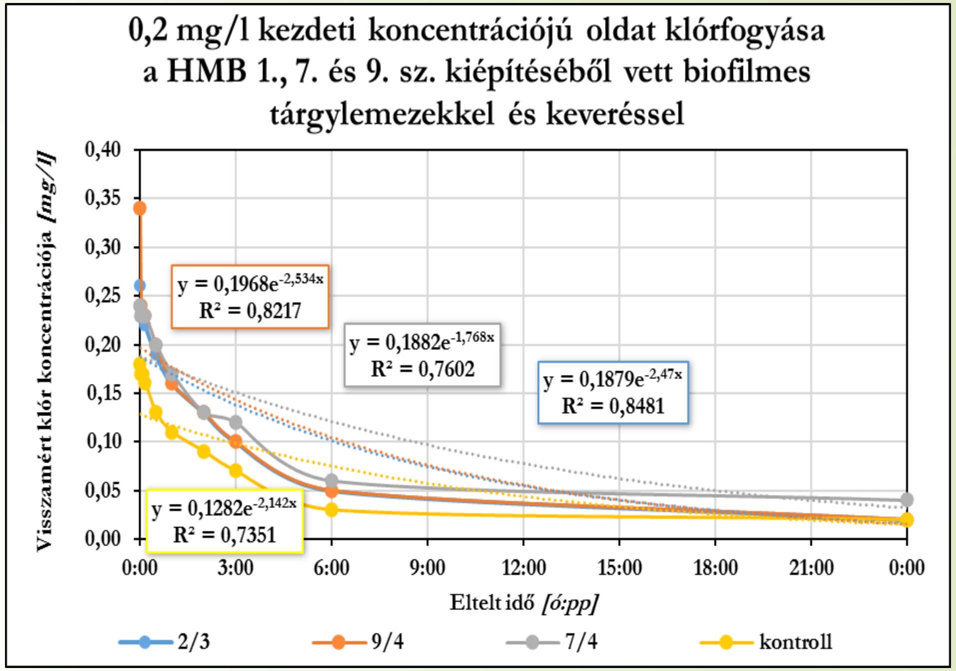
Modeling of chlorine decay kinetics in water supply networks

First steps: Laboratory measurements from on-site sampling and model pipeline



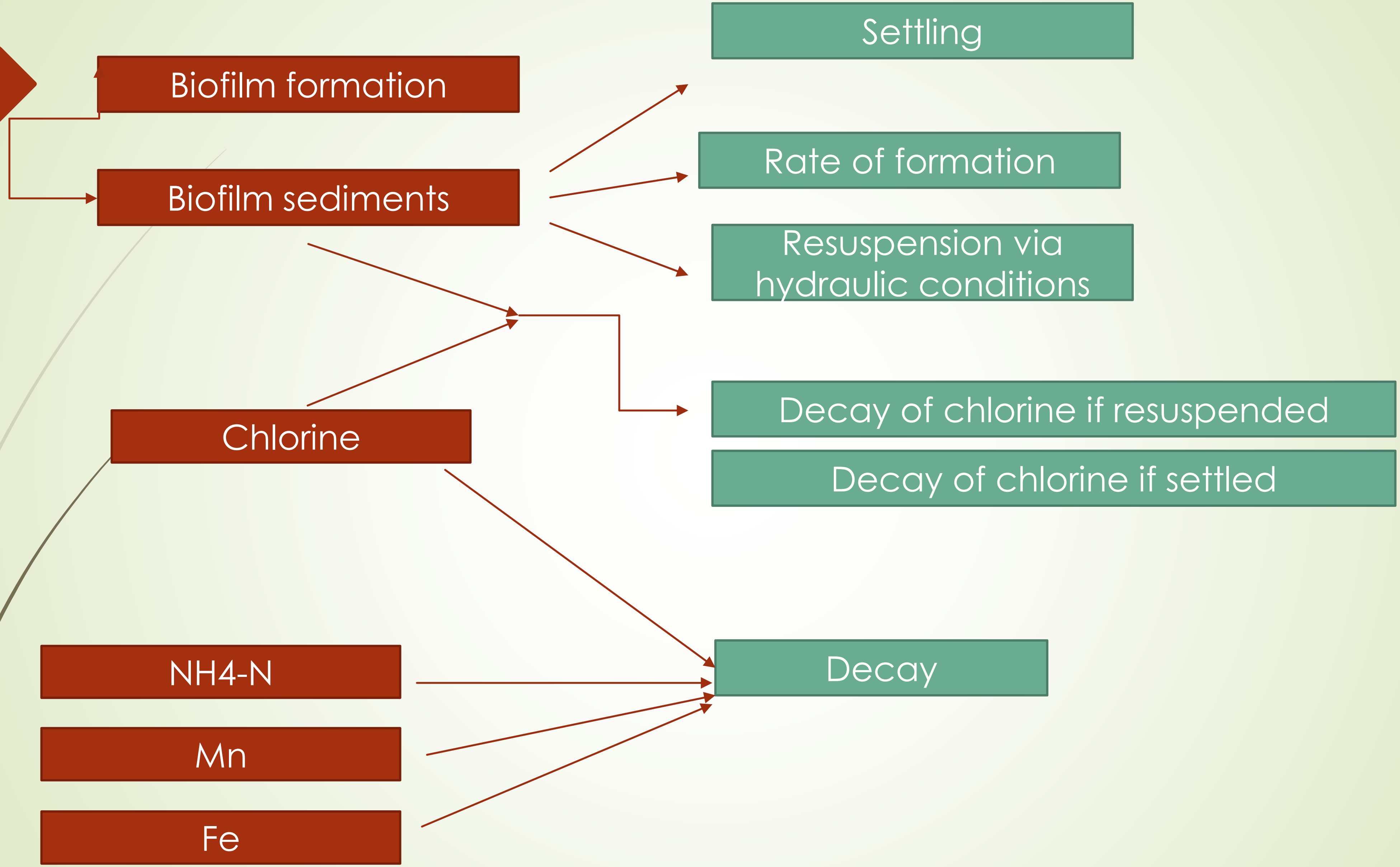
Biofilm formation

Formation of sediments

- Rate of formation
- Resuspension via hydraulic conditions
- Settling

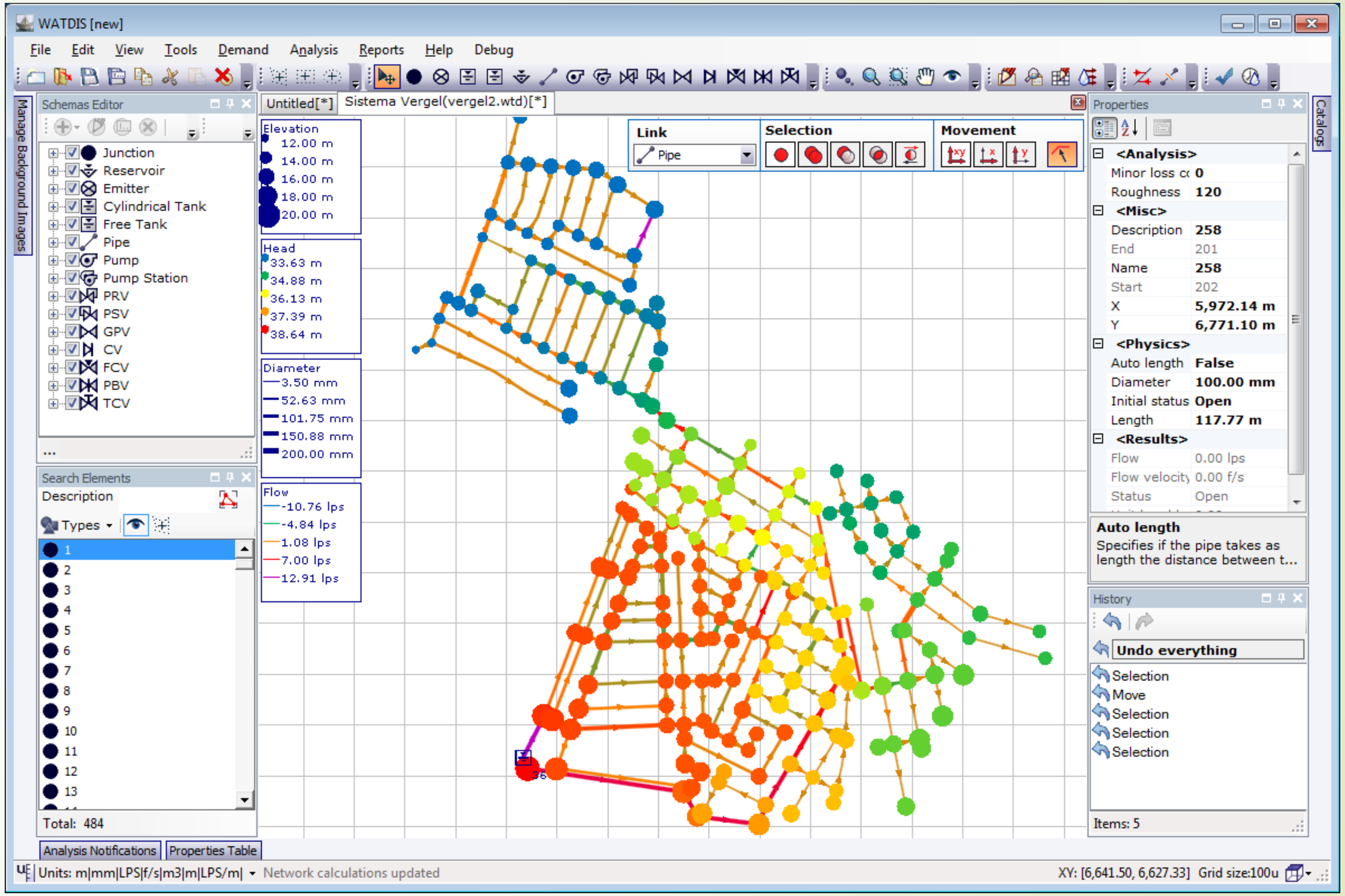
Chlorine

- Decay of chlorine if resuspended
- Decay of chlorine if settled


Biofilm formation
Biofilm sediments
Chlorine
NH4-N
Mn
Fe
Settling
Rate of formation
Resuspension via hydraulic conditions
Decay of chlorine if resuspended
Decay of chlorine if settled
Decay

Modelling tools

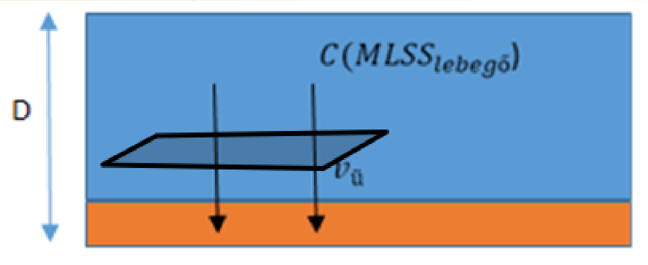
- Hydraulics: Epanet 2
- Water quality: MSX
- Plotting via: WaterCad



MSX:

- Uses epanet
- Allows for implementation of custom differential equation system
- Allows for wall and bulk phase
- Can simulate quality section in single pipes

Sediments settling



$$M = C(MLSS_{resuspended}) * V$$

$$r\,[\%] = \frac{dT * v_{ü} * A}{V}$$

$$\frac{dM}{M} = \frac{dT * v_{ü} * A}{V}$$

$$\frac{\partial C(XMLSS_{settled})}{\partial t} = \frac{v_{ü}\, C(XMLSS_{resuspended})}{D} \max(0; 1 - \frac{a * C_{XMLSS\_settled}}{K_{XMLSS\_settled} + C_{XMLSS\ settled}})$$

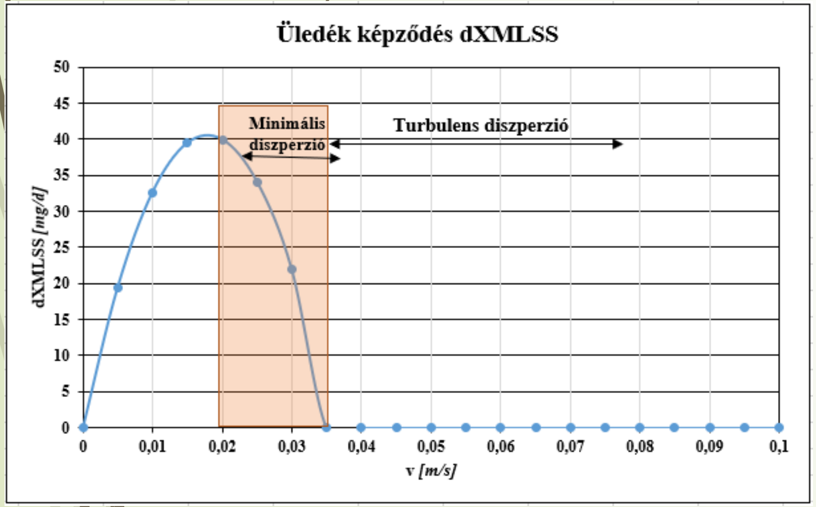
$$\frac{\partial C(XMLSS_{resuspended})}{\partial t} = -\frac{v_{ü}\, C(XMLSS_{resuspended})}{D} \max(0; 1 - \frac{a * C_{XMLSS\_settled}}{K_{XMLSS\_settled} + C_{XMLSS\ settled}})$$

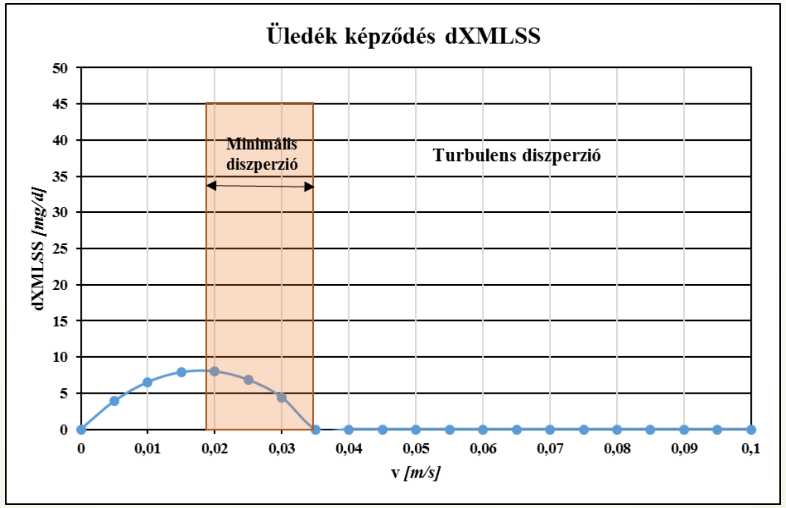
Sediment formation rate

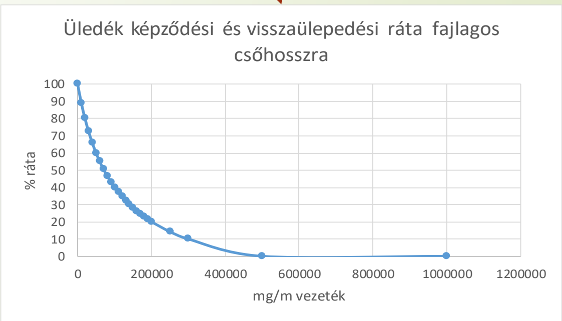
$$\frac{\partial C(MLSS_{settled})}{\partial t} = |k_1 * v_{\text{átl}} + k_2| * v_{\text{átl}} * D * 10\pi \max(0; 1 - \frac{a * C_{XMLSS\_settled}}{K_{XMLSS\_settled} + C_{XMLSS\ settled}})$$

- *k1=-3,8*
- *k2=0,136*
- *k3=10π24*

- *v>0 [m/s]*
- *v<0,035 [m/s]*



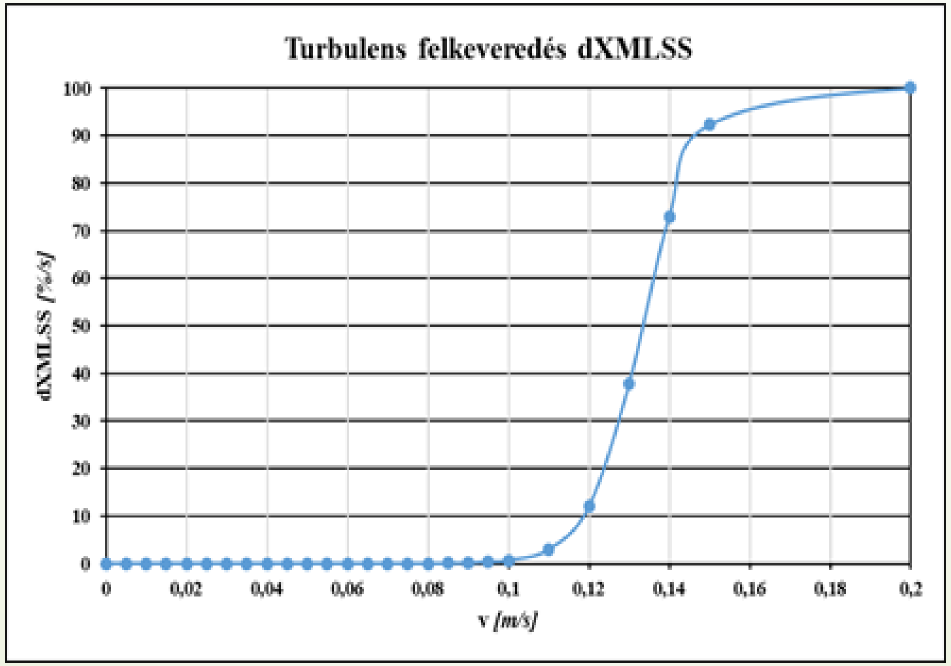




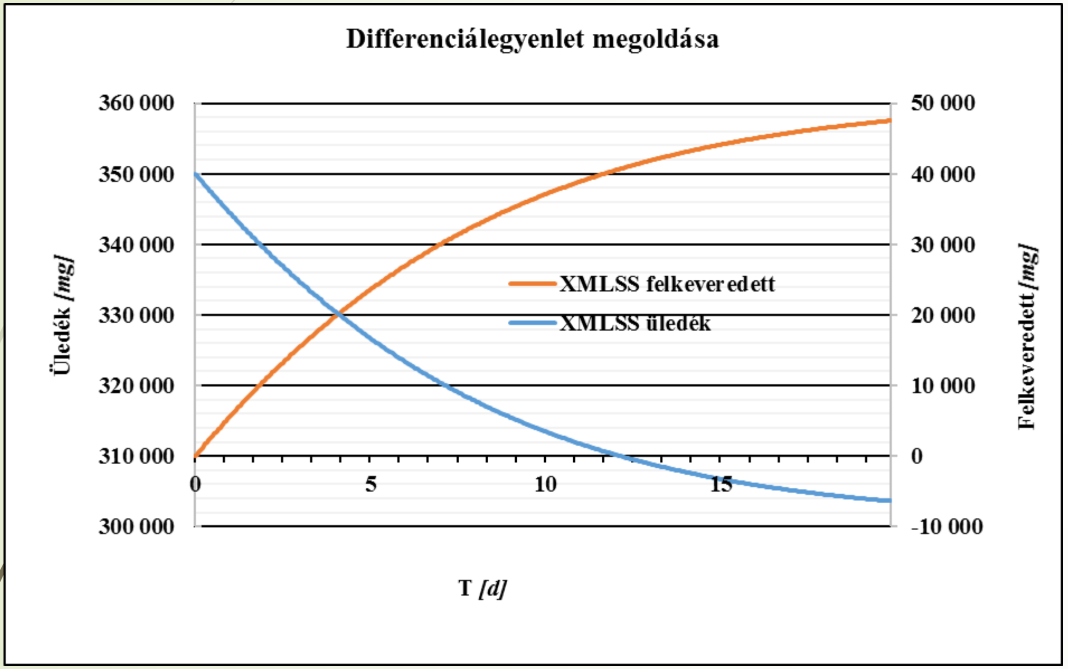
Resuspension

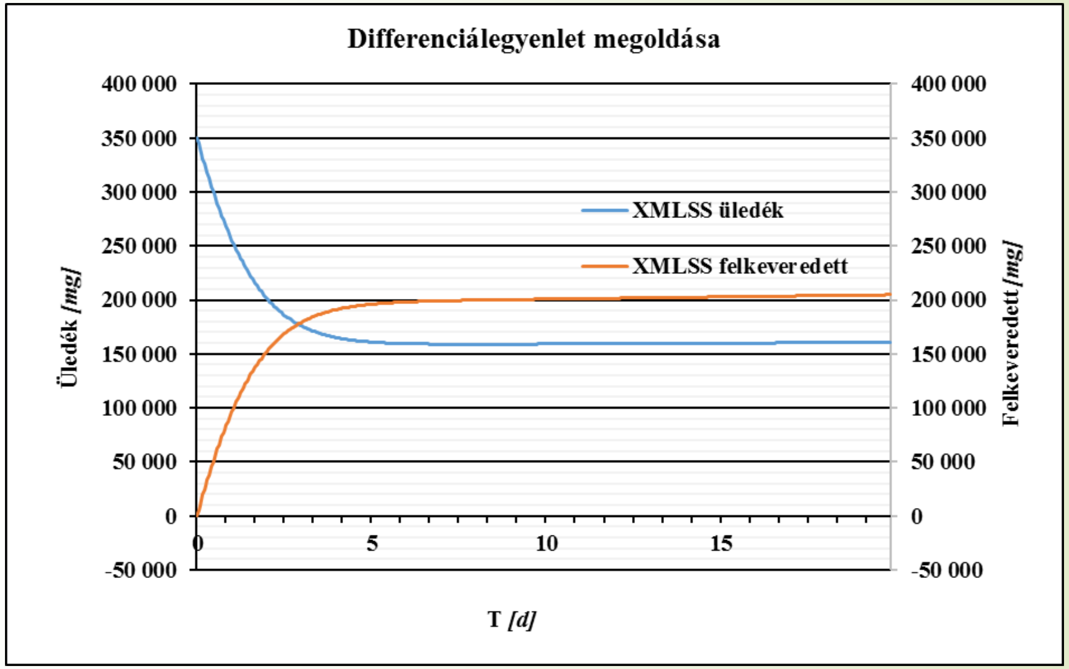
$$\frac{\partial C(MLSS_{resuspended})}{\partial t} = \frac{1}{1+e^{(-35v_{avg}+8)}} C(MLSS_{settled})$$

$$\frac{\partial C(MLSS_{settled})}{\partial t} = -\frac{1}{1+e^{(-35v_{átl}+8)}} C(MLSS_{settled})$$

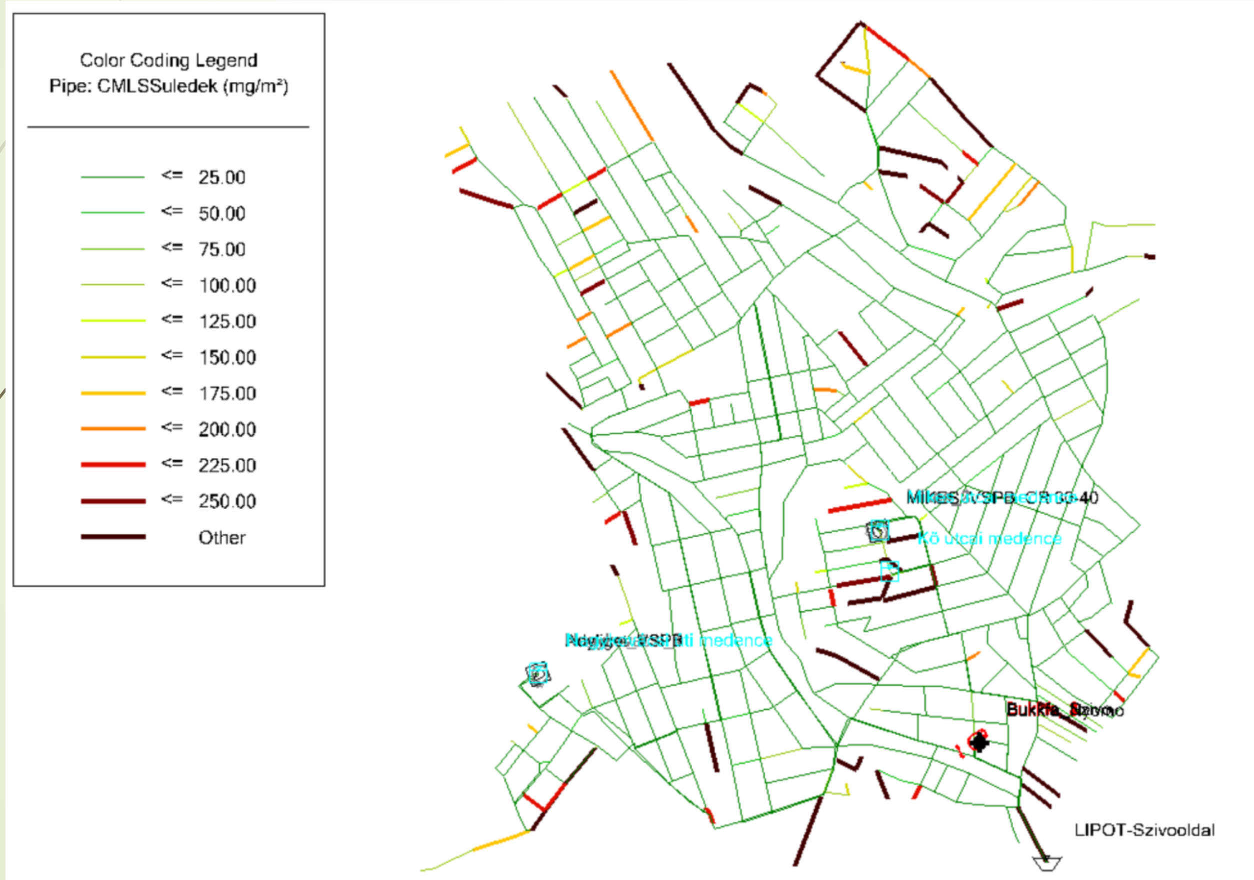


Putting all together

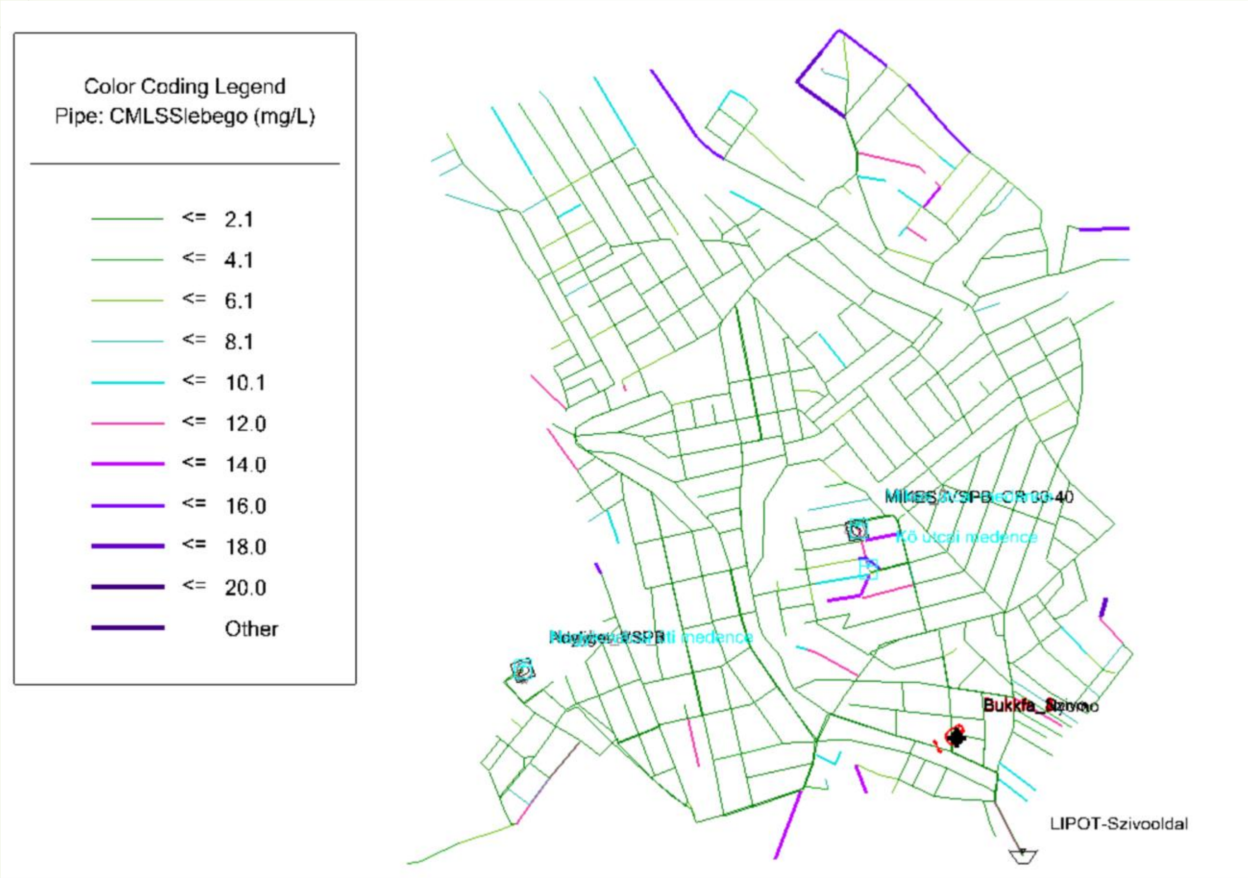


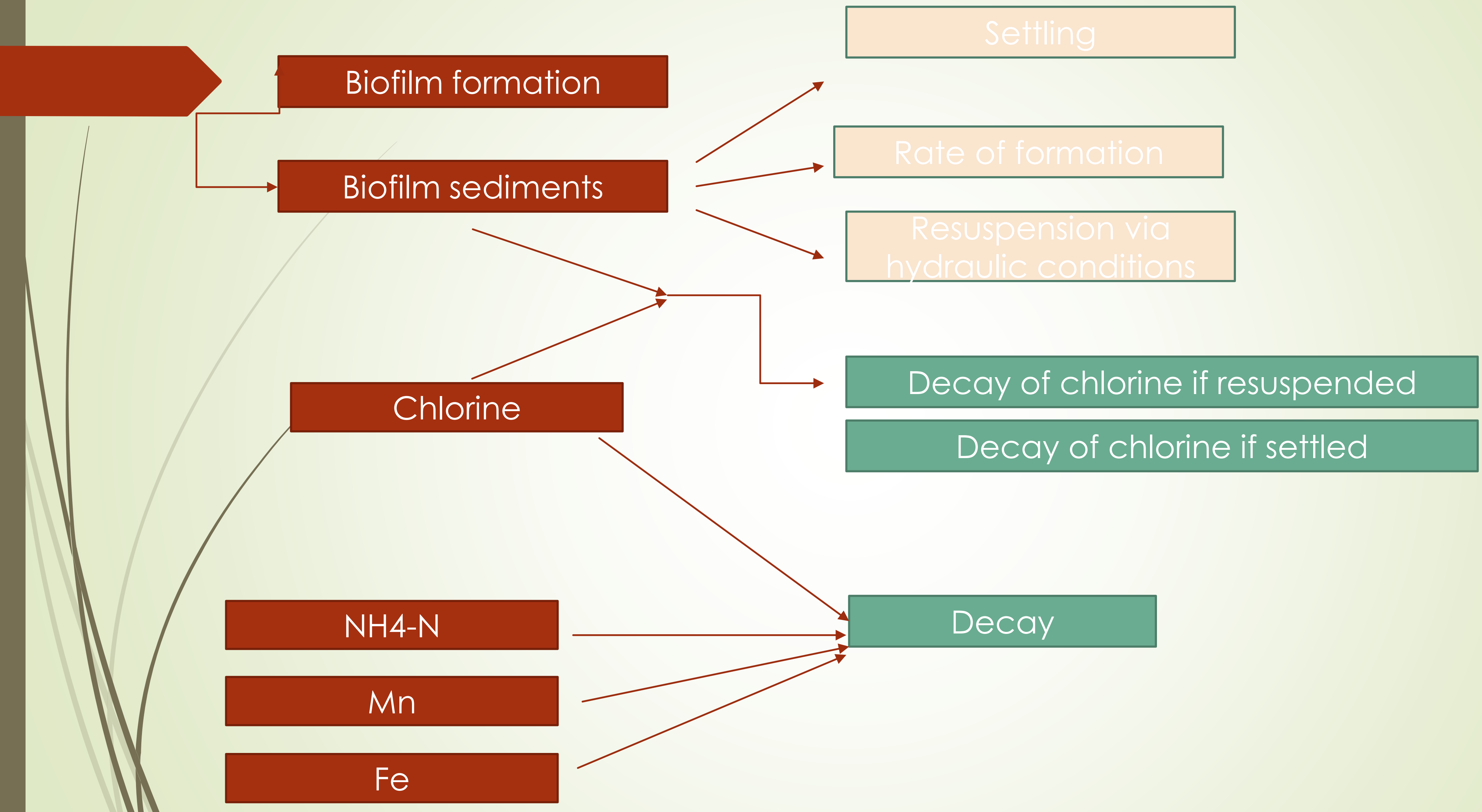


Simulation of sediment formation

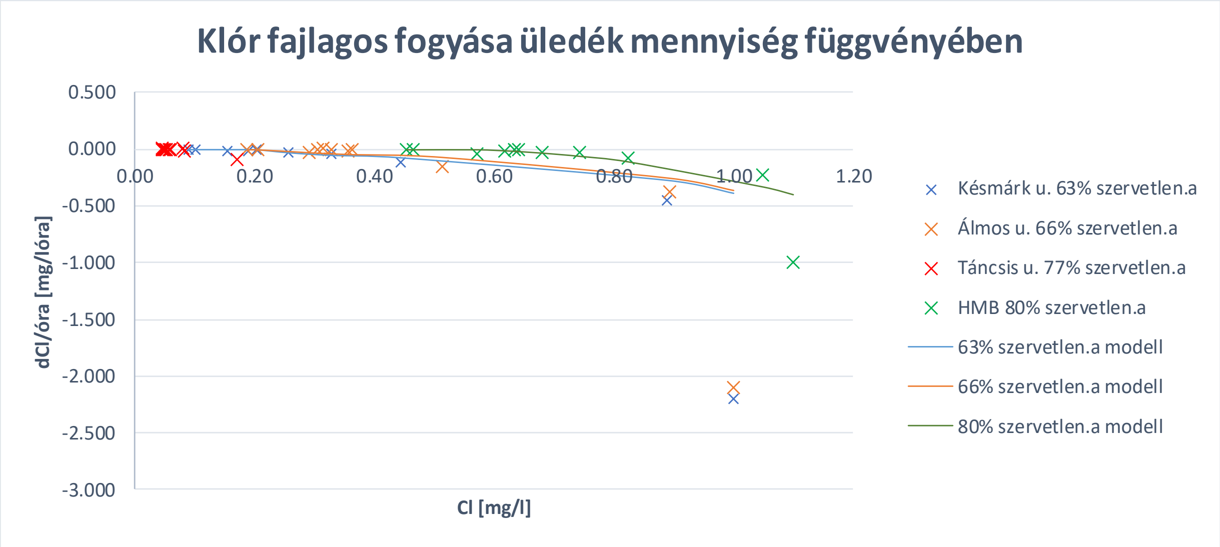


Simulation results for resuspension

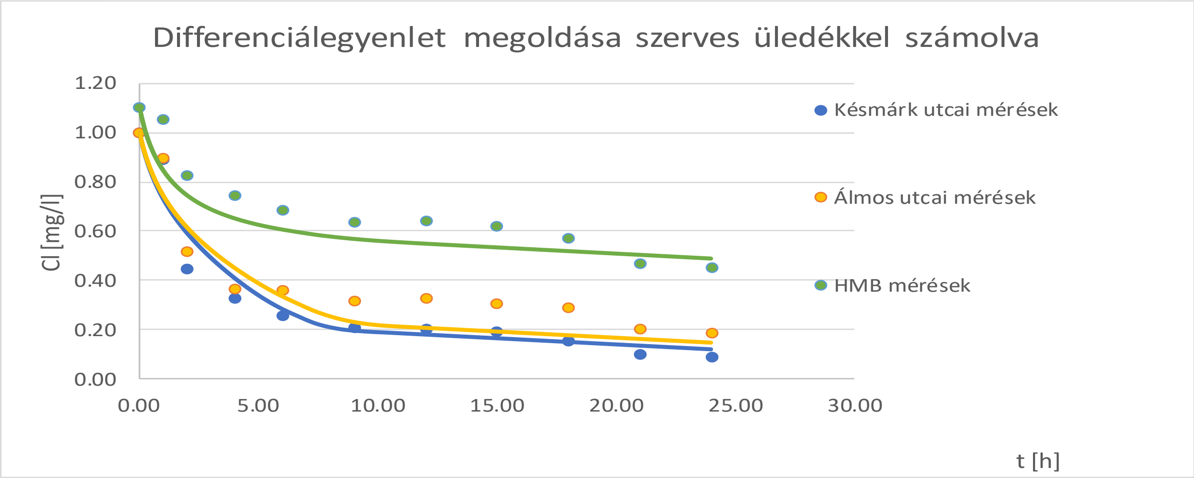



Biofilm formation
Biofilm sediments
Settling
Rate of formation
Resuspension via hydraulic conditions
Decay of chlorine if resuspended
Decay of chlorine if settled
Chlorine
NH4-N
Mn
Fe
Decay

Decay of chlorine if settled sediment is present

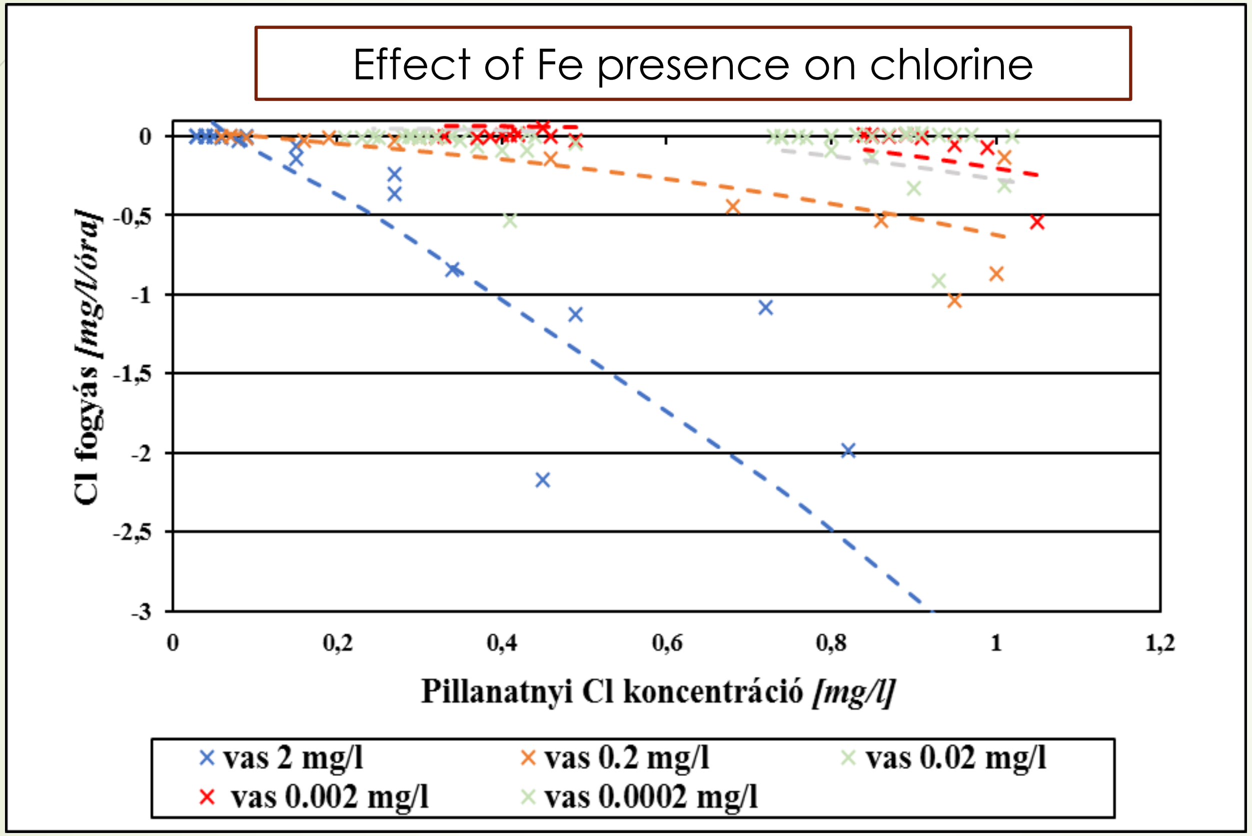


$$\frac{\partial Cl}{dt}[\mathrm{h}] = \min\left(-0.005 * C_{inert};\ \sqrt[3]{\frac{C(MLSS_{üledék})}{36}} * \left[a_1 + a_{10} * \left[a_2 * \sqrt{C_{inert}} + a_3 * \mathrm{Cl} + a_4 * (\mathrm{Cl} * a_5 - a_6)^2 + a_7 * e^{(\mathrm{Cl} * \sqrt{C_{inert}} * a_8) + a_9}\right]\right]\right)$$



Hydrant flush
Results and model

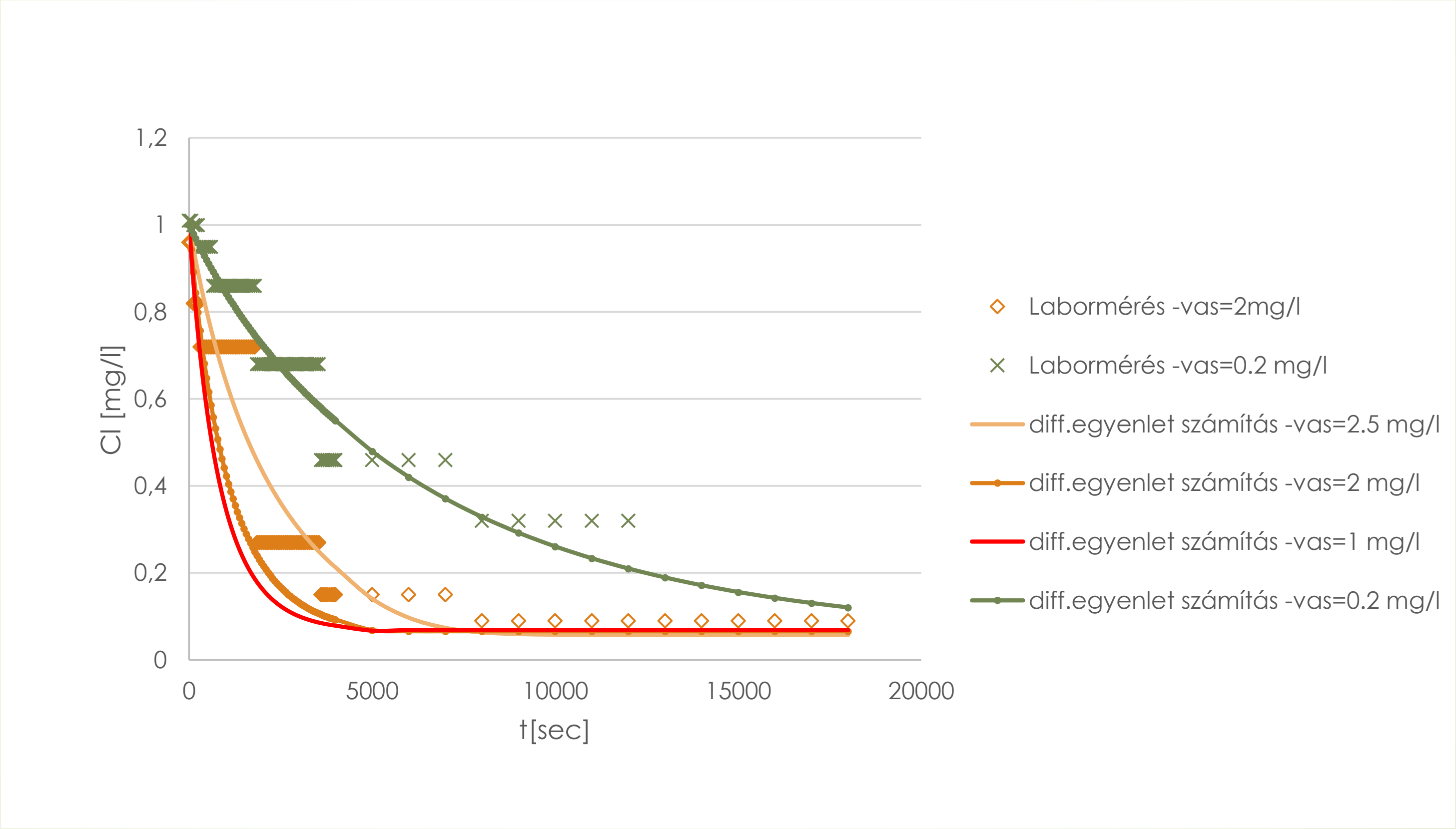
Decay of chlorine by disolved Fe



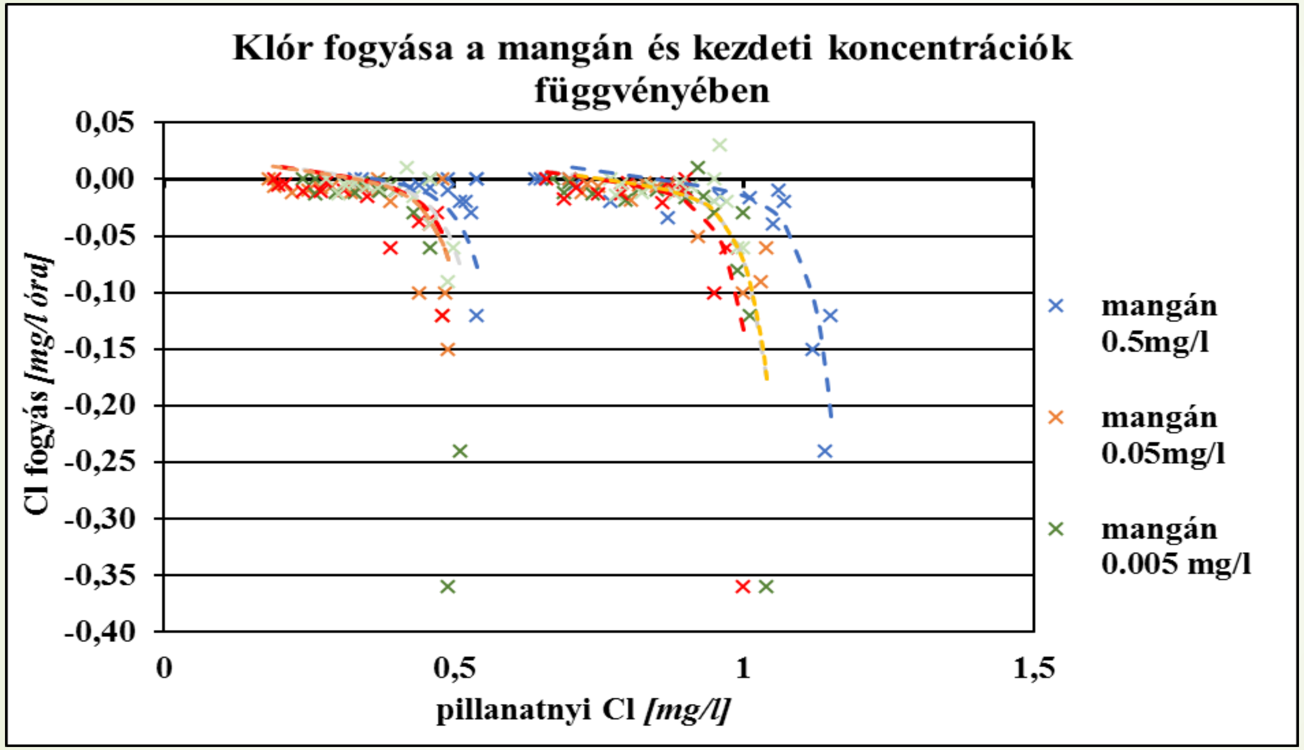
$$\frac{\partial Cl}{dt}[\text{óra}] = a_1 + a_2 * \text{Fe} * \text{Cl} + a_3 * \text{Cl} + a_4 * (\text{Cl} - a_5)^2 + a_6 * e^{a_7 * (\text{Cl} * \text{Fe} * a_8) + a_9}$$

Parameter	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
Calibrated value	1,378	-2	-0,323	-0,6	0,604	0,947	-1,8	8,5	-1,4	-1,38	-0,61	0,264

Decay of chlorine by Fe presence, solving the differential equation



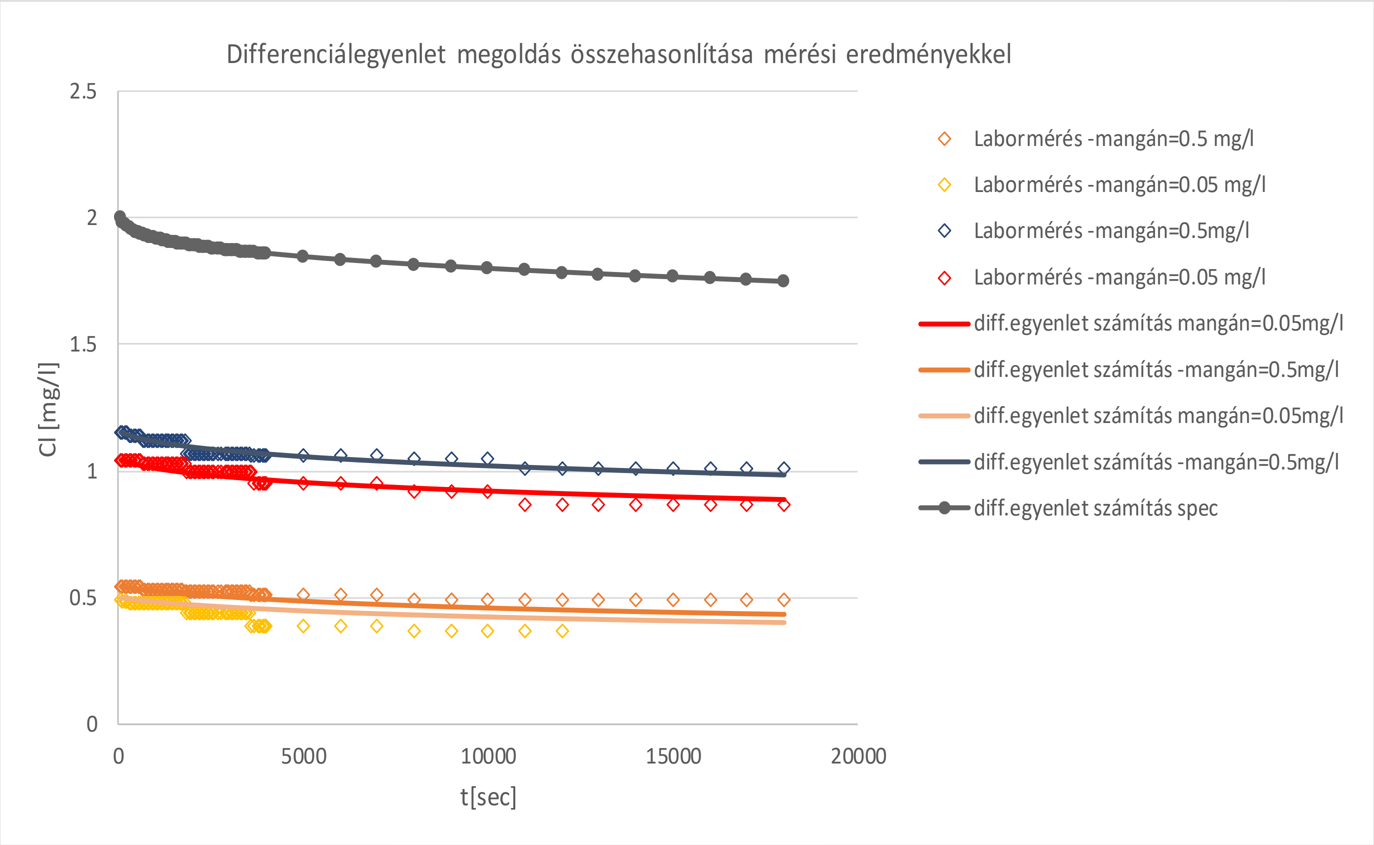
Decay of chlorine by Mn



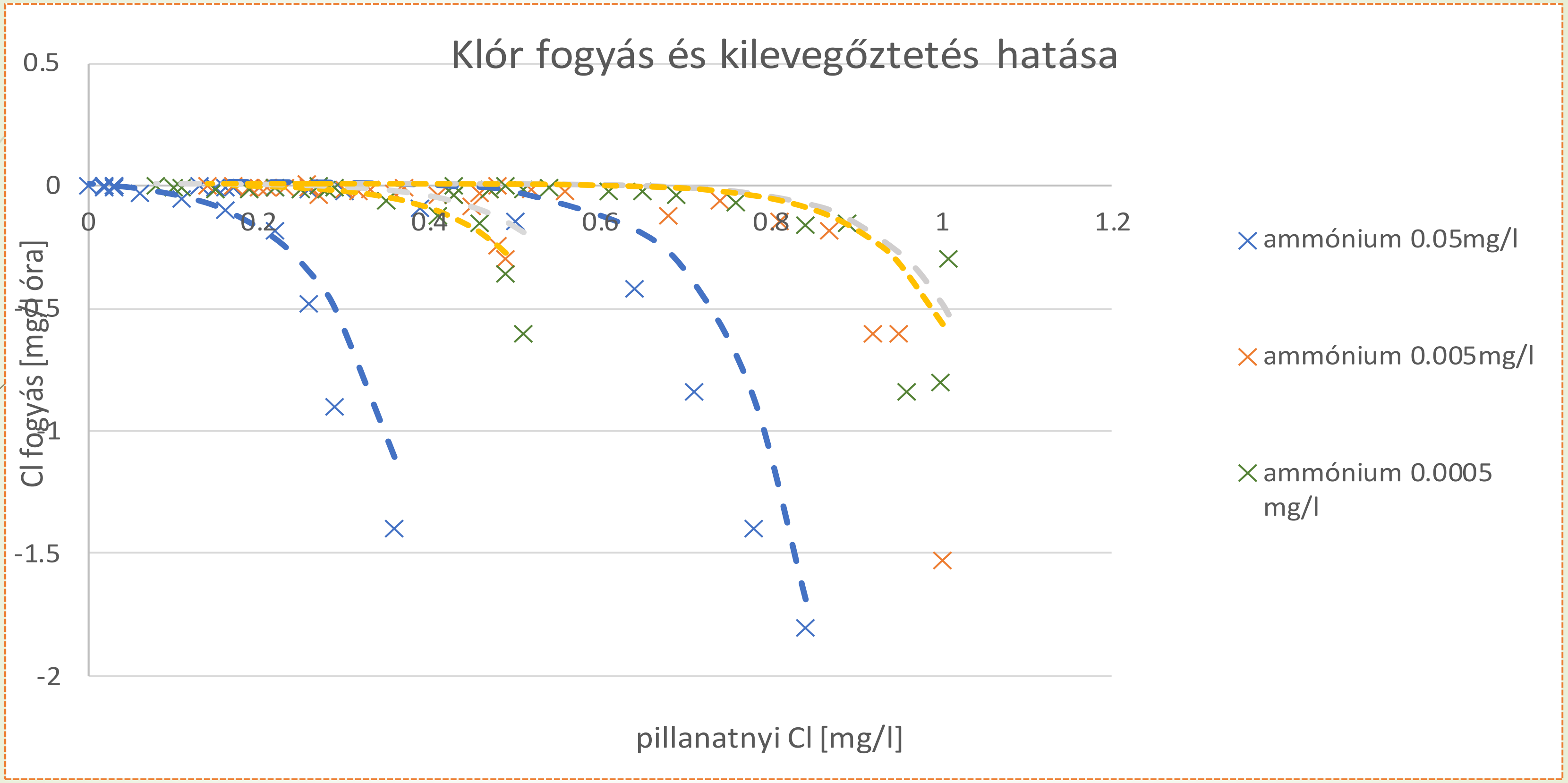
$$\frac{\partial Cl}{dt}[óra] = a_1 + a_2 * 3^{a_3*(Cl+a_4*(Cl-Cl_0)+a_5)} + a_6 * Cl_0 + a_7 * Cl$$

a_1	a_2	a_3	a_4	a_5	a_6	a_7
-0.002	-7.08	1.55	14.21	-3.28	0.055	-0.072

Decay of chlorine by Mn presence, solving the differential equation



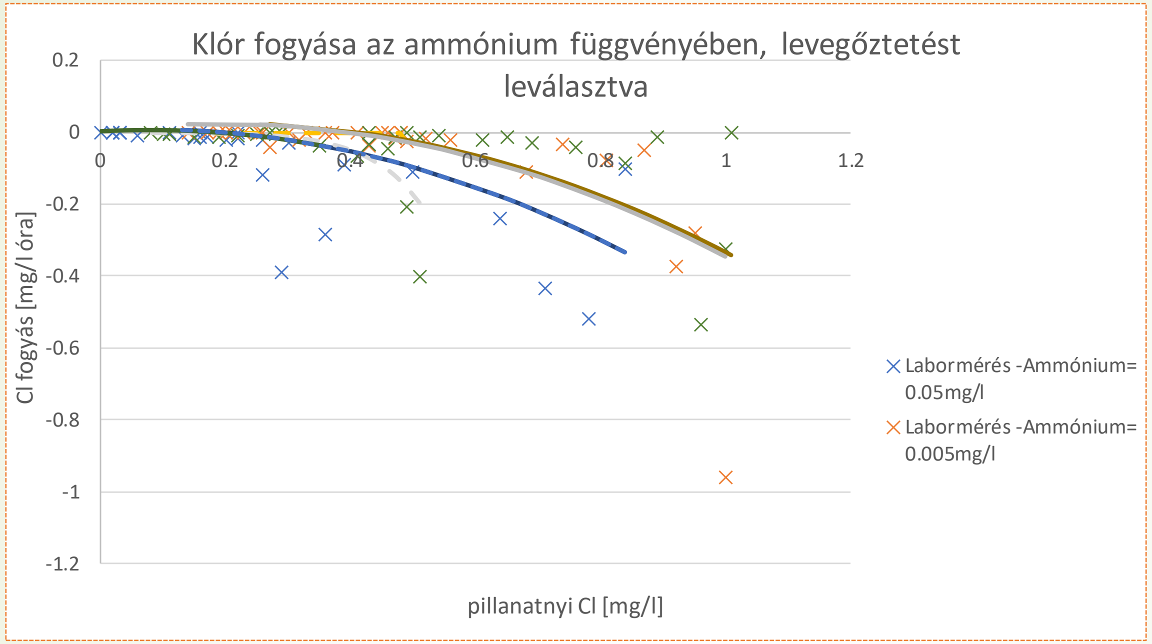
Decay of chlorine by Ammonium presence



$$\frac{\partial Cl}{dt}[h] = a_1 + a_2 * {a_6}^{a_3*(Cl+a_4*(Cl-Cl_0*a_7)+a_5)} * f_2$$

$$f_2 = \frac{1}{Cl0^{0.68}} * a_8 * NH4^{a_{10}} + a_9 * 1/(1 * a_{11} + Cl) + 0.2$$

Decay of chlorine by Ammonium presence



$$\frac{\partial Cl}{dt}[\mathrm{h}] = a_1 + a_2 * \mathrm{NH4} * \mathrm{Cl} + a_3 * \mathrm{Cl} + a_4 * (\mathrm{Cl} - a_5)^2 + a_6 * e^{a_7*(\mathrm{Cl}*\mathrm{NH4}*a_8)+a_9}$$

Parameter	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
Value	1,338	-8	0,17	-0,56	0,05	-1,34	-1	-4	-0,005

Decay of chlorine by Ammonium presence, solving the differential equation