République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Université 8 Mai 1945 Guelma

Faculté des Sciences et de la Technologie

Département de Génie Civil et d'Hydraulique

Laboratoire de Génie Civil et d'Hydraulique (LGCH)

THÈSE

EN VUE DE L'OBTENTION DU DIPLOME DEDOCTORAT EN 3ème CYCLE

Domaine : Sciences et Technologie Filière : Hydraulique

Spécialité : Hydraulique

Présentée par

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Intitulée

Contribution à la gestion des eaux pluviales en milieu urbanisé : cas de la ville de Guelma

Soutenue le : 29/05/2022 Devant le Jury composé de :

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Année Universitaire : 2021-2022

Dedication

To my parents

To my brothers and sisters Khadija, Youcef, Semia, Messouda,Meriem, and Yassmine.

To all my family

To my friends

I dedicate this Thesis.

Brahim Abdelkebir

Acknowledgement

Above all I thank Allah who guided me throughout my life, who allowed me to educate myself and get this far in my studies. He, Allah the Greatest of all, gave me courage and patience to go through all the hard times, and that allowed me to maintain my goal in this challenge.

I would particularly like to thank my supervisors: Professor **MAOUI Ammar** and **MOKHTARI Elhadj**. I want to express my deep gratitude for the support with which they have guided and encouraged me, and for allowing me to complete this work in the best conditions.

Professor **MAOUI** is wholeheartedly appreciated for his commitment and honest support. He pulled the line of the path I have followed in this work. He helped me and provided me with precious advice, to finalize this thesis.

Dr **MOKHTARI** is thanked for his commitment and loyal support.

My appreciations as well go to mentor Professor **MANSOURI Rachid** for doing me the honor and the immense pleasure of accepting to preside over the jury.

I warmly thank Dr **KHEROUF Mazouz** who accepted to be part of the jury.

I would also like to thank Dr **MERAD Dounia** who agreed to be a member of this jury.

My deep respect goes to my teachers from the Hydraulics Department Graduation Guelma, in particular, Mr. MANSOURI R, Mr. NOUAOURIA S, Mr. KHROUF M, Mr. BOUTHELDJA For their advice, guidance and help.

My sincere thanks go to my colleague Bellom F, for his services andencouragement.

I would also like to thank all those who facilitated the long work required by this studynamely: Dr. ENGEL Bernard, Dr. CHEN Jingqiu and Dr. ABOELNOUR Mohamed Lab members Department of Agricultural and Biological Engineering, University of PURDUE, USA.

ملخص:

تتميز منطقة قالمة الواقعة شمال شرق الجزائر بمناخ شبه رطب. إن الفيضانات الدورية التي حدثت في السنوات الأخيرة يفضلها معدل التحضر. الهدف من هذه الدراسة هو إيجاد طريقة تجعل من الممكن تقليل حجم الجريان السطحي في حوض الدراسة ، باستخدام تقنيات حديثة فعالة دون اللجوء إلى التقنيات التقليدية لزيادة أبعاد شبكة الصرف الصحي ، والتي ستكون مكلفة. تم تطبيق نمذجة جريان هطول الأمطار بواسطة نموذج PC-SWMM على البيانات المرصودة ، خلال الفترة من 13 نوفمبر 2008 إلى 3 ديسمبر 2008 . بعد التحقق تمامًا من صحة نموذج PC-SWMM في حوض قالمة ، يتم استخدامه في الحماية من الفيضانات ، باستخدام ما يسمى بالنمذجة في الوقت الفعلي والتي تعتمد على مبدأ تجديد المياه. تم استخدام استراتيجية تطوير منخفضة التأثير (LID) لتقليل حجم الفيضانات وتقليل تدفق الذروة. يمكن أن يؤدي تنفيذ العديد من ممارسات LID (المخالفات البيولوجية ، وخنادق التسلل ، والأرصفة القابلة للاختراق ، وحدائق الأمطار وبراميل المطر) إلى تقليل حجم الجريان السطحي من 4.04 إلى 76.01 ٪ وذروة التدفق بمقدار 2.02 عند 51.74 ٪ لحدث مدته 10 سنوات . من خلال النتائج التي تم الحصول عليها ، يمكن أن يكون LID نهجًا فعالًا بشكل واضح لحل مشكلة الفيضانات في مستجمعات المياه الحضرية. يمكن لنموذج PCSWMM محاكاة تأثيرات ممارسات LID أن نموذج PCSWMM قادر على مساعدة المصممين والمنفذين وصانعي السياسات في تقييم آثار ممارسات LID على تقليل الجريان السطحي.

الكلمات المفتاحية: قالمة، فيضان، PCSWMM، نظم المعلومات الجغرافية، LID

Résumé :

La région de Guelma située au Nord -Est Algérien se caractérise par un climat sub-humide. Les inondations périodiques survenues ces dernières années sont favorisées par le taux d'urbanisation important. L'objectif de cette étude est de trouver une méthode permettant de réduire le volume de ruissellement superficiel dans le bassin d'étude, en utilisant des techniques modernes efficaces sans recourir aux techniques classiques d'augmentation des dimensions du réseau d'assainissement, qui seraient coûteuses. La modélisation pluie-débit par le modèle PC-SWMM est appliquée sur les données observées, durant la période du 13 novembre 2008 au 03 décembre 2008. Après avoir complètement validé le modèle PC-SWMM sur le bassin de la Guelma, il est utilisé pour la protection contre les crues, en utilisant ce qu'on appelle la modélisation en temps réel qui repose surle principe de la reconstitution de l'eau. Une stratégie de développement à faible impact (LID) a été utilisée pour réduire la taille des crues et réduire le débit de pointe. La mise en œuvre de plusieurs pratiques LID (biorétentions, tranchées d'infiltration, chaussées perméables, jardins de pluie et barils de pluie) pourrait potentiellement réduire le volume de ruissellement de 4,04 à 76,01 % et le débit de pointe de 2,02 à 51,74 % pour un événement de 10 ans. A travers les résultats obtenus, le LID peut être une approche clairement efficace pour résoudre le problème des inondations dans les bassins versants urbains. Le modèle PCSWMM peut simuler les impacts des pratiques LID. Le modèle PCSWMM s'est avéré capable d'aider les concepteurs, les exécutants et les décideurs à évaluer les effets des pratiques LID sur la réduction du ruissellement.

Mots clés : Guelma, Inondation, SIG, PCSWMM, LID

Abstract:

The region of Guelma located in the North-East of Algeria is characterized by a sub-humid climate. The periodic floods that have occurred in recent years are favored by the rate of urbanization. The objective of this study is to find a method making it possible to reduce the volume of surface runoff in the study basin, byusing efficient modern techniques without resorting to conventional techniques of increasing the dimensions of the sewerage network, which would be expensive. The rainfall-runoff modeling by the PC-SWMM model is applied to the observed data, during the period from November 13, 2008 to December 3, 2008. After having completely validated the PC-SWMM model on the Guelma basin, it is used for flood protection, using what is called real-time modeling which is based on the principle of water replenishment. A low impact development strategy (LID) was used to reduce the size of the floods and reduce the peak flow. The implementation of several LID practices (bioretentions, infiltration trenches, permeable pavements, rain gardens and rain barrels) could potentially reduce the volume of runoff from 4.04 to 76.01% and the peak flow by 2 .02 at 51.74% for a 10-year event. Through the results obtained, the LID can be a clearly effective approach to solve the problem of flooding in urban watersheds. The PCSWMM model can simulate the impacts of LID practices. The PCSWMM model has been shown to be able to help designers, implementers and policy makers assess the effects of LID practices on runoff reduction.

Keywords: Guelma, Flood, GIS, PCSWMM, LID

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List of Acronyms and Symbols

Acronymes	
BMP	Best Management Practice
DWF	Dry Weather Flow
DEM	Digital Elevation Model
GIS	Geographic Information System
SRTM	Shuttle Radar Topography Mission
LULC	Land Use Land Cover
ANRH	Agence Nationale des Ressources Hydriques
PC-SWMM	Personel Computer-Storm Water Management Model
NWSRFS	National Weather Service River Forecasting System
CN	Curve Number
NRCS	Natural Ressource Conservation Service
SCS	Soil Conservation Service
NSE	Nash-Sutcliffe Efficiency coefficient
LID	Low Impact Devlopement
EPA	Environmental Protection Agency
S RTC	Sensitivity-based Radio Tuning Calibration
AMC	Antecedent Moisture Condition
SUDS	Sustainable Urban Drainage Systems
LIUD	Low Impact Urban Design and Development
WSUD	Water-Sensitive Urban Design
IMPs	Integrated Management Practices
ONA	Office National de l'Assainissement

General Introduction

General Introduction

Floods are the most prevalent natural phenomena in the world, which can cause massive material and human damage to facilities and physical structures. They ultimately disrupt sustainabledevelopment (Abdelkebir et al., 2021). The frequency of floods has increased in recent decades, whether at the national or global level, due to climate change and irregular urbanization, especially in underdeveloped countries (de Freitas & Ximenes, 2012).

Algeria has suffered in recent decades from floods, perhaps the most prominent of which is the flood that affected Bab El Oued district (Algiers) on 10 November 2001 caused one of the most unique and worst disasters that leaded over 800 fatalities, 150 missing persons, 30,000 people left homeless, in addition to net economic damages of over 250 million euro. It causes a huge psychological shock. The second important floods, in and around the Algerian oasis town of Ghardaia on 2 October 2008, are caused by heavy rains have killed at least 33 people and injured 50and approximately 2,000 families left homeless. Many other floods happened in many Algerian cities. This floods event are often characterized as rapidly developing events which leave little time for people to take actions to reduce damage to property and the risk to life. This flood event is actually a flash flood event; this type is not well known in Algeria. (Hamouda & Boulmaiz, 2020)

Indeed, recent developments in geographic information systems (GIS) have made it possible to model and represent real geographic phenomena of computerized spatial database through which they can be stored, analyzed and displayed (Kvamme, 1999).

Use GIS includes, among other things, spatial modeling of the landscape, analysis of the useland, flood modeling, and environmental planning (Ogden et al., 2001).

We highlighted on the Guelma catchment in our study due to the periodic floods it has known in recent years, due to the irregular demographic growth rate, which clearly contributed toan increase in the percentage of impermeable areas compared to the permeable areas, The Guelma catchment elevation ranges from 0 to 500 m. It is characterized by a semi-humid climate with an average annual precipitation of about 400 mm/year and average temperatures ranging from 34.9 °C in summer to below 10.1 °C in winter.

The general objective of the study is to reduce the volume of surface runoff in the study catchment by using effective modern techniques without resorting to the classic techniques of increasing the dimensions of the sewage network, which would be costy.

This document includes the following chapters:

- The first chapter is devoted to the presentation of the problem and draws up, from the analysis of the scientific literature, a state of the data and the methods allowing to estimate the urban flooding.
- The second chapter presents the study area, with particular emphasis on the characteristics of the studied watershed.
- The third and fourth chapter is devoted to the analysis of precipitation and runoff at the scale of the studied watershed.
- The fifth chapter deals with the effectiveness of the proposed techniques for reducing the volume of runoff and controlling flooding.

Finally, the general conclusion summarizes the main results, and offers research perspectives since the scope of the theme still deserves many other developments.

Chapter 1
State of the Art

1. Introduction

Flood is a term used to indicate an enormous volume of precipitation. If there is an outflow of water in a location, it is said to have been flooded. The condition created where the water becomes uncontrollable is said to have been flooded. The flood can take various forms, such as in the form of heavy rainfall, when the dam is breached. In addition, the loss of snow also contributes to floods.

Floods contribute to overflowing and extensive delivery of water, but are not considered healthy for drinking purposes. As a result, floods carry with them a variety of diseases such as typhoid, cholera, and many others (Venkataramanan et al., 2019) .

Floods are one of the most common phenomena in the world (Goncalves et al., 2018). Flood is typically caused by natural causes. It can also be caused by man-made causes. It causes tremendous damage to life and property. There are also common sources of floods. Any of the notable among them include:

- Significant rainfall: irrigation systems and efficient infrastructure help during heavy rainfall. They help pump polluted water into rivers in a simple way. However, in cases of heavy flooding, the de devices will stop operating. As a result, flood is triggered.
- The flooding of the rivers: people living near the rivers are still at risk of life from the overflowing of the rivers. A string of dams were designed to avoid such a scenario. However, if these dams are not well maintained, they will cause floods and tremendous destruction.
- Collapsed Dams: in the case of heavy flooding, the dams installed tend to fail. As a result, causing the flood situation to become even more serious for the people living around.
- Snowmelt: the condition of floods occurs at the time of the high melting of snow due to excessive precipitation and other causes. Adopting sustainable steps for extreme rainfall will aid in coping with the flood situation.
- Deforestation: destroying trees in a careless way, i.e. deforestation is also a big cause of man made floods. Trees avoid soil erosion, as well as crop losses. The landscape is also enriched with more and more trees. This also blocks the huge flow of rain, which stops flooding.
- Climate change: climate change triggered by human practices often contributes to the possibility of floods. Human beings cut trees in vast numbers, thereby affecting the mechanism of photosynthesis. As a result, increased levels of carbon dioxide in the atmosphere cause climate change that poses a danger to natural hazards such as hurricanes, etc
- Emission of Greenhouse Gasses: combustion of fossil fuels, human influences, emissions both deplete the level of the ozone layer and raise the level of greenhouse gases, becoming a significant cause of man-made flooding;
- Other Factors: damaged supply lines allow the outflow of water but result in less damage. There is also water streaming from the washing machines. In comparison, the overflow of dishwashers worsens the problem. Also, the lack of proper sewage systems adds to the destruction of this natural disaster

Floods are classified into two main categories by source and by mechanism as shown in the **Tab1.1**

Tab 1.1. Flood-Definition-and-Types (Istomina et al., 2005)

		Definition	Example
Types of Floods	By Source	Flood of the River: flood correlated with high water in rivers, lakes, Mountain streams, canals, lakes, including melting snow.	Fig.a
		Rain Flood: flood-related floods and water-borne areas From rain or melted snow. Can provide municipal flood waters, or High flood in non-urban counties.	Fig.b
		Flood from Groundwater: Flood associated with flooding an area due to an increase of water level above ground level. May include an increase in ground and underground water due to the high of surface water.	Fig.c
		Onshore Storm: Flood correlated with floods and coastal area Lands, from river heads and tidal lakes.	Fig.d
		Flood from Hydrotechnical Devices: Flood associated with floods Area due to the collapse of the dam systems.	Fig.e
	By Mechanism	Normal Swelling: overflow of the region due to a rise in the water volume.	Fig.f
		Water Transfer: by flood systems – floods of the region due to flooding Shift of water, e.g. via the crown of the river bank.	Fig.g
		Failure of Structure: storms or technical facilities – floods and floods Area caused by devastation or disruption or by natural or technological flooding. Banks or technical systems, including retention problems. The structure, the wings of the floodgate.	Fig.h
		Blockage Flood: Flooding of a natural or natural environment. Artificial obstruction of the watercourse	Fig.i

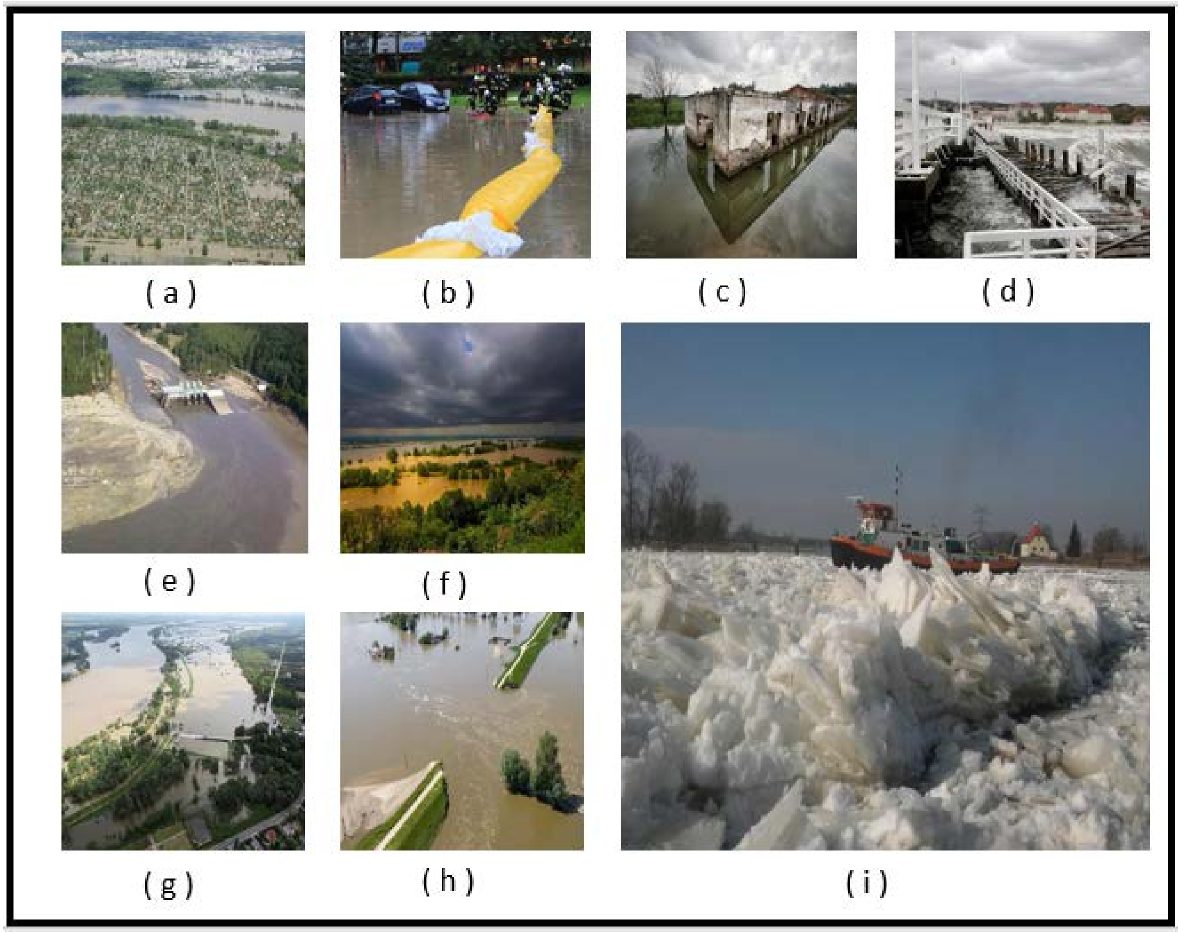


Fig 1.1 (a, b, c, d, e, f, g, h, i) the types of floods.

1.2. Floods on Global and Local Scale

1.2.1 Floods on Global Scale

Flood hazard caused nearly 0.6 trillion USD worth of damage (28% of the total from all disasters) in the 20 years since 1992 (Güneralp et al., 2015). Over the period 1980-2013, flood losses exceeded 1 $ trillion globally, and resulted in ca. 220,000 fatalities (Dottori et al., 2016).

According to the international disaster database EM-DAT, 2,470 floods have occurred internationally over the past twenty years from 1999 to 2009. 147,457 people lost their lives and thedamage was estimated at 372.5 billion US $ (EM-DAT, 2015). The occurrence of floods varies afrom country to country on the basis of a variety of geological, spatial, developmental and even administrative factors Fig1.2.

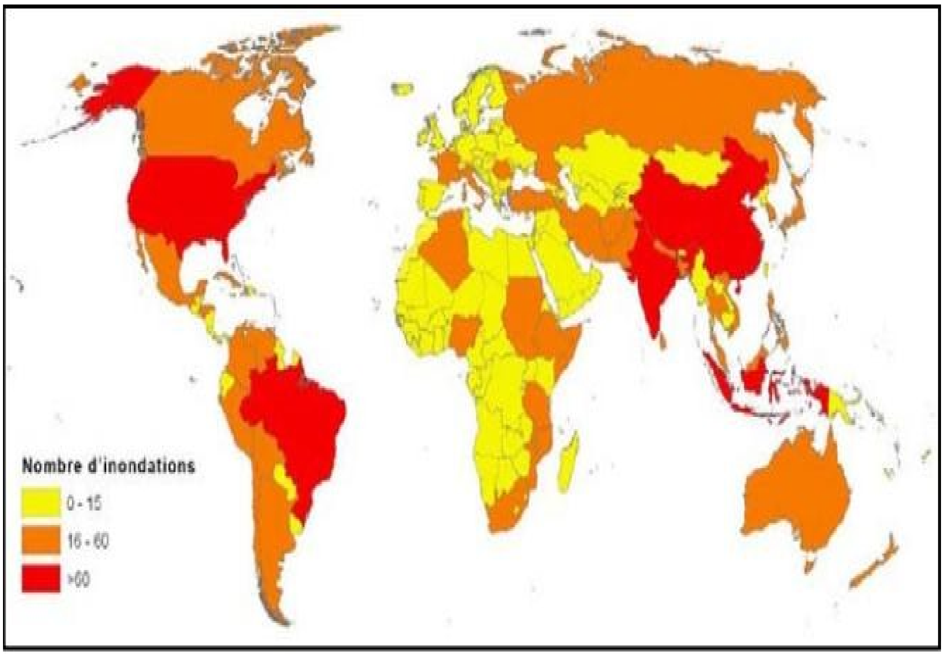


Fig 1.2 Map of floods per country during the period 1974 - 2003 (EM-DAT, 2015)

1.2.2 Floods on Local Scale:

Algeria, like other countries in the world, has undergone floods, which, in our view, seem more deadly and destructive than those do, which have happened in the Mediterranean basin. Over the last decade, we have been able to collect data from a few storms, like (Minist et al., 2019):

- October 05-06, 2011 (Oued Ferrane and Hai El Fidayine El Bayadh) 10 deaths and dozens of missing people during 3 days of flooding.
- May 28, 2006 (Boukhanéfis Sidi Bel Abbes).
- November 10-11, 2001 (Bab El Oued - Algiers): torrential rains, 733. Victims, 30,000 homeless and significant material damage.
- October 22, 2000 (Western Algeria): more than 24 deaths.
- October 1994 (several regions of the country): 60 deaths and dozens of missing during ten days of flooding.
- October 20, 1993 (Western Algeria): 22 deaths and 14 injured in Oued Rhiou:

According to the census carried out by the civil protection services, one municipality in three is expected to be partly or completely submerged. Such floods are the most frequent and devastatingof natural disasters. Often, they exceed the size of a national tragedy. Fig1.3 indicates the magnitude of the floods in Algeria.

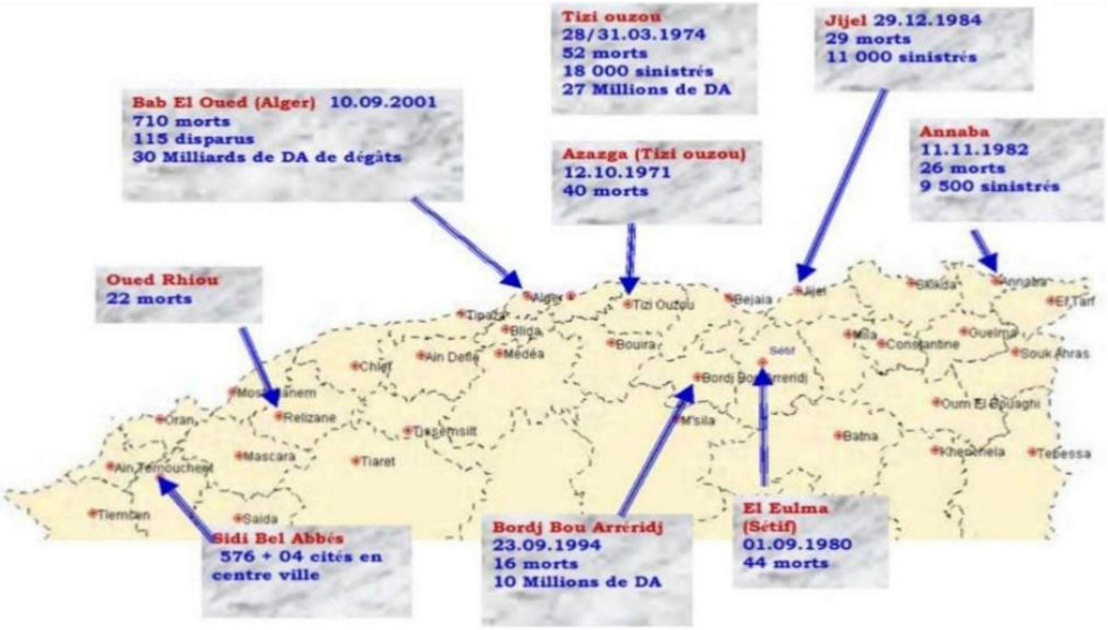


Fig1.3 Significant cases of flooding in Algeria (Sumi et al., 2022)

1.3 Urbanization and Its Impacts

1.3.1 Urbanisation

Human effect on the physical and biological processes of the Earth's surface is not a new manifestation of industrial societies; rather, it is widespread throughout our history. When human populations have risen, so has their footprint, that between 30 and 50 per cent of the Earth's surface has now been transformed. Much of this land is not covered by a pavement; in fact, less than 10%of this transformed surface is genuinely "urban." However, urbanization induces extensive land change outside its immediate boundaries, especially in visibly rural areas, by changes in agriculture and forestry that sustain the urban population. In the immediate borders of towns and suburbs, shifts in environmental environments and urbanization patterns are among the most radical of any human activity (Kabbani, 2015).

1.3.2 Urban Hydrology

The state of the art sees urban hydrology as a "master variable driving ecological degradation." However, developments in this research aim to enhance the management of urban stormwater in order to improve sanitation and public health, the restoration of the environment and the viability of cities and the protection of floods. Predicting the consistency of storm water accurately depends on the powerful simulation of the river. Therefore, the first inputs for modeling urban storm water quality disposed of in water sources are urban hydrology components. Movement and circulation of water in the sense of urban hydrology are regulated by physical processes referred to as the hydrological cycle. The hydrological period in urban environments, Fig 1.4 consists of the following stages:

- Precipitation.
- Interception.
- Infiltration: in addition to being affected by perviousness of land surfaces, the capacity of soil infiltration is also affected by antecedent precipitation such as short-interval high intensity rains coming after dry periods. A minimal steady infiltration rate is approached after one to two hours.
- Depression storage and detention: precipitation that is trapped in superficial depressions of different depths and sizes.
- Overland flow.
- Gutter storage: usually has a greater effect in reducing peak flows than detention surfaces
- Conduit storage: the volume stored in the pipe may reduce the peak flow rate of the hydrography precipitation, which is defined in hydrology as water hitting the earth's surface in either liquid or solid form, is the key input into the hydrological cycle course. Precise assessment of precipitation in urban catchments is a prerequisite for determining the rainfall-runoff response. Precipitation may take one of the following forms: snow, ice, hail, or its variants, such as sleet and drizzle. Precipitation variables are atmospheric humidity and pressure, temperature and climate. The major features of precipitation are :
    - Volume, with units of area x depth.
    - Duration or time period of rainfall event.
    - Intensity, with units of velocity.
    - Frequency or the return period of a certain storm.

Cities or populated areas are affected by precipitation. In urban areas, recently built soils, which have different thermal properties than historically natural soil, alter processes in boundary layers, producing what is known as urban thermal islands.

Sometimes, their influence is spread to the downwind of metropolitan areas. Interception is the amount of precipitation absorbed by plant roots, canopy or some other type of soil. Interception limits the amount available from the initial process of the storm. The drastic consideration of the Soil Conservation Service is that the original abstraction must be fulfilled before the water is eligible for runoff. This initial abstraction is meant to be equal to the storage potential of the soil. In urban areas, however, precipitation intercepted by vegetation is not as significant as that held onand evaporated from the building surfaces and roofs. In the urban watershed, the enlarged area ofthe impervious areas reduces infiltration and greatly increases the amount of surface runoff. Several techniques are available for the estimation of drainage volumes and concentrations in urban watersheds.

- ✓ Unit hydrograph methods such as: Espey Ten-Minute Unit Hydrograph, SCS Unit Hydrograph, and Time-Area Unit Hydrographs.
- ✓ Soil conservation service methods: TR-55 Graphical Peak Discharge Method, and TR-55Tabular Hydrograph Method.
- ✓ Santa Barbara Unit Hydrograph Method.
- ✓ USGS regression equations.
- ✓ The Rational Method.
- ✓ The Kinematic-Rational Method.

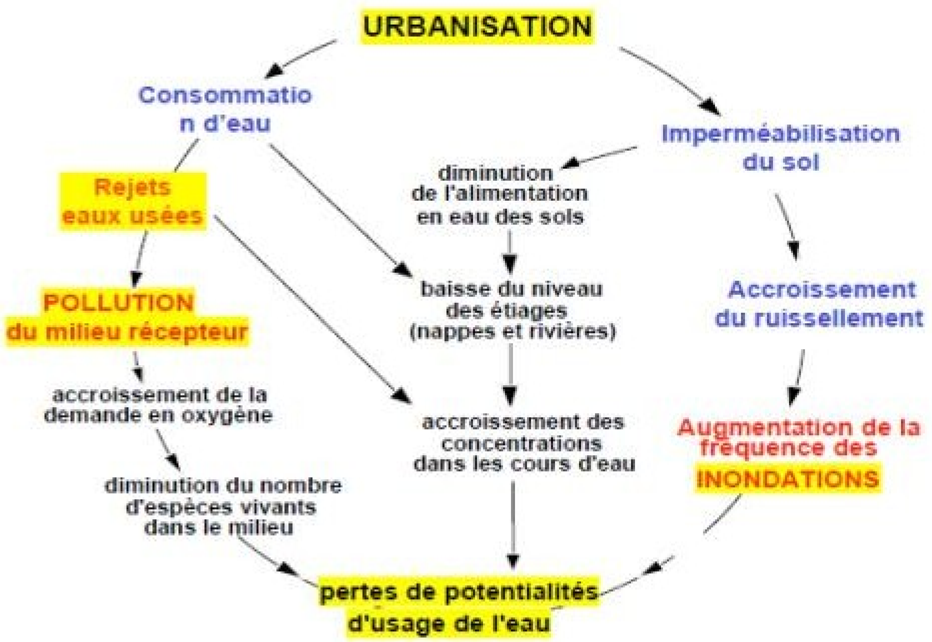


Fig1.4 Impact the urbanization of the urban hydrological cycle (Vue et al., 2018)

1.4 Sewage Urban

In the past, the fundamental philosophy of reducing flood risk in metropolitan areas has been to reduce urban flooding by redesigning vast pipe network campaigns to boost the system's drainagecapacity (building wider pipes, upgrading the surface collection system, etc.).

Although this methodis effective in eliminating local flood problems, increased volumes and peak urbanization- determined flows also cause downstream flood problems along with runoff and depletion of natural receiving water sources. Moreover, this method is typically inefficient and anti-economic when dealing with large and complicated drainage schemes or with older networks in heavily urbanized areas, such as the middle of certain ancient municipalities. In such cases, sewage systems are frequently overwhelmed with storm water and floods arise along with frequent rains.

On the basis of the previous considerations, new architecture techniques, based on the principle of hydrological invariance, were introduced to implement more natural and less invasive solutions for the preservation and/or disposal of surface water runoff. According to this new strategy, a variety of storm water retrofit practices (BMPs) have been introduced along with other available watershed conservation techniques to mitigate pollution, restore habitat and stabilize stream morphology as part of a comprehensive watershed restoration policy. Namely, storm water retrofits consist of a set of structural storm water activities, such as infiltration and storage, intendedto minimize peak runoff flow, alleviate erosive fluxes, reduce contaminants in storm water runoff, and cultivate opportunities for better aquatic habitat. Such solutions need public approval because they require installation, repair and control costs that can be viewed as unnecessary and unmotivated steps merely directed at enhancing the landscape. Consequently, the population residing in flood-prone regions must be immune to urban floods in the first instance until structural steps can be regarded as appropriate costs.

1.4.1 Sewer Systems

Sanitary sewers carry waste water from homes and businesses to waste water treatment plants. They consist of pipes, manholes, and pumping stations and their role is to maintain water quality because it’s necessary for good public

1.4.2 Types of Sewerage System

The appropriate option of the appropriate sewage network has some advantages, in particular with respect to flood protection and water quality, but attention must be given to the economic aspect of the individual type and the sewage network can be divided into three groups:

- Combined System.
- Separate System.
- Partially Separate System.

1.4.2.1 Combined Sewerage System

In a combined system, the same sewer is intended to carry both the domestic sewage, industrial wastes as well as the surface and the storm water flow.

a. Situation for Adoption :

- ✓ Rainfall is even throughout the year.
- ✓ Both the sanitary sewage and the storm water have to be pumped.
- ✓ The area to be severed is heavily built-up and space for laying pipes is notenough.
- ✓ Effective or quicker flows have to be provided.
- ✓ If the sewers are laid along with the overall development of the area, combinedsystem is preferred.

b. Advantages :

- ✓ Rainwater keeps sewage fresh making it easier and more economical fortreatment purpose.
- ✓ Dilution also helps, this being in itself a method of treatment;
- ✓ Automatic flushing is provided by water.
- ✓ This is the simplest method of collection and house plumbing economies.

c. Disadvantages:

- ✓ The bigger size of the sewer would involve larger excavation.
- ✓ Overflowing under worst conditions may endanger public health.
- ✓ Cost of pumping and treatment would increase due to the large quantity of sewage to be handled.
- ✓ The dry weather flow is a small amount of the total flow, the large size of the sewer would often result in causing silting up due to low velocity of flow during the dry period of the year.

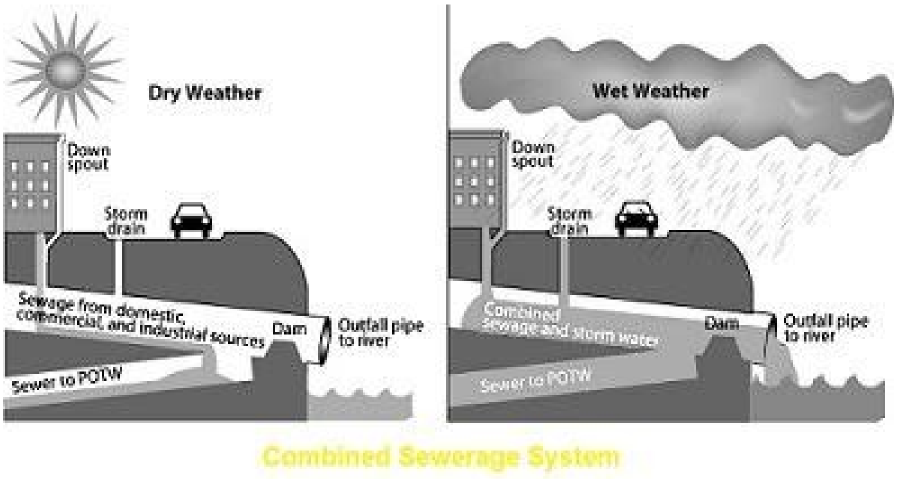


Fig 1.5 Schema of Combined Sewerage System

1.4.2.2 Separate Sewerage System

In a separate system, the domestic sewage and industrial wastes are carried in one set of sewers whereas the storm and surface water are carried in another set of the sewer.

a. Situation for Adoption :

- ✓ Where rainfall is uneven.
- ✓ Sanitary sewage is to have one outlet and other outlets for store or surface water are available. Sanitary sewage is to be pumped. Separate sewer must be placed deeper and the storm water drains nearer the surfaceto economies excavation.
- ✓ If the ground has steep slopes, it is easier to convert storm water through an opendrain to the natural stream.
- ✓ Finance available are small but sanitary drainage is imperative.
- ✓ If the subsoil is hard, it is difficult and costlier to lay combined sewer of large size.

b. Advantages :

- ✓ Being smaller in size, the sewers are economical.
- ✓ The surface water may be takenin open or closed conduit or drains at or near the surface and discharged at suitable outlets, thus greatly simplifying the design of sewers of stormwater drains.
- ✓ There is no risk of stream pollution as no storm overflows are to be provided; The quantity of sewage to be treated is small, the disposal or the treatment workscan be economically designed.
- ✓ If the pumping of sewage at the treatment works is necessary, pumping costwould be much

less as there is no need to pump the storm water.

c. Disadvantages :

- ✓ Unless laid at a steep gradient, self-cleaning velocity in the sewer cannot be assured and flushing shall have to be done.
- ✓ This may prove unsatisfactory andexpensive.
- ✓ Risk of encroachment by unauthorized rainwater collection and consequentoverflows of sewage may be there.
- ✓ Double house plumbing is another disadvantage.
- ✓ Two sewers or drains in a streetleading to greater obstruction of traffic which repairs to any one of them are being carried out.
- ✓ Maintenance costs of two systems are greater than that for one.

Fig 1.6 Schema of Separated Sewerage System

1.4.2.1 Partially Separate System

A partly separate scheme is a variation of a separate system in which separate sewers discharged from household water and agricultural waste often include a portion of the surface drained from the backyards and roofs of the property.

a. Why we need partially separate system?

It may raise that a combined system of sewerage has not been found quite suitable under tropical Indian conditions for reasons outlined below:

- ✓ Concentrated and heavy rainfall during the monsoon period, which at most placeslast for only 3 to 4 months in a year. Thus, there is a considerable variation in thequantity of sewerage flow during the twelve months of the year.
- ✓ Inadequate amounts of waste of waters reaching the sewers because of a vast tract of intervening unsewered areas or due to the other reasons so that the dry weather flow(DWF) is generally a tiny proportion of the total flow.
- ✓ The low economy and limited funds available.
- ✓ Difficulties in the operation and maintenance of the system due to inadequate supervision of less qualified staff. Local bodies in charge of the work usually do notpay much attention to keeping trained and skilled staff.

A partly separate scheme is a variation of a separate system in which separate sewers discharged from household water and agricultural waste often include a portion of the surface drained from the backyards and roofs of the property. The underground sewage system carries either sanitary or residential sewers from which rainwater can also be discharged from the backyard and roofs of the homes. In the other side, the stormwater from the front of the house and the surface wash of the streets and roads can, at some distance, divide into the watercourse flowing close or to the same low-lying area.

a. Advantages :

- ✓ It simplifies the drainage of the houses.
- ✓ It provides reasonable sizes of sewers and is economical.
- ✓ The rainwater provides some safeguard against silting in the sewer.

b. Disadvantages :

- ✓ Low velocity during the dry period.
- ✓ Storm overflows may be found necessary.

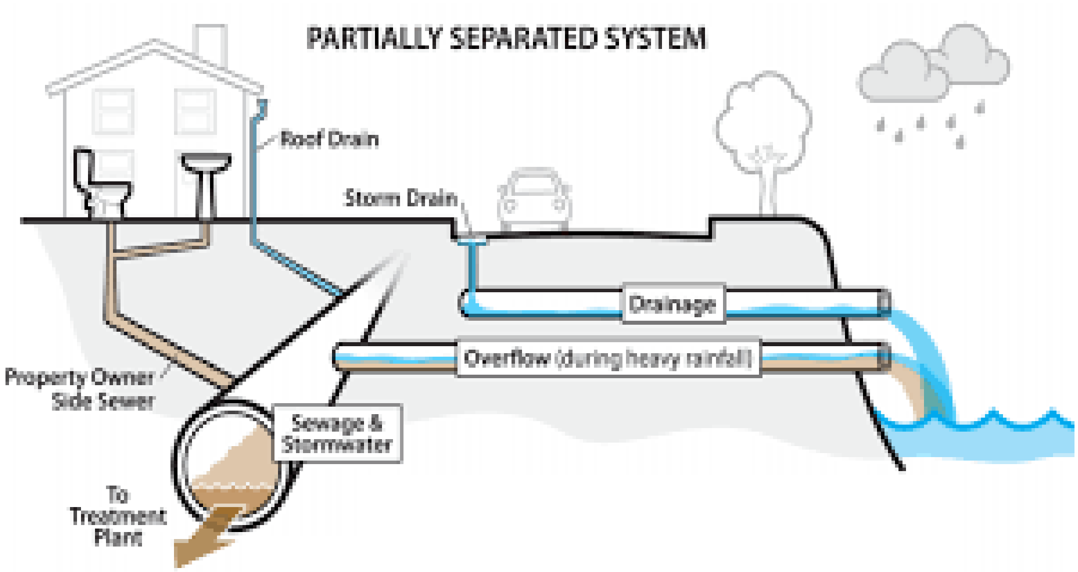


Fig 1.7 Schema of Partially Separate System

1.5 Urban pollution in Algeria

Algeria, like other countries in the world, has not been spared by the pollution crisis, which has become a political and social issue. The problem has been compounded by pollution and refuse spread around the world. In urban and rural areas as well as in industrial installations this problem poses significant threats to the environment and to public health. Pollution rates have continued to increase which can be attributed mainly to toxic gasses and smoke from factories, especially chemical ones, as well as to CO2 emissions from vehicles. This is in comparison to the unregulated usage of fertilizers and chemicals, which has intensified environmental emissions and agricultural degradation for human use.

In this context, French researcher Jacques Moussafir, chairman and director general of the Qatar-based Aria Technology Company for environmental pollution monitoring, said in an interview with el-Massa newspaper on 5 February 2016 that Algeria has one of the highest rates of pollution in the world, which requires intervention by environmental protection authorities to devise mechanisms to minimize gas emissions and to protect cities from theassociated dangers. According to a report by Harvard University in 2018, Algeria is among the countries at the greatest risk due to its strong reliance on food that lacks nutrients as the concentration of CO2 in the air rises. This was the same inference reached by the World Bank and the Center for Health Measurements and Assessment, the academic institute concerned with accelerating health development.

In the 2016 Joint Study on Air Quality Prices, the two organizations emphasized that Algeria is one of the most industrialized countries in the world, alongwith Mexico, China, India and the Middle East. The study also noted that the pollution-related mortality rate was 10% in 2013. 1.6 Policy for the control of storm water in Algeria: historical text, journal, research in the fourth table, statistics express the pollution rates in Algeria, updated for May2018.

Tab 1.2. Pollution rates in Algeria (Talbi et al., 2018)

Pollution in Algeria		
Field	Percent (%)	Classification
Air Pollution	54,49	Moderate
Drinking Water Pollution and Inaccessibility	43,75	Moderate
Dissatisfaction with Garbage Disposal	76.74	High
Dirty and Untidy	68.59	High
Noise and Light Pollution	44.74	Moderate
Water Pollution	54,23	Moderate
Dissatisfaction to Spend Time in the City	54,49	Moderate
Dissatisfaction with Green and Parks in the City	70,72	High
Purity and cleanliness in Algeria		
Field	Percent (%)	Classification
Air quality	45,51	Moderate
Drinking Water Quality and Accessibility	56,25	Moderate
Garbage Disposal Satisfaction	23,26	Low
Clean and Tidy	31.41	Low
Quiet and No Problem with Night Lights	55.26	Moderate
Water Quality	45.77	Moderate
Comfortable to Spend Time in the City	45.51	Moderate
Quality of Green and parks	29.28	Low

1.6 Conclusion

In this chapter, the bibliographic research on the term flood and the extent of its classification within natural disasters is covered. Flood type diagnosis serves as a strong support for choosing the appropriate flood simulation model in addition to other considerations such as the topographical, ecological and even catchment type because the problem of flooding is particularly complex to manage. Protecting agglomerations from this type of disaster requires the involvement of several disciplines in order to determine the various parameters contributing to their formation as well as the appropriate solutions.

Since the study of floods in our case will be in an urban catchment that is usually drained by sewerage network, the light will be shed as a main goal controlling the flow of waste water and rainwater and other liquid waste produced by human activities, in order to protect public health and preserve the physical environment. For this, urban sanitation uses different techniques to manage pollution and protect the urban environment against flooding.

Chapter 2

Presentation of the study area

2.1. Introduction

The Guelma city basin was chosen as a case study for our research. As it provided most of the necessary data needed in our research project, and because the type of catchment is urban, the administrative policy adopted in managing the sewage networks during a period of storms is different from the rural catchments where several considerations are taken such as economic, human and even social considerations. Availability and accuracy of data is very important for correct diagnosis of the sewage network and for assessing the impact of storm water on urban catchments.

2.2. Geographic Location

The Guelma catchment is part of the Seybous watershed (Fig 2.1) which is coded by 14 according to the classification of the Hydrographic Basin Agencies (Aichouri et al., 2015). The Guelma catchment, is situated about 60 km south of the Mediterranean Sea and Annaba metropolis between 36°21' and 36°32' N in latitude, and 7° and 8°E in longitude in northeastern Algeria as shown in (Fig 2.2). The catchment elevation ranges from zero to 500 m (Fig 2.3). It is characterized by a semi-humid climate with an average annual precipitation of about 400 mm/year and average temperatures ranging from 34.9 ˚C in summer to below 10.1 ˚C in winter. The soil typeis clay loam with a land slope varying from 3.6% to 17.5%.

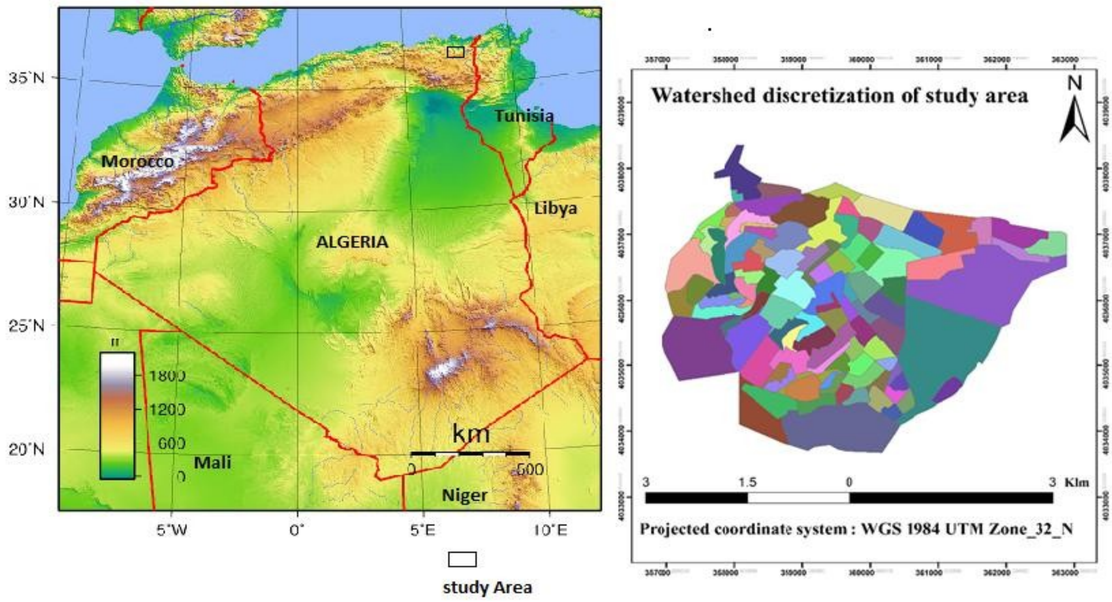


Fig 2.1. Map of the location of the study area Guelma Catchment (colored polygons represent sub-watersheds).

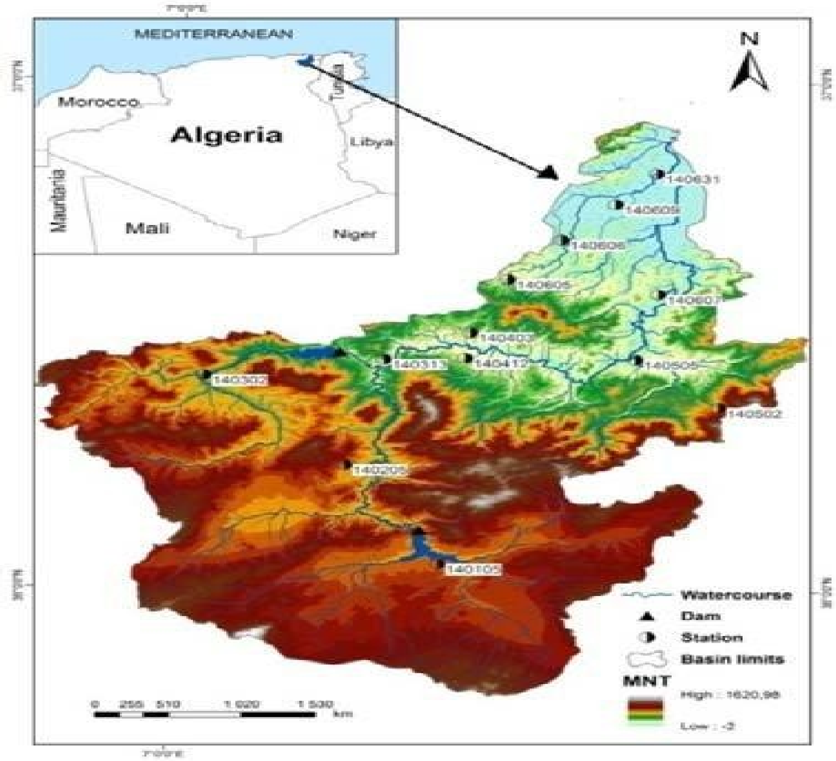


Fig 2.2. Seybous watershed presentation.

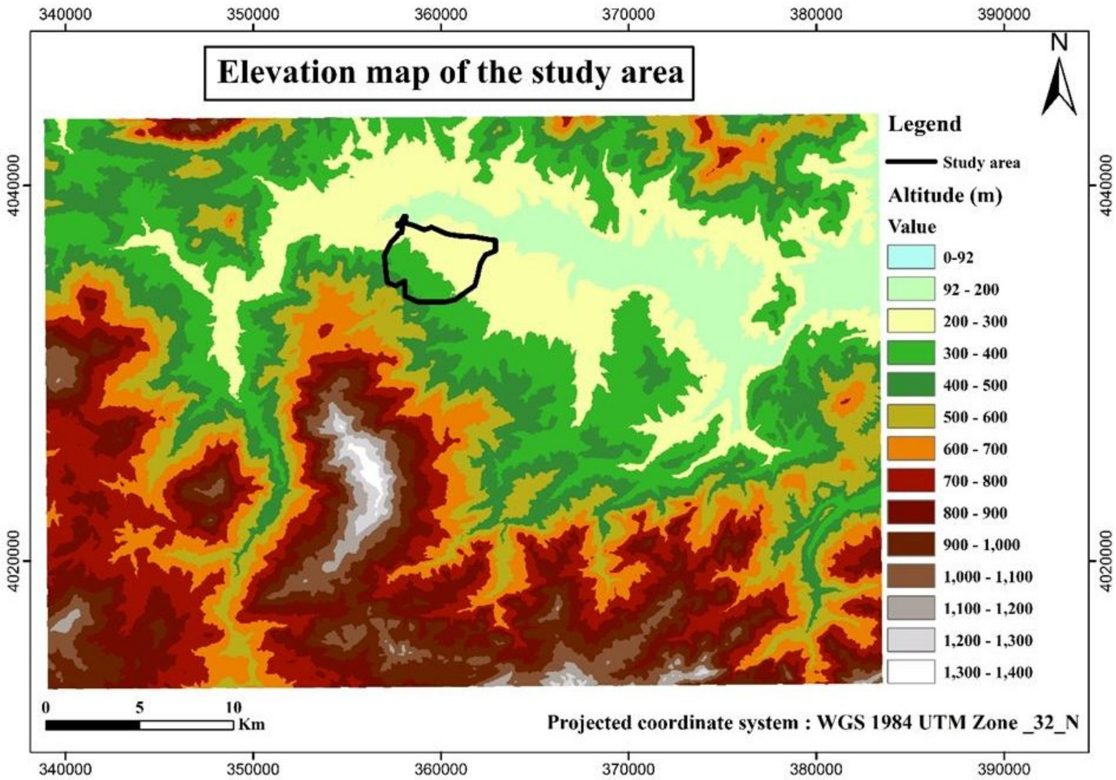


Fig 2.3. Elevation map of the study area

2.3. Morphometric Characteristics of the Catchment

Knowing the physical properties of the watershed is necessary to extract the necessary parameters as the main inputs for the model to be used. Therefore, we used to download the digital elevation model (DEM) Fig 2.3 from the NASA agency and treat it by using the Arc-Toolbox-box tool by combining Geographic Information System (GIS).

The analysis and processing of the digital elevation model contributed to the extraction of slope maps, land uses and elevations, and the diagnosis of the drainage network.

The study of the catchment type was also covered by calculating the GRAVELIUS indice.The index accepted by hydrologists to characterize the shape of a catchment is the GRAVELIUS compactness index which is the ratio of the perimeter of the basin to that of a circle of the samearea:

$$Kc = 0,28 * \frac{P}{\sqrt{A}} \text{.........} \quad (2.1)$$

Were:

P: The perimeter of the basin Km

A: The area of the basin Km^2

If :

- ✓ K_c<=1 the shape of the catchment is circular ;
- ✓ K_c<=1,12 the shape of the catchment is square ;
- ✓ K_c approximate to 1 the shape of the catchment is compact ;
- ✓ K_c greater than 1,1 the shape of the catchment is elongated.

In our case study, the GRAVELIUS indice is 2,1 so according to the GRAVELIUS classification. We conclude that the shape of the Guelma Catchment is pressurized

The table 2.1 summarizes the most prominent parameters that were calculated through the temporal and spatial analysis of the digital elevation model.

Tab.2.1 Morphometric characteristics of the Catchment

Parameter	Code	Unit	Value
Area	A	Km2	17,259222
Perimeter	P	Km	31,190961
GRAVELIUS indice	K_c	/	2.1
Classification	/	/	pressurized
Equivalent rectangle length	L_R	Km	14,3787544
Equivalent rectangle width	l_R	Km	1,2
Roche slope index	I_p	%	17,17
Overall slope index	I_o	%	6,05
Average altitude	H_{moy}	m	198
Maximum altitude	H_{max}	m	486
Minimum altitude	H_{min}	m	184
Torrentiality coefficient	C_t	/	799,05

2.4. Digital Elevation Model

The scale of the digital elevation model (DEM) and the accuracy of landscape data determine the ability to comprehend watershed processes (Hancock, 2005). Advances in computational modeling for hydrology, geomorphology, and prediction relate to the DEM and its reliability. In our study, we used the well-known data from the Shuttle Radar Topography Mission (SRTM), having 30 meters resolution from https://earthexplorer.usgs.gov/, with processing and analysis of DEM by using Arc GIS 10.3. It enabled us to calculate and determine hydrological and morphometric parameters. The latter will serve as inputs to the model, which confirms once again the necessity of the accuracy of the DEM.

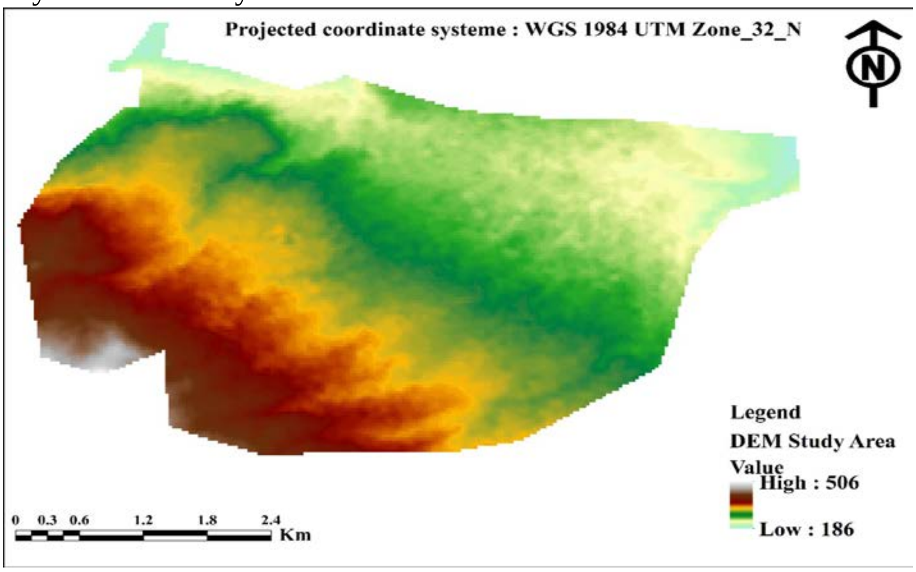


Fig 2.4. Digital elevation model of the study area.

2.5. The Slope of Catchment

By treating and analyzing the digital elevation model, we deduced the value of the mean slope, which was about 14 percent (%), in the case of taking the study area as a single pool without divisions also, the direction of the inclination was uniform, as it was from the north towards the south, and this is what makes the surface runoff take place through gravity, which does not require the need to put pumps or pits. In locations that have negative slopes.

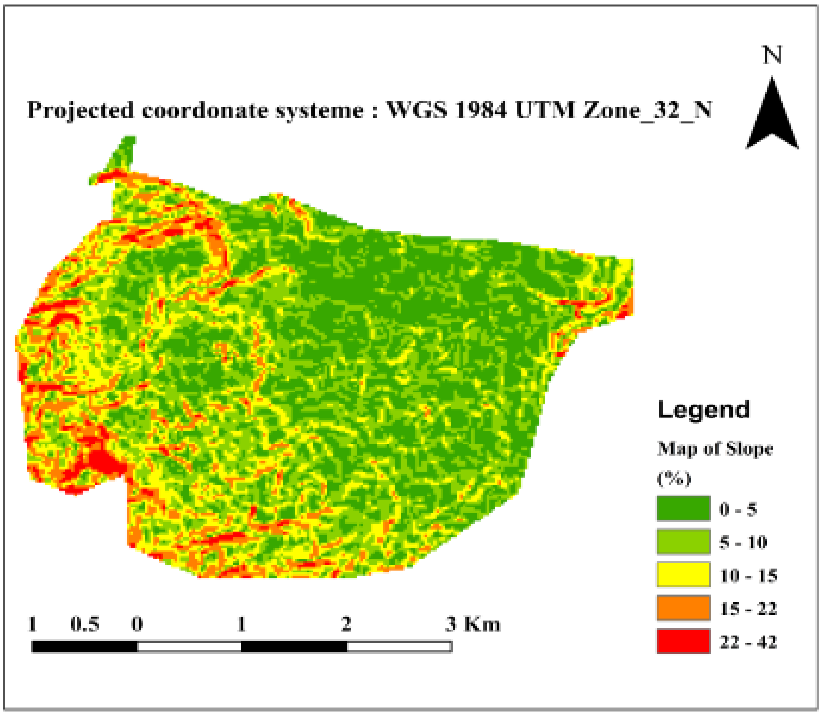


Fig 2.5. Slope map of the study area.

2.6. Land Use and Land Cover (LULC) of Catchment

Land use are commonly used to define the topographical characteristics of the Earth, and itis important for the research of land form evolution, soil erosion, and hydrological modeling (Jiang et al., 2018). We used unsupervised image classification from the 2018 DEM SRTM data to classifythe land use/land cover of the Guelma watershed. The remote sensing system adopts the classification of images by clustering of image pixels to a set of classes in such a way that pixels in the same class have similar properties (Oyekola & Adewuyi, 2018). The user knows only the number of spectral categories and categories based on numerical information in the data (i.e. pixel values for either ranges or indicators). Aggregation algorithms are used to define the natural statistical collection of data that will allow signature file identification for each category.

Signature files were created from the raw data set to give the program an idea of what type of pixel value it should try to match with that class. First, an uncensored image categorization was performed using the ISODATA compilation method to classify the image into the desired categories from which five were created from the raw data set to give the program an idea of what type of pixel value it should try to match with that class. First, an uncensored image categorization was performed using the ISODATA compilation method to classify the image into the desired categories from which five (5) categories were effectively identified. The land use results obtained from the analysis are shown in Figure 2.4. The percentage of land uses for the study watershed is shown in the Tab.2.2.

Tab. 2.2 The percentage of Land Use for the study watershed.

LU	Percentage (%)
Water	18
Agricultural Land	25
Green spaces	19
Buildings	23
Road	15

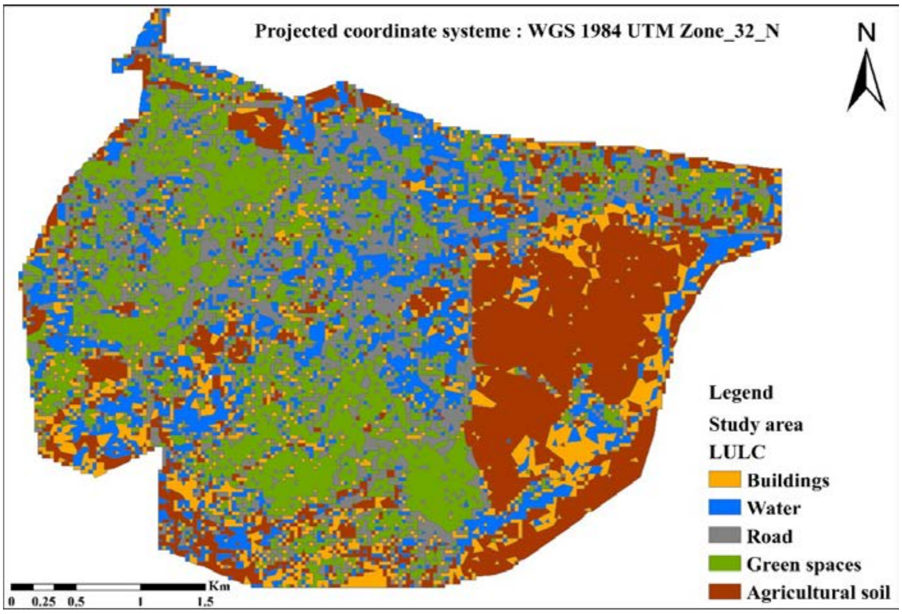


Fig 2.6. Land Use Land Cover of the Guelma Catchment

2.7 Hydrography

The main outlet of the entire Guelma watershed is essentially the Seybouse wadi which takes its source at the western end of the group, collects all the runoff water from the inter-communal territory and drains it to the east, then further towards the North, towards the Mediterranean Sea.

The hydrographic network is presented by many more or less deep chaâbas and the main tributary es of Wadi Seybouse are:

- To the south, and on the right bank, the Wadi Skhoune which crosses the agglomeration of Guelma by an entirely covered underground channel, the Wadi Maiz forming the limit between the communes of Guelma and Belkheir, and finally Wadi Zimba which limits the agglomeration of Belkheir to the east.
- To the north, on the left bank, the El Khenga wadi crosses the city from north to south and the Wadi Emmechem which limits it on the south side.
- Apart from the Seybouse wadi which has a perennial flow, all the other wadis and chaabas are temporary watercourses. The valley of the Wadi Seybouse is often flooded during the rainy periods either by overflow of runoff water, or by discharge of water from flow lines.

2.8 Hydrogeology

The study of geological formations likely to constitute aquifers. Their water storage capacities and their contributions to groundwater supply depend on their permeability and the geological nature of the rocks. From the lithological nature of the land, we determined two types of formations:

- Formations favorable to the development of porous aquifers (permeable formations). They are characterized by a small permeability, linked to the presence of interconnected interstitial voids, microscopically comparable to a continuous medium represented by Quaternary alluvium which can only provide small aquifers of little interest. Because their thickness is small and by the Oligocene aquifer called the Numidian aquifer, represented by the Numidian sandstones which outcrop at the surface in several points of the study area and which in this case constitute a free lying on the underlying formations of impermeable Numidian clays.
- Formations favorable to the development of karstic aquifers are linked to a large permeability and a particular lithology (carbonate formations). They characterize a heterogeneous and discontinuous environment in which water flows through channels andpipes of large dimensions (karst pipes) with collection function with the possible existenceof large capacity cavities represented by the aquifer complex of the carbonate formations ofthe Cretaceous, formed by limestones and marnocalcaries, their power can reach 400 m.

2.9. Geology

Geology is the study of the emergence of rocks and their formation in the subterranean layers, but their effect on surface runoff is usually neglected due to slow infiltration, especially in urban catchments like ours. The geology of the Guelma catchment is varied from place to place, butit is predominantly Lake tuffs and limestone, with a small percentage of Soltanien figure 2.5

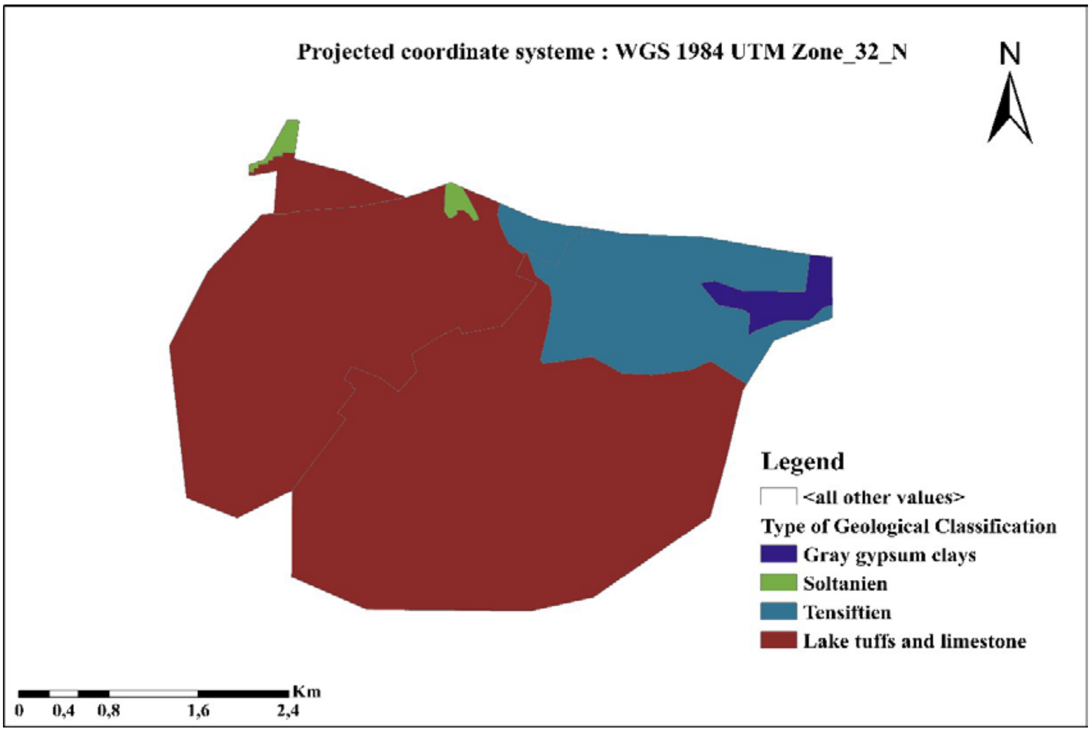


Fig 2.7. Geological map of the Guelma Catchment.

2.10. Climatic Characteristics

Climatic factors have a permanent impact on the social and economic life of a region, Guelma catchment is dominated by a sub-humid climate We can classify:

2.10.1. Rainfall

Precipitation is the entire layer of water quantified by rainfall, it comes from various origins:rain, snow, etc.

a. ***Average annual precipitation:*** The pluviometric map of the National Agency for Hydraulic Resources (A.N.R.H) shows an overall decreasing distribution of precipitation from North to South, and from West to East. Indeed, in the region of Guelma the precipitation is varied between 336.8 mm and 928.8 mm, the following table mentions the annual variations of precipitation of the stations of: Guelma for a period (1990-2012):

Table 2.3 Total annual precipitation (mm) (ANRH)

Years	Precipitation (mm)
1990	530
1991	572.7
1992	877.6
1993	486
1994	470.2
1995	603.5
1996	652.2
1997	556
1998	625.4
1999	517
2000	427.7
2001	407.6
2002	523.7
2003	928.8
2004	778
2005	532.2
2006	484.1
2007	692
2008	376.5
2009	729.3
2010	653.7
2011	451.6
2012	336.8

b. ***Average monthly and seasonal precipitation:*** It is the height of water collected by rainfall, snow and hail in the form of condensation. To know the distribution and the orographic influence, we used the station of Guelma which is part of the upper valley of the Seybouse. The monthly distribution of precipitation over the year immediately influences the flow regime and water tables. Table 2.3 shows that the month of December is the rainiest with a maximum of 88.36 mm obtained at the Guelma station.

Table 2.4 Average monthly precipitation Guelma station (ANRH)

Station	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Mai**	**Juin**	**Jui**	**Aou**
Guelma	**39,78**	**41,47**	**70,16**	**88,36**	**80,99**	**68,27**	**60,82**	**55,52**	**50,09**	**17,18**	**4,28**	**12,65**

The subdivision of the rains of the year for each season is made according to the agricultural seasons (Autumn: (Sep, Oct, Nov), Winter: (Dec, Jan Feb), Spring: (Mar, Apr, May), Summer: (JuiJul, Aou). Observing Table 2.4, we see that the two spring and winter seasons are the rainiest with rainfall = around 404.04 mm or 68.52% of the annual rainfall for the station of Guelma.

Table 2.5 Seasonal distribution of precipitation. (ANRH)

Seasons		**Autumn**		**Winter**		**Spring**		**Summer**	
Station	**Period**	**(mm)**	**(%)**	**(mm)**	**(%)**	**(mm)**	**(%)**	**(mm)**	**(%)**
Guelma	**1990/2020**	**151.41**	**25.67**	**237.61**	**40.29**	**166.43**	**28.22**	**34.11**	**5.78**

2.9.1. Temperature

The air temperature factor has a great influence on the water balance because it conditions evaporation and actual evapotranspiration. The data processed concern the only station of Guelma with a period of 23 years.

Table 2.6 Monthly average temperatures (ANRH)

Years	Temperature (C°)
1990	25.7
1991	24.1
1992	24.2
1993	24.1
1994	25.8
1995	24.2
1996	23.1
1997	23.4
1998	23.3
1999	24.1
2000	24
2001	24.4
2002	23
2003	21.5
2004	25.5
2005	24.7
2006	24.6
2007	22.3
2008	22.9
2009	22.7
2010	23.4
2011	24.3
2012	24

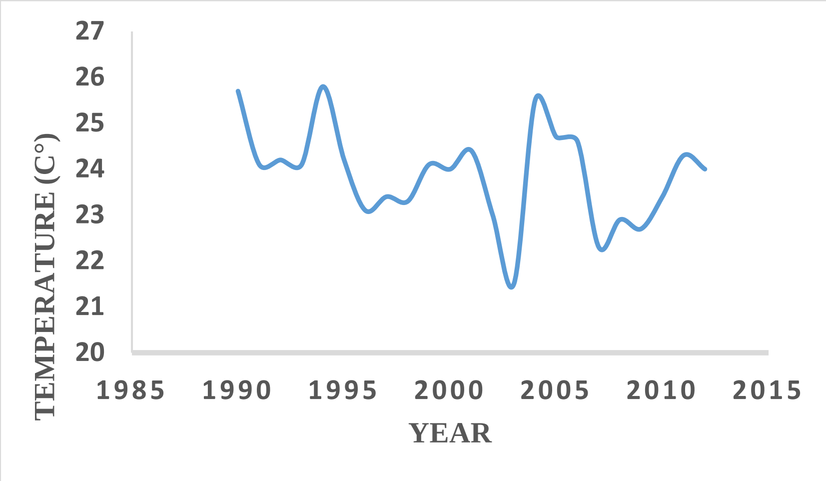


Fig 2.8. Curve of temperature distribution of the Guelma Catchment.

2.11. Drainage Network :

The drainage area has an area of 1726 ha drains 03 major Subcatchments "Subcatchment of Wadi Skhoun, Subcatchment of Maiz Wadi and Subcatchment of Constantine Road has different component **Table 2.4.** The drainage network **Fig 2.6** Is of unitary type with gravity flow and repression. It consists of pipes ranging in diameter from 200 mm to 2000 mm and with a length of around 185 km, a Roman gallery over 2.0 km in stone and a channeled Skhoun river over 3.2 km long.

Table 2.7. Parameter of drainage network.

Parameter	Value
Linear network of the drainage network	185 Km
Number of manholes	4890
Number of storm weirs	4
Direct discharges to the natural environment	9
Number of lifting stations	2
Wastewater treatment plant	1
Average waterproofing coefficient	75%

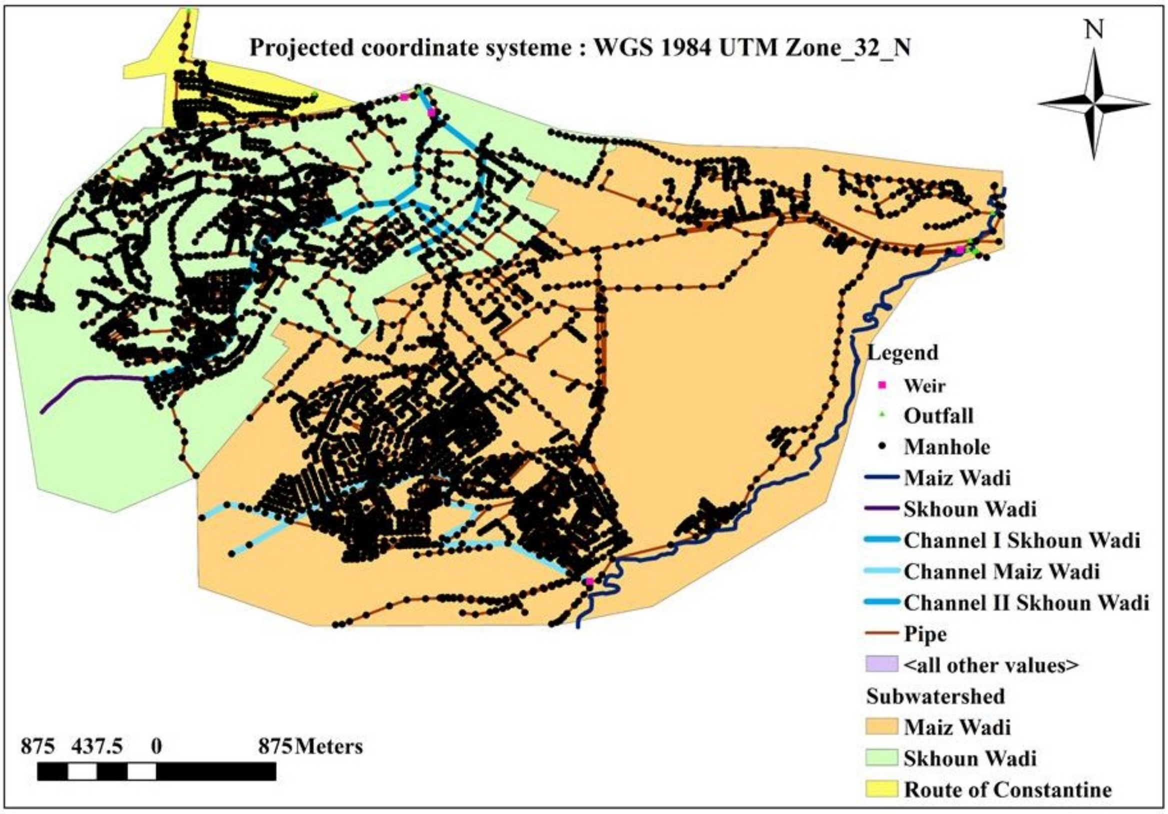


Fig 2.9. Drainage area of the Guelma catchment.

2.12. Conclusion

The study area is an urban catchment with an area of 17,26 Km2 and a perimeter of 31,19 Km, and its average slope is 10,1%, the catchment type was classified as broad pressurized, The study area elevation ranges from 186 to 506 m. It is characterized by a semi-humid climate with an average annual precipitation of about 400 mm/year and average temperatures ranging from 34.9 °C in summer to below 10.1 °C in winter. he distribution of land use was as follows: 23% Building, 15% road, 25% agriculture, 19% green areas, and 18% water bodies.

Chapter 3
Hydrological and Hydraulic Modeling

3.1. Introduction

In addition to the morphological and geological factors, there are also weather conditions, and by virtue of the fact that the study pool has a semi-humid climate, these conditions are usually represented by rainfall.

Modeling rain and analyzing its distribution in space and time is essential and important because it will serve as a main input that the model needs for simulation and the input is accurate. This means that we have come close to the correct diagnosis of hydrological behavior (Casper et al.,2012)

The climatic equipment of the study basin is satisfactory in principle. It is especially the casethat we used single data, because the study area is small, gave the first impression about the climaticequipment, but it is necessary to conduct statistical tests to document these data and correct some ofthe lapses that may be encountered.

In Urban catchments, the hydrological response at rain time is diagnosed via two major parts of the modeling: hydrological and hydraulic modeling, taking into account the type of model that fits with the objectives of the study.

Smart diagnosis of the hydrological response in times of rain is beneficial to decision-makers in developing well-controlled strategies that are effective in terms of role and economical in terms of cost (Christophe depres, 2003).

3.2. Overview of African's Climate

Africa's climates are diverse and varied: varied because they range from wet equatorial regimes, to seasonal tropical regimes, to subtropical Mediterranean-type climates, and varied because all of these climates show differing degrees of temporal variability, especially with regard to rainfall. Comprehension and forecasting these inter-annual, inter-decade and multi-decade climate changes has been a major challenge facing Africa and African climate scientists in recent years (Hulme et al., 2001).

The types and classifications of climates in the African continent Fig.3.1 are different and differ from region to region and may be different even in the same region, especially if the latter hasa large area.

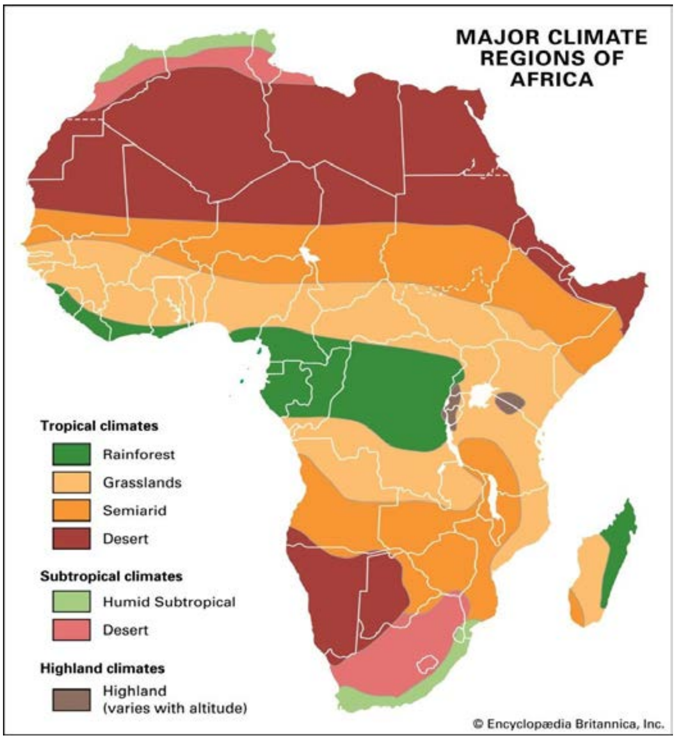


Fig 3.1 Major Climate regions of Africa (Rao et al., 2019)

3.3. Overview of Algeria's Climate

climate is diverse, making it difficult to generalize about the weather. However, one can say that in the north of Algeria, the weather is very similar to that found in Mediterranean countries. https://www.world-guides.com/africa/north-africa/weather Algeria has experienced three types of climate. Up north the region gets a Mediterranean climate where the summers are hot and dry while the winters are generally wet, yet mild. The areas with higher plateaus enjoy a continental climate with higher temperatures on a daily basis. Rainfall in these parts is occasional and normally does not last for a long time. Near the Sahara Desert, rainfall is erratic and comes in short spells. The topography has something to do with the climate variation in Algeria.

This is why the country receives a lot of sunshine and rainfall along the coast, experiences occasional frost and snow inland, and has winds during both the summer and winter season. Northern Algeria lies within the temperate zone, and its climate is similar to that of other Mediterranean countries, although the diversity of the relief provides sharp contrasts in temperature The coastal region has a pleasant climate, with winter temperatures averaging from 10° to 12° C (50° to 54° F) and average summer temperatures ranging from 24° to 26° C (75° to 79° F). Rainfall in this region is abundant—38 to 69 cm per year, and up to 100 cm in the eastern part— except in the area around Oran (Ouahran), where mountains form a barrier against rain-carrying winds. When heavy rains fall (often more than 3.8 cm/1.5 in within 24 hours), they flood large areas and then evaporate so quickly that they are of little help in cultivation.

Farther inland, the climate changes; winters average 4° to 6° C (39° to 43° F), with considerable frost and occasional snow on the massifs; summers average 26° to 28° C (79° to 82° F). In this region, prevailing winds are westerly and northerly in winter and easterly and northeasterly in summer, resulting in a general increase in precipitation from September to December and a decrease from January to August; there is little or no rainfall in the summer months. In the Sahara Desert, temperatures range from –10° to 34° C (14° to 93° F), with extreme highs of 49° C (120° F). There are daily variations of more than 44° C (80° F). Winds are frequent and violent. Rainfall is irregular and unevenly distributed.

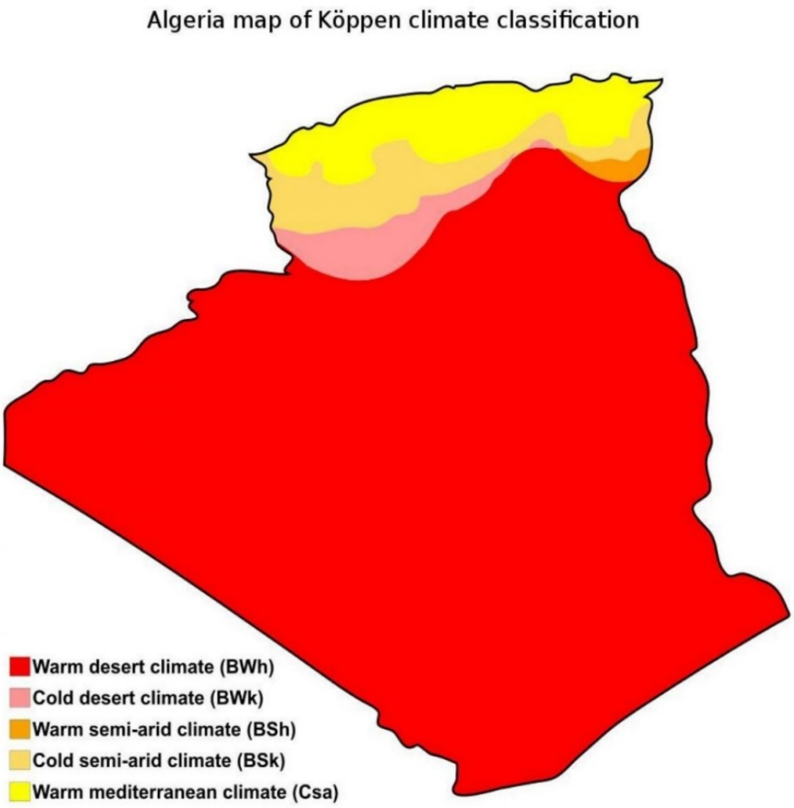


Fig 3.2 Algeria map of Köppen climate classification (Geddes & Grosset, 2005).

3.4. Hydrologic Modeling

What happens and how does rainfall affect urban catchments? This is a question that urban hydrologists have asked themselves in recent years when trying to integrate the hydrologic and hydraulic processes that affect the hydrologic response of urban catchments.

To help address this question and improve understanding and prediction of hydrologic response in highly urbanized catchments, the Personal Computer-Storm Water Management Model (PC-SWMM) was developed. While urban catchments vary dramatically from natural watersheds, there are similarities that allow features of the groundbreaking geomorphologic instantaneous unit hydrograph model designed for natural watersheds to be applied to urban catchments (Cantone & Schmidt, 2011).

Thus, the study of urban hydrology has evolved to better the control of urban water sources for public health and sanitation, flood prevention, and, more recently, environmental and city liveability protection. (Fletcher et al., 2013).

This probabilistic approach differs significantly from conventional deterministic models used to design and simulate urban sewage systems in that it does not have the burdensome input data criteria that complex deterministic models do.

In hydrological modeling, Geographic Information Systems (GIS) are usually used to extractthe parameters by creating a database that is often joined by government administrative bodies concerned with the matter. GIS also contribute to extracting maps of trends, land uses, the hydrographic network by processing satellite images (Merkel et al., 2008).

3.5. Hydraulic Modeling

Hydraulic modeling is a supplementary phase to hydrological modeling Fig.3, which usuallyuses the parameters extracted from both the processing and analysis of satellite images or through field survey and these parameters are as inputs into hydraulic modeling.

Hydraulic modeling is from the surface to the level of the sewage network, which usually must be taken into account the conclusion of permeability accurately, especially since the land uses are different and heterogeneous, unlike the rural catchments.

The hydraulic modeling output is the flow which is in the form of an outlet towards treatment plants or natural outputs such as rivers and seas. Resorting to the calibration and validation stage by comparing the calculated flows with the observed flows is considered a necessity to evaluate the simulation results, especially since the issue is related to inundation maps for different return period.

In the catchment of the study, these maps can help public, media, emergency mangers and others visualize the spatial extent and depth of flood waters this is called sustainable development (Chi Choi, 2013).

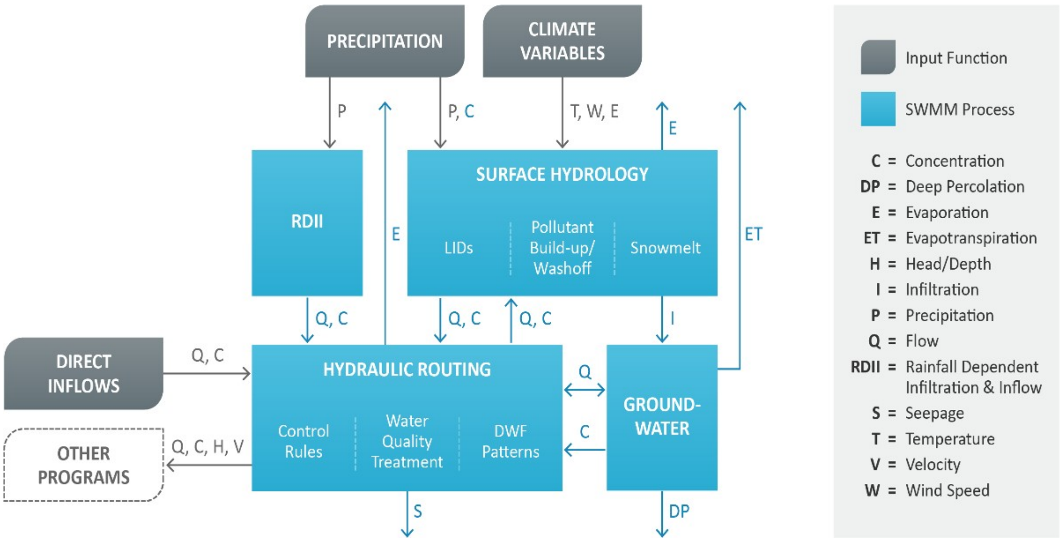


Fig 3.3 Flowchart of hydrologic and hydraulic models (Kastridis & Stathis, 2020).

3.6. History of Runoff Prediction

Early hydrologists calculated surface runoff with limited data and simple computational techniques. The first widely used runoff method was the Rational Method published by Thomas Mulvaney in 1851, which used rainfall intensity, drainage area, and a runoff coefficient to determine the peak discharge in a drainage basin (Beven & Kirkby, 1979).

The coefficient determining the relationship between the amount of rainfall and runoff was studied heavily and led to a graphical technique for estimating the amount of runoff. The graphical technique uses a sequence of graphs showing antecedent precipitation, week of the year, soil water retention index, and precipitation in the past six hours to calculate the amount of runoff. This technique is still used in the conceptual model, National Weather Service River Forecasting System (NWSRFS).

More recently, the unit hydrograph concept was introduced to conceptualize a catchment's response to a storm event based on the superposition principle (Ramírez, 2010). The unit hydrograph made it possible to separate base flow and storm event runoff from streamflow **Fig.4** With increased computing power and a deeper understanding of hydrological processes, runoff models have become more sophisticated. (Xu, 2015).

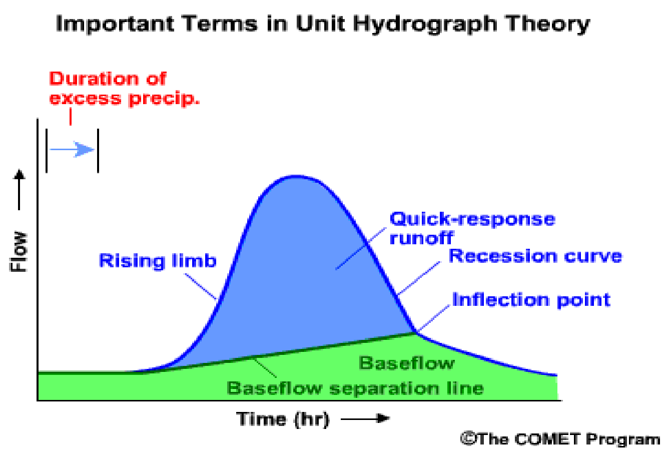


Fig 3.4 the unit hydrograph separation into quick response runoff from a storm event and baseflow.

3.7 Structure of Model

A model's structure determines how runoff is calculated. Some are easily used with few variables, while others require a vast number of interconnecting variables. Model structure varies from simple to complex, based on the governing equations. Models are listed below in order of increasing complexity, with empirical models being the simplest and physical mechanistic models the most complicated. Physical and conceptual models need thorough understanding of the physics involved in the movement of surface water in the hydrological cycle (Knightes, 2017). The three structural categories of runoff models, with strengths and weaknesses for each are displayed in Table 3.1.

Table 3.1 Comparison of the basic structure for rainfall-runoff models (EPA, 2017).

Table 3.1 Compariso	Empirical	Conceptual	Physical
Method	Non-linear relationship between inputs and outputs, blac box concept	Simplified equations that represent water storage in catchment	Physical laws and equations based on real hdrologic reponses
Strengths	Small number of parametres needed be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability very fine scale
Weaknesses	No connection between physical catchment, input data distortion	Does not consider spatial variability within catchment	Calibration needed, site specific
Best Use	In ungauged watersheds, runoff is The only output needed	When computational time or data are limited.	Have great data availability on a small scale
Examples	Curve Number, Artificial Neural Networks	HSPF, TOPMODEL, HBV, Stanford	MIKE-SHE, KINEROS, VIC, PRMS

3.8 Analysis of Precipitation and Runoff

Knowledge of the hydrological behavior of collection basins with a view to modeling is as important as knowledge of networks. In fact, due to the unitary nature of the sanitation networks in the watershed of Guelma, the reaction of the collection basins to rainfall events has a strong impact on the hydraulic operation of the system which should be characterized as precisely as possible.

In particular, it is important to know by watershed the distribution of permeable and impermeable surfaces then a more in-depth analysis makes it possible to characterize the hydrological behavior ofthe collection basin, first of all, the response time to a rain events in the collection watershed was evaluated. The best indicator for evaluating this lag time is the concentration time, which corresponds to the time taken by the drop of water furthest hydraulically from the outlet to reach it, its estimate can be obtained from numerous empirical formulas while we used Shaake and Geyer formula:

$$T_C = 1{,}75 * L^{0{,}24} * S^{-0{,}16} * C^{-0{,}26} \qquad \ldots\ldots\ldots\ldots \textbf{(3.1)}$$

While:

- T_C: Concentration time (min),
- L: Characteristic length of the watershed (m),
- S: Slope (m/m),
- C: runoff coefficient,

This method is suitable for urban watersheds with an average slope between 3% and 10%, which is the case in our study (AREAS, 2013).

3.8.1 Rainfall data processing

ANRH data from the Guelma station were used. The series of maximum annual rainfall studied extends from 1972 to 2008, i.e. 37 hydrological years Table 3.2. which allows a more adequate statistical analysis of the maximum annual rainfall generating floods. Fig .3.5 shows the annual chronology of maximum annual rainfall.

Tab 3.2 the maximum annual rainfall of study area.

Year	Ra.max	Year	Ra.max
1972	43	**1991**	44
1973	28	**1992**	82
1974	24.3	**1993**	48
1975	22	**1994**	35.5
1976	39.5	**1995**	38
1977	38.3	**1996**	15
1978	36.4	**1997**	51
1979	29.8	**1998**	56
1980	42	**1999**	100
1981	41.7	**2000**	32
1982	46	**2001**	36
1983	62.7	**2002**	68
1984	58.7	**2003**	51
1985	22.9	**2004**	72
1986	48.4	**2005**	68
1987	25	**2006**	48
1988	39.5	**2007**	39
1989	34	**2008**	37.8
1990	44		

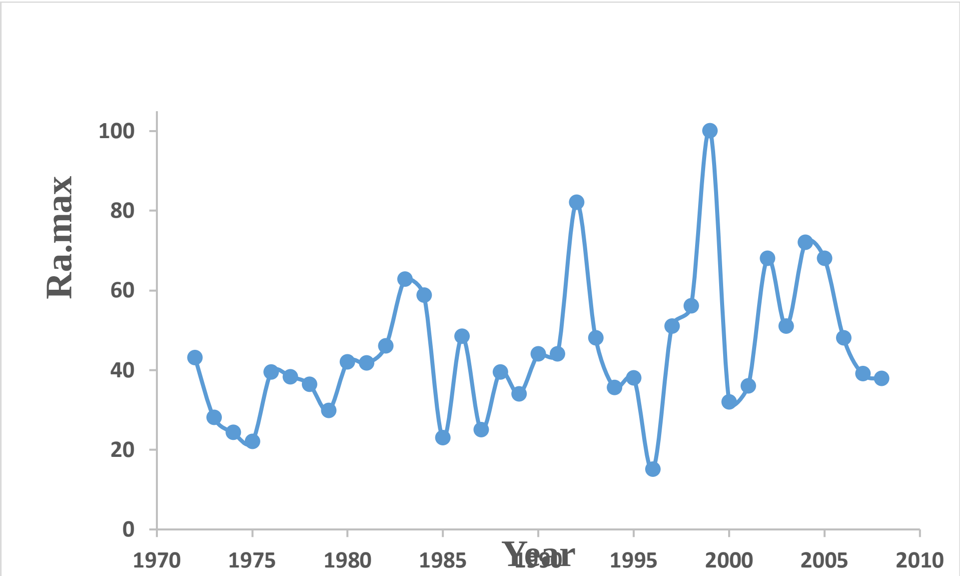


Fig 3.5 Chronological variability of maximum annual rainfall.

3.8.2 Adjustment of the data of rainfall according to the distribution laws

3.8.2.1 Homogeneity test

Verifying the homogeneity of any time series is a necessity in mathematical logic, in our case, we chose the Wilcoxon test to calibrate the homogeneity of the Guelma station. The results obtained were satisfactory as shown in Table 3.3 and Table 3.4.

Tab 3.3 Classification of rainfall data for samples.

Echantillon 1 X	Echantillon 2 Y	X∪Y	Rang	Origine	Rang
43	39.5	15	1	Y	1
28	34	22	2	X	2
24.3	44	22.9	3	X	3
22	44	24.3	4	X	4
39.5	82	25	5	X	5
38.3	48	28	6	X	6
36.4	35.5	29.8	7	X	7
29.8	38	32	8	Y	8
42	15	34	9	X	9
41.7	51	35.5	10	Y	10
46	56	36	11	Y	11
62.7	100	36.4	12	X	12
58.7	32	37.8	13	Y	13
22.9	36	38	14	Y	14
48.4	68	38.3	15	X	15
25	51	39	16	Y	16
	72	39.5	17	X	17
	68	39.5	18	Y	18
	48	41.7	19	X	19
	39	42	20	Y	20
	37.8	43	21	X	21
		44	22	Y	22
		44	23	Y	23
		46	24	X	24
		48	25	Y	25

		48	26	Y	26
		48.4	27	X	27
		51	28	Y	28
		51	29	Y	29
		56	30	Y	30
		58.7	31	X	31
		62.7	32	X	32
		68	33	Y	33
		68	34	Y	34
		72	35	Y	35
		82	36	Y	36
		100	37	Y	37

Tab 3.4 Results of Wilcoxon test.

W x	**234**
W min	**233.03**
W max	**564.97**

Since it is W min < W x < W max. We can conclude that the Guelma station is homogeneous.

3.8.2.2 Adjustment according to GUMBEL's law

GUMBEL's law is a frequency model very often used to describe the statistical behavior of extreme values.

Tab 3.5 results of adjustment by GUMBEL's law.

T	q	XT	Ecart-type	Confidence interval (95%)
100.0	0.9900	99.3	11.3	77.1 - 121
50.0	0.9800	89.7	9.70	70.7 - 109
20.0	0.9500	77.0	7.59	62.1 - 91.9
10.0	0.9000	67.2	6.01	55.4 - 79.0
5.0	0.8000	56.9	4.45	48.2 - 65.6
2.0	0.5000	41.4	2.64	36.3 - 46.6

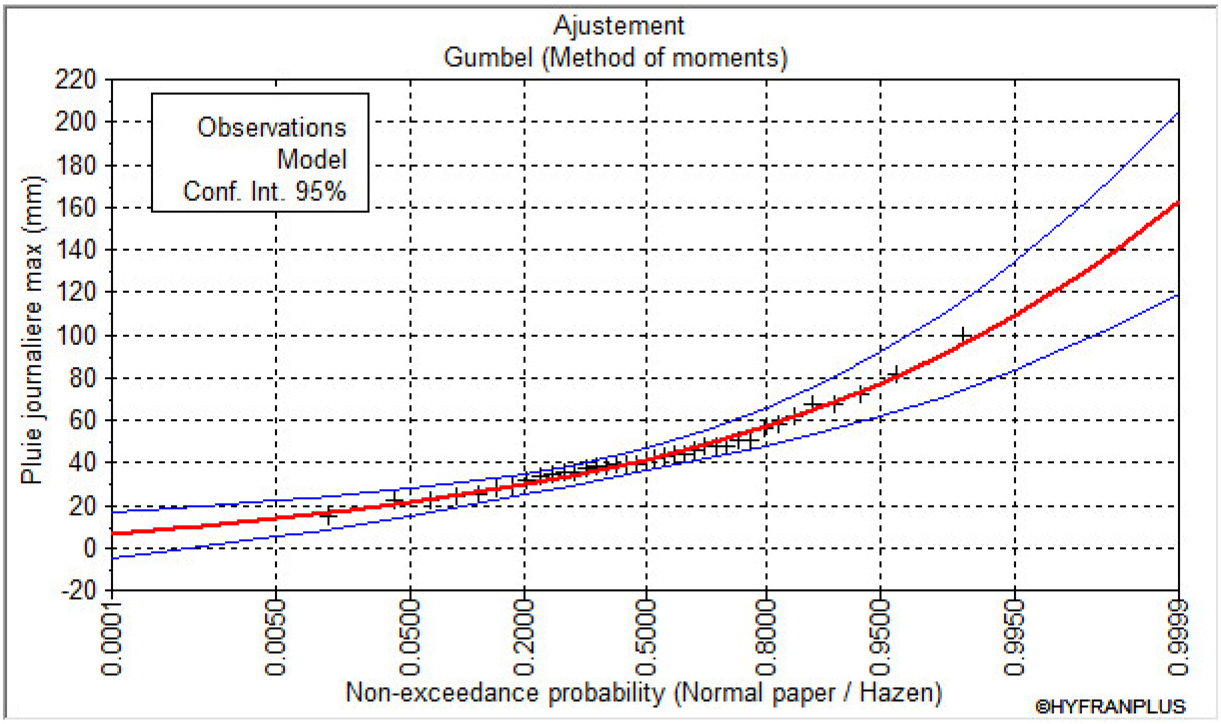


Fig 3.6 Curve of adjustment by GUMBEL's law.

3.8.2.3 Adjustment according to GALTON's law

This law has an expression almost identical to that of the normal law except that there is a logarithmic transformation near.

Tab 3.6 results of adjustment by GALTON's law

T	q	XT	Ecart-type	Confidence interval (95%)
100.0	0.9900	102	12.7	77.1 - 127
50.0	0.9800	91.7	10.4	71.2 - 112
20.0	0.9500	78.2	7.74	63.0 - 93.4
10.0	0.9000	67.9	5.90	56.3 - 79.5
5.0	0.8000	57.2	4.28	48.8 - 65.6
2.0	0.5000	41.2	2.64	36.1 - 46.4

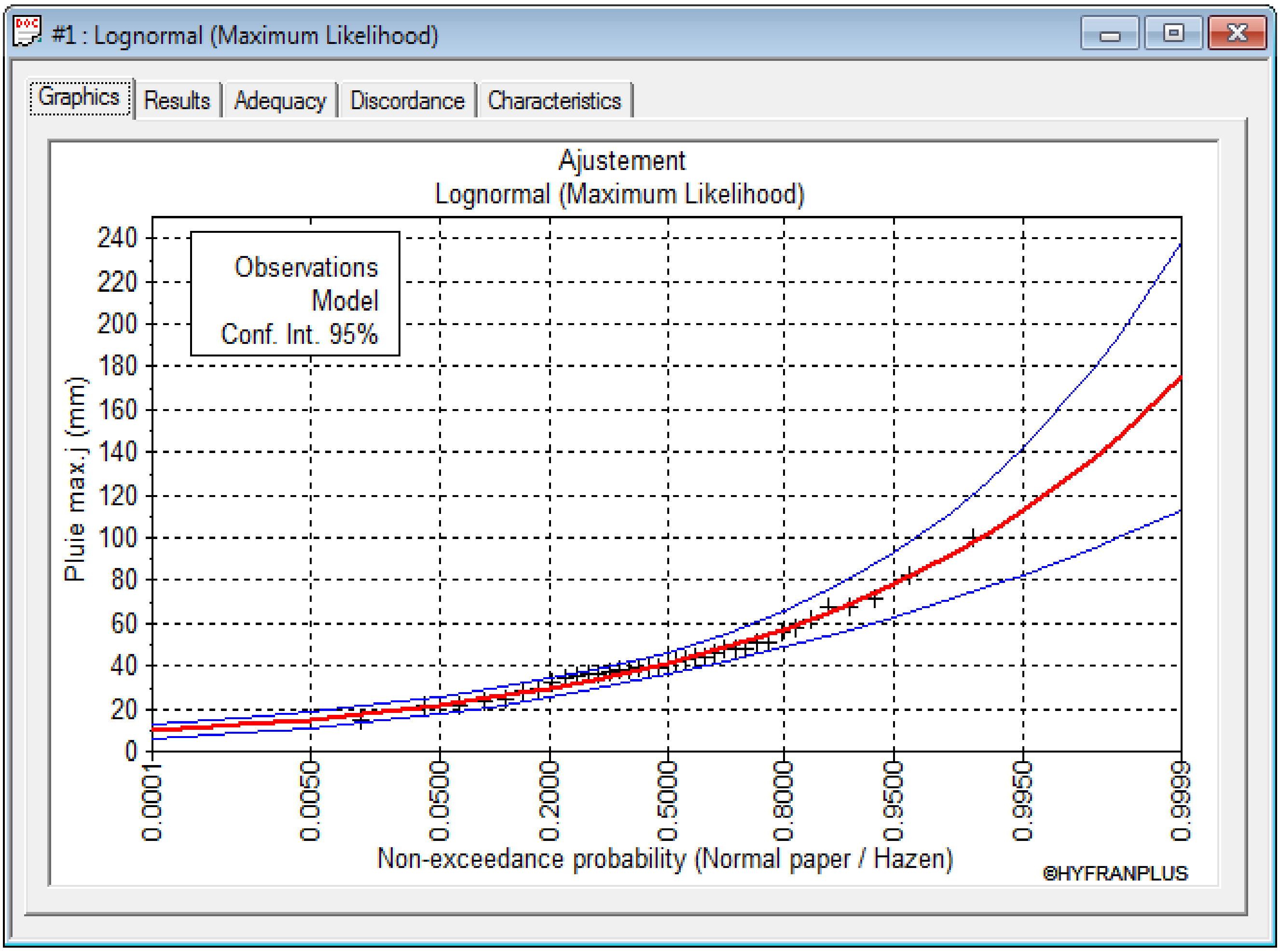


Fig 3.7 Curve of adjustment by GALTON's law

3.8.3 Chi square test (χ2):

Tab 3.7 GUMBEL's law.

X ².tab	12.59
Result of the statistic: X ². cal	6.6
p-value	0.359
Degrees of freedom	6
Number of classes	9

Tab 3.8 GALTON's law.

X ².tab	11.07
Result of the statistic: X ². cal	3.3
p-value	0.359
Degrees of freedom	6
Number of classes	9

Since it is X2.tab > X2. cal where both laws are accepted, in our case we chose the GUMBEL's law because When we compare Fig 3.5 of the adjustment according to the GUMBEL distribution with Fig 3.6 of the adjustment according to the GALTON distribution, it is clear that the GUMBEL distribution fits better than the GALTON distribution at the value's peak rainfall. The hydrological model makes it possible to transform the rain into runoff flow entering the network. It consists

3.8.4 From a Hydrological Model (production function)

This model makes it possible to account for runoff losses. The application of these lossestransforms the raw rainfall (precipitated rainfall) into rainfall contributing to runoff (net rainfall):

- Initial losses: due to the filling of soil depressions and retention by vegetation. They are equal, after setting, to 10 mm for permeable surfaces
- Continuous losses: these take into account the continuous infiltration of water into the soil during the rainfall event. Only permeable surfaces are then concerned (no infiltration for impermeable surfaces). The coefficient is then 0.8 as shown in the image below extracted from the PC-SWMM software. This means that 20% of the flow generated by the rain will infiltrate and 80% will. runoff

3.8.5 From a Net Rainfall / Flow Rate Transformation Model (transfer function)

This model transforms the net rain (contributing to runoff) into a flow rate chronicle (hydrograph) entering the network. This model takes into account the morphological characteristics of the watersheds (surface, length, slope, ...) to determine their response time. The model chosen is the SCS model. this hydrological method is based on the assumption that the ratio between the volume infiltrated at time t, F (t) (after satisfaction of the initial losses) and the maximum retention potential S is equal to the ratio of the sum of the net rainfall Pn on the sum of the gross rainfall Pb minus the initial losses Pi. To estimate the maximum retention capacity of soils S (mm), the methoduses a coefficient of aptitude for intermediate runoff, the Curve Number CN.

3.9 Calibration and Validation of Model

3.9.1 Principale

The calibration of the model consists in adjusting the value of certain calculation parameters so that the operation of the network is correctly reproduced, and in particular within the framework of this study the flows and volumes rejected by the storm overflows. The setting is a delicate exercise because the reaction of the network to the rain is strongly dependent on the type of rain (intensity, duration, shape of the hyetogram).

In summary, the calibration is only an adjustment of parameters, that is to say the measured and simulated curves must be quite close, in particular in terms of general shape. If the calculation results in a radically different curve, a questioning of the configurations is necessary, i.e. the structure of the model and / or the injections in the model must be modified.

3.9.2 Choice and Analysis of Events and Set Points

The first step in the calibration is the identification of the calibration events, from an analysis of the results of the measurement campaign Fig.3.5, satisfying the following conditions:

- The maximum number of measurements is available for the concerned day.
- The measurement curves do not present any singularity, for example linked to an incident on the network.

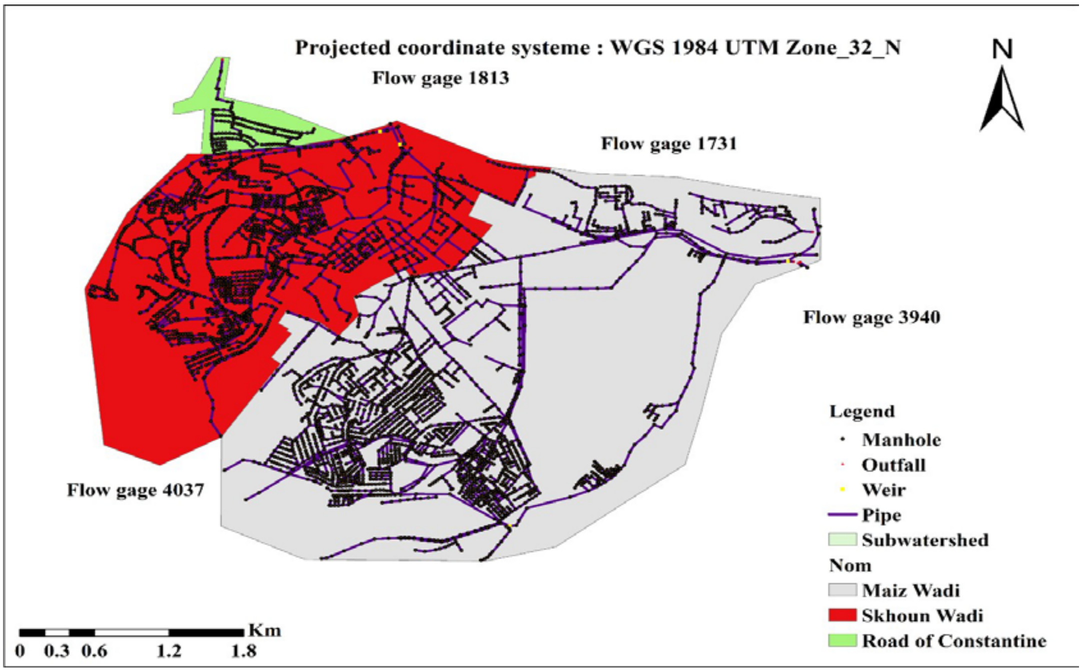


Fig 3.8 Location of flow gauges.

3.9.3 Calibration and Sensitivity Analysis

Flow calibration was carried out for a continuous simulation period from 04-11-2008 to 03- 12-2008 Table 3.2. We used the Sensitivity-Based Radio Tuning Calibration Tool to calibrate the most influential parameters on the flow and total volume. Sensitivity analysis was conducted to finalize the parameters that have the largest effect on the model efficiency at this study site and therefore minimize the number of parameters to be improved. Sensitivity analysis is conducted by changing some parameters while keeping the remaining parameters constant in the PCSWMM model, which aims to identify parameters whose variance induces substantial changes in the model outputs. In t, we selected elevation of the junction's invert, Manning’s roughness coefficient, the imperviousness percentage, and depth of depression storage as parameters to explore (Table 3.10).

Table 3.9 Calibration and validation rainfall event data from the study location.

Event date	Total rainfall (mm)
15-Nov-08	18.8
16-Nov-08	28.6
17-Nov-08	4.6
18-Nov-08	0.6
23-Nov-08	2.2
24-Nov-08	0.2
2-Dec-08	2.2
3-Dec-08	3.4

The visual comparison to assess the efficiency of the model in calibration and verification, is not sufficient, although we have observed good proximity between the observed and the modelled flow time series. Therefore, we resorted to comparison with statistical parameters; Nash-Sutcliffe Efficiency coefficient (NSE) (Nash & Sutcliffe, 1970), and Root Mean Square Error (RMSE), and the coefficient of determination (R^2) were utilized to define the goodness-of-fit between observed and simulated data. NSE is dimensionless and varies from negative infinity to one (one indicates good model performance). RMSE provided overall error magnitude with small values signaling a more accurate model.

NSE, RMSE, and $R^2$are calculated as follows:

$$\text{NSE}=1-\frac{\sum_{i=1}^{N}(Q_{i,Sim}-Q_{i,Obs})^2}{\sum_{i=1}^{N}(Q_{i,Obs}-\bar{Q}_{Obs})^2} \quad \ldots\ldots\ldots\ldots\ldots \ldots(3.2)$$

$$RMSE=\left(\frac{\sum_{i=1}^{N}(Q_{i,Obs}-Q_{i,Sim})^2}{N}\right)^{1/2} \quad \ldots\ldots\ldots .(3.3)$$

$$R^2=\frac{\sum_{i=1}^{N}(Q_{i,Obs}-\bar{Q}_{Obs})(Q_{i,Sim}-\bar{Q}_{Sim})}{\sqrt{\sum_{i=1}^{N}(Q_{i,Obs}-\bar{Q}_{Obs})^2(Q_{i,Sim}-\bar{Q}_{Sim})^2}} \ldots\ldots\ldots (3.4)$$

Where $Q_{i,Obs}$ is the observed flow, $Q_{i,Sim}$ is the simulated flow at time t = I, Q_{Obs} is the average observed discharge, and N is the number of observations.

Tab 3.10 Calibration parameters for PCSWMM.

Parameters	Surface type	Initial value	Calibrated value	Uncertainty value (%)
Impervious cover (%)	-	GIS-estimation	60 % of the initial	50
Manning's n for pervious area	Grass/tree	0.1		50
Depth of depression storage on impervious area (mm)	-	2	0.7	50
Depth of depression storage on pervious area (mm)	-	5.1	7.1	50
Percent of impervious area with no depression storage (%)	-	25	35	50
Elevation of junction's invert (m)	-	GIS-estimation	2% of the initial	5
Manning's n for conduit	Reinforced concrete	0.013	0.03	10

Like any mathematical model, the effectiveness and reliability of the model was evaluated at visual comparison level and statistical parameters comparison level. The results presented were after calibration of the most sensitive parameters on flow value and volume. The calibration was in the main pipes 1731, 1813 and 3940, and the validation was in main pipe 4037 as shown in (Figure .3.5). These pipelines are connected and close to the outlets of the sewage network, and this makes the value of the flow real regardless of some losses that are caused by friction and sedimentation at the level of the sewage network. We did not address the evaluation of the base flow in this study, as its value is usually neglected compared to the direct flow, especially as the urban catchment where the percentage of infiltration is not valuable, unlike the rural catchment, which are desirable and preferable to evaluate. The values of R2 were between 0.76 and 0.96 for the calibration and 0.74 for the validation, and the NSE results were between 0.70 and 0.88 for calibration and validation was 0.74. Based on the visual comparison between the simulated and observed flow (Figure .3.6). In addition to the results shown in Table 3.4. We can conclude that the model has the capacity, effectiveness and reliability to predict flow in the study and related urban watersheds in a satisfactory manner. This conclusion provides support to estimate the impact of investment **phase.**and implementation of LID.

Tab 3.11 Evaluation of the statistics coefficients of calibration and validation

Identification of flow gage	NSE	R^2	RMSE	Max flow (m^3/s)	
				Predicted	Observed
1813	0.70	0.78	0.23	0.45	0.48
3940	0.88	0.96	0.02	0.07	0.10
1731	0.76	0.76	0.07	0.20	0.22
4034	0.74	0.74	0.02	0.09	0.07

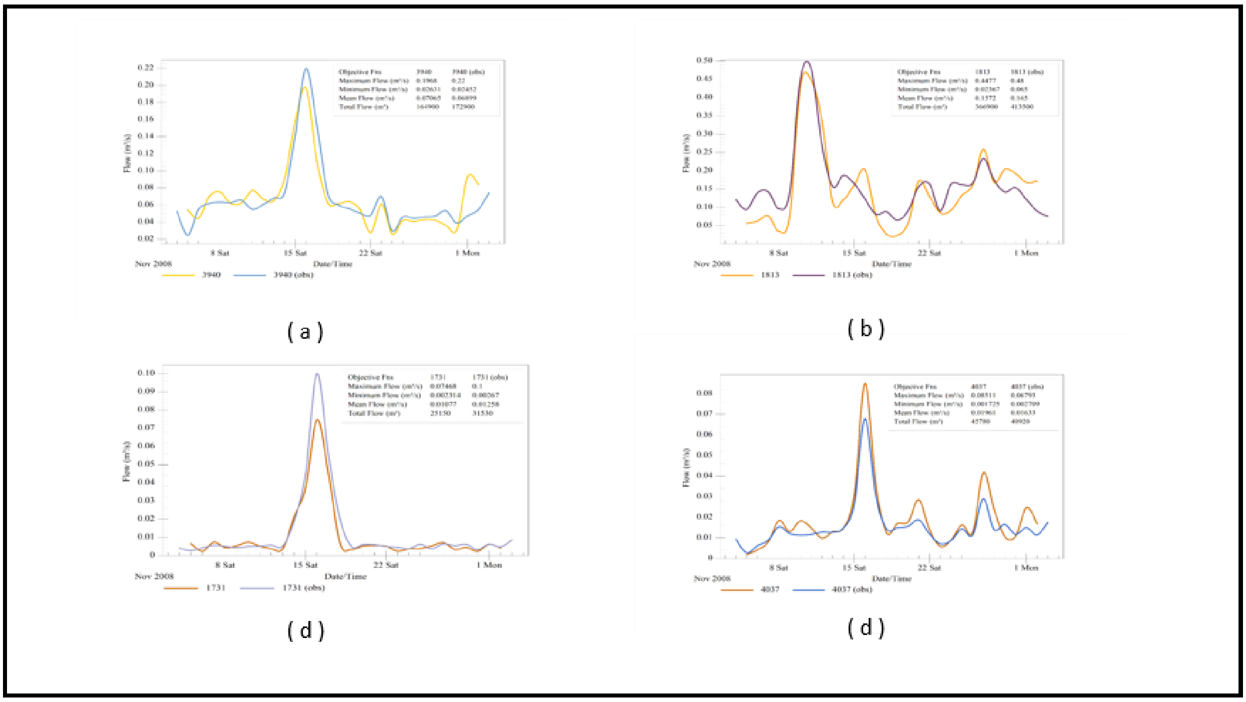


Fig 3.9 Predicted and observed maximum flows of calibration events at flow gauges (a, b, c) and validation at flow gauge (d).

3.10 Design Storm Construction

The PCSWMM model was applied to examine Low Impact Devlopement (LID) practices performance, including 3h Desbordes storms with 10-year return periods. Design storms were derived from rainfall intensity-duration-frequency curves Fig.3.7 for measured rainfall at the Guelma Rainfall Station from 1972 to 2008. Desbordes storms are calculated based on the Montana equation as follows:

$$\mathbf{P\ (mm) = \quad a(T)^{*}} t^{1-b(t)} \ \mathbf{\ldots\ldots\ldots\ldots\ldots\ (3.5)}$$

Where T is the event return period; a (T) represents independent of aggregation time so that the family of curves in T are parallel; a (T) is specified by the inverse function of a (T), moreoverthe parameter b describes the dynamics of the extreme rainfall process as a function of the durationt (Laouacheria et al., 2019)

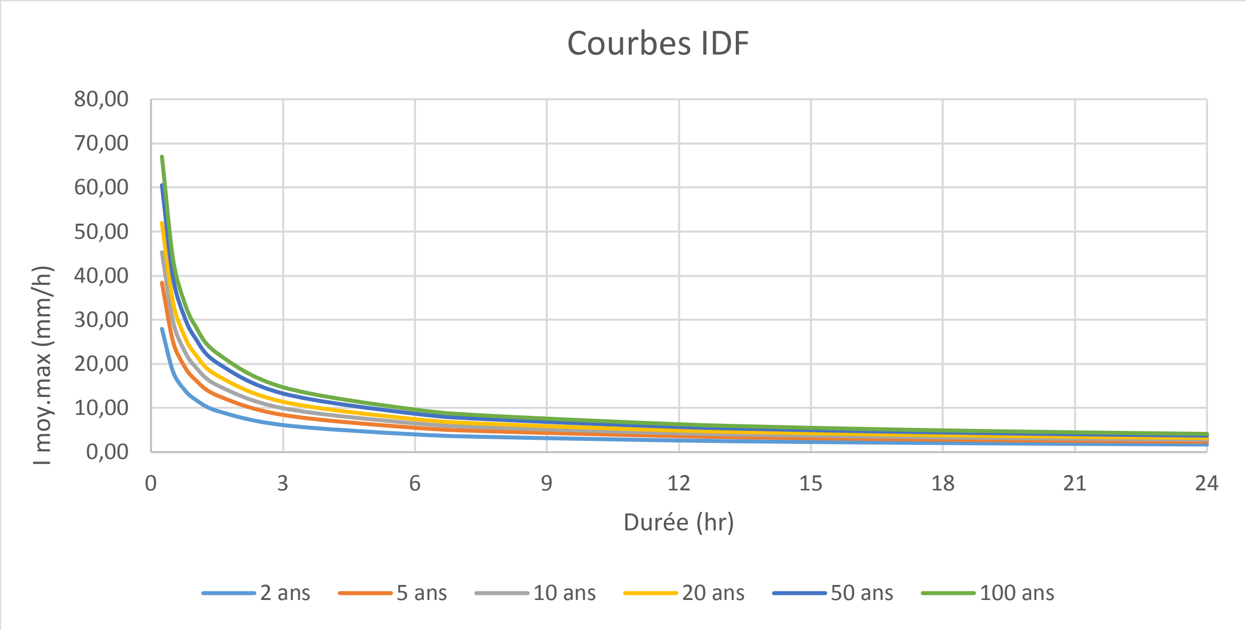


Fig 3.10 Intensity-duration-frequency curves for the Guelma Watershed.

The parameters a and b for various design storms are detailed in Table 3.5

b	15 min-1h	1h-6h	6h-24	a	15 min-1h	1h-6h	6h-24
2 Yr	0.741	0.736	0.737	2 Yr	6.46	6.35	6.38
5 Yr	0.739	0.738	0.751	5 Yr	8.75	8.71	9.44
10 Yr	0.738	0.738	0.732	10 Yr	10.28	10.25	9.91
20 Yr	0.739	0.741	0.732	20 Yr	11.76	11.86	11.25
50 Yr	0.741	0.738	0.74	50 Yr	13.76	13.64	13.77
100 Yr	0.74	0.739	0.739	100 Yr	15.16	15.13	15.11

3.11 Conclusion

In this chapter, we dealt with the simulation of hydrological modeling that used to be an entrance to hydraulic modeling. We also dealt with calibration to extract the most sensitive parameters on the outputs of the flows and volumes. Parameters were respectively: Impervious cover (%), Manning's n for pervious area, depth of depression storage on impervious area (mm), depth of depression storage on pervious area (mm), percent of impervious area with no depression storage (%), elevation of junction's invert (m), and Manning's n for conduit.

Chapter 4
Rainfall-Runoff Modeling Using the PC-SWMM Model

4.1 Introduction

Diagnosing the hydrological response in periods of rain has always been a hindrance for researchers, especially in urban catchments, where the structure of the geomorphological structure is complex compared to its counterpart in rural catchments. Therefore, designers, researchers and modelers have resorted to designing models in recent decades to diagnose urban floods and assess their amplitude. Among these models is the PC-SWMM model.

Numerous studies and reports at the level of different regions of the world have proven the efficiency and reliability of the model in addressing several problems in the field of urban hydrology and hydraulics.

For example, (Asghar, 2018; Kim et al., 2018; McPhee, 2019; Neupane, 2018) evaluated the effectiveness of Low Impact Development (LID), green infrastructure and other best management practices for reducing surface runoff. Also (Azawi & Sachit, 2018; Dressel, 2014; Irvine et al., 2015; Talbot et al., 2016) has been shown the ability of model to improve water quality by reducingpollutant loads and (Fernandez et al., 2019; Marvin, 2018; State & Survey, 2001) prove the model's ability to determine the size and configuration of effective detention ponds and their appurtenances for flood control and water quality protection. On the other hand, (Abdelrahman et al., 2018; Nazariet al., 2016; Randall et al., 2017; Sañudo et al., 2020; Schmitt et al., 2005; Waters et al., 2003; Yanget al., 2019) demonstrated the efficiency of the model to design, and analyze dual drainage systems for flood control.

The aim of this study is to reach a real diagnosis of the hydrological response during the rainy period by comparing the simulated outputs from the flows and volumes with their relative numbers of observed volumes and flows.

4.2 Presentation of the PC-SWMM model

The Personnel Computer Storm Management Model (PCSWMM) is a software based on the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM). SWMM is a well-known model used for hydrodynamic approaches and also allows for a range of different LID controls to be modeled in a simulation to retain and temporarily store storm water runoff from a site (Goncalves et al., 2018). In PCSWMM, the rainfall runoff process is conceptualized using material and water flow between its environmental sectors.

All the processes. can be assigned into four compartments: atmospheric compartment; land surface compartment; transport compartment; and ground water compartment (Akhter & Hewa, 2016).

The PCSWMM model consists of different modules or blocks. The main blocks are the runoff block, transport block, and the storage and treatment block. Runoff block generates runoff and quality constituents in rainfall. The transport block is used for kinematic wave routing and for additional dry weather and quality routing, while the storage and treatment block are used for reservoir routing, simulating of treatment, and processing of storage quality. Hydraulic routing of flow is executed by the Extended Transport of Extran Block. During a simulation period, PCSWMM can trace the quantity and quality produced at each sub-catchment Fig 4.1.

In addition, itcan track the quality of water, flow rate, and flow depth in pipes and channels. LID and BMPs can be modeled to reduce impervious and pervious runoff and associated pollutants transport Fig 4.2 (Rossman, 2010).

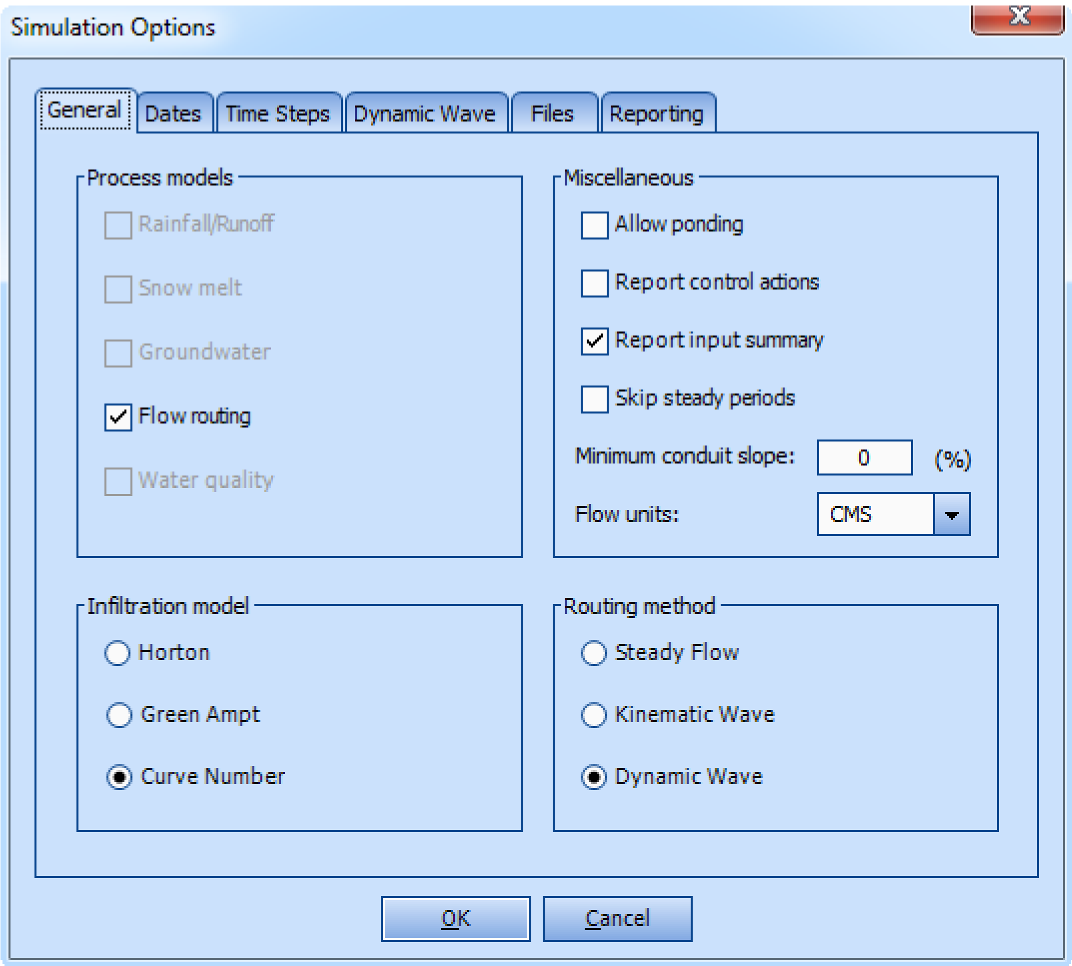


Fig 4.1 Simulation option of PC-SWMM Model.

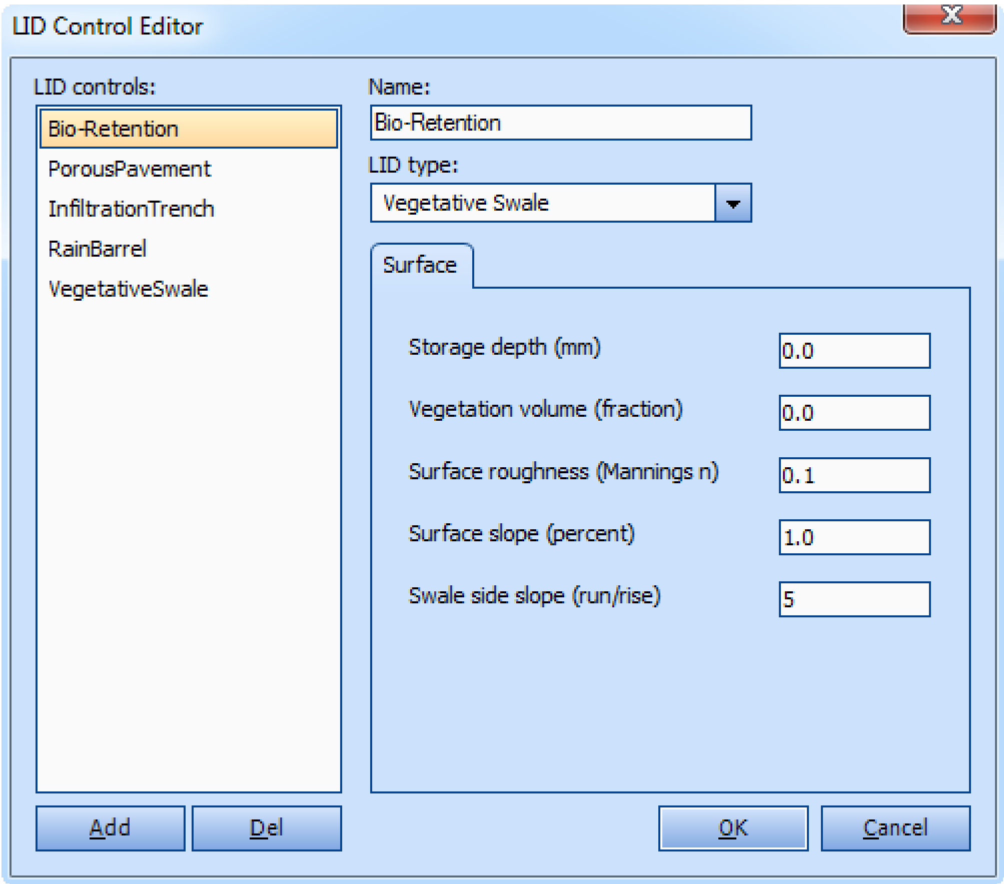
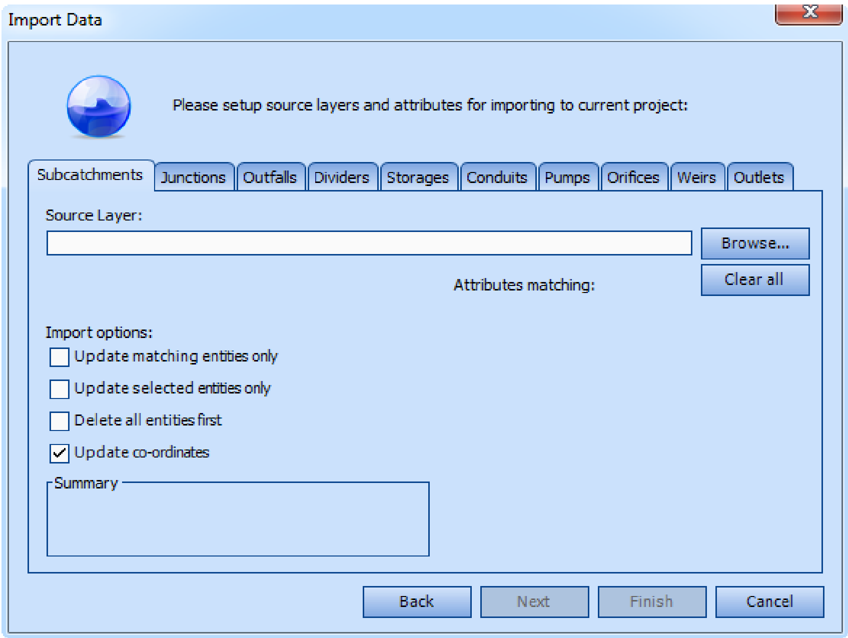
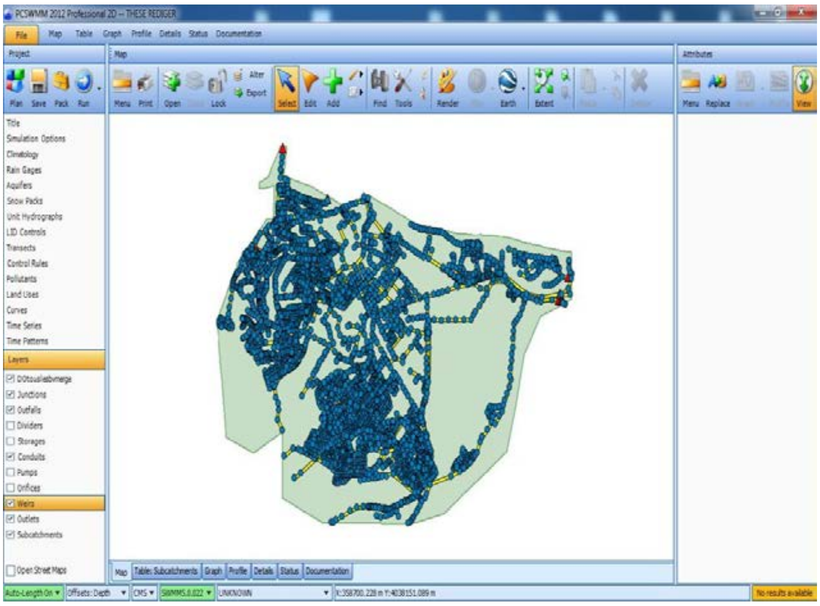


Fig 4.2 Construcion of LID in PC-SWMM Model.

PC-SWMM also allows importing a database in several forms (shp.kmz, csv, cad, inp...) and withits true geographical reference Fig 4.3 and Fig 4.4.



(a)



(b)

Fig 4.3 PC-SWMM Model importation database from GIS.

The hydrological component of PCSWMM functions on impervious and pervious sub-catchments that can include depression storages. PCSWMM has the capability of accounting for different hydrologic processes that produce runoff, including (Rossman, 2010):

- Rainfall of time-varying nature.
- Still surface water evaporation.
- Accumulation and thawing of snow.
- Rainfall capture in depression storages.
- Rainfall infiltration.
- Seepage of infiltration into groundwater.
- Infiltration of water between groundwater and drainage network.
- Nonlinear reservoir routing for overland flow.
- Intercepting and retention of rainfall-runoff by different low impact measures.

In addition, the hydrologic component of PCSWMM calculates pollutant load buildup and washoffof subcatchments. PCSWMM's abilities are (Rossman, 2010):

- Buildup of dry-weather pollutants on lands.
- Washoff of pollutants during storms from lands.
- Rainfall contribution.
- Dry-weather buildup reduction due to street cleaning.

- Washoff loads reduction due to BMPs.
- Input from sanitary systems and user specified input at any location during dry weather to drainage network.
- Water quality elements routing.
- Water quality pollutants reduction due to natural processes in channels/pipes or by treatmentin storage units.

PCSWMM has hydraulic modeling capabilities that route runoff and water quality constituents through open channels, closed pipes, storage-treatment basins, etc. These capabilities are (Rossman, 2010) :

- Modeling networks of different sizes.
- Handling different shapes of pipes and channels.
- Modeling flow dividers, pumps, weirs, orifices, and storage treatment units.
- Using different routing methods such as kinematic wave or full dynamic wave or steady state.
- Inputting external flows and water quality input from surface runoff, ground interflows, infiltrations, dry weather sanitary flows, and inflows defined by the user.
- Handling different flow regimes like backwater, free surface, surcharging, surface ponding and flooding, and reverse flow.
- Using rating curves for inlet controls.
- Handling control rules for operation of pumps, openings for orifices, and levels of weir crest.

For calibration of PC-SWMM models, certain parameters need to be examined to check which are more sensitive than others. (Kabbani, 2015b) examines the most sensitive parameters in the SWMM runoff block and transport block. In the runoff block, the basic parameters are (Kabbani, 2015b):

- Percent of imperviousness.
- Manning’s runoff coefficient.
- Ground slope.
- Detention depth.
- Infiltration rate.
- Width of the overland flow.

On the other hand, the main components of transport block are (4):

- Percent of imperviousness.
- Number of conduits in a given length
- Conduit length.
- Surcharge condition.
- Conduit slope.
- Conduit Manning's roughness coefficient.

The most sensitive parameters in the runoff block are: percentage of imperviousness and width of overland flow, while those for the transport block are: conduit length and Manning's roughness coefficient (Kabbani, 2015b). In another study on large urban catchments that used the optimization procedure, the most sensitive parameter was imperviousness and the least sensitive parameter was Manning's roughness for surface flow.

4.3 Advantages of PCSWMM over other Models

PCSWMM was chosen for this research due to its special capabilities of having the GIS engine that can handle the latest GIS data formats and support of the SWMM engine from EPA. The inherited capabilities from the SWMM model that are useful for this study are its dynamic hydraulic and hydrological modeling capabilities of simulating runoff quantity and quality in urban areas. It can be used for single event or long-term continuous events with time varying hyetographs,depression storage, and different infiltration methods. It can be used to model large complicated drainage networks with different conduit shapes and sizes. Moreover, it has three 36 options for routing storm water flows which are: steady state, kinematic wave, and dynamic wave. Also, it can model the wash off of pollutants from land surfaces and route the pollutant concentration through the drainage network. In addition to its ability to model BMPs, PCSWMM can also model the reduction of pollution concentration through treatment in storage units or by natural processes in thedrainage network (Environmental Protection Agency (Kabbani, 2015b).

Finally, the SRTC (Sensitivity-based Radio Tuning Calibration) tool facilitates calibration ofthe model through the use of uncertainty percentage chosen by the user for certain model parameters. When running SRTC, PCSWMM model executes two runs of the model for the extreme highest and lowest percentage of the chosen uncertainty range. The SRTC tool provides a slider for the user to fine tune the parameters that best suit observed time series.

4.4 Rainfall-Runoff Transformation by Modeling

At the level of deterministic modeling, the Rainfall-Runoff rate transformation is done by succession of two sub models: a production function and a transfer function.

4.4.1 Production Function

This sub-model makes it possible to deduce the net rain from the gross rain by several methods

4.4.1.1 Horton Method

Empirical model of the representation of infiltration on permeable soils. Horton's model consists of expressing the normal infiltration capacity - of a soil in the form next:

$$f(t)= f_c+(f_0-f_c) * e^{-Kt}$$

With

- **f_0** : soil infiltration capacity in mm /h.
- **f_c** : capacity of salted soil infiltration mm/h.
- **k :** positive time constant.

This model gives a good approximation of the infiltration curves in a saturated soil in its horizon superficial or in strongly vegetated soil, it is however very poorly suited for bare and dry soils whether water / air interface problems in the superficial zone are important.

4.4.1.2 Green Ampt Method

This Model is based on simplifying assumptions which imply a schematization of the infiltration process:

$$i(t) = K_s \left[1+ \frac{h_0-h_f}{Z_f(t)} \right]$$

With:

- Kc: hydraulic conductivity at saturation mm / h
- H_0: surface pressure load (mm)
- H_f: pressure load at the humidification front (mm);
- Z_f:depth reached by the humidification front (mm)

4.4.1.3 SCS Method

The SCS CN method has been used globally to achieve several goals such as Management of water supplies, simulation of urban storm water systems and calculation of runoff (Chen et al., 2017). It can be expressed as:

$$\mathbf{Q} = \frac{(P-0.2)^2}{P+0.8S}, \quad P \geq 0.2\,S \qquad (1)$$

$$Q = 0, P < 0.2\,S$$

Where :

- Q is runoff depth in mm,
- P is storm rainfall in mm.
- S is potential maximum retention or infiltration in mm.

Using equation (1), S is estimatedusing runoff CN:

$$\mathbf{S} = \frac{25400}{CN} - 254 \qquad (2)$$

Where CN represents runoff potential of land cover-soil complex characteristics impactedby antecedent moisture condition (AMC) of soil and land use management.

4.4.2 Transfer Method

The purpose of the sub-model is to transform the results (net rain) of the production functioninto a hydrograph (flow) of flow entering the network of collectors.

4.4.2.1 Linear tank Model

This is the most commonly used model for urban watersheds due to its simplicity in terms ofrequested parameter (it contains only one parameter). In this model we can consider that the basin pouring can be represented by a reservoir with an inlet (net rain) and a drain (flow at the outlet) and a storage function. The model is therefore established by combining:

A storage equation linearly relating the stored volume to the outgoing flow:

$$V_s\,(t) = K.\,Qs\,(t)$$

$$\frac{dV_s}{dt} = Q_e(t) - Q_s\,(t)$$

- K single parameter of the homogeneous model has a time called lag-time or response time(S);
- Q_e(t): flow net rainfall rate (m3 / s);
- Qs (t): flow rate at the outlet (m3 / s);
- V_s (t): instantaneous volume stored in the watershed (m3).(Huber et al., 1975)

4.4.2.2 Non-linear reservoir model

In order to better represent the nonlinear character of transient free surface flows, someresearchers have proposed to use nonlinear storage models.

The nonlinear reservoir method is based on the coupling of the continuity equation and theequation by Manning-Strickler. The continuity equation is written:

$$\frac{dv}{dt}A* \; \frac{dd}{dt}A*t - Q \ldots\ldots\ldots\ldots f_1$$

The Manning-strickler equation:

$$Q= W * \frac{1}{n} \; (d - dp)^{\frac{5}{3}} * S^{\frac{1}{2}} \ldots\ldots\ldots\ldots f_2$$

With:

- V: volume of water in the watershed (m3).
- A: the area of the watershed (m).
- d: draft (m).
- t: time (s).
- dp : height of stored water (m).
- i: intensity of net rain (mm/s).
- Q: outlet flow (m3 / s).
- W: basin width (m).
- n: manning coefficient.
- S: slope of the land.

The combination of equations (f1) and (f2) gives the equation for nonlinear reservoirs.

$$\frac{dd}{dt} = i - \frac{dd \;\; W}{dt \; A*n} (d - dp)^{\frac{5}{3}} * S^{\frac{1}{2}} \ldots\ldots\ldots\ldots f_3$$

This equation can be written in the following form:

$$\frac{d_2 - d_1}{dt} = i - \frac{W}{A*n} (d_1 + \frac{1}{2}(d_2 - d_1))^{\frac{5}{3}} * S^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots f4$$

The equation is solved, as a function of time, according to the iterative Newton Raphson method, in order to obtain the value of d2. Once this value is known, the stream flow is calculated by (f2). In all the hydrological methods used in modeling, time is a main element in determining flow rates, from the production function (change in infiltration capacity) to the transfer function (change in flow rates). On the other hand, in Caquot's method the flow is instantaneous and infiltration is constant (runoff coefficient) (Huber et al., 1975).

4.4.2 Routing Method

Flow routing is a mathematical procedure to determine the evolution of throughput overtime and space. It makes it possible to determine the evolution of the speed, the magnitude of the flow as a function of time and of the length traveled in the reach (Bellier & Ducharne, 2008).

Flow routing models that are based on simplifications of the Saint-Venant equations are less accurate than those based on the numerical solutions of all the Saint-Venant equations. However, they are very valuable tools for people who wish to determine its behavior in a river with the aim, for example, of carrying out works there. All of these routing models are based on the Saint-Venant equations which are made up of the conservation equation of mass (continuity equation) and the dynamic equation. (Bellier & Ducharne, 2008).

4.4.2.1 Muskingum's Method

The Muskingum method is a hydrological flow routing model with lumped parameters, which describes the transformation of discharge waves in a river bed using two equations. The first one is the continuity equation (conservation of mass) and the second equation is the relationship between the storage, inflow, and outflow of the reach (the discharge storage equation) (Baláž et al., 2011).

The Muskingum equation is defined by the following relationship:

$$S(t) = k\,[x\,I(t) + (1-x)\,Q(t)] \qquad (3)$$

The parameter k is in seconds and x is dimensionless. From equation (3) we can calculate the outgoing flow Q (t) only from storage S (t) and the upstream flow I (t).

$$Q(t) = \frac{S(t) - k\,x\,I(t)}{k(1-x)} \qquad (4)$$

The parameter x represents a weighting factor whose values are between [0-0.5] even if in the case of most rivers it is between [0.1-0.3]. If x is equal to zero then the volume of water stored depends only on the downstream conditions but if x is equal to 0.5 then the storage is a function of the flow rate because the incoming flow has the same "weight" as the flow outgoing.

The parameter k is the travel time of the wave in the reach. It is defined by the following relation:

$$K=\frac{L}{ue}\ldots\ldots\ldots\ldots..(5)$$

With:

- L: being the length of the reach in m;
- Ue: la vitesse moyenne de l’onde en m/s ;
- K: the travel time in s;

4.4.3.2 Muskingum Cunge Method

In the absence of observed flow data, the Muskingum-Cunge method may be used for parameter estimation. This concept is also applied when measured flow data are available, but with significant degree of uncertainty (Elbashir, 2011)

The Muskingum-Cunge parameters are calculated based on the flow and the channel characteristics. This method involves the use of a finite difference scheme for solving the Muskingum equation, where the parameters in the Muskingum equation are determined based onthe grid spacing for the finite difference scheme and the channel geometry characteristics (Elbashir, 2011)

The Muskingum-Cunge has two formulations, which relate the estimation of the routingcoefficients with the methods of mathematical solution.

$$K=\frac{\Delta x}{c}\ldots\ldots\ldots\ldots\ldots(6)$$

$$X=\frac{1}{2}\left(1-\frac{q}{S_0\, C\, \Delta X}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

With:

- c: Wave celerity (m/s);
- ΔX:the stream reache length (m);
- S_0: Channel bed slope (m);
- q; discharge per unit width (m^2/s);

4.5 Conclusion

The commissioning of modeling as a tool for understanding the hydrological functioning of watersheds, and for decision support is one of the best recognized methods that are both simple and successful. With this in mind, the part was primarily interested in applying an appropriate modular combination of the PCWMM model to one of the sub-basins of the Wadi Guelma catchement.Then, after having been validated on at least one of the preselected events, the study looked at the use of this model to predict the future hydrological behavior of the basin vis-à-vis climate change and water modification scenarios. 'land use.

After having fully validated the PCSWMM model on the Guelma catchment, it can be used for flood protection. Using what is called real-time modeling which is based on the principle of reconstitution of the flow at the outlet for each time step for which the rainfall data is measured, consequently we can reconstitute the hydrograph of a flood as the rainfall height is recorded. This alarm system is more effective than the one based on measuring the height of the water in the river upstream of the watershed.

Chapter 5

Evaluating Low Impact Development Practice Performance

5.1. Introduction

Strategies have been explored in recent years to decrease the impacts of surface runoff resulting from unrefined urban development and climate change (Eckart et al., 2017; Zhang & Chui,2018) these strategies have the same role, but they differ in name by country and the size of use. Forexample, we find Low Impact Development (LID, USA), Sustainable Urban Drainage Systems (UK), Low Impact Urban Design and Development (New Zealand), and Water-Sensitive Urban Design (Australia) (Eckart et al., 2017). Water quality and groundwater recharge can also be improved using these techniques (Ahiablame, Engel, et al., 2012)

In this chapter, we highlight the evaluation of the effectiveness of Low Impact Development(LID) in reducing runoff. Prior to that, we discussed the results of calibration and validation of the model through visual comparison and by calculating the statistical parameters between the simulated and observed flows.

In addition to the recent results reached by researchers in recent decades in the effectiveness of LID (Ahiablame et al., 2013; Ahiablame, A. Engel, et al., 2012; Ahiablame, Engel, et al., 2012; Garg, 2018; Goncalves et al., 2018; Kabbani, 2015b; Li et al., 2018; Liu et al., 2016; Liu, Ahiablame, et al., 2015; Liu, Bralts, et al., 2015; Martin et al., 2015; Song & Chung, 2017; Sun et al., 2014) our results were also encouraging to invest in (LID), which supports the reliability and effectiveness of this strategy as a modern technique in reducing surface runoff instead of classic techniques.

5.2 Description of LID Technologies

Experts and specialists have created many LID techniques, and each of them has its strengths, weaknesses, and conditions of use. In some cases, it will serve as a complete scenario combined, and in some times it will serve as a single scenario, due to the purpose of the study.

5.2.1 LID Practices and Benefits

The LID site design approach is a precise arrangement of natural and engineered technologies. The devices, or Integrated Management Practices (IMPs), function as a comprehensive system across the site to achieve the goals of:

- Peak flow control;
- Volume reduction;
- Water quality improvement (filter and treat pollutants);

- Water conservation;

Tab 5.1. LID Practices and Benefits (Shafique & Kim, 2015).

LID PRACTICE / DEVICE	PEAK FLOW CONTROL	VOLUME REDUCTION	WATER QUALITY IMPROVEMENT	WATER CONSERVATION
Bioretention Cell	*	*	*	
Citern	*	*		*
Curbless Parking Lot Islands	*	*	*	
Downspout Disconnecion	*	*	*	
Grassed Swale	*	*	*	
Green Roof	*		*	
Infiltration Trench	*	*	*	
Narrow Road Design	*	*	*	
Permeable Pavers/Pavement	*	*	*	
Rain Barrel	*	*		*
Rain Garden	*	*	*	
Sand Filter	*		*	
Tree Box Filter	*		*	
Tree Planting	*	*		

5.3 Common LID Practices

Below are examples of common LID practices. A brief overview of the storm water controlsthat can be implemented on a project is also included. The techniques should be evaluated for their suitability for each project:

5.3.1 Bioretention Cell (Rain Garden)

A bioretention cell (strip or trench) is an engineered natural treatment system consisting of a slightly recessed landscaped area constructed with a specialized soil mixture, an aggregate base, an underdrain, and site-appropriate plant materials that tolerate both moist and dry conditions. The site is graded to intercept runoff from paved areas, swales, or roof leaders. The soil and plants filter and store runoff, remove petroleum products, nutrients, metals, and sediments, and promote groundwater recharge through infiltration. The cells are designed to drain in 24 hours, with no risk of standing water and breeding of mosquitoes.

A rain garden typically does not have the full spectrum of engineered features that bioretention cells have, such as underdrains and the entire soil mix. They can be designed and built by homeowners and located near a drainage area, such as a roof downspout.

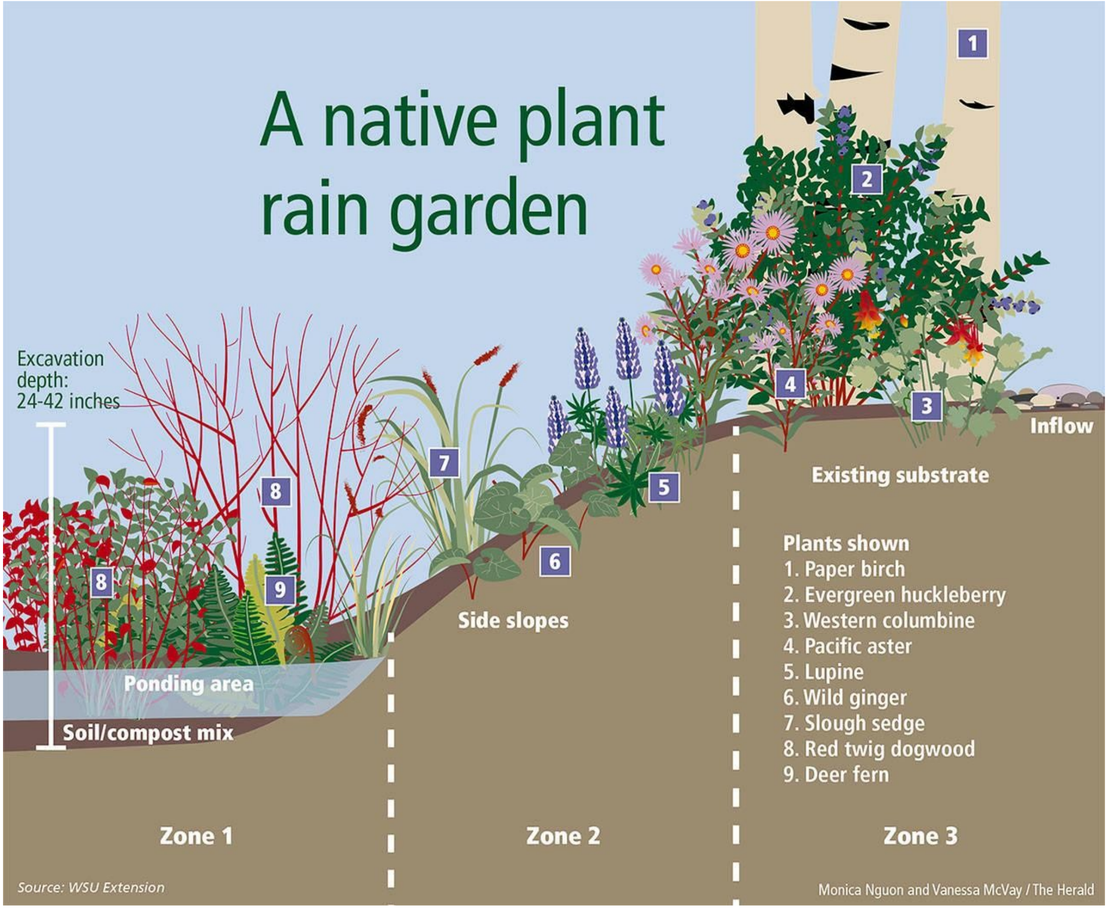


Fig 5.1 Rain Garden (Geddes & Grosset, 2005)

Typical Uses: Parking lot islands, edges of paved areas (roads or parking lots), adjacent to buildings, open space, median strips, swales.

Land Use: Ideal for commercial, industrial, and residential (urban, suburban, ultra-urban). They are widely used in transportation projects (highway medians and rail projects). They are suitable fornew construction and retrofit projects.

Approximate Cost: Residential costs average $3–$4 per square foot of size plus excavation and soil amendment costs. Plant materials are comparable to conventional landscaping costs. Commercial, industrial, and institutional site costs can range from $10–$40 per square foot, based on the need forcontrol structures, curbing, storm drains, and underdrains.

Maintenance: Routine maintenance is required and can be performed as part of the regular site landscaping program (i.e., biannual evaluation of trees and shrubs, regular pruning schedule). The use of native, site-appropriate vegetation reduces the need for fertilizers, pesticides, excessive water, and overall maintenance requirements.

Additional Benefits: Easily customized to various projects (size, shape, and depth) and land uses; enhances aesthetic value of site; uses small parcels of land, easements, right-of-ways; easily retrofitted into existing buildings/open space.

5.3.2 Vegetated Swale (Bio-Swale)

A vegetated or grassed swale is an area with dense vegetation that retains and filters the first flush of runoff from impervious surfaces. It is constructed downstream of a runoff source. After the soil-plant mixture below the channel becomes saturated, the swale acts as a conveyance structure to a bioretention cell, wetland, or infiltration area. There is a range of designs for these systems. Some swales are designed to filter pollutants and promote infiltration and others are designed with a geo- textile layer that stores the runoff for slow release into depressed open areas or an infiltration zone.

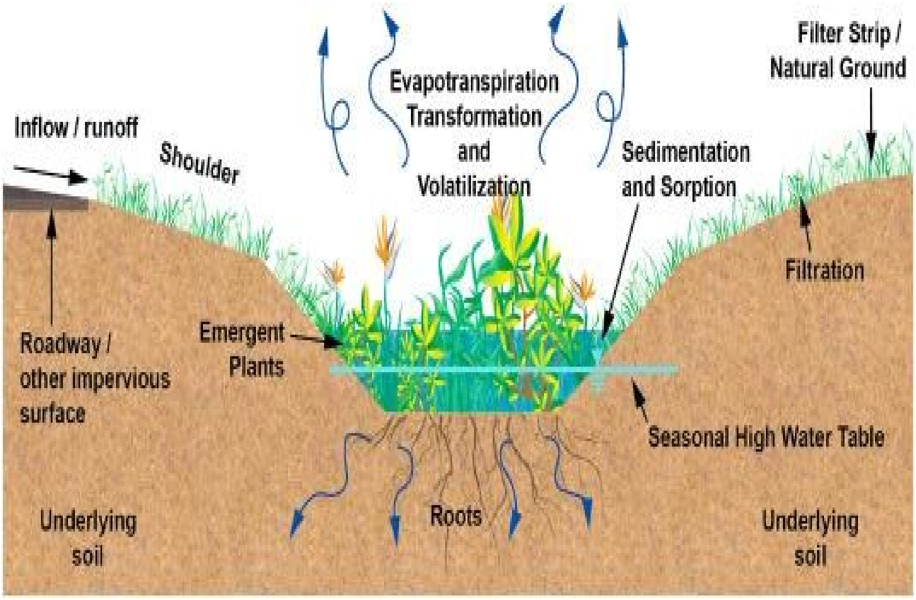


Fig 5.2 Vegetated Swale. (Geddes & Grosset, 2005)

Alternative Devices**:** Filter strip or vegetated buffer.

Typical Uses: Edges of paved areas (roads or parking lots), parking lot islands, intermediarycommon spaces, open space, or adjacent to buildings.

Land Use: Commercial, industrial, residential (urban, suburban, ultra-urban); transportation projects (highway medians and rail projects); new construction and retrofit projects.

Approximate Cost: $0.25 per square foot for construction only; $0.50 per square foot for design andconstruction.

Maintenance: Routine maintenance is required. Maintenance of a dense, healthy vegetated cover; periodic mowing; weed control; reseeding of bare areas; and clearing of debris and accumulated

sediment.

Additional Benefits: Easily customized to various projects (size, shape, and depth) and land uses; enhances aesthetic value of site; uses small parcels of land, easements, right-of-ways; easily retrofitted into existing buildings/open space.

5.3.3 Permeable Pavement

Disconnecting impervious areas is a fundamental component of the LID approach. Roofs, sidewalks, and paved surfaces are disconnected from each other to allow for more uniform distribution of runoff into pervious areas. Conveying runoff into vegetated areas keeps the water from directly entering the storm drain network, reduces runoff volume, and promotes distributed infiltration.

Since paved surfaces make up a large portion of the urban (or developed) landscape, the use of permeable pavement is very effective at stabilizing the hydrologic condition of a site. Permeable surfaces can be used in conjunction with subsurface infiltration galleries (subsurface retention facilities) as seen in Section 6.

A secondary benefit of permeable paving is its performance in snowy conditions. Cahill Associates reports an increase in demand for the installation of permeable asphalt in the Northeast as a result of reduced maintenance costs (snow shoveling and desalting) due to rapid snowmelt on permeable surfaces.

Types of permeable pavement include permeable asphalt, permeable concrete, grid block pavers, plastic grids, vegetated grids, Belgium block (in photo), turf block, gravel, cobbles, brick, natural stone, etc.

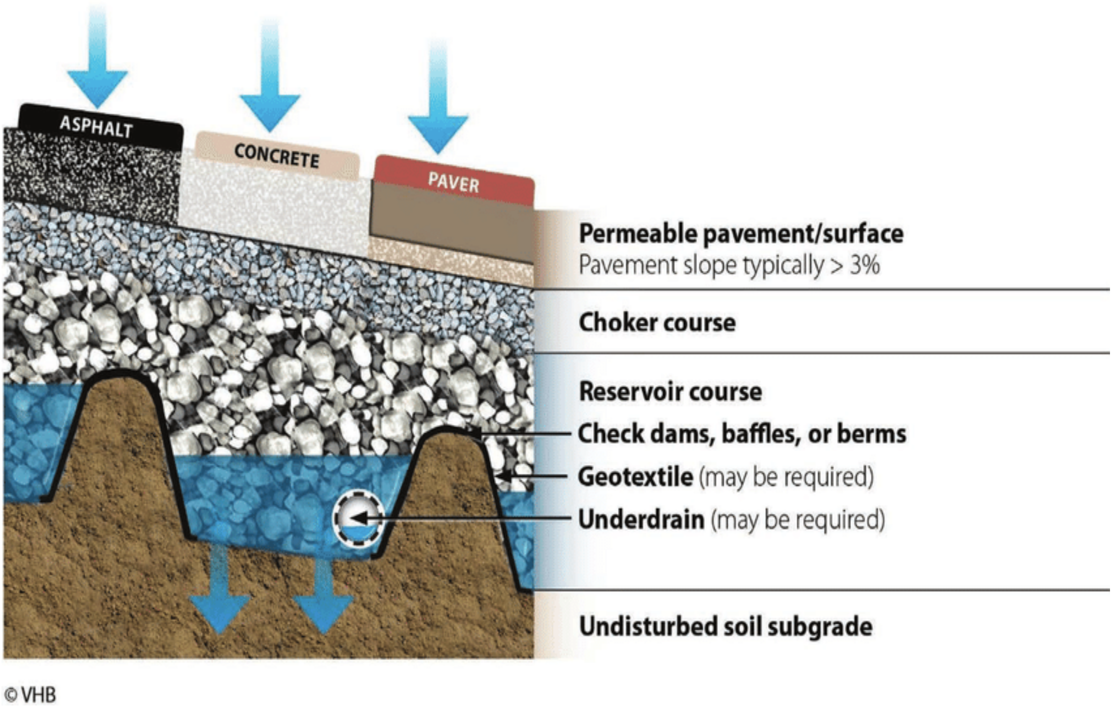


Fig 5.3 Permeable Pavement. (Geddes & Grosset, 2005)

Typical Uses: Parking bays, parking lanes, sidewalks, roads. Blocks and porous pavement are generally used in high traffic parking and roadway applications; respectively grid systems are more commonly used in auxiliary parking areas and roadways.

Land Use: Ideal for commercial, industrial, and residential (urban, suburban, ultra-urban); suitablefor new construction and retrofit projects.

Approximate Cost: Varies according to product. Typically, the cost is higher than conventional paving systems; however, they help reduce the overall storm water infrastructure costs.

Maintenance: Varies according to product. Routine street sweeping will sustain the infiltration capacity of voids. Porous concrete/asphalt require annual vacuuming, to remove accumulated sediment and dirt.

Additional Benefits: Easily customized to various projects and land uses; enhances aesthetic valueof site; easily retrofitted into existing paving configurations.

5.3.4 Subsurface Retention Facilities

Subsurface retention facilities are typically constructed below parking lots (either permeable or impervious) and can be built to any depth to retain, filter, infiltrate, and alter the runoff volume and timing. This practice is well suited to dense urban areas. Subsurface facilities can provide a considerable amount of runoff storage. Similar techniques include gravel storage galleries, sand filters, infiltration basins, and infiltration trenches (for areas with space constraints)

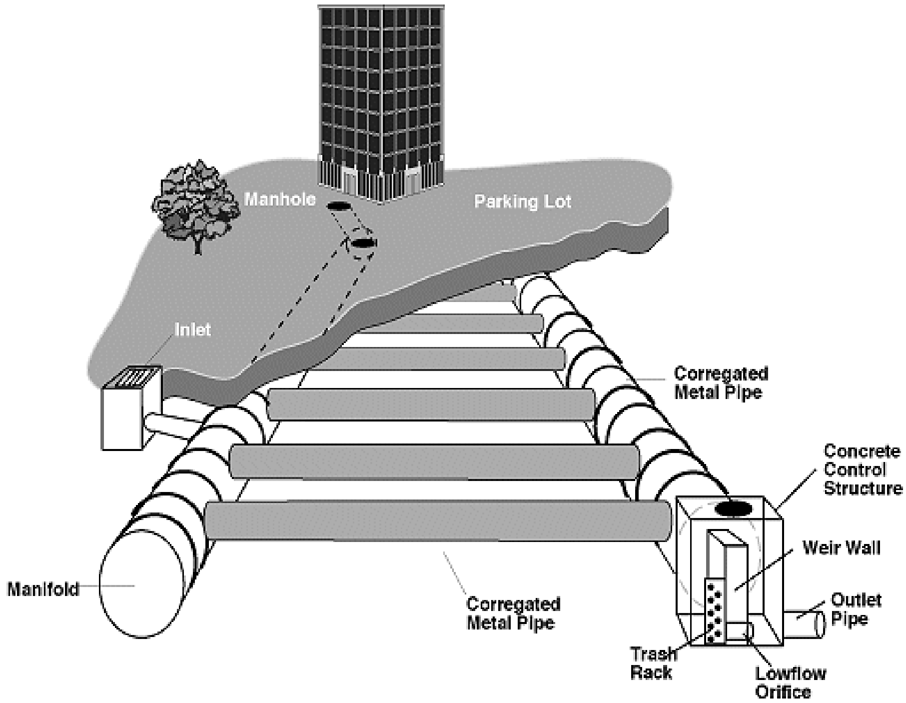


Fig 5.4 Subsurface Retention Facilities. (Geddes & Grosset, 2005).

Typical Uses: Parking lots, sidewalks, and roads.

Land Use: Ideal for commercial, industrial, and residential (urban, suburban, ultra-urban); uitable for new construction and retrofit projects.

Approximate Cost: Costs are typically higher than conventional paving systems; however, they help reduce the overall storm water infrastructure costs (land allocated for ponds, cost of pipes, inlets, curbs/gutters).

Maintenance: Varies according to manufacturer; routine street sweeping and vacuuming will retaininfiltration capacity of voids.

Additional Benefits: Easily customized to various projects and land uses; enhances aesthetic value of site; easily retrofitted into existing paving configurations.

Design Specs and Supplementary Information: These are specialized systems and should be designed by, or under the direct supervision of, an appropriate licensed professional. The reduction of street widths (i.e., from 36' to 24') can result in a cost savings of approximately $70,000 per mile in street infrastructure costs (estimated paving cost = $15 per square yard).

Land Use: Residential, commercial, industrial.

5.3.5 Tree Box Filter

Tree box filters are essentially 'boxed' bioretention cells that are placed at the curb (typically where storm drain inlets are positioned). They receive the first flush of runoff along the curb and thestorm water is filtered through layers of vegetation and soil before it enters a catch basin. Tree box filters also beautify the streetscape with landscape plantings such as street trees, shrubs, ornamental grasses, or perennials and can be used to improve the appearance of an area or to provide habitat

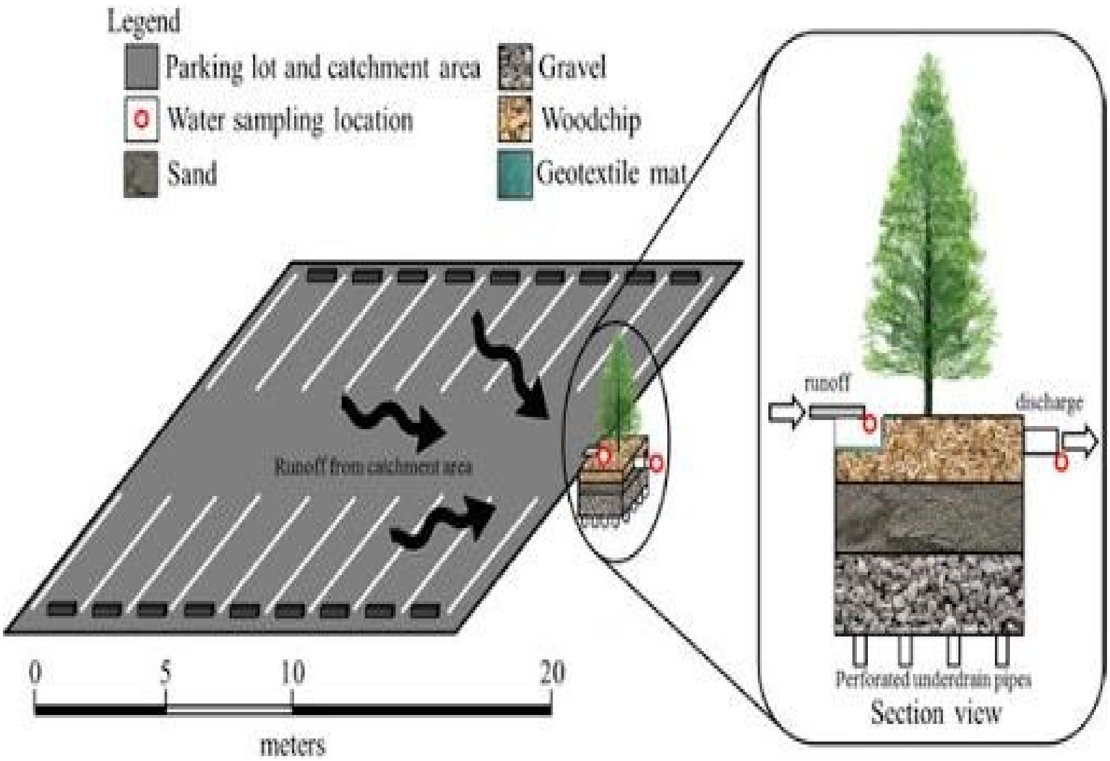


Fig 5.5 Tree Box Filter. (Geddes & Grosset, 2005).

***Typical Uses*:** Positioned along the curb of a street; particularly effective at targeting point source pollution in urban areas by retrofitting/ replacing existing storm drains.

Land Use: Commercial, residential (urban, suburban, ultra-urban), and industrial areas. ***Approximate Cost:*** Approximately $6,000 per unit per 1/4 acre of impervious surface. This estimate includes two years of operating maintenance and filter material and plants. Additional costs include installation and annual maintenance. Installation is approximately $1,500 per unit(varies with each site).

Maintenance: Tree box filters require more specialized maintenance to ensure filter media is not clogged and there is no accumulation of toxic materials, such as heavy metals. Maintenance is typically performed by Departments of Transportation or agencies responsible for storm drain maintenance. Annual manufacturer maintenance is $500 per unit; owner maintenance costs are approximately $100 per unit.

Additional Benefits: Improves water quality and enhances the community.

5.3.6 Disconnected Downspouts

Downspouts can be disconnected from underdrains and the runoff directed to vegetated areas to reduce runoff volume, promote infiltration, and change runoff timing. https://www.wbdg.org/

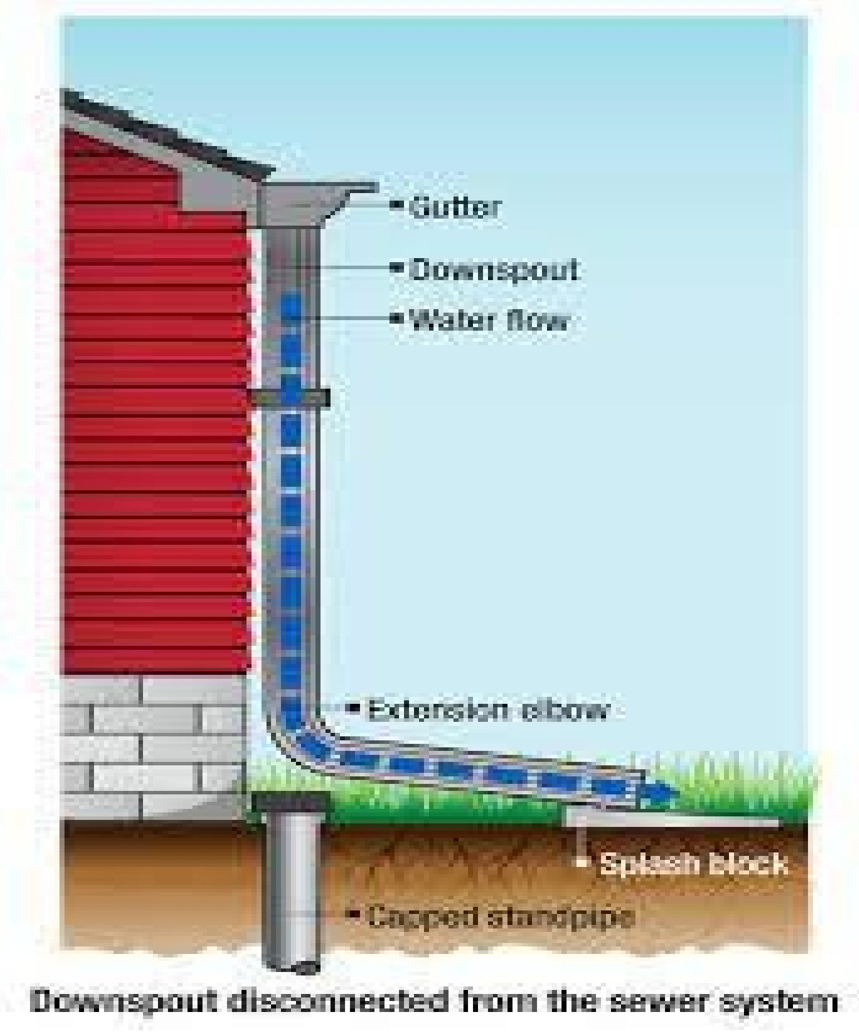


Fig 5.6 Disconnected Downspouts. (Geddes & Grosset, 2005).

5.3.7 Rain Barrels and Cisterns

Rain barrels are placed outside of a building at roof downspouts to collect and store rooftop runoff for later reuse in lawn and garden watering. They can be used to change runoff timing and to reduce runoff volume. Rain barrels have many advantages in urban settings. They take up very littlespace, are inexpensive, and are very easy to install. Cisterns are larger storage facilities for non- potable use in residential, commercial, or industrial applications. They store water in manufactured tanks or underground storage areas. They can be used with any type of roof structure to intercept runoff and reduce runoff volume. The water can be treated and used for domestic purposes,fountains, pools, gray water, air conditioning, and other purposes. Both cisterns and rain barrels can be implemented without the use of pumping devices, instead relying on gravity flow.

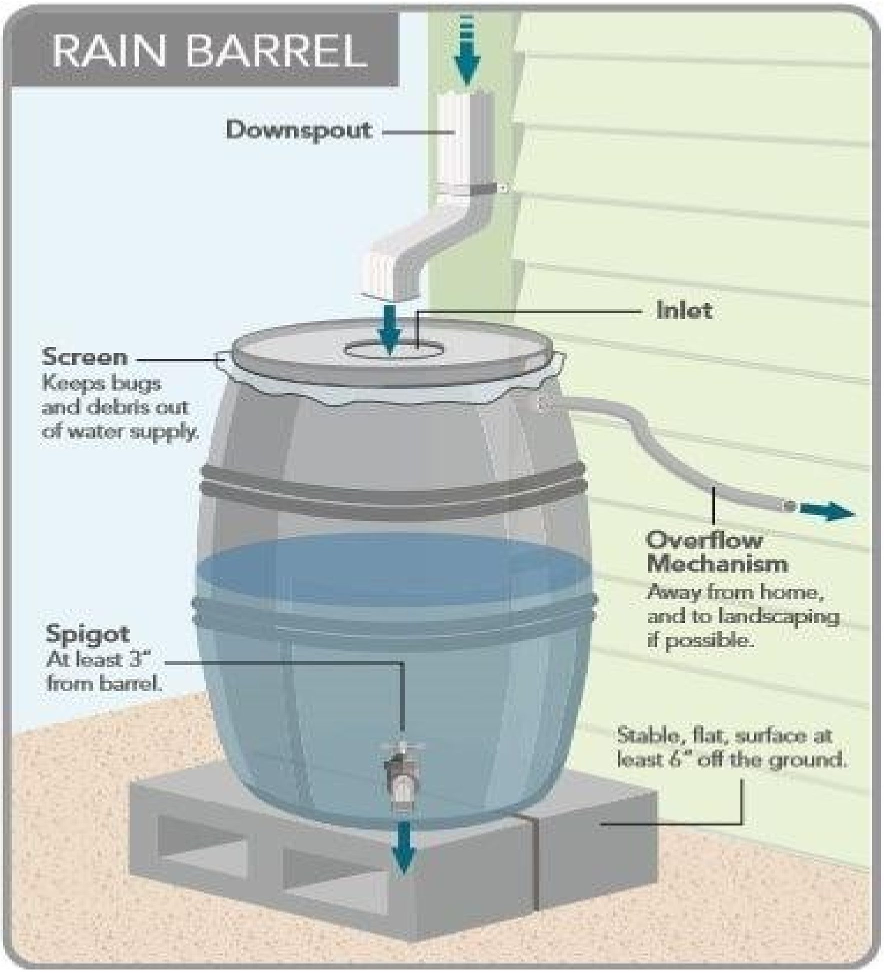


Fig 5.7 Rain Barrels and Cisterns. (Geddes & Grosset, 2005).

Typical Uses: Placed outside of homes or businesses to irrigate landscaping.

Land Use: Residential, commercial, industrial.

Approximate Cost: Rain barrels cost approximately $120; the cost of cisterns varies depending on their size, material, location (above or below ground), and whether they are prefabricated or constructed on site. They range in volumes from hundreds of gallons for residential use to tens of thousands of gallons for commercial and industrial use.

Maintenance: Rain barrels require regular maintenance by the home/ business owner, including draining after rainstorms and removal of leaves and debris collected on screens. Cisterns, along withall their components and accessories, should undergo regular inspection at least twice a year.

5.3.8 Site Appropriate Landscaping

When selecting plants for a landscape design, it is important to have knowledge of the site conditions. Plant materials should be selected for their form, color, and texture, as well as solar, soil, and moisture requirements. Plants that do well in various micro-climates on a site are considered "site appropriate." It is increasingly recommended that native plants (vegetation that grows naturally in particular climates or regions) be used because of their performance, site enhancement, and life-cycle cost benefits. Native plants typically cost more initially (depending on local availability); however, they are more cost-effective in the long run because they require less water and fertilizer, and are more resistant to local pests and diseases than non-native ornamentals. Life-cycle costs are reduced due to reduced maintenance and replanting requirements. Native plantsare also known to be very effective in managing storm water because many species have deep root systems which stabilize soil and facilitate the infiltration of storm water runoff. Additionally, native plants provide habitat for local/regional wildlife

Care should be taken to not plant invasive species as they tend to crowd out the native species. Some common groundcovers, shrubs, and vines are invasive and are prohibited from being planted. Refer to your state list of invasive plants.

Fig 5.8 Site Appropriate Landscaping**.**

5.3.9 Other LID Technologies Include

a. Green Roofs

Vegetated rooftops that use a plant-soil complex to store, detain, and filter rainfall. They reduce runoff volume and improve runoff timing. These multilayered systems use a lightweight soil mixture and sedums (not grass) to provide energy conservation benefits and aesthetic improvementsto buildings. They can be used on expansive concrete roof buildings ("big boxes") or small-scale residential roof structures.

Fig 5.9 Green Roofs. (Geddes & Grosset, 2005)

b. Soil Amendments and Aeration

Soil amendments increase the infiltration and water storage capabilities to reduce runoff from a site. Additionally, the compost, lime, or organic materials alter the physical, chemical, and biological characteristics of the soils to improve plant growth. Aeration of the soil, which can be done in conjunction with routine mowing activities, can increase the storage, infiltration, and pollutant filtering capabilities of grassed areas.

c. Pollution Prevention Lawn Care

Proper fertilizer and pesticide applications will significantly contribute to lowering nutrients and chemical impairments. These include fall fertilization to decrease nutrient runoff.

5.4 Choosing the Location of LID

After simulating the study catchment on 3h Desbordes storms with 10-year return periods, several submerged pipes were recorded Annex B , but the study strategy related to the management of storm water is related to reducing surface runoff water through the establishment of LID, whichin turn increases the permeable areas instead of the impermeable areas. These techniques are effective and even contribute to environmental diversity and improvement Water quality instead of the classic techniques that depend on changing the submerged pipes with other pipes of larger diameter, and the cost of this strategy is usually exaggerated compared to the LID.

The optimal choice of location for establishing LID is a key factor to achieve the goal of the study **Table 5.2.** Therefore, several factors must be taken into account before construction, such as the type of Land Use Land Cover (LULC), slopes, cost value, etc. LID was also chosen to be established near the areas that were known to be flooded during periods of rain. These areas were identified through the report of the Office National de l'Assainissement (ONA), which conducted field survey after the period of rainfall.

Tab 5.2 Condition of implementation LID.

Type of LID	Location	Area(m^2)	N°	Percent of total area (%)
Bio-retention	Commercial, industrial, and residential (urban, suburban, ultra-urban)	2000	429	5
Infiltration trench	Adjacent to roadways or impervious paved areas	4000	1000	23.2
Permeable pavement	Parking bays, parking lanes, sidewalks, roads	4000	980	23.2
Rain garden	Placed outside of homes or businesses to irrigate landscaping	1000	4520	26.2
Rain barrels	installed at the bottom of a downspout	50	1000	2.9

5.2 Results Discussion

After successfully calibrating the model, we evaluated several scenarios (S_0: baseline/without LID, S_1 : Bio-retentions, S_2 : infiltration trenchs, S_3 : permeable pavements, S_4 : rain gardens, S5 : rain barrels, and $S_{Combined}$: with all LID practices) for a 10-year design storm and assessed the efficiency of these scenarios by calculating the peak flow rate and total volume of the various previous scenarios compared to the baseline scenario S_0 (without LID).

The S combined was more effective than other scenarios while the peak flow reduction and total volume reduction were 55% and 75% respectively, since it occupies most of the study space toimplement LID practices.

The perception of this scenario changes if its cost is taken into account. While S5 was the least effective while the rate of peak flow reduction and total volume reduction were about 1% and 2% respectively.

Implementation of a single LID type is not sufficient to reduce peak flow especially since the study area is large and has a variety of LULC with inequality of its slopes, so we pursued combined LID in different scenarios as reported in Table 5.3.

The effectiveness of each LID was different in limiting the peak of flow values because of several criteria including the area of each unit (m2), number of replicate units, and percentage of impervious areas treated (%).

In addition, it takes general considerations such as types of land uses and land cover (LULC)and their slopes. We chose the type of each LID based on expert recommendations and guidance that depended on the above considerations. These recommendations are usually structured in the form of guides and manuals. However, in our evaluation of the performance of these LID practices, we did not take into account administrative considerations such as the cost of each scenario and technical considerations such as the practice effectiveness for climate change and changes in LULC in the future.

These results remain acceptable as a first step in the evaluation of LID. The results are encouraging when compared to related research on LID as modern strategies for reducing runoff. For example, (Li et al., 2018) found that LID could reduce runoff by 43.1–53.4%, (Guo et al., 2019)demonstrated that the implementation of LID reduced runoff 20.7%–63.2%, while (Bae & Lee, 2020) demonstrated that investing in paired LID reduced runoff 11% –13%.This research was considered as a support and a catalyst, and at the same time it is necessary to invest in LID strategies as new and modern techniques suitable for decision-makers, taking into account the economic considerations of the cost of investment, climate change and random demographic growth, especially in developing countries.

Tab 5.3 Summary of flow and runoff volume reduction for implementation of LID in study Catchement.

Scenario	Peak Flow reduction %	Volume total reduction %
S_0 : Baseline without LID	0	0
S_1 : Bio-retention	1.47	3.96
S_2 : Infiltration trench	7.96	19.21
S_3 : Permeable pavement	7.93	18.96
S_4 : Rain garden	9.23	21.86
S_5 : Rain barrels	0.84	2.29
$S_{Combined}$: with all LID	54.66	75.21

5.2 Flow prediction

The Flow, volume and runoff depth Tab 5.4 was predicted for different return period based on intensity-duration-frequency curve (IDF), The sewage network is usually designed or diagnosedusing the rain return of ten years (Salvan, 2017),

Tab 5.4 Flow, volume and runoff depth predicted.

Return period (T)	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
Flow (m3/s)	41.04	67.88	82.35	105.92	132.23	153.13
Volume (m3)	198.98	291.67	356	418	500.22	563.31
Runoff Depth (mm)	11.54	16.91	20.64	24.2	29.01	32.66

5.2 Conclusion

This chapter introduces a recent new approach to mitigating floods in urban catchments that usually results from the negative impacts of urbanization. The study watershed has an area 1726 ha and elevation ranged from 0 to 500 meters and also it has semi-humid climate with average annual precipitation of about 400 mm/year. The soil type is clay loam with a land slope varying from 3.6% to 17.5%. The performance of various LID scenarios has been assessed from two aspects, which were flood volume reduction and peak flow reduction. The implementation of multiple LID practices (bio-retentions, infiltration trenchs, permeable pavements, rain gardens, and rain barrels) could potentially reduce runoff volume by 4.04 –76.01%, and peak flow 2.02 – 51.74% for a 10-yearevent. Through the results obtained, LID can be a clearly effective approach in solving the problem of floods in urban watersheds. Based on the analysis performed, we can conclude the PCSWMM model can simulate LID practices impacts. The PCSWMM model proved to be capable of supporting designers and implementers and decision makers in assessing the effects of LID practices on reducing runoff during the planning and implementation stages to achieve sustainable development.

We aspire in future research to ameliorate PCSWMM’s performance by combining LID practices with best management practices (BMP), especially if more data are available and at the same time compare its results with other models that are specialized in urban watersheds. Although this study mainly focused on evaluating the effectiveness of LIDs in limiting surface runoff, it did not take other considerations such as water quality treatment into consideration. The ideal cost scenario is ignored for several reasons, most notably the lack of sufficient spatiotemporal data for this considerat.

General Conclusion

General Conclusion

Finally, the general conclusion summarizes the main results, and offers research perspectives since the scope of the theme still deserves many other developments. At the end of this study, we believe we have contributed to understanding the problems of urban floods, in particular in the Guelma Catchment.The main objective of the study being the understanding of the phenomenon and the estimation of urban floods through developing modern strategies and techniques to manage storm water without resorting to changing the dimensions of the sewage networks. This work, based on the data observed, during the period from 13 Nov 2008 to 03 Dec 2008, was carried out on the Guelma Catchment.

The Guelma Catchment represents a sample of the basins of northern Algeria which witnessed many floods in separate areas of the study catchment during periods of rainfall.The commissioning of modeling is a tool for understanding the hydrological functioning of watersheds, and decision support is one of the best recognized methods that are both simple and successful.

The rainfall-discharge modeling by the PC-SWMM model was primarily interested in applying an appropriate modular combination of the PC-SWMM model. Then, after having been validated on at least one of the preselected events, the study looked at the use of this model to predict the future hydrological behavior of the basin vis-à-vis different return period. After having completely validated the PC-SWMM model on the Guelma Catchment, it can be used for flood protection, using what is called real-time modeling which is based on the principle of reconstituting the water. Flow at the outlet in each time step for which the rainfall datais measured.

Consequently, we can reconstitute the hydrograph of a flood as the rainfall height is recorded. A strategy of Low Impact Development (LID) was used to reduce the size of the floods and reduce the peak flow. A strategy was used to reduce the volume of floods and reduce the peak flow.This technique was used because of its proven efficiency and credibility in reducing flood risks through many researches published in recent decades. The performance of various LID scenarios has been assessed from two aspects, which wereflood volume reduction and peak flow reduction.

The implementation of multiple LID practices (bio-retentions, infiltration trenches, permeable pavements, rain gardens, and rain barrels) couldpotentially reduce runoff volume by 4.04 –76.01%, and peak flow 2.02 –51.74% for a 10-year eventThis alarm system is more effective than the one based on measuring the height of the water in the river upstream of the watershed. We aspire in future research to ameliorate PCSWMM's performance by combining LID practices with best management practices (BMP), especially if more data are available and at the same time compare its results with other models that are specialized in urban watersheds. Althoughthis study mainly focused on evaluating the effectiveness of LIDs in limiting surface runoff, it did not take other considerations such as water quality treatment into consideration. The ideal cost scenario is ignored for several reasons, most notably the lack of sufficient spatiotemporal data for this consideration.

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Appendixes

Appendixes A

TABLE A1. Land use categories and associated CN (AMC II).

Land Use	CN for Hydrologic Soil Group (AMC II)			
	A	B	C	D
Buildings	77	85	90	92
Green Areas	67	78	85	89
Road	98	98	98	98
Agricultural Soil	64	75	82	85
Water	0	0	0	0

TABLE A2. Adjustments to selected CN for AMC I and AMC III

CN (AMC II)	Factors to Convert CN to AMC I and III	
	AMC I (dry)	AMC III (wet)
10	0.4	2.22
20	0.45	1.85
30	0.5	1.67
40	0.55	1.5
50	0.62	1.4
60	0.67	1.3
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1	1

TABLE A3. Montana coefficient for the Guelma Catchment.

b	15 min-1h	1h-6h	6h-24	A	15 min-1h	1h-6h	6h-24
2 Yr	0.741	0.736	0.737	2 Yr	6.46	6.35	6.38
5 Yr	0.739	0.738	0.751	5 Yr	8.75	8.71	9.44
10 Yr	0.738	0.738	0.732	10 Yr	10.28	10.25	9.91
20 Yr	0.739	0.741	0.732	20 Yr	11.76	11.86	11.25
50 Yr	0.741	0.738	0.74	50 Yr	13.76	13.64	13.77
100 Yr	0.74	0.739	0.739	100 Yr	15.16	15.13	15.11

Appendixes B

TABLE B1. Node flooding summary.

Node	Hours Floodes	Maximum Rate (CMS)	Time of max occurrence		Total Flood Volume (10^6 l)
			Days	(hr:min)	
1	199.41	0.684	3	12:05	2.226
1001	0.1	0.45	3	12:05	0.069
1002	0.01	0.131	3	12:03	0
1004	0.01	0.157	3	12:04	0.001
1013	0.01	0.084	2	22:06	0.001
1014	0.01	0.137	3	12:05	0.001
1016	0.05	0.149	3	12:06	0.01
1017	0.01	0.074	3	12:05	0
1023	0.01	0.05	3	12:05	0
1176	0.01	0.019	3	12:10	0
1179	0.39	0.398	3	12:04	0.087
1180	0.35	0.266	3	12:08	0.216
1181	0.18	1.697	0	14:01	0.137
1182	0.09	0.185	3	12:04	0.015
1183	0.05	0.18	3	12:04	0.016
1184	0.04	0.206	3	12:04	0.019
1185	0.02	0.144	3	12:05	0.006
1186	0.01	0.092	3	12:05	0
1245	0.01	5.089	28	20:55	0.202
1246	0.03	21.264	28	20:55	1.138
1247	0.07	64.17	0	14:01	5.126
1248	0.13	69.957	20	11:28	9.062
1249	0.05	34.473	15	01:44	1.733

1250	0.02	29.863	26	20:01	1.021
1251	0.01	26.32	26	20:02	0.641
127	0.02	6.807	0	14:01	0.341
1277	0.01	2.413	0	14:01	0.018
1278	0.01	1.366	0	14:01	0.01
1279	0.01	1.281	0	14:01	0.007
1563	0.01	0.073	0	17:12	0
1564	0.02	0.034	0	17:12	0.01
1565	0.01	0.046	0	14:01	0
1566	0.02	0.416	0	14:01	0.012
157	1.36	0.695	4	16:01	0.522
1574	0.93	1.234	3	12:05	0.913
1575	0.01	0.172	2	08:05	0.002
1582	0.02	1.789	0	14:01	0.081
1588	0.01	0.05	3	12:02	0.001
1589	0.78	3.174	3	12:05	2.261
159	1.41	0.384	0	14:01	0.112
160	189.51	0.212	3	12:04	2.508
1697	0.67	0.451	3	12:05	0.369
1698	0.33	0.551	3	12:05	0.194
1768	0.01	0.059	3	12:04	0
1768	426.6	9.026	0	14:02	8.617
1940	107.17	1.067	3	12:05	4.549
1943	2.29	0.044	3	12:06	0.078
2046	0.01	0.048	3	12:04	0
2083	0.01	0.056	3	12:03	0
2084	0.04	1.503	3	14:01	0.104
2085	0.16	0.244	0	12:05	0.076
2086	0.01	0.056	3	12:04	0
2087	0.01	1.503	3	12:04	0
2088	0.01	0.244	3	12:04	0
2089	0.01	0.056	3	12:04	0
2090	0.01	1.503	3	12:04	0
2091	0.01	0.244	3	12:05	0.006
2092	0.02	0.056	3	14:01	0.004
2115	0.04	0.06	0	14:01	0
2117	0.01	0.054	0	14:01	0.112
2118	0.04	0.097	0	12:05	0.001
2265	0.01	0.089	3	12:06	0.569
2305	1.11	0.166	3	12:04	0.002
2306	0.01	0.066	3	12:05	0.002
2307	0.01	0.107	3	12:05	0
2349	0.01	1.425	3	12:05	0
2350	0.01	0.041	3	12:05	0
2351	0.02	0.386	0	14:01	0.02
2372	0.01	0.288	0	22:30	0

3229	0.01	0.078	3	12:04	0
3235	2.84	0.654	4	02:12	3.981
3237	284.44	0.122	3	12:02	4.686
3244	4.06	1.013	3	12:05	2.165
331	0.01	0.035	3	12:03	0
3347	0.01	0.001	27	14:09	0
3349	216.85	0.243	0	14:01	1.526
3350	0.02	0.719	0	14:01	0.038
3357	0.54	0.094	3	12:03	0.105
3358	0.01	0.017	3	12:02	0
3359	0.01	0.036	3	12:03	0
3360	0.17	0.227	3	12:05	0.047
3363	0.02	0.831	0	14:01	0.022
3370	0.03	0.483	28	20:55	0.023
3374	0.01	0.121	26	20:01	0.003
3375	9.78	0.19	25	23:21	0.052
3376	0.01	0.047	20	11:23	0.001
3411	0.03	0.148	0	14:01	0.008
3416	0.01	0.058	26	20:01	0
3417	0.02	0.268	0	14:01	0.007
3499	0.001	0.879	0	14:01	0.001
3502	0.02	1.588	0	14:01	0.017
3509	22.96	1.193	3	12:05	4.62
3536	0.02	2.921	0	14:01	0.13
3537	0.01	1.321	0	14:01	0.003
3550	0.01	0.082	3	12:04	0
3551	0.02	2.438	0	14:01	0.0129
3556	0.01	0.947	0	14:01	0.005
3586	0.02	1.002	0	14:01	0.04
3600	0.09	12.253	7	14:57	1.795
3601	0.13	3.805	0	22:30	0.695
3602	0.08	2.515	3	10:32	0.1
3603	0.01	3.758	7	15:07	0.182
3604	0.08	2.737	3	10:32	0.454
3607	0.04	11.686	5	17:01	0.935
3656	0.01	3.365	0	14:01	0.022
3657	1.08	0.942	3	12:07	2.121
3658	0.26	0.797	3	12:07	0.24
3668	0.01	0.081	3	12:06	0