UNIVERSITATEA TEHNICĂ DE CONSTRUCȚII BUCUREȘTI
FACULTATEA DE HIDROTEHNICĂ
DEPARTAMENTUL INGINERIE HIDROTEHNICĂ

THE INTERACTION BETWEEN WETLANDS AND SURFACE WATER

1. HYDROLOGICAL LINKS BETWEEN WETLANDS AND SURFACE WATER

Wetlands are often encountered in environment with low energetic impact, characterized by low water velocity. This aspect is partly due to the small slope of the land surface, which is approximately flat (Orme, 1990). Wetland surface is extending or contracting with the increase and decrease of water level. Because of this, the volume of water that can be stored in certain wetlands are significant, thus attenuating negative hydrological phenomena. At the same time, the low velocities facilitates the retention of nutrients and sediments.

For an adequate characterization of the behavior of wetlands from a hydraulic point of view, three essential variables must be defined:

- Water level;
- Hydroperiod;
- Retention time.

Water level

Water level is important to determine the water depth (using the terrain's elevation as reference) and subsequently, the existing conditions for the development of a certain type of vegetation can be evaluated. Greater depths disadvantage vegetation development. In the shallow water, significant quantities of emergent vegetation can be found, both alive and dead conditions. Therefore, water level is also an indicator of the types of existent vegetation that can be found in wetlands. Also, water level represents an indicator for dissolved oxygen in the soil-water assembly *(Cowardin et all, 1979).*

Water level is usually represented through the water level hydrograph. Basically, it is a graphical representation of water level in time, using a curve. The water level hydrograph (as well as the flow rate hydrograph) is characterized through an ascendent branch, determined by the time of growth, the maximum level and a descending branch (which usually lasts until the next rain event), which is characterised by the time of decrease and is naturally less than the time of growth. The time of growth represents the duration between the peak of the rain event and the maximum level. It is reduced in urban areas with high percentage of impervious areas and subsequent higher flow velocities and has higher values in forest areas, where many obstacles throughout the flow can be found.

Hydroperiod

Hydroperiod represents the variation in time of water level. By marking the existence / absence of water, the duration and distribution of water levels in the wetland, the duration and frequency of water level disturbances are monitored. Wetlands show great variability in this regard. Hydroperiod is the evolution over time between the sum of inlets and the sum of outlets.

Hydroperiod is a distinctive feature of hydrological variability, which describes the variation of water level in time and space (Acosta and Perry, 2001; King and others, 2004).

Different approaches can be used to characterize water level changes in the wetland over time, such as:

- water level hydrograph - possible multiannual, seasonal or daily hydrological variations can be represented (Figure 1); it is noted that the hydroperiod is marked for several water levels;

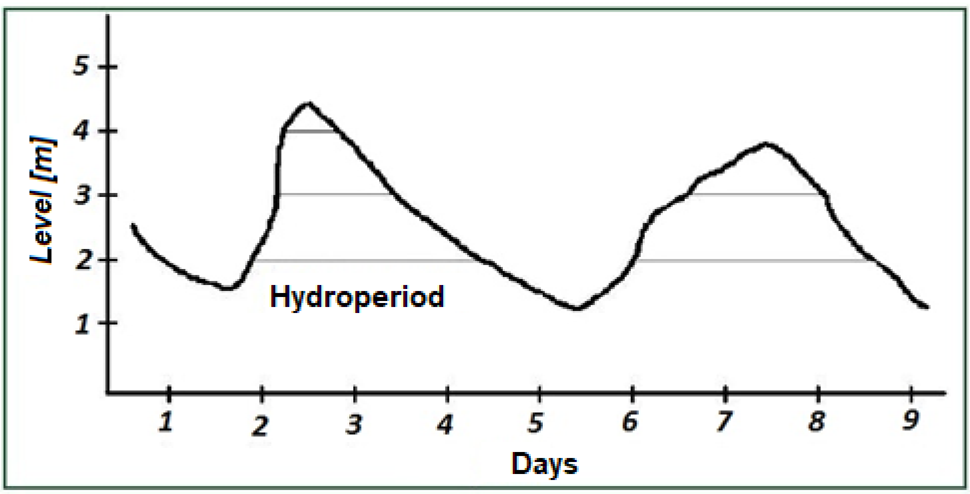

Figure 1. Hydrograph for a period of a few days

- water level – duration curve (figure 2.a) - it is described as being the duration of the flood corresponding to exceeding a certain level. It is obvious that at a lower level, the duration is longer. Basically, it quantifies the period for which a certain level is exceeded or reached. *This approach must take into account the seasonal nature of floods, requiring the division of data into appropriate sets (Mitsch and Gosselink, 2000)*;

- water level-frequency curve (figure 2.b) – differently from water level-duration curve, through this type of representation it can be observed how many times a certain level is exceeded in a period that is unspecified. *This approach involves making a table with cumulative frequencies, based on which the probabilities of exceeding are calculated (McCuen, 1998).*

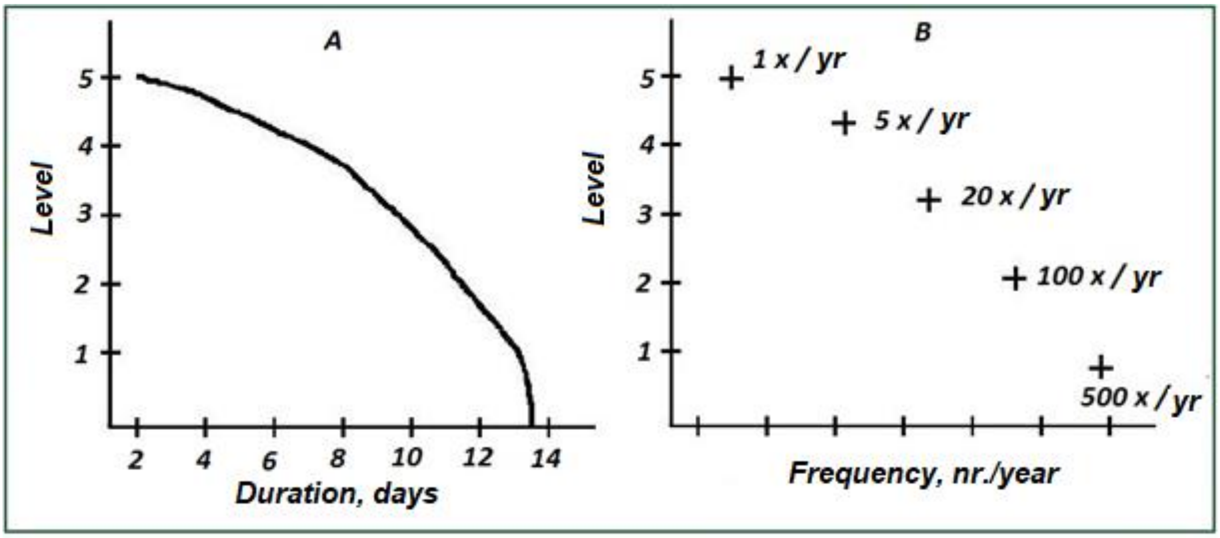

Figure 2. A) Level-duration curve; B) level-frequency curve

- water level-duration-frequency curve (figure 3) – such sort of family of curves is constructed to overcome the inconvenience of using one or the other of the curves shown in figure 2, a and b. *They are similar to the IDF curves (intensity- duration-frequency), used in precipitation analysis (McCuen, 1998).*

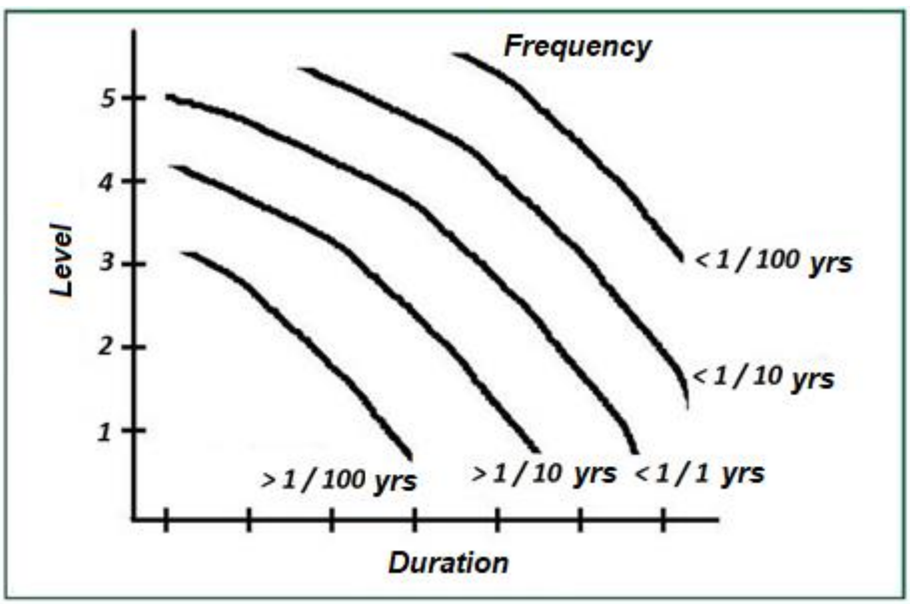

Figure 3. Level-duration-frequency curve (LDF)

The characterization of the hydroperiod is a much more difficult requirement in the case of large wetlands with a complex hydrological regime than small wetlands.

At the same time, important differences of the behavior from the hydrological point of view from one wetland to another can be observed.

Retention time

Retention time or transit time is the duration of time that an elementary volume of water spends inside a wetland from inlet to outlet. There are wetlands where the water moves with high velocity, the retention time being low as well as others where the water has a very low velocity, the retention time being high. The retention time can be expressed as the ratio between the volume of water in the wetland and the flow of water in the wetland.

$$t_r = \frac{V}{Q} \tag{1}$$

This formula can be applied in the following conditions:

- the flow is similar with a piston : first in – first out ;
- permanent flow (constant);
- a single input / output;
- atmospheric and groundwater exchanges are negligible.

If the conditions listed above are not met, only an indicative retention time is identified by using the formula. In reality, it can be very different from the calculated value due to the mixture of water that takes place in the wetland, the presence of a large number of entry and exit points or a variable flow over time. In these situations, the retention time varies both in time and space. Only when a system is simple, the functions that describe the distribution of retention time within the wetland can be determined. *For a system in which the mixture is complete and the inputs are constant over time, an exponential function can be used to determine the distribution of retention times in the wetland (Law and Kelton, 1991).*

In certain cases, different parts of a wetland behave distinctly. While the water velocity in some is almost zero, the flow is significant in others. The same equation can be used at the level of each sector/area of the wetland, using the volume accumulated for each of them and the input and output flow corresponding to the characteristic sections of each sector/area.

When dealing with dynamic systems, it is difficult to calculate a retention time. It varies over time as the recharge rate changes. The retention time increases when the outflow is higher than the inflow and decreases when the inflow is higher.

In order to validate and / or determine the correct values for retention time, tracer tests may be used. By adding a tracer at the injection point and monitor its concentration at the exit point. A curve is then constructed, which describes the variation in concentration over time. The average retention time in the wetland is the one corresponding to the value of the outlet concentration at half of the injected concentration (Rasmussen, 2008).

There is a close connection between the retention time and the hydroperiod: important fluctuations of the level translate into low retention time; however, this rule is not generally valid: if only the inlet flow rate changes, the retention time is in this case a long one.

The key of proper water management in wetlands is to find the optimal combination of the three variables: water level, hydroperiod and retention time. This can be obtained only after knowing all the components that directly or indirectly influence the hydrological regime of the area, their assessment and the running through models as many scenarios as possible, from which to choose the one that meets the desired conditions in different situations. The engineer operating this assembly must take into account the environmental factors and the ecological changes that it brings to the area by changing the hydrological conditions. Any operation must be aimed to maintain the ecological balance. The situation is reversed in the case of artificially constructed wetlands, where it is desired to create hydrological conditions that previously did not exist, in order to support grow of desired vegetation. Basically, it is started from the ecological objective that a wetland must achieve and the combination of variables that generate the optimal hydrological regime to satisfy them is determined.

Flows between surface waters and wetlands occur due to a large number of transfer mechanisms:

- exceeding the banks during floods;
- direct exchange when a open channel crosses the wetland;
- along the lake boundaries or estuary boundaries in the case of coastal wetlands.

Connectivity between surface water and wetlands can be constant (continuous) or temporary. The fow in river / open channels can be divided in 2 components (Figure 4): the base flow and the precipitation flow. The base flow is the flow component corresponding to the flow in dry periods, while the precipitation flow occurs as a response to a rainfall event. The rainfall flow is added to the base flow. The latter would have been maintained if the rainy event had not occurred.

Flows exchanged between wetlands and surface water can be assessed using flow control instruments / hydraulic structures such as those listed below:

- **weirs** - require a stilling basin upstream to reduce / neglect the kinetic term in the calculation; they are not suitable in the case of water with high sediment transport as clogging occurs and maintenance costs become very high; the solution with side overflows is often used for water access to the wetland from an open channel (Figure 5);

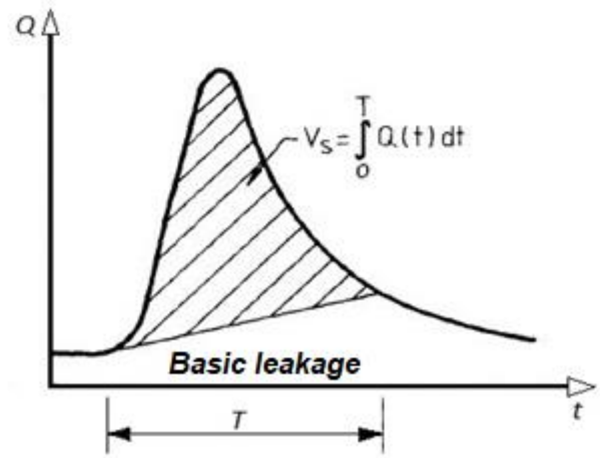

Figure 4. Flow hydrograph for a rain event (after Drobot and Șerban, 1999)

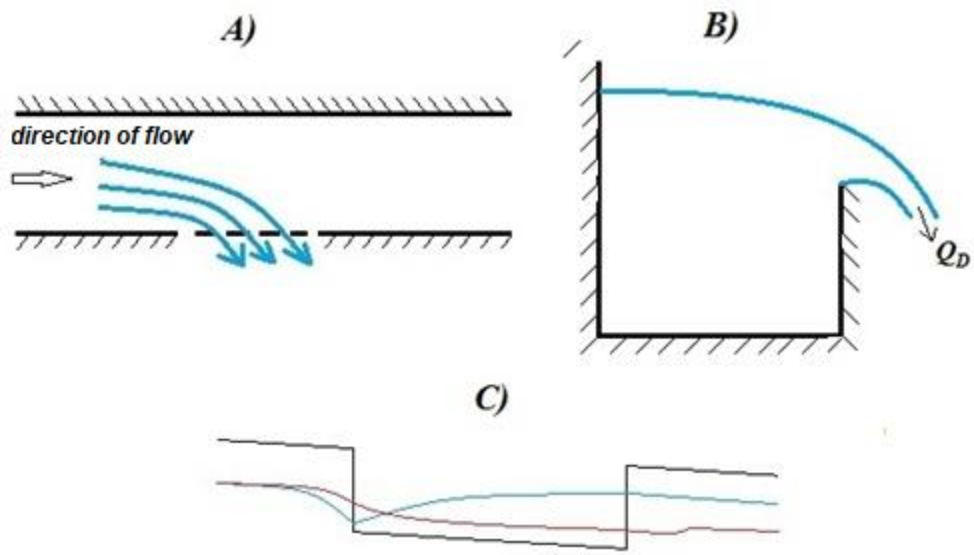

Figure 5. Side weir
A) plan view; B) cross section; C) longitudinal profile;

- **calibrated channels** - have the advantage that sediments are entrained due to the high water velocity and thus clogging is avoided; solutions that can be used (figure 3) such as Parshall channels (fig.6A), H-type (fig.6B), Montana type (fig.6C), RBS type (fig.6D), or those with trapezoidal section (Figure 6); in these situations there is no need for a stilling basin upstream; they has the disadvantage that they can be blocked with ice, wood or other debris, thus affecting the measurements;

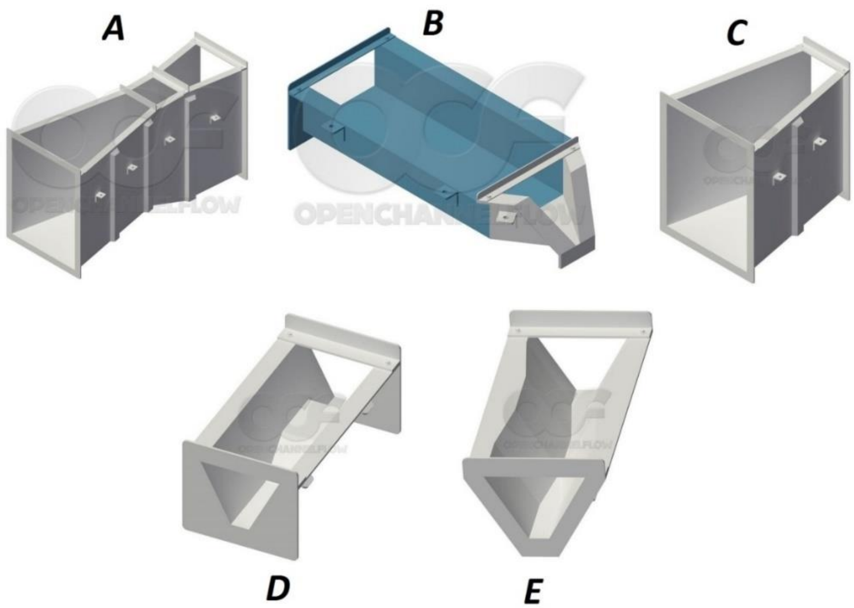

Figure 6. Types of calibrated channels for flow measurements
A) Parshall; B) type H; C) Montana; D) RBS; E) Trapezoidal
(from *www.openchannelflow.com)*

- **open channel / culverts** – are the least accurate; for most situations, one of the 4 possible combinations in terms of flow equation can be choosen. Regardless the existing flow conditions, it is recommended to maintain the same section along the entire length of the channel/culvert and to prevent access of floating objects:
  (a) both upstream and downstream sides are submerged – the calculation is made on the basis of the head difference between the two limits of the culvert/pipe, similar to pressurized pipes;
  (b) free surface on upstream sede and submerged flow on downstream side – in this case the Manning equation is used;
  (c) submerged conditions on upstream side and free surface flow on downstream side – in this case the flow is assimilated to the orifice flow;
  (d) both free surface conditions on upstream and downstream sides – as in case (b), using the Manning equation.

In the case of open channels the flow is determined on the basis of the cross section and by measuring the water velocity (v) along the section. Because the velocity and depth of the water are not constant throughout the section, the total flow is approximated as the sum of the flows for each subdivision:

$$Q = \int A \cdot v \ dA \backsim \sum_{i=1}^{n} v_i A_i \quad (2)$$

where: A is the cross-section area, n is the total number of subdivisions into which the cross-section is divided, v_i is the average velocity in each subdivision, A_i is the area of each subdivision.

For shallow water, the average velocity is recorded at about 60% of the water depth, measured from the free surface downwards. In the case of those with greater depths, the average speed is calculated as the average of the speeds recorded at depths of 20% and 80% of the total water depth.

Wetlands located nearby the rivers are supply by surface water, during periods when levels are high, as a result of flowing into the river floodplain by exceeding the banks. The duration of this phenomenon is closely related to the duration and intensity of precipitation.

Side weirs

The side overflows (a general scheme is shown in Figure 7) are often used as a constructive solution for water access in newly created wetlands or under ecological reconstruction process. Globally, a multitude of experimental and theoretical studies have been carried out over time on side overflows. Each of the solutions has its own particularities, so that different cases exist, especially due to the flow regime and the geometry of the weirs. Among the specialists who contributed to the development of the literature on this topic are: Frazer (1957), Subramanya and Awasthy (1972), Ranga Raju and others (1979), Hager (1987), Singh and others (1994), Swamee and others (1994).

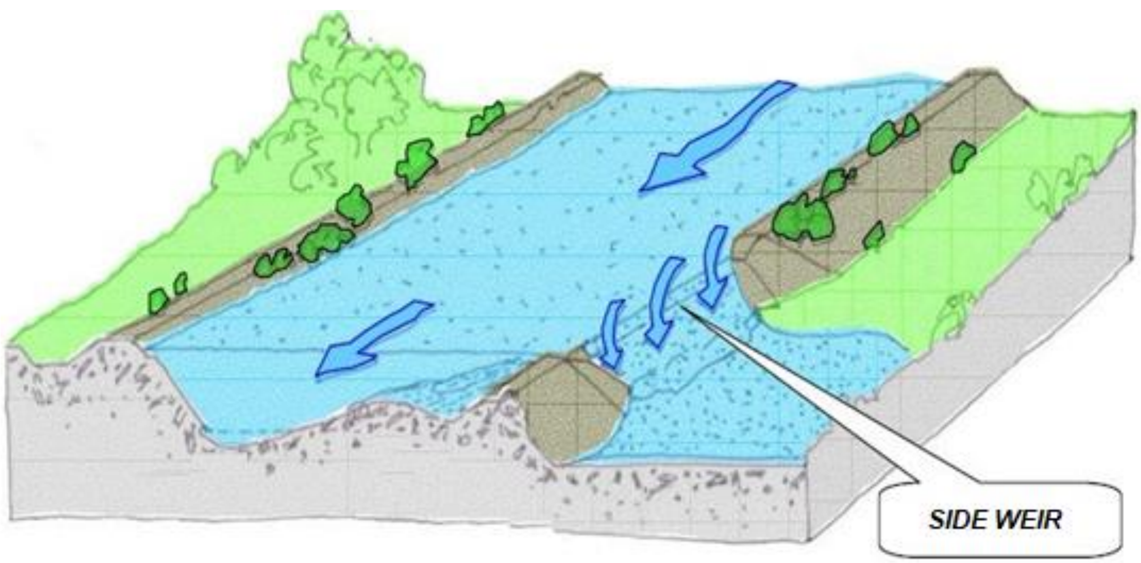

Figure 7. Side weir: general scheme (after B. Rosier, 2007)

Some of the results of the studies will be presented below, especially those related to the calculation of the discharged flow in wetlands from a river / open channel. In all the studied materials, special attention is paid to the corresponding appreciation of the flow coefficient - Cd.

Flow over a side overflow is a particular case of variable flow in space, in which the flow is decreasing. Lateral overflows can be used in channels where the flow is either subcritical (Fr <1) or supercritical (Fr> 1). From a hydraulic point of view, the flow behavior is different, for each of the two cases described. The subcritical regime is most often found in practice and for this reason the following calculations are valid in such a situation. Depending on the water depth in downstream side of the flow and the solution adopted, the movement regime near the side overflow is found in one of the following cases: subcritical regime, with hydraulic jump or supercritical regime (after Naudasher, 1992).

In order to calculate the discharged flow over a side weir, both the energy equation (figure 8) and the momentum conservation principle are applied. Chow (1973) considers the application of the energy equation appropriate in this situation, especially because the principle is directly applicable.

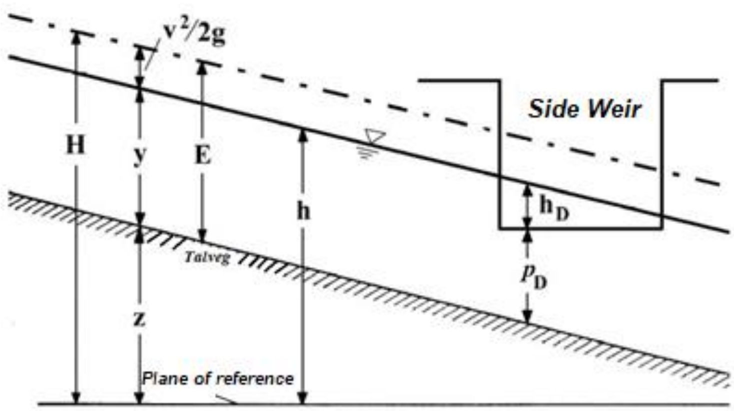

Figure 8. Longitudinal profile, total load (H), specific energy (E), pressure load (h) and head over the weir (h_D) (processed after B. Rosier, 2007)

Assuming that the piezometric slope is equal to the channel slope (means constant specific energy $E = y + \frac{Q^2}{2g \cdot A^2}$ and the Coriolis coefficient α = 1 (means that the velocity is constant and uniform in the section) the general equation for calculating the specific flow per unit

[1] Fr = Froude number, is a dimensionless quantity defined as the ratio between the inertial and gravitational forces acting on the fluid. It is calculated with the relation $Fr = \frac{v^2}{g \cdot h}$, or according to other authors $Fr = \frac{v}{\sqrt{g \cdot h}}$. When Fr = 1, h becomes h_{cr} - critical depth and specific $\left(E = h + \frac{\alpha v^2}{2 \cdot g}\right)$ of the section is minimal. In the case of the subcritical regime (Fr <1), the water depth is greater than the critical depth, while in the case of the supercritical regime the water depth is less than the critical depth. It bears this name in honor of the English scientist (physicist and engineer, specializing in fluid dynamics and naval hydrodynamics) William Froude, who first enunciated this principle.

length of the weir can be written as:

$$q_D = \frac{2}{3} \cdot C_D \cdot \sqrt{2 \cdot g} \cdot (y - p_D)^{3/2} \quad (3)$$

where: C_D is the flow coefficient, p_D is the weir height over the channel bed. Exponent 3/2 has the following explanation (Del Giudice and Hager, 1999): *an integer represents the pressure load over the level of the weir ridge, without taking into account the kinetic load; the difference consisting of half of the whole represents the approximation of the velocity over the weir.*

A side weir is built to divert / discharge a certain flow. Therefore, it is very important to know with the highest possible degree of accuracy of the flow and implicitly of the C_D flow coefficient. Borghei et al. (1999) state that according to a weir design principles, the main objective is to know as accurately as possible the discharged flow and detailed knowledge of the weir load along it becomes a secondary objective. In the longitudinal profile in **Figure 9** are presented the main geometric and hydraulic parameters of a side overflow and which help to interpret the variables involved for the correct assessment of the flow coefficient.

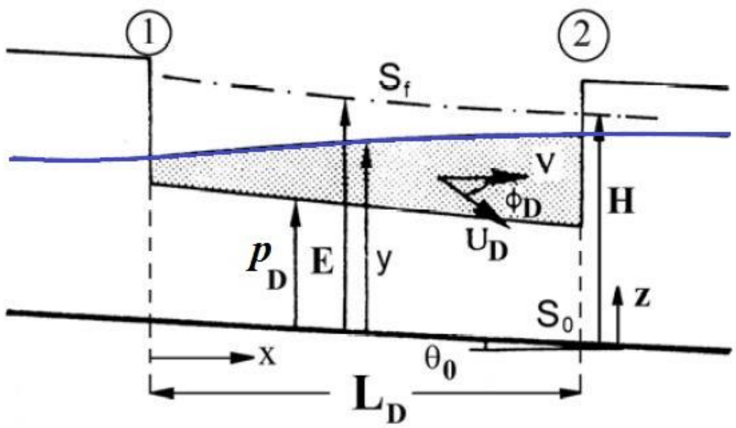

Figure 9. Side weir: longitudinal profile in which the main flow variables are represented *(processing according to Sinninger and Hager, 1989)*

As can be seen in the figure above, the inlet section is marked with ″ 1 ″ (located upstream of the weir) and the exit section with ″2″ (located downstream of the weir). S_f is the hydraulic slope and S_0 is the channel slope. Using dimensional analysis, it is found that C_D is a function of:

$$C_D = f\left(Fr_1, \frac{p_D}{y_1}, \frac{y_1}{L_D}, \frac{L_D}{B}, \frac{E_1}{L_D}, S_0, \dots\right) \quad (4)$$

where y is the water depth, L_D is the length of the weir, B is the width at the free surface, E is the specific energy in section and S_0 is the slope of the channel.

In the literature exist various formulas for the correct assessment of the flow coefficient, mainly based on different geometric shapes of the weir. Table 1 shows some of them (by the names of the authors who proposed them based on the experiments performed), valid for side overflows with rectangular section and sharp edge.

Table 1. Calculation relations for flow coefficient,
for a side weir with a rectangular section
(after B. Rosier, 2007)

Author	Calculation ralations for flow coefficient
Frazer (1957)	$C_D = 0{,}55 - 0{,}115 \cdot {Fr_1}^2 - \frac{0{,}017 \cdot E_1}{L_D}$
Subramanya & Awasthy (1972)	$C_D = 0{,}611 \cdot \sqrt{1 - \frac{3 \cdot {Fr_1}^2}{2 + {Fr_1}^2}}$
Ranga Raju & others (1979)	$C_D = 0{,}81 - 0{,}60 \cdot Fr_1$
Hager (1987)	$C_D = 0{,}485 \cdot \sqrt{\frac{2 + {Fr_1}^2}{2 + 3 \cdot {Fr_1}^2}}$
Singh & others (1994)	$C_D = 0{,}33 - 0{,}18 \cdot Fr_1 + 0{,}49 \cdot \frac{p_D}{y_1}$
Borghei & others (1999)	$C_D = 0{,}7 - 0{,}48 \cdot Fr_1 - 0{,}3 \cdot \frac{p_D}{y_1} + 0{,}06 \cdot \frac{L_D}{B}$
Swamee & others (1994)	$C_D = 0{,}447 \cdot \left[\left(\frac{44{,}7 \cdot p_D}{49 \cdot p_D + y}\right)^{6{,}67} + \left(\frac{y - p_D}{y}\right)^{6{,}67}\right]^{-0{,}15}$

Coastal wetlands are similar in many respects to "continental" wetlands, except that they represent the "transition" from land to sea / ocean. Such areas have certain unique features that make them different from both terrestrial and marine ecosystems. They are the result of the combination between the repetitive phenomenon of flooding and the soils that are found near the water surface, which favors the ecological diversity and productivity of these areas.

In some coastal wetlands, accumulation takes place during high tide. The result of these daily exchanges, particularly important in terms of quantity, are the unique conditions we find in such areas. If the wetland is supplied simultaneously with fresh water, the situation becomes even more special as changes in water quality are important, making it very difficult to assess what type of ecosystem can adapt to such conditions.

2. THE ROLE OF WETLANDS IN WATER RESOURCES MANAGEMENT

The intelligent and rational use of wetlands is an extremely important factor in the management of water resources both quantitatively and qualitatively. At local level they can be critical, if the topographical and / or geological conditions limit the application of other technical solutions. Examples are the slope wetlands, with an essential role in collecting and mitigating runoff on slopes, or treatment wetlands for small communities, where the adoption of other solutions is expensive.

The use of wetlands for flood mitigation is receiving increasing attention, although it is still unknown / difficult to quantify the exact effect that different types of wetlands have in this regard. However, it is easy to notice that all types of wetlands make a certain contribution to flood mitigation and their role in regulating river flows is obvious, but has not been empirically proven.

In the context of climate change, the understanding of how rain events generate floods is constantly improving, especially in the area of risk management but also on the theoretical side where the amazing evolution of hardware power facilitates the acquisition of huge amounts of data, used especially for statistical processing. Considerable interest is shown in flood forecasting systems, which are now built in an interactive way in terms of land use and land cover. The ability of these sub-basins (wetlands) to delay run-off during high-risk events, with a low probability of occurrence, is of great importance for decision-makers in charge of flood and flood risk management.

Wetlands are widely recognized as essential components of the environment, through their invaluable values for biodiversity conservation and, in particular, their hydrological role at local or regional scale (Rasmussen, 2008).

Wetlands, both natural and artificial (built), can provide essential functions in the process of water management and environmental protection, in terms of quantity and quality:

- Flood mitigation on rivers (e.g. floods on Danube river occured in 2006);
- Reduction of negative effects produced by runoff on slopes / floods, especially in hilly areas;
- Compensatory measures in urban areas where expansion of the urban area occurs and green spaces are transforming to impervious areas;
- Ecological area used to enhance biodiversity and improve the landscape, especially in heavily built urban areas;
- Agricultural area: fishing and use of abundant vegetation;
- Wetland with a treatment role, especially for removal of nutrients and sediments. Solution widely used in developed countries for water treatment in rural areas / small communitites.

Flood mitigation on rivers

Lateral accumulations modify the flood wave hydrograph in the peak area (M. Șelărescu and M. Podani, 1993). The access of the accumulated water is done after exceeding the weir crest, respectively the inlet flow (Q_{AD}) from **Figure 10**. Depending on the transport capacity to which the access was designed, the maximum flow in natural regime of the flood (Q_{MAX}) is reduced to at the Q_{MAX} value. The time t_c corresponds to the time of increase of the flood in natural regime while t_u represents the time necessary to fill the lateral storage. t_c' corresponds to the moment when the water discharge from the lateral storage to the river occurs. This moment exist because the water level in the storage area is higher than in the river / channel. The attenuation in a lateral storage depends both on the maximum flow in natural regime and on the shape of the flood wave in natural regime. Also, the attenuation in lateral storage depends on the water level – flow rate relation on the river at the intake *section (M.Șelărescu and M. Podani, 1993).*

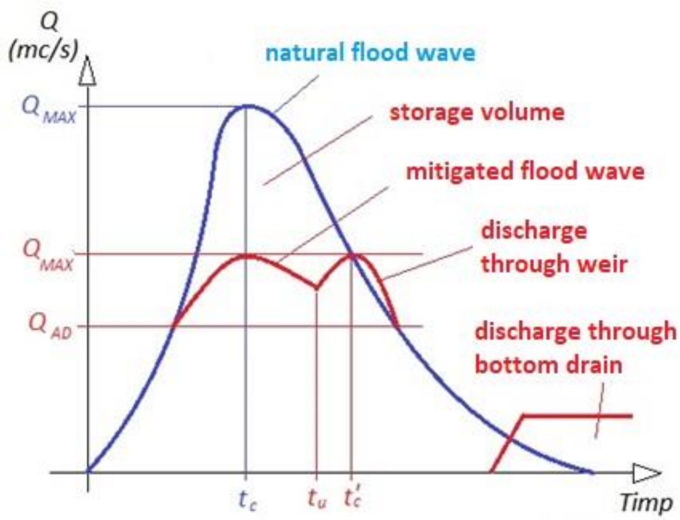

Figure 10 The effect of lateral storage on the flood wave
(processed after M.Șelărescu and M. Podani, 1993)

The main role of wetlands in relation to surface water is to mitigate floods. In addition to the obvious function of reducing the water velocity during floods, wetlands can also reduce the flood waves propagation speed. This phenomenon occurs when the water velocity decreases, while the flow rate increases.

The flood wave propagates at a different speed than the speed of the water. The speed of the wave propagation, also known as *„celerity" (c)*, is defined as the change in flow rate *(dQ)* per unit area in the cross section *(dA)*.

$$c = \frac{dQ}{dA} = \frac{d(v \cdot A)}{dA} = v + A \cdot \frac{dv}{dA} \qquad [m/s] \tag{5}$$

where $Q = A \cdot v$ is the flow rate, A is the cross-sectional area and v is the average water velocity in the calculation section.

Equation (5) indicates that the wave propagation velocity is equal to the water velocity plus another term, which is positive if the water velocity increases with increasing flow area (or with increasing water level, it is equivalent), or, negatively if the water speed decreases as the flow area or level increases. In other words, the wave propagation velocity is higher than the average water velocity if the average water speed increases with increasing level and vice versa, the speed is lower than the average water speed if it decreases with increasing level.

Wetlands serve to retain water during floods, producing the following effects:

- reduce the maximum flow rate in the downstream river sections;
- the average water velocity decreases;
- increase the propagation time of the flood wave.

Wetlands built for protection against the negative effects of runoff

From the analysis of the idealized hydrograph in Figure 11 it is observed that the flow on the slope is the most important component of the discharge from a river, both from the point of view of the maximum flow and the speed evolution of the phenomenon. For this reason, the negative effects produced by such phenomena must be properly managed, as wetlands can be an advantageous solution. They can be used in combination with a drainage system / gutters.

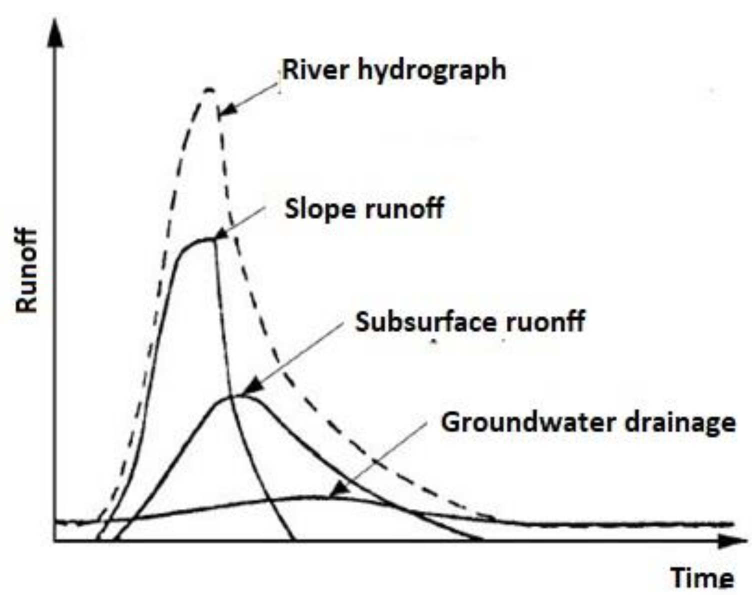

Figure 11. Idealized hydrograph
(from P. Stanciu, 1998)

3. ECOLOGICAL IMPACT ASSESSMENT AS A RESULT OF THE CHANGE IN THE HYDROLOGICAL REGIME

Wetlands evolve over time. Natural phenomena such as sediment deposition or erosion and human interventions such as excessive development of upstream sectors have an direct impact on wetlands.

In order to be aware of the hydrological changes that are brought to wetlands, it is necessary to know the ways in which they are built and develop. Thus, wetlands are the result of extensive hydrological and geological processes:

- Rivers are developping their floodplain area that provide the perfect conditions for appearance of wetlands;
- Runoff on slopes due to ice melting of glaciers, leaves behind favorable conditions for the appearance of wetlands;
- tectonic movements and subsidence processes lead to the appearance of depressionary areas, where wetlands cound appear;
- aquifers developed on limestone formations, dissolve the rock over time, leaving behind depressions in which wetlands can form;
- following the process of accentuated erosion, important quantitative sediments are transported outside the riverbeds. Thus, the channel bottom is lowering and the banks become higher. The result is a reduction of the free water surface and a reduction of supply flows to the wetlands as a result of lower frequecy of banks exceeding during high water.

Once they formed, the aging phenomena occurs itself on the wetlands by clogging them with various sediments, which arrived here due to the upstream erosion. The clogging process can be slow (it is the case of wetlands with a small river basin) or a fast one (it is the case of nutrient-rich courses, with important river basins).

Depending on the natural forces to which they are subjected, wetlands are facing a continuous process of formation / disappearance. Practically, from a hydrological point of view, it permanently changes its condition. Maintaining hydrological balance is the key factor in wetland management. With the occurrence of the clogging phenomenon, a number of other aspects arise that must be taken into account in water management: the volumes that can be stored are reduced, the retention time decreases, the water depth also changes, thus changing the hydroperiod.

Being part of a hydrological cycle in a permanent dynamic, wetlands must be analyzed together with their adjacent ecosystems. Particular attention should be paid to basins upstream of the wetland as any hydrological changes will also have an effect on the wetland. In certain situations, various compensatory measures can be taken to mitigate the impact of hydrological changes on wetlands.

The human impact on wetlands can be substantial (*Azous and Horner, 2001*). In general, the effect of these changes is to increase sediment transport and nutrient concentration. The evolution of these phenomena leads to the reduction of storage volume and to the development of organic sediments.

Wetland recharge rate can increase, by collecting surface runoff from urban, industrial or agricultural areas to the wetland. At the same time, hydraulic structures such as reservoirs, channels or dams can reduce water access to the wetland, thus altering the natural hydrological regime. However, the role that most of these structures play is to drain the wetland.

Flows discharged from wetlands may increase as a result of the execution of drainage ditches, canals, regularization of sections or as a result of the removal of natural barriers of plant origin.

Wetlands in urban areas

In addition to the obvious role that wetlands in urban areas play in reducing the maximum flow of surface and subsurface runoff, they are also an extremely important factor in maintaining good water quality, being able to retain significant amounts of sediment and / or soluble compounds. (Butler and Davies, 2011)

Figure 12 shows a wetland built in an urban environment. Usually, the functions provided by these areas are multiple, they capture the first part of the rain known as the most polluted. At the same time, in such hydrotechnical constructions, important volumes can be stored and the concentration time is delayed - an extremely important aspect in urban water management.

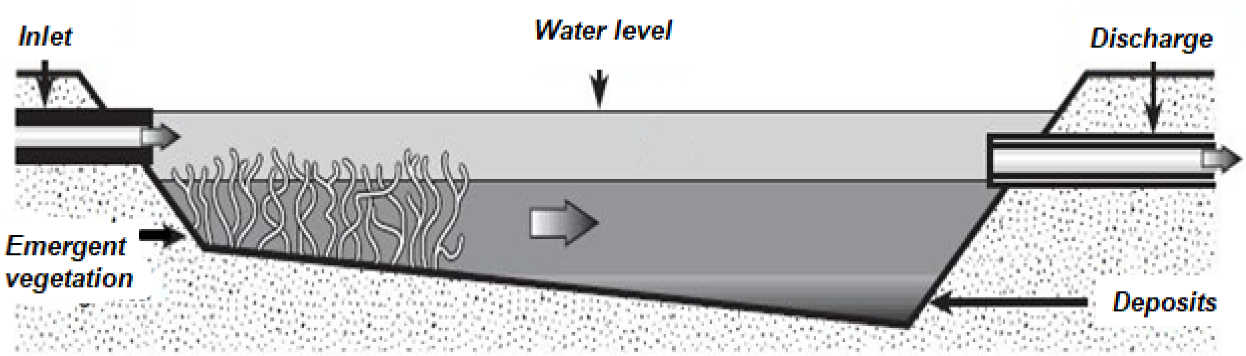

Figure 12. Functional scheme for a wetland in an urban environment
(after Butler and Davies, 2011)

These constructions may be those used in most cases for ″source flood control″, such as:

- retention cells - contain vegetation over a drainage bed made of gravel / sand;
- infiltration trenches - are narrow ditches filled with gravel;
- porous pavements - are excavated surfaces filled with gravel and paved with porous concrete or mixed asphalt;
- trenches with vegetation - are canals or depressions covered with vegetation that have the role to slow down the runoff and to increase the infiltration rate.

Resolution XI, adopted in Bucharest (2011) by the contracting parties to the RAMSAR Convention, establishes practical principles for the planning and management of wetlands located in urban areas and adjacent areas:

1. Conservation of wetlands in urban space;
2. Construction and Re-Construction of wetlands;
3. Understanding the values offered by wetlands;
4. Commitment of stakeholders;
5. Integrated planning.

EVALUATION OF WATER BALANCE IN THE WETLAND

Water level, hydroperiod and retention time are influenced and controlled by hydrological connections: inlets and outlets. The state that characterizes a wetland is largely due to water intake and losses. The water balance represents the difference between inputs and outputs. Exchanges can take place: with the atmosphere, with groundwater, with surface waters or by the action of tides (where appropriate). The amount of exchanges (positive for those that represent inlets in the wetland, respectively negative for those that are outlets) influences the water level in the wetland. Both atmospheric and hydrogeological conditions are in some cases extremely important. In most cases, however, the exchanges with surface water are dominant.

The concept can be summarized mathematically, by the following equation:

$$dQ = I - E = \frac{dV}{dt} \tag{6}$$

where: dQ is the difference between the inlet flow (I) and the outlet (E), dV is the difference in the volume stored in the wetland during dt.

Due to the connection between the water level and the volume stored in the wetland given by the capacity curve (**Figure 13**), any increase in the stored volume corresponds to an increase in the water level.

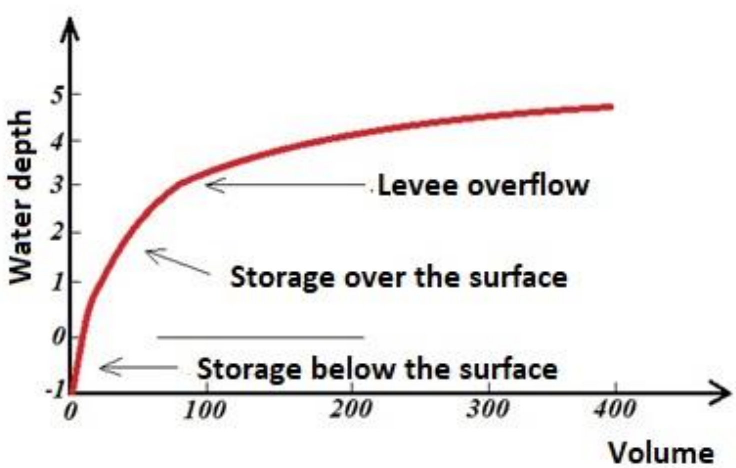

Figure 13. Theoretical capacity curve of a wetland

The above relationship becomes more complicated when the water level drops below the surface of the ground. In this situation, the minerals and organic matter that make up the soil eliminate less water due to their porosity and water retention property.

The change in levels in the wetland over time can be described by the following mathematical relation:

$$dh = \frac{dV}{A} = \frac{dQ}{A} dt \quad (7)$$

where dh is the change in water level, $dV = dQ \cdot dt$ is the change in volume in the wetland, $dQ = I\text{-}E$ is the difference between the flow in and out of the wetland, dt is the time step and A is the storage area corresponding to the wetland, equal to the volume corresponding to a change in level equal to unity.

Changes in water levels over time indicate that the wetland accumulates water during periods of rainfall and losses water during periods of drought. The water level represents the accumulation in time and space of hydrological changes, thus showing that wetlands are sensitive even to small disturbances of environmental conditions.

To construct the capacity curve of a wetland or, in other words, to determine the relationship between level and surface or volume, the following types of data can be used: topographic maps, topometric and / or topobatimetric surveys to make cross sections, orthophotoplans at different elevation levels. Spatial analysis software allows the manipulation and storage of all these data sets in geographic databases, easy to process and view. Thus, digital terrain models can be built, three-dimensional, facilitating the design with a good precision of the capacity curves.

In addition to the water balance, the mass balance can be also calculated, corresponding to the suspended or dissolved materials and which are transported with the water (solid flow). Mathematically, this relationship can be written as follows:

$$\frac{dM}{dt} = d\hat{I} = \hat{I}_1 - \hat{I}_2 \quad (8)$$

where M is the mass of suspended or dissolved matter, *dM* is the change in mass between 2 sections, *dt* is the time step, $d\hat{I}$ is the change in load, $\hat{I}_1$ is the load at the point of entry and $\hat{I}_2$ is the load at the exit point.

In most cases, water quality measurements do not refer to the determination of the load but to the concentration of the solution. The relationship between load and concentration is based on the relationship:

$$\hat{I} = C \cdot Q \quad (9)$$

where Q is the flow rate.

The concentration of the tracer can be used in some cases to determine the volume of water in the wetland. For example, if a certain amount of a tracer is added, then it is completely mixed in the wetland and the concentration is measured, the volume of water can be found. The relation will be used, making the assumptions that once the complete mixing is done, the concentration of the tracer is the same at any point in the wetland:

$$C = \frac{M_t}{V_A} \rightarrow V_A = \frac{M_t}{C} \tag{10}$$

where V_A is the volume of water in the wetland, M_t is the added tracer mass, C is the tracer concentration.

The set consisting of level measurements and tests with tracers leads to the estimation / calculation of the water balance. For this purpose, the three equations presented above are used:

- the water balance equation;
- mass conservation equation;
- the relationship for determining the concentration.

There are four types of wetland supply / discharge sources in the balance equation:

- atmospheric changes: precipitation, snow melting, evaporation and perspiration
- exchanges with the underground environment;
- surface water exchanges;
- exchanges due to tides in coastal areas.

Figure 14 (adapted from Brinson, 1993) shows a general scheme of hydrological exchanges, both inputs and outputs. For example, exchanges with the atmosphere include evapotranspiration and precipitation alike. It is noted that this scheme does not include wetlands affected by the tide.

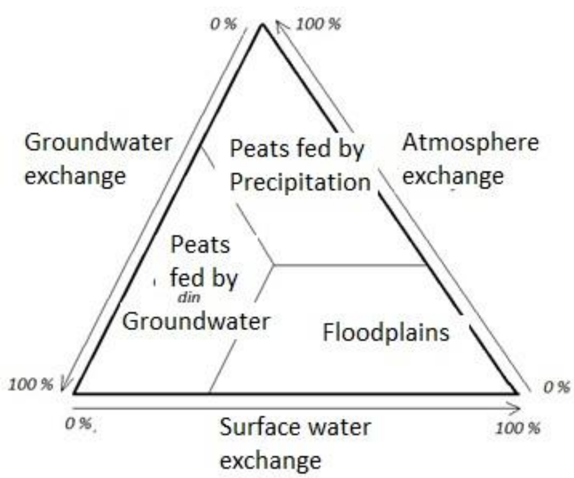

Figure 14. Relationship between hydrological exchanges and wetland types
(adaptation after Brinson, 1993)

As Brinson (1993) mentioned, wetlands are characterized by different inputs and outputs on the time scale. For example, the wetland receives water during the ascending branch of a flood hydrograph and releases water during the descending branch. Another example is the wetlands fed by a mechanism, underground source, and the discharge occurs through another mechanism, evapotranspiration. Adequate water management in such cases consists in identifying and understanding the dominant mechanisms from a quantitative point of view. Table 2 presents the specific values for different components of the water balance identified in North America (after Rasmussen, 2008).

Table 2. Illustrative values for components of water balance (mm / year) for different types of wetlands *(after Rasmussen, 2008)*

Type of wetland	Atmosphere		Surface waters		Groundwater	
	Precipitations	Evapo-transpiration	Inlets	Outlets	Inlets	Outlets
Swamp	1100	1600	10	30	100	300
Underground-fed peat bog	900	700	0	200	0	0
Flood area adjacent to rivers	1000	1400	3000	2900	300	0
Prairie rock-holes	600	400	0	0	100	300

The United States Environmental Protection Agency (EPA) distinguishes four general types of wetlands. The criteria are: soil, landscape, climate, hydrological regime and water chemistry, vegetation and anthropogenic impact. The four types are as follows (after EPA - Wetland types):

- marshes - are surfaces that are periodically saturated, flooded or where water stagnates; it is characterized by a herbaceous (non-woody) vegetation, adapted to the humidity conditions encountered. These areas may or may not be affected by tidal action. The continental ones (without the influence of the tides) are mainly found in depression areas where there are no drainage systems, floodplains or shallow areas located along the contours of rivers or lakes;
- swamps - are areas fed mainly by surface waters; are characterized by the presence of trees and shrubs; they are distinguished by very moist soils in the growing season and by stagnant water in the rest of the periods;
- bogs - are depressed areas fed exclusively by precipitation and are usually found on the glacial relief; is characterized by porous deposits consisting of peat, short trees and bushes, moss carpets;
- fens - are areas fed mainly from underground sources; are covered with grass, sedge, reeds and reeds, wildflowers; willows or birches may be present; as well as depressions, are often formed on glacial relief.

Atmosphere exchanges

Exchanges between wetlands and the atmosphere are important in most cases, and can sometimes be crucial. Such processes are:

- precipitation;
- evaporation;
- transpiration.

These processes must be properly evaluated to establish the water balance. Precipitation can occur in various forms:

- rain;
- snow melting;
- hail;
- sleet;
- snow;
- fog;
- dew;
- frost.

Precipitation usually occurs as a discrete event, characterized by intensity, duration, frequency and spatial extent. Monthly or seasonal averages are used to describe precipitation along with long-term variability associated with climate change. In order to characterize a site rainfall, precipitation regionalizations can be used, in which for the calculation of the balance records are required, either conventional or based on measurements at built-in or adjacent hydrometeorological stations.

Water losses from wetlands by evaporation occur at the free surface of the water and those by perspiration at the leaves and stem of plants. The combination of these processes is called evapotranspiration (ET) and can have a significant effect on water levels. Evaporation dominates when the free surface of the water is dominant, to the detriment of vegetation. On the other hand, transpiration dominates in cases where vegetation is abundant. The intensity with which evapotranspiration occurs is conditioned by the surface of the stems and leaves, the temperature of the air, water, plants, atmospheric humidity, wind speed and the potential of soils exposed to solar radiation.

Evapotranspiration loss values are generally similar for nearby localized wetlands (Kadlec, 1988). This phenomenon is justified by the regional uniformity of the energy source for vaporization (the sun) and by the similar availability of water in neighboring areas. Wetlands covered with dead vegetation have low evapotranspiration rates due to lack of transpiration, shade created by plants and reduced wind speed. Where the phenomenon of eutrophication occurs, it is expected that the intensity of evapotranspiration will be high due to the intense development of vegetation and implicitly the increase of the value of plant transpiration.

Evaporation theory states that evaporation / condensation is a function of the energy capacity of liquid and gaseous water. Water vapor pressure (the measure of water content in the atmosphere) is a first indicator of energy status. Dalton's law makes the connection between the intensity of evaporation, the difference in vapor pressure at the air-water interface, and the vapor pressure in the atmosphere at a certain distance from the air-water interface:

$$E = c\ (e_i - e_a) = c[RH_i e_s(T_i) - RH_a e_s(T_a)] \tag{11}$$

where: E - evaporation rate, c - evaporation rate coefficient, e_i - vapor pressure at the air-water interface, e_a - vapor pressure in the atmosphere at a certain distance from the air-water interface, e_s (T_a) - vapor pressure at saturation , expressed as a function of air temperature T_a.

The evaporation rate coefficient depends on the wind speed and the type of evaporation surface, whether it is water or soil. Vapor pressure in air, $e_a = RH_a\ e_s\ (T_a)$, is the product of the relative humidity of the air (RH_a) and the vapor pressure at saturation (e_s), as a function of air temperature T_a.

The relationship between saturated vapor pressure and temperature for liquid water at standard atmospheric pressure is:

$$e_s = 6{,}11\ exp\left(\frac{17{,}3\ T}{T+237{,}3}\right) \tag{12}$$

where: e_s - saturated vapor pressure in hPa (1 hPa = 1 millibar) and T is the temperature in ^{0}C.

The state of the liquid at the air-water interface depends on the potential / pressure of the fluid at the interface. If the free surface is present, then the pressure of the fluid at the interface is zero and the potential of water in the atmosphere immediately above the limit is equal to the partially saturated pressure of water in the atmosphere (called saturation vapor pressure). In this case, the relative humidity of the air, just above the limit is 100% (water-saturated vapors). If the water potential is negative at the water surface, due to the osmotic potential, or negative pressures are recorded in the soil pores, the relative humidity above the limit will no longer be 100%. Equilibrium relative humidity (RH) is a function of fluid potential (y) and temperature (T):

$$RH = exp\left[\frac{y}{RT}\right] \tag{13}$$

where R is the constant of gaseous water vapor.

4. MONITORING OF WETLANDS

The water level in the wetland can be determined using measuring equipment such as hydrometric sight/stick (**Figure 15**).

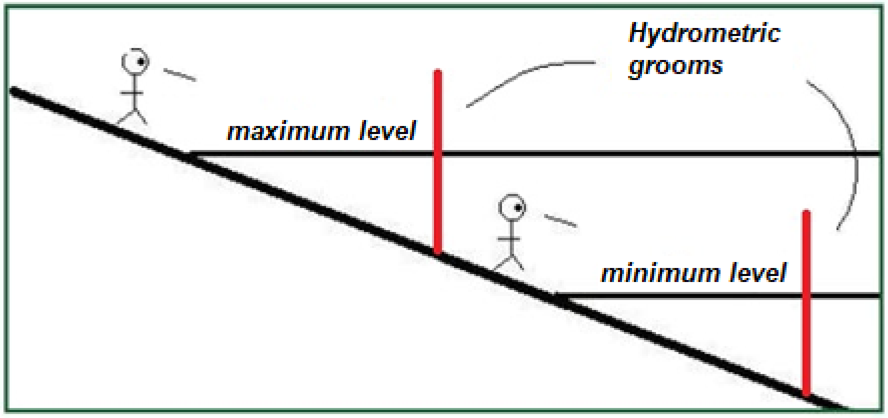

Figure 15. Hydrometric sight to determine the water level

Given the low cost of such equipment, a larger number of sights may be installed, placed at different depths but relating to the same reference system or allowing the absolute elevation to be read. At all times there will be at least one equipment that is not submerged. In this way you can easily read the level at any time, during high water levels it can be seen from the shore and at low water you will read the submerged equipment in case of high water.

In case the water level is below ground level, piezometers can be used. In (figure 16) is presented a group of piezometers installed to determine the water level in several layers. This approach is especially practiced when water exchanges between underground layers (drainage or infiltration) are anticipated. The piezometer is a perforated tube with a small diameter that is installed in the soil at a certain depth (Black, 1996). The perforated area must be narrow enough so that the interference of the layers is minimal and the piezometer must be positioned in a single hydrogeological layer. The depth to the free surface of the water can be measured later inside the piezometer using different techniques: a roulette, a thread, etc. There are also modern equipment that can get the depth from the ground surface to the free surface of the water: probes with light or sound signal (they have a sensor installed at the end inserted in the tube / drilling and when the interaction with water is there , send a signal to the surface equipment via the connection cable); ultrasonic probes (emit a signal / wave that is reflected on the surface of the water; knowing the propagation speed and recording the time you can get the distance to the water).

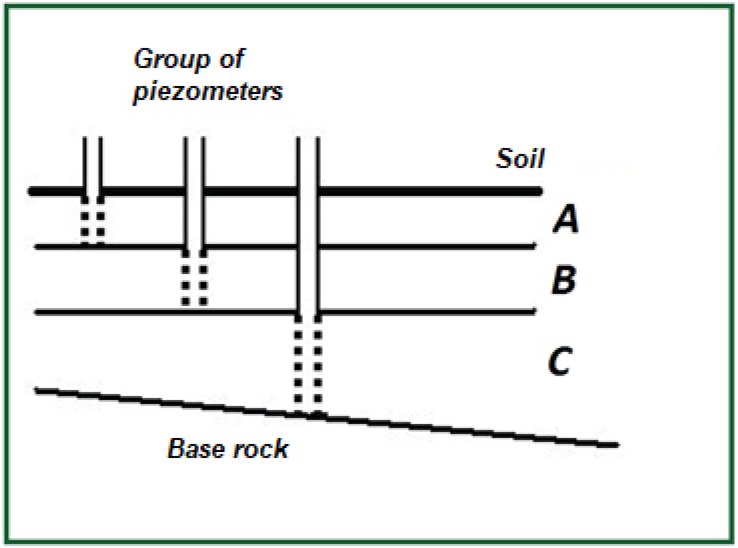

Figure 16. Installation of the group of piezometers to determine possible vertical flows between the soil layers on which the wetland was formed *(after Rasmussen, 2008)*

Precipitation and evaporation can be measured using meteorological stations (rain gauges) and evaporimeters, respectively. These equipments are affordable and provide good information on daily exchanges with the atmosphere. A single station is sufficient for small pools (up to 100 ha), but in the case of larger areas more stations are needed, especially where the temporal and spatial variation of rainfall is significant.

Evaporation rate measurements can be used to estimate the intensity of evapotranspiration. A single piece of equipment is probably enough in most cases. Potential evapotranspiration derived from instrument estimates can be used to describe site conditions. The location in which it is installed must provide accuracy to the measurements by avoiding the effect of shading or shelter from the wind. For the instrument coefficients, defined as the ratio between the current evapotranspiration and the measurements using the measuring instrument, values between 0.54 and 5.3 were found (Carter et al., 1979).

Current technology allows the installation of automatic rain recording equipment, but these have higher costs than manual. Automatic evaporometers have a lower degree of accuracy than manual ones and, in this regard, further studies are needed to increase their accuracy. If evaporation measurements are not possible, measurements of solar radiation, temperature, relative humidity and wind speed may be used as an alternative.

In order to monitor the intensity of the processes, daily graphs are made on which precipitation and evaporation are marked. The difference between the 2 components is related to the water level in the wetland. In atmospheric exchange-dominated systems, the water level rises during precipitation and decreases when evaporation is the dominant process.

[2] evaporimeter is composed of an open tank or a pan in which the lowering of the water level under the action of evaporation in measured. *(Hydrology UNESCO Glossaire).*

6. INTEGRATION OF WETLANDS INTO MANAGEMENT PLANS

Ecological conservation and reconstruction of wetlands must be objectives of the management plans carried out at the level of the river basins to which they belong. The rational use of wetlands is strictly necessary both for the proper management of water resources and for reducing the ecological impact of changes in the hydrological regime through various human actions.

Integrated management of water resources and / or river basins is defined by the World Bank as *a perspective that integrates water resources so as to respect and ensure adequate dimensions in terms of social, economic, technical and environmental protection* (www.worldbank.org). WWF (World Wild Fund) describes integrated river basin management as *the process of coordinating, conserving, managing and developing water resources, land use and other resources in related sectors within the same river basin, in order to maximize economic and social benefits. derived from water resources so as to be in balance with the protection and ecological reconstruction of ecosystems adjacent to wetlands* (www.panda.org).

Resolution VIII (Management and distribution of water resources in order to maintain the ecological functions of wetlands) given by the Ramsar Convention provides a set of principles to initiate and implement the integration of wetlands in management plans at the national level and at the level of river basins . These can be:

a) *sustainable development - a main objective*
- adequate protection against the impact of land and water use within and in the vicinity of the river basin to which the wetland is a part;
- protection must include the provision and distribution of water to ecosystems adjacent to wetlands;

b) *clarity of the process*

The process includes all decisions taken in order to adopt a river basin management plan. These must be clear and known to all stakeholders. Debates on this subject must be an ongoing concern, from which the best decisions can result.

c) *balance in participation and decision-making power of stakeholders*

Stakeholders must be fairly represented and decision-making power properly distributed to avoid subjectivism of the parties. As they are administrative entities in different fields such as land use, water resource allocation or river basin management, the common goal of protecting and rational use of wetlands must bring the parties to a common denominator.

d) *the credibility of the scientific measures adopted*

The methods used must be debated and evaluated by the scientific communities within the specialized institutes, in the academic environment or by internationally recognized specialists. All these specialized meetings must have a public character and the dissemination of the results must be carried out in national and international publications alike.

e) *transparency in the implementation process*

Once defined and agreed, the procedures for basin management, water distribution and wetland management must be implemented correctly and transparently.

f) *management flexibility*

Like other ecosystems, wetlands are a complex in a continuous evolution and change, characterized by a certain degree of uncertainty. The management strategy must be able to be adopted during the implementation process so as to meet the new requirements identified.

g) *responsibility of decision makers*

It is necessary for decision-makers to assume the objectives they undertake through the procedures they agree to. On the other hand, if for objective reasons a certain objective cannot be achieved, the body which has undertaken to achieve it must provide solid and well-documented explanations to all stakeholders. At the same time, it is recommended that an independent control and / or monitoring body pursue the proposed objectives.

h) *transversal cooperation in order to elaborate and fulfill the policies*

All government agencies with responsibilities and responsibilities in the areas of land use, water resources and wetlands must cooperate to adjust their policies and strategy at the global level in order to achieve the objectives at both national and basin level.

In order to improve the process of integrating wetlands into basin-level management plans, attention must be focused on at least three areas of interest:

a) support policies

Creating an appropriate legislative and institutional environment to promote cooperation between different sectors, institutions on the one hand and groups of other stakeholders on the other.

b) communication, education, participation and awareness (CEPA)

Support programs to support the communication of operational policies and needs as well as objectives for various sectors, primarily those concerned with water resources and wetlands.

c) the succession and synchronization of planning and management activities

As these are entities with activities in different branches of development, close cooperation is needed so that processes are not interrupted due to lack of communication or synchronization.

The integration of wetlands into basin-level management plans is associated with a number of challenges for bodies with this responsibility. The challenges have been identified from the processes carried out in this regard in countries where the results are good but have been difficult to implement. From the case studies referred to in Resolution VII of the Ramsar Convention, various obstacles are identified, such as:

- extension from local to basin level (higher) - may occur as a result of: insufficient attention to ensuring an adequate legislative, institutional framework at national and or basin level; establishing and promoting mechanisms for cross-cutting dialogue between sectors and stakeholders as well as identifying and proposing common objectives.
- implementation of management plans - as a result of an inadequate staging of activities at river basin level.
- both previous points simultaneously - may occur due to lack of technical and financial resources for the proper implementation of CEPA programs.

In order to develop appropriate legislation, the Ramsar Convention recommends a number of issues to be considered:

- identification, allocation and distribution of water resources to ensure the needs of all ecosystems, including marine or coastal ones;
- issuing appropriate approvals for water collection and use;
- the use of water for domestic and industrial consumption, the adequate treatment of wastewater and its return respecting the quality parameters;
- water use in agriculture, mitigation of negative effects produced by large hydrotechnical structures, water restitution, limitation of the use of pesticides and / or other compounds in agriculture;
- determining the water quality standards for use for different purposes;
- rules and orders regarding the collection and use of groundwater;
- economic and financial policies and instruments that refer to drinking water, water for agriculture, industry or other uses;
- water and land conservation;
- identification of species that have a significant impact on water resources;
- delegation of certain regulations or attributions to the appropriate institutions at the level of river basins;
- application of strategies based on spatial planning and development initiatives that have an impact on water resources and wetlands within basins.

The European Union Water Framework Directive (adopted on 23 October 2000) supports and recommends the implementation of basin-level management plans, integrating all types of water resources and their rational use (without producing negative effects). The key objectives set by the Directive are:

- extending protection for both surface and groundwater;
- reaching the good state of the waters until an imposed moment;
- water management based on basin level management;
- combined approach to emission limit values and quality standards;
- reaching adequate prices;
- greater involvement of citizens;
- legislative optimization.

Such management plans have been developed in most Member States for river basins and, at a higher level, for transboundary basins such as the Danube, Elbe, Rhine, Meuse or Odra by setting up internationally represented Commissions.

The International Commission for the Protection of the Danube River (ICPDR) was born in 1998, becoming the main decision-maker on behalf of the Danube River Protection Convention (DRPC). Thus, a common platform was created for the sustainable use of water resources at the basin level which is closely related to the ecology of the aquatic environment but also for an integrated management at the river basin level. The ICPDR expert group coordinated the development of a management plan for the entire Danube basin, in accordance with the principles of the European Union Water Framework Directive. In 2000, within the ICPDR, the Group of Experts in Ecology was born, with a supporting role in the activities regarding the conservation and sustainable development of the Danube riparian ecosystems, both terrestrial and wetlands.

For the integration of wetlands in the management plans, it is recommended to follow some essential steps, identified based on the experience of some specialists / groups of specialists. These steps are in fact a succession of actions and / or activities that lead to the achievement of the proposed objectives. Mention the following:

- a preparatory phase at national level - ensuring a legislative, institutional, policy framework that allows the proper integration of wetlands in basin management plans and, at the same time, the conservation and rational use of wetlands;
- a preparatory phase at basin level - involves the analysis and potential revision of the legislative and institutional framework, with applicability at river basin level;
- a planning phase - conducting hydrological, biophysical and socio-economic studies to assess the activities required in carrying out the plans;
- an implementation phase - involves the parallel development of activities for the implementation of management plans at the basin level and management plans for associated wetlands;
- an analysis phase - involves tracking behavior from an operational point of view such as monitoring certain variables, data analysis, reporting and system feedback. At the same time, the long-term plan must be flexible so as to achieve the proposed objectives.

BIBLIOGRAPHY

Albold, A., Wendland, C., Mihaylova, B., Galt, H., (2011) Constructed wetlands: Sustainable wastewater treatment for rural and peri-urban communities in Bulgaria. *German Federal Environment Foundation.*

Andreev, A., Talmaci, I., Șabanova, G., Josan, L., Josu, V., Izverskaia, T., Munteanu, A., Barcari, I., și alții (2008) Convenția Ramsar și zonele umede de importanță internațională în Republica Moldova, *Societatea ecologică „Biotica“,* Chișinău.

Antipa, G., (1910) Regiunea inundabilă a Dunării – Starea ei actuală și mijloace de a o pune în valoare, București.

Brull, A., Bohemen, H.v., Costanza, R., Mitsch, W.J., (2011) Benefits of ecological engineering practices, *Procedia Environmental Sciences*, Elsevier.

Buttler, D., Davies, J.W., (2011) – Urban drainage, third edition, *Taylor & Francis*.
Cowardin, L.M., Carter, V., Golet, F.C., LaRoe, E.T., (1979) Classification of wetlands and deepwater habitats of the United States. *US Department of the Interior – Office of Biological Services.*
Drobot, R., Șerban, P., (1999) Aplicații de hidrologie și gospodărirea apelor, *Edituda HGA,* București.
Durrans, S.R., Ahmad, M., Barnard, T., Hjorth, P., Pitt, R., (2007) Stormwater Conveyance Modeling and Design, *Bentley Institute Press,* Exton, Pennsylvania, USA.
Elton, E., Giudice, L., Montgomery, K., Roberti, L., (2011) The impacts of urbanization on the hydrology of wetlands: A literature review, *Toronto and region conservation authority.*
EPA – Environmental Protection Agency, (2001) Types of wetlands, USA.
Ghermandi, A., v.d. Bergh, J., Brander, L., Groot, H., Nunes, P., (2009) The values of natural and constructed wetlands: a meta-analysis. *Tinbergen Institute.*
Handbook 10 – Ramsar Convention, 4th Edition (2010) Water allocation and management – Guidelines for the allocation and management of water for maintaining the ecological functions of wetlands.
Handbook 9 – Ramsar Convention, 4th Edition (2010) River basin management - Integrating wetland conservation and wise use into river basin management.
Hattermann, F.F., Krysanova, V., Habeck, A., Bronstert, A., (2006) Integrating wetlands and riparian zones in river basin modelling, *Ecological Modelling,* Elsevier.
Kadlec, R., Wallace, S., (2009) – Treatment wetlands, second edition, *Taylor & Francis*.
Kadlec, R.H., Free surface wetlands for phosphorus removal: The position of the Everglades Nutrient Removal Project. *Ecological Engineering*. Elsevier.
Kruchek, B.L., (2003) Extending wetlands protection under the RAMSAR treaty's wise use obligation.
Lai, X.J., Huang, Q., Jiang, J.H., (2012) Wetland inundation modeling of Dongting Lake using two-dimensional hydrodynamic model on unstructured grids, *Procedia Environmental Sciences,* Elsevier.
Lake, P.S., Bond, N., Reich, P, (2007) Linking ecological theory with stream restoration. *Freshwater Biology.*
Mitsch, W.J., (2011) Wetland utilisation in the world: Protecting sustainable use.
Orme, A.O., Feddema, J.J., (1990) Wetland loss and substitution by the section 404. Permit program in southern California. *Environmental Auditing.*
Powell, S.J., Letcher, R.A., Croke, B.F.W., (2008) Modelling floodplain inundation for environmental flows: Gwydir wetlands, Australia, *Ecological Modelling,* Elsevier.
Rasmussen, T., (2008) Methods for Evaluating Wetland Condition – Wetland Hydrology, *EPA – United States Environmental Protection Agency – Office of Water*.
Rosier, B., (2007) Interaction of side weir overflow with bed-load transport and bed morphology in a channel, Teză doctorat – *Ecole Polytechnique Federale de Lausanne,* Elveția.
Sonntag, D.H., Cole, C.A., (2008) Determining the feasibility and cost of an ecologically-based design for a mitigation wetland in central Pennsylvania, USA. *Landscape and Urban Planning,* Elsevier.
Șelărescu, M., Podani, M., (1993) Apărarea împotriva inundațiilor, *Editura Tehnică București*.

Vlotman, W.F., (1989) Discharge measurement structures – 3rd Edition, *International Institute for Land Reclamation and Improvement,* Wageningen, Olanda.

Williams L., Harrison, S., O'Hagan, A.M., The use of wetlands for flood attenuation, *Report for An Taisce by Aquatic Services Unit,* University College Cork.

Zaharia, V., (2013) Interacțiunea zonelor umede cu apele de suprafață, *Raport de cercetare I, Universitatea Tehnică de Construcții București – Facultatea de Hidrotehnică*, București.