



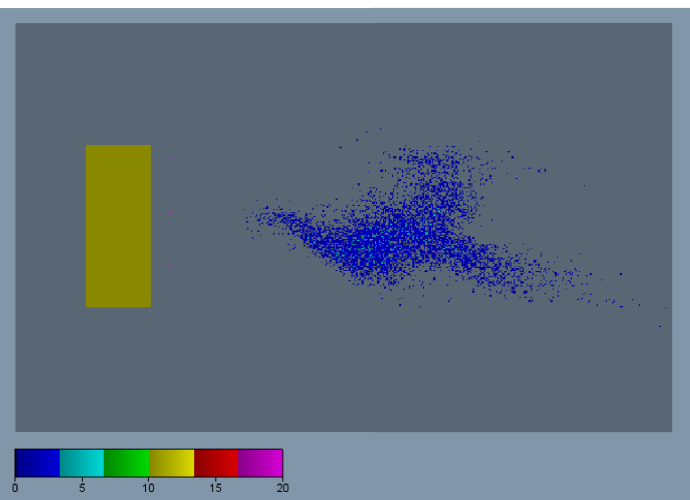
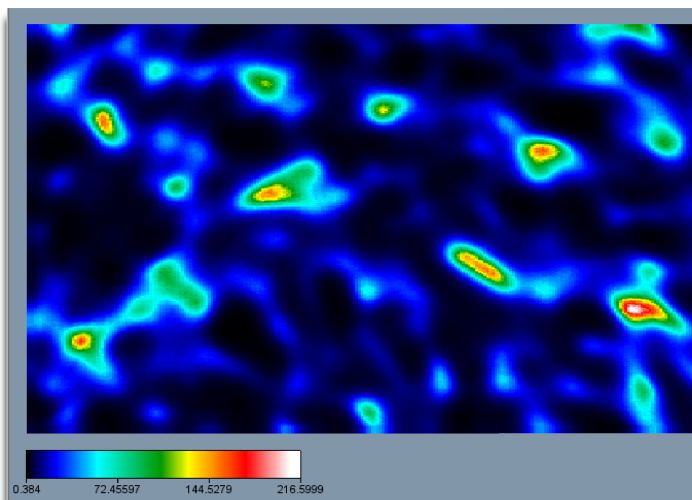
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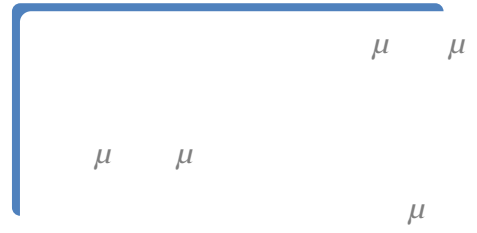
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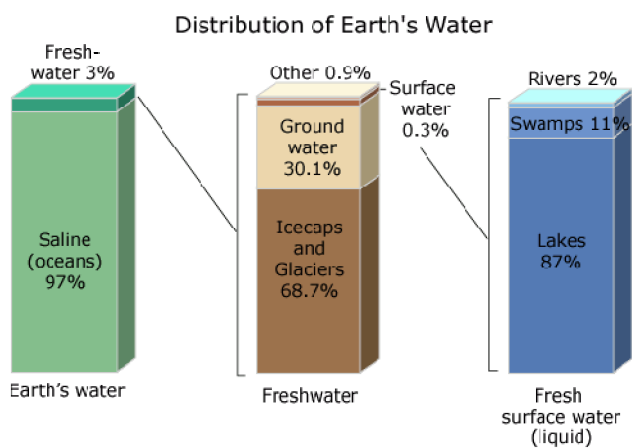
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GRANULAR DRAINAGE MATERIAL

MOISTURE BARRIER LAYER

LANDFILL GAS TO FLARE STATION OR TO ENERGY UTILIZATION PLANT

FINAL CLAY AND SYNTHETIC CAP WITH VEGETATION

GAS MONITORING PROBE

GROUND WATER MONITORING WELL

STORM WATER CONTROL BERM

WORKING FACE

IN PLACE REFUSE

GAS COLLECTION WELL

LEACHATE TO TREATMENT PLANT

RAINWATER RETENTION POND

STORMWATER OUTLET

EXISTING GROUND

GROUND WATER

MODERN LANDFILL DESIGN

DRAINAGE LAYER

SYNTHETIC LINER

COMPACTED CLAY LINER

PERFORATED LEACHATE COLLECTION PIPE

LEACHATE COLLECTION SUMP WITH RISER

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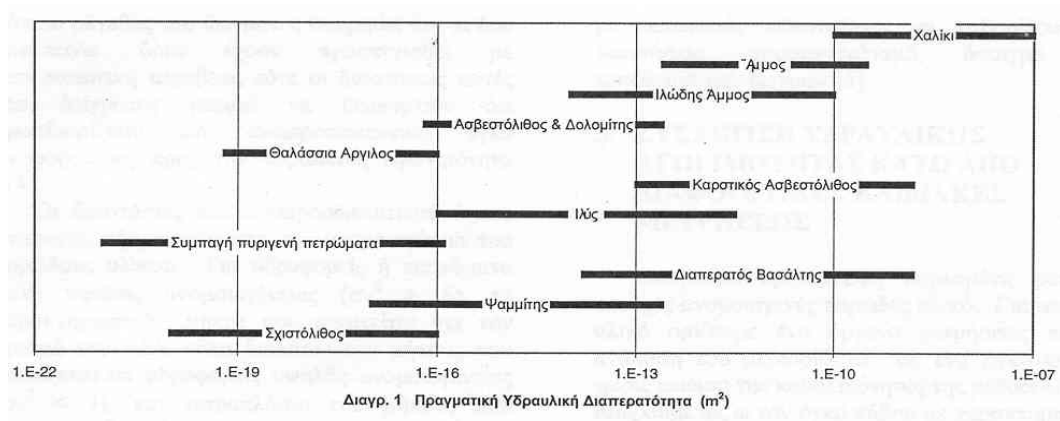
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$$Y = Y_0 + \beta Y_1 + \beta^2 Y_2 + \dots \quad (2.2)$$

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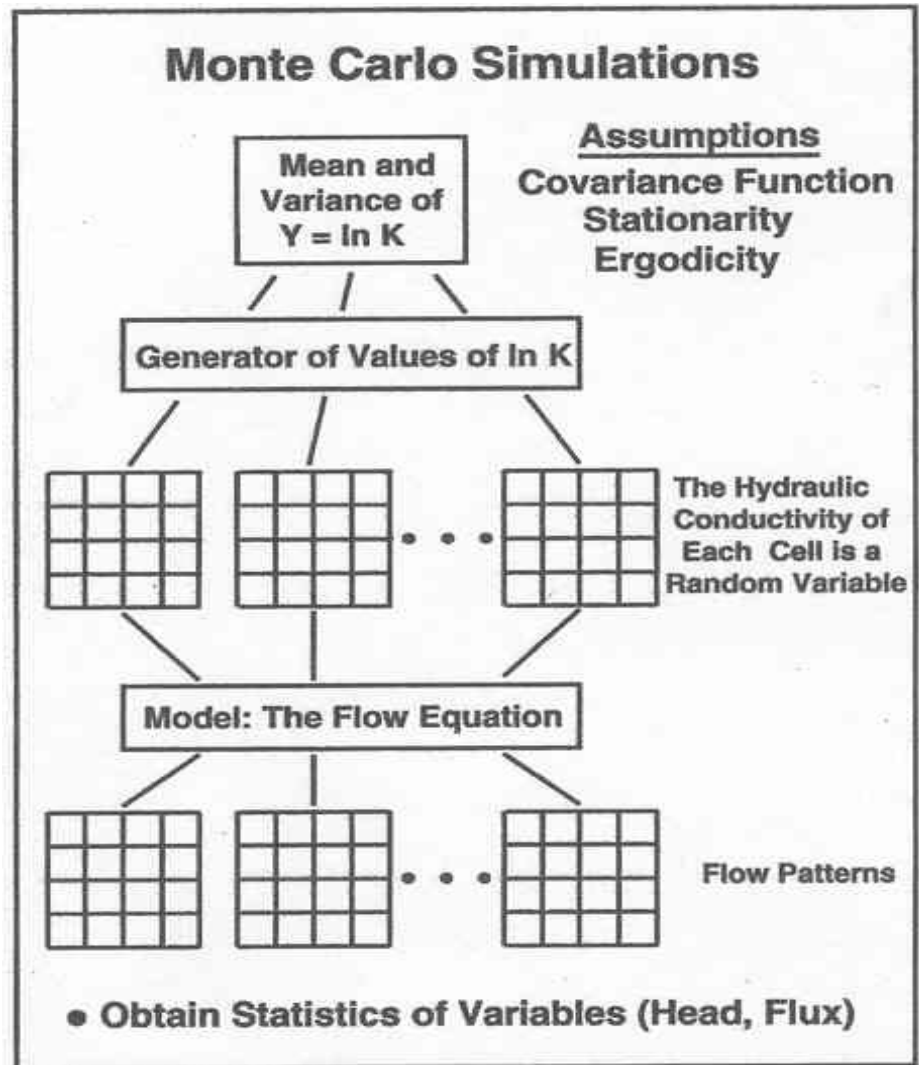
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3.1 : μ Log-Normal μ μ (Y=logK, K cm/sec) (Freeze, 1975)

Source	Rock or Soil Type	N	$\hat{\mu}_y$	$\hat{\sigma}_y$
<i>Bennion and Griffiths</i> [1966]	Conglomerate	3,018	-4.59	0.94
	Sandstone	56,991	-5.38	0.61
	Marly limestone	7,060	-5.38	0.46
	Vuggy limestone	17,162	-5.60	0.53
<i>Law</i> [1944]	Sandstone		-3.36	0.20
	Sandstone		-3.82	0.40
	Sandstone		-4.60	0.40
	Sandstone		-5.46	1.00
<i>McMillan</i> [1966]	Sandstone		-5.52	0.65
	Sandstone		-4.60	0.32
	Sand and gravel		-	0.44
	Sand and gravel	42	-	0.72
	Sand and gravel	16	-	0.54
	Clay loam	33	-5.41	0.45
<i>Willardson and Hurst</i> [1965]		330	-4.00	0.85
		287	-4.60	0.93
	Silty clay	339	-4.96	0.78
		36	-4.46	1.56
		352	-3.00	0.93
	Loamy sand	121	-2.68	0.86

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$$Y = \ln X \quad (3.1)$$

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(Yenigul, 2006, Freeze, 1975, Sudicky, 1986),

$$f_X(x) = \frac{1}{x\sigma_Y\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \mu_Y)^2}{2\sigma_Y^2}\right] \quad (3.2)$$

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$$X_A = \mu_X = E(x) = \exp(\mu_Y + 0.5\sigma_Y^2) \quad (3.3)$$

$$\sigma_X^2 = [\exp(\sigma_Y^2) - 1] [\exp(2\mu_Y + \sigma_Y^2)] \quad (3.4)$$

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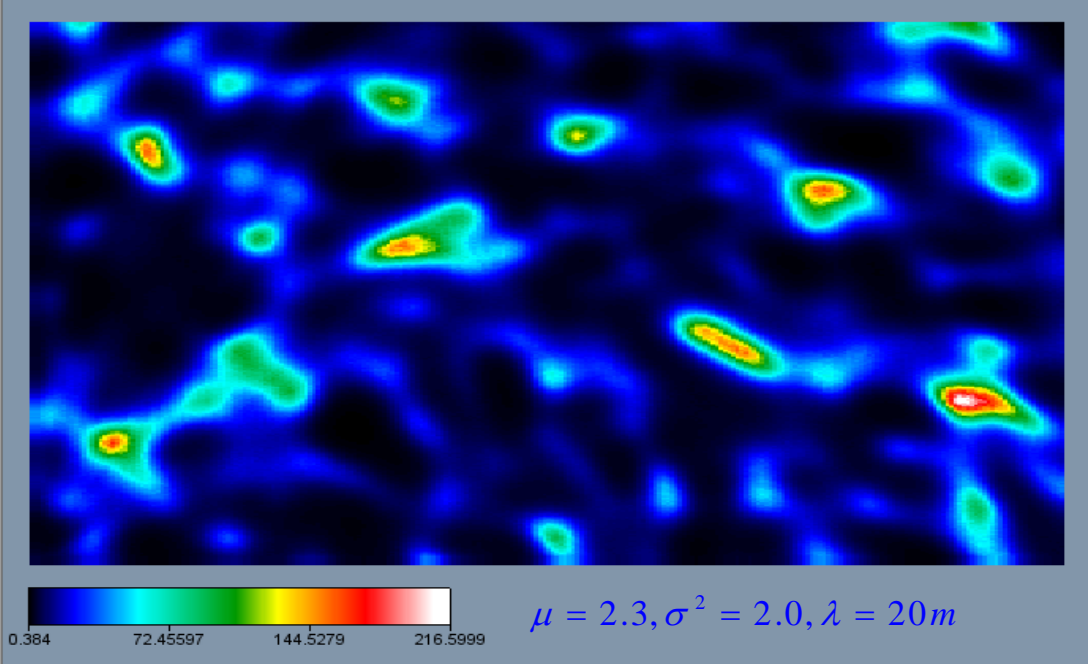
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Source	Medium	σ_f	Correlation Scale, m	Overall Scale, m
<i>Bakr</i> [1976]	sandstone aquifer	1.5–2.2	0.3–1.0 V	100
<i>Smith</i> [1978]	outwash sand	0.8	0.4 V	30
<i>Delhomme</i> [1979]	limestone aquifer	2.3	6300 H	30,000
<i>Binsariti</i> [1980]	basin fill aquifer	1.0	800 H	20,000
<i>Russo and Bressler</i> [1981]	Hamra Red Medi-terranean soil	0.4–1.1	14–39 H	100
<i>Luxmoore et al.</i> [1981]	weathered shale subsoil	0.8	<2 H	14
<i>Sisson and Wierenga</i> [1981]	silty clay loam soil (alluvial)	0.6	0.1 H	6
<i>Viera et al.</i> [1981]	Yolo soil (alluvial fan)	0.9	15 H	100
<i>Devary and Doctor</i> [1982]	alluvial aquifer (flood gravels)	0.8	820 H	5,000
<i>Byers and Stephens</i> [1983]	fluvial sand	0.9	0.1 V >3 H	5 14
<i>Hoeksema and Kitanidis</i> [1985]	sandstone aquifer	0.6	45,000 H	5×10^5
<i>Hufschmied</i> [1985]	sand and gravel	1.9	0.5 V	20
<i>Sudicky</i> [1985]	outwash sand	0.6	0.1 V	20

Correlation scales based on e^{-1} correlation distance; H, horizontal sampling, V, vertical sampling.

$$\frac{\lambda}{\Delta x} \geq 1 + \sigma_Y^2 \quad (3.5)$$

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(Bear, 1987).

(Sarris, 1999, Desbarats, 1992).

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$$K \frac{\partial h}{\partial x} \approx K \left(i + \frac{1}{2}, j, k \right) \left[\frac{h(i+1, j, k) - h(i, j, k)}{\Delta x} \right] \quad (3.10)$$

$$\begin{array}{ccccccc} K \left(i + \frac{1}{2}, j, k \right) & & \mu & & \mu & & \mu & & \mu & \mu \\ \mu & (i, j, k) & & (i+1, j, k), & & \mu & & \mu & & \mu \end{array}$$

$$K \left(i + \frac{1}{2}, j, k \right) = \frac{2K(i+1, j, k)K(i, j, k)}{K(i, j, k) + K(i+1, j, k)} \quad (3.11)$$

$$\mu \quad , \quad \mu \quad \quad \quad Y \quad Z$$

$$K \frac{\partial h}{\partial y} \approx K \left(i, j + \frac{1}{2}, k \right) \left[\frac{h(i, j+1, k) - h(i, j, k)}{\Delta y} \right] \quad (3.12)$$

$$K \frac{\partial h}{\partial z} \approx K \left(i, j, k + \frac{1}{2} \right) \left[\frac{h(i, j, k+1) - h(i, j, k)}{\Delta z} \right] \quad (3.13)$$

$$K \left(i, j + \frac{1}{2}, k \right) = \frac{2K(i, j+1, k)K(i, j, k)}{K(i, j, k) + K(i, j+1, k)} \quad K \left(i, j, k + \frac{1}{2} \right) = \frac{2K(i, j, k+1)K(i, j, k)}{K(i, j, k) + K(i, j, k+1)}$$

$$\begin{aligned} & \frac{K \left(i + \frac{1}{2}, j, k \right) \left[\frac{h(i+1, j, k) - h(i, j, k)}{\Delta x} \right] - K \left(i - \frac{1}{2}, j, k \right) \left[\frac{h(i, j, k) - h(i-1, j, k)}{\Delta x} \right]}{\Delta x} + \\ & + \frac{K \left(i, j + \frac{1}{2}, k \right) \left[\frac{h(i, j+1, k) - h(i, j, k)}{\Delta y} \right] - K \left(i, j - \frac{1}{2}, k \right) \left[\frac{h(i, j, k) - h(i, j-1, k)}{\Delta y} \right]}{\Delta y} + \\ & \frac{K \left(i, j, k + \frac{1}{2} \right) \left[\frac{h(i, j, k+1) - h(i, j, k)}{\Delta z} \right] - K \left(i, j, k - \frac{1}{2} \right) \left[\frac{h(i, j, k) - h(i, j, k-1)}{\Delta z} \right]}{\Delta z} = 0 \end{aligned} \quad (3.14)$$


$$\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}, \mu_{35}, \mu_{36}, \mu_{37}, \mu_{38}, \mu_{39}, \mu_{40}, \mu_{41}, \mu_{42}, \mu_{43}, \mu_{44}, \mu_{45}, \mu_{46}, \mu_{47}, \mu_{48}, \mu_{49}, \mu_{50}, \mu_{51}, \mu_{52}, \mu_{53}, \mu_{54}, \mu_{55}, \mu_{56}, \mu_{57}, \mu_{58}, \mu_{59}, \mu_{60}, \mu_{61}, \mu_{62}, \mu_{63}, \mu_{64}, \mu_{65}, \mu_{66}, \mu_{67}, \mu_{68}, \mu_{69}, \mu_{70}, \mu_{71}, \mu_{72}, \mu_{73}, \mu_{74}, \mu_{75}, \mu_{76}, \mu_{77}, \mu_{78}, \mu_{79}, \mu_{80}, \mu_{81}, \mu_{82}, \mu_{83}, \mu_{84}, \mu_{85}, \mu_{86}, \mu_{87}, \mu_{88}, \mu_{89}, \mu_{90}, \mu_{91}, \mu_{92}, \mu_{93}, \mu_{94}, \mu_{95}, \mu_{96}, \mu_{97}, \mu_{98}, \mu_{99}, \mu_{100}$$

(3.15)

(3.16)

(3.17)

(3.18)

(3.19)

(3.20)

$$) (3.21)$$

2

$$\begin{aligned}
G(i, j, k)h(i, j, k) &= A(i, j, k)h\left(i + \frac{1}{2}, j, k\right) + B(i, j, k)h\left(i, j + \frac{1}{2}, k\right) + \\
C(i, j, k)h\left(i, j, k + \frac{1}{2}\right) &+ D(i, j, k)h\left(i - \frac{1}{2}, j, k\right) + E(i, j, k)h\left(i, j - \frac{1}{2}, k\right) + \\
&+ F(i, j, k)h\left(i, j, k - \frac{1}{2}\right)
\end{aligned} \quad (3.22)$$

μ μ Dirichlet
 $X=0$ $X=L_x$,
 μ Neumann, μ μ
 $Y=0, Y=L_y, Z=0$ $Z=L_z$ μ .
 $\mu\mu$ μ μ
 μ μ μ (Line Successive
Over Relaxation Method; Young, 1950), — $\mu\mu$
Desbarats [1992] — μ Saris [1999]. μ μ '
 μ , μ μ μ
 μ μ μ μ
 μ , μ 10^{-5} . μ
 μ μ $h(i, j, 1)$ μ μ .

3.5.3

μ μ Darcy, μ μ μ
 μ
 $\mathbf{u} = \frac{K_{xx}}{\varepsilon} \frac{\partial h(x, y, z)}{\partial x} \hat{u} + \frac{K_{yy}}{\varepsilon} \frac{\partial h(x, y, z)}{\partial y} \hat{v} + \frac{K_{zz}}{\varepsilon} \frac{\partial h(x, y, z)}{\partial z} \hat{k}$ (3.23)
 ε . μ , μ μ ,
 $K = K_{xx} = K_{yy} = K_{zz}$ μ

$$u_x = \frac{K}{\varepsilon} \frac{\partial h(x, y, z)}{\partial x}, \quad u_y = \frac{K}{\varepsilon} \frac{\partial h(x, y, z)}{\partial y}, \quad u_z = \frac{K}{\varepsilon} \frac{\partial h(x, y, z)}{\partial z} \quad (3.24)$$

μ

μ

$$\begin{aligned}\frac{\partial h(x, y, z)}{\partial x} &= \frac{h(x_{+1}, y, z) - h(x_{-1}, y, z)}{2\Delta x} \\ \frac{\partial h(x, y, z)}{\partial y} &= \frac{h(x, y_{+1}, z) - h(x, y_{-1}, z)}{2\Delta y} \\ \frac{\partial h(x, y, z)}{\partial z} &= \frac{h(x, y, z_{+1}) - h(x, y, z_{-1})}{2\Delta z}\end{aligned}\tag{3.25}$$

$$\begin{aligned} & \left(\begin{array}{ccccccc} & -1 & +1 & \mu & & \mu & \mu \\ \mu & & \mu & & & & \end{array} \right) \cdot \left(x = 0, x = L_x \right) \\ & \left(y = 0, y = L_y \right) \quad \mu \quad , \end{aligned}$$

$$\begin{aligned}\frac{\partial h(x, y, z)}{\partial x} &= \frac{h(x, y, z) - h(x_{-1}, y, z)}{\Delta x} \\ \frac{\partial h(x, y, z)}{\partial y} &= \frac{h(x, y, z) - h(x, y_{-1}, z)}{\Delta y}\end{aligned}\quad (3.26)$$

3.6

3.6.1

6.1 μ -

μ μ -

μ μ μ ,

μ μ . μ μ

μ

, , μ μ μ

μ μ μ μ

. μ , μ

μ , μ ,

μ μ .

μ - μ μ μ

(Bear, 1972)

$$\begin{aligned} & \frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} + v_z \frac{\partial C}{\partial z} - \frac{\partial}{\partial x} \left[D_{xx} \frac{\partial C}{\partial x} + D_{xy} \frac{\partial C}{\partial y} + D_{xz} \frac{\partial C}{\partial z} \right] - \\ & - \frac{\partial}{\partial y} \left[D_{yx} \frac{\partial C}{\partial x} + D_{yy} \frac{\partial C}{\partial y} + D_{yz} \frac{\partial C}{\partial z} \right] - \frac{\partial}{\partial z} \left[D_{zx} \frac{\partial C}{\partial x} + D_{zy} \frac{\partial C}{\partial y} + D_{zz} \frac{\partial C}{\partial z} \right] = 0 \end{aligned} \quad (3.27)$$

C μ μ t $(x, y, z), \mu$ v_x, v_y
 v_z μ x, y, z μ
 D_{ij}, μ $i, j=1, 2, 3,$ μ
 (Bear, 1972)

$$D_{i,j} = (a_T |v| + D_m) \delta_{ij} + (a_L - a_T) \frac{v_i v_j}{|v|} \quad (3.28)$$

δ_{ij} Kronecker, $a_L [L]$ μ , $a_T [L]$, D_m
 μ $|v| = \sqrt{v_x^2 + v_y^2 + v_z^2}$ μ .
 C μ μ 2-D
 $\partial C / \partial y(x, 0, t) = 0, \partial C / \partial y(x, L_y, t) = 0$ $t \geq 0$ $C(x, y, 0) = 0$ $0 \leq x \leq L_x, 0 \leq y \leq L_y$.

3.6.2 μ μ (Random Walk, RW)

μ μ μ μ μ μ .
 μ μ μ () μ
 μ
 μ , μ , μ
 (Uffink, 1990). μ μ μ
 1980 (Prickett et al., 1981) μ μ .
 μ μ μ ,
 μ . μ μ μ
 μ μ μ . μ
 μ - μ μ μ , μ
 μ . μ μ ,
 μ μ μ μ
 μ . μ μ
 (Uffink, 1990).

μ μ RW μ μ . μ μ
 μ μ μ μ μ
 μ , μ μ μ μ μ

μ . ' , μ μ (μ),
 μ μ μ μ , μ μ
 μ , μ μ
 μ .
 μ μ μ μ μ μ μ
 μ μ μ μ μ μ μ
. μ μ μ μ ,
 μ μ μ μ μ μ
. μ ,
 μ μ μ ,
 μ μ μ μ , μ
 μ μ μ (Uffink, 1990).
 μ RW, μ μ
 μ μ μ μ
 μ μ , μ μ μ .
 μ μ μ ,
 μ , μ
- , μ μ μ
 μ μ . μ μ ,
 μ μ μ .
 μ μ μ .
 μ , μ , μ RW
 μ μ μ μ .
 μ μ μ μ μ (Fokker-Planck
Equation) - .
 μ , Fokker-Planck.
, μ μ ,
 μ
(Uffink, 1990).

$$\mu \quad \mu \quad \mu \quad \mu \quad \mu, \quad \mu \quad \mu$$

$$\mu \quad \mu \quad \mu$$

$$\mu, \mu \quad \mu \quad \mu \quad \mu \quad \sigma.$$

$$\begin{array}{ccccccc} & & \mu & & \mu & & \mu \\ - & & & & & & \\ M_0(g) & \mu & x_0, \mu & \mu & & \alpha_z & \mu \end{array}$$

$$C_0 = M_0 / \varepsilon B, \quad \varepsilon \quad B \quad \mu \quad \mu \quad \mu \quad . \quad (3.29) \quad (3.30),$$

$$\sigma = \sqrt{2\alpha_L v_x t} \quad (3.32)$$

$$(3.30) \quad \text{Fokker-Planck (Uffink, 1990),}$$

$$\begin{aligned}
X_p(t + \Delta t) = & X_p(t) + v_x \Delta t + \left(\frac{\partial D_{xx}}{\partial x} + \frac{\partial D_{xy}}{\partial y} + \frac{\partial D_{xz}}{\partial z} \right) \Delta t + \frac{v_x}{|v|} R_1 \sqrt{2\alpha_L |v|} \Delta t - \\
& - \frac{v_y}{|v|} R_2 \sqrt{2\alpha_T |v|} \Delta t - \frac{v_z}{|v|} R_3 \sqrt{2\alpha_T |v|} \Delta t
\end{aligned} \tag{3.33}$$

$$\begin{aligned}
& X_p(t), Y_p(t) \quad \mu \quad \mu \quad t, \Delta t \\
& \mu, R_1, R_2 \quad \mu \quad \mu \quad \mu \\
& \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad (0) \quad \mu \quad \mu \quad (1), \quad \alpha_L, \alpha_T \quad \mu \\
& (3.6).
\end{aligned}$$

μ

The diagram illustrates two types of dispersion in a porous medium:

- Left (Mechanical Dispersion):** Shows a cross-section of a porous medium with pores (Πορώδες Υλικό) and particles (Σωματίδιο). Arrows indicate the flow direction (Μέση Ροή). The process is labeled as Εγκάρσια Διασπορά (transverse dispersion).
- Right (Molecular Dispersion):** Shows a concentration profile (Συνιστώσα Μετατόπισης Λόγω Μεταφοράς) spreading over time (Διαμήκης Διασπορά) due to random molecular motion (Συνιστώσα Τυχαία Μετατόπισης Λόγω Διασποράς). The resulting profile is labeled as Κανονικές Κατανομές Μετατόπισης Λόγω Διασποράς (normal distribution of displacement due to dispersion).

$$(3.28), \quad \mu$$

34

(3.35)

(3.36)

(3.37)

 $\mu \quad \mu$

(3.38)

(3.39)

(3.40)

(3.41)

$$v_x, v_y \quad \mu \quad \mu \quad x, y$$
$$\nu \quad \mu \quad .$$

3.6.4 μ

[illegible]

$$\alpha_L \approx \text{average grain diameter} \quad (3.42)$$

$$\alpha_T = \frac{1}{10} a_L \quad (3.43)$$

 μ ,

μ (Spitz and Moreno, 1996)

$$\alpha_L = 0.1 \text{ travel time} \quad (3.44)$$

μ Yenigul [2005],

$$\alpha_T \quad \mu \quad \mu \quad 0.001 \text{ m} \quad \mu \quad \mu \quad 0.200 \text{ m}$$

3.6.5

[illegible]

$$C_{ij}(t) = \frac{M_0 n_{ij}(t)}{N \varepsilon b_{ij} \Delta x \Delta y} \quad (3.45)$$

$$C_{ij}(t) = \mu_{ij}(t, n_{ij}(t)) \quad (i, j) \in N, \quad \mu_{ij}(t, n_{ij}(t)) = b_{ij} + \varepsilon_{ij}(t) \quad (3.45),$$

μ μ μ μ . , μ μ
μ .
, μ μ
μ μ ,
μ . μ Δt
μ Δx μ
μ v_{max} (Tompson and Gelhar, 1990).

$$\Delta t \ll \frac{\Delta x}{v_{\max}} \tag{3.46}$$

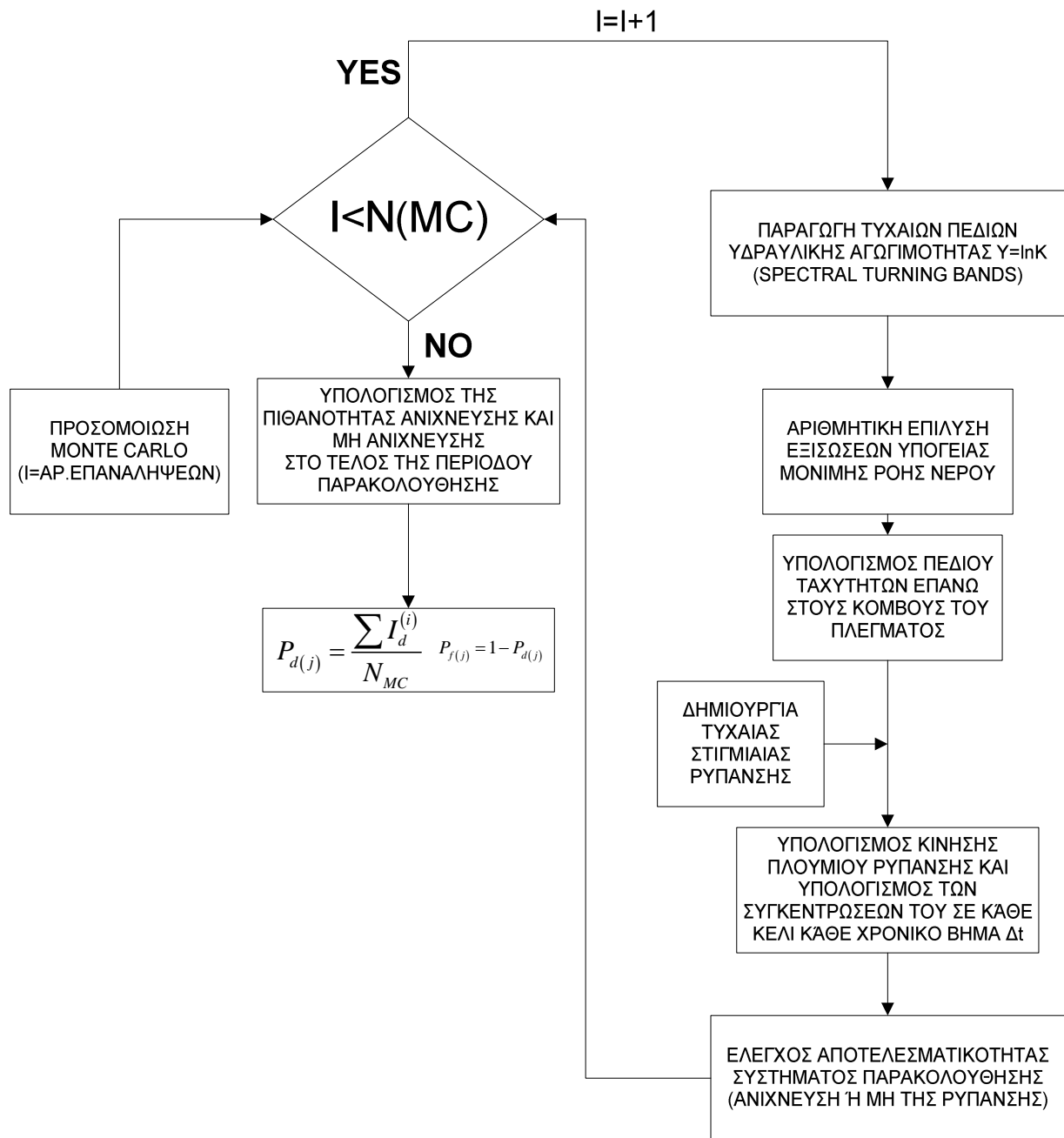
4.

4.1

4.1.

4.1 : μ

/	μ	μ	μ
1		, Monte Carlo	2-D μ μ STBM
2		μ	μ , μ μ
3		, μ	μ μ , μ
4		μ	μ μ , μ μ
5	μ	μ	μ μ , μ μ μ μ
6		μ	μ μ μ μ , μ μ μ
7		, μ μ	μ μ μ μ , μ μ μ μ μ
8		μ	μ μ , μ μ



4.3

μ μ μ μ
 FORTRAN 77. μ μ
 μ (3-D)
 (2-D). μ μ
 μ , . μ μ
 .

4.3.1 μ μ μ

μ μ (FLOW.INP),
 μ $\mu\mu$ μ μ
 μ , μ , μ μ μ
 μ , μ μ μ . μ μ
 μ μ μ μ
 $\mu\mu$, μ , μ
 μ .

4.3.2 μ μ μ *Monte Carlo*

μ μ $\mu\mu$.
 μ μ
 μ .
 μ :

4.3.2.1 μ μ *STBM*

μ 2-D μ K μ μ
 μ μ μ TUBA (version 2.11),
 μ μ . μ μ $\mu\mu$
 μ , μ μ μ
 μ . μ μ ,
 μ Zimmerman Wilson
[1990].

4.3.2.2

2-D μ μ
Sarris [1999] μ μ 3-D ,
Desbarats [1992]. μ μ
 μ h μ
. , μ , μ μ 2-D μ
 μ , μ Z μ (1) μ μ .
 μ μ μ (x, y, 1).
, μ μ Z $\mu\mu$, μ
 μ μ . μ μ

μ 2-D, μ μ μ
 μ μ μ , μ μ μ
 μ , ,

4.3.2.3

μ μ μ μ 2-D μ
 μ . μ
 x, y μ μ . μ
 μ x .

4.3.2.4

μ μ μ μ .
 μ 3 . :
1.: μ μ μ μ μ
. , μ μ
 μ μ (0). μ , μ
 μ μ ,
 \mathbf{V}_0 .
2.: μ . , μ ,
 μ μ μ μ ,
 μ . μ ,
 μ μ μ μ v_x, v_y
 μ , μ μ μ
 μ μ (

4.2).

$$\begin{cases} v_x(1,1) = (1-a)(1-b)v_x(i,j) \\ v_x(2,1) = (1+a)(1-b)v_x(i+1,j) \\ v_x(1,2) = (1-a)(1+b)v_x(i,j+1) \\ v_x(2,2) = (1+a)(1+b)v_x(i+1,j+1) \end{cases} \quad (4.2)$$

$$\mu \quad \mu \quad \mu$$

$$a = 2(x - [x] - 0.5) \quad (4.3)$$

$$b = 2(y - [y] - 0.5) \quad (4.4)$$

$$\begin{aligned} [x], [y] \quad \mu \quad x, y \cdot \quad \mu \quad \mu \quad v_x \\ v_y \quad \mu \quad \mu \quad \mu \quad (4.2), \end{aligned}$$

$$v_{x(par)} = \frac{v_x(1,1) + v_x(2,1) + v_x(1,2) + v_x(2,2)}{4} \quad (4.5)$$

$$v_{y(par)} = \frac{v_y(1,1) + v_y(2,1) + v_y(1,2) + v_y(2,2)}{4} \quad (4.6)$$

$$\begin{aligned} 3.: \quad \mu \quad \mu \quad \mu \quad \mu \\ \mu, \quad \mu \quad \Delta t \quad \mu \quad \mu \\ (3.33) \quad (3.34). \end{aligned}$$

$$4.: \quad \mu$$

$$5.: \quad (\mu) \quad \mu$$

$$\begin{aligned} 6.: \quad \mu \quad \mu \quad \mu \quad \mu \\ \mu \quad \mu \quad \mu \quad \mu \end{aligned}$$

$$\begin{aligned} 7.: \quad \mu \quad \mu \quad \mu \quad \mu \\ \mu \quad \mu \quad \mu \quad \mu \end{aligned}$$

$$8.: \quad \mu \quad \mu \quad \mu \quad \mu$$

4.4.2

μ

μ

μ

.

μ

.

3, 4, 6 12

μ $\mu\mu$ Δs μ

d

. . . . L μ μ μ

$\Delta s / L$ (normalized well spacing, nws) μ $\mu\mu$

. . . . d / L (normalized distance from source, ndfs) (Yenigul, 2005).

4.4.3 μ μ

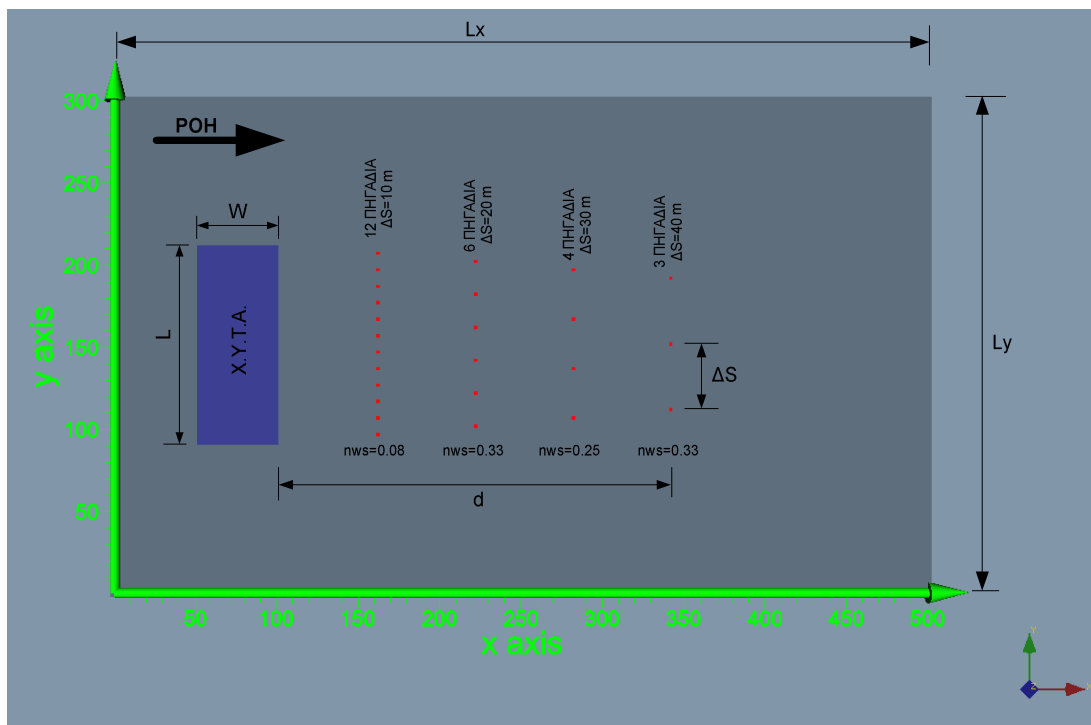
$$\begin{array}{ccccccc}
\mu & \mu & & \mu & & & y = 0m \text{ ,} \\
y = 300m & & \mu & & x = 0m \text{ ,} & x = 500m. & \mu \\
\mu & & & \mu & & & \mu \\
\mu & & \mu & 0.001m. & & \mu & \mu \\
\mu & & \mu & & & \mu & \mu & \mu & 2.3 \text{ ,} \\
\mu & \mu & K = 10m / day \text{ ,} & & \mu & & \mu & \mu \\
\mu & \sigma_Y^2 = 0 & \sigma_Y^2 = 2.0. & & Y & & \mu & , \\
\mu & \mu & \mu & 20m. & \mu & & \mu & .
\end{array}$$

4.4.4 μ μ μ μ

[illegible]

2000, Yenigul et al. [2005]

$$C_0 = \frac{M/\varepsilon}{m^3} = \frac{1000gr/0.25}{m^3} = 4000mgr / lt$$



4.3 :

0.35% C_{TH} , C_0 , $14mg / lt$ 28 $\Delta x = \Delta y = 2m$ C_{TH} $\Delta x = \Delta y = 1m$, C_{TH} 7.

4.2 : μ

Απόσταση από ΧΥΤΑ	Ndfs	Χρόνος Προσομοίωσης		Χρονικό Βήμα (Δt, Ημέρες)
		Έτη	Ημέρες	
15	0.125	10	3650	1
30	0.250	15	5475	1
60	0.500	20	7300	1
120	1.000	20	7300	1
150	1.250	30	10950	1
240	2.000	30	10950	1
300	2.500	30	10950	1

μ , μ
 μ μ . μ
 μ μ μ . μ 3, 4, 6
12 (4.3). $\mu\mu$ μ
 μ , μ
 μ μ $y = 90\ m$ $y = 210\ m$,
. . . . ,
 μ μ

$$\mu \quad \mu \quad \mu$$
$$\mu \quad , \quad \dots \quad (4.3).$$

... (4.3).

 μ

.

 μ

,

 $4\,m^2\,.$

• • • •,

,

$$\Delta x = \Delta y = 1 \text{ m}$$
 $\frac{1}{4}$

,

 μ

.

 μ μ μ μ μ

.

4.3: μ

	μ	μ					
		.1	.2	.3	.4	.5	.6
1	μ	500 m					
2	μ	300 m					
3	μ (x= y)	2 m	1 m				
4	μ (x= y)	2 m	1 m				
5	μ , L	50 m					
6	μ , W	120 m					
7	μ =lnK, μ	2.3					
8	μ , 2	0.00	0.50	0.75	1.00	1.50	2.00
9	μ ($x=y$)	20 m					
10	μ	0.001 m					
11	μ , L	0.01 m	0.20 m	0.50 m	1.00 m	2.00 m	
12	μ , T	0.001 m	0.020 m	0.050 m	0.100 m	0.200 m	
13		0.25					
14	μ	10 - 30 (ndfs)					
15	μ , t	1 μ					
16	μ	12	6	4	3		
17	μ	0.08	0.17	0.25	0.33		
18	μ	0.125	0.250	0.500	1.000	1.250	2.000 2.50
19	μ , G_{TH}	0.35% x ζ					

μ (X μ).

μ ,

$\sigma_L = \sqrt{2\alpha_L v_x t}$ (5.6)

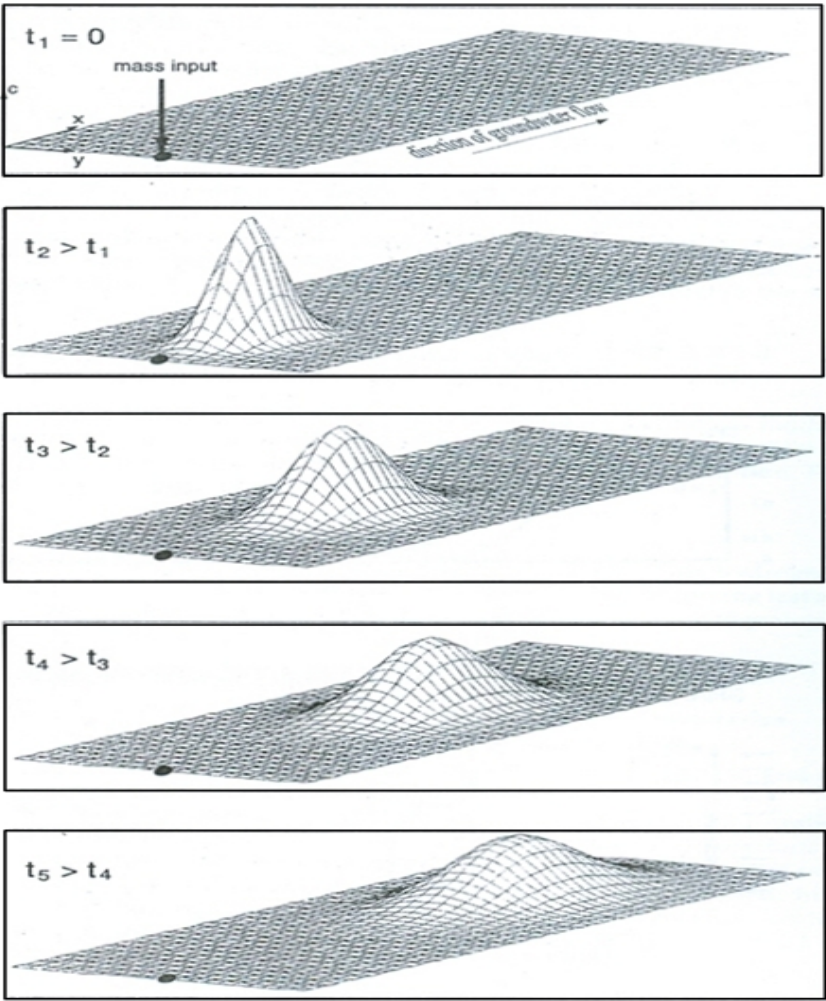
$\sigma_T = \sqrt{2\alpha_T v_x t}$ (5.7)

μ x = v_x t

μ μ

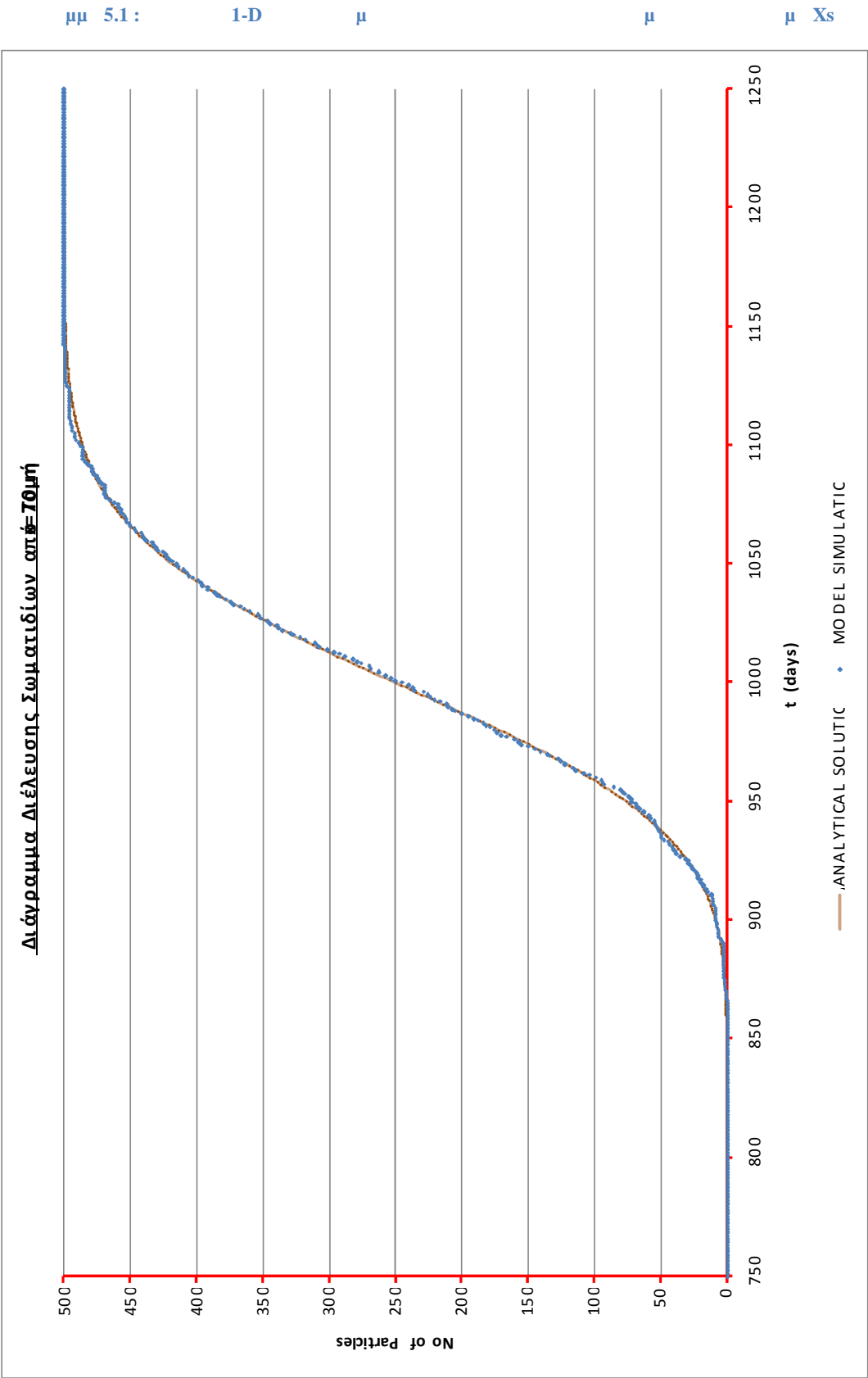
$C_{max} = \frac{\Delta M}{4\pi \epsilon b v_x t \sqrt{\alpha_L \alpha_T}}$ (5.8)

μ μ 5.1.



5.1 : μ 2-D μ (Spitz and Moreno,1996)

μ μ μ μ 1-D μ μ , μ .



5.2.2

 μ 2-D

$$\mu_{\text{eff}} = \mu_{\text{eff}}^{\text{eff}} + \mu_{\text{eff}}^{\text{eff}} + \mu_{\text{eff}}^{\text{eff}}, \quad (5.4)$$

μ μ $C_{x,y}$ μ (x, y) . μ , μ
 μ μ

μ

(5.4), Simpson

2-D μ Simpson,

$$\begin{aligned}
C_{i,j} &= \int_i^{i+1} \int_j^{j+1} C(x,y) dx dy \approx \\
&\approx \frac{\Delta x \Delta y}{9} \left\{ \left[C(x_0, y_0) + 2 \sum_{i=1}^{(n/2)-1} C(x_{2i}, y_0) + 4 \sum_{i=1}^{n/2} C(x_{2i-1}, y_0) + C(x_n, y_0) \right] + \right. \\
&+ 2 \left[\sum_{j=1}^{(m/2)-1} C(x_0, y_{2j}) + 2 \sum_{j=1}^{(m/2)-1} \sum_{i=1}^{(n/2)-1} C(x_{2i}, y_{2j}) + 4 \sum_{j=1}^{(m/2)-1} \sum_{i=1}^{(n/2)-1} C(x_{2i-1}, y_{2j}) + \sum_{j=1}^{(m/2)-1} C(x_n, y_{2j}) \right] + \\
&+ 4 \left[\sum_{j=1}^{m/2} C(x_0, y_{2j-1}) + 2 \sum_{j=1}^{m/2} \sum_{i=1}^{(n/2)-1} C(x_{2i}, y_{2j-1}) + \sum_{j=1}^{m/2} \sum_{i=1}^{n/2} C(x_{2i-1}, y_{2j-1}) + \sum_{j=1}^{m/2} C(x_n, y_{2j-1}) \right] + \\
&\left. + \left[C(x_0, y_m) + 2 \sum_{i=1}^{(n/2)-1} C(x_{2i}, y_m) + 4 \sum_{i=1}^{n/2} C(x_{2i-1}, y_m) + C(x_n, y_m) \right] \right\}
\end{aligned} \tag{5.12}$$

4.4

$$\mu \qquad \qquad \qquad \mu \qquad \qquad \mu \qquad \qquad \mu$$

5.1.

Δεδομένα Εισόδου			
x_0	100 m	α_L	0.1
y_0	150 m	α_T	0.01
M	1000 gr	t_{total}	1500 days
ε	0.25	Δt	1 day

Y

ΧΥΤΑ

ΘΕΩΡΗΤΙΚΗ ΚΑΤΑΝΟΜΗ
ΣΥΓΚΕΝΤΡΩΣΕΩΝ

ΠΛΟΥΜΙΟ

Y=150 m

X

55

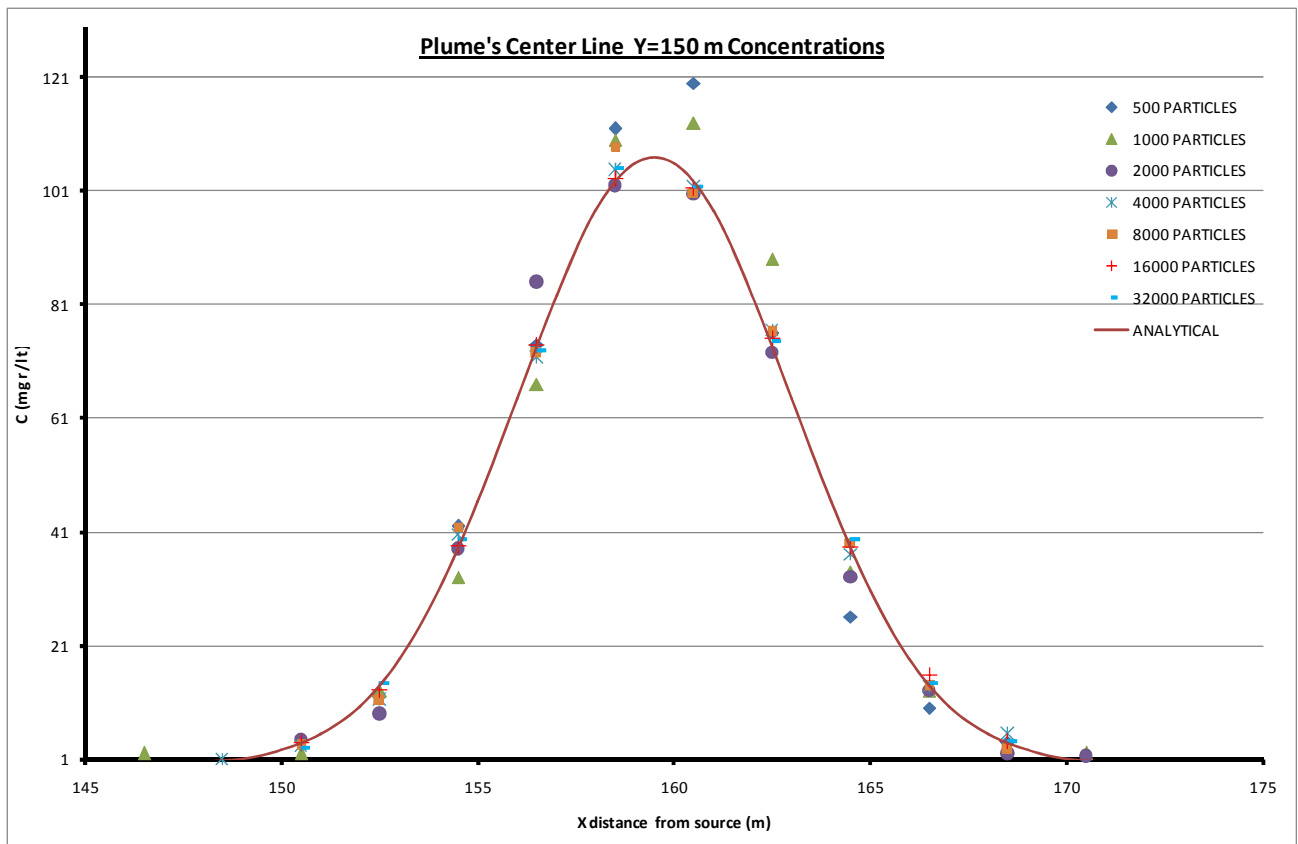
5.2 μ μ μ , μ 1000 μ μ μ μ μ 5.2 - μμ 5.5.

5.2 : μ μ μ

Πλήθος Σωματιδίων	Σχετικός Υπολογιστικός Χρόνος
500	0.50
1000	1.00
2000	1.75
4000	3.25
8000	6.25
16000	12.25
32000	16.75

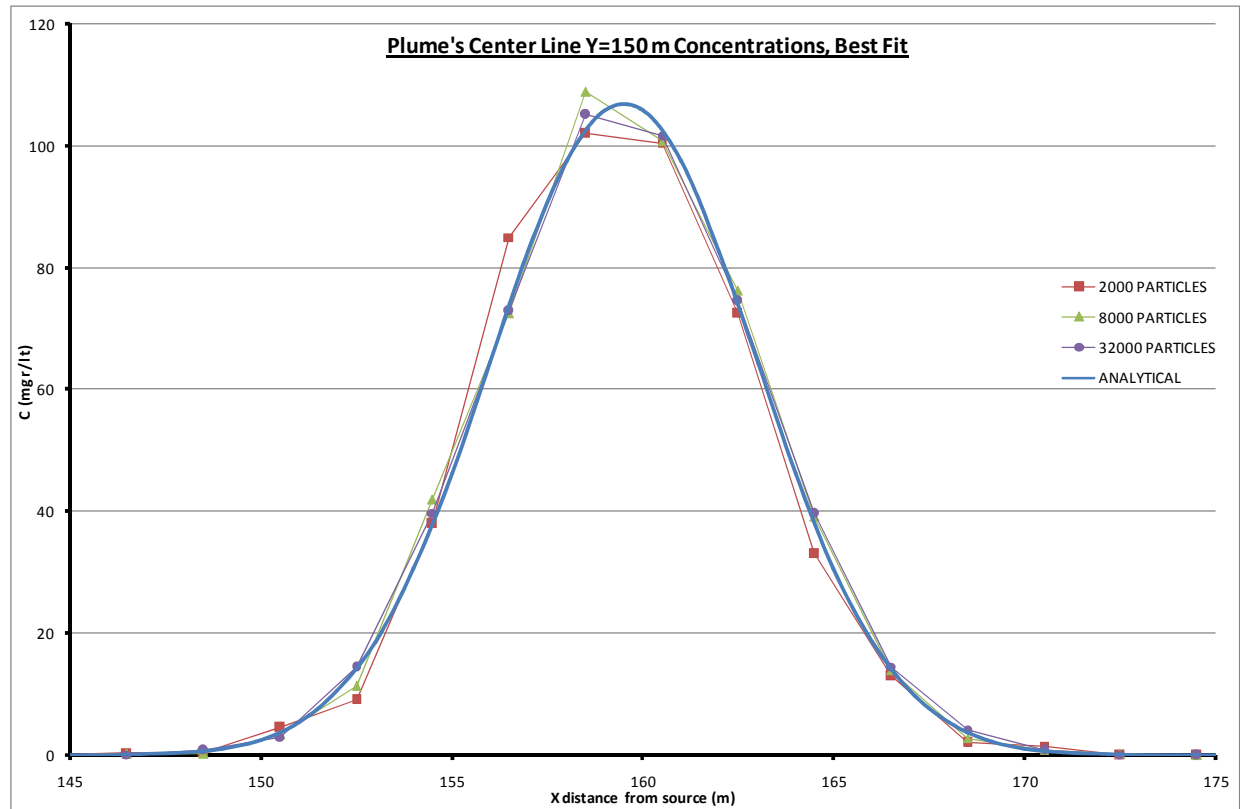
μμ 5.2 : μ

μ



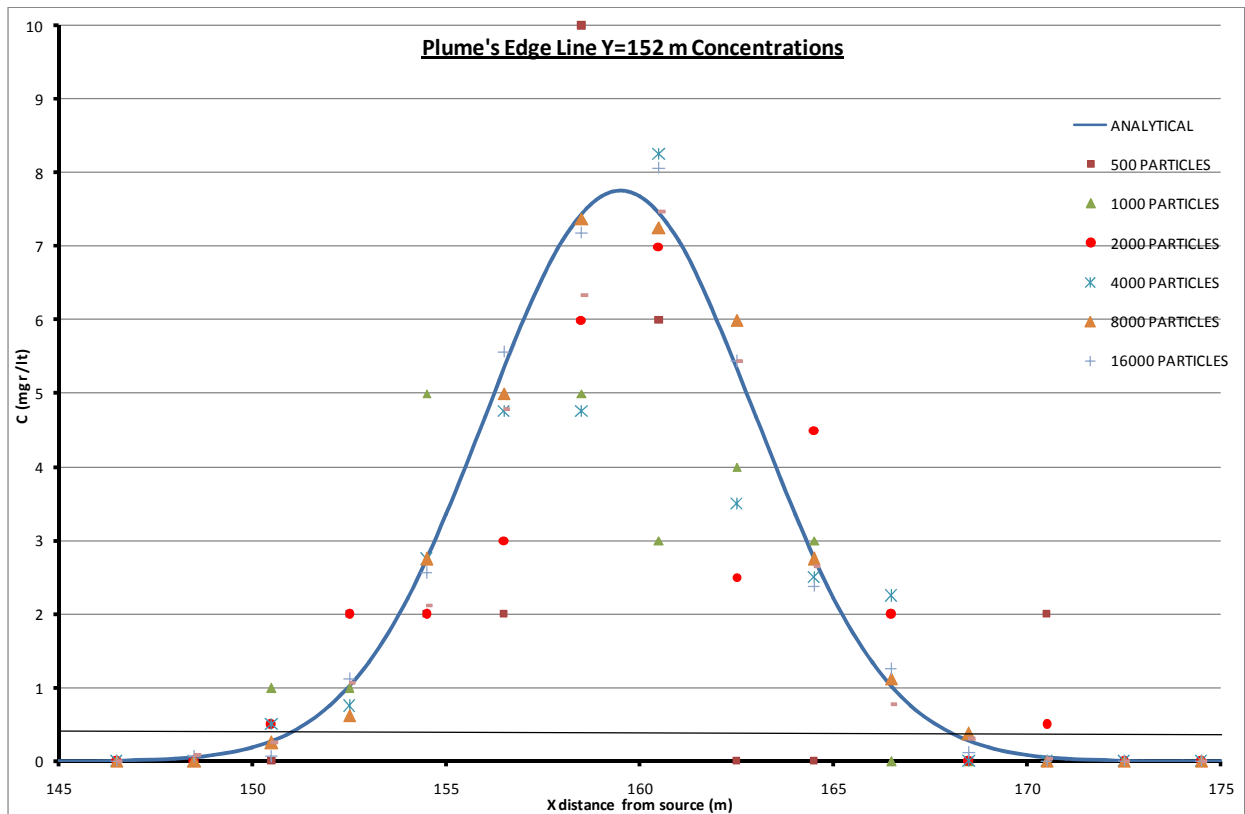
μμ 5.3 :

μ



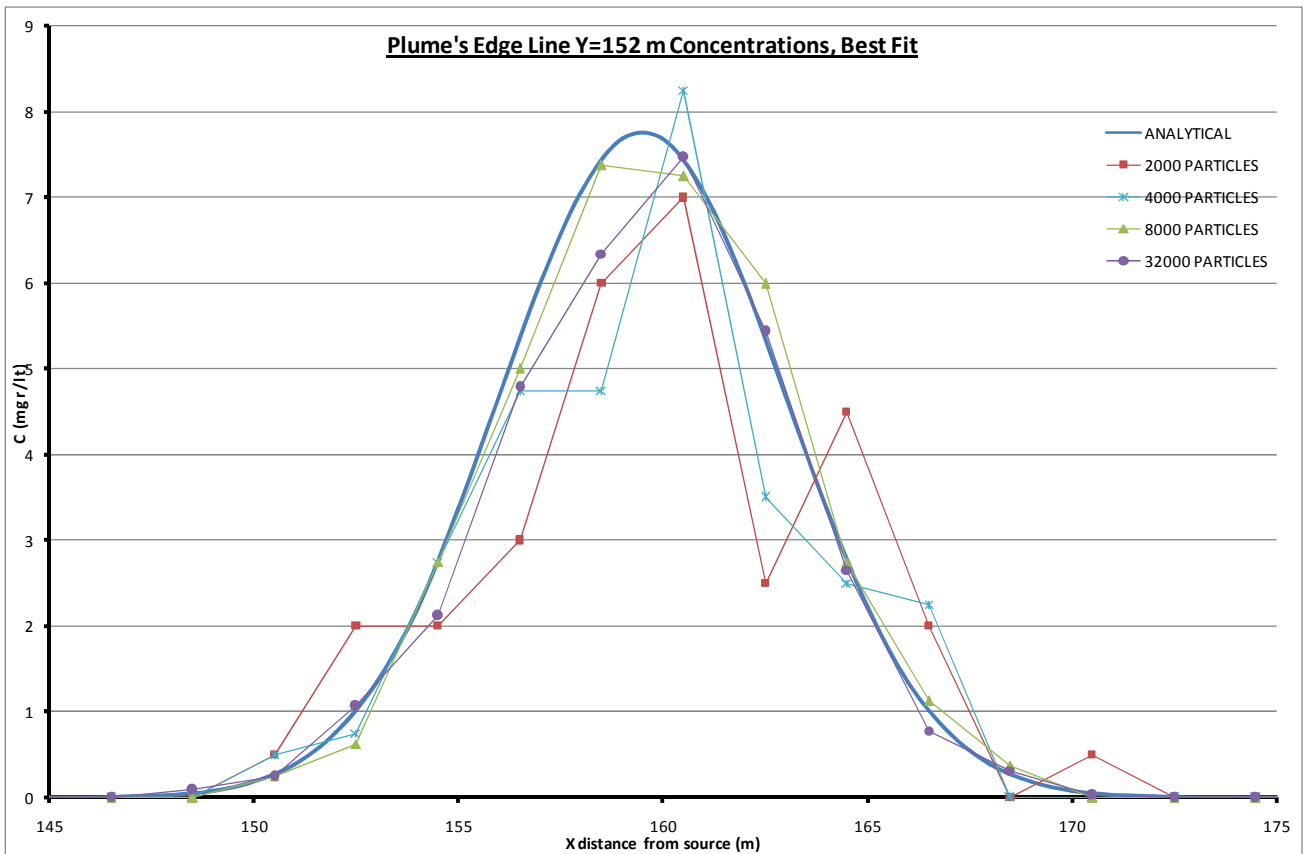
μμ 5.4 :

μ



μμ 5.5 :

μ



μ ,

μμ

μ ,

μ

μ

2000

μ

,

μ ,

μ

32000

(μμ 5.3, 5.3).

,

μ

μ

μ

μ

8000

μ

.

μ

μ

μ

2000

μ

μ

,

μ

4000

μ

μ

μ

μ

μ

μ

4000

μ

,

μ

μ

μ

μ

μ

2000

μ

.

μ

Yenigul et al [2005]

μ

,

μ

μ

.

[illegible]

μ

μ 10000 , μ 5.3 , μ

μ 0.2 (0.2%) ($\mu\mu$ 5.7). μ ,

μ μ μ μ $\mu\mu$ $\mu\mu$ 5.6, 0 2000

, $\mu\mu$ 5.8, μ μ

μ 500 ,

μ . , μ μ μ

, ,

μ . , μ

μ μ , 500 10000, μ

500 μ μ . ,

μ μ μ $\mu\mu$ $\mu\mu$ 5.7 $\mu\mu$ 5.9, μ

μ μ μ μ μ μ .

μ μ

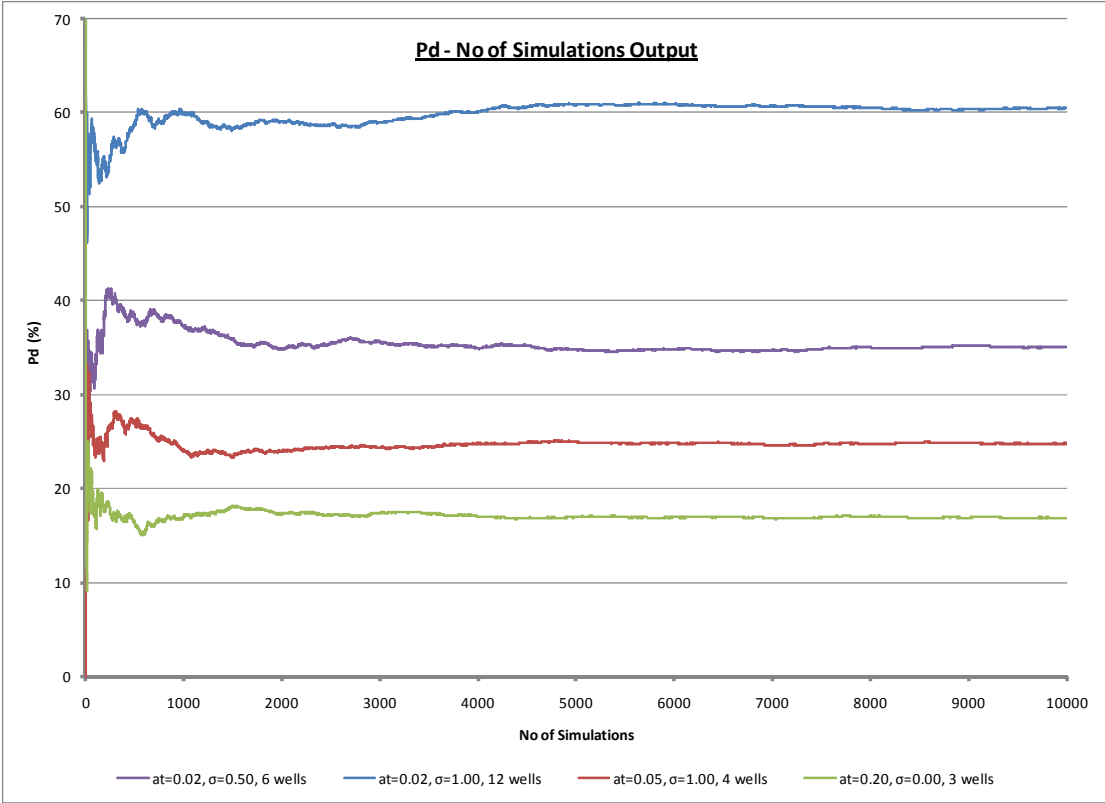
. μ , , μ μ μ ,

μ 500 μ Monte Carlo, μ μ ,

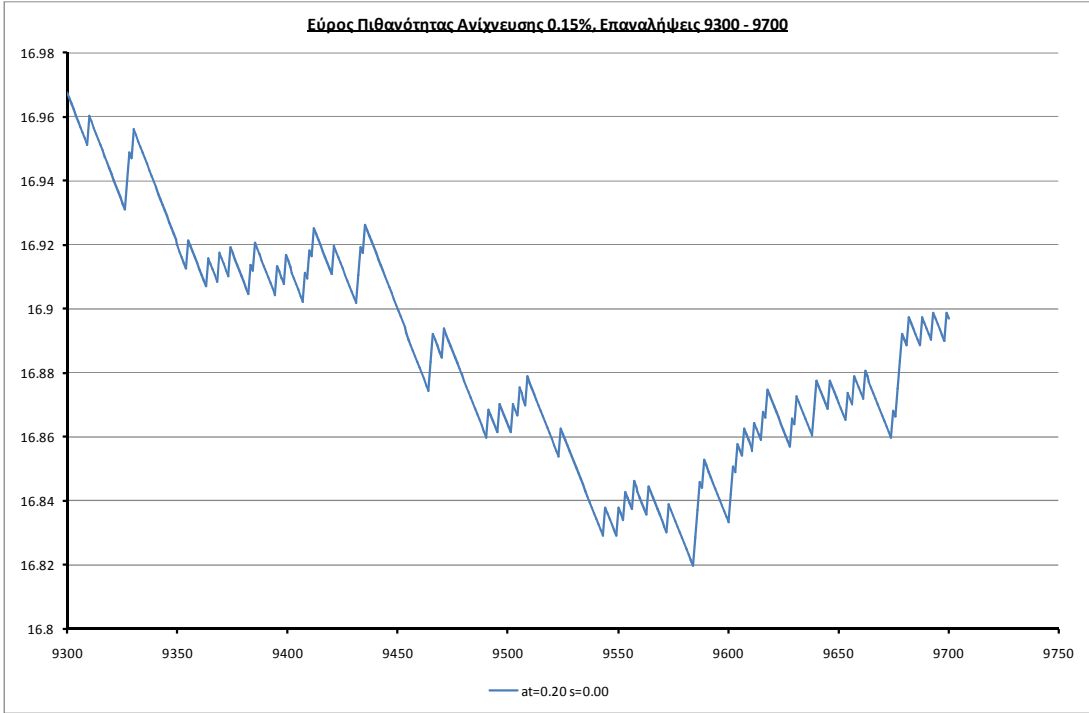
μ , μ , μ
2% . μ , μ μ

Yenigul et al (2005).

μμ 5.6 : μ μ μ

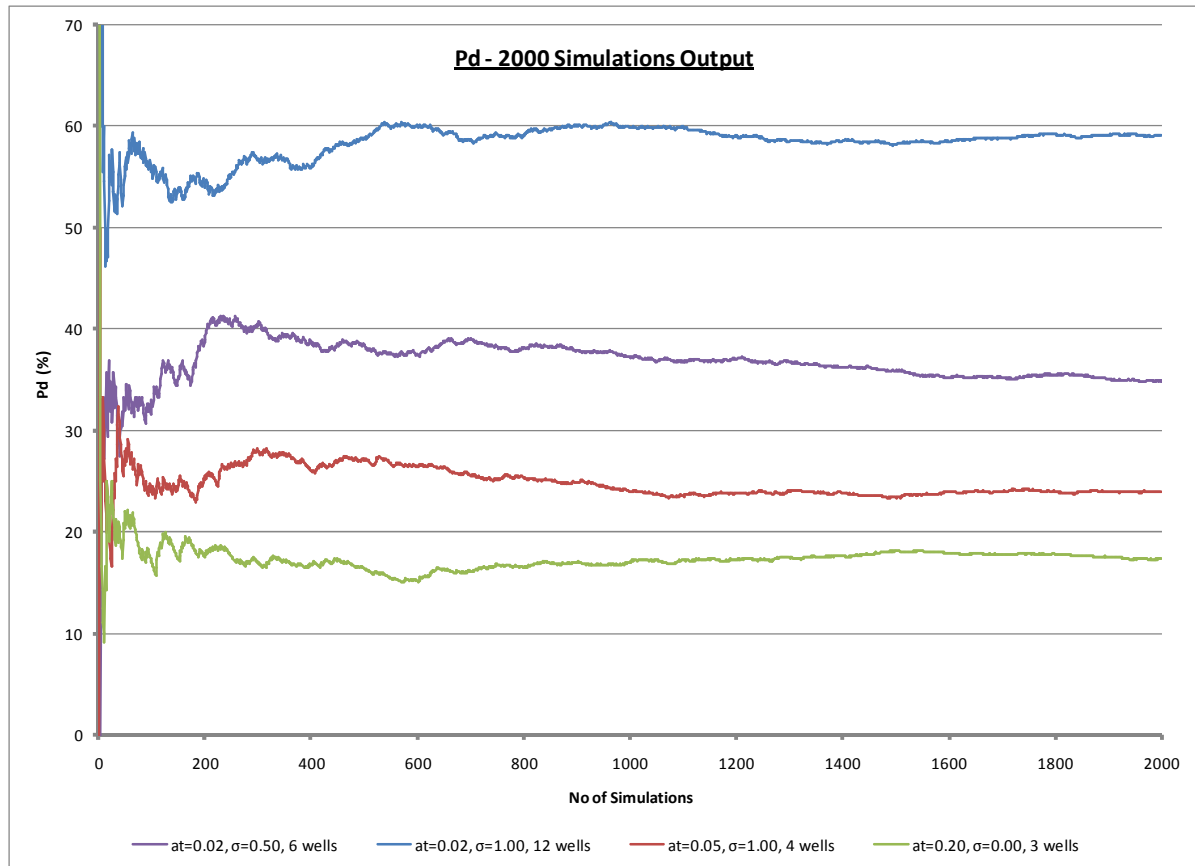


μμ 5.7 : 9300-9700

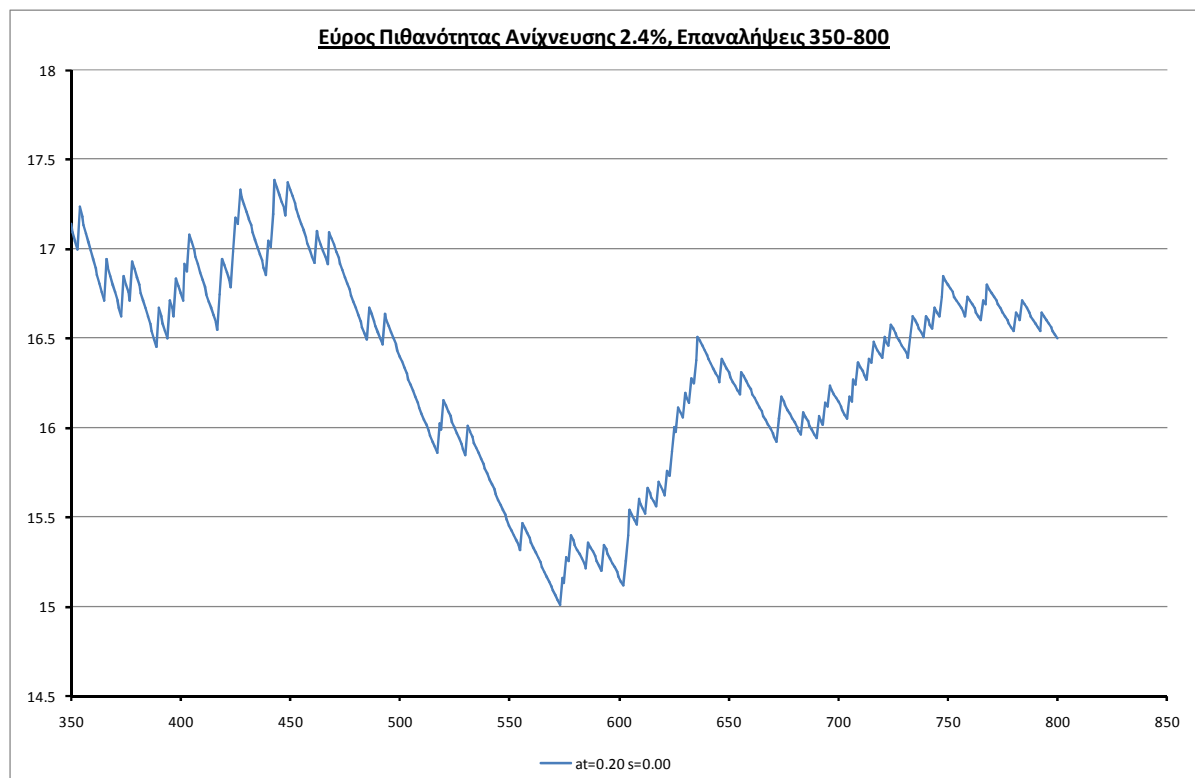


$\mu\mu$ 5.8 : μ

0-2000

 $\mu\mu$ 5.9 : μ

350-800



6. μ μ

6.1 μ μ

μ

, μ

. , :

- μ 3, 4, 6 12
- . . . , μ μ
μ , 0.125, 0.25, 0.50, 1.00, 1.25, 2.00 2.50
- μ μ 0.00, 0.50, 0.75, 1.00, 1.50 2.00
- μ 0.001m, 0.02, 0.05m, 0.10m 0.2m.

μ μ μ

μ .

μ μ μ

μ Yenigul et al (2005). μ

6.5.

, μ μ μ μ μ

. μ Δx Δy μ 1m

μ μ $1m^2$ $4m^2$ μ , μ μ

μ . μ ,

μ $1m^2$.

μ , μ μ μ

μ μ , μ

μ μ $C_{TH} = 14mgr / lt$, μ 28

μ , μ . μ , μ μ (3.45), μ

μ 8000 2000, μ . μ

, 500 × 300 ,

μ μ μ
 μ .

6.2 μ

μ μ μ , μ 3, 4, 6 12 ,
 μ . μ μ
 L, 0.33L, 0.25L, 0.17L 0.08L.
 , μ μ
 , , μ
 , μ , 0.125L
 2.00L. μ μ σ_Y μ 0.00, 0.50, 0.75,
 1.00, 1.50 2.00. μ μ μ 4.3.
 6.1. μ μ μ μ
 , μ μ
 .

6.2.1 μ

μ 6.1, (3)
 μ . μ
 μ μ μ ,
 μ 23.0%. μ ,
 μ μ μ μ μ
 — μ — μ
 (3) , μ μ
 . μ μ (3)
 μ
 . μ , μ
 80%,
 . μ μ , μ μ
 , μ μ . μ
 , μ μ μ — μ

100 % —

μ μ μ , (20).

μ μ μ 6.1 μ
 μ , μ ,
 μ , μ
 μ μ ,
 μ . μ , 6.1.

6.1 : Pd

σ_y		0.00		0.50		0.75		1.00		1.50		2.00	
$a_T(m)$	nws												
		nfds(max)	Pd (%) (max) (Model)	nfds(max)	Pd (%) (max) (Model)	nfds(max)	Pd (%) (max) (Model)	nfds(max)	Pd (%) (max) (Model)	nfds(max)	Pd (%) (max) (Model)	nfds(max)	Pd (%) (max) (Model)
0.001	0.33	2.50	13.8	1.25	12.4	1.00	7.0	0.50	7.6	0.50	8.2	0.25	7.6
	0.25	2.50	16.8	1.25	14.6	1.00	13.2	0.50	14.4	0.50	12.0	0.25	12.4
	0.17	2.50	27.6	1.25	20.6	1.00	21.8	0.50	18.4	0.50	19.6	0.25	15.6
	0.08	2.50	48.4	1.25	38.6	1.00	37.4	0.50	36.6	0.50	35.4	0.25	37.0
0.02	0.33	2.00	23.0	1.00	18.6	0.50	17.6	0.50	18.2	0.50	16.2	0.25	13.4
	0.25	2.00	26.8	1.00	24.0	0.50	23.6	0.50	23.6	0.50	20.6	0.25	18.6
	0.17	2.00	38.0	1.00	38.4	0.50	36.0	0.50	32.4	0.50	36.2	0.25	29.2
	0.08	2.00	78.6	1.00	64.4	0.50	64.0	0.50	58.8	0.50	54.0	0.25	53.8
0.05	0.33	0.50	19.6	0.50	20.2	0.50	18.8	0.25	18.2	0.25	18.6	0.25	14.0
	0.25	0.50	27.8	0.50	25.8	0.50	22.0	0.25	27.2	0.25	24.2	0.25	21.2
	0.17	0.50	42.4	0.50	31.6	0.50	33.8	0.25	40.0	0.25	34.4	0.25	32.4
	0.08	0.50	81.6	0.50	72.6	0.50	65.2	0.25	65.8	0.25	60.2	0.25	59.8
0.10	0.33	0.25	20.8	0.125	22.2	0.125	17.6	0.125	18.2	0.125	17.8	0.125	16.6
	0.25	0.25	23.4	0.125	23.6	0.125	27.8	0.125	25.0	0.125	23.0	0.125	21.6
	0.17	0.25	40.2	0.125	37.6	0.125	37.8	0.125	39.0	0.125	34.8	0.125	35.4
	0.08	0.25	81.0	0.125	73.0	0.125	70.0	0.125	70.0	0.125	63.4	0.125	59.2
0.20	0.33	0.125	16.4	0.125	14.2	0.125	14.6	0.125	10.2	0.125	12.8	0.125	10.6
	0.25	0.125	22.0	0.125	18.8	0.125	16.2	0.125	17.8	0.125	16.6	0.125	13.6
	0.17	0.125	32.6	0.125	30.8	0.125	25.0	0.125	27.4	0.125	22.2	0.125	22.0
	0.08	0.125	61.2	0.125	52.4	0.125	48.8	0.125	51.8	0.125	45.2	0.125	41.0

6.2.2

.

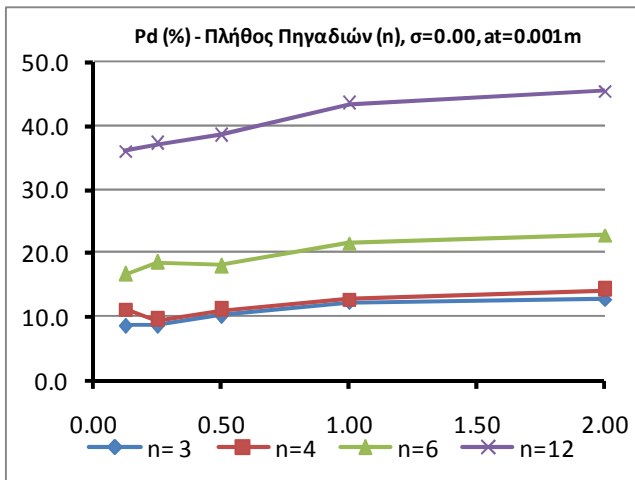
μ . μ , $\sigma_Y = 0.00$, μ μ
 μ ($\alpha_t = 0.001$) μ μ
 μ ($P_d = 13.80\%$) . μ μ
 μ μ , μ μ (6.2).

μ , μ μμ μμ 6.1 - μμ 6.3
 μ μ
 , μ μ 0.001m, 0.05m 0.20
 μ ($\sigma_Y = 0.00$) ($\sigma_Y = 1.00$) ,
 μ .
 μ , μ μ
 μ . μ
 , μ , μ μ
 , μ . μ
 μ μ μ

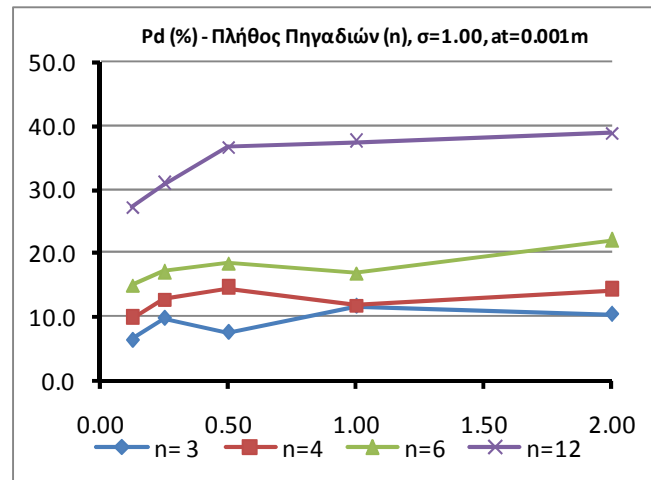
6.2 : Pd μ (=0.00 =1.00)

		σ_Y	0.00					1.00				
α_t	nws/ndfs		0.125	0.25	0.50	1.00	2.00	0.125	0.25	0.50	1.00	2.00
0.001	0.33		8.6	8.6	10.2	12.2	12.8	6.4	9.8	7.6	11.6	10.4
	0.25		11.2	9.4	11.0	12.8	14.2	9.8	12.8	14.4	11.8	14.2
	0.17		16.6	18.6	18.0	21.6	22.8	15.0	17.1	18.4	16.8	22.0
	0.08		36.0	37.0	38.4	43.4	45.4	27.2	30.8	36.6	37.4	38.8
0.05	0.33		17.0	19.0	19.6	21.2	3.0	15.2	18.2	16.0	6.7	0.0
	0.25		25.6	25.2	27.8	17.0	3.2	23.4	27.2	21.2	9.0	0.0
	0.17		34.4	42.4	42.4	32.8	6.5	35.0	40.0	31.0	9.6	0.0
	0.08		76.6	78.0	81.6	73.0	8.1	61.2	65.8	60.0	23.4	0.0
0.20	0.33		16.4	12.2	2.0	0.0	0.0	10.2	6.6	0.0	0.0	0.0
	0.25		22.0	14.6	2.2	0.0	0.0	17.8	7.4	0.0	0.0	0.0
	0.17		32.6	24.8	2.0	0.0	0.0	27.4	13.0	1.2	0.0	0.0
	0.08		61.2	43.6	7.0	0.0	0.0	51.8	29.2	1.8	0.0	0.0

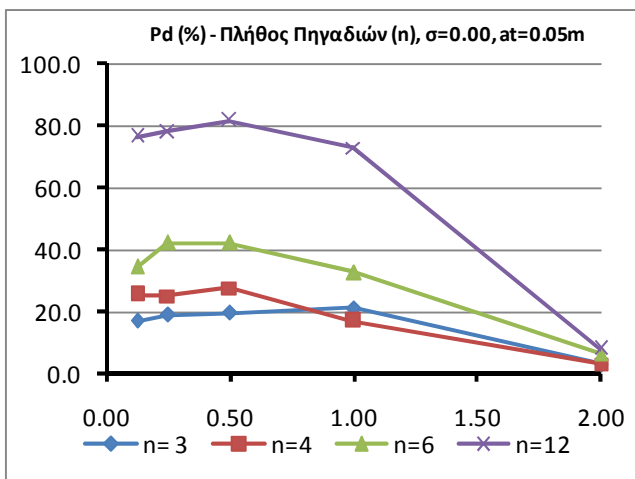
μ 6.1 : Pd μ



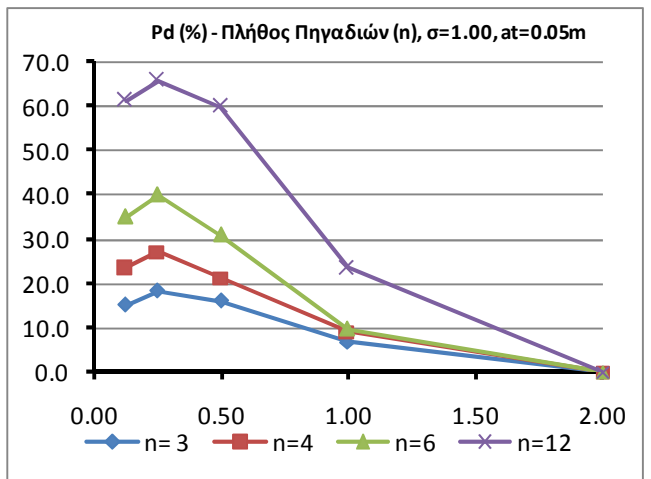
μ ($=0.00$ $=1.00$), $\epsilon=0.001$



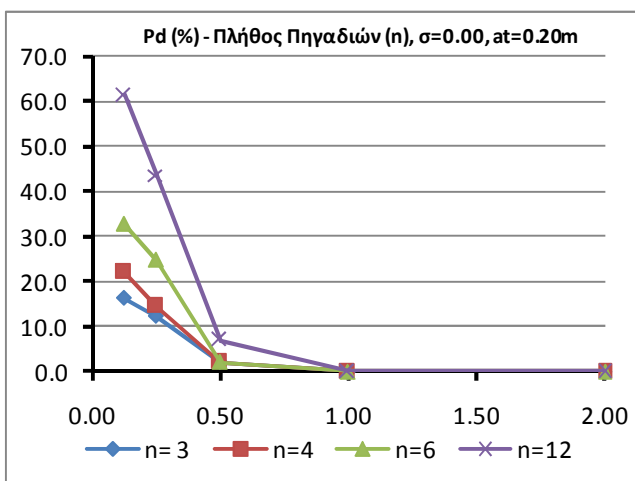
μ 6.2 : Pd μ



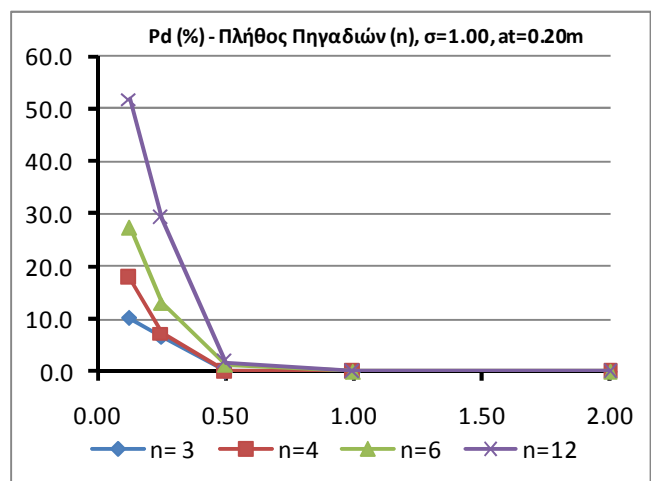
μ ($=0.00$ $=1.00$), $\epsilon=0.05$

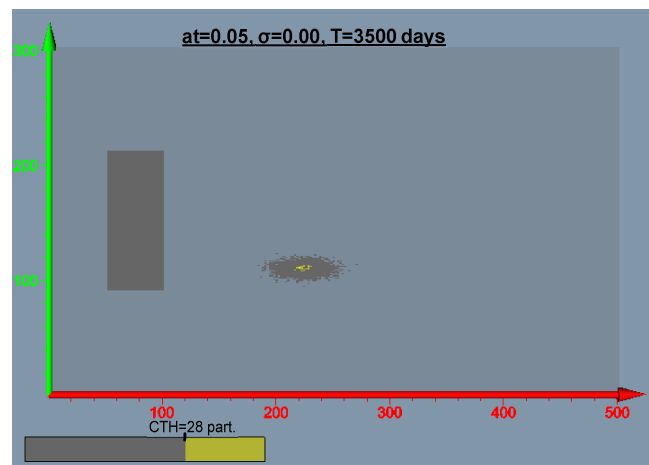
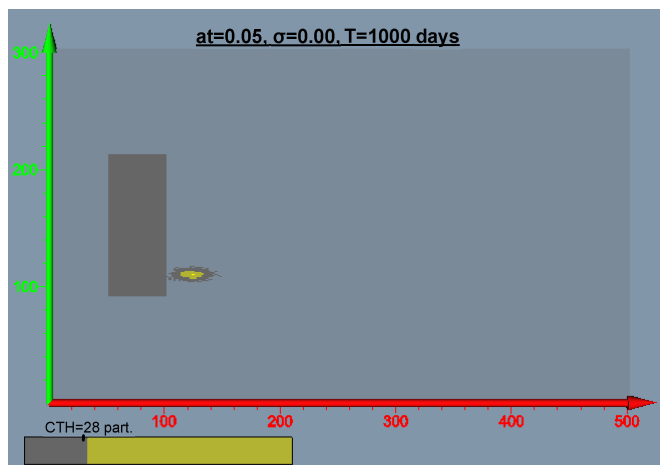


μ 6.3 : Pd μ



μ ($=0.00$ $=1.00$), $\epsilon=0.20$





μ μ μ C_{TH} μ μ
 μ μ , μ , μ μ
 μ , μ μ μ μ
 μ μ μ
 μ , μ μ μ μ
 μ , μ , μ .
 μ μ μ μ μ
 μ μ μ 6.3. μ μ
 μ μ , μ μ μ μ
 μ μ . , μ
 μ , μ μ μ μ
 μ .
 μ μ μ 7.4 7.5,
 $(\sigma_Y = 0.00 \quad \sigma_Y = 1.00)$,
 $(ndfs=0.125 \quad ndfs=0.50)$,
 μ μ . μ (μ 6.4) μ ,
 μ 0.125 , μ μ
0.10 m. μ 0.50, μ
 μ 0.05 m.
 μ , μ ,
 μ (μ 6.5) , μ
 μ μ , μ μ (2
4) μ μ μ μ μ
(6 12) . μ , μ ,
 μ
.

6.3 :

 μ

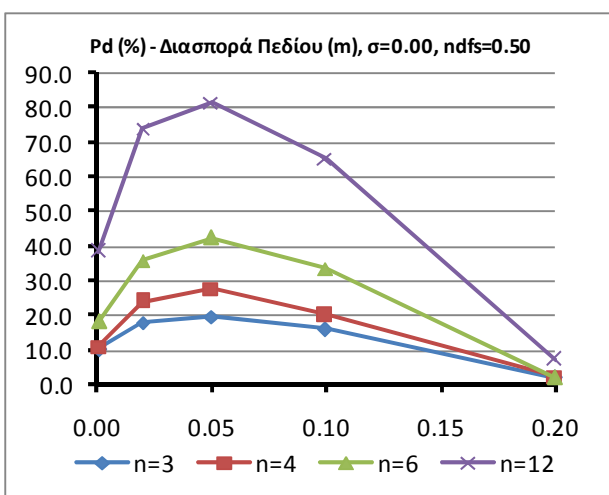
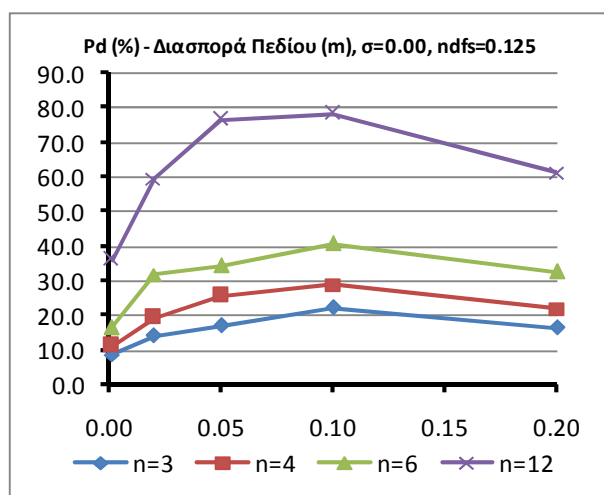
	ndfs	0.125					0.5				
σ_Y	nws/ α_t	0.001	0.02	0.05	0.10	0.20	0.001	0.02	0.05	0.10	0.20
0.00	0.33	8.6	14.2	17.0	22.2	16.4	10.2	17.8	19.6	16.0	2.0
	0.25	11.2	19.4	25.6	28.8	22.0	11.0	23.8	27.8	20.0	2.2
	0.17	16.6	31.8	34.4	40.8	32.6	18.0	35.8	42.4	33.4	2.0
	0.08	36.0	59.6	76.6	78.2	61.2	38.4	74.0	81.6	65.4	7.0
	ndfs	0.125					0.5				
σ	nws/ α_t	0.001	0.02	0.05	0.10	0.20	0.001	0.02	0.05	0.10	0.20
1.00	0.33	6.4	16.0	15.2	16.0	10.2	7.6	18.2	16.0	6.4	0.2
	0.25	9.8	17.4	23.4	22.4	17.8	14.4	23.6	21.2	9.6	0.8
	0.17	15.0	25.6	35.0	36.6	27.4	18.4	32.4	31.0	16.2	1.0
	0.08	27.2	54.8	61.2	67.4	51.8	36.6	58.8	60.0	26.6	1.6

 $\mu\mu$ 6.4 :

Pd

 μ μ

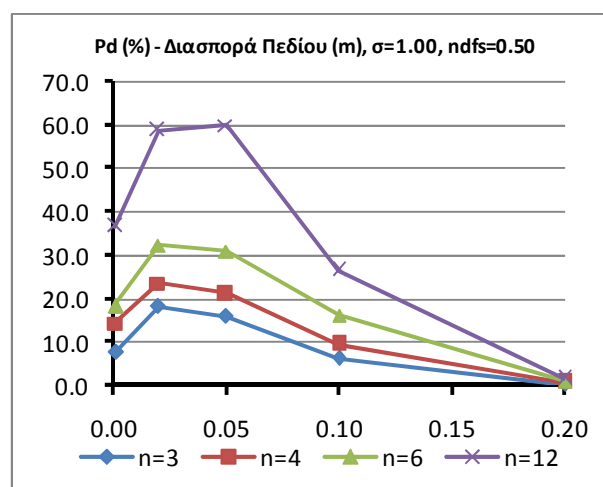
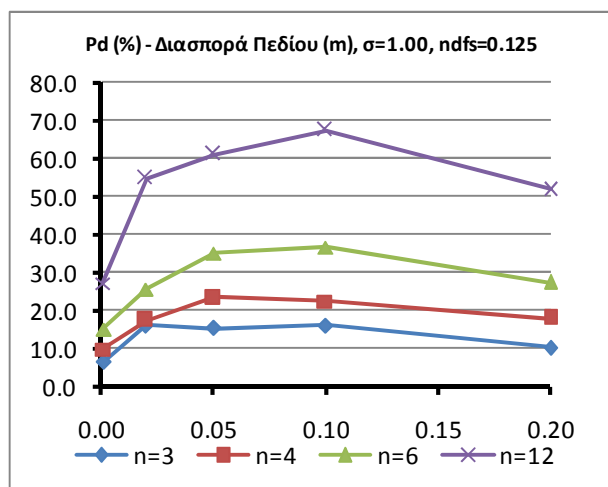
(ndfs=0.125 ndfs=0.50)

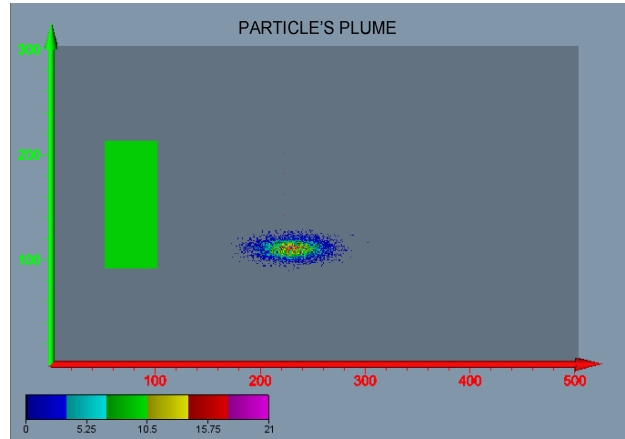
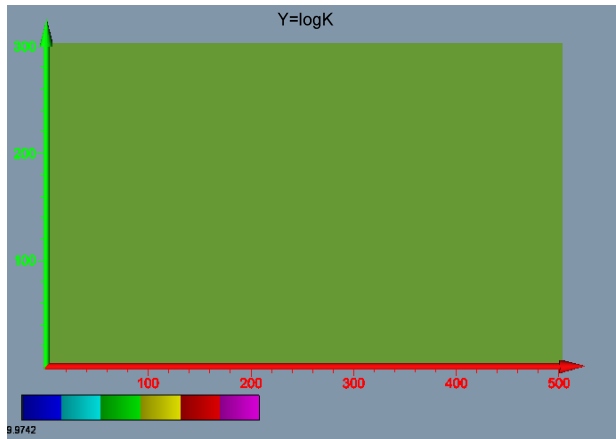
 $\mu\mu$ 6.5 :

Pd

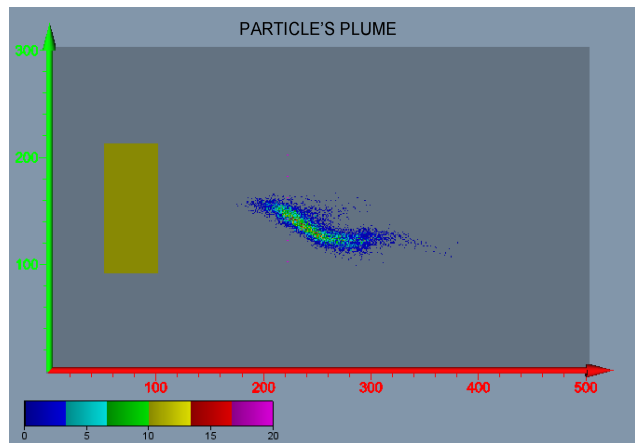
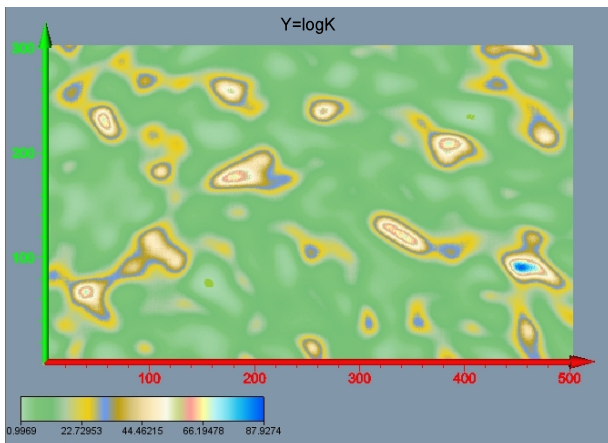
 μ

(ndfs=0.125 ndfs=0.50)

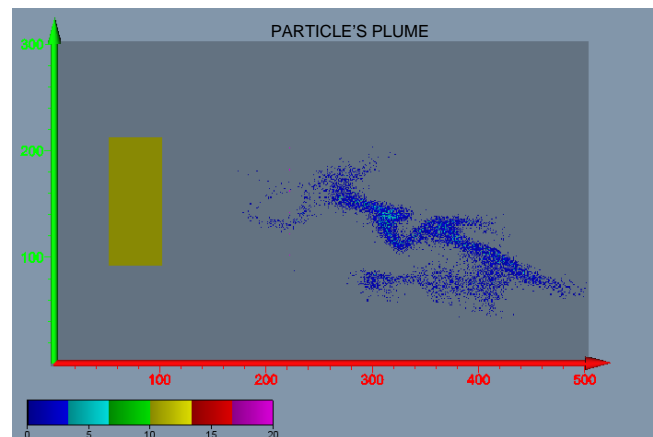
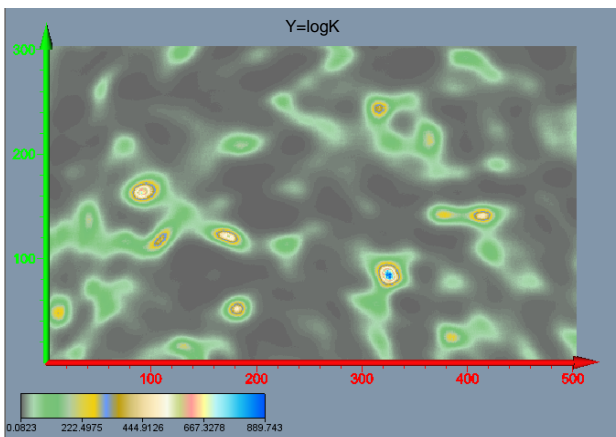




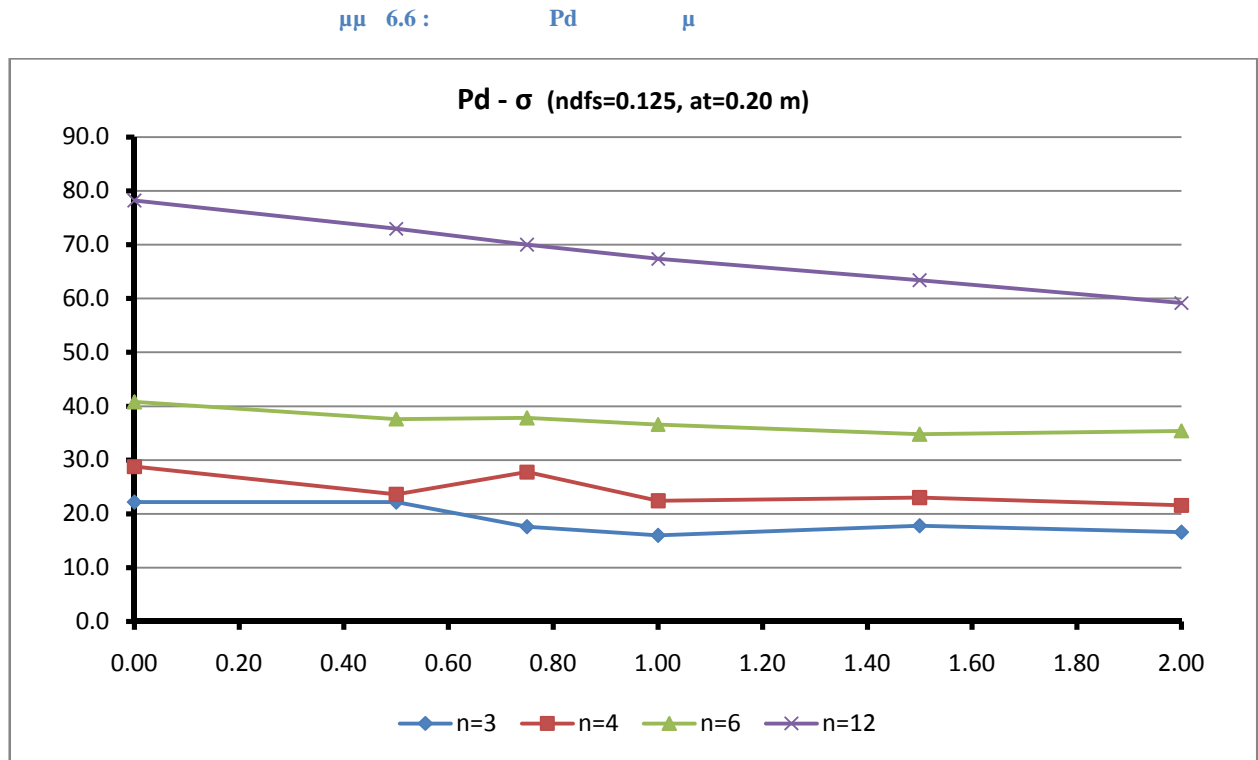
6.2 : μ μ μ ($=0.00$, $t=0.10m$, $t_{sim}=3650$ days)



6.3 : μ μ μ ($=0.50$, $t=0.10m$, $t_{sim}=3650$ days)



6.4 : μ μ μ ($=0.00$, $t=0.10m$, $t_{sim}=3650$ days)



6.3

μ μ *Yenigul et al. (2005)*

(TBRWM)

Yenigul et al [2005].

Yenigul et al [2005],

6.5.

μ
0.0 % 11.9 % (6.5).

120 μ (120x500=60000),

8 % . μμ μμ μμ 6.7

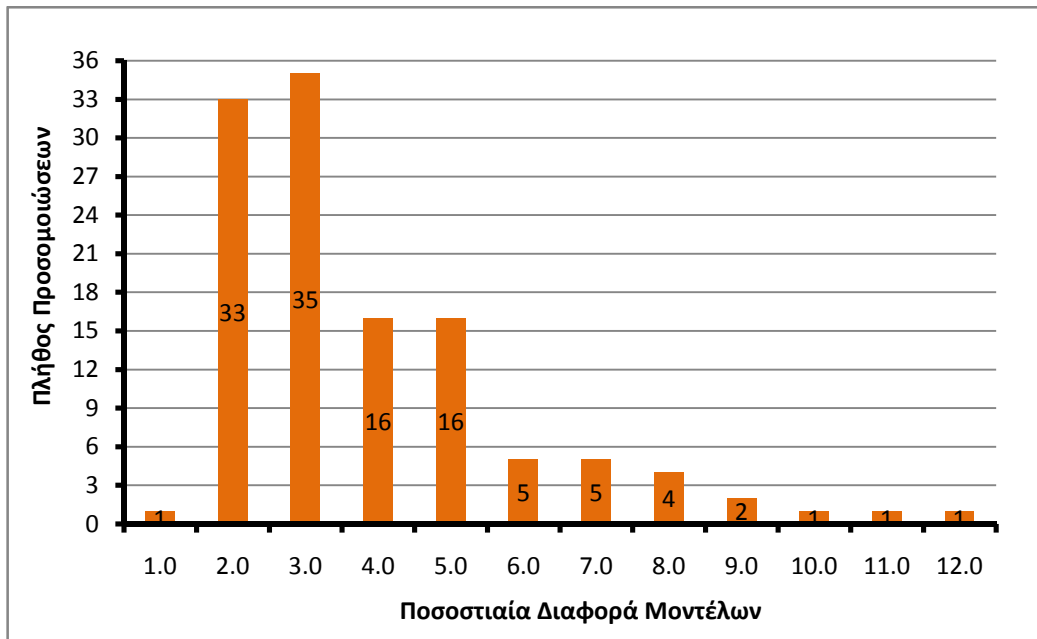
$$\mu \qquad \qquad \qquad \mu \qquad \qquad \mu$$
$$\mu \quad \mu \quad \mu$$

3%, μ μ 2.5 %.

6.5 :

 μ μ

σ_y	0.00	0.50	0.75	1.00	1.50	2.00
at(m)	nfs(max)	nfs(max)	nfs(max)	nfs(max)	nfs(max)	nfs(max)
0.001	0.33 2.50 11.0 13.8 -2.8 0.25 2.50 17.0 16.8 0.2 0.17 2.50 27.0 27.6 -0.6 0.08 2.50 50.0 48.4 1.6	1.25 12.0 12.4 -0.4 1.25 16.0 14.6 1.4 1.25 22.0 20.6 1.4 1.25 45.0 38.6 6.4	1.00 12.0 7.0 5.0 1.00 16.0 13.2 2.8 1.00 19.0 21.8 -2.8 1.00 45.0 37.4 7.6	0.50 9.0 7.6 1.4 0.50 12.0 14.4 -2.4 0.50 22.0 18.4 3.6 0.50 38.0 36.6 1.4	0.50 8.0 8.2 -0.2 0.50 12.0 12.0 0.0 0.50 16.0 19.6 -3.6 0.50 37.0 35.4 1.6	0.25 8.0 7.6 0.4 0.25 12.0 12.4 -0.4 0.25 15.0 15.6 -0.6 0.25 35.0 37.0 -2.0
0.02	0.33 2.00 19.0 23.0 -4.0 0.25 2.00 27.0 26.8 0.2 0.17 2.00 43.0 38.0 5.0 0.08 2.00 78.0 78.6 -0.6	1.00 17.0 18.6 -1.6 1.00 26.0 24.0 2.0 1.00 38.0 38.4 -0.4 1.00 70.0 64.4 5.6	0.50 16.0 17.6 -1.6 0.50 21.0 23.6 -2.6 0.50 38.0 36.0 2.0 0.50 66.0 64.0 2.0	0.50 15.0 18.2 -3.2 0.50 21.0 23.6 -2.6 0.50 34.0 32.4 1.6 0.50 65.0 58.8 6.2	0.50 15.0 16.2 -1.2 0.50 21.0 20.6 0.4 0.50 33.0 36.2 -3.2 0.50 60.0 54.0 6.0	0.25 15.0 13.4 1.6 0.25 21.0 18.6 2.4 0.25 28.0 29.2 -1.2 0.25 55.0 53.8 1.2
0.05	0.33 0.50 15.0 19.6 -4.6 0.25 0.50 25.0 27.8 -2.8 0.17 0.50 43.0 42.4 0.6 0.08 0.50 76.0 81.6 -5.6	0.50 20.0 20.2 -0.2 0.50 25.0 25.8 -0.8 0.50 33.0 31.6 1.4 0.50 73.0 72.6 0.4	0.50 17.0 18.8 -1.8 0.50 34.0 22.1 11.9 0.50 37.0 33.8 3.2 0.50 74.0 65.2 8.8	0.25 17.0 18.2 -1.2 0.25 26.0 27.2 -1.2 0.25 37.0 40.0 -3.0 0.25 72.0 65.8 6.2	0.25 17.0 18.6 -1.6 0.25 24.0 24.2 -0.2 0.25 35.0 34.4 0.6 0.25 68.0 60.2 7.8	0.25 18.0 14.0 4.0 0.25 25.0 21.2 3.8 0.25 36.0 32.4 3.6 0.25 64.0 59.8 4.2
0.10	0.33 0.25 20.0 20.8 -0.8 0.25 0.25 27.0 23.4 3.6 0.17 0.25 40.0 40.2 -0.2 0.08 0.25 79.0 81.0 -2.0	0.125 18.0 22.2 -4.2 0.125 26.0 23.6 2.4 0.125 38.0 37.6 0.4 0.125 76.0 73.0 3.0	0.125 18.0 17.6 0.4 0.125 25.0 27.8 -2.8 0.125 35.0 37.8 -2.8 0.125 71.0 70.0 1.0	0.125 18.0 18.2 -0.2 0.125 24.0 25.0 -1.0 0.125 33.0 39.0 -6.0 0.125 68.0 70.0 -2.0	0.125 18.0 17.8 0.2 0.125 21.0 23.0 -2.0 0.125 33.0 34.8 -1.8 0.125 61.0 63.4 -2.4	0.125 16.0 16.6 -0.6 0.125 21.0 21.6 -0.6 0.125 25.0 35.4 -10.4 0.125 53.0 59.2 -6.2
0.20	0.33 0.125 15.0 16.4 -1.4 0.25 0.125 18.0 22.0 -4.0 0.17 0.125 31.0 32.6 -1.6 0.08 0.125 64.0 61.2 2.8	0.125 11.0 14.2 -3.2 0.125 17.0 18.8 -1.8 0.125 29.0 30.8 -1.8 0.125 54.0 52.4 1.6	0.125 11.0 14.6 -3.6 0.125 18.0 16.2 1.8 0.125 26.0 25.0 1.0 0.125 50.0 48.8 1.2	0.125 11.0 10.2 0.8 0.125 18.0 17.8 0.2 0.125 25.0 27.4 -2.4 0.125 48.0 51.8 -3.8	0.125 11.0 12.8 -1.8 0.125 15.0 16.6 -1.6 0.125 23.0 22.2 0.8 0.125 40.0 45.2 -5.2	0.125 10.0 10.6 -0.6 0.125 13.0 13.6 -0.6 0.125 19.0 22.0 -3.0 0.125 37.0 41.0 -4.0

 μ 6.7: μ μ  μ μ

6.8 -

 μ

6.13,

 μ μ μ μ

,

 μ μ μ μ μ

(seeds)

 μ

,

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 μ μ μ

(5.3)

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.

,

TBRWM,

500,

5%,

, μ

α_L , σ_Y , μ

μ

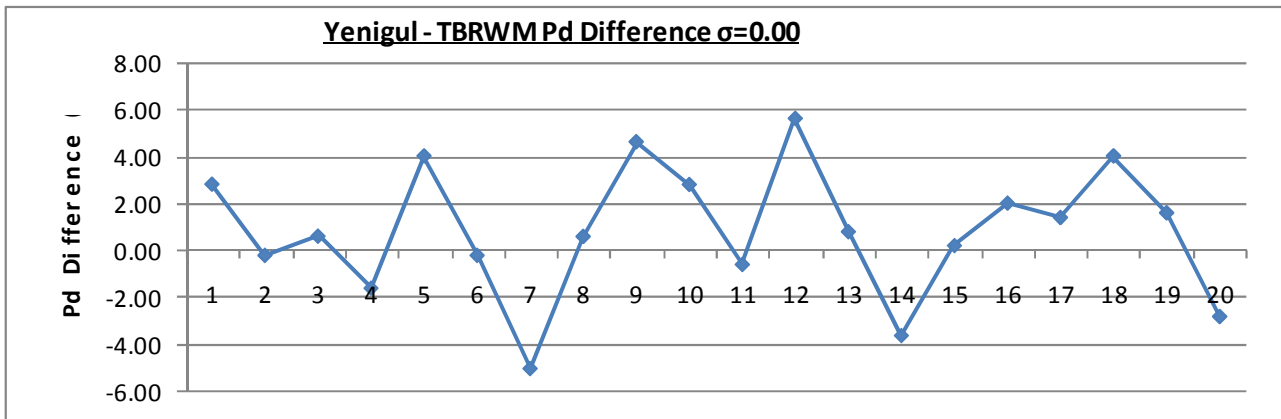
.

μμ 6.8 :

 μ

Pd

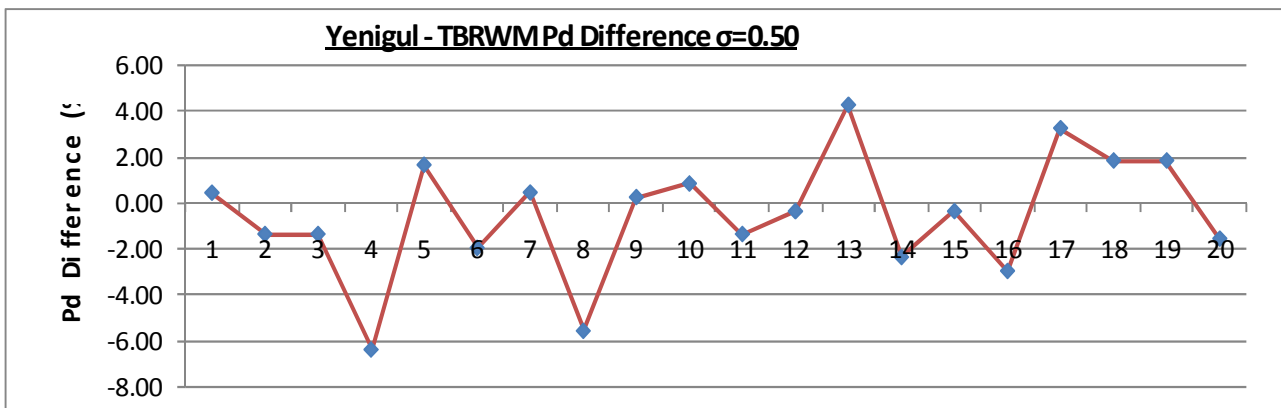
$\mu = 0.00$



μμ 6.9 :

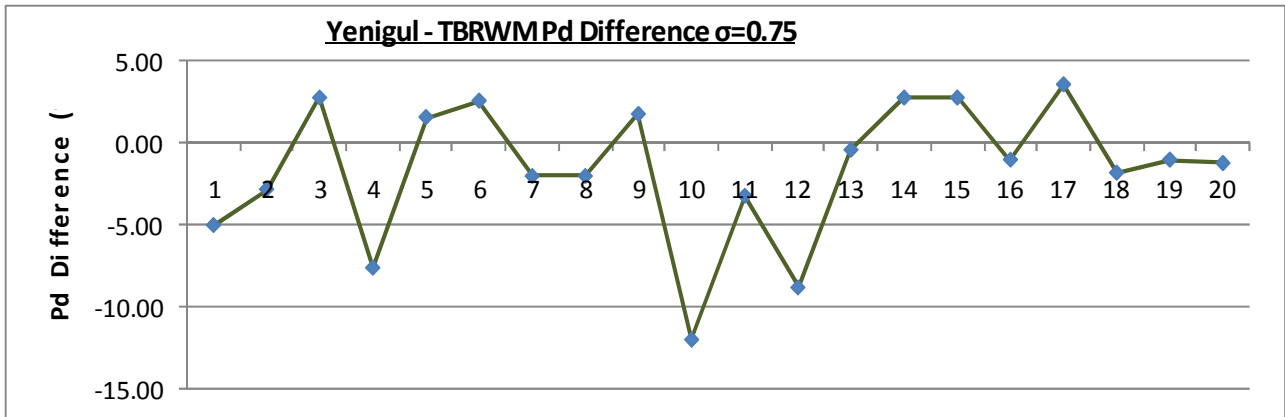
μ

Pd

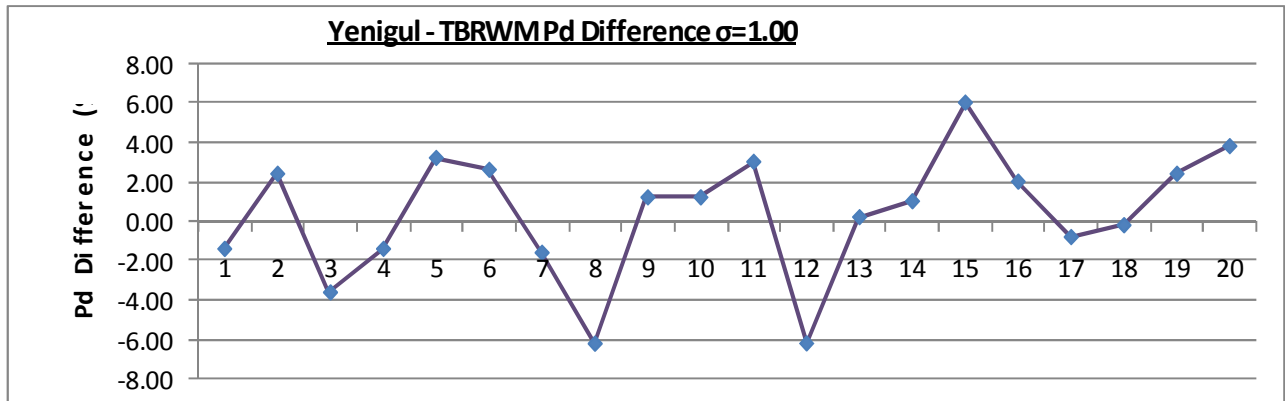
 $\mu = 0.50$ 

$\mu\mu$ 6.10 : μ

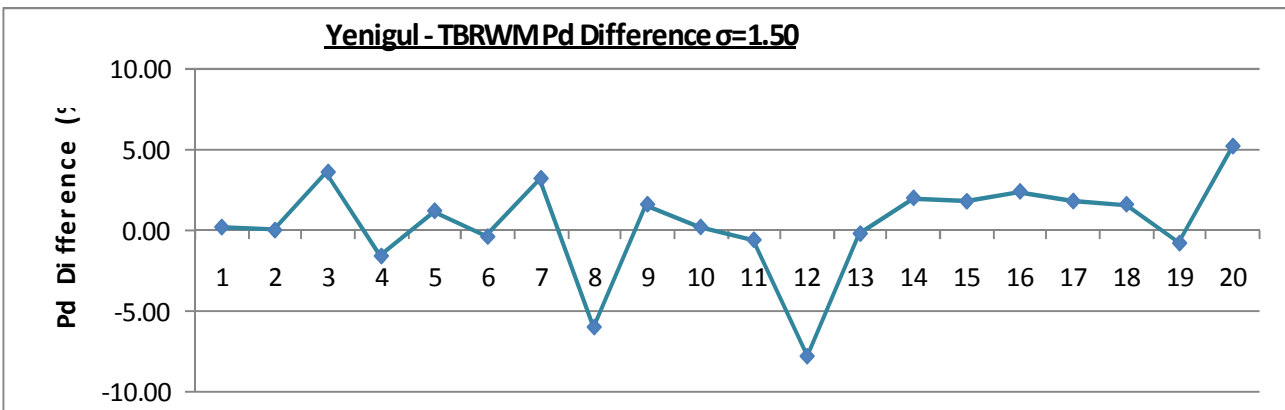
Pd

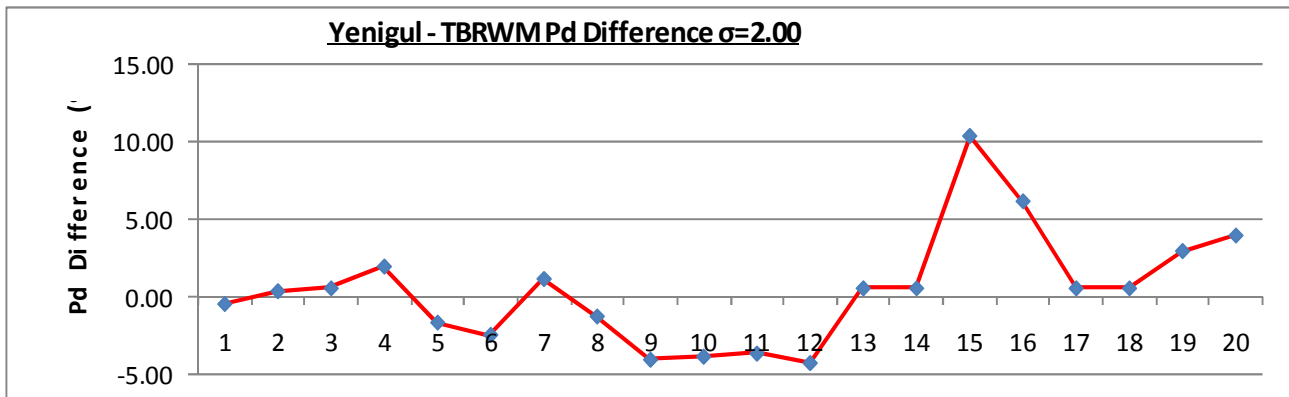
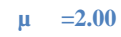
 $\mu = 0.75$  $\mu\mu$ 6.11 : μ

Pd

 $\mu = 1.00$  $\mu\mu$ 6.12 : μ

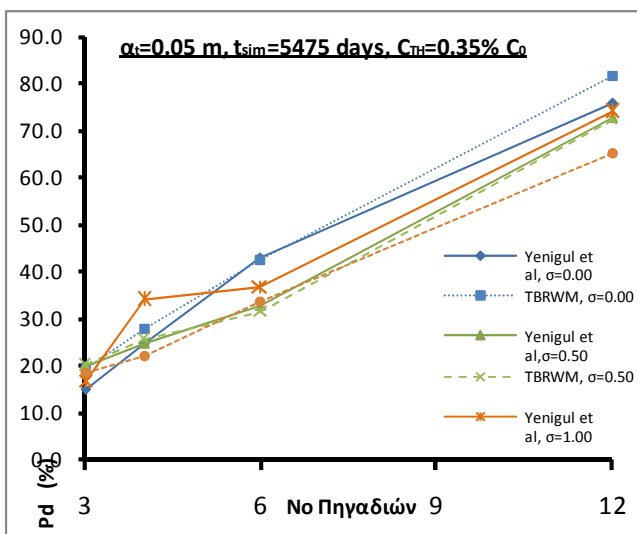
Pd

 $\mu = 1.50$ 

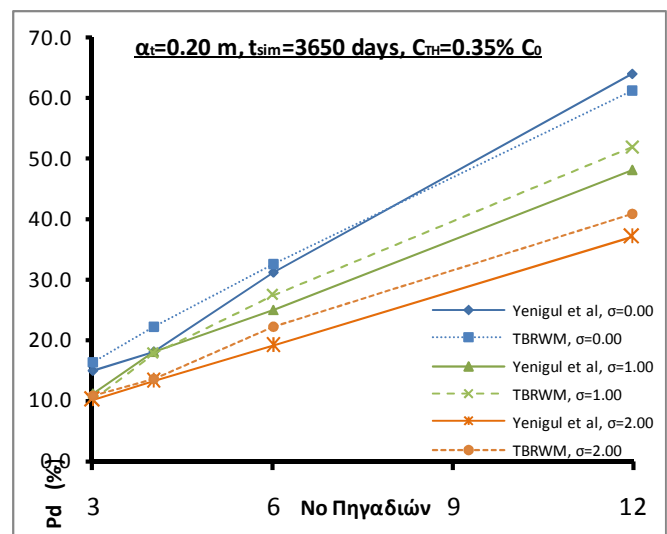


The results of the TBRWM model are compared with the results of the Yenigul et al [2005] model. The results of the TBRWM model are compared with the results of the Yenigul et al [2005] model. The results of the TBRWM model are compared with the results of the Yenigul et al [2005] model.

μμ 6.14 :



, Yenigul et al - TBRWM (ndfs=0.125 0.50)



6.4 μ μ μ

μ μ ,

6.1, μ μ

μ

μ . μ , μ

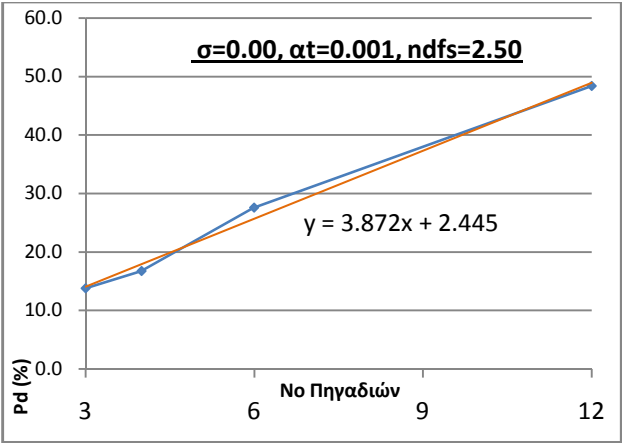
μ μ 6.15,

(1) – (15)

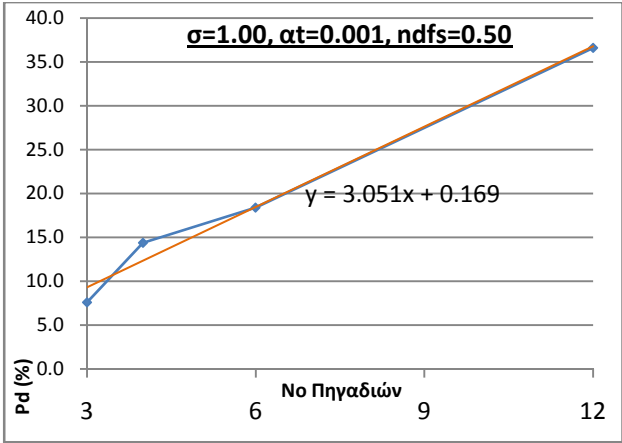
μ μ ,

μ σ_Y .

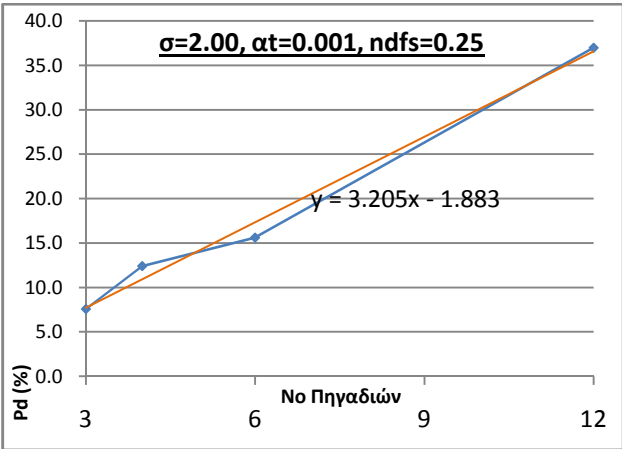
μ 6.15: Pd - () (1-15)



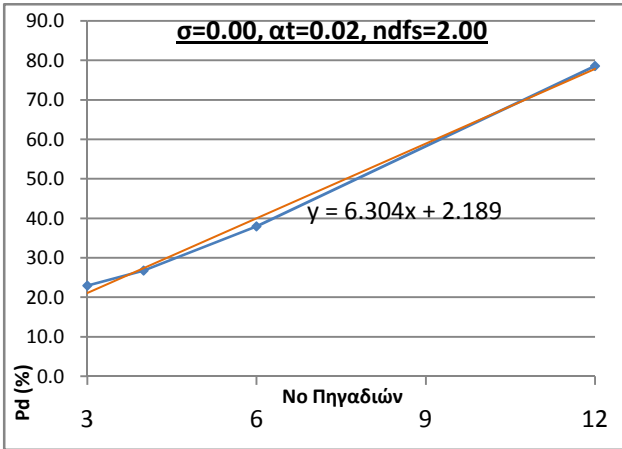
(1)



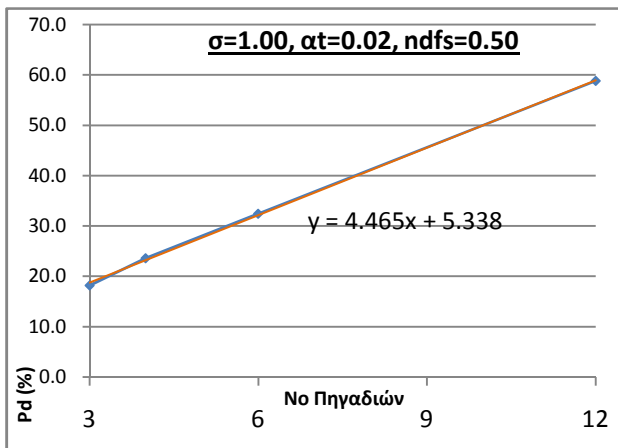
(2)



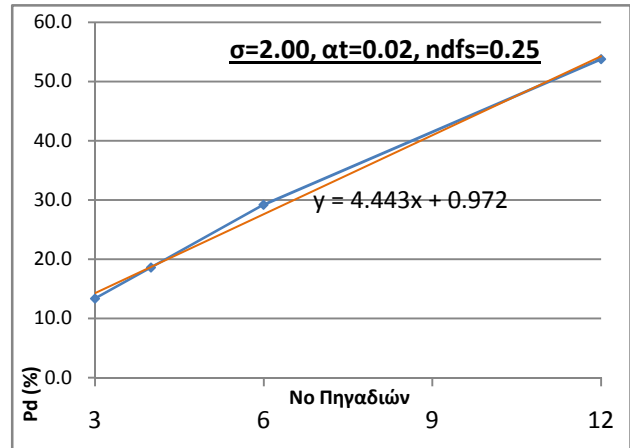
(3)



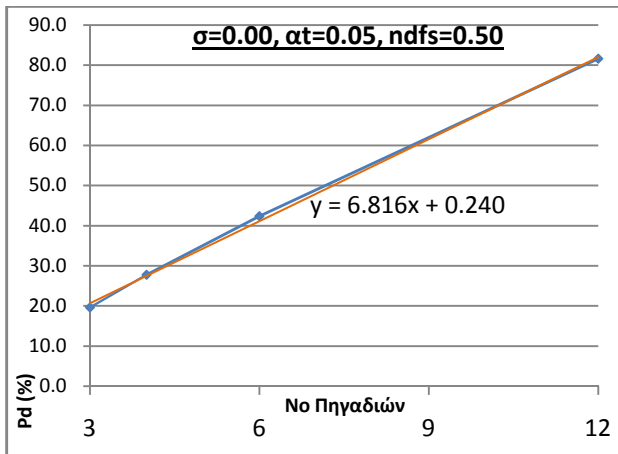
(4)



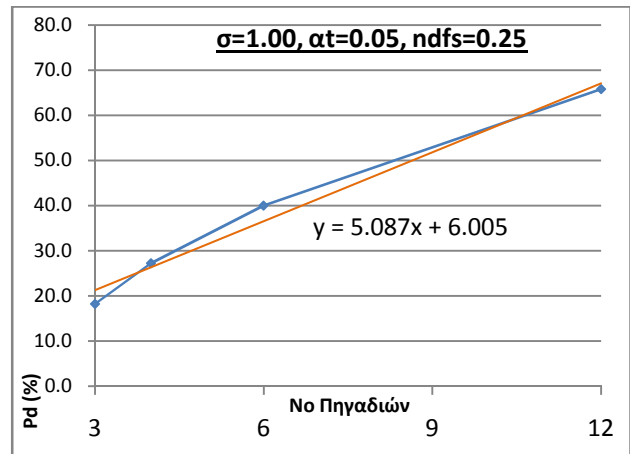
(5)



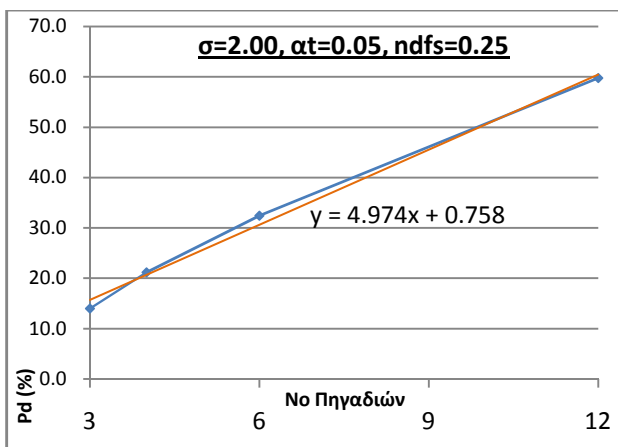
(6)



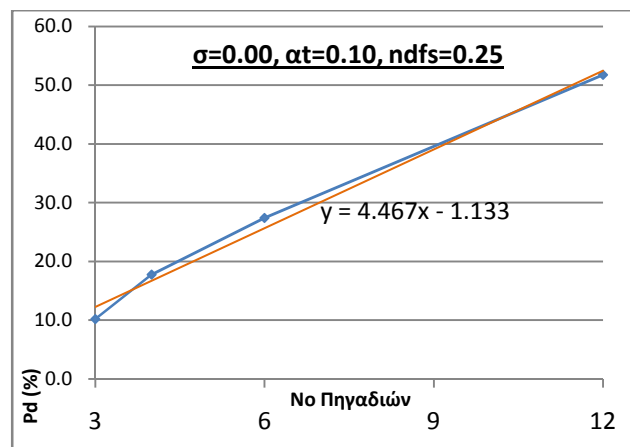
(7)



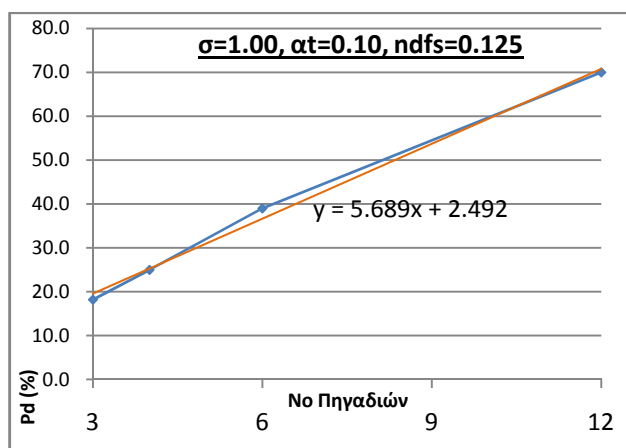
(8)



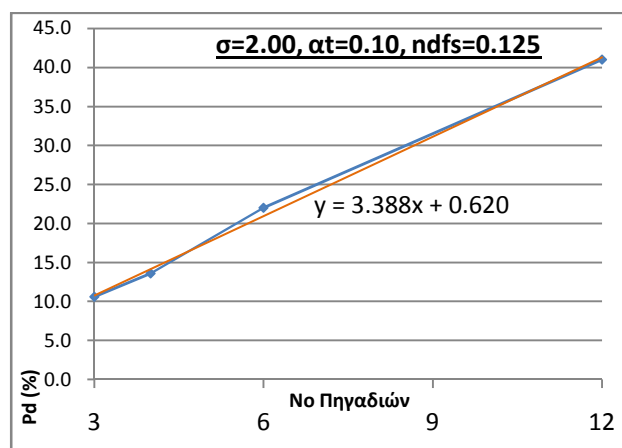
(9)



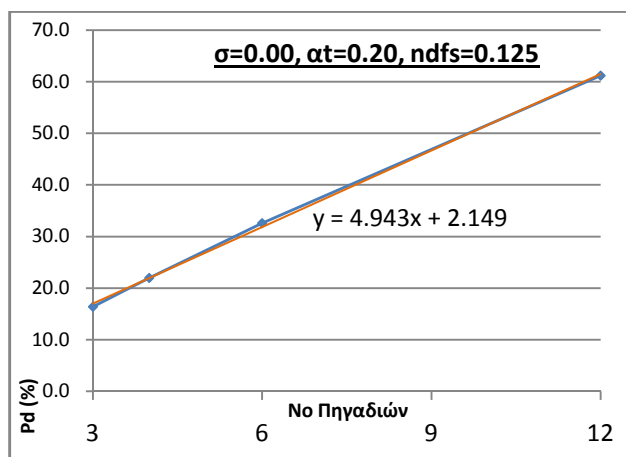
(10)



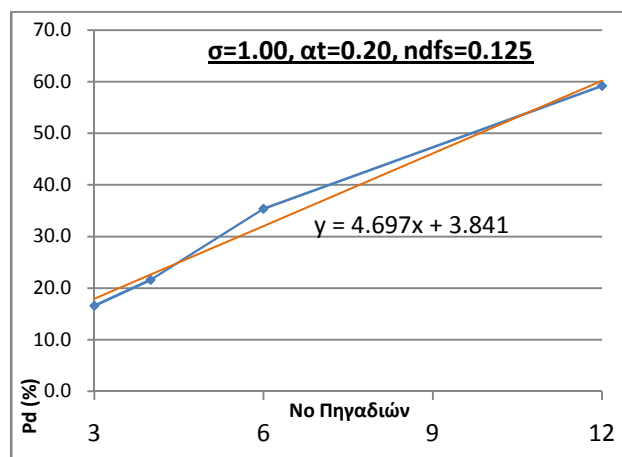
(11)



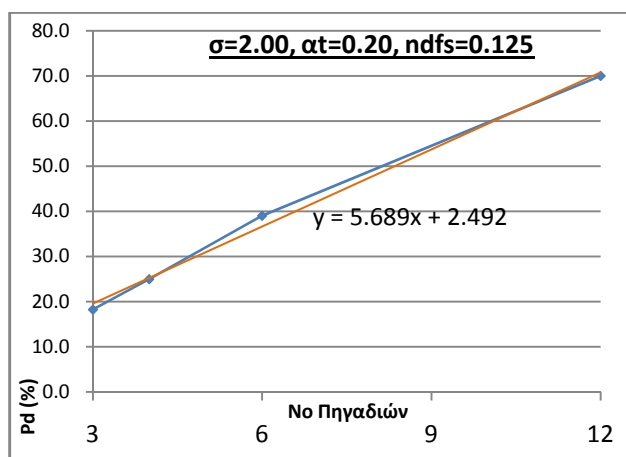
(12)



(13)



(14)



(15)

μ
μ , μ μ μ
, μ μ (soft data)
, μ μ
, μ μ μ , μ
. . . . , μ μ μ μ
μ μ μ , , μ μ
μ μ μ μ .

- μ μ :
- μ μ μ μ
μ μ μ μ , μ
.
 - ,
μ μ .
 - , μ μ μ .
 - μ μ
 - , .
 - μ μ , μ
, μ
μ 15.5%.

μ , μ μ
. . . . μ 6.6,
μ μ μ
μ (1) – (15) μ μ μ 6.15. μ
, μ μ :

$$P_{d(emp)} = \frac{120n}{3L} \left(4 \frac{d\alpha_t}{0.5 \cdot 0.05} - 5e^{-100(\alpha_t - 0.001)} - 5e^{-100(0.2 - \alpha_t)} - 2\sigma_Y + 15.5 \right) \quad (6.1)$$

, ,

$$P_{d(emp)} = \frac{40n}{L} \left(160d\alpha_t - 5e^{-100(\alpha_t - 0.001)} - 5e^{-100(0.2 - \alpha_t)} - 2\sigma_Y + 15.5 \right) \quad (6.2)$$

n , L μ , d
 μ μ L , α
 μ μ μ σ_Y μ μ μ
 μ μ .
 μ μ μ μ μ
 μ μ TBRW. μ μ μ .
 μ μ (6.2) . μ
 μ μ μ μ μ
 μ μ , μ
 μ .

6.6 :

 μ $\mu\mu$

7.13

at	σ	ndfs	$[\alpha]$	$[\beta]$
0.001	0	2.50	4	2
0.001	1	0.50	3	0
0.001	2	0.25	3	-2
0.020	0	2.00	6	2
0.020	1	0.50	4	5
0.020	2	0.25	4	1
0.050	0	0.50	7	0
0.050	1	0.25	5	6
0.050	2	0.50	5	1
0.100	0	0.25	4	-1
0.100	1	0.13	6	2
0.100	2	0.13	3	1
0.200	0	0.13	5	2
0.200	1	0.13	5	4
0.200	2	0.13	6	2

6.7

 μ μ μ

μ TBRWM μ μ (6.2).

μ μ μ μ μ 0.0 %

10.0 % (μ) μ μ μ μ .

μ μ , μ μ

μ μ , μ μ 3.2

% .

σ	0.00				0.50				0.75				1.00				1.50				2.00								
	$a^+(m)$		nws		nfts(max)		Pd (%) (max) (Model)		Pd (%) (max) Empirical		Pd (%) (Model)-Pd (%) (Empirical)		nfts(max)		Pd (%) (max) (Model)		Pd (%) (max) Empirical		Pd (%) (Model)-Pd (%) (Empirical)		nfts(max)		Pd (%) (max) (Model)		Pd (%) (max) Empirical		Pd (%) (Model)-Pd (%) (Empirical)		
0.001	0.33	2.50	13.8	11.0	2.8	1.25	12.4	9.8	2.6	1.00	7.0	9.3	-2.3	0.50	7.6	8.7	-1.1	0.50	8.2	7.7	0.5	0.25	7.6	6.6	1.0				
0.001	0.25	2.50	16.8	14.5	2.3	1.25	14.6	12.9	1.7	1.00	13.2	12.2	1.0	0.50	14.4	11.4	3.0	0.50	12.0	10.1	1.9	0.25	12.4	8.7	3.7				
0.001	0.17	2.50	27.6	21.4	6.2	1.25	20.6	19.0	1.6	1.00	21.8	18.0	3.8	0.50	18.4	16.8	1.6	0.50	19.6	14.9	4.7	0.25	15.6	12.8	2.8				
0.001	0.08	2.50	48.4	45.4	3.0	1.25	38.6	40.4	-1.8	1.00	37.4	38.2	-0.8	0.50	36.6	35.7	0.8	0.50	35.4	31.6	3.8	0.25	37.0	27.2	9.8				
0.02	0.33	2.00	23.0	21.4	1.6	1.00	18.6	17.1	1.5	0.50	17.6	15.0	2.6	0.50	18.2	14.5	3.7	0.50	16.2	13.5	2.7	0.25	13.4	11.7	1.7				
0.02	0.25	2.00	26.8	28.2	-1.4	1.00	24.0	22.6	1.4	0.50	23.6	19.8	3.8	0.50	23.6	19.1	4.5	0.50	20.6	17.8	2.8	0.25	18.6	15.4	3.2				
0.02	0.17	2.00	38.0	41.5	-3.5	1.00	38.4	33.2	5.2	0.50	36.0	29.1	6.9	0.50	32.4	28.1	4.3	0.50	36.2	26.2	10.0	0.25	29.2	22.7	6.5				
0.02	0.08	2.00	78.6	88.1	-9.5	1.00	64.4	70.6	-6.2	0.50	64.0	61.9	2.1	0.50	58.8	59.8	-1.0	0.50	54.0	55.6	-1.6	0.25	53.8	48.1	5.7				
0.05	0.33	0.50	19.6	19.7	-0.1	0.50	20.2	18.6	1.6	0.50	18.8	18.1	0.6	0.50	18.2	15.6	2.6	0.25	18.6	14.6	4.0	0.25	14.0	13.6	0.4				
0.05	0.25	0.50	27.8	26.0	1.8	0.50	25.8	24.6	1.2	0.50	22.0	24.0	-2.0	0.25	27.2	20.6	6.6	0.25	24.2	19.3	4.9	0.25	21.2	18.0	3.2				
0.05	0.17	0.50	42.4	38.2	4.2	0.50	31.6	36.2	-4.6	0.50	33.8	35.2	-1.4	0.25	40.0	30.3	9.7	0.25	34.4	28.4	6.0	0.25	32.4	26.4	6.0				
0.05	0.08	0.50	81.6	81.1	0.5	0.50	72.6	76.9	-4.3	0.50	65.2	74.8	-9.7	0.25	65.8	64.4	1.4	0.25	60.2	60.3	-0.1	0.25	59.8	56.1	3.7				
0.10	0.33	0.25	20.8	19.7	1.1	0.13	22.2	16.7	5.5	0.13	17.6	16.2	1.4	0.13	18.2	15.7	2.5	0.13	17.8	14.6	3.1	0.13	16.6	13.6	3.0				
0.10	0.25	0.25	23.4	26.0	-2.6	0.13	23.6	22.0	1.6	0.13	27.8	21.3	6.5	0.13	25.0	20.7	4.3	0.13	23.0	19.3	3.7	0.13	21.6	18.0	3.6				
0.10	0.17	0.25	40.2	38.2	2.0	0.13	37.6	32.4	5.2	0.13	37.8	31.4	6.4	0.13	39.0	30.4	8.6	0.13	34.8	28.4	6.4	0.13	35.4	26.5	8.9				
0.10	0.08	0.25	81.0	81.2	-0.2	0.13	73.0	68.7	4.3	0.13	70.0	66.7	3.3	0.13	70.0	64.6	5.4	0.13	63.4	60.4	3.0	0.13	59.2	56.2	3.0				
0.20	0.33	0.125	16.4	14.6	1.7	0.125	14.2	13.6	0.6	0.125	14.6	13.1	1.5	0.125	10.2	12.6	-2.4	0.125	12.8	11.6	1.2	0.125	10.6	10.6	0.0				
0.20	0.25	0.125	22.0	19.3	2.7	0.125	18.8	18.0	0.8	0.125	16.2	17.3	-1.1	0.125	17.8	16.7	1.1	0.125	16.6	15.3	1.3	0.125	13.6	14.0	-0.4				
0.20	0.17	0.125	32.6	28.4	4.2	0.125	30.8	26.5	4.3	0.125	25.0	25.5	-0.5	0.125	27.4	24.5	2.9	0.125	22.2	22.5	-0.3	0.125	22.0	20.6	1.4				
0.20	0.08	0.125	61.2	60.4	0.8	0.125	52.4	56.2	-3.8	0.125	48.8	54.2	-5.4	0.125	51.8	52.1	-0.3	0.125	45.2	47.9	-2.7	0.125	41.0	43.7	-2.7				

1	2022	100
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[illegible]

6.5 μ

μ μ ,
μ μ μ Δx = Δy = 2 m , μ μ
250x150 , μ μ μ .
, μ μ μ 3.4.1,
μ μ μ μ μ μ .
μ — ,
, μ μ μ 2 × 2 = 4 m² .
μ , μ , μ
μ μ 4 m² . , μ μ
μ μ μ μ . ,
, μ μ TBRWM μ
. μ Δx = Δy = 1 m , μ μ
μ μ μ 500x300 μ
μ 1m² .
μ μ
, μ μ 2000 μ , μ , μ
μ μ , μ
. μ C_{TH}=14 mg/lit, μ
, μ 28 μ .
μ 28/14=2 μ /mg/ . μ
, μ , μ μ ,
μ μ μ μ 2000 , μ μ (3.45),
μ C_{TH}=14 mg/lit μ 7 μ .
μ μ μ μ 7/14=0.5 μ /mg/ ,
μ μ μ μ μ
μ μ (4), μ
μ .
μ μ μ μ
μ μ μ . μ
, μ μ 28/14=2

μ /mg/ . , μ μ μ μ
 μ μ μ μ μ , , μ
 μ , 8000 . μ
 , , μ ,
 μ μ μ μ μ
 μ . , μ
 , μ μ μ μ μ
 μ μ μ
 .

6.5.1 μ μ

μ , μ μ μ
 μ ($\alpha_i = 0.001m$) μ μ μ
 μ $\sigma_Y \mu$ 1.00.
 μ μ μ , μ
 250x150, μ
 μ ,
 .
 μ μ 500x300, 250x150, μ
 Yenigul et al [2005] 6.9.
 μ
 μ μ μ , , μ
 .

6.5.2 μ μ 500x300

μ μ μ
 μ μ μ 500x300
 μ 250x150. μ ,
 :
 1. μ μ ($\alpha_i \leq 0.05$), μ μ
 , μ μ 5 % μ

σ		0.00					0.50					1.00				
$a_t(m)$	nws	0.00					0.50					1.00				
		$nfds(max)$	Pd (%) (max) (Yenigul et al, 2005)	Pd (%) (max) (250x150 TBRW Model)	Pd (%) (max) (500x300 TBRW Model)	TBRWM(250x150)-TBRWM(500x300)	$nfds(max)$	Pd (%) (max) (Yenigul et al, 2005)	Pd (%) (max) (250x150 TBRW Model)	Pd (%) (max) (500x300 TBRW Model)	TBRWM(250x150)-TBRWM(500x300)	$nfds(max)$	Pd (%) (max) (Yenigul et al, 2005)	Pd (%) (max) (250x150 TBRW Model)	Pd (%) (max) (500x300 TBRW Model)	TBRWM(250x150)-TBRWM(500x300)
0.02	0.33	2.00	19.0	23.0	19.8	3.2	1.00	17.0	18.6	18.6	0.0	0.50	15.0	18.2	17.6	0.6
	0.25	2.00	27.0	26.8	26.0	0.8	1.00	26.0	24.0	24.9	-0.9	0.50	21.0	23.6	21.0	2.6
	0.17	2.00	43.0	38.0	38.8	-0.8	1.00	38.0	38.4	40.6	-2.2	0.50	34.0	32.4	32.2	0.2
	0.08	2.00	78.0	78.6	82.6	-4.0	1.00	70.0	64.4	67.8	-3.4	0.50	65.0	58.8	57.0	1.8
0.05	0.33	0.50	15.0	19.6	20.2	-0.6	0.50	20.0	20.2	21.8	-1.6	0.25	17.0	18.2	24.6	-6.4
	0.25	0.50	25.0	27.8	30.6	-2.8	0.50	25.0	25.8	27.0	-1.2	0.25	26.0	27.2	23.5	3.7
	0.17	0.50	43.0	42.4	43.0	-0.6	0.50	33.0	31.6	41.0	-9.4	0.25	37.0	40.0	36.0	4.0
	0.08	0.50	76.0	81.6	87.2	-5.6	0.50	73.0	72.6	69.3	3.3	0.25	72.0	65.8	67.2	-1.4
0.10	0.33	0.25	20.0	20.8	21.4	-0.6	0.125	18.0	22.2	18.5	3.7	0.125	18.0	18.2	17.4	0.8
	0.25	0.25	27.0	23.4	26.0	-2.6	0.125	26.0	23.6	29.8	-6.2	0.125	24.0	25.0	21.6	3.4
	0.17	0.25	40.0	40.2	43.7	-3.5	0.125	38.0	37.6	41.0	-3.4	0.125	33.0	39.0	36.6	2.4
	0.08	0.25	79.0	81.0	86.3	-5.3	0.125	76.0	73.0	77.5	-4.5	0.125	68.0	70.0	65.6	4.4
0.20	0.33	0.125	15.0	16.4	18.2	-1.8	0.125	11.0	14.2	15.2	-1.0	0.125	11.0	10.2	9.9	0.3
	0.25	0.125	18.0	22.0	26.2	-4.2	0.125	17.0	18.8	22.8	-4.0	0.125	18.0	17.8	17.9	-0.1
	0.17	0.125	31.0	32.6	37.0	-4.4	0.125	29.0	30.8	33.8	-3.0	0.125	25.0	27.4	30.8	-3.4
	0.08	0.125	64.0	61.2	77.8	-16.6	0.125	54.0	52.4	63.4	-11.0	0.125	48.0	51.8	55.0	-3.2

6.9 :

 μ μ

500x300

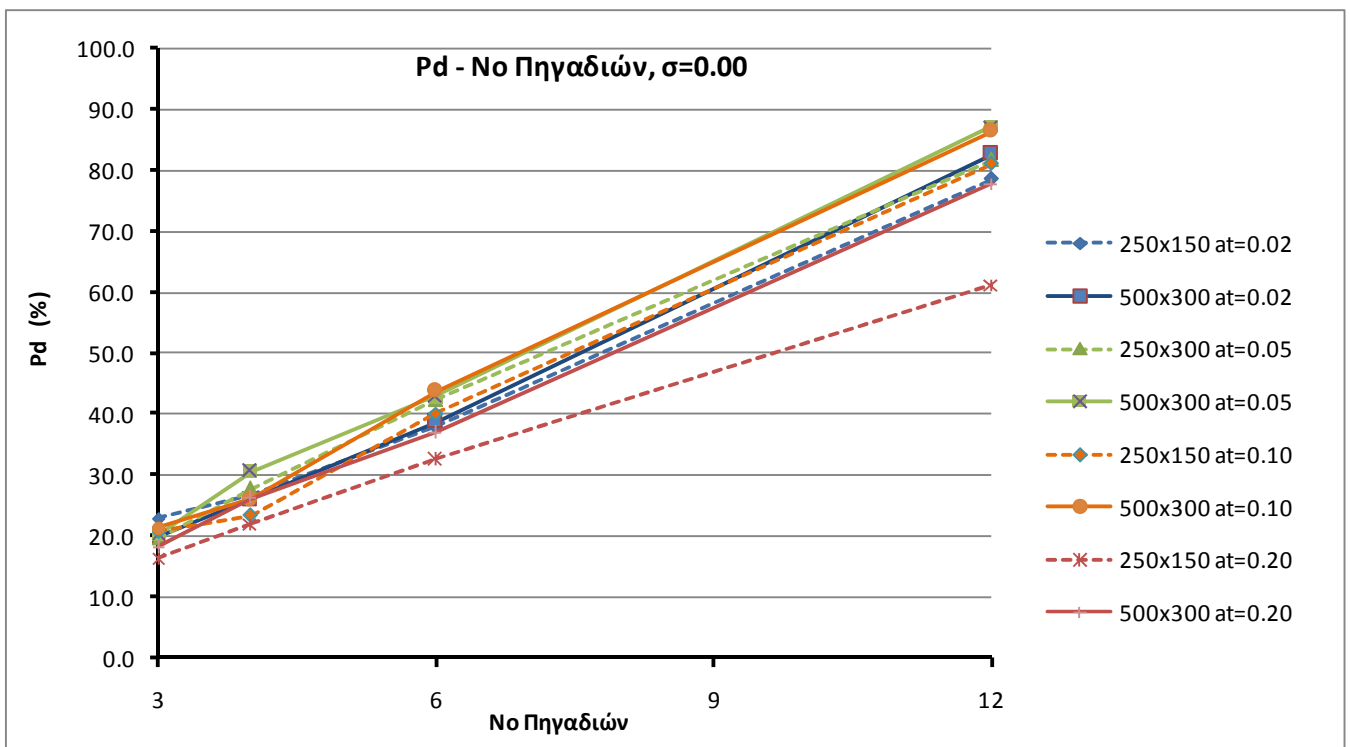
 μ

250x150

 μ μ . μ μ

2. μ μ μ μ $(\alpha_t > 0.05)$, μ
- μ μ μ
- μ , μ μ
3. μ
- μ $(\alpha_t = 0.20)$.
4. μ (6)
- (12)
5. μ 500x300 μ
- μ Monte Carlo.
6. μ , ,
- μ μ TBRW 500x300 Yenigul et al [2005].

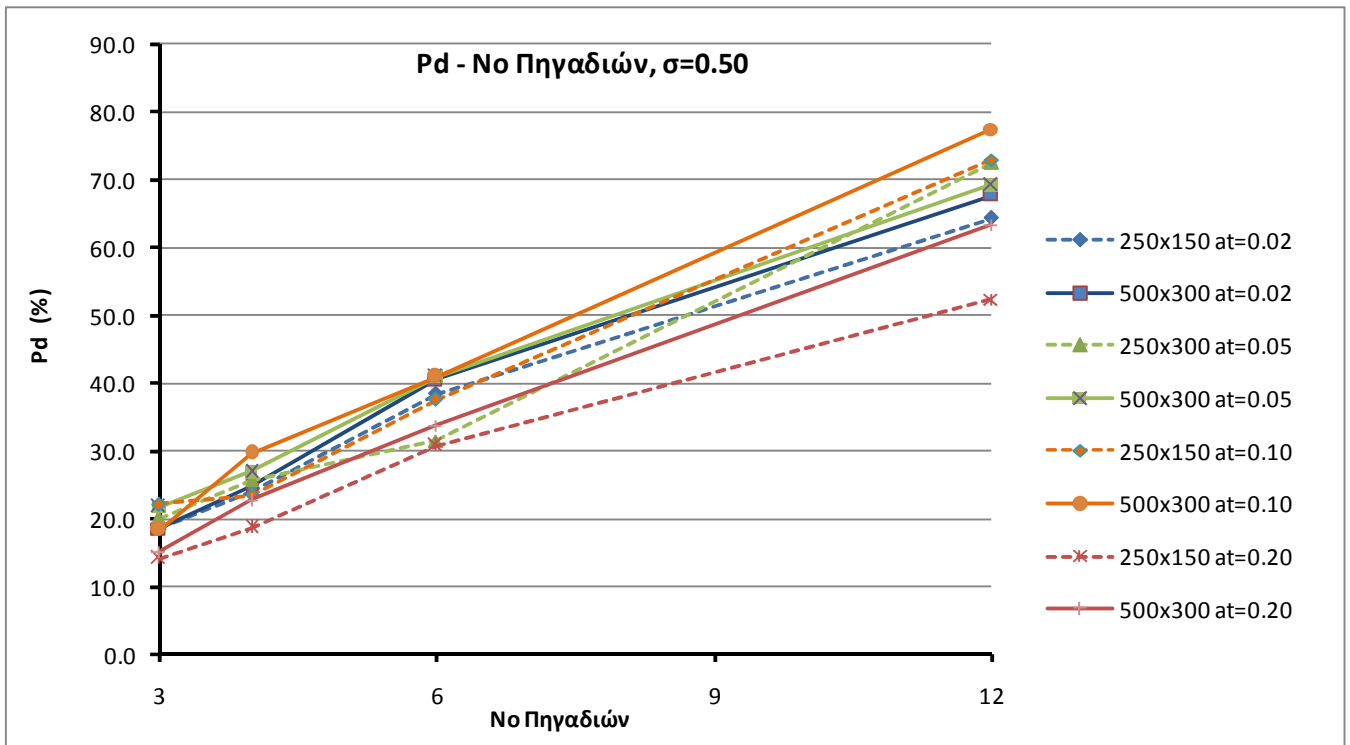
$\mu\mu$ 6.16 : $\mu\mu$ Pd 250x150 500x300 μ



μm 6.17 : μm Pd

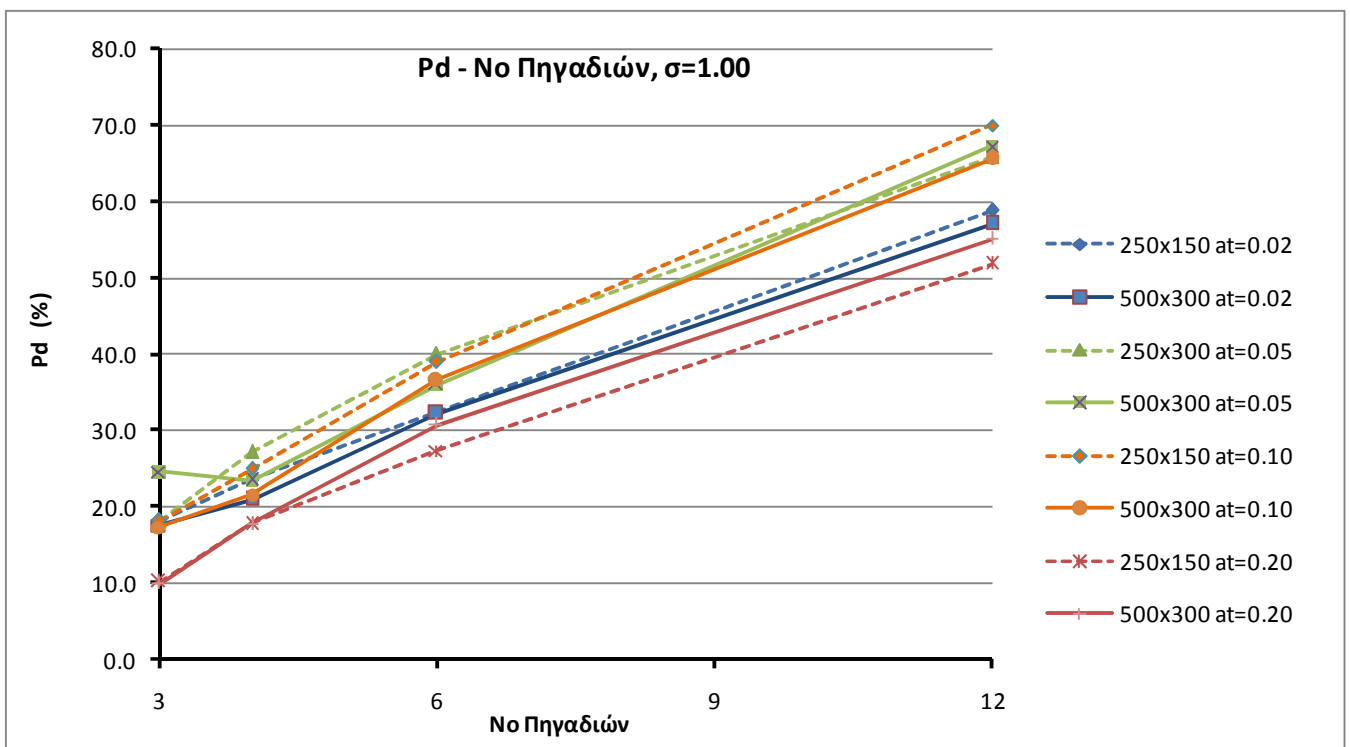
250x150

500x300

 μm 6.18 : μm Pd

250x150

500x300

 μ μ ,

,

 μ μ , μ μ

,

 μ

μ . , μ
 μ , μ μ μ μ , μ
 μ μ μ μ .
 μ μ μ ,
 μ μ 32000 μ . μ μ
 μ Monte Carlo , μ
 μ
 μ . , μ 500,
 250x150. μ , μ μ μ
 μ Monte Carlo. μ μ
 , μ 2000 .
 , μ μ
 μ μ . μ ,
 μ μ 32000 μ 500x300 2000 .
 μ μ ,
 8x4x4=128 .
 μ μ μ μ μ
 μ μ μ ,
 μ , 250x150 μ 2000 μ , μ
 μ μ μ
 , 500x300 μ ,
 μ μ . μ μ
 μ μ , μ μ
 μ , (6.5). ,
 μ μ μ ,
 μ 6.9, μ μ
 μ μ (6) (12)
 .
 , , μ x y , μ μ
 μ . μ μ , μ
 μ , μ μ .
 , , (3.5) (Ababou et al., 1985) μ μ

93

4. μ .
 μ , μ
 μ . , μ
 ,
 μ , μ
 μ μ μ .

5. μ
 . μ μ
 μ ,
 μ μ .

6. μ ,
 μ μ μ μ ,
 , μ
 μ μ μ .

7. μ μ μ μ
 – , μ μ ,
 μ μ , μ μ
 μ

$$P_{d(emp)} = \frac{40n}{L} (160d\alpha_t - 5e^{-100(\alpha_t - 0.001)} - 5e^{-100(0.2 - \alpha_t)} - 2\sigma_Y + 15.5) \quad (7.2)$$

8. μ μ μ $0.001 < \alpha_t < 0.20m$, μ
 μ μ μ ,

$$P_{d(emp)} = \frac{n}{L} (6400d\alpha_t - 80\sigma_Y + 620) \quad (7.3)$$

9. μ μ μ μ ,
 μ . , μ
 , μ
 μ μ μ (μ
 μ) , ,
 μ Monte Carlo. μ

3. μ , μ
4. μ μ .
5. μ , μ .
6. μ μ .
7. μ TBRW , μ .
8. μ μ μ , μ , μ , μ .

μ A. μ

A.1

$$\left\{ \left[x, Z(x, \zeta_i) \right], x \in \mathfrak{R}^n \right\}, \quad i = 1, 2, 3, \dots, m, \quad Z(x, \zeta_i)$$

A.2

[illegible]

A.3

 μ

A.1.3

$$\mu \quad Z_\mu \quad ,$$

$$P(z) = Prob\{Z \leq z\} \quad (\text{H.1})$$

$\text{Prob}\{A\}$ μ A , $P(A)$ μ
 A , z μ μ μ . μ
 μ μ $P(A) \in [0, 1]$, $z \in (-\infty, +\infty)$.

A.2.3

$p(z)$ μ μ Z

$$p(z) = \lim_{\Delta z \rightarrow 0} \frac{\text{Prob}\{z < Z \leq z + \Delta z\}}{\Delta z} = \frac{dP(z)}{dz} \quad (\text{H.2})$$

μ μ μ

$$P(z) = \int_{-\infty}^z p(z) dz \quad (\text{H.3})$$

$p(z)$, , $[z^{-1}]$,
 μ μ μ Δz , (.3), μ
 .

A.3.3

μ μ

μ μ ()
 μ μ μ μ ,
 μ μ μ μ μ . μ Z
 μ μ μ $\{Z_1, Z_2, \dots, Z_n\}^T$, Z_1, Z_2, \dots, Z_n μ ,
 z μ μ Z

$$P(z_1, z_2, \dots, z_n) = \text{Prob}\{Z_1 \leq z_1, Z_2 \leq z_2, \dots, Z_n \leq z_n\} \quad (\text{H.4})$$

μ μ μ $P(-\infty, -\infty, \dots, -\infty) = 0$

$P(+\infty, +\infty, \dots, +\infty) = 1$.

A.4.3

μ

μ μ Z

$$p(z) = \lim_{\substack{\Delta z_1 \rightarrow 0 \\ \Delta z_n \rightarrow 0}} \frac{\text{Prob}\{z_1 < Z_1 \leq z_1 + \Delta z_1, \dots, z_n < Z_n \leq z_n + \Delta z_n\}}{\Delta z_1 \Delta z_2 \dots \Delta z_n} = \frac{\partial^n P(z)}{\partial z_1 \partial z_2 \dots \partial z_n} \quad (\text{H.5})$$

$$P(z) = \int_{-\infty}^z p(z) dz = \int_{-\infty}^{z_1} \dots \int_{-\infty}^{z_n} p(z) dz_1 \dots dz_n \quad (\text{H.6})$$

A.5.3

$$\begin{array}{ccccccc} & & \mu & & \mu & & Z_n & & \mu \\ & & & & & & & & \\ Z, \mu & & \mu & & \mu & & n-1, n-2, \dots, 1 & & \mu & & \mu \end{array},$$

$$P(z_n | z_{n-1}, z_{n-2}, \dots, z_1) = \text{Prob} \{ Z_n \leq z_n | z_{n-1} < Z_{n-1} \leq z_{n-1} + \Delta z_{n-1}, \dots, z_1 < Z_1 \leq z_1 + \Delta z_1 \} \quad (\text{H.7})$$

$$P\{A|B\} \quad \mu \quad , \quad \mu \quad \mu$$

$$\text{Pr ob}\{A|B\} = \frac{\text{Pr ob}\{A \cap B\}}{\text{Pr ob}\{B\}} \quad (\text{H.8})$$

μ , μ , μ
 μ μ μ μ μ μ μ
 . , μ μ μ μ
 , μ μ μ μ (Hard Data) .

A.6.3

$$p(z_n|z_{n-1}, \dots, z_1) = \frac{\partial P(z_n|z_{n-1}, \dots, z_1)}{\partial z_n} \quad (\text{H.9})$$

$$p(z_n|z_{n-1}, \dots, z_1) \mu, \mu,$$

$$p(z_n | z_{n-1}, z_{n-2}, \dots, z_1) = \frac{p(z)}{p(z_1, z_2, \dots, z_{n-1})} \quad (\text{H.10})$$

$$p(z_n | z_{n-1}, z_{n-2}, \dots, z_1) = \frac{p(z_1, z_2, z_3, \dots, z_n)}{p(z_1, z_2, \dots, z_{n-1})} \quad (\text{H.11})$$

$$p(z_1, z_2, z_3, \dots, z_n) = p(z_1) \cdot p(z_2) \cdot \dots \cdot p(z_n) \quad (\text{H.12})$$

A.4

A.1.4

100

$\nu(x)$ μ , μ μ ,
 , $|\nu|$ μ , i $i-th$
 .

μ , μ

$$\bar{Z}_i = \frac{1}{n} \sum_{j=1}^n Z_i(x_j) \tag{H.15}$$

n μ μ ,
 j $j-th$ μ .

➤ μ
 μ μ μ μ .

$$Var[Z_i] = \sigma_{z_i}^2 = \overline{[Z_i(x) - \bar{Z}_i]^2} = \frac{1}{|\nu|} \int_{\nu(x)} [Z_i(x) - \bar{Z}_i]^2 dx \tag{H.16}$$

μ

$$\sigma_{z_i}^2 = \frac{1}{n-1} \sum_{j=1}^n [Z_i(x) - \bar{Z}_i]^2 \tag{H.17}$$

, μ ,

$$\sigma_{z_i}^2 \approx \bar{Z}_i^2 - (\bar{Z}_i)^2 \tag{H.18}$$

➤ μ
 μ μ μ μ μ
 μ . ,

$$Cov(Z_i(x+s), Z_i(x)) = \frac{1}{|\nu|} \int_{\nu(x)} [Z_i(x+s) - \overline{Z_i(x+s)}] [Z_i(x) - \bar{Z}_i] dx \tag{H.19}$$

s μ . , μ

$$\text{Cov}(Z_i(x+s), Z_i(x)) = \frac{1}{n(s)} \sum_{j=1}^{n(s)} [Z_i(x+s) - \overline{Z_i(x+s)}] [Z_i(x) - \bar{Z}_i] \quad (\text{H.20})$$

$n(s)$ μ μ μ s .

A.2.4 *(Ensemble Statistics)*

μ μ μ μ
 μ μ μ
 . , μ :

➤ μ

$$E\{Z(x_0)\} = \int_{-\infty}^{+\infty} z(x_0) p(z) dz \quad (\text{H.21})$$

x_0 μ μ μ , $p(z)$
 $Z(x)$ μ , $E\{ \}$ μ μ μ .
 μ μ m ,

$$E\{Z(x_0)\} \approx \frac{1}{m} \sum_{i=1}^m Z_i(x_0) \quad (\text{H.22})$$

➤ μ

$$\sigma_{z(x_0)}^2 = E\left\{ [Z(x_0) - E\{Z(x_0)\}]^2 \right\} = \int_{-\infty}^{+\infty} (Z(x_0) - E\{Z(x_0)\})^2 p(z) dz \quad (\text{H.23})$$

, μ μ m ,

$$\sigma_{z(x_0)}^2 \approx \frac{1}{m-1} \sum_{i=1}^m [Z_i(x_0) - E\{Z(x_0)\}]^2 \quad (\text{H.24})$$

, ,

$$\sigma_{z(x_0)}^2 = E\{Z^2(x_0)\} - (E\{Z(x_0)\})^2 \quad (\text{H.25})$$

$$\begin{array}{c} \text{---} \mu \text{---} \\ \mu \qquad \qquad \mu \end{array}$$

$$Cov(Z(x+s), Z(x)) = \int \int_{-\infty}^{+\infty} p(z(x+s), z(x)) dz(x+s) dz(x) \quad (\text{H.26})$$

$$\begin{array}{ccccccc} p(z(x+s), z(x)) & & & & & & Z(x) \\ x+s & x & \mu & \mu & m, & & \end{array}$$

$$Cov(Z(x+s), Z(x)) \approx \frac{1}{m} \sum_{j=1}^m [Z_j(x+s) - E\{Z_j(x+s)\}] \cdot [Z_j(x) - E\{Z_j(x)\}] \quad (\text{H.27})$$

A.3.4 μ - μ

$$\begin{array}{ccccccc} \mu & \mu & \mu & & & & \\ \mu & \mu & & \cdot & , & \mu & \mu \\ & & & & & & \mu \\ & & & & & & : \end{array}$$

$$\begin{array}{ccccccc} \text{i.} & \mu & \mu & & \mu & & \mu \\ & & & \mu & \mu & & \end{array}$$

$$E\{Z(x)\} = \mu(z) \quad (\text{H.28})$$

$$\begin{array}{ccccccc} \text{ii.} & \mu & & & \mu & & \\ & \mu & & \mu & (x_i - x_j) = s_{ij} & & \\ & \mu & \cdot & , & , & & \end{array}$$

$$Cov(Z(x_i), Z(x_j)) = E\{[Z(x_i) - E\{Z(x_i)\}][Z(x_j) - E\{Z(x_j)\}]\} = Cov(s) \quad (\text{H.29})$$

$$\mu \qquad \qquad \mu \qquad \qquad \mu \quad x, \qquad ,$$

$$Var[Z(x)] = Cov(0) = \sigma_z^2 \quad (\text{H.30})$$

$$\begin{array}{ccccccc} \mu & & \mu & , & \mu & (\mu) \\ & & \mu & \cdot & \mu & , \mu & \end{array}$$

μ μ μ μ μ μ
 . μ , μ
 μ , μ .

A.4.4

- μ , μ ,
 μ . :
- i. μ μ μ x , ,
- ii. s μ , μ $Z(x+s) - Z(x)$
 μ μ s . μ

$$\text{Var}\{Z(x+s) - Z(x)\} = E\{(Z(x+s) - Z(x))^2\} - (E\{Z(x+s) - Z(x)\})^2 \quad (\text{H.31})$$

$$, \quad E\{Z(x+s) - Z(x)\} = 0 ,$$

$$\text{Var}\{Z(x+s) - Z(x)\} = E\{(Z(x+s) - Z(x))^2\} = 2\gamma(s) \quad (\text{H.32})$$

$\gamma(s)$ μ μ - μ μ μ μ μ
 μ μ μ s .
 μ , μ
 μ , ,
 .

A.5.4

μ μ μ μ μ μ μ μ
 μ μ μ μ μ μ μ μ , μ ,
 μ μ μ μ μ μ μ (Paleologos,
 2005). , μ μ μ μ
 μ μ μ μ μ μ μ μ
 (μ) μ μ
 . μ , μ μ μ

μ B. μ μ

μ Monte Carlo μ μ .
μ , μ μ , μ μ
μ μ
μ . μ
μ , μ .
μ μ μ
μ μ μ “ ” (seed) μ
μ , μ μ μ
μ .
μ μ μ μ μ
μ . μ μ μ ,
μ , μ Poisson , μ gamma.
μ μ μ
μ [0,1].
μ μ μ μ , μ
μ μ μ μ μ
μ , μ μ
μ .
μ
μ μ :

B.1 μ μ μ

μ μ μ [0,1].
μ μ . μ
“Multiplicative Congruence Method” μ . μ
μ ,

$$N_i = MODULO(AN_{i-1},M)$$

(I.1)

(I.2)

$$U_i = N_i / M \quad (I.3)$$

i μ (1, 2), N_i
, M A μ , U_i μ μ
μ [0,1], *MODULO* μ μ μ
 (AN_{i-1}) μ M . μ M A ,
μ M 2^{b-1} , b μ (32-bit
μ $b=32$), A μ μ $2^{b/2}$. μ
“ ” (seeder), μ μ M .
μ μ μ
[0,1] μ “Multiplicative Congruence Methods”,
μ “Subtractive Method”. Knuth
μ μ Press W.H., Flannery B.P.,
Teukolsky S.A., Vetterling W.T. [1987].

B.2

μ μ

μ

μ J. Leva
[1992] μ Kinderman Monahan [1977].
μ μ
μ , μ μ μ μ
μ μ . μ μ (Leva, 1992):
1. μ μ $P=(u,v)$, μ μ \mathbb{R}^2 .
μ μ μ u v
μ μ μ [0,1]. , $v=1.7156(v-0.5)$, μ
μ v μ μ μ $(-r,r)$, $r=\sqrt{2/e}=0.8578$.

2. μ μ $Q = x^2 + y(ay - bx)$, $x = u - s$, $y = |v| - t$
 μ $(s, t) = (0.449871, -0.386595)$ μ .
 μ $a = 0.19600$ $b = 0.25472$.
3. μ P $Q < 0.27597$ () μ 6.
4. P $Q > 0.27846$ () μ 1.
5. P . $v^2 > -4u^2 \ln u$,
 μ 1.
6. μ μ μ μ . μ
 μ μ v/u μ P .

C. Turning Bands Method

μ , μ

(0) μ . μ

Matheron [1973], , μ Journal
[1974], 2-D Mantoglou and
Wilson [1982].

[illegible]

C.1

μ $Z_i(u) = 1, 2, \dots, N$ N μ μ

μ μ μ μ u , μ

$\rho_l(u_0)$, u_0 μ μ . , μ

μ

$$Z_s(x, y, z) = \frac{1}{\sqrt{N}} \sum_{i=1}^N Z_i(u) \quad (\text{J.1})$$

, , μ ,

s (simulated). μ μ μ

μ (0). μ μ $\rho_l(u_0)$

μ $\rho(u_0)$ (Mantoglou and Wilson, 1982, Mantoglou, 1987)

$$\rho_l(u_0) = \frac{d}{du_0} [u_0 \rho(u_0)] \quad (\text{J.2})$$

$$\int_0^s \frac{\rho_l du_0}{\sqrt{(s^2 - u_0^2)}} = \frac{\pi}{2} \rho(s) \quad (\text{J.3})$$

s .

(J.3) μ $\rho_l(u_0)$ μ $\rho(s)$.

, μ Mantoglou and Wilson [1982] μ μ μ

μ μ μ μ

.

C.2 Spectral Turning Bands Method (STBM)

μ 2-D (J.3),

μ μ $\rho_l = f(\rho(s))$,

μ μ μ

μ μ μ
 μ . Fourier

$$S_l(\omega) = \frac{\sigma_z^2}{\gamma} S(\quad) \quad (\text{J.4})$$

$S_l(\omega)$ μ μ $S(\quad)$ μ μ
 . μ μ STBM
 .

C.1.2 μ $\mu\mu$

$$X(u) = Z(u) + iY(u),$$

$$X(u) = \int_{all \omega} e^{i\omega u} dW(\omega) \approx \sum_{all \omega} e^{i\omega_j u} dW(\omega_j) \quad (J.5)$$

$$(0). \quad X(u) = \int_{-\infty}^{\infty} f(x) e^{ux} dx$$

$$\text{Re } X(u) = Z(u) = \int_{\partial W} |dW(\omega)| \cos(\omega u + \phi_\omega) \quad (\text{J.6})$$

$$\mu \qquad \mu \qquad \mu \qquad \mu \qquad \mu$$

$$Z_i(u) = \sum_{j=1}^M \left| dW(\omega_j) \right| \cos(\omega_j u + \phi_j) \quad (\text{J.7})$$

$$\phi_j \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad 0 \quad 2\pi, M$$
$$\mu \quad \mu \quad \mu \quad \mu \quad , \quad \omega_j = (j - 0.5)\Delta\omega,$$
$$j = 1, 2, \dots, M, \Delta\omega \quad \mu \quad \omega_{\max}/M, \quad \omega_{\max}$$

$$\mu \quad \mu \quad \mu \quad \mu \quad \left| dW(\omega_j) \right|$$

$$\mu \quad \mu$$

$$\left| dW(\omega_j) \right| = \left[4S_l(\omega_j) \Delta\omega \right]^{1/2} \quad (J.8)$$

$$S_l(\omega_j) \quad \mu \quad \mu \quad Z(u)$$

$$\mu\mu \quad .$$

$$S_l(\omega_j) \quad \mu \quad \left[-\omega_{\max}, +\omega_{\max} \right]. \quad (J.8)$$

$$(J.7) \quad \mu \quad \mu \quad \mu\mu \quad i$$

(Shinozuka and Jan, 1972)

$$Z_i(u) = 2 \sum_{j=1}^M \left[S_l(\omega_j) \Delta\omega \right]^{1/2} \cos(\omega'_j u + \phi_j) \quad (J.9)$$

$$\omega'_j = \omega_j + \delta\omega. \quad \delta\omega \quad \mu \quad , \quad \mu \quad \mu$$

$$\mu \quad \mu \quad \mu \quad -\Delta\omega'/2 \quad \Delta\omega'/2 \quad \mu \quad \Delta\omega' = \Delta\omega/20,$$

$$\mu \quad .$$

$$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \Delta\omega$$

$$\mu \quad \mu \quad \omega_{\max} = M\Delta\omega. \quad \mu \quad \mu$$

$$\text{FFT}, \quad \mu$$

$$\mu \quad M, \Delta\omega, \Delta u, \omega_{\max} \quad u_{\max} \quad [\text{Tompson et al., 1989}].$$

$C.2.2$ μ μ μ $\mu\mu$

$$\mu \quad \mu \quad \mu \quad \mu \quad \mu\mu \quad \mu \quad \mu \quad \mu\mu \quad .$$

$$\mu \quad \mu \quad \mu\mu \quad \mu \quad , \quad \mu$$

$$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$$

$$2\text{-D} \quad 3\text{-D} \quad . \quad (\text{Mantoglou and Wilson, 1982}), \quad \mu \quad ,$$

$$\mu\mu \quad \mu \quad \mu \quad \mu \quad \mu$$

$$\mu \quad \mu \quad ,$$

$$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad . \quad ,$$

$$\mu \quad \mu\mu \quad \mu \quad (8) \quad (16) \quad \mu \quad \mu$$

μ . μ μ $\mu\mu$.

C.3.2 μ

$Z_i(u_n)$ $\mu\mu$ i μ n μ

μ μ

μ . $\Delta\omega$ μ

μ , μ μ M

μ μ ()

$\omega_{\max} = M\Delta\omega$. (Mantoglou and Wilson, 1982) μ M μ

μ 50 100, ω_{\max} 40 μ

μ .

C.4.2

μ Δu μ $\mu\mu$

μ μ $\Delta x, \Delta y$ μ μ .

μ μ

μ (Mantoglou and Wilson, 1982).

C.5.2 μ $\mu\mu$

μ $\mu\mu$ μ μ

μ μ μ .

C.6.2 μ

μ $Z_s(x, y, z)$, ,

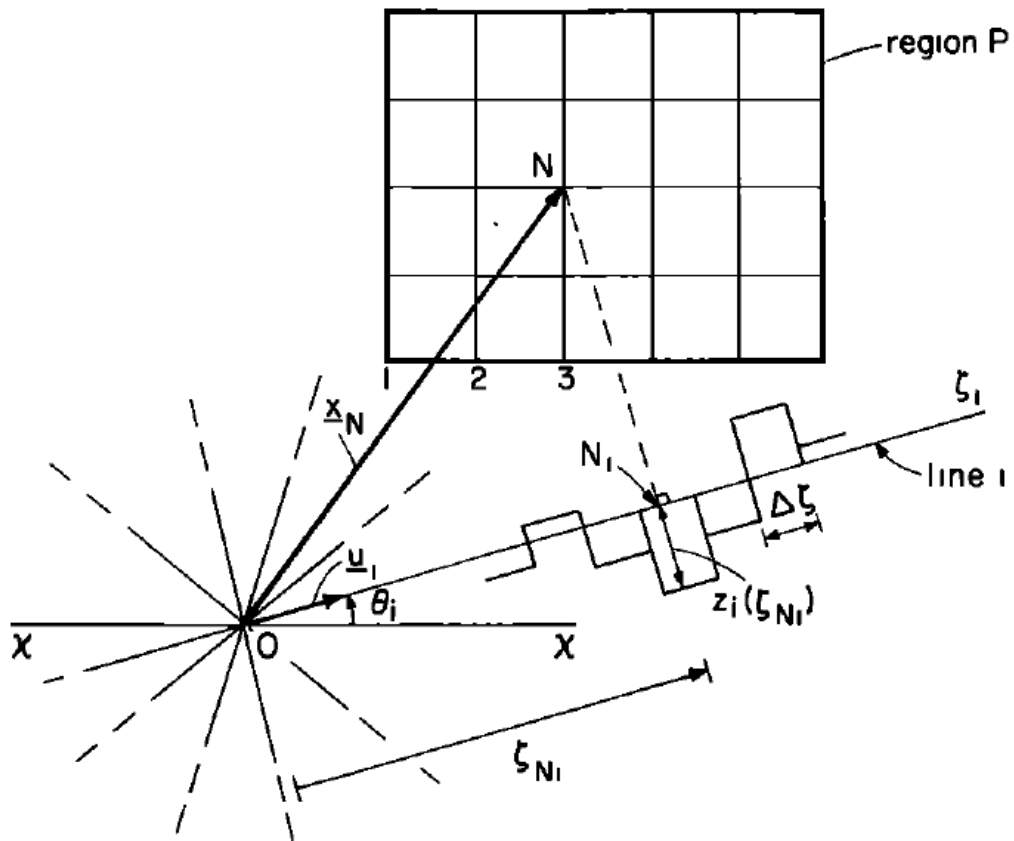
μ μ $\mu\mu$ L μ μ ,

μ $Z_i(u)$ μ μ

μ n $\mu\mu$, μ

μ μ x , , μ

μ μ $L^{1/2}$ μ (Elfeki, 1996).



C.1 : μ ' Turning Bands (Mantoglou and Wilson,1982)

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