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Modelling for Sustainable Development: Inundation Risk Management and Decision Making in Water Sector

Sellami Mohamed Habib^{1,2} and Siddiki Ezeddine¹

¹Laboratory of Thermal Radiation, Department of Physics,
Faculty of Science of Tunis, University Tunis- El Manar

²Department of Hydraulic, Superior Institute for Rural Engineering,
Medjez El Bab, University Jendouba
Tunisia

1. Introduction

Actually, for all the world, at different levels and scales (international, national, regional, local, zone) there is an urgent request suggested by scientific experts, environmentalists, academicians, decision makers, policy makers, economists, sociologists consisting to propose models and tools based on mathematical formulations using new technology in the purpose to study the physics phenomenon behind floods in order to give solutions minimising their effects and to make the right decision concerning the water sector (resources, adduction network and distribution network) for all human usages: domestic, services, agricultural, industrial.

In fact, climatic change, short violent precipitation, inundation risk management, protecting infrastructures and agriculture fields from water streaming, diminution of water resources, rehabilitation of the water networks either for the resources, adduction or distribution, long drought, soil erosion and degradation, diminution of plant productivity, high price of agronomic product, research of new water resources, economical management of the existing ones, new and adaptable techniques for hydro-agricultural management, soil type and soil occupation cartography, biodiversity conservation are subjects that we hear every time in our days and that exhaust all the rings of the economic chain from the farmer, through the consumer and citizens, to the decision maker at the planet level.

How the scientific research can contribute to give responses to those occupations and avoid the dangers that menace the humanity? Which outlooks it can propose and models it can develop to encourage the farmer and the consumer, to secure citizens and to orient decision makers about flood management and water sector protecting and renewing?.

In this chapter I will raise the basic equations to use in order to formulate the physics phenomenon linked to flood management and water sector protecting. Many reflections points will be revolted in the purpose to develop models in the service of the environment enhancement and to participate in the resolution of the problems suggested above. Results

from experimental study done at laboratory level to estimate the effect of streaming through planes liable to flooding will be mentioned. A first application of a model established using the geographic information system to analyse the water sector for all usages to a region in the North-east of Tunisia (Siliana) would be detailed.

2. Calculus for floods monitoring and their risk management

Monitoring floods and managing their risks necessitate first methods and tools to foresee the instant of averse happening, their intensities and the geographical positions of their descents (Martin 2010, Nor Azliza 2006, Plate 2002). Which means to formulate the transport phenomenon at the atmosphere level. Second we have to follow the streaming on the ground by detecting their geographical directions, estimating the debit of the flows and quantifying their energies. Which signify to calculate the water height, water velocity in all directions and the pressure exerted by the streams. We can then make maps for vulnerable zones the most menaced by inundation and classify the other by priority linked to a degree of averse danger (Martin 2010, Li B et al 2006, Evan et al 2006). Also, on the ground we can evaluate the resistance level against streaming for human infrastructure either in urban or rural regions, for soils and for vegetation canopies. Which make us capable to propose the adequate technical solutions for protecting human properties, to envisage the ideal places for implanting new projects (buildings, infrastructures, agriculture fields...) and finally to reserve the suitable budget for planes liable to flooding (United States Department of Agriculture. Natural Resources Conservation Service (USDANRCS) 2010, 2011, Nor Azliza 2006).

2.1 Formulating atmospheric water circulation to localise the precipitation

In plus of the water evaporated from soils, lakes, oceans, the amount of water transpired by plant canopies constitutes a mass of humid air that will absorb and emit energy, losses or gains material, moves up, and participates with the action of earth rotation (Coriolis force) and atmospheric vapour pressure difference in the formation of wind, cloud displacement and giving out precipitation. The mass of air has tendency to displace vertically from position of high pressure to another characterised by a weak pressure value. The effect of earth rotation will generate the displacement of that mass in different directions. The direction of motion of the air mass represents the wind direction and the speed of its displacement is exactly the wind velocity (Sellami 2011). Localising the geographic position of averse and pelting rains and determining their intensities consist in fact to map the atmospheric water pressure and to estimate the wind velocity for all directions. The most used equations formulating the problem suggested above are the atmospheric primitive equations. They are well used in meteorology and oceanography for numerical models of time forecasting and when simulating the future behaviour of the atmosphere (Edward 2010, Firth Robert 2006, Beniston 1998, Pielke Roger A 1984.).

A general analytical solution of the primitive equations that consider the latitude and the altitude and formulating wind velocities in all directions and the potential pressure is (Sellami 2011, Edwards 2010, Comolet R. 1963):

$$[u, v, \Phi] = [\hat{u}, \hat{v}, \hat{\Phi}] e^{i(s\lambda + \sigma t)} \quad (1)$$

u, v : Coordinates of the wind speed, respectively zonal and meridional
 Φ : geo-potential for the pressure difference

Knowing the fact that the air pressure at a point in the atmosphere is defined as the weight of air column above that point per surface unity we can deduce clearly the close link between the repartition of air pressure in the atmosphere, wind velocities and precipitation. We can then present a more explicit formula as relationship between air atmospheric pressure and wind velocity (Edward 2010, Comolet R. 1963):

$$V = \|\vec{V}\| = \frac{1}{\rho f} \sqrt{\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2} \quad (2)$$

f : Coriolis parameter proportional to the earth rotation
 P : Water vapour pressure at a designed point in the atmosphere
 x, y : Coordinate of a point in atmosphere
 \vec{V} : Velocity vector
 ρ : Volumic mass

The vertical direction is not considered because in the hypothesis adopted we have neglected the vertical variation on behalf of the horizontal ones.

So we can say that estimating the wind speed in all positions of the atmosphere, monitoring its variation over time permit to localise the zone of low pressure, indicator of minimum local pressure and precipitation, the zone of high pressure, indicator of maximum local pressure, fine weather and absence of precipitation.

2.2 Formulating the streaming after precipitation

In the case of inundation, the flowing of the free water on the planes liable to flooding, either for urban or rural zones, obeys the fact that the scales for the vertical variation of motion are neglected in front of those horizontals and that the representation of all phenomenon by surface coordinates (not on the space) is well sufficient. With those considerations, the Navier Stockes equations (combination between the equation of mass conservation, equation of energy conservation and equations of motion conservation) are transformed to the Saint Venant equations also said « shallow water equations » which are the most used for modelling the fluvial flowing (Pascal 2009, Brett et al 2008, Lorenzo et al. 2008, Aldrighetti 2007, Berreksi et al 2006, Li B et al 2006, Hostache 2006, Ranjit and Steven 1995, Comolet R. 1963). They are represented by the following system:

$$\frac{\partial h}{\partial t} + \frac{\partial(uh)}{\partial x} + \frac{\partial(vh)}{\partial y} = 0 \quad (3)$$

$$\frac{\partial}{\partial t}(uh) + \frac{\partial}{\partial x}\left(u^2h + g\frac{h^2}{2}\right) + \frac{\partial}{\partial y}(uvh) = gh(S_{0x} - S_{fx}) \quad (4)$$

$$\frac{\partial}{\partial t}(vh) + \frac{\partial}{\partial x}(uvh) + \frac{\partial}{\partial y}\left(v^2h + g\frac{h^2}{2}\right) = gh(S_{0y} - S_{fy}) \quad (5)$$

S_{0x} : Slope of the planes liable to flooding bottom's according to x direction

S_{0y} : Slope of the planes liable to flooding bottom's according to x direction

S_{fx} : Friction slope according to x direction

S_{fy} : Friction slope according to y direction

h : Water height on the plane

u : Water longitudinal speed for x direction

v : Water transversal speed for y direction

g : Gravity acceleration

The friction slopes can be expressed as follow (Pascal 2009, Berreksi et al 2006):

$$S_{fx} = \frac{n^2 u \sqrt{u^2 + v^2}}{h} \left[\frac{B(x) + h}{bh} \right]^{\frac{1}{3}} \quad (6)$$

$$S_{fy} = \frac{n^2 v \sqrt{u^2 + v^2}}{h} \left[\frac{B(x) + h}{bh} \right]^{\frac{1}{3}} \quad (7)$$

n : Maning Coefficient

B : Width of the streaming water layer

x : Coordinate x representing the direction of the water flow

The Width of the streaming water layer is expressed by:

$$\frac{B(x)}{b_1} = \frac{1}{2} \left[1 + \left(\frac{x}{b_1 F_1} \right)^{3/2} \right] \quad (8)$$

$B(x)$: Width of the streaming water layer at the longitudinal coordinate x from a zero point

b_1 : Width at the upstream

F_1 : Incident Froude Number

The resolution of those equations either numerically or analytically permits to determine the streaming water height and the streaming water speed at every point on the plane liable to inundation by considering the ground topography (Syme 2008, Smith et al. 2006, Huthoff and Augustijn 2006). Then we can calculate the energy accompanying the flow for every position by (Moghadam 2010, Davide et al. 2009, Lorenzo et al. 2008, Yen Ben Chie 2002, Arcement and Schneider 1981):

$$E_{flow} = \rho g z + P_r + \frac{1}{2} \rho U^2 \quad (9)$$

E_{flow} : Energy accompanying the flow of water

P_r : Pressure

U : Water speed

Z : Height

ρ : Water density

The power that accompanies the water running is known by stream power and represents a measure of energy transfer. It can be computed by (Davide et al. 2009, Arcement and Schneider 1981):

$$W_{str-p} = \omega R_h S_{ws} U \quad (10)$$

W_{str-p} : water stream power

ω : Water specific weight

R_h : Hydraulic radius

S_{ws} : Water surface slope

U : Water velocity

So we can evaluate if human properties (houses, buildings, ponds, vegetation canopies...) can resist to that energy also we can propose the appropriate techniques and fences capable to absorb that energy and protect our constructions (Bewsher Consulting 2009, Syme 2008, Hilary and James 2007, Zhang et al 2005). Finally we can say that the equations proposed and that we will detailed later could be bases to establish tools for economic flood damage assessment and after reserving the adequate budget (United States Department of Agriculture. Natural Resources Conservation Service (USDANRCS) 2010, Bewsher Consulting 2009, Nor Azliza 2006, Zhang et al 2005). We will in the following paragraphs formulate the resistance of obstacles to water flowing in order to test if they can dissipate the flow power and after to foresee the risk of damage.

2.3 Formulating the resistance of obstacle to water streaming

In the case of inundation, the flow of water streaming through plains either in rural or urban zones will suffer resistance from all existing obstacles on its scheme. Those obstacles can be plant canopies (grass, single separated trees, agriculture fields, forests, wetlands) or buildings, houses, and infrastructures (hydraulic constructers, barrages, bridges, roads...)(Bewsher Consulting 2009, Lorenzo et al. 2008, Syme 2008). Modelling the force of resistance of every obstacle to the effect of water streaming after averse permits to evaluate the risk of damage in every region or zone, to diagnose the resistance situation of all installed projects, to propose technical solutions ameliorating the toughness for the different components of new projects (emplacement, specie of vegetation for agriculture projects, material of construction and architecture for infrastructure, buildings and houses) so we minimise the risk of losses after floods, to size up tools and techniques absorbing the power of water flow and protecting human properties (USDANRCS 2011, Roca and Davison 2010, Bewsher Consulting 2009, Hilary and James 2007, Moghadam 2007, Nor Azliza 2006, Zhang et al 2005, Plate 2002, Martin 2001). To do so we will try in this part to give a general formulation of obstacle resistance.

2.3.1 Resistance Force of vegetation to water streams

Modelling for hydrological or agriculture studies, at regional scale or at vegetation field scale, necessitates to express the phenomenon of water flowing and streaming by considering the effects of roughness, shear, friction and drag for both soil type and vegetation specie (Sadeghi et al 2010, Mauro 2009, Baptist et al 2007, Austin 2007, Huthoff and Augustijn 2006, Arcement and Schneider 1981). Those effects intervene, generally, in the

expression of the bulk energy losses coefficients and every kind of vegetation canopy could be considered as a type of superficial roughness. Depending on its height, density, flexibility, distribution and species, it can significantly decrease the capacity of river or waterway, extending flow resistance; alter backwater profiles and exchange sediment transport and deposition. (Roca and Davison 2010, Yen Chang Chen et al 2009, Yen Ben Chie 2002). To investigate the resistance effect of vegetation we must differentiate between the flexible vegetation like grass plants and less flexible vegetation (bushes, trees), and we have to consider the cases when the plants are partially or totally submerged (Mauro 2009, Moghadam 2007, Maarten et al 2005, Yen 2002, Juha 2004). We will try in the following reasoning to give a general formulation for the problem.

In order to propose an expression for the drag force taking in account the physical effect of vegetation, we apply force balance between gravitational force, drag force and friction force for a uniform flow in the direction of vegetation.

The drag force for submerged vegetation can be expressed by (Mauro N. 2009, Fredrik et al 2007, Juha 2004, Ranjit and Steven 1995, Arcement and Schneider 1981):

$$F_{drag}^{sub,vi} = \rho \frac{U_{sub,vi}^2}{2} \chi_{dc}^{sub} C_{veg}^{sub} \quad (11)$$

$F_{drag,i}^{sub}$: Drag force for the submerged vegetation inside a limited volume v_i

ρ : Water specific density

χ_{dc}^{sub} : Drag coefficient for submerged vegetation

$U_{sub,vi}$: Velocity averaged over time for the submerged vegetation inside the limited volume v_i

C_{veg}^{sub} : Vegetation area coefficient for submerged vegetation

For partially submerged vegetation we give the following expression:

$$F_{drag}^{p-sub,vi} = \rho \frac{U_{p-sub,vi}^2}{2} \chi_{dc}^{p-sub} C_{veg}^{p-sub} \quad (12)$$

$F_{drag}^{p-sub,vi}$: Drag force for the partially submerged vegetation inside a limited volume v_i

$U_{p-sub,vi}$: Velocity averaged over time for the partially submerged vegetation inside the limited volume v_i

C_{veg}^{p-sub} : Vegetation area coefficient for partially submerged vegetation

χ_{dc}^{p-sub} : Drag coefficient for partially submerged vegetation

The mean velocity of flow through emergent vegetation can be expressed by (Fredrik et al 2007, Baptist et al 2007, Ranjit and Steven 1995)

$$U_{p-sub} = \sqrt{\frac{\frac{2gS_0}{\chi_{dc}^{p-sub} m_{sd} D}}{1 + \frac{2}{h \chi_{dc}^{p-sub} m_{sd} D} f}} \quad (13)$$

The mean velocity of water flow through submergent vegetation is:

$$U_{sub} = \sqrt{\frac{\frac{2gS_0}{\chi_{dc}^{sub} m_{sd} D}}{1 + \frac{2}{k \chi_{dc}^{sub} m_{sd} D} f}} \quad (14)$$

h : Height of water

k : Height of the resistance layer function of vegetation height

m_{bsd} : Bed surface density

S_0 : Bed slope

D : Diameter of plant stem

f : Friction coefficient

The drag coefficients for the submerged and partially submerged vegetation are generally calculated by (Davide et al. 2009, Baptist et al 2007, Maarten et al 2005, Ranjit and Steven 1995):

$$\chi_{dc}^{sub} = C_{veg}^{sub} \left(\frac{h}{h_{veg}} \right) \frac{2gS_{wa}}{U_{sub}^2} \quad (15)$$

$$\chi_{dc}^{p-sub} = C_{veg}^{p-sub} \frac{2gS_0}{U_{p-sub}^2} \quad (16)$$

h : Water height

h_{veg} : Vegetation height

B : Water stream width

S_0 : Longitudinal slope of the bed

S_{wa} : Wetted area

A general formulation of the vegetation area coefficient can be given by:

$$C_{veg} = \frac{2\beta}{d_s} \quad (17)$$

β : Aerial coefficient of plant depending on vegetation type and configuration

d_s : Distance between stems

The roughness coefficients for both submerged and partially submerged vegetation are (Davide et al. 2009, Baptist et al 2007, Maarten et al 2005, Ranjit and Steven 1995):

$$C_{rough}^{sub} = \left(\frac{h^{\frac{1}{6}} h_{veg}^{\frac{1}{2}}}{\sqrt{2g}} \right) \sqrt{\chi_{dc}^{sub}} \quad (18)$$

$$C_{rough}^{p-sub} = \left(\frac{h^{\frac{2}{3}}}{\sqrt{2g}} \right) \sqrt{\chi_{dc}^{p-sub}} \quad (19)$$

C_{rough}^{sub} : Roughness coefficient for the submerged vegetation

C_{rough}^{p-sub} : Roughness coefficient for the partially submerged vegetation

A general formulation of the friction coefficient for a densely vegetated flood plain can be expressed by (Arcement and Schneider 1981):

$$f = n_0 \sqrt{1 + \left(\frac{\chi_{edc} A_{fav}^{tot}}{2g A_{sa}^{cr-fl} L_{ch}} \right) \left(\frac{1}{n_0} \right)^2 R_h^{\frac{4}{3}}} \quad (20)$$

χ_{edc} : Effectif drag coefficient

A_{fav}^{tot} : Total frontal area of vegetation blocking the flow in square meter

A_{sa}^{cr-fl} : Cross sectional area of flow

n_0 : Maning's boundary roughness coefficient

L_{ch} : Length of the channel in meter

R_h : Hydraulic radius in meter

2.3.2 Modelling overland flooding of urban areas: Resistance Force of urban obstacle to water streams

For the urban zone, where the obstacles resisting to flow are not flexible, the water flowing between houses and buildings, through roads and fences suffered a lost of load as results of the roughness effect exerted by every obstacle (Syme 2008). This roughness effect is generally expressed by a friction coefficient depending on the size of the obstacle (height, width, length, weight...) and the area it occupies (Peng and Athol 2004, Martin 2001). The physics signification of the friction coefficient is that it translates the roughness degree and the resistance power to water flow of obstacles and their retardance effects (Brett et al 2008, Hilary and James 2007, Yu D. and Lane 2006). To make empirical formulas for the friction factor based on global experimental studies that could be extrapolated at large scale for flood management, many researchers, on behalf of a dimensional analysis, suggested that the friction factor could be formulated as function of the following parameters (Yen Chang Chen et al 2009, Nian-sheng. 2008, Juha 2004, Kidson et al. 2002, Yen Ben Chie 2002:

$$f = F(N_{fr}, P_{og}, P_{ofl}, P_{orsub}, P_{od}) \quad (21)$$

N_{fr} : Froude number ($= \frac{U}{\sqrt{gD_h}}$)

U : Water velocity

g : Gravity acceleration

D_h : Hydraulic diameter for the open channel

P_{og} : Parameter characterising the obstacle geometry

P_{ofl} : Parameter characterising the obstacle flexibility

P_{orsub} : Parameter characterising the obstacle relative submergence

P_{od} : Parameter characterising the obstacle density

A general expression for friction factor that can be used for all flowing regimes is (Nian-Sheng.C. 2008):

$$\frac{1}{f} = \left(\frac{Uh}{24\nu}\right)^\alpha \left(1.8 \log \frac{Uh}{2.1\nu}\right)^{2(1-\alpha)\beta} \left(2 \log \frac{11.8h}{k_s}\right)^{2(1-\alpha)(1-\beta)} \quad (22)$$

k_s : Roughness size depending on the type of obstacle

h : Water height in a determined position

U : Water speed

ν : Cinematic viscosity

α, β : Coefficients characterising the type of micro-flowing

They are expressed empirically as follow:

$$\alpha = \frac{1}{1 + \left(\frac{Uh}{\nu 850}\right)^9} \quad \text{and} \quad \beta = \frac{1}{1 + \left[\frac{Uh}{\nu} \times \frac{160h}{k_s}\right]^2} \quad (23)$$

A general expression of the drag force corresponding to urban obstacles (house, building, fences, cars, ...) can be given by (Brett et al 2008, Juha J.A. 2004):

$$F_d^i = \frac{1}{2} \rho C_d^i A_r^i U^2 \quad (24)$$

F_d^i : Drag force for the obstacle i

C_d^i : Drag coefficient for the obstacle i

A_r^i : Reference area for the obstacle i

U : Water speed

ρ : Water specific density

A relationship between the drag coefficient and the friction factor can be expressed by (Brett et al 2008, Juha 2004, Yen Ben Chie 2002)

$$f^i = 4C_d^i \frac{A_r^i}{A_b^i} \quad (25)$$

f^i : Friction factor for the obstacle i

A_b^i : Bottom area for the obstacle i

Flooding in urban areas presents a range of challenges to the modellers due to the complexity of the flow patterns and paths that occur (Syme 2008, Smith et al. 2006). In fact the major problems signalled are how to give a drag coefficient or friction factor the most appropriate to every kind of building, house, fence...? How considering the storage effect?, how to represent the blockage of interior and exterior walls?, if to model the buildings as porous?. The additional complexity that occurs due to fence collapses, debris blockages, and the displacement of cars and other obstructions how to calculate their effects? Actually, the global tendency of many researchers is to determine the drag coefficient by kind of obstacle from experimental data at laboratory level and to extrapolate the results for real cases (Sadeghi et al 2010, Mauro 2009, Nian-Sheng. 2008, Fredirik et al 2007, Ranjit and Steven 1995, Julien 2002, Kidson et al. 2002, Martin 2001, Guellouz and Tavoularis 2000, Julien and Wargadalam 1995). It is the objective of the following paragraph.

2.4 Experimental study at laboratory level

We will erect in this part the first results from an experimental protocol we have realised at laboratory level to determine the effect of obstacles on water flowing through an open canal. The system is composed from a storage tank linked to a pump, which aspires and delivers water to a second tank occupied with a filter installed at the upstream of the canal. On the exhaust pipe of the pump there is a control weir permitting to fix the discharge debit. The driven water crosses the canal, reaches the down river, and falls in the storage tank to be forced again toward the up river. Between the down stream and the storage tank we have installed a water balance to measure the repressed debit. The study consists to measure, every 0.5 m inside the canal, the water height and the water speed for different obstacle positioning scenarios 's and many discharge debits. The scenarios are when the canal is without obstacles (S_0), canal with one rectangular obstacle placed one meter from the upstream (S_1), canal with two rectangular obstacles the second is at four meters from the upstream (S_2) and canal with three obstacles the third has a convex form and is placed at the middle of the rectangular ones which means at 2.5 m from the upstream (S_3). The extrapolation of the results to real scale can be easily done when considering the size of the obstacle, the geometry of its form and the values of the debit which are analogous to the streaming flow for the floods (Sadeghi et al 2010, Moghadam et al. 2010, Pascal 2009, Limantara 2009, Yen Chang Chen et al 2009, Davide et al. 2009, Lorenzo et al. 2008, Chao and Peifang 2007, Berreksi et al 2006, Peng and Athol 2004, Kidson et al. 2002, Guellouz and Tavoularis 2000). The results from measurement of the water height for the four scenarios and for one discharge debit ($Q_1 = 6.9767 \cdot 10^{-3} \text{ m}^3/\text{s}$) are presented in the following figure.

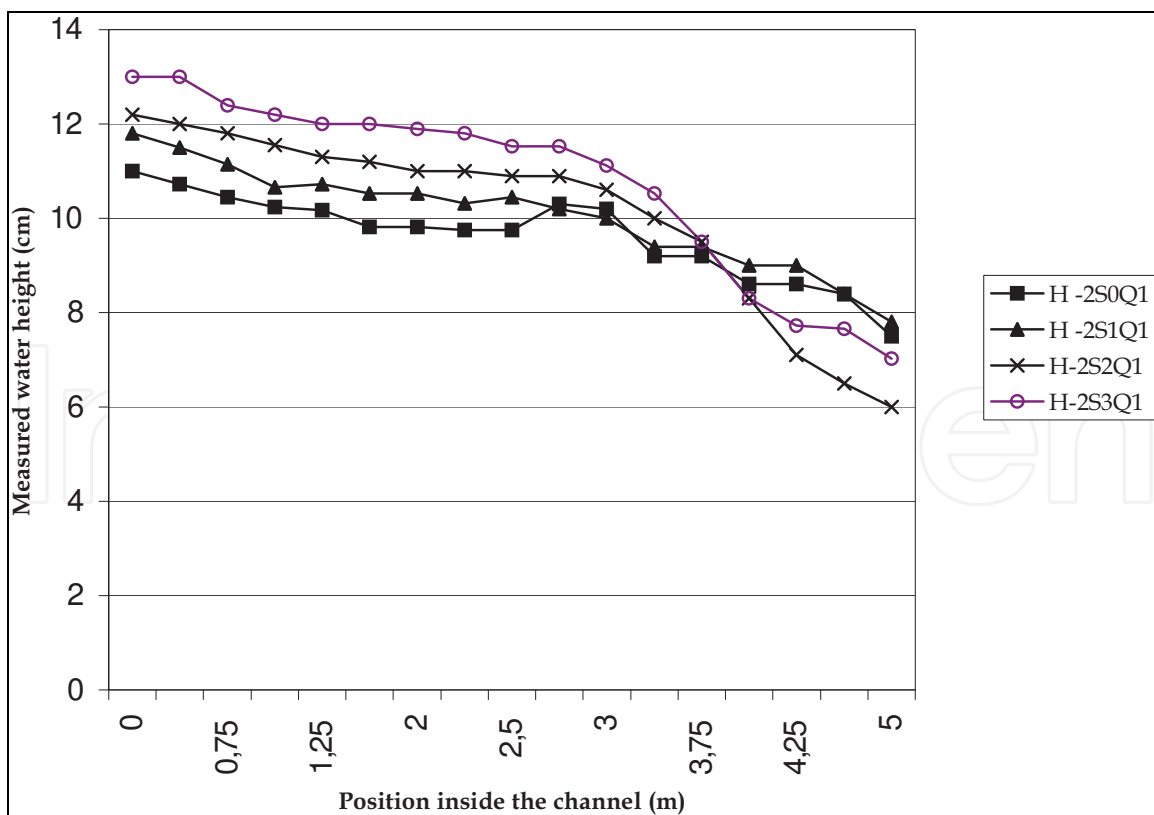


Fig. 1. Variation of water height inside an experimental channel for four scenarios of obstacle positioning

We note clearly that the water height decreases from the upstream to the downstream of the canal for all the scenarios. We notice also that between the upstream of the canal till the position 4 m inside, the height of water is the most important for the scenario three obstacles, followed by the scenario two obstacles, one obstacle and finally canal without obstacles. Which revolt the effect of obstacle number on the flowing. At the down stream we remark that water height for the four scenarios are very closes to each other and that the height is the most important for the scenarios canal without obstacle and canal with one obstacle. Compared to results from other experimental studies, our work is promising (Pascal 2009, Berreksi et al 2006). The importance of this experimental study is that the correspondent results could be used to validate an eventual resolution of the shallow water equations either analytically or numerically and also to determine the drag coefficients associated to each obstacles which can be extrapolated for real cases (Andrew et al 2006). It's the purpose of a future work in preparation.

3. Calculus for the decision making in the water sector

Knowing the fact that floods on urban or rural zones affect directly the water circuit by two contradictories phenomenon. The first is the risk to damage the hydraulic infrastructures, forages, pumping stations, pipes, adduction/distribution networks...(USDANRCS 2010, 2011). The second is that the surplus water that accompanied inundation can enhance our water resources for the surface ones or the groundwater. So proposing model for completely managing the inundation risk must necessarily be done by revolting the necessaries equations formulating the water circuit monitoring (Martin 2010, Yangwen et al 2007, Chao and Peifang 2007, Evan et al 2006, Li B et al 2006).

As consequence, we will put in at this part, the different steps to follow, the mathematical equations/models and the necessary materials that can be used to control, to monitor and to evaluate, by geographical position, the actual and future situation of water circuit: water availability at the resources level, the state of the adduction/distribution networks, the consumer requirements (agricultural sector, industrial sector, service sector). So we can after evaluate if the existing resources and water networks could satisfy all consumers categories and for what time, to propose solutions of rehabilitation, to install new schemes of water networks for the consumers not yet connected or for those whose the existing network could not assume their water need in the future

3.1 Calculus for water resources

Generally there are two classes of resources: the surface resources and the ground water resources. The amount of water available is generally linked to climatic conditions: precipitation, temperature, and evaporation. The prediction of resources efficiencies can be done easily for any region by applying this reasoning: After limiting the different surface lakes, all waterways, the different water sheets (water table and deep water sheet) in every region, we consider every one of them as a closed system for which we apply the balance equation. This later is presented as the equilibrium between the inflow, out flow, income and lost of water for every system defined. It can be written in global form as follow (Mauro 2009, Sellami 2008, Yangwen et al 2007, Chao and Peifang 2007]:

$$\Delta V_w = V_{i,w} + (P + Q_{l,in}) - (Q_e + Q_{l,out}) \quad (26)$$

ΔV_w : variation of water volume in the defined system

$V_{i,w}$: initial water volume in the defined system

P: precipitation

$Q_{l,in}$: the lateral inflow for the defined system from all the directions

Q_e : water lost by evaporation from the defined system

$Q_{l,out}$: the lateral outflow for the defined system from all the directions

So then we can formulate the fictive water debit at a determined time for the defined system by:

$$Q_f = \frac{\Delta V_w}{\Delta t} \quad (27)$$

Q_f : fictitious water flux

ΔV_w : variation of water volume in the defined system for the desired period

Δt : variation of time in the defined system for the desired period

The determination of every term in the balance equation depends on the climatic conditions, soil structure, soil occupation and the geologic characteristics in the region studied. We can measure them directly by using the necessary apparatus and methods (piezometric and geological mapping, hydrological measurements, meteorological measurements).

If we consider the system occupied by water as a reservoir, its volume is calculated by the following relationship (Yangwen et al 2007):

$$V_r = A_{occ} \times H_{tot} \quad (28)$$

V_r : Total volume of the reservoir

A_{occ} : Area or extent occupied by the water

H_{tot} : Total height of the reservoir (distance between the bottom and the top for the considered system)

The volume of water contained in the reservoir is defined by:

$$V_w = A_{occ} \times H_w \quad (29)$$

V_w : Water volume in the reservoir

H_w : Water height inside the reservoir (distance between the bottom and the surface of water sheet)

For the surface resource, they are formed from the hydrographical networks (rivers), natural lakes, barrages lakes', and natural water sources. Their localisations are possible by establishing numerical maps and land numerical models using land altimetry measures, thematic maps and aerial photos (satellite and planes). We must limit the fluvial network (length and capacity of the primary line water, secondary line water, tertiary line water...) and we have to determine the capacities of the existing lakes (geographical localisation, extent and water height).

The water volume existing in a river can be calculated by (Yangwen et al 2007):

$$V_{river} = L_{river} A_{sriver}^{sec} \quad (30)$$

A_{river}^{sec} : Area of the river lateral section (wet surface of a river)

L_{river} : Length of the river

V_{river} : Water volume of a river

The debit through a river can be expressed as follow (Comolet 1963):

$$Q_v = S_m C \sqrt{R_H i} \quad (31)$$

S_m : Wet surface of the river

R_H : Hydraulic radius of the river

i : Slope of the river

C : Friction coefficient

For the ground water and table water resources, they are considered, generally, as non-renewable resources. They don't depend largely on climatic parameters but they are sustained our days to an overexploitation. Determining the amount of water that exists, for how time it can assume our needs and the possibility of their artificial recharges are questions that we can model (Younes et al 2010; Mauro N. 2009). So we must make a geological sweeping, a piezometric scanning and mapping and we have to make many types of forage for testing and controlling the existing sheets and to discover if possible the new ones. Then by using thematic maps and models for underground hydraulic we can elaborate equations for water sheet folding, expanse, height and volume. By utilising the statistical studies, land use plan, agricultural maps, economic plans, directing plans for development by region we can propose mathematically relationships for the evolution of water consumption by sector and by region. We can then determine the life duration of the ground water and the amount of water to add when thinking to their recharge. The most used equations formulating the debit of their exploitation are (Comolet 1963):

For the table water:

$$Q_v = \pi k \frac{(h_1^2 - h_2^2)}{\ln \frac{R}{r_0}} \quad (32)$$

Q_v : Pumped debit

h_1 : Piezometric height at the position of action radius (R)

h_2 : Water height in the pumping well

r_0 : Radius of the pumping well

k : Hydraulic conductivity

R : Action radius of the pumping well

For a captive ground water we write:

$$Q_v = 2\pi h_0 k \frac{h_1 - h_2}{\ln \left(\frac{R}{r_0} \right)} \quad (33)$$

Q_v : Pumped debit

h_1 : Piezometric height at the position of action radius (R)

h_2 : Water height in the pumping well

r_0 : Radius of the pumping well

k : Hydraulic conductivity

R : Action radius of the pumping well

h_0 : Distance between the two substratums

3.2 Calculus for the adduction/distribution water networks

The adduction/distribution networks are defined as the course that the water flow follows from the source to the consumer. Our days, in rural or urban zones, to assume the water needed at time and to avoid its loss in route there is tendency to conduct the water by special canalizations (pipes, conduits), hydraulic accessories and apparatus (pump, tanks, treatment stations, floodgates, bends, diaphragm...). The differentiation between adduction and distribution is arbitrary. It depends on the sector to supply with water and is only to facilitate the conception of the network when making hydraulic studies. Generally, the adduction part is that from the sources to the tank or to the series of tanks for water storage and treatment. The distribution is that from the tanks to the consumer: fields and plants for agricultural sector, houses for potable sector (service sector) and factories for the industrial sector. Calculating a water network signifies determining the length of pipes, their diameters, nature or material of fabrication, number of conduits sections', types and number of hydraulic accessories, their capacities (surface, volume, power, energy...) and finally the cost. There are many mathematical relationships, formulas and models that are used to make the hydraulic calculus. They are based on the energy balance between the initial points of the network (resource) to the end point of the network (entrance to the consumer property). This energetic balance is formulated by the theorem of Bernoulli expressed as follow:

$$H_{\text{initial}} = H_{\text{final}} + J_{\text{initial-final}} \quad (34)$$

H_{initial} is the energy at the initial point of network

H_{final} is the energy at the final point of the network

$J_{\text{initial-final}}$ is the total lost of energy between the initial point and the final point of the network

Generally, between the initial and final points of a water line, and because of topographical problems, we have to consider many particular points where there is change of slope, change of direction and/or obstacles. They are called knots. The distance between two successive particular points (knots) defines the length of a pipe section. If we note A and B the two successive knots, we can, by applying the Bernoulli theorem to the pipe section AB, write (Sellami and Trabelsi 2009, Sellami2008, Comolet 1963):

$$H_A = H_B + J_{A-B} \quad (35)$$

$$H_A = z_A + \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + J_A \quad (36)$$

$$H_B = z_B + \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + J_B \quad (37)$$

$$J_{A-B} = j_{A-B} L_{A-B} + J_A + J_B \quad (38)$$

H_A, H_B : are the energy at, respectively, point A and point B

z_A, z_B : are the altitudes of, respectively, point A and point B

J_{A-B} : is the total lost of energy in the pipe section AB

j_{A-B} : Linear lost of energy in the pipe

J_A, J_B : are the singulars lost of energy due to contact with hydraulic accessory at, respectively, the points A and B

L_{A-B} : Length of the pipe section AB

P_A, P_B : are the pressures at, respectively, point A and point B

V_A, V_B are the water velocities at the knots A and B

The total lost of energy J_{A-B} , is defined as the sum of the singular energy lost (J_A and J_B) and the linear energy lost between A and B (j_{A-B}).

For every hydraulic accessory in the network corresponds a particular singular energy lost (floodgates, bends, diaphragm, change of section...). We give the general formula:

$$J_A = \alpha_A \frac{V_A^2}{2g} \quad (39)$$

J_A : Singular energy lost for the knot A

g : Gravity

V_A : Water velocity at the knot A

α_A : Coefficient of singularity for the knot A

While for the linear energy lost there are many empirical formulas. They express generally the linear energy lost by the water inside the pipes as function of the diameter, the water flow, the conduit roughness and the nature of fabrication material. We can give here as example the following (Sellami and Trabelsi 2009, Ennabli 2001, Punmia and Ashok, 1998):

Blasius formula:
$$j = 7.77 \cdot 10^{-4} Q^{1.75} D^{4.75} \quad (40)$$

Scimemi formula:
$$Q = 48.8 D^{2.68} j^{0.56} \quad (41)$$

Bresse formula :
$$D = 0.32 Q^{0.4} j^{-0.2} + 0.005 \quad (42)$$

Formule de Colebrook :
$$V = 61.5 D^{0.68} j^{0.56} \quad (43)$$

Formule de Hazen-William:
$$V = 0.355 C D^{0.63} j^{0.54} \quad (44)$$

Formule de Darcy :
$$j = \frac{\lambda}{D} \frac{V^2}{2g} \quad (45)$$

Formule de Flamant Masoni :
$$j = k \frac{\frac{7}{5} V^4}{D^4} \quad (46)$$

Formule de Manning :

$$j \times 10^6 = 3120 \frac{V^2}{D^{1.5}} \quad (47)$$

Formule de Maurice Levy:

$$V = 36.4 \sqrt{\frac{D}{2} j (1 + \sqrt{\frac{D}{2}})} \quad (48)$$

Where Q is the debit (m³/s), j is the linear lost of energy (m/m), D is the pipe diameters (m), V water velocity (m/s), λ coefficient for energy lost

So we have to know the altitude of the particular points (from topographical measurements and level curves maps) and the pressure needed to assume the distribution of water to all the consumers which must be superior to the highest manometric level at the streamside. By applying the Bernoulli theorem for every pipe section we can deduce all the needed parameters for the hydraulic network conception. I must signal here that there are many models and soft wares that can be used and that they are established from the precedent reasoning and formulas (Sellami & Trabelsi 2009, Sellami 2008).

3.3 Calculus for the consumer level

In the conception of a hydraulic network, we must begin by defining the consumers. This means calculating the amount of water they need and the minimum pressure permitting to lead water to the consumer at the highest manometric level now and in the future.

As said above, there are three categories of consumers depending on their activities: agricultural activities, industrial activities and services activities.

3.3.1 For the agricultural activities

The amount of water to lead is that needed by the plants in the field and by field in the region for all vegetal speculations that exist. There are many models permitting to estimate the water needed by plants as function of the physiological characteristics of every specie (leaf area index, sap flow, stomata resistance...), soils types (texture, structure, permeability, porosity...), climatic parameters (solar radiation, temperature, precipitation, evaporation, transpiration, heat...) and the economical and demographic evolution by region. Their use is possible and it depends on the precision asked. We present here a simple and general formula permitting to calculate the amount of water needed by plants in the field (Sellami 2011, Sellami 2008, Sellami and Sifaoui 2008, Battaglia and Sands 1997, Tournebize and Sinoquet, 1995):

$$Q = K_c * ETP \quad (49)$$

Q : amount of water needed

K_c: cultural coefficient that depends on the types of plants and soils

ETP: potential evapotranspiration

For the water needed by plants in the future, it can be evaluated as function of demographic evolution, the sort of tolerant vegetation to install as food, the type of industrial culture to implant, the evolution of the agro-alimentary industry and the climatic change. So we must know the economical and political orientations for the durable development by region and

we have to utilize the agricultural maps, land-use plan, the data basis for vegetations characteristics, the gene banks, climatic data basis, models for plants transpiration, biosphere models, circulation and climatic models. (Ciret and Henderson-Sellers, 1997b, Sellers et al 1986).

3.3.2 For the industrial activities

The amount of water needed depends on the type of product and the different process used inside the industry. So we must do multi audit studies to evaluate the real need by process for every product. A general formulation of the water needed by type of industry can be formulated as follow (Sellami 2011):

$$Q_{ind,k} = \sum_j (\sum_i Q_{prd,i}^{proc,j} \times N_{prd,i}^{j-k}) \quad (50)$$

For a zone where there is many industry the total water needed by a defined unity can be expressed globally by:

$$Q_{ind-zone} = \sum_k Q_{ind,k} \quad (51)$$

$Q_{ind,k}$: Amount of water needed by a defined unity for the industry k

$Q_{prd,i}^{proc,j}$: Amount of water needed by a defined unity for the product i in the process j

$Q_{ind-zone}$: The amount of water needed by a defined unity for an industrial zone

$N_{prd,i}^{j-k}$: Defined unity for the product i in the process j for the industry k

The defined unity can be a linear meter unity from the occupied surface, m² unity from the occupied area, m³ unity from the occupied volume, unity of mass (kg), number of product....

We can give here some examples of water needed by sort of industry: for the textile industry (cotton tissue) we need 4500 l/kg (the defined unity is a kg of product), for dairy industry we need 10 l/l milk (the defined unity is a litre of product), for the paper industry we need 222 - 330 m³ /t, for the sugar industry we need 1929 m³ /t (the defined unity is a tonne of product), For bovine, mutton and goat meat we need 13 500 m³/t, for poultry meat we need 4100 m³/t, for eggs we need 2700 m³/t, for olive oil industry we need 11350 m³/t, for soybean oil industry we need 5405 m³/t, for sunflower seed oil we need we need 7550 m³/t, for palm oil we need 5500 m³/t, dates industry we need 1660 m³/t, Apples 387m³/t, Bananas 499m³/t oranges and citrus we need 378 m³/t, onions we need 168 m³/t, tomatoes 130 m³/t, coffee 5790 m³/t, for the cotton 496 m³/t (Chapagain et al 2006, Zimmer and Renault 2000).

For the future, the water needed is evaluated as function of the orientation of the durable development axis by region, census studies, economic plan, the technology evolution and the market demand. We can intervene here to advice about what industry to install in what region after studying the water circuits (Sellami 2011, Sellami and Trabelsi 2009).

3.3.3 For the service activities

The amount of water needed here is that to consume as potable water. It depends on the number of residents by region, their requirement in comfort, their evolution in the future. We have to use the census studies and the statistical models to evaluate the change in the future. They are generally based on the following equations (Sellami et Trabelsi 2009, Sellami 2008, Baroudi et al 2006, Ennabli 2001):

For the demographic evolution we have:

$$P_y = P_{y_0} (1 + \tau)^{y - y_0} \quad (52)$$

P_y : is the population number for the year (y)

P_{y_0} : is the population number for the reference year (y_0)

τ : is the population evolution rate

For the consumption evolution we have:

$$C_y = C_{y-1} (1 + \Gamma)^n \quad (53)$$

C_y : is the water consumption for the year (y)

C_{y-1} : is the water consumption for the year (y-1)

n: number of years for which we estimate the consumption

Γ : consumption evolution rate

4. Representation of data on numerical support

We will identify here the data processing support to use in order to make the link between data bases, maps, models and equations established and to show the results in maps, graphics, tables formats and files. So we can evaluate the actual situation, take decision and intervene at moment. Also, we can foresee the future state for the resources, networks and consumers, propose the adequate scenarios for management, rehabilitation and development. After propounding the necessaries equations, mathematical models, software and maps to use, we can organize the data we dispose in the form of a data conceptual model, data logical model data physical model and land numerical model. The GIS tools' to utilize are (Sellami and Trabelsi 2009):

- The equations presented above for the direct calculation for the two parts
- Epanet 2.0 for hydraulic calculus and pressure verification
- ENVI 4.2: The environment for visualizing image to elaborate the land numerical model
- ArcView GIS 3.2 to digitalize the information layers from maps, to organise the data tables and to make the link with mathematical models and software of calculus
- Power AMC Designor 6.0 for data arrangement
- Hydrogen as interface of link with hydraulic calculus
- 3D Analyst and Spatial Analyst for spatial and 3 D analysis and representation

Depending on the quantity of items and data basis we dispose (input), the thematic maps/plans to realise (output) are those representing the different information layers needed in decision making (proposing a solution scenario). We list here the following: geologic maps, hydrographic network maps (primer, secondary, tertiary rivers), topographic maps for the land numerical model, soil type maps, land use maps, lakes and table water maps, grounds waters maps, adduction and distribution network maps, hydraulic accessories maps, knots

maps. After, we have to make the hydraulic calculus for the proposed scenario in order to accept or refuse it. Here with a block diagram for the modelling approach:

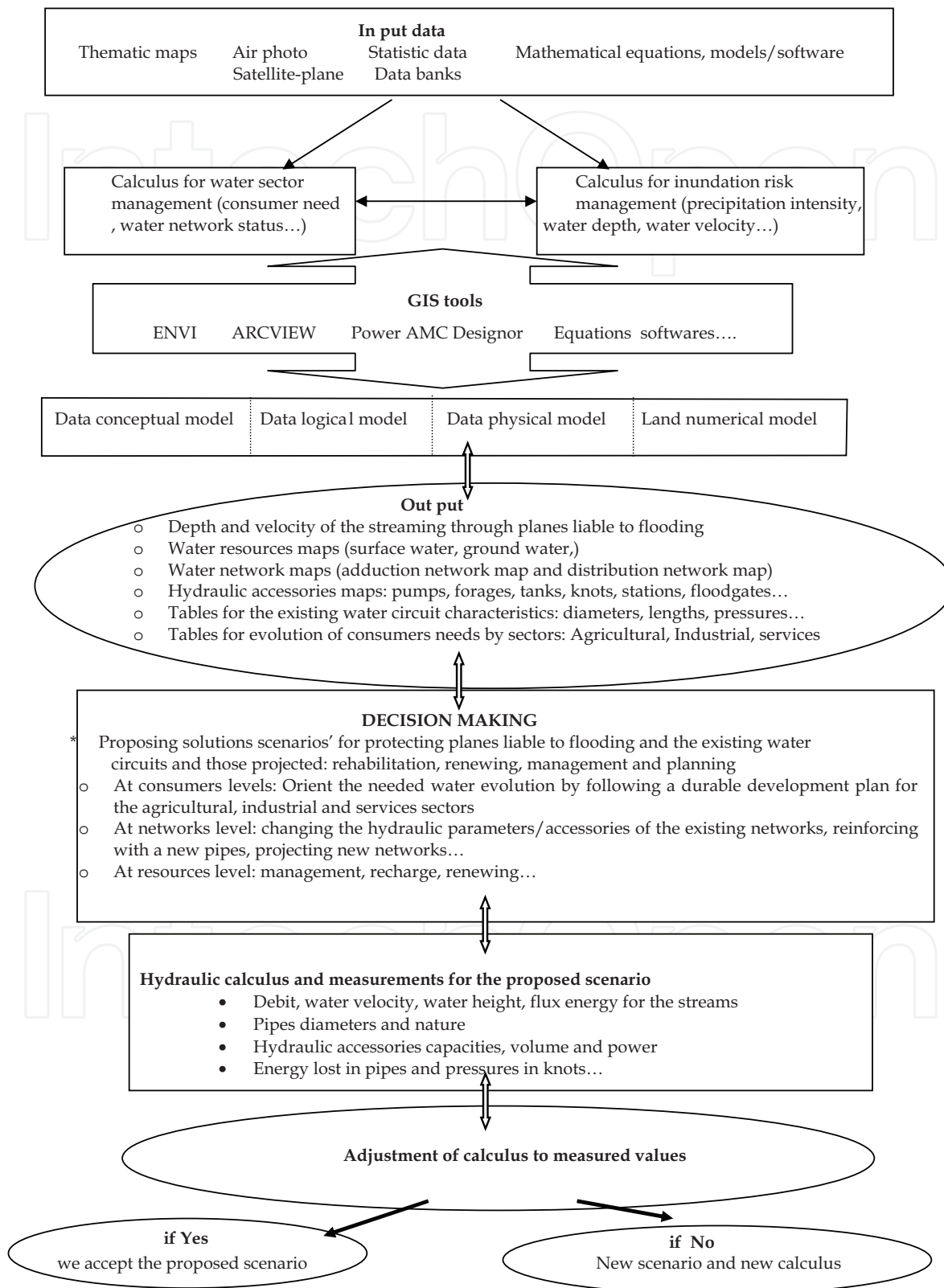


Fig. 2. Block diagram for the modelling approach functioning

The same reasoning and the same tools were used for the region of SILIANA as we will present later.

5. Results from partially validation of the modelling approach

A first application of the model has been done to the region of SILIANA in the West-North of Tunisia (Sellami and Trabelsi 2009). At the beginning we have identified, limited and evaluated the water resources available (surfaces resources, ground water resources, artificial resources...). After, by using the necessaries equations, we have diagnosed the different adduction/distribution networks that exist and calculated their hydraulic parameters: the lengths of pipes, diameters, pressures and debit at different positions, types and capacities of hydraulic accessories, risk of conduits corrosions and filling, risks of pipe damage and water leak. Experimental verification of calculus has been done by measurement of pressure and water flow at different positions (GPS, pressure captors, debit captors). Finally we have distinguished all types of water consumers in the region, calculated their water needs and determined those connected to the water network and those who are not yet connected.

By using the GIS tools and the brut data we dispose, we have established the multi-layers information map'. It is presented in figure 3. It comports the following items: Topographic layer (level curves), hydrographic networks layer (first, secondary and tertiary river lines), geologic layer, forages for ground water resources layer, adduction network layer, hydraulic accessories layers.

After using the necessary calculus and the existing databases we have numerated the actual water distribution network. We have deduced the next results:

- Geographical situation:

The zone studied is referenced by these coordinates: Longitude 2° 27' 33"; Latitude: 71° 18' 16", Altitude: 400 and 460 m NGT

- Water resources:

Because the flow in the rivers networks is irregular, the region is supplied by water only from ground water sheet via 4 forages. Here with their characteristics (table n°1):

Forages	Altitude (mNGT)	Static level (mTN)	Debit (l/s)
Ramlia	438	-17.1	16
Siliana II Bis	457	-19	26
SI 14	438.62	-25	20
Elguabel	449.4	-20	25

Table 1. Characteristics of the water resources

- Adduction and distribution water networks:

We have verified the hydraulic calculus for the existing adduction/distribution networks and we have measured at different points of the network the pressures, debits and conduits diameters for the adjustment. Table n°2 offers the main features:

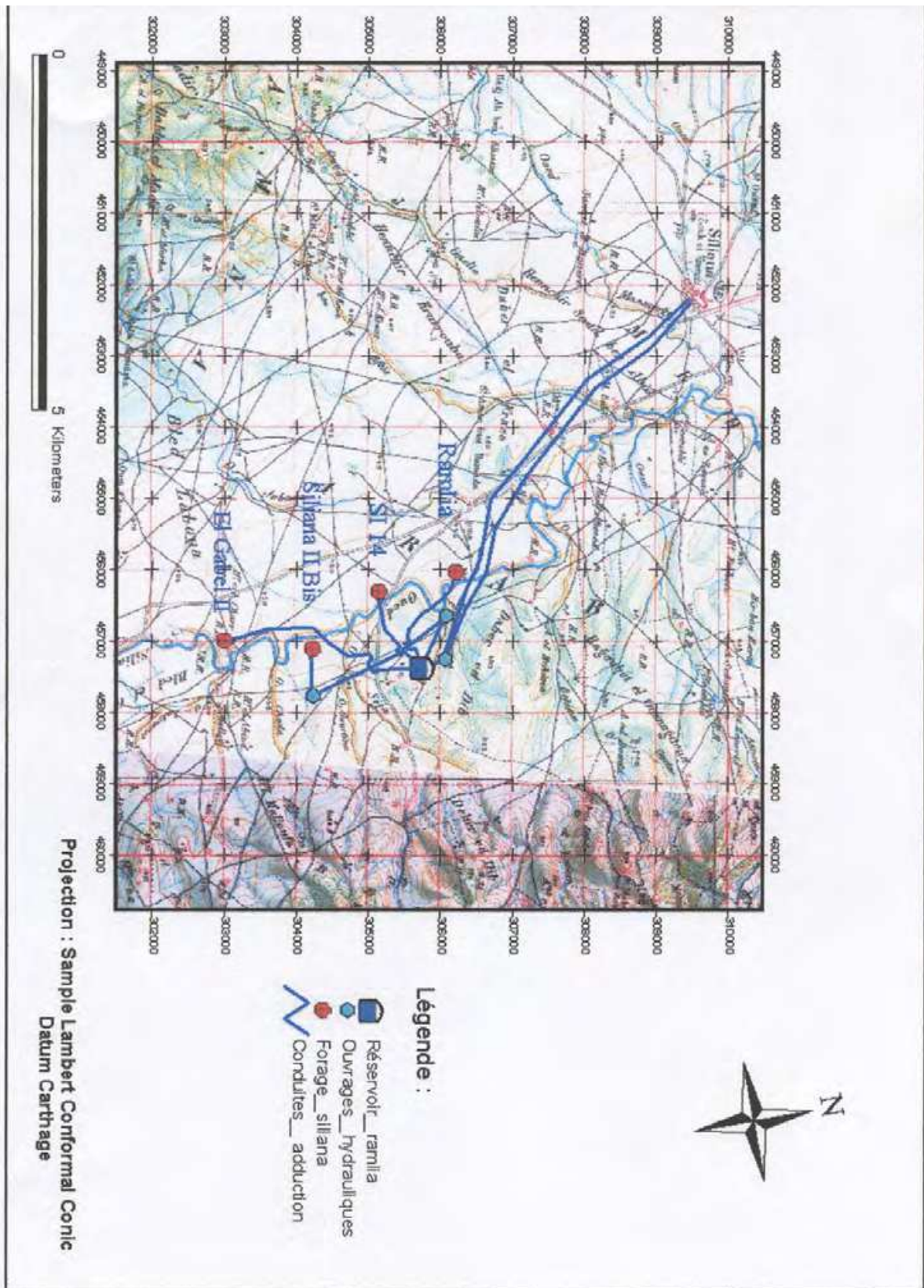


Fig. 3. A thematic maps representing the superposition of the following information layers: topographic maps, geologic map, rivers network map, adduction network map, hydraulic accessories map, water resources map (forages)

	Sections number	Nature	Mean diameter	Total mean length
Adduction network	7	AC, PE, Fonte	200 – 315 mm	25189 m
Distribution network	718	AC, PE, PVC	80 – 250 mm	248038 m

Table 2. Characteristics of the adduction/distribution networks

- For the consumer:

We have evaluated the amount of water needed by the consumers actually and in the future, those who are connected and those who are not yet connected. The principal results for the evolution of the daily volume for consumption and resources from 2006 to 2030 are propounded in table n°3.

year	2006	2010	2015	2020	2025	2030
Water needed	3964 m ³ /day	4401 m ³ /day	5022 m ³ /day	5738 m ³ /day	6563 m ³ /day	7515 m ³ /day
Resources	7517 m ³ /day	7517 m ³ /day	7517 m ³ /day	7517 m ³ /day	7517 m ³ /day	7517 m ³ /day

Table 3. Evolution of the daily water volume for the consumptions and resources

We can say that the existing resources assume the needed water until the year 2030. So we must think to a new resource or to a technical solution like recharging the existing resources or installing a new storage tank.

After modelling the water network functioning situation for the year 2007, we have remarked that there is five pressure levels in the network: less than 20 m, between 20 and 40 m, between 40 and 50 and more than 60m (Sellami and Trabelsi 2009). But for the majority of knots, the pressure is between 20 and 40 m which is a threshold fixed by the Tunisian National Society of Water Distribution for each subscriber. The singular knots for which we have recorded feeble pressures are between 10 and 20 m and those for which we have registered high pressures are not too distant from 50 m and for both the problem is due to the subscriber altitude. So there is no real problems of pressure for the year 2007.

Figure 4 shows the calculated prevention of the pressure and the energy lost for the year 2030 in the adduction and distribution networks.

We notice a high pressures (much more than 50 m) and an important lost of energy (more than 3 m/km) in the pipes of the high zone. We can suggest here many scenarios of rehabilitation. After hydraulic modelling, we have proposed to replace many conduits sections by others with a diameter varying between 400 and 500 mm. The new pressure and energy lost repartitions for the year 2030 appears in figure 5.

For all the pipes, we notice a net amelioration for the pressure (between 20 and 50 m) and for the energy lost (between 1 and 2 m/km). The same reasoning and simulation could be effectuated for different paces of time (daily, monthly, yearly...) in order to take the appropriate decision at time.

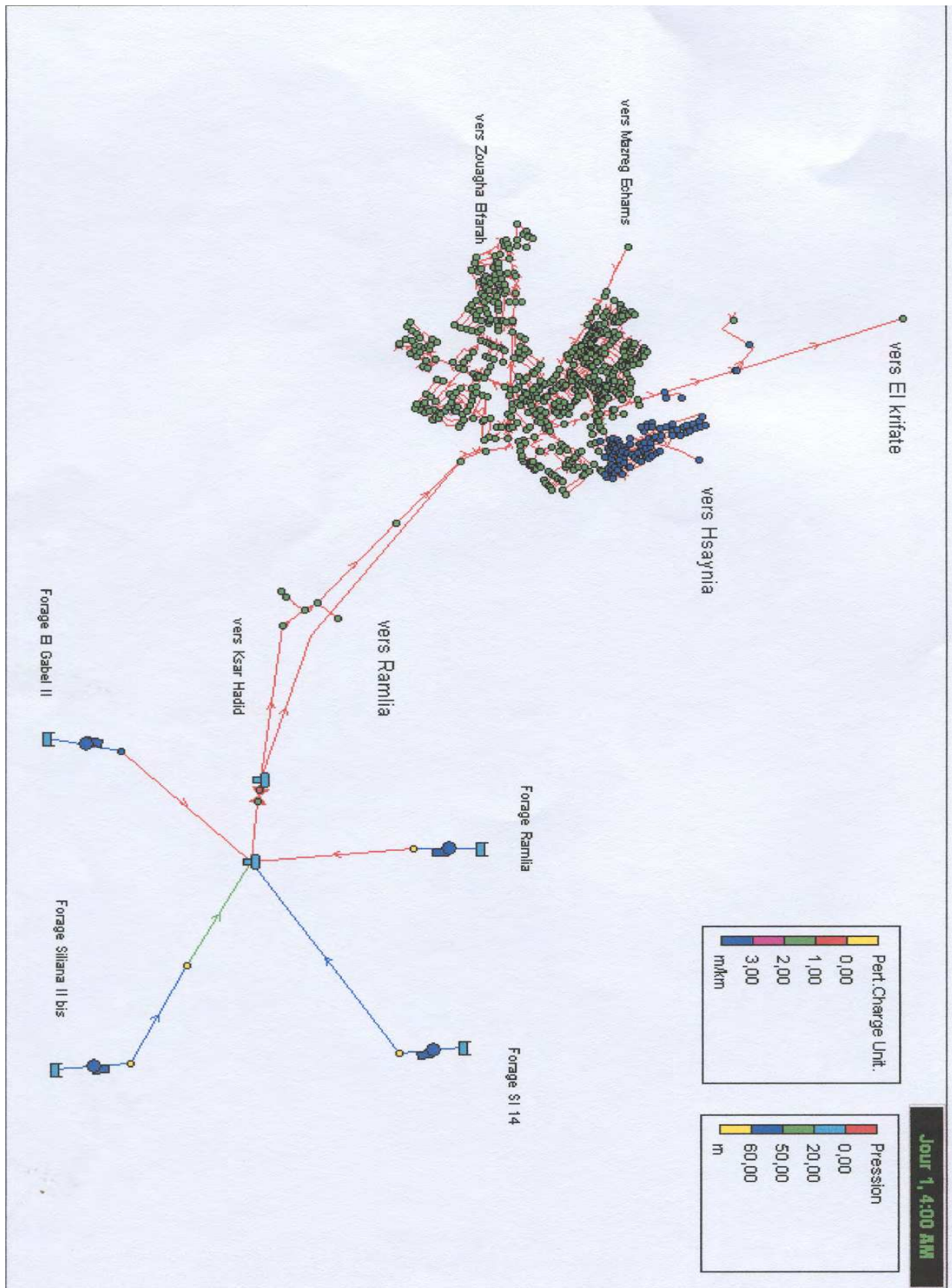


Fig. 4. Modelling of pressure and energy lost in the adduction/distribution networks without rehabilitation scenarios for the year 2030

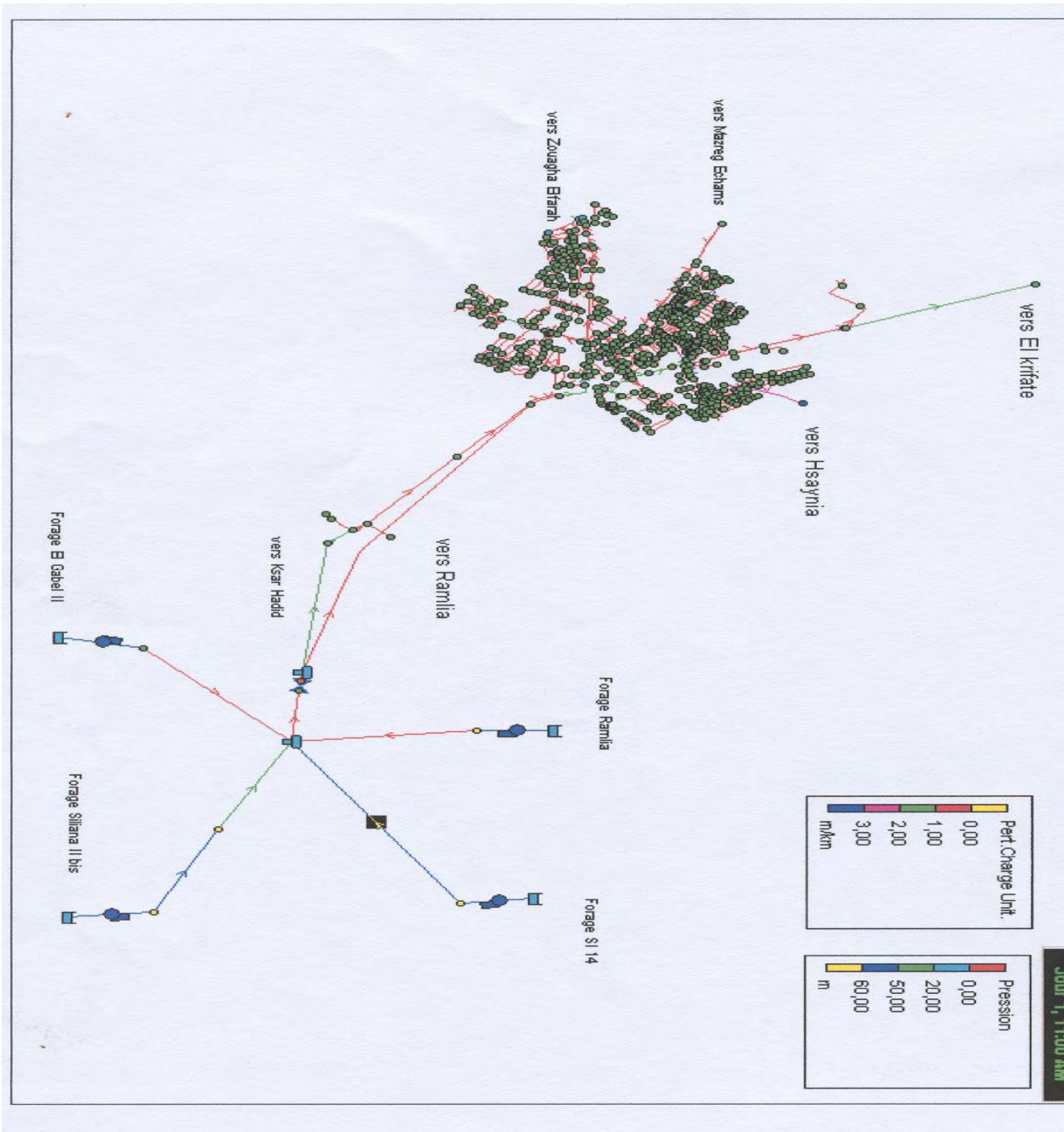


Fig. 5. Modelling of pressure and energy lost in the adduction/distribution networks after applying scenarios of rehabilitation for the year 2030

6. Conclusion

The modelling approach presented here is constituted from two complementary parts. In the first we have revolted the necessary equations to use when to evaluate the inundations effects and to manage their risks. In this sense and as beginning, we have disengaged the formulations to foresee the timing of precipitation descent, to position the averse starting and to estimate their intensities so we can localise the plains liable to floods and map the most vulnerable zones. After we can avert the decision makers about for what region we

must be prepared first and which budget we can reserve and advice them where to install our new projects. To characterise the streaming after precipitation we must be able to detect the directions of flows, their speeds and the water depth in all position of plains by considering the topography and the sorts of obstacles either in rural or urban zones. To reach that purpose we have developed a system of linear equations which can be easily resolved either analytically or numerically and permitting the estimation of those parameters. The resistance of obstacles (vegetation canopies, agriculture fields, buildings and houses, hydraulic infrastructures, water resources, forages, water adduction/distribution networks, roads/ bridges networks...) to water flow must be estimated in order to evaluate the risk of their damage as function of averse intensity for many scenarios, to size means and tools absorbing the power of water flow or deviating the water speed, to invent the adequate material of construction and to architect the efficient positioning of our projects inside villages or towns in the objective to protect human properties. To do so we have aroused the appropriate reasoning and detailed the useful formulas calculating the drag coefficients and friction factors by kind of obstacle for divers cases (totally submerged, partially submerges, flexible, solid) in either rural or urban zone.

The complete modelling of the inundation risk management can not be done successfully without responding to the question how to manage the water circuit. Because the floods have tow antagonistic effects on that circuit: on one hand they can damage the water networks (forages, pumps, treatment stations, pipes system, hydraulic accessories...), on the other hand the surplus water flowing over plains can be exploited to enhance the water resources either the surface water resources or the ground water resources. In this meaning we have evolved a basic methodology with the necessary formulas and tools permitting to test, evaluate and monitor both the actual and future situations of the water resources, the adduction/distribution network pipes and the consumers water need. It provides an interface to connect mathematical models and software to thematic maps and data basis in the hope to be capable to take momentarily the appropriate decision about the adequate solution and scenario for management, rehabilitation, renewal and projection

A first application of this model has been done for the water circuit of SILIANA region in the West-North of Tunisia. After exploiting the disposed data basis and thematic maps and by applying the mathematical models established, we have diagnosed the actual water circuit till the year 2007, we have estimated the yearly evolution of water volume for both resources and consumers and we have calculated the pressure repartition in all the knots of the adduction/distribution network until the year 2030. We have realised that the resources could not satisfy the consumers after 2030 and that we will have pressures insufficiencies in many zones of the network. We have proposed a scenario of rehabilitation, we have calculated the new hydraulic parameters of the network propounded and we have prescribed the correspondent map. We notice a net amelioration.

Finally we allow our self to say that the out puts of this approach could be easily analysed, interpreted and brought up to date and the making decision process could be ran for a moment. But a work for ameliorating this approach is needed particularly by using new and more precise models for estimating the water needed and its evolution for the agricultural, industrial and services sectors

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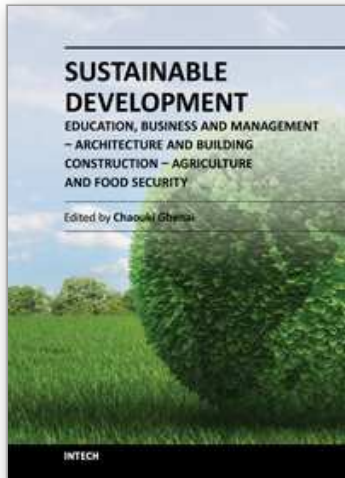
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Securing the future of the human race will require an improved understanding of the environment as well as of technological solutions, mindsets and behaviors in line with modes of development that the ecosphere of our planet can support. Some experts see the only solution in a global deflation of the currently unsustainable exploitation of resources. However, sustainable development offers an approach that would be practical to fuse with the managerial strategies and assessment tools for policy and decision makers at the regional planning level. Environmentalists, architects, engineers, policy makers and economists will have to work together in order to ensure that planning and development can meet our society's present needs without compromising the security of future generations. Better planning methods for urban and rural expansion could prevent environmental destruction and imminent crises. Energy, transport, water, environment and food production systems should aim for self-sufficiency and not the rapid depletion of natural resources. Planning for sustainable development must overcome many complex technical and social issues.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
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InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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