Modelling Aquifer Pollution Near Livestock Farms Using Advanced Hydroinformatic Tools

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Abstract
Animal husbandry is one of the main causes of water pollution. Therefore, one of the important problems to be solved in the design, execution and operation of livestock farms is the achievement of a reliable system of collection, treatment and evacuation/storage of wastewater and animal manure resulting from the process of animal husbandry, so that pollutants do not infiltrate in groundwater. However, accidents can occur in the operation of these systems, and wastewater and animal manure can seep into groundwater, determining their pollution. This paper aims to present a way to model the propagation of pollutants in groundwater in the vicinity of livestock farms, using the PMWIN software, an advanced hydroinformatic tool. On the basis of the results obtained from the modelling, the competent authorities can determine the extent of the pollution and the necessary measures to be taken to reduce the negative effects on groundwater quality.

Keywords: animal manure, groundwater, livestock farms, modelling, pollution, wastewater

1. Introduction

Groundwater is the largest freshwater reservoir in the world, representing more than 97% of all available freshwater reserves (excluding glaciers and caps glacier). Because groundwater flows slowly through the subsoil, the impact of human activities can affect it over a long period of time.
As the surface water networks are also supplied from groundwater, the quality of groundwater will ultimately be reflected in the quality of surface water. That is, the effect of human activities on groundwater quality will have an impact on the quality of directly dependent aquatic ecosystems and terrestrial ecosystems.
The European regulatory framework for groundwater was born in the late 1970s, and now includes numerous directives for the protection of groundwater against pollution caused by certain hazardous substances.
One of the most important is the Integrated Pollution Prevention and Control (IPPC) Directive 96/61/ EEC, which lays down measures to prevent or reduce air, water and underground pollution. The Directive applies to a significant number of major industrial activities, with a high pollution potential, such as the energy sector, metal production and processing, the mining and chemical industries, the food industry, waste management facilities, as well as non-industrial activities, such as livestock farms [1].
Animal husbandry is one of the main causes of water pollution. Therefore, one of the important problems to be solved in the design, execution and operation of livestock farms is the achievement of a reliable system of collection, treatment and evacuation/storage of wastewater and animal manure resulting from the process of animal husbandry, so that pollutants do not infiltrate in groundwater. However, accidents can occur in the operation of these systems, and wastewater and

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animal manure can seep into groundwater, determining their pollution [2, 3].

The specific sources of groundwater pollution for the period of operation of livestock farms may come from: domestic wastewater, which results from the use of water for sanitary purposes; technological wastewater from the sanitation of halls; potentially clean rainwater; sewage from the manure deposition platform [4, 5].

The factors that can induce an impact on groundwater in the area of the location of livestock farms are: defects in the sewerage network of domestic wastewater; improper sealing of the manure platform or cracking of the sealing system of the manure collection platform, leachate storage tank or domestic wastewater; improper storage of manure; accidental leaks of petroleum products and mineral oils from various machines, but which are minimal [6].

2. Materials and methods

A way to model the propagation of pollutants in groundwater in the vicinity of livestock farms is the use of hydroinformatic tools.

Hydroinformatics is a branch of informatics which concentrates on the application of information and communications technologies in addressing the increasingly serious problems of the equitable and efficient use of water for many different purposes.

On the technical side, in addition to computational/classical hydraulics, hydroinformatics use techniques of artificial intelligence, such as artificial neural networks vector machines and genetic programming. These are used together with large collections of observed data in order to generate a computationally efficient simulator tool of that model for some purpose.

Hydroinformatics draws on and integrates hydraulics, hydrology, environmental engineering and many other disciplines. It can be applicate at all points in the water cycle from atmosphere to ocean, and in human interventions in that cycle such as urban drainage and water supply systems. It provides support for decision making at all levels from governance and policy through management to operations [7].

One such hydroinformatic tool is PMWIN (Processing MODFLOW) software, developed by Simcore Software, USA, for simulating and predicting groundwater conditions and groundwater/surface-water interactions. Is one of the most complete three-dimensional groundwater and transport simulation systems in the world.

The text and the companion full-version software (PMWIN) offer a totally integrated simulation system. PMWIN comes with a professional graphical user-interface, supported models and programs and several other useful modeling tools. The model tools include a Presentation Tool, a Result Extractor, a Field Interpolator, a Field Generator, a Water Budget Calculator and a Graphic Viewer. The typical user is working as a hydrogeological or environmental consultant, in a water company, in a regulatory agency or a university [8].

PMWIN simulates the groundwater flow within the aquifer is simulated in MODFLOW using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated [9].

In PMWIN, an aquifer system is replaced by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells) [10].

To exemplify the modeling of groundwater pollution using advanced hydroinformatics tools, a poultry farm was chosen.

Pollution scenario: cracking of the foundation of the leachate storage basin, thus resulting in the infiltration in groundwater of a discharge of 1 l/s wastewater; permanent source.

The input data are:

- domain area 3.24 km^2 (1.8 km x 1.8 km)
- the aquifer is unconfined, homogeneous and isotropic
- the top and bottom elevations of the aquifer are 60 m and 0 m, respectively
- the aquifer is simulated using a grid of one layer, 60 columns and 60 rows
- grid spacing is regular (30 m x 30 m)
- the layer type is unconfined
- two boundaries are fixed hydraulic head boundaries and two boundaries are no-flow boundaries
- the average horizontal hydraulic conductivity is 0.000145 m/s; the effective porosity is 0.22
- three water extraction boreholes for various uses, with a 6 l/s discharge for each.

The situation plan and the domain discretization, respectively the location of the farm, of the crack point of the foundation of the leachate storage basin, as well as the location of the three extraction boreholes are presented in Figure 1. Also in Figure 1 are shown the boundary conditions on the domain boundary.

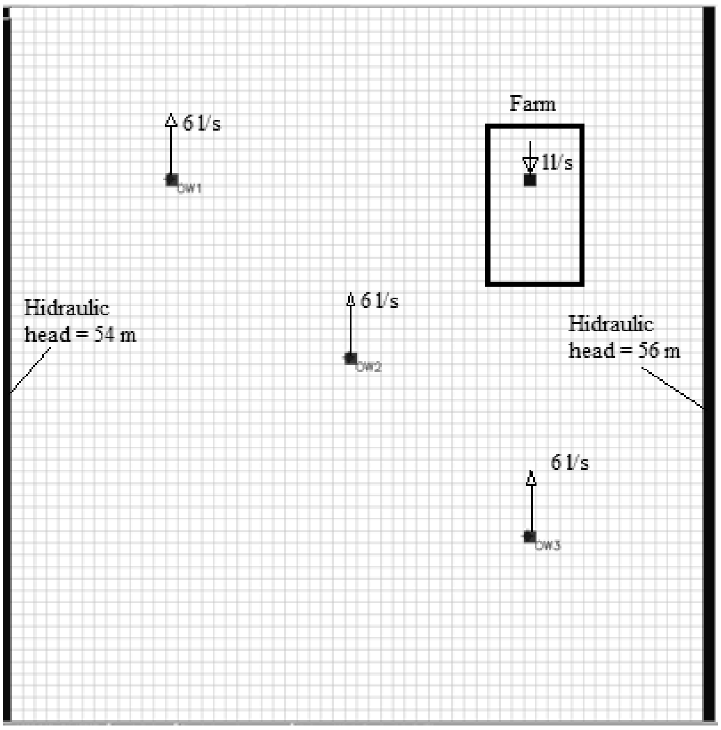

Figure 1. Situation plan

3. Results and discussion

Simulations are making in calibrated model in different significant time period: 5, 25 and 55 years. The hydroips lines and the trajectory of the pollutant are presented in Figure 2. Results are presented in figures under polluted extending areas with different concentrations (isoconcentrations) for 5, 20 and 55 years (Figure 3, 4 and 5).

The variation of the pollutant concentration in the extraction boreholes is shown in Figure 6.

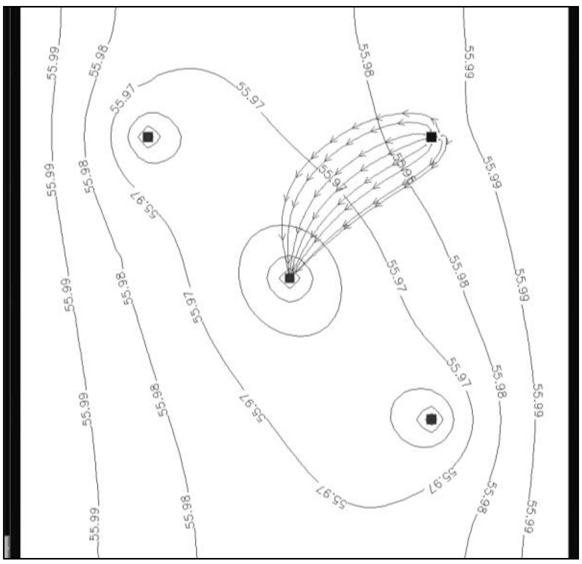

Figure 2. Hydroips lines and the trajectory of the pollutant

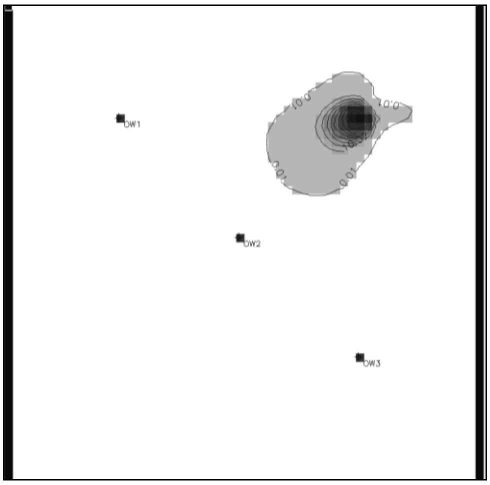

Figure 3. Concentration at 5 years

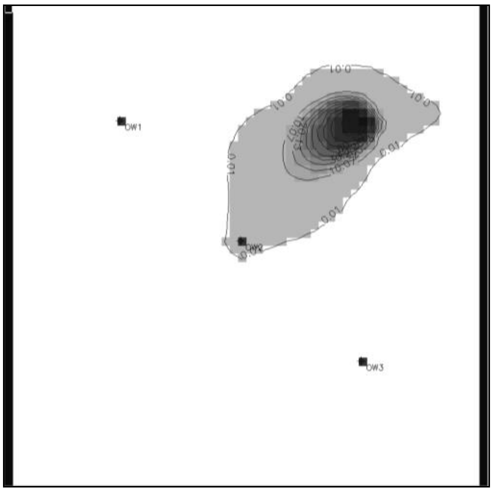

Figure 4. Concentration at 25 years

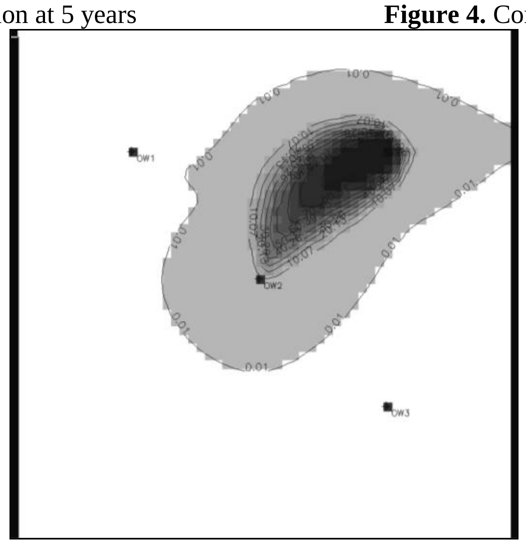

Figure 5. Concentration at 55 years

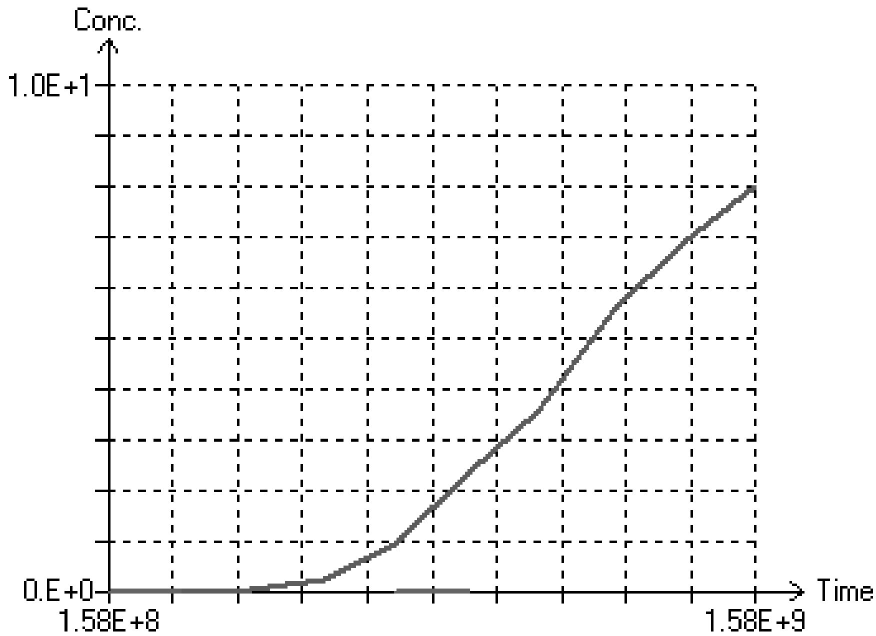

Figure 6. The variation of the pollutant concentration in the extraction boreholes (OW2)

From the simulation results it can be seen that the pollutant only reaches extraction boreholes 2, in about 22 years.
Is too mentioned in modeling isn't necessary to specify polluted mature.
Concentration is a general parameter and maybe serve base for calculation an absolute concentration (for example mg/l) for all dissolved pollutants in water.
In order to obtain results with a degree of accuracy as high as possible after modeling, more attention must be paid to the necessary input data. Thus, detailed pedological, hydrological and topographic studies must be performed in the studied area. Also, detailed laboratory analyzes of pollutants with risk of infiltration into the field must be made, in order to know the concentrations of different dangerous substances.

4. Conclusions

Result of simulation are permitted quantity exactly evolution of concentrations in time for all points of polluted zones.
This think is especial important to make technical to limit, reduce or eliminate a pollution.
On the basis of the results obtained from the modelling, the competent authorities can determine the extent of the pollution and the necessary measures to be taken to reduce the negative effects on groundwater quality.
The specialists must determine whether measures are needed to reduce or prevent the infiltration of pollutants into groundwater. Also, when establishing these measures, a technical-economic analysis must be made regarding the costs/benefits of maintaining the operation of livestock farms, the costs of implementing the measures considered necessary for protection, respectively the costs of treating the affected groundwater, to bring them back at an adequate quality.

References

1. European Commission, Protecţia apelor subterane în Europa. Noua Directivă a apelor subterane – consolidarea cadrului legislativ al Uniunii Europene, 2009.
2. Horablaga, A., Lixandru, B., Petrovici, M., Sinitean, A., Marin, A. A., Morariu, F., Horablaga, M., Morariu, S., Use of benthic macroinvertebrates in the diagnosis of Bega river water quality and self-purification process, "Gheorghe Asachi" Technical University of Iasi, 19(3), 2020, 505-510.
3. Morariu, F., Lixandru, B., Petrovici, M., Sinitean, A., Vlad, F. M., Ferencz, M. A., Cherciu, M. R., Marin, A. A., Horablaga A., Research Regarding the Use of Benctonic Macro Invertebrates on Bega River Water Quality Determination in the Timisoara Area, Animal Science and Biotechnologies, 2019, 52(2).
4. Marin, A. A., Lixandru, B., Cioban, G., Morariu, S., Vlad, F. M., Ferencz, M. A., Petrovici, M., Sinitean, A., Morariu, F., Research regarding on pollution monitoring with the help of benctonic macroinvertebrates at Bega river near Timisoara, GLOREP Conference, Timisoara 15-17 November, Conference Proceeding, 2018.
5. Morariu, F., Lixandru, B., Ciobanu, Gh., Morariu, S., Vlad, F. M., Ferencz, M. A., Petrovici, M., Sinitean, A., Marin, A. A., Research regarding the effect of the urban community on the distribution of benctonic macroconvertebrates in the Bega river near the town of Timisoara, GLOREP Conference, Timisoara 15-17 November, 2018, Conference Proceeding
6. Marin, A. A., Lixandru, B., Petrovici, M., Sinitean, A., Morariu, F., Popescu, D., The structure and dynamics of macrozoobenthic communities of the Bega River Water, Bulletin USAMV, series Agriculture, 2016, 73(1), 53-58.
7. Wikipedia, 2021. Home page address: https://en.wikipedia.org/wiki/Hydroinformatics#
8. Chiang, W. H., 3D-Groundwater Modeling with PMWIN A Simulation System for Modeling Groundwater Flow and Transport Processes, second edition, Springer, The Netherlands, 2005, pp.1-7
9. Civil Engineering Software Database, 2021. https://www.cesdb.com/pmwin.html
10. Simcore Software, 2021, https://www.simcore.com/files/pm/v11/tutorial1.pdf?a=2020120601