design value of the surface BOD loading is:

24 °C ⟶ λ_s = 330.5 kg/ha/d

Considering the different BOD influent concentrations in primary and secondary facultative ponds, areas can be calculated as following:

$$A_f = \frac{10 \cdot L_{i.} \cdot Q}{\lambda_s}$$

$Q = 15.000\ m^3/d$;
$\lambda_s = 330{,}5$ kg/ha/d.

Primary facultative pond: $L_i = 200\ mgBOD_5/l$ ⟹ $A_{fI} = 90771\ m^2 \sim 9.1$ ha

Secondary facultative pond: $L_i = 64.0\ mgBOD_5/l$ ⟹ $A_{fII} = 29047\ m^2 \sim 2.9$ ha

Retention time is given by the equation:

$$\theta_f = \frac{A_f \cdot D}{Q_m}$$

A_f = area facultative pond [m^2];
D = depth of the facultative pond [m];
Q_m = mean flow [m^3/d] = $Q_m = \frac{Q_i + Q_e}{2}$

Calculation of the effluent flow of the facultative pond takes into account the evaporation of the water that in Cali can be estimated in a value of 4.8 mm/d.

$$Q_e = Q_i - 0.001 \cdot e \cdot A_f$$

Q_i = influent flow to the facultative pond [m^3/d];
e= net evaporation rate [mm/d];
A_f = area facultative pond [m^2].

Considering a depth of the facultative pond of 2 m for the primary facultative pond and 1.5 m for the secondary facultative pond (primary facultative pond need depth for sedimentation of the solids of the raw wastewatwer), the calculation of the retention time is given by:

$$\theta_f = \frac{2 \cdot A_f \cdot D}{\left(2Q_i - 0.001 \cdot e \cdot A_f\right)}$$

D = 1.5 m,;
e = 4.8 mm/d;
$Q_i = 15000\ m^3/d$.

Primary facultative pond: Af_I = 90771 m2 ⟹ θ_{fI} = 12.3 d

Secondary facultative pond: Af_{II} = 29047 m2 ⟹ θ_{fII} = 2.9 d

A minimum value of 4 days for temperatures ≥ 20°C is used to minimize hydraulic short-circuiting and to give the algae sufficient time to multiply.
Recalculation of the area of the secondary facultative pond is necessary:

θ_{fII} = 4 d ⟹ $$A_{fII} = \frac{2 \cdot Q \cdot \theta_f}{\left(2D + 0.001 \cdot e \cdot \theta_f\right)}$$ = 39746 m^2 ~ 4 ha

To guarantee a surface BOD loading of 330.5 kg/ha/d, totally are necessary for each plant:

Primary facultative pond	A_{fI} = 9.1 ha	θ_{fI} = 12.3 d
Anaerobic + Secondary facultative ponds	$A_a + A_{fII}$ = 4.5 ha	$\theta_a + \theta_{fII}$ = 5 d

- ***BOD removal***

BOD removal in facultative ponds depends by the temperature.
The concentration of BOD in the effluent of the facultative pond is given by:

$$L_e = \frac{L_i}{\left(1 + k_1 \cdot \theta_f\right)}$$

Where k_1 is the first-order rate constant for BOD_5 removal [d^{-1}], in which dependence by temperature is given by:

$$k_{1(T)} = k_{1(20)} \cdot \left(1.05\right)^{T-20}$$

Values of k_1 at 20 °C are different for primary and secondary ponds:

		T = 24 ºC	
Primary facultative pond:	$k_{1(20)} = 0.3\ d^{-1}$	⟹	L_e = 36.5 $mgBOD_5/l$
Secondary facultative pond:	$k_{1(20)} = 0.1\ d^{-1}$	⟹	L_e = 43.1 $mgBOD_5/l$

The Colombian Decree 1594 of year 1994 fixes the BOD removal to reach to a value of 80 %.
Primary and secondary facultative ponds have respectively BOD removal of 81.7 and 78.5 %.
A rock filter is necessary to decrease the algal BOD in the effluent that corresponds to the 70 % of the total.

- ***TSS Removal***

TSS are removed in the facultative ponds in a percentage of 75 %, with values in the effluent of:

Primary facultative pond:	TSS_i = 188 mg/l	⟹	TSS_e = 47.0 mgTSS/l
Secondary facultative pond:	TSS_i = 65.8 mg/l	⟹	TSS_e = 16.5 mgTSS/l

- ***Nitrogen Removal***

No total Nitrogen removal is assumed for an aerobic pond; nitrogen removal happens only in facultative and maturation ponds.

Total nitrogen removal is estimated from the following equation (Reed et al., 1995):

$$N_e = N_i \cdot e^{-\left(0.0064 \cdot 1.039^{T-20}\right) \cdot \left(\theta + 60.6 \cdot (pH - 6.6)\right)}$$

$$pH = 7.3 \cdot e^{0.005 \cdot Alk}$$

N_e = Total Nitrogen effluent [mg/l];
N_i = Total Nitrogen influent [mg/l];
T = Temperature [ºC];
Alk = Alkalinity [mgCaCO$_3$/l].

Ammonia removal is given by:

$$Amm_e = \frac{Amm_i}{1 + \left(5.035 \cdot 10^{-3} \cdot \frac{A}{Q}\right) \cdot e^{1.540 \cdot (pH - 6.6)}}$$

From measurements in the year 2000 about the wastewater of Cali, data of Total Nitrogen, Ammonia and Alkalinity in the influent are:

Total Nitrogen $_{in}$ = 51.2 mg/l;

Ammonia $_{in}$ = 18.9 mg/l;

Alkalinity = 193.6 mgCaCO$_3$/l ⟹ pH = 8

In the effluent of the facultative ponds so there are:

Primary facultative pond:	Total Nitrogen $_{effl}$ = 24.3 mg/l,	Ammonia $_{effl}$ = 14.8 mg/l
Secondary facultative pond:	Total Nitrogen $_{effl}$ = 25.9 mg/l,	Ammonia $_{effl}$ = 16.8 mg/l

- **Phosphorus removal**

Mara et al. (2001) give a value of Phosphorus removal in series of WSP of about 50 %.

Considering a value of Phosphorus in the influent of 4.7 mg/l (from measurements in year 2000), in the series of anaerobic + secondary facultative pond the value of P in the effluent is:

$$P_e = P_i \cdot (1 - \Pr emoval) = 4.7 \cdot (1 - 0.50) = 2.4 \text{ mg/l}$$

- ***Human intestinal nematode eggs removal***

Removal of human intestinal nematode eggs is given by:

$$R = 100 \cdot \left(1 - 0.41 \cdot e^{-0.49 \cdot \theta + 0.0085 \cdot \theta^2}\right)$$

Primary facultative pond: R = 99.6 %, $Eggs_{in}$ = 100 eggs/l ⟹ $Eggs_{effl}$ = 0.4 eggs/l

Secondary facultative pond: R = 93.4 %, $Eggs_{in}$ = 25.3 eggs/l ⟹ $Eggs_{effl}$ = 1.7 eggs/l

- ***Fecal Coliforms removal***

Fecal Coliforms in the effluent is given by:

$$FC_e = \frac{FC_i}{1 + k_b \cdot \theta_f} \qquad k_b = 2.6 \cdot (1.19)^{T-20}$$

Primary facultative pond: FC_{in} = 5,00E+07 E Coli/100ml ⟹ FC_e = 7.69E+05E Coli/100ml

Secondary facultative pond: FC_{in} = 8,05E+06 E Coli/100ml ⟹ FC_e = 3,68E+05E Coli/100ml

- ***Effluent flow***

The effluent flow is given by:

$$Q_e = Q_i - 0.001 \cdot e \cdot A_f$$

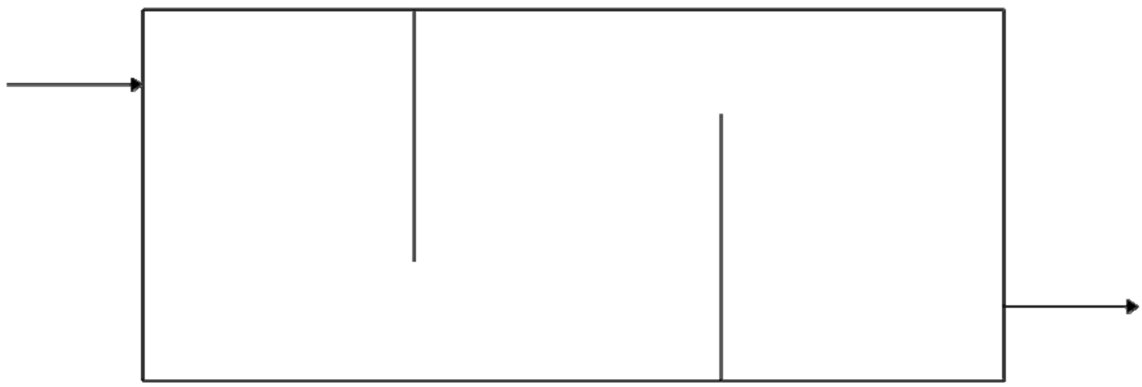
Considering evaporation in Cali of 4.8 mm/d:

Primary facultative pond: Af_I = 90771 m2 ⟹ Qe = 14564 m^3/d

Secondary facultative pond: Af_{II} = 29047 m2 ⟹ Qe = 14809 m^3/d

FACULTATIVE POND WITH BAFFLES

To increase the removal efficiency of the facultative ponds is possible to design them with baffles considering several reactor in series.



Appling the same methodology shown above for each cell in series, is possible to obtain a much better effluent with the same area requirements.

Final concentrations of primary and secondary ponds are shown in succession:

Primary facultative pond:

BOD_e = 13.1 mg/l

TSS_e = 2.9 mg/l

$Ammonia_e$ = 14.4 mg/l

Helminthes eggs = 0.027 eggs/l

E. Coli = 4609 E. Coli/100ml

Secondary facultative pond:

BOD_e = 40.9 mg/l

TSS_e = 16.5 mg/l

$Ammonia_e$ = 16.7 mg/l

Helminthes eggs = 0.3 eggs/l

E. Coli = 2,05E+04 E. Coli/100ml

The World Health Organization gives the guidelines for wastewater use in agriculture (*WHO guidelines for the safe use of wastewater, excreta and greywater*, Volume II, 2006).

The guidelines take into account, for high mechanized restricted irrigation (sugar cane culture), removal of human intestinal nematode eggs and Escherichia Coli as:

< 1 human intestinal nematode eggs / l

3 Log_{10} units reduction (Influent 5,00E+07 E.Coli/100ml ---> Effluent = 5,00E+04 E.Coli/100ml)

The effluent of facultative ponds with baffles can be reuse directly for crop irrigation without further tertiary treatment but a rock filter is anyway necessary.

After facultative ponds without baffles is instead necessary a maturation pond.

ROCK FILTER

Rock filters design is based on the following equation:

$$A_{rf} = \frac{Q_i}{HLR \cdot D_{rf}}$$

Q_i = wastewater flow [m^3/d];
HLR = hydraulic loading rate [m^3 of facultative pond effluent / m^3 of gross rock filter volume / day].
D_{rf} = wastewater depth in the rock filter.

In tropical climate should be used a value of HLR between 0.5-1 d^{-1} (Mara and Johnson, 2007).
A hydraulic loading of 1 m^3 per m^3 of rock filter volume per day was found to be more appropriate than one of 2 $m^3/m^3/d$ in northeast Brazil at 25 ºC (Mara et al., 2003).

Assuming a HLR = 1 d^{-1} and D_{rf} = 0.6 m, area of rock filter that follow the facultative ponds is:

after Primary facultative pond: ⟹ A_{rf} = 24.274 m^2 ~ 2.4 ha
after Secondary facultative pond: ⟹ A_{rf} = 24.682 m2 ~ 2.5 ha

Assuming a porosity of the rock filter of 0.4, the hydraulic retention time is given by:

$$\theta = \frac{\varepsilon \cdot V}{Q} = 0.4 \text{ d}$$

BOD removal in the rock filter is about 60 %

TSS removal in rock filter is given by:

$$TSS_e = 0.88 \cdot TSS_i - 1.92 \cdot \theta \cdot T$$

TSS_i = Total suspend solids in the influent [mg/l];
θ = retention time in the rock filter [d];
T = temperature.

MATURATION POND

To reach values gives by the WHO for effluent reuse can be designed a maturation pond that follows the facultative pond without baffles with a depth of 1 m and a HRT of 3 days.

Design of maturation ponds is given by the following equations:

- *Area requirement:*

$$A = \frac{2 \cdot Q_{in} \cdot \theta}{2 \cdot D + 0.001 \cdot e \cdot \theta}$$

$$Q_e = Q_i - 0.001 \cdot e \cdot A$$

- *BOD removal:*

$$L_e = \frac{L_i}{\left(1 + k_1 \cdot \theta_m\right)}$$

$$k_1 = k_{20} \cdot \left(1.05\right)^{T-20}$$ $k_{20} = 0.05\ d^{-1}$ for maturation ponds

- *TSS removal* = 30 %

- *Ammonia removal*

$$Amm_e = \frac{Amm_i}{1 + \left(5.035 \cdot 10^{-3} \cdot \frac{A}{Q}\right) \cdot e^{1.540 \cdot (pH - 6.6)}}$$

- *Human intestinal nematode eggs removal* = 90 % with 3 day of retention time

- *Escherichia Coli removal:*

$$FC_e = \frac{FC_i}{1 + k_b \cdot \theta_m} \qquad k_b = 2.6 \cdot \left(1.19\right)^{T-20}$$

To reach the values proposed by the WHO for effluent reuse are necessary:

Primary facultative pond: a maturation pond with retention time of 3 days and area of 4.3 ha.

Secondary facultative pond: a maturation pond with retention time of 3 days and area of: 4.4 ha

CONSTRUCTED WETLAND

CWs are secondary treatment units and must be preceded by a septic tank or an anaerobic pond.

In succession a sub-surface horizontal-flow CW is considered in series to the anaerobic pond already designed.

Input data are the same of the design of the facultative pond, which CWs are compared in terms of area requirement to obtain the same BOD removal.

Considering the model proposed by Reed et al. (1995), sub-surface flow CWs are normally designed for BOD removal as a plug flow reactor:

$$L_e = L_i \cdot e^{-k_t \cdot \theta}$$

L_e = BOD effluent;
L_i = BOD influent;
k_t = first-order rate constant for BOD removal [d^{-1}];
θ = retention time.

Dependence of the first-order rate constant for BOD removal is considered by the equation:

$$k_t = k_{20} \cdot (1.06)^{T-20}$$

k_{20} = first-order rate constant for BOD removal at 20 ºC [d^{-1}];
T = temperature.

The hydraulic retention time is given by:

$$\theta = \frac{V}{Q} = \frac{\varepsilon \cdot A \cdot D}{Q}$$

V = CW volume [m^3];
Q = influent flow [m^3/d];
ε = gravel porosity [-];
A = CW area [m^2];
D = CW depth [m].

Considering:

Q = 15.000 m^3/d;

T = 24 °C;

L_i = L_e of the anaerobic pond = 64 mg_{BOD}/l;

L_e = L_e of the facultative pond after rock filter unit = 17.2 mg_{BOD}/l;

ε = 0.4;

D = 0.6 m.

Reed et al. assume the following first-order rate constants for BOD removal at 20 ºC:

Sub-surface horizontal-flow CW $k_{20} = 1.104\ d^{-1}$ $\xrightarrow{T = 24\ ºC}$ $k_t = 1.394\ d^{-1}$

Area can be calculated by:

$$A = \frac{Q \cdot \ln(L_i / L_e)}{kt \cdot D \cdot \varepsilon}$$

Sub-surface horizontal-flow CW: A = 58922 m^2 ~ 5.9 ha θ = 0.94 d

Recalculating the area for a retention time of 1 day:

A = 62500 m^2 ~ 6.3 ha θ = 1 d

Considering the k-C* model (Kadlec and Knight, 1996) the following equations have been used to calculate the CW area:

$$\ln\left(\frac{C_e - C^*}{C_i - C^*}\right) = -\frac{k}{q}$$

C_e = effluent pollutant concentration [mg/l];
C_i = influent pollutant concentration [mg/l];
C^* = backgroung concentration [mg/l];
k = first-order areal rate constant [m/yr];
q = hydraulic loading rate [m/yr].

Rearranging the terms and considering conversion factors:

$$A = \left(\frac{0.0365 \cdot Q}{k}\right) \cdot \ln\left(\frac{C_i - C^*}{C_e - C^*}\right)$$

A = [ha]
Q = [m3/d]

The concentration in the effluent of all pollutants is given by:

$$C_e = C^* + \left(C_i - C^*\right)\cdot e^{\left(-\frac{k\cdot A}{0.0365\cdot Q}\right)}$$

Values of first-order areal rate constant and background concentration are showed in succession:

Table 4.2. First-order areal rate constant and background concentration values for SF CWs

	BOD	TSS	Total Nitrogen	Ammonia	Phosphorus
k20 [m/yr]	180	1000	27	34	12
θ	1,06	1	1,05	1,04	1
C* [mg/l]	3,5+0,053*Ci	7,8+0,063*Ci	1,5	0	0.02
θ	1	1,065	1	1	1

Considering the influent and effluent BOD_5 concentration of the facultative pond:

$L_i = L_e$ of the anaerobic pond = 64 mg_{BOD}/l;

$L_e = L_e$ of the facultative pond without baffles after rock filter unit = 17.2 mg_{BOD}/l;

Using the k-C* model, CW has an area of:

A = 4.1 ha

With a retention time of:

θ = 0.66 d

Retention time is too small so the recalculation of the area is necessary.

Using a retention time of 1.03 d is the area of the constructed wetlands is **6.44 ha** that is equal to the sum of the area of the secondary facultative pond the rock filter in series.

The sub-surface horizontal-flow CW can be compared with the secondary facultative pond + rock filter in terms of area requested.

Using the values in Table 4.2 and the equation of the k-C^* model for the calculation of the effluent concentration of the pollutants, the following values have been found:

BOD_{5in} = 64 mg/l ⟹ BOD_{5eff} = 8.6 mg/l;

TSS_{in} = 15.4 mg/l ⟹ TSS_{eff} = 15.4 mg/l;

Total $Nitrogen_{in}$ = 32.3 mg/l ⟹ Total $Nitrogen_{eff}$ = 19.1 mg/l;

$Ammonia_{in} = 18.9$ mg/l ⟹ $Ammonia_{eff} = 9.6$ mg/l

$Phosphorus_{in} = 4.8$ mg/l ⟹ $Phosphorus_{eff} = 3.9$ mg/l

Removal of E. Coli has been taken of 99%:

Fecal $Coliforms_{in}$ = 8.05E+06 Ecoli/100ml ⟹ Fecal $Coliforms_{eff}$ = 8,05E+04 E.coli/100ml

Helminth eggs are totally removed by the sub-surface wetland system[2].

The effluent has a flow of:

$$Q_e = Q_i - 0.001 \cdot e \cdot A = 14550 \text{ m}^3/\text{d}$$

It wouldn't be possible use the effluent of the CW unit for crop irrigation, in fact the value of E. Coli in the effluent is much more higher than the limit suggested by the World Health Organization.

Mara (2006) affirms that CWs cannot used for crop irrigation as there are no generally accepted design equations for E. coli removal and that CWs are not a viable alternative or addition to waste stabilization ponds.

To reuse the effluent of the CW system would be necessary a 3 days-maturation ponds in series to the CW unit with an area of 4.4 ha and a depth of 1 m.

[2] Mara (2003) affirms that helminth egg removal in the gravel bed of horizontal-flow wetlands is very efficient with removal of all eggs in the first 25 m of length of the gravel bed.

FISHPOND

In succession the alternative for integrated agricultural-aquacultural reuse of the effluent using a wastewater-fed fishpond is presented.

Designing fish pond is based on the surface loading of total Nitrogen (λ^{TN}) of 4 kgN/ha/d (Mara, 2003).

Fishpond area is given by the equation:

$$A = \frac{10 \cdot TN_i \cdot Q}{\lambda^{TN}}$$

The retention time is given by:

$$\theta = \frac{2 \cdot A \cdot D}{2 \cdot Q - 0.001 \cdot e \cdot A}$$

The depth of the fishpond is assumed of 1 m.

The concentration of fecal coliforms is given by:

$$FC_e = \frac{FC_i}{1 + k_b \cdot \theta} \qquad k_b = 2.6 \cdot (1.19)^{T-20}$$

Moreover in order to protect the fish from free ammonia toxicity, the concentration of NH_3 should be < 0.5 mgN/l.

The percentage of free ammonia in aqueous solution is given by:

$$p = 100 \cdot (10^{pk_a - pH} + 1)^{-1}$$

Where:

$$pk_a = 0.09018 + \left(\frac{2729.92}{T[k]} \right)$$

In fishponds pH values are usually between 6.5 and 7.5 (Mara, 2003). Taking a value of pH of 7.5 and the design temperature of 24 °C (297 K) the percentage of free ammonia in the aqueous system is 1.63 %.

To reduce the fishpond area a repartition of the flow is necessary. With 1/4 of the flow fishing ponds have the following areas and HRT:

After Primary facultative pond: 22.2 ha, HRT = 71.3 d

After Anaerobic pond + Secondary facultative pond: 24.0 ha, HRT = 76.7 d

After Anaerobic pond + Constructed wetland: 32.77 ha, HRT = 113.5 d.

In the 3 cases the effluent can be reused for crop irrigation (E. Coli have a 3 Log_{10} units reduction) and the concentration of ammonia is less than 0.5 mg/l.

Fish production can be estimated considering the fish density in the pond (3 fish/m^2), the average fish weigh (200 g), fish mortality (30%) and the number of harvest per year (3) and the volume of the fishing pond.

In the 3 alternatives the fish production for each of the 2 planned plats is respectively: 279 t/y, 302 t/y and 413 t/y.

NATURAL SYSTEMS COMPARISON

The schemes considered in the 3 alternative are presented in succession.

Figure 4.2. Alternative A

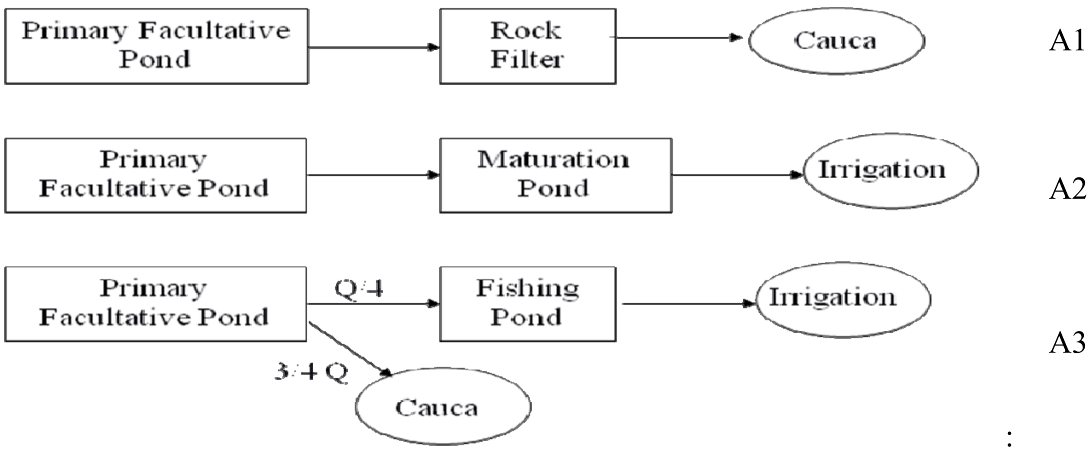


Figure 4.3. Alternative B

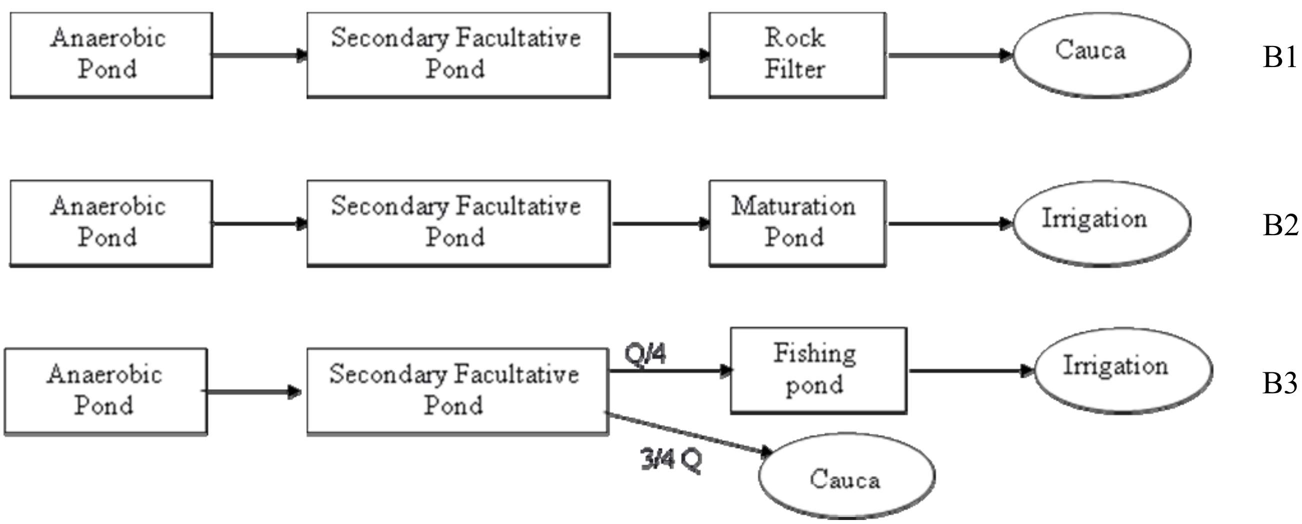
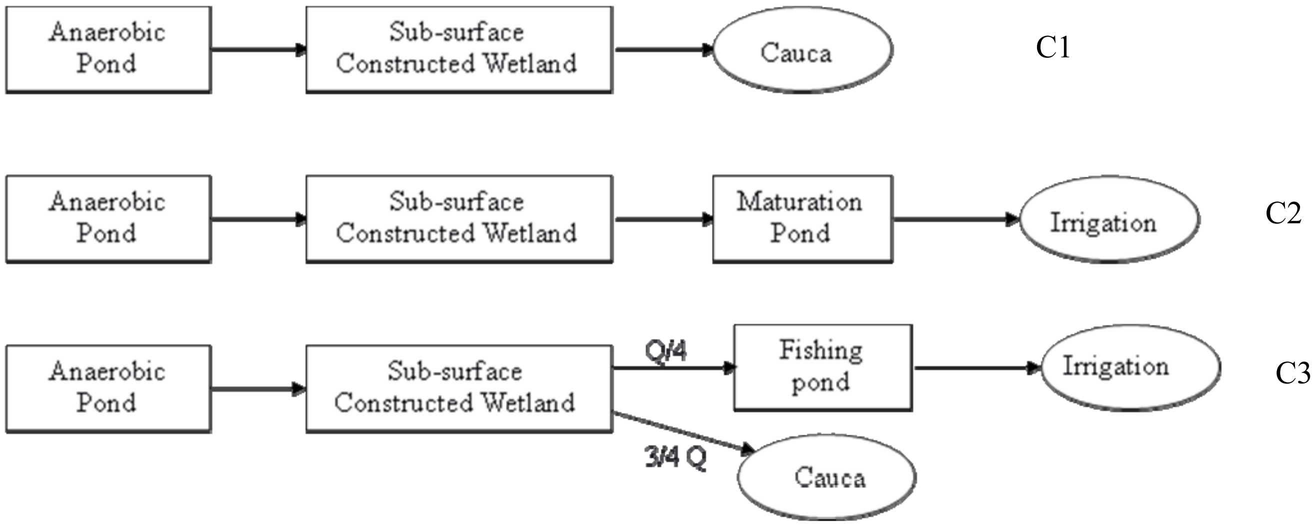


Figure 4.4. Alternative C



Has shown previously, alternative A1,A3 and B1,B3 can have has final receptor the irrigation instead of Cauca river if facultative ponds with baffles are implemented.

Design parameters of the 3 alternatives are shown in succession. The ratio between length and width is taken of L:W = 3:1.

Table 4.3. Alternative A

	A	HRT	D	L	W
	ha	d	m	m	m
Primary facultative pond	9,08	12,3	2	500	181,5
Rock Filter	2,43	0,4	0,6	260	93,4
Maturation pond	4,34	3	1	350	123,9
Fishing pond	22,16	71,3	1	800	277

Table 4.4. Alternative B

	A	HRT	D	L	W
	ha	d	m	m	m
Conventional anaerobic pond	0,5	1	3	120	41,7
High rate anaerobic pond	0,42	0.75	4-2	112.5	37.5
Secondary facultative pond	3,97	4	1,5	345	115,2
Rock Filter	2,47	0,4	0,6	270	91,4
Maturation pond	4,41	3	1	360	122,5
Fishing pond	23,98	76,7	1	840	285,4

Table 4.5. Alternative C

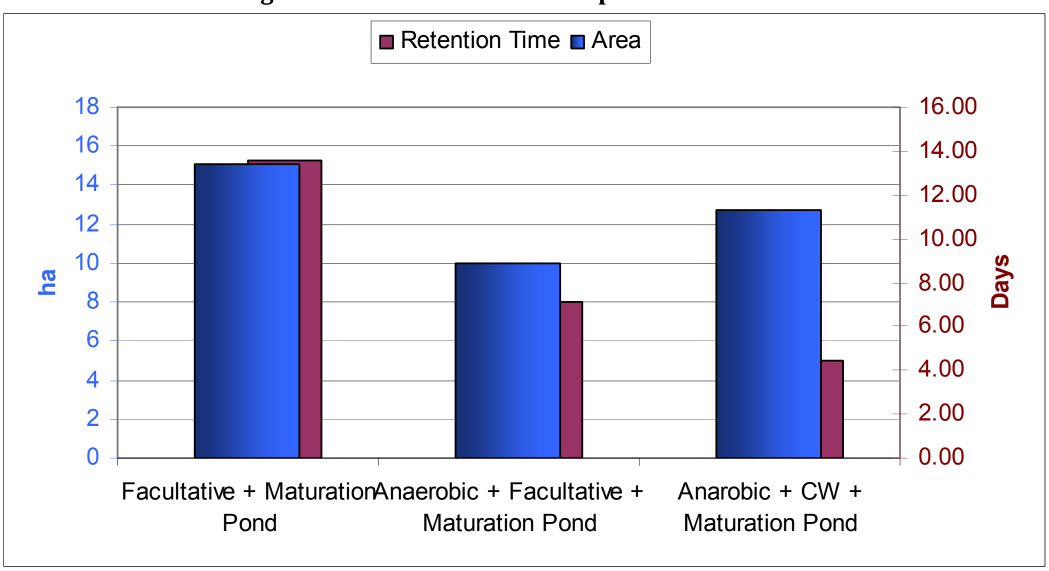
	A	HRT	D	L	W
	ha	d	m	m	m
Conventional anaerobic pond	0,5	1	3	120	41,7
High rate anaerobic pond	0,42	0.75	4-feb	112.5	37.5
Sub-surface CW	6,44	1,03	0,6	430	149,7
Maturation pond	4,38	3	1	360	121,5
Fishing pond	32,4	111,9	1	950	341,1

Comparison considering the implementation of maturation pond units is shown following:

Table 4.6. Removal efficiencies comparison

Natural systems	BOD	TSS	Total Nitrogen	Ammonia	Helminthes	E. Coli
	%	%	%	%	%	%
Facultative + Maturation Ponds	84,1	82,5	52,4	31,5	99,96	99,91
Anaerobic + Facultative + Maturation Ponds	81,3	93,9	49,4	21,9	99,83	99,96
Anarobic + CW + Maturation Ponds	95,3	94,3	31,1	40,9	100,00	99,00

Figure 4.5 - Area and HRT comparison



The combination of anaerobic and facultative ponds seems the best one in terms of area requirement. Moreover a CW system would need a big volume of gravel (37500 m^3) and more maintenance that will influence the costs.

The cost evaluation that is presented in the next chapter confirms these conclusions.

CHAPTER 5

Cost evaluation

Four main items, that include the biggest construction costs, have been considered to give a first idea about the budget needed to build the plant.

- land
- excavation
- impermeabilization
- gravel

Unitary costs showed in table 5.1 have been taken from real experiences in Colombia (El Cerrito Project, 2007-2008).

Table 5.1. Unitary costs

	COP[3] /m2	€*/m2	COP*/m3	€*/m3
Land cost	20000	6.67		
Excavation			14000	4.67
Liner	14000	4.67		
Gravel			80000	26.67

Values of excavation, liner and gravel take into account costs for installation and movement of material.

Considering design parameters shown previously, is possible to estimate construction costs for the designed alternatives. Values are referred to one of the two planned plants.

Table 5.2. Alternative A – Construction costs [€]

	Land	Excavation	Liner	Gravel	**TOTAL**
Primary facultative pond	605.143	847.200	423.600	0	1.875.943
Rock Filter	161.826	67.967	113.278	388.381	731.451
Maturation pond	289.204	202.443	202.443	0	694.089
Fishing pond	1.477.483	1.034.238	1.034.238	0	3.545.960

[3] 1 € is equal more or less to 3000 COP (Colombian Pesos)

Table 5.3. Alternative B – Construction costs [€]

	Land	Excavation	Liner	Gravel	**TOTAL**
Anaerobic pond	33.333	70.000	23.333	0	126.667
Secondary facultative pond	264.971	278.219	185.480	0	728.670
Rock Filter	164.547	69.110	115.183	394.913	743.752
Maturation pond	294.067	205.847	205.847	0	705.761
Fishing pond	1.598.349	1.118.844	1.118.844	0	3.836.037

Table 5.4. Alternative C – Construction costs [€]

	Land	Excavation	Liner	Gravel	**TOTAL**
Anaerobic pond	33.333	70.000	23.333	0	126.667
Sub surface CW	429.167	180.250	300.417	1.030.000	1.939.833
Maturation pond	291.720	204.204	204.204	0	700.127
Fishing pond	2.160.103	1.512.072	1.512.072	0	5.184.248

It's possible to check if these costs are realistic considering the guidelines for wastewater reuse of WHO of year 2006, in which costs per inhabitant are indicated for several natural treatment systems.

Table 5.5. Construction and Operating&Maintenance costs suggested by World Health Organization (WHO guidelines for the safe use of wastewater, excreta and greywater, 2006)

	Construction [US$/pe]	Operation&Maintenance [US$/pe]
Facultative Pond	15 – 30	0.8 – 1.5
Anaerobic + Facultative	12 – 30	0.8 – 1.5
Anaerobic + Facultative + Maturation Pond	20 – 40	1.0 – 2.0
Constructed Wetland	20 – 30	1.0 – 1.5

Considering half of the total population for each of the two planned treatment plants of 119.458 inhabitants, it is possible to estimate costs and compare them with costs calculated previously and check if they are realistic.

Table 5.6. Comparison between estimated construction costs and costs estimated with WHO guidelines

	Construction COSTS (Estimated) [€]	Construction COSTS (Calculated) [€]
Facultative Pond	> 1.194.580 < 2.389.160	1.875.943
Anaerobic + Facultative	> 955.664 < 2.389.160	855.337
Anaerobic + Facultative + Maturation Pond	> 1.592.773 < 3.185.547	1.561.098
Constructed Wetland	> 1.592.773 < 2.389.160	1.939.833

From Table 5.5 it is possible to see that O&M costs are considered for each year as a 5% of the construction costs. This value is taken to estimate O&M costs.

The NPV (Net Present Value) has been used to estimate the operation and maintenance costs for a period of 20 years with a discount rate of 13.92% (the same that EMCALI used for its conventional alternatives).

$$NPV = \sum_{i=1}^{n} \frac{value_i}{(1+rate)^i} \qquad \text{n = number of years}$$

In the following tables are showed the total costs that are the sum of construction costs and the NPV of O&M costs for a period of 20 years (considering a yearly inflation of the 5%) , for both two planned plants. Costs for construction of facultative ponds with and without baffles have been considered the same.

Table 5.7. Alternative A – total costs

	Construction [€]	O&M [€/year]	**TOTAL [€]**
FP + RF	5.214.788	260.740	7.565.570
FP + MP	5.140.064	257.004	7.457.160
FP + Fishing Pond	10.843.806	542.190	15.732.101

Table 5.8. Alternative B – total costs

	Construction	O&M (COP/year)	**TOTAL [€]**
AP + FP + RF	3.198.178	159.908	4.639.888
AP + FP + MP	3.122.196	156.110	4.529.654
AP + FP + Fishing Pond	9.382.746	469.138	13.612.408

Table 5.9. Alternative C – total costs

	Construction	O&M (COP/year)	**TOTAL [€]**
AP + CW	4.133.000	206.650	5.996.121
AP + CW + MP	5.533.254	276.662	8.027.597
AP + CW + Fishing Pond	14.501.496	725.074	21.038.644

AP: anaerobic Pond; FP: Facultative Pond; MP: Maturation Pond; RF: Rock Filter; CW: Constructed Wetland

These costs give an order of magnitude of the work. A detailed economic methodology would be necessary to give an exhaustive cost evaluation.

Moreover considering the implementation of fish ponds in the 3 alternatives, results about fish selling are presented in succession, considering one more time the NPV to calculate the profit in 20 years.

Table 5.10. Fishpond profit

	Fish Production [t/year]	Profit[4] [€/year]	Profit 2030 [€]
Alternative A	558	1.489.304	13.427.302
Alternative B	604	1.610.830	14.522.965
Alternative C	816	2.177.384	19.630.918

Money coming from fish culture would justify, in a period of 20 years, costs estimated for construction and maintenance of the fishing pond systems.

Moreover need to consider the money coming from reuse of wastewater for sugar cane irrigation and energy production from biogas in high rate anaerobic pond.

These topics need a more detailed economic analysis.

Appling prevention and minimization strategies, is possible to reduce the production of wastewater. In particular implementing the following strategies is possible to estimate a wastewater reduction of the 50%.

- water loss control in the housing., installation of low water consumption devices;
- participation in training programs about the efficient use of water and the use of new technologies;
- economic incentives for encourage water consumption reduction;
- rainwater use;
- implementation of grey-water recirculation systems;

[4] A value of 4.000 COP/pound (equal to 2.67€/kg more or less) has been considered to calculate fish culture profit.

Appling the design methodology with a decreasing of 50% of the flow influent, half areas and costs are finding without decreasing the wastewater quality.
Anyway is necessary to take into account that application of some of these strategies need time and are not immediately applicable, but anyway they have a big influence in wastewater treatment costs.

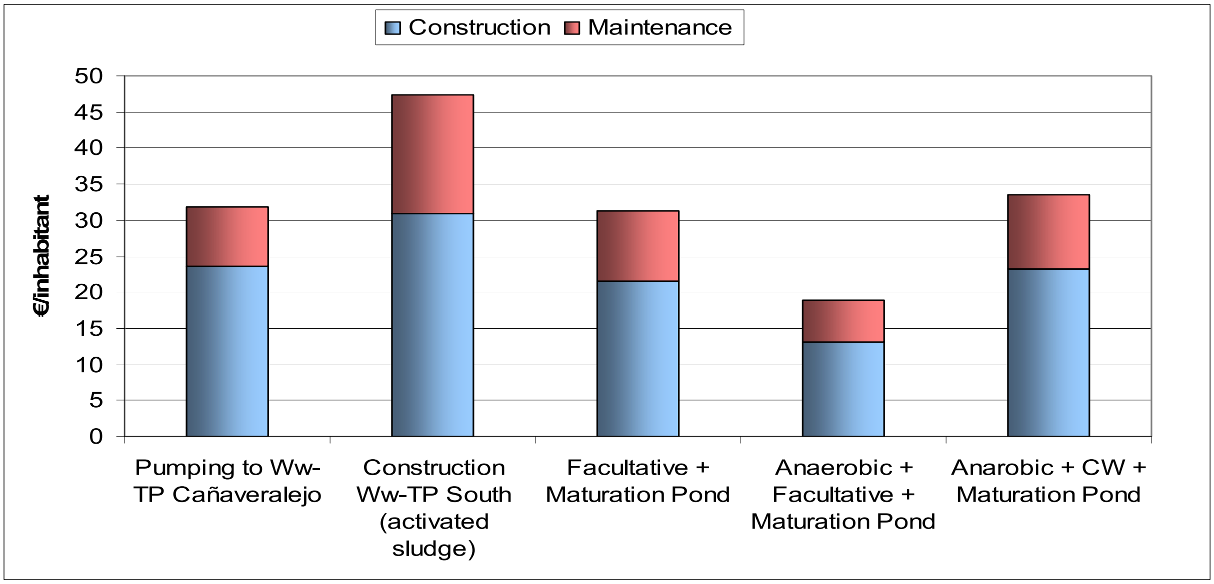
It is also possible to compare the results about cost evaluation with the costs give from EMCALI for conventional solutions on wastewater pollution control of the expansion area of Cali-Jamundí.
Alternatives taken into account by EMCALI concern pumping the wastewater to Cañaveralejo treatment plant and the construction of a conventional activated sludge treatment plant named Ww-TP South.

EMCALI considered a population in year 2030 of 450.880 inhabitants. Analyses performed about historical series of population densities, as shown in Chapter 3, carried to estimate the future population in a value of 238.916 that has been used for natural system design.
A comparison can be performed considering the total cost per inhabitant for the different solutions.
Total costs considered by EMCALI for its conventional solutions are shown in Table 5.11.

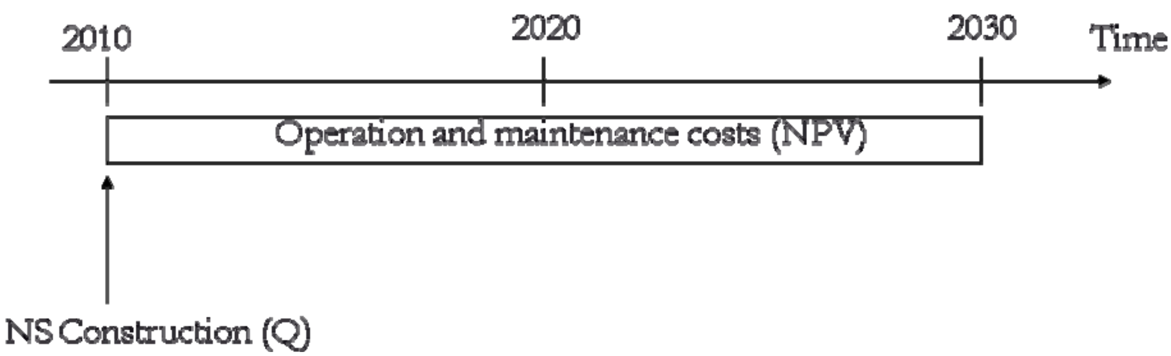
	Construction costs	Operation and maintenance costs
Pumping to Cañaveralejo treatment plant	31,871,900,000 COP	11,067,100,000 COP
	10.623.967 €	3.689.033 €
Construction WwTP-South (activated sludge)	41,866,300,000 COP	22,192,900,000 COP
	13.955.433 €	7.397.633 €

Comparison between the different technologies considering implementation of maturation pond units is proposed in succession.

Figure 5.1. Alternative comparison – costs per inhabitants



In this situation the construction of the 2 plants is planned at t=0 as shown below.



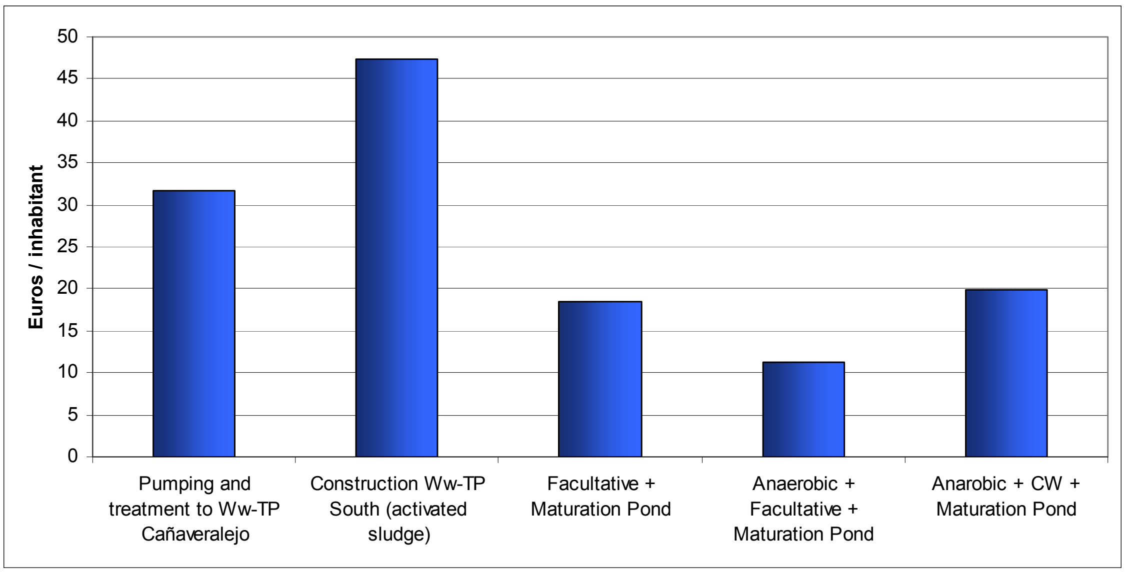
From Figure 5.1 is possible to see that all the natural systems has economical benefits towards the construction of the new wastewater treatment plant with activated sludge WwTP-South, moreover the effluent of natural system is better and can be used for crop irrigation.

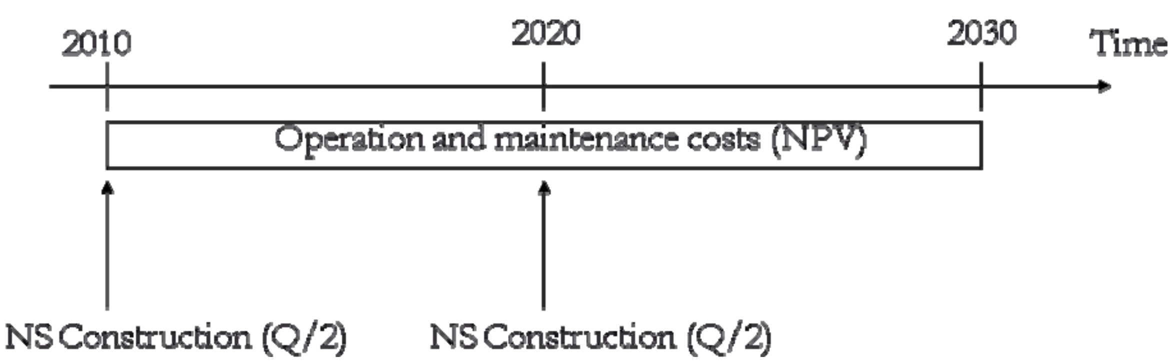
The costs of the alternative planned by EMCALI that consider to use existing infrastructure (pumping the wastewater to Cañaveralejo treatment plant) don't consider the costs for treatment of the water so the O&M costs have to be increased to take into account the treatment. Also in this case natural systems are better in terms of water quality and costs.

Moreover is possible to show another scenario in which the plant is constructed in 2 steps, the first plant whit Q/2 at t=0 and the second one at t=10 years.

In this way is possible to put costs for construction of the second plant in the calculation of the NPV with a consequently decreasing of total costs as shown in Figure 5.2.

Figure 5.2. Alternative comparison – costs per inhabitants (construction in two steps)

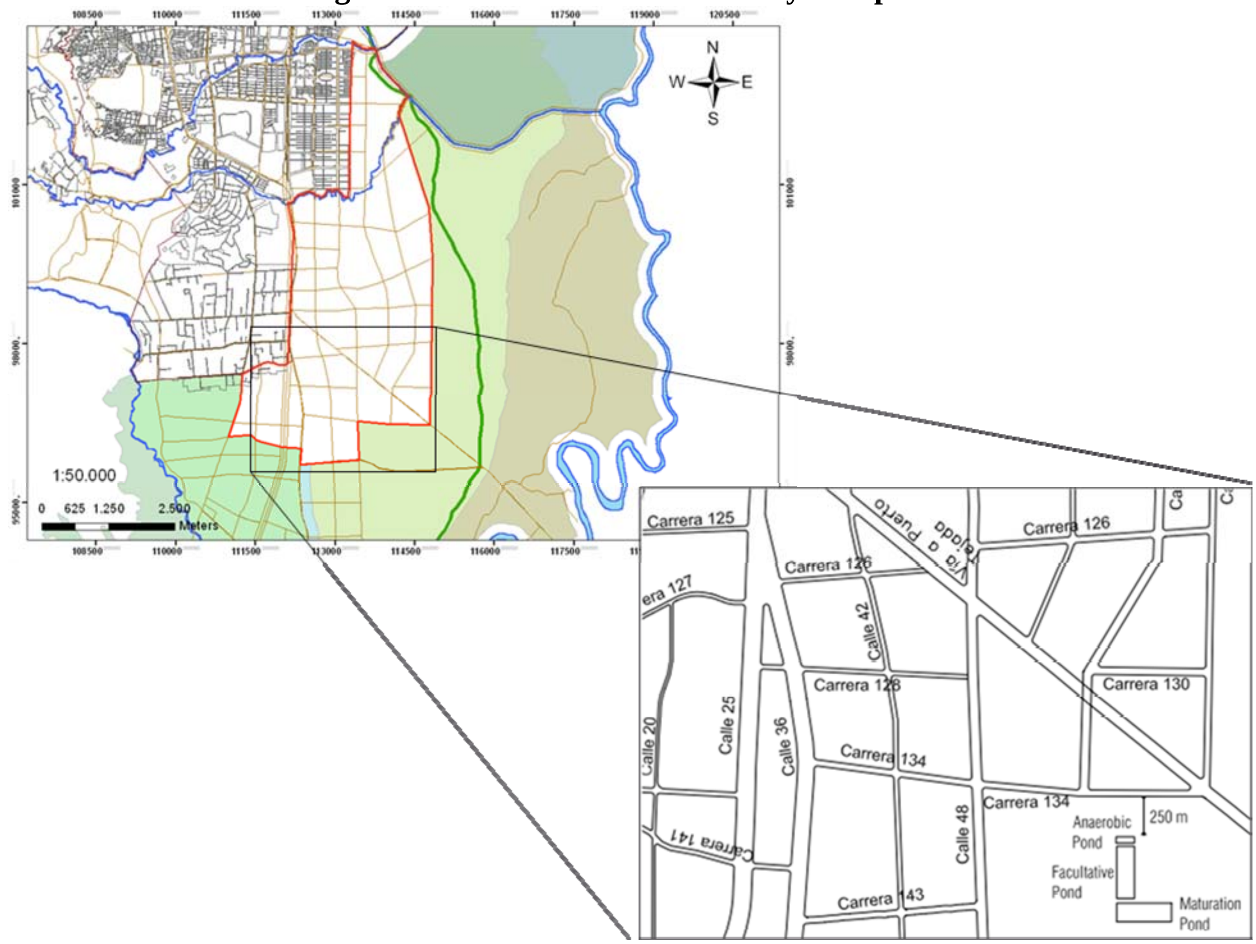




The alternative that considers a series of anaerobic and facultative pond seems the best in terms of area requirement and costs.

In Figure 5.3 is presented a scheme of one of the two plants to give an idea of the surface area required to build the plant.

Figure 5.3. Scheme of one natural system plant.



CONCLUSIONS AND RACCOMENDATION

- From this work is possible to conclude that natural system for wastewater pollution control in the expansion area of Cali-Jamundi can be satisfactory applied.

- They have economical benefits towards the conventional alternatives planned by EMCALI.

- Applying natural systems is possible to reuse the effluent for sugar cane culture present in the zone. Implementing high rate anaerobic ponds would by possible energy generation from the biogas produced. Implementation of fishponds is also possible. These initiatives make the wastewater treatment sustainable and can support economically the process.

- Further detailed economical analyses are recommended in particular towards reuse of effluent and biogas. Also a study on water demand for sugar cane cultures is necessary and need to add to the study geotechnical and geological analyses.

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