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The use of rainwater as process water in a factory : software aided evaluation methodology and case studies

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Factories often have large roof and/or paved surface areas which drain off large amounts of rainwater without collecting, storing and using it as process water. Storing such rainwater in tanks for later use as process water however can save money and/or comply with environmental legislation on saving water. Simulation software can be used for an efficient and reliable comparison between several rainwater storage and usage scenarios. Moreover, buffering tanks with a delayed discharge facility which level out disposal peaks of excess rainwater from heavy rainfall can also be introduced. As a result, the simulation software RAINBOW was developed at VITO in order to model rainwater networks at factories. The program runs under Matlab-Simulink and allows to simulate different rainwater network configurations and to determine optimal volumes of rainwater storage tanks. For delayed rainwater discharge during heavy rainfall peaks, the software also allows to design adequate buffering tanks with a controlled discharge flow. A broadly applied strategy of delayed rainwater discharge in sewer systems during heavy rainfall can prevent flooding in residential areas. The software approach is illustrated in two case-studies.

1. Introduction

The scarcity of water, for both the production of potable or process water, is of increasing concern in many countries. As an example, a study in 2003 of the Flemish Government showed that a drastic 75 % reduction of deep groundwater consumption was needed in the Belgian provinces of East- and West Flanders, in order to stabilize the heavily solicited ground water level. Most of this water was used in agriculture and industry. As a result, these sectors were stimulated by specific legislation to adapt their water consumption and switch to a more rational water usage. The Flemish Government induced this by informative promotion actions, higher environmental taxes and a stricter legislation with respect to groundwater usage licences. In this way the factories were obliged to find alternative water sources, e.g. surface water and rainwater.

In order to evaluate the possible use of rainwater in a factory, while taking into account the specific production and infrastructure, a technical and economic feasibility study is obvious. Simulation software allows for a fast and efficient estimate of the design (buffer tank capacities) and costs of a rainwater aided process water supply system [1]. Different software approaches do exist and in one approach, complex hydrodynamic models are deployed which mostly envisage the design of complete sewer systems (villages, cities, …). In another approach, specific calculation models allow for a basic design [2] or to perform some estimates of the economic relevance to use rainwater as process water from some elementary basic data [3].

Next to the rainwater capture and storage infrastructure, facilities can also be provided for the smoothing out of discharge peaks in drainage systems. Such delayed discharge facilities are designed to obtain a restricted discharge flow (mostly related to a specific drainage value expressed as litres per second and per hectare) into the drainage system (sewer) during heavy rainfall. They even envisage to minimize the frequency of overflows to a restricted number per year.

2. The Development Of The Rainbow Software

2.1 Objective of the software

VITO developed RAINBOW to optimally design a rainwater collection and storage system in a factory. Such a design envisages the dimensioning of rainwater storage systems as process water sources. The software also allows to design additional buffering systems which delay the discharge of excess rainwater during extra-ordinary rainfall periods and inform in this way about the frequency, and therefore the possible control, of such emergency discharges. RAINBOW supports the envisaged technical and economical feasibility study. Each simulation allows to determine the degree to which the actual process water can be replaced by rainwater, the size of the storage facilities which are correspondingly needed and the optimal configurations within the rainwater network at the factory. Simulations are fast and allow a quick comparison between different scenarios.

2.2 Methods

In principle, a rainwater evaluation study involves the design of an appropriate network which links the available rainwater collecting surface areas (roofs, paved areas, …) and the "process water users". As a result of the stochastic characteristics of the supply of rainwater by rainfall, there is a need of correctly dimensioned storage tanks. A first step is a concise study of the existing rainwater transport infrastructure at the factory. In older buildings the integration of rainwater piping into a delivery system, feeding the rainwater buffering tanks, could be difficult. For new or renovated buildings, such adjustment is mostly straightforward. As for the quality of the rainwater, roofs showing a low degree of contamination can be selected. Rainwater from pavements can also be considered if the contamination (from e.g. car or truck motor oil spillage) is restricted. For each selected surface, the "run-off coefficient" needs to be estimated. Such coefficients are linked to the fact that rainwater is transported much easier from sloping and smooth surfaces when compared to flat and rough surfaces.

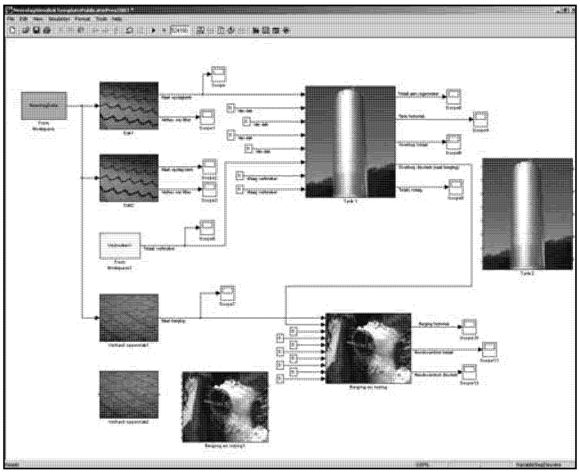

Figure 1 RAINBOW dialog window

Within RAINBOW, up to five different surfaces can be connected to one specific rainwater storage tank, while any number of storage tanks can be created through a straightforward copy/paste action in the dialog window (as illustrated in Figure 1). In the same way, up to three process water users in the factory can be connected to each rainwater storage tank. RAINBOW allows the input of the consumption data of process water users with a resolution of one hour. Next to the rainwater storage tanks, it is also possible to define tanks for temporary buffering and controlled discharging of excess rainwater during exceptional heavy rainfall events. Hence RAINBOW enables the design of any configuration. A simulation is then initiated by introducing a first guess value for the tank storage volume, while producing e.g. the following typical results (the list is not exhaustive) :

- the ratio of the rainwater consumption versus the total process water consumption (rainwater supply efficiency ; 100 % if all process water is supplied by rainwater)
- the level within the rainwater storage tank(s) as a function of time
- the volume and frequency of excess rainwater that has been discharged in a delayed mode
- …

By simulating for a series of storage tank volumes, the rainwater degree of supply can be plotted against the tank volume, as illustrated in Figure 2. Such curves allow to select a tank storage volume which assures an optimal rainwater usage but at an acceptable investment cost. From the graph it is obvious that the rainwater degree of supply increases rapidly at lower tank volumes but then shows a flattening trend at higher volumes. As a result, the increase in investment cost associated with an increased tank volume is no longer compensated by the corresponding gain in the rainwater supply efficiency. An optimum occurs along the curve.

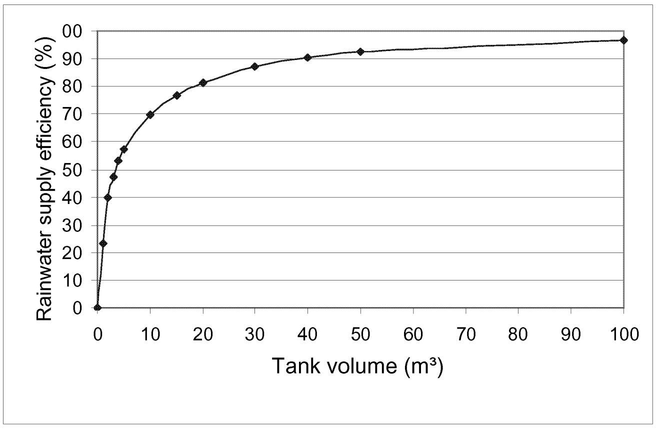

Figure 2 Rainwater supply efficiency

The simulation also allows to evaluate the delayed discharge of excess rainwater through a buffering tank with a controlled flow outlet facility.

2.3 Meteorological data

Strong seasonal fluctuations with unpredictable yearly shifts are of course typical for the stochastic rainfall process. The use of long term statistical rainfall data, up to 20 or even up to 30 years, is strongly recommended [4]. This is important when designing buffering tanks for a delayed excess rainwater discharge during stormy rainfall, since the frequency of emergency spills should be restricted to a minimum. The rainfall data series should also show a specific time based resolution since this determines the accuracy of the simulation. In one case, the dimensioning of rainwater storage tanks could be sufficiently accurate if the rainfall data would be based on a daily time basis and if the volumes of the storage tanks would be larger than the daily rainwater consumption as process water. In the same case however, the dimensioning of the buffering tanks for the delayed discharge of excess rainwater would need a much higher time resolution, since such tanks need a shorter time frame with respect to the storage and delayed disposal. As a result, a resolution of ten minutes intervals is recommended.

The combination of a time based resolution of ten minutes and a long term period of 30 years has two practical and economical drawbacks. A time period of 30 years requires the purchase of expensive 30-years, ten minutes based, rainfall data which should be linked to the region of interest. A data-series of such size also increases the total simulation time significantly. As a result, it was decided at VITO to implement ten minutes based rainfall data series but only based on one year periods. These already allow for a sound estimate of the required storage volumes of the rainwater tanks. By using a time period of one year with a ten minutes resolution, it is also still possible to simulate the effect of e.g. a reference year showing a profound rainfall (“wet year”) and a reference year showing a shortage of rainfall (dry year).

2.4 Software tool

When trying to model in detail all the rainwater transport phenomena (roof, piping, …) by rigorous hydrodynamic mathematical equations (including e.g. differential equations), an expensive and time consuming procedure is the result. This is not feasible from a economical point of view. A pragmatic and economical approach is evidently preferred. However, a pragmatic and approximate approach with corresponding simplifications and assumptions should have a minimal impact on the validity of the simulation outcome. As a first modelling approximation within the RAINBOW the assumption was made that a time series resolution of ten minutes is sufficient and that within each time interval of ten minutes the collected amounts of rainwater can be calculated accordingly through e.g. the roof surface areas and down flow coefficients. It was also assumed that during a time interval of ten minutes all transport is realized from a roof to a storage tank. Since such an approach avoids the programming of data shifts within time series in order to simulate hydraulic delaying effects. Hence a pragmatic principle of a simplified mass balance within each ten minutes time interval was assumed : collected rainwater arrives within the same interval of ten minutes and if consumed by a user, is also transported to that user within the same time interval.

Matlab-Simulink allows for a convenient handling of time series based models and thus simulation of dynamic systems. It is possible to use pre-programmed system blocks which can be positioned and easily connected to one another in a graphical way in order to obtain a system model. Each block has a set of input and output ports in that respect which are linked inside the block to a set of variables. The values of these variables are a function of time and are therefore dynamic. Moreover, dedicated system blocks can be defined, including system block parameters (such as roof surface area, down flow coefficients, …). As shown in Figure 1 individual system blocks representing roofs, storage tanks, buffering tanks with controlled discharge flows and paved surfaces can be created and multiplied by conventional based copy/paste actions. Each block shows outputs which can be linked to scopes as to evaluate quickly the behaviour of the system e.g. the amplitude and frequency of emergency discharges of excess rainwater from buffering tanks. In this way the volume of such a buffer tank can be adapted until the amplitude or frequency is below a specific value. The process water users are also designed as Simulink system blocks, based on ten minutes time intervals while the input of the process water consumption data is extracted from a Microsoft Excel worksheet. The process water users system blocks are connected to e.g. a rainwater storage tank in the same way as a roof or pavement system block, but summed within such a block as a negative contribution, equal to a consumption of rainwater.

3. Case Studies

3.1 The use of rainwater at a textile factory

A feasibility study was performed for a textile factory. The possible use of rainwater and a delayed discharge of excess rainwater was evaluated. Two large areas were available for rainwater collection. The first area of 5000 m^2 was selected to provide rainwater to a first storage tank situated at the back of the factory in a way that the rainwater could be used for cooling processes. From the low hardness of rainwater, a maximum of 70 % rainwater was allowed into the mixture (with water from the regular water supply network) of the cooling process water, as to avoid corrosion risks within piping and metal based structural components. A second area of 6400 m^2 was designed to store rainwater for use in the front side of the building. The second tank would supply rainwater for sanitary use. After the input of the water consumption data and a complete simulation of all scenarios, the rainwater supply efficiency curves revealed tank volumes of respectively 150 m^3 and 50 m^3, according to about 80 % of the process water demand. Some simulation results are illustrated in Figure 3 showing the rainwater supply efficiency curve, the water demand and the amount of used rainwater for the surface area of 6400 m^2. All results from the multiple simulations can not be discussed here as a result of the imposed limit on textual space of this publication.

In the simulation, ten minutes based meteorological rainfall data from the year 1990 were used while the time span of one year was considered adequate to correctly design the storage tanks. These same data were also used to verify the risk of unaccepted overflow of the legally imposed buffer tank volume of 200 m^3 per hectare of paved surface area. From the simulations the conclusion could be drawn that for the reference year of 1990 there was no single emergency discharge during the complete year, thus also proving the functionality of such legally imposed buffering volume.

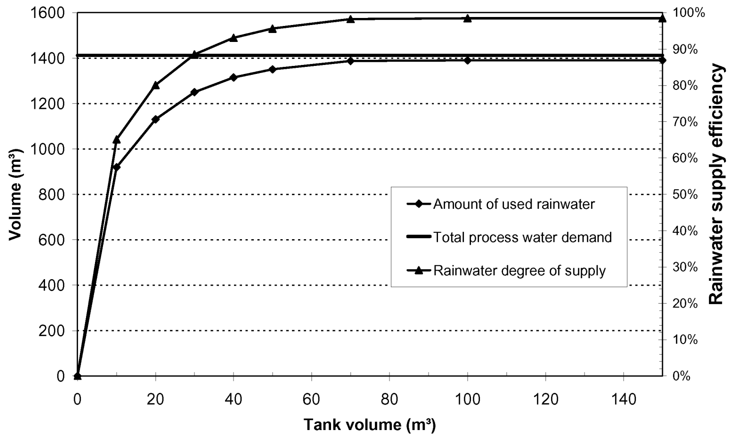

Figure 3 Simulation results for the 5000 m² surface area (selected tank volume of 50 m³)

3.2 The use of rainwater at an electronics company

A company which produces electronic components yearly consumes about 24000 m³ of process water, being extracted from a potable water network at a cost of 1.5 Euro per m³. From the large roof and paved surface areas at the company, a large potential of recoverable rainwater for use as process water existed. A total roof area of 3.9 hectare was connected to a large collector which discharged the rainwater to surface water. In addition, the company has a large parking-place of about 3.4 hectare. Typical processes at the company are cooling tower (7000 m³/year), steam production (1700 m³/year) and humidity control of the production hall (1530 m³/year). Next to these three individual processes, sanitary use is also an important water consumer (6400 m³/year).

After consulting the company's managers, four strategies were selected for a rainwater usage evaluation. In a first scenario, the storage of the rainwater from the main building in two tanks : one tank to provide water to the considered three individual processes and one tank for sanitary purposes. A second scenario also incorporates the additional rainwater being collected from the parking-place on top of the first scenario. A third scenario involves the configuration of the second scenario but for only one storage tank instead of two tanks. A fourth scenario involves the configuration of the first scenario but for only one storage tank instead of two tanks.

The conditions for the four scenarios ware simulated in RAINBOW and the rainwater supply efficiency curves were produced, with the meteorological rainfall data of 1990 as a reference. After pinpointing optimal tank storage volumes, the simulation was also done for the reference year 1976 as a very dry year and the reference year of 1981 as a very wet year. The results are shown in Table 1, including the yearly savings. In the first scenario with two tanks, a total savings on water use of 19950 Euro is achieved while the fourth scenario shows that one tank results in the same level of savings of 19900 Euro. When including the parking-place, the total amount of collected rainwater increases and the third scenario (one tank) then shows increased savings on process water costs of 21000 Euro which is somewhat lower in savings as in the second scenario (total savings of 22350 Euro).

It can be mentioned that the rainwater supply efficiency for the third scenario in a dry year decreases to 75 % and increases in a wet year to 88 %, when compared to 84

% in the “normal” year. It can also be indicated that the rainwater supply efficiency for the fourth scenario in a dry year decreases to 66 % and increases in a wet year to 89 %, when compared to 80 % in the “normal” year.

Table 1 Comparison of the four scenarios for the second case study

Scenario	Tank – Water user	Tank volume (m^3)	Rainwater supply efficiency (%)	Savings (Euro/year)
Scenario1 (roof only)	tank 1 - sanitary	300	89	8 500
	tank 2 - three processes	500	75	11 450
Scenario 2 (roof & parking-place)	tank 1 - sanitary	300	91	8 650
	tank 2 - three processes	600	89	13 700
Scenario 3 (roof & + parking-place)	tank - sanitary & three processes	500	84	21 000
Scenario 4 (roof only)	tank - sanitary & three processes	800	80	19 900

4. Conclusions

Rainwater can be a viable source of process water in a company. A feasibility study can be done by using software tools which help to simulate the collected amounts of rainwater, tank storage behaviour (design, overflows, …) and simultaneous water consumption. RAINBOW can be helpful in the fast simulation of multiple scenarios. In this way, optimal storage tank volumes can be calculated as well as the design of buffering tanks to control the delayed discharge of excess rainwater during extremely high rainfall events.

References

1. Herrmann T. and Schmida U., Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. Urban Water, **1**, 307-316, 1999
2. Fewkes A., Modelling the performance of rainwater collection systems : towards a generalised approach. Urban Water, **1**, 323-333, 1999
3. Thomas J.S., Le Pol J., Gillet S. and Phan L., SIRRUS : evaluation of the technical and economic profitability of rainwater on an industrial site. Water Science and Technology, **46,** # 6-7, 71-76, 2002
4. Vaes G., Willems P. and Berlamont J., Rainfall input requirements for hydrological calculations. Urban Water, **3**, 107-112, 2001
5. Gishi E., Bressan D.L. and Martini M. Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of south eastern Brazil. Building and Environment, **42**, 1654-1666, 2006