MamPec

Application at low exchange conditions

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Contents

1 Summary

MamPec 1.4 (Marine Antifoulant Model to Predict Environmental Concentrations) is a generic chemical fate model specifically developed for the prediction of antifoulant concentrations in the environment. Based on user defined dimensions and environmental conditions of a harbour, the MamPec model estimates water exchange between harbour and environment. Processes included are:

1. filling and emptying by the tide;
2. horizontal eddy generated in the harbour entrance by the passing main flow;
3. vertical circulation currents in the harbour generated by density differences between the water inside and outside the basin.

Under specific conditions of low tide, low flow and no density differences other processes can become important in the exchange:

1. non-tidal water level changes
2. wind induced exchange

These processes are not yet included in the MamPec model version 1.4. In this study we assess the importance of these processes in a specific case: the Finnish marina Uittamo.

Conclusions:

- In the absence of tide, the default calculation of horizontal eddy generation should be adapted. The value estimated by the MamPec model for tidal conditions should be multiplied by a factor 3.14 (pi) for non-tidal conditions.
- In the absence of tide, non-tidal water level changes become important. The effect should be incorporated in the exchange volume in the MamPec marina definition. We based the estimation below on a 5 year series of hourly water level measurements near Turku.
- Under conditions of very low flow velocities, no tide and/or no density differences wind induced effect becomes important. Based on a the wind distribution over a 30 year period (1971-2000) we calculated the effect of those occurrences where the wind direction is perpendicular to the harbour entrance.

An overview of the calculated exchange volumes for the Uittamo marina in Finland are given in the table below:

Table 1 Exchange volumes (m3/tide) in example case study of Uittamo marina.

Process	MamPec 1.4 Uittamo, default settings	MamPec, corrected for low tide conditions
Horizontal flow exchange	2.628	8.250
Non tidal water level exchange	not taken into account	4.370
Wind driven exchange	not taken into account	4.000[1] to 12.500[2] (8.250 avg)
Total	2.628	16.620– 25.120

1) local average wind velocity (at 10 m): 2 m/s
2) local average wind velocity (at 10 m): 5 m/s

Based on this study, the setting for the exchange in the Uittamo marina should be manually corrected to 20.870 m3/tidal period .

2 Introduction

MamPec (Marine Antifoulant Model to Predict Environmental Concentrations) is a generic chemical fate model specifically developed for the prediction of antifoulant concentrations in the environment. First released in 1999 the MamPec model provides a state-of-the-art prediction of environmental concentrations of antifouling products in five generalised 'typical' marine environments (open sea, shipping lane, estuary, commercial harbour, yachting marina). The user can specify different environment dimensions and properties. Based on these user-defined conditions, different hydraulic water exchange scenarios are calculated.

In general, the exchange of water between a harbour basin and an estuary/sea is caused by three phenomena (Eysink and Verinaas, 1983; Eysink, 1988):

1. filling and emptying by the tide;
2. horizontal eddy generated in the harbour entrance by the passing main flow;
3. vertical circulation currents in the harbour generated by density differences between the water inside and outside the basin.

Based on either default or user defined parameters the MamPec model calculates the water exchange. This value can be changed by the user.

Under specific conditions of low tide, low flow and no density differences other processes can become important in the exchange:

3. non tidal water level changes
4. wind induced exchange

These processes are not yet included in the MamPec model.
In this study we look at the importance of these processes in a specific case: the Finnish Marina Uittamo.
The Finnish authorities have chosen to implement the MamPec model in their risk assessment based authorisation process of antifouling products .Further, national exposure scenarios have been developed by Finnish Environment Institute. The Finnish Marina Uittamo has been selected as a typical marina. Dimensions and environmental conditions for the Marina as proposed by the Finnish authorities have been kindly provided by the Finnish Environment Institute.

3 Exchange processes

In general, the exchange of water between a harbour basin and an estuary/sea is caused by three phenomena (Eysink and Verinaas, 1983; Eysink, 1988):

1. filling and emptying by the tide;
2. horizontal eddy generated in the harbour entrance by the passing main flow;
3. vertical circulation currents in the harbour generated by density differences between the water inside and outside the basin.

These three processes are included in the MamPec model. Based on either default or user defined parameters the model calculates the water exchange between harbour/marina and the environment. The exchange volume can be manually changed by the user.

Under specific conditions of low tide, low flow and low density differences other exchange processes become more important in the exchange:
1. non-tidal water level changes
2. wind induced exchange

These processes are not yet included in MamPec (version 1.4). If these processes are important, their resulting water exchange should be added manually to the calculated exchange from the MamPec model.

The table below shows the dimensions and properties of the 'default Marina' in the MamPec program and the user defined Finnish Uittamo marina. It is clear that in the case of Uittamo, where the tidal amplitude is zero, the density exchange is zero and the flow velocity is very low (1 cm/s) other exchange processes should be considered.

Table 2 Dimensions and settings of the default MamPec marina and the Uittamo marina

Parameter	default marina	Uittamo	unit
Length	400	420	m
Width	400	140	m
Depth	3.5	2.2	m
Width Mouth	100	420	m
Mouth depth	3.5	2.2	m
Tidal period	12.41	12.41	h
Tidal amplitude	1	0	m
Flow velocity	1.0	0.01	m/s
Density difference	0.1	0	kg/m3
Flushing	0	0	m3/s
Silt	35	25	g/m3
Nett sedimentation velocity silt	0.5	0.5	m/d
Depth sediment layer	0.1	0.05	m
Density sediment	1000	1000	kg/m3

Parameter	default marina	Uittamo	unit
Fraction OC in sediment	0.03	0.05	g/g
Dissolved organic carbon	2	5.2	mg/l
Particulate Organic carbon	1	0.2	mg OC/l
Temperature	20	10	oC
Salinity	34	4.6	psu
pH	8	8	
Background conc.	0	0	μg/l
Total Exchange/ tide	243420	2628	m3/tidal period
Exchange as % of volume	43 %	2 %	% of marina volume / tidal period

In the example of the Uittamo marina the only exchange found is caused by horizontal exchange due to the flow in front of the harbour mouth.

3.1 Water exchange by horizontal eddy in harbour entrance

A current passing the entrance of a basin generates an eddy in this entrance. Steep velocity gradients generate an exchange of water by turbulence. Through this mechanism water from the outside penetrates the eddy and from there further into the harbour. The rate of this mechanism depends on flow velocities in front of the harbour basin, the size of the entrance and the tidal prism. The rate of "horizontal water exchange" can be approximated by the formula (Graaf and Reinalda, 1977):

$$Q_h = f_1.h.b.u_0 - f_2.Q_t$$

Q_h = rate of horizontal water exchange
f_1, f_2 = empirical coefficients depending on geometry of the basin
h = depth of entrance
b = width of entrance
u_0 = main flow velocity due to rising tide ($h.b.u_{tide}$)
u_{tide} = tidal in and out flow velocities in the entrance

The formula is valid for rivers (Qt=0) and in tidal areas during flood. Qh is almost negligible during ebb. Hence in tidal areas substitution of $h = h_0 - \eta \cos \omega t$ and $u_0 = u_{0,\max} \sin \omega t$ and integration over the flood period (t=0 to T/2) yield the total volume per tide by horizontal exchange:

$$V_h = f_1.h_0.b.\frac{u_{0,\max}}{\pi}T - f_2.V_t$$

where:
V_h = total water exchange volume per tidal period by horizontal exchange

h_0 = depth in entrance relative to mean sea level
$u_{0,max}$ = maximum flow velocity during tidal period
T = tidal period
V_t = tidal prism of harbour

Typical values for coefficients f1 and f2 are generally within ranges 0.01-0.03 and 0.1-0.25 respectively.
The current version of MamPec assumed the existence of a tidal period so this formula is incorporated in MamPec. However in the absence of tide the formula reduces to :

$$V_h = f_1.h_0.b.u_{0,avg}T_t$$

$u_{0,avg}$ = average flow velocity in front of harbour entrance

This formula is not yet incorporated in MamPec but will be implemented in future versions. In the absence of a tide the current calculation of horizontal water exchange in MamPec is underestimated by a factor π.

Conclusion:
In current MamPec version (1.4) the parameterisation of the horizontal water exchange calculation assumes the occurrence of tide. The velocity in front of the harbour should be the maximum flow velocity during a tidal period. In the absence of tide the MamPec model underestimates the exchange and the input should be corrected.

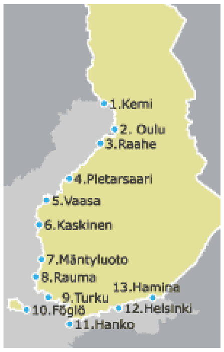
Workaround : In the absence of tide use the average flow velocity in front of the harbour mouth and multiply this value with π.

Example Uittamo:
There is no tide, therefore the average flow velocity (0.01 m/s) should be set to 0.01 * π (0.0314 m/s). This correction changes the exchange volume from: 2.628 m^3/tide to 8.250 m^3/tide.

3.2 Non-tidal water level changes

In the current version of the MamPec model water level changes are solely related to tidal effects. In the absence of tide, there is no option in the MamPec model for non tidal water level changes, except to add them manually to the calculated exchange.
The Finnish marina is assumed to be situated on the south or south west coast of Finland. The coast is assumed to have an archipelago as it is outside Turku (south-west Finland) and Helsinki. The average tidal amplitude is zero.
In the absence of tide, water level differences still occur based on large scale water movement or wind related water setup. Due to the large (spatial) scale of these processes they are difficult to model with a ‘local scale’ model such as MamPec.

To estimate the importance of non-tidal water level changes in this specific area, we looked at water level measurements at the Turku station (see map)



The Turku measurement location is at 60°26' N 22°06' E .
Daily average water level measurements (based on hourly measurements), together with the daily minimum and maximum values have been obtained from the Finnish Institute of Marine Research for a 5-year period (1998-2002).

During that period the average daily difference between low and high water level was 14.4 cm. The minimum daily difference is 3 cm, the maximum 77 cm.
Like tide, water level changes will give an exchange between marina and the sea.
Based on the average daily difference an exchange volume can be estimated:

$$V_t = h_{daily\_avg}.width.length.\frac{T}{24}$$

Vt	= exchange volume per tidal period
h_{daily_avg}	= average difference between daily maximum and minimum water level
width. length	= area harbour
T	= tidal period

In this approach the maximum difference in water levels over a 24 hour period is taken and then normalized to tidal frequency. It does assume that on average over 24 hours the water level fluctuates and approaches a maximum height difference only once. The water level changes are non tidal and most likely caused by large scale wind and atmospheric pressure effects, which are relatively slow processes (i.e. scale of days, not minutes/hours). It is therefore expected that the frequency of water level fluctuations will be in the same order of magnitude.
To validate this approach we analysed in detail hourly water level measurements at Turku for 2002 (8759 data points).
Based on the daily minimum and maximum water levels the average daily water level difference in 2002 was 14.3 cm. Based on the hourly measurements of the fluctuations in 2002 , the daily average water level difference amounts to 17.7 cm.
This value is quite close to the one based on the daily minimum and maximum values (approx. 20 % higher). The estimate based on the daily maximum difference seems therefore a reasonable approach, requiring much less data than with hourly measurements. The daily maximum difference approach slightly underestimates the actual exchange (20 % in case of Turku).

We advise to include the approach based on the daily minimum and maximum values in the next version of MamPec. The estimation methods of non-tidal water level changes will be included in the help file of future MamPec releases.
The help file should also mention that if one has reason to assume a much higher frequency of water level fluctuations, one should make a proper estimation, based on hourly measurements.

For the Uittamo marina, using the daily maximum water level difference results in a non-tidal water exchange of 4.370 m3/tidal period

3.3 Wind effect on exchange

When wind blows over a water surface, interaction of wind and water consists of shear stress at the surface and sometimes a normal pressure component on a wavy surface. Internal friction exists both in the air flow as in the water flow, as well as friction between water and bed-layer and walls. These interactions cause various phenomena which are relevant for the marina – sea exchange:

1. Vertical wind velocity profile

Wind velocity at the actual water surface and water velocity are identical. Generally the wind velocity at surface level is much lower than at some meters above the surface. The vertical wind velocity profile over a water body is generally estimated to be of logarithmic shape. The velocity at the water surface is in the order of 3 – 3.5 % of the wind speed at 10m.

2. Vertical water velocity profile

In an originally stagnant water system the wind causes a surface current velocity u_s by shear stress. The internal shear stress in the water gives rise to a vertical velocity profile, mostly of logarithmic shape near the water surface.

Velocity profile for wind driven currents

Given:
U = depth averaged velocity (due to wind only)
D = Water depth (in m)
z_b = bottom roughness height (in m)
W = Wind force (in m/s)

The velocity profile (velocity as function of z – height) is given as:

$$u(z) = \kappa^{-1} u_{*s} \ln \{(h - z_b)/(h-z)\} + u_{*b}/\kappa * \ln(z/z_b) \qquad \text{For } z_b \leq z \leq h - z_s$$

$$= 0 \qquad \text{For } 0 \leq z \leq z_b$$

$$= u_s \qquad \text{For } h - z_s \leq z \leq h$$

With:

u_s = Wind driven velocity at water surface (usually 3-3,5 % * W); input par.
z_s = Surface roughness height (in m)
$= (h/z_b)^{**}(u_{*b} / u_{*s}) * h * \exp(-u_s * \kappa / u_{*s})$
κ = Von-Karmans constant = 0.41
u_{*b} = bottom stress velocity
$= (\kappa * U - u_{*s}) / \{\ln(h/z_b) - 1\}$
u_{*s} = Surface stress velocity
$= W * (rhoa/rhow * Cd)^{½}$
Cd = Wind drag coefficient = 63e-4 * (1. + 0.1*ABS(W))

If the wind direction drives the water flow parallel to the harbour entrance this results in a flow velocity which is included in the MamPec model as input. The setting chosen for the Finnish marina of 0.01 m/s is a lower estimate, based on local current measurements which are in the order of several centimetres per second. The effect of this parallel flow is included in the MamPec model.
However when the wind is perpendicular to the harbour entrance, the surface flow in the harbour would cause a bottom return flow. The vertical velocity profile is shown in the next figures. In order to estimate the effect of wind on the exchange we setup a simple 3D model of the MamPec marina schematisation.

Detailed 3D model

A schematic model has been set up to calculate the exchange flow in a harbour basin as a result of inland wind and a minor alongshore current (0.01 m s^{-1}). The model is schematic in the sense that only the basic flow conditions were simulated. The water body has been assumed to be homogeneous and any eddies in the horizontal plane that may occur in the basin have not been verified. Furthermore, some assumptions with respect to the wind setup along the open boundaries were made for running of the model (see below for details).

The model was setup using Delft3D-FLOW.

The grid used is shown in Figure 1. The boundaries are chosen far enough from the area of interest (the harbour entrance), so that any circulations that may appear along the open boundaries do not affect the solution.

The grid size in the harbour is a uniform 14 m by 10 m. Further away from the area of interest the grid sizes increase.

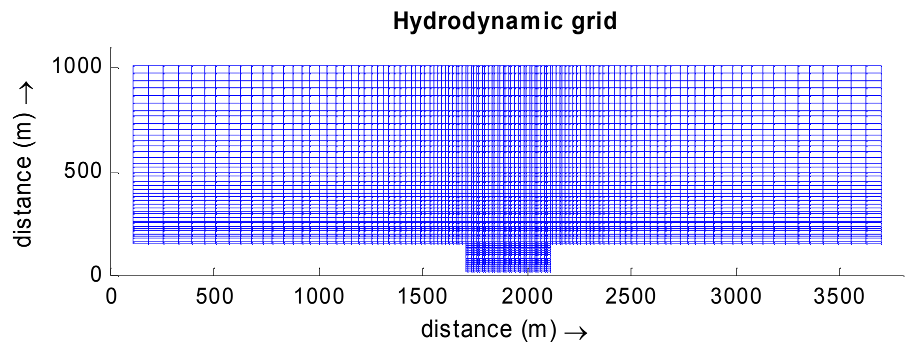


Figure 1: Hydrodynamic grid

The bathymetry in the model is schematised by a uniform depth of 2.2 m. Bottom roughness is incorporated in the model by means of a Chezy bottom friction coefficient with a value of 65.0 $m^{1/2}$ s^{-1}.

The background flow in the model is 0.01 m s^{-1}, flowing from the left to the right (using Figure 1 as a reference). This is done by prescribing this velocity on the right hand side boundary and prescribing the gradient of the water level on the left hand side open boundary (Neumann type boundary). On the upper boundary, a fixed water level is prescribed. The other boundaries are closed.

Table 3 Boundery settings 3D model

Boundary section	**Type**	**Prescribed value**
left	water level gradient	$-0.486 \cdot 10^{-8}$
right	velocity (logarithmic)	0.01 m s^{-1} (depth averaged)
upper	water level	$1.81 \cdot 10^{-5}$ m to 0.0 m
lower	closed	-

Note: At the upper boundary section the water level is interpolated linearly from the left ($1.81 \cdot 10^{-5}$ m) to the right (0.0 m).

For the vertical eddy viscosity, the k-epsilon turbulence closure is used. For horizontal eddy viscosities, the Horizontal Large Eddy Simulation (HLES) feature of Delft3D is used. This feature allows for the calculation of flow separation and eddy generation by sharp bends in the geometry.

Four runs with wind speeds of 0.0 m s^{-1}, 2.0 m s^{-1}, 5.0 m s^{-1} and 10.0 m s^{-1} have been made with this model. This direction of the wind in those four runs was inland.

The exchange flow has been calculated by adding up all the fluxes perpendicular to the interface between the harbour and the ambient water body. This has been done separately for both the positive and negative fluxes, thereby yielding the exchange flows:

Wind speed at 10 m (m/s)	Additional exchange flow at entrance
2.0 m/s	0.9 m3/s
5.0 m/s	2.8 m3/s
10.0 m/s	6.8 m3/s

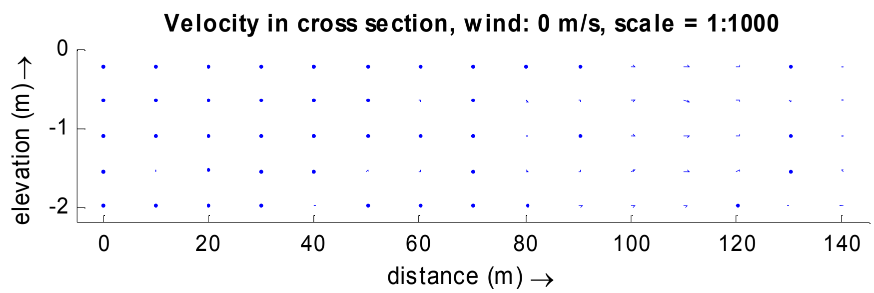


Figure 2 Flow velocity in harbour – cross sectional view, open boundary is on the right; 0 m/s

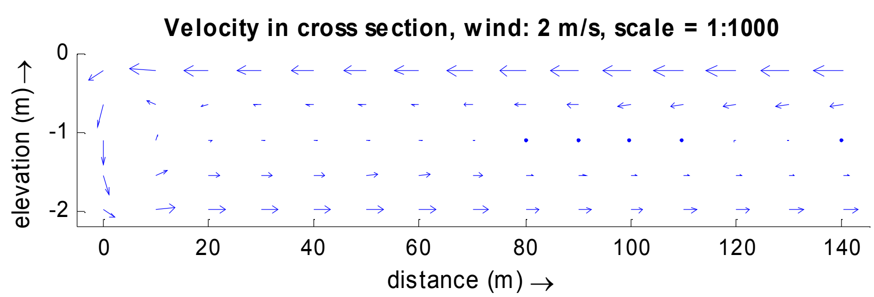


Figure 3 Flow velocity in harbour – cross sectional view, open boundary is on the right; 2 m/s

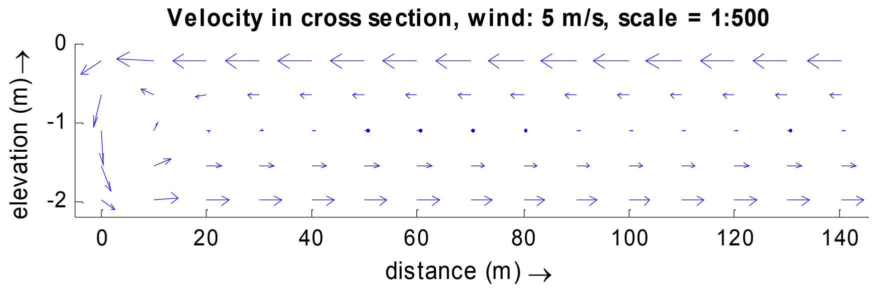


Figure 4 Flow velocity in harbour – cross sectional view, open boundary is on the right; 5 m/s

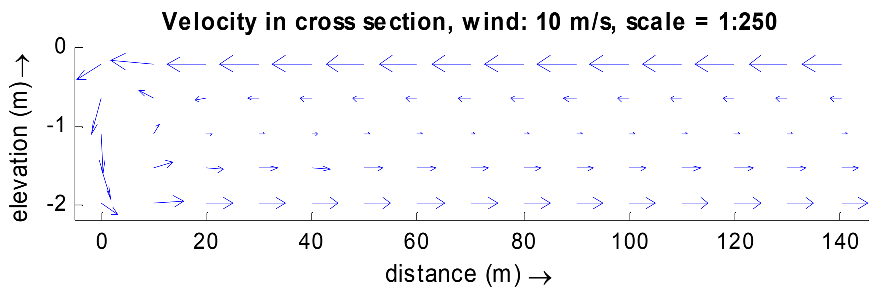


Figure 5 Flow velocity in harbour – cross sectional view, open boundary is on the right; 10 m/s

The actual wind distribution for several locations along the south – south-western coast of Finland are given in the next table (Drebs, A., A. Nordlund, P. Karlsson, J. Helminen, P. Rissanen; 2002).
The wind distribution has been calculated from four daily observations 0, 6, 12, 18 UTC. The table contains the percentages and average speeds of the 10-minute-observation-hour mean winds, divided into eight principal directions. Period 1971 – 2000.

Table 4 Wind distribution and velocities 1971-2000

Station name	N m/s	N %	NE m/s	NE %	E m/s	E %	SE m/s	SE %	S m/s	S %	SW m/s	SW %	W m/s	W %	NW m/s	NW %
Maarianhamina lentoasema	4.4	17	3.6	7	3.4	6	4.4	9	5.4	20	4.5	15	3.8	8	4.7	10
Korppoo utö	6.7	11	6.1	8	6.8	9	6.2	10	6.8	15	7.2	19	6.6	14	7.1	14
Kotka ranki	4.5	11	4.8	10	5.7	10	5.0	9	5.8	13	6.5	22	5.3	15	4.3	10
Inkoo Bågaskär	5.0	11	5.2	9	7.1	11	6.2	8	6.2	11	6.3	21	5.2	18	4.2	9
Hanko Russarö	5.9	10	5.6	8	6.5	12	5.4	8	6.6	13	6.7	19	5.6	16	5.5	12
Rauma kuuskajaskari	5.7	10	4.1	9	4.3	10	4.5	15	5.8	15	6.7	16	6.5	10	6.9	13
average	5.4	12	4.9	9	5.6	10	5.3	10	6.1	15	6.3	19	5.5	14	5.5	11

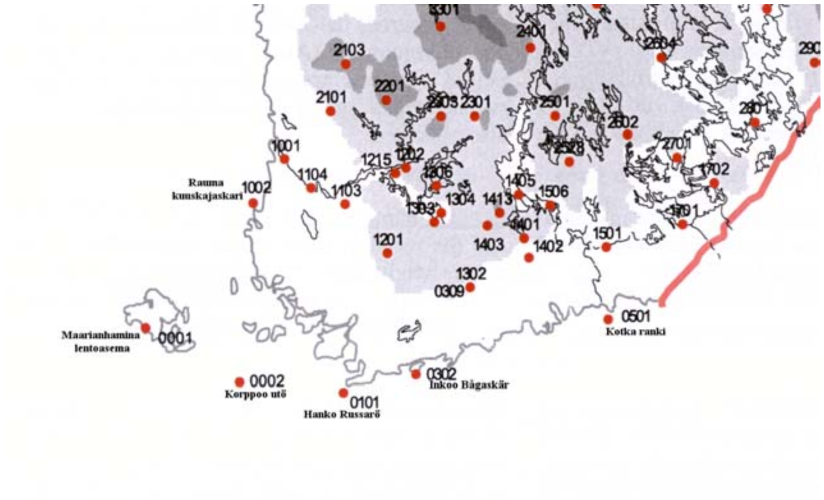


Figure 6 Location of wind stations

The relevant wind direction for the wind to be perpendicular to the marina entrance depends off course on the exact situation of the harbour. In general from the locations at the coast winds from the S to W would be likely candidates.
Winds from these directions average about 5.3 – 6.3 m/s. Occurrence depends on the location and varies from 8 % (for both W and SE winds) to 22 % (for SW winds).

A tentative assumption that 10 % of the time the wind is directed more or less perpendicular to the harbour entrance, with an average wind speed of 5 m/s, leads for the Uittamo marina to an additional wind-driven exchange of 2.8 m3/s (is 12.500 m3/ tidal period).
The actual exchange due to wind effects would also depends on the actual layout of the harbour and the free fetch area in front of the harbour. The way the harbour is schematised for the Uittamo marina (harbour entrance as wide as the harbour itself), leads to maximal wind driven exchange. Under less favourable conditions we can assume a smaller wind driven exchange effect. Taking the exchange at a wind speed of 2 m/s wind as an lower estimate this would give a wind driven exchange of approx 4.000 m3/tidal period.

4 Conclusions

The current version (1.4) of MamPec calculates the exchange between harbours and their environment based on the occurrence of horizontal flow, tide and/or density differences. In general these processes determine the exchange. Under conditions of very low flow, no density differences and no tide, other processes become important which are not yet included in the MamPec model (version 1.4). An overview of the implications for an example case of the Uittamo marina in Finland are given in the table below.

Table 5 Exchange volumes (m3/tide) in example case study of Uittamo marina.

Process	MamPec 1.4 Uittamo default settings	MamPec, corrected for low tide conditions
Horizontal flow exchange	2.628	8.250
Non tidal water level exchange	not taken into account	4.370
Wind driven exchange	not taken into account	4.000 to 12.500 (8.250 avg)

Based on this study, the setting for the exchange in the Uittamo marina as defined in the example should be manually corrected to 20.870 m3/tidal period .

5 References

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