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WWER-type NPP Spray Ponds Screen

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ABSTRACT

The objective of this study is to develop a protection screen of WWER-type NPP spray ponds. The screen design is to ensure reduction of the water droplets blown by the wind and, if possible, their return back to the spray ponds. The cooling capacity of the ponds is not to be changed below the design level for safety reasons. Computational Fluid Dynamics analysis is used to assess the influence of each design variant on the behavior of the water droplets distribution. Two variants are presented here. The one with plants is found not feasible. The second variant, with steel screen and terrain profile modification is selected for implementation.

KEY WORDS: windscreen, spray ponds, computational fluid dynamics (CFD), WWER-type nuclear power plant, wind simulation, water droplets, complex turbulent flow, stationary conditions, windbreak planting

INTRODUCTION

The objective of this study is to develop a protection screen of WWER-type NPP spray ponds. The screen design is to ensure reduction of the water droplets blown by the wind and, if possible, their return back to the spray ponds. The cooling capacity of the ponds is not to be changed below the design level for safety reasons.

Two general approaches are possible for solving the problem – active measures for controlling the spray ponds equipment performance, depending on the meteorological conditions and passive measures, invariant of the meteorological conditions and not requiring the spray ponds equipment control. The study focuses on the passive measures, i.e. the aim is to reduce the wind velocity above the spray ponds zone, to change the direction of the wind locally and to ensure return of the water droplets back to the ponds.

Forty cases of fluid flows above the spray ponds zone are simulated, based on analysis of the available input data and the site conditions. CFD simulation is done with the FASTEST/3D program package. The mathematical model is based on the Reynolds-averaged Navier-Stokes and continuity equations and k-ε turbulence model, describing the fluid motion in complex turbulent flow at stationary conditions. The model consists of a system of six nonlinear partial differential equations. The droplets are approximated as ideal spheres. Two types of simulations are carried out – a study on the wind velocity field in the vicinity of the spray ponds (FS-1) and a study on the distribution of the water droplets (FS-2).

In the first phase of the project, two types of practical technical solutions are developed for the screen variants – for changing the wind direction and reducing its velocity, and for catching the water droplets carried by the wind. Feasibility study for the forty variants is performed. Based on it, a variant for detailed design in the second phase of the project is selected. This is the variant for a system of windscreens, which are realized with windbreak planting. The location of the windbreaks is shown in Figure 1, as follows:

- Windbreak #1 - at 89 m to the west of the spray ponds, 3 m wide, 18.5 m high
- Windbreak #2 – at 31 m to the west of the spray ponds, 1.5 m wide, 18.5 m high
- Windbreak #3 - at 20 m to the east of the spray ponds, 1.5 m wide, 10 m high

This height of plants is for case SP12-PWB-High. The vegetation height is half the above given in case SP12-PWB-Low, 8 years after planting.

Since each windbreak system is unique, in the second phase of the project analysis of the soil data is performed and detailed modeling of the plants performance in the event of wind is developed, taking into account their permeability. The measures for as-built site preparation, weed control, planting and replanting, as well as the time necessary for achieving of considerable effect, are assessed. It is estimated that this variant is not feasible.

Another variant for wind protecting (case SP12-SWB-10/22) is developed based on results from the analysis of the already studied models. The windscreen is situated at a distance of 20 m from the spray ponds, see windscreen #4 in Figure 1. The screen is with 50 % permeability. It is made of light structural steel panels. Additional measure is modification of the terrain profile in order to achieve more uniform distribution of wind velocity in the zone of the spray ponds.

In this paper we present the results obtained by 3D simulation of the flow and droplets distribution in case of plant windbreaks, as well as the results obtained by 2D simulation of the flow in case of steel windbreak combined with terrain profile modifications.

THEORETICAL BACKGROUND OF THE NUMERICAL COMPUTATIONS

The investigated flow is a three-dimensional turbulent phenomenon with a complex geometry of the site. First, the fluid flow induced by the wind is investigated by a standard CFD approach. A special numerical technique for porous flows is applied at the locations of the windbreaks (e.g. plants). After the solution of the velocity distribution has been obtained, the behavior of a large number of water droplets with different size is tracked in the space to obtain their final destination – back in the spray ponds or distributed somewhere downwind in the site.

Solving the fluid flow due to wind

The numerical method is based on the three-dimensional Reynolds-averaged Navier-Stokes equations. The system of partial differential equations governing fluid flow is closed by solving two additional transport equations: for the turbulent kinetic energy k and for its dissipation rate ε, and so the total number of partial differential equations becomes six. The standard version of the k-ε turbulence model is used in this investigation. The discretisation is made by the finite volume method on a collocated numerical grid. The SIMPLE-algorithm is utilized for coupling the velocity and pressure fields. The numerical code FASTEST/3D is used in the investigation. It was originally developed at LSTM, University of Erlangen-Nuernberg, and adapted afterwards by the authors for environmental and room air flow problems [5], [6]. More details about the method and its algorithmic details can be found in Peric [4] and in FASTEST Manual [1].

Treatment of porosity

From a fluid dynamics point of view the space in the vicinity of the plants is treated as a porous flow. In the present study the approach described in [2] is utilized. The porous media are modeled by the addition of a momentum source added to the standard fluid flow equations. In the case of homogenous porosity the inertial loss term has the form:

$$S_i = -0{,}5 \cdot (C_2 \cdot \rho \cdot |v_i| \cdot v_i) \tag{1}$$

where S_i is the source term for the i^{th} (x, y or z) momentum equation, C_2 is the inertial resistance factor and v_i is the corresponding velocity component (along x, y or z). In the case of plant windbreak (case SP12-PWB-High) this kind of a source-term has been distributed exactly over the control volumes, where the plants are located taking into account the triangular shape of the plants. In the case of steel windbreak (case SP12-SWB-10/22) the source-term has been applied to only one column of control volumes in the x-direction. In this case the value of the coefficient C_2 (which has a meaning of a minor losses coefficient) has been set from literature sources to be equal to 3.6.

Equations of motion of the dispersed phase

The droplet phase is treated by the Lagrangean approach. When the two phases have a quite large density ratio (density of water particles ρ_P to density of fluid/air ρ_F) the droplet motion equations for droplet location and velocity components can be summarized as follows (see [3]):

$$dx_P/dt = u_P; \qquad dy_P/dt = v_P; \qquad dz_P/dt = w_P \tag{2a}$$

$$\frac{d}{dt}\begin{vmatrix} u_P \\ v_P \\ w_P \end{vmatrix} = \tfrac{3}{4}\ \nu\, \rho_F\, Re_P\, C_D(Re_P)\ /\ (\rho_P\, d_P^2) \begin{vmatrix} u_F - u_P \\ v_F - v_P \\ w_F - w_P \end{vmatrix} + (\rho_P - \rho_F)/\rho_P \begin{vmatrix} 0 \\ 0 \\ -g \end{vmatrix} \tag{2b}$$

with the Reynolds number defined as:

$$Re_P = d_P\, v_{rel} / \nu \tag{2c}$$

In the above equations x_P, y_P and z_P are the coordinates of the particle under consideration, u_P, v_P and w_P are its velocities and t is the time. Velocities with index *`F'* correspond to the fluid, surrounding the particle, C_D is the drag coefficient (it is a function of Re_P), g is the gravitational constant; v_{rel} is the relative velocity of the droplet with respect to the fluid surrounding it, d_P is the diameter of the droplet and ν is the cinematic viscosity of the fluid (air).

COMPUTATIONAL DETAILS

The dimensions of the spray ponds investigated are 65 x 68 [m]. The computational field includes a quite large area upwind of the spray ponds - 130 [m], see Figure 1 and Figure 2. The reason for this is, that the terrain profile has a decisive effect on the velocity distribution over the spray ponds as found in the preliminary two-dimensional investigations. Only one of the six spray ponds is included in the simulation so that the final dimensions of the computational domain are 313 x 110 x 120 [m]. The distribution of the particles is tracked at a distance of 600 [m] downwind the spray ponds, assuming that downwind a distance of 100 [m] the site has an even plane shape.

The numerical grid applied for SP12-PWB-High case consists of 128 x 57 x 48 = 350 208 nodes. A typical CPU-time for a case investigated takes about 3.5 days on a Pentium IV PC with 1500 GHz. For SP12-SWB-10/22 case a two-dimensional grid (only x and z directions) with the same distribution of the points has been applied.

For the calculation of droplets 16 groups with the following diameters are considered: 50, 75, 100, 150, 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900 and 1000 [μm]. In each group 9000 droplets are assumed evenly distributed over the volume above the spray ponds (initial position for tracking of the trajectories). Thus the total amount of droplets tracked for each of the investigated cases is 16 x 9000 = 144 000 for which about 5 hours computational time is required.

RESULTS AND DISCUSSIONS

The main wind direction taken from meteorological data is from west to east (Figure 1) so that this flow situation is studied. Further analysis of the meteorological data shows that 90 % of the time the wind speed is below 7 [m/s] so that this wind speed is chosen for the investigation as being a typical unfavorable wind condition at the location of the spray ponds.

Figure 3 shows the current status (case SP12-now) of the x-velocity component distribution in a x-z plane (y= 32 m), which is at the middle of the first spray pond. It can be seen that the u-velocity component (along x-axis) in the whole region with droplets above the spray ponds is quite large – between 4 and 6 [m/s]. This high velocity is the reason why relatively high percentage of droplets land outside of the spray pond (in eastward direction). The distribution of the droplets – i.e. the cumulative curves with the locations where the droplets land - is shown in Figure 6 and Figure 7. More than 55% of the droplets with a size of d=100 [μm] and more than 15% of those with a size of 250 [μm] are blown by the wind. Unfortunately, no information is available for the mass distribution of the water droplets with respect to their diameter, which makes impossible an accurate statement of the mass of the lost droplets.

Figure 4 shows the x-velocity component distribution in SP12-PWB-High case. It is clearly seen that the plant windbreak causes an effective protection from the wind and the zone above the spray ponds has a limited u-velocity speed with a value of approximately 1 [m/s]. As a consequence – all droplets with a size 250 [μm] and even those with a size of 100 [μm], land back in the spray pond, see Figures 6 and 7.

In case SP12-PWB-Low (when the plants have not reached the planned height) the number of droplets with a diameter of 100 [μm], which are not blown away from the spray ponds, is reduced with 50% compared to the current situation (case SP12-Now).

The variant with windscreen from light structural steel panels combined with terrain modification has been selected as final one, see windbreak #4 in Figure 1. In this case (case SP12-SWB-10/22) the wind protection will be achieved immediately after its construction, the effect from it does not depend on vegetation adaptation to as-is conditions. The u-velocity distribution above the site and the spray pond is shown in Figure 5. Quite effective wind protection is achieved – the velocity above the spray pond where the droplets reside is between 1.0 and 2.0 [m/s]. This variant is considered as quite successful from the viewpoint of its protection properties. It is planned to continue the investigation in a way, which is similar to the SP12-PWB-Low and SP12-PWB-High cases - a complete three-dimensional CFD-modeling together with a detailed analysis of the pathlines of the water droplets will be carried out.

CONCLUSIONS

Different variants for a protection screen of WWER-type NPP spray ponds are studied.

Computational Fluid Dynamics is used to assess the influence of each design variant. The influence of the terrain shape, the screen location, shape, height and permeability is estimated by two-dimensional investigations. Technical solutions for the different variants are developed. Feasibility study is performed for selecting one of the variants for detailed analysis.

For the selected variant – a system of windbreak planting, the behavior of the water droplets is studied with three-dimensional analysis. Parallel study for selecting the most appropriate type of plants is carried out, including laboratory tests of the soil at screen locations. Based on the as-is condition of the soil, the initial assessment of the price for realization of this screen variant is increased considerably.

A new variant for windscreen is proposed. Analysis data from previous variants is applied, combined with measures for modification of the terrain in the vicinity of the spray ponds. In this way uniform distribution of the wind velocity above the spray ponds is achieved. This is the final variant for windscreen, which is proposed for implementation.

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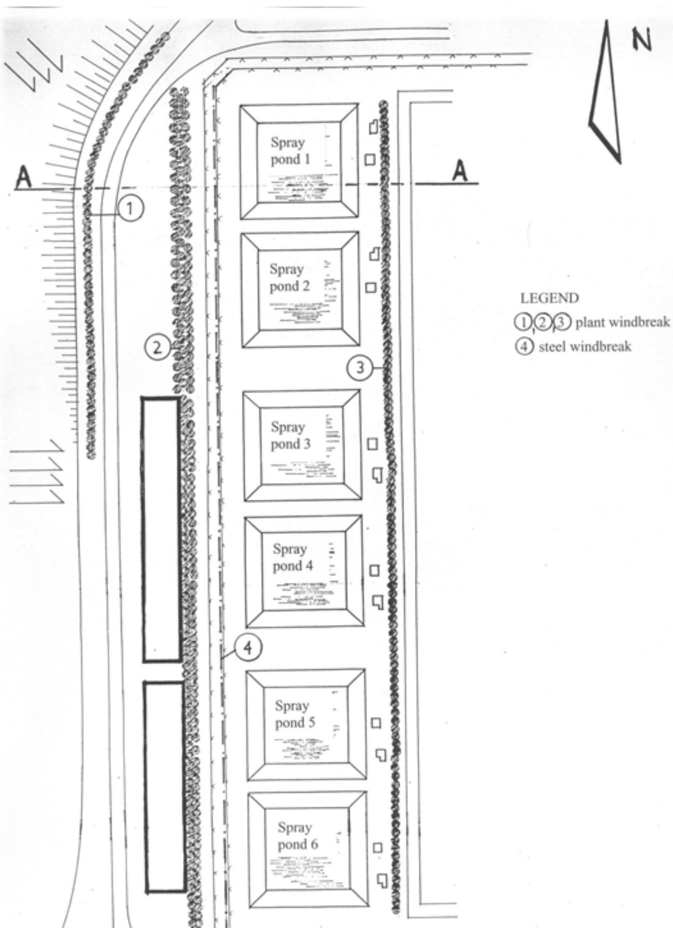

Figure 1 Spray ponds layout. Windbreaks locations

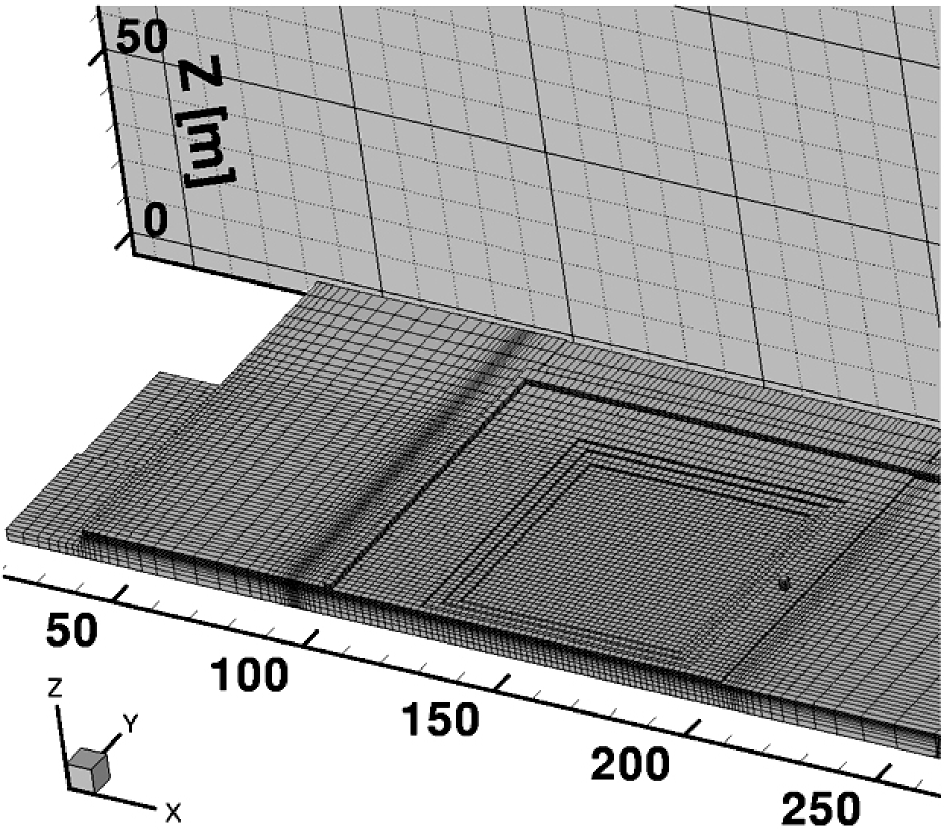

Figure 2 The geometry of the computational domain with the northern spray pond and the numerical grid

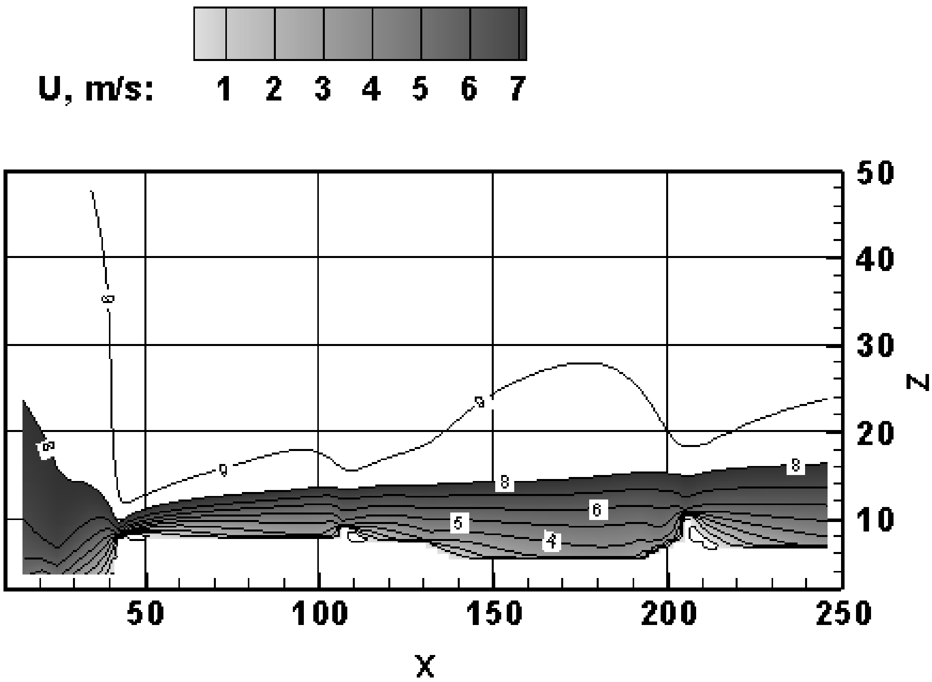

Figure 3 X-velocity component contours plot in case SP12-now.

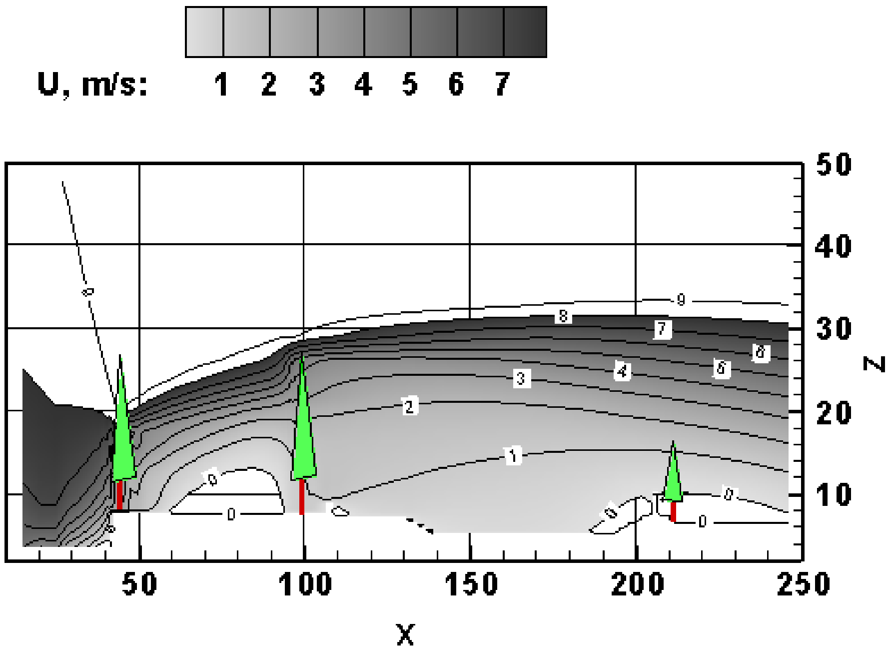

Figure 4 X-velocity component contours plot in case SP12-PWB-High.

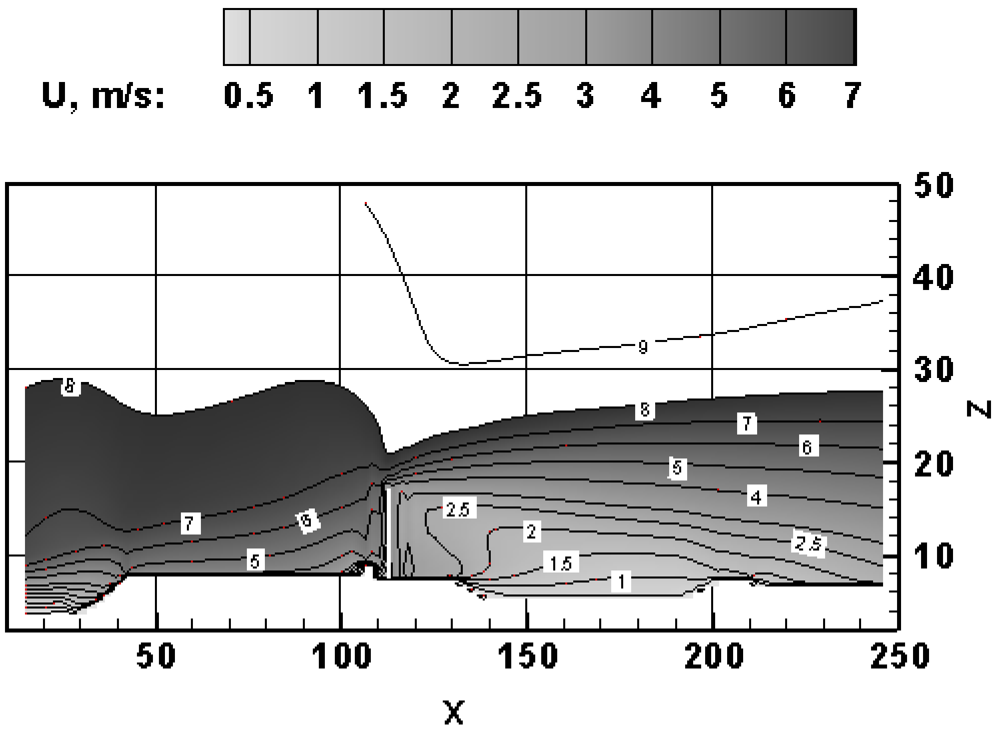

Figure 5 X-velocity component contours plot in SP12-SWB-10/22 case.

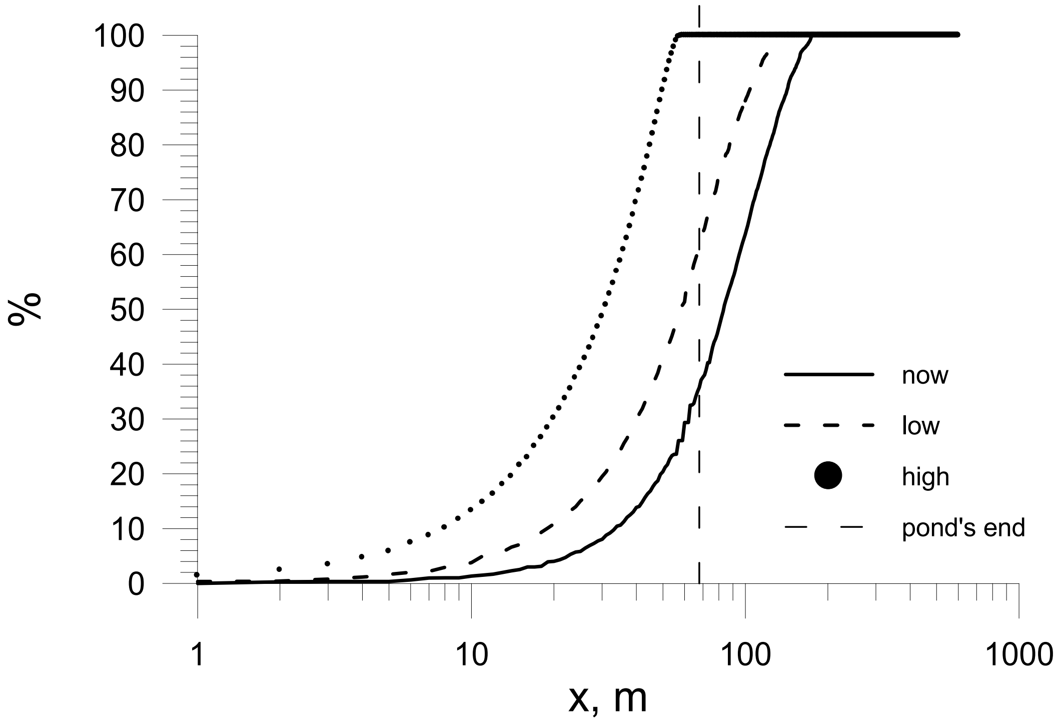

Figure 6 Droplets distribution with a diameter d=100 μm (the x-axis origin is located at the beginning of the spray pond). (Cases SP12-Now, SP12-PWB-Low, SP12-PWB-High)

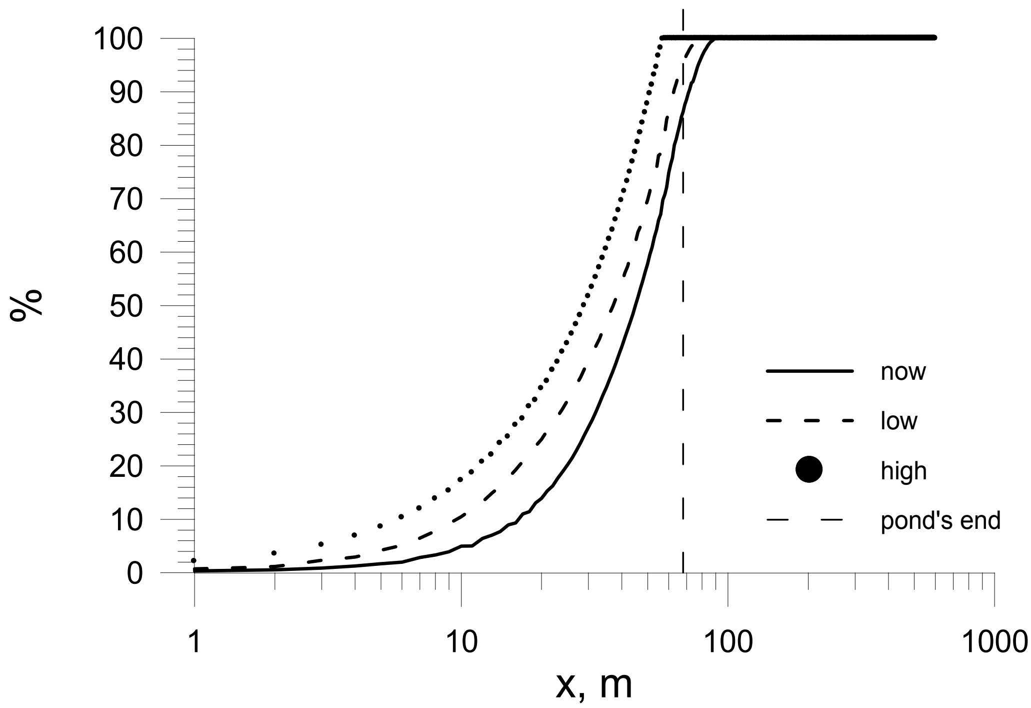

Figure 7 Droplets distribution with a diameter d=250 μm (the x-axis origin is located at the beginning of the spray pond). (Cases SP12-Now, SP12-PWB-Low, SP12-PWB-High).