INCOME Water Care

Improved Management of Contaminated Aquifers by Integration of Source Tracking, Monitoring Tools and Decision Strategies

Integrated program of activities for sanitation of contamination sites and pollution sources, with priorities, exemptions and uncertainties evaluation

Geological Survey of Slovenia

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- DSS for improvement of chemical status of the aquifers (DSS-2)
- CD - DSS-2 application with instructions for use

1 Introduction

Integrated program of activities for sanitation of contamination sites and pollution sources, with priorities, exemptions and uncertainties evaluation consist of:

- Program of activities with priorities, where recommended sanitation measures, based on results of project INCOM, are summarised.
- DSS for improvement of chemical status of the aquifers (DSS-2) – application which was developed for optimisation of sanitation measures for improvement of chemical status of the aquifers.

The activities were performed by Geological survey of Slovenia within the project INCOME (LIFE07 ENV/SLO/000725). The main objective of the project is long-term effective management of aquifers and preservation of the quality of these water resources for future generations. The project is co-financed by European Commission, Municipality of Ljubljana and Ministry of the Environment and Spatial Planning of Republic of Slovenia.

2 Program of activities with priorities

The first priority measure is implementing prevent and limit objectives:

To prevent an input into groundwater means: There should be no significant increase in concentration of pollutants in the groundwater, even at a local scale. All measures deemed necessary and reasonable to avoid the entry of hazardous substances into groundwater, should be taken.

Limit applies to all non-hazardous pollutants. All measures necessary to limit inputs into groundwater should be taken so as to ensure that such inputs do not cause deterioration in status or significant and sustained upward trends in the concentration of pollutants in groundwater.

2.1 Point sources

Decreasing emissions of substances by waste water:

All the emissions of waste water that are under obligation of emission monitoring (industry, landfill) should provide the measures/plan for reduction of mass of pollutants entering the sewage system or ground.

All other activities that produce wastewater (except households) should report to the sewage manager the list of substances that will be emitted and the estimation of yearly mass of substances that will be used in the work process.

Sewage system manager should precisely monitor the mass balance of emitted quantity of substances and amount of all substances coming to the treatment plant.

Sanitation and reconstruction works on sewage system should follow the priority: 1) age of construction, 2) material of construction, 3) water protection areas VVO I and VVO II a, 4) branches along the main emissions flows from industry.

In the every spatial planning cycle, the community should provide the plan of decreasing the overall mass of substances entering into the ground from traffic and manipulation surfaces.

Any exemption from preventing input into ground can be made under certain conditions inputs. This could be performed for inputs which are considered by the competent authorities to be of a quantity and concentration so small as to obviate any present or future danger of deterioration in the quality of the receiving groundwater. The consideration has to be made by risk analysis methodology required by the Rules on criteria for the designation of a water protection zone (Ur.l. RS, št. 64/2004). The risk analysis has to assess the quality of receiving water not only at the discharge point but also directly below the input in the groundwater (Point of compliance - POC 1). Prevent and limit monitoring have to be provided for those exemptions where there could be significant uncertainties in prediction of site specific impacts and designing additional measures.

In the community's Ordinances on spatial planning conditions for planning zones the part regulating the waste water emissions: Roofed surfaces should be recommended instead of open manipulation surfaces to diminish the waste water quantities and reusing the clean water from the roof to recharge the aquifer. All the wastewater from surfaces that could contain hazardous substances should be preferentially emitted in the sewage system.

The most important is to perform the thorough inspection of sewage system in the wider area of Dravlje and further on the area of the considered highest risk of contamination from sewage.

The plan for renovation of sewage system has to include the area of the highest risk of pollution from sewage system between Dravlje and Savlje (BŠV-1/99) as a priority area.

All the discharges of industrial waste water (especially containing chromium) should be thoroughly inspected, controls of real content of contaminants in discharge sites should be regularly measured in the mentioned area.

In Ljubljansko polje area there are indications that some industrial liquid waste (organic solvents etc.) is illegally drained into the sewage system. The system for control of such praxis should be prepared, to prevent further groundwater contamination by organic chemicals.

In the line of observation wells between Dekorativna, Mercator, Vodovodna, LMP-1/06, Navje, GZL, PAC-9, Hrastje (multiple wells), BŠV-1/99, LP Zadobrova and Perlez analysis of nitrate, chromium-tot, chromium-6 should be analysed twice a year and results regularly free accessible on the internet.

The mass of chlorides, for icing prevention, discharging into the ground and sewage should not be increasing.

2.2 Dispersed sources

Regular exchange of data between waterworks and agriculture sectors should be established: 1) quality of water in all monitoring points, 2) actual trends of nitrogen and pesticides concentrations in groundwater, 3) measurements of nutrients and pesticides in the soil, performed by agriculture monitoring and control activities, 4) actual list of active substances in plant protection products in the actual agriculture practice, 5) manure plans and actual distribution of plant cultivation.

Specialized experts should be nominated to communicate between agriculture and waterworks sectors. They should prepare: 1) the plan to select and stimulate the agriculture measures, the most efficient for groundwater quality, from the list of basic agriculture environmental programme, 2) the plan for optimization of nutrients and plant protection products use and decreasing the surpluses, 3) proposal for adequate incentives and subsidies. This should be performed in regular 6 years cycles, following water management plans and spatial planning.

All the efforts should be made to prevent the use of organic active substances for plant protection in the narrowest water protection area VVO I and to limit as much as possible in the direct recharge zone VVO II a.

Agricultural land should be in any case retained as non built up – green areas in the water protection areas VVO I and VVO II a.

2.3 Improvement of monitoring network

An agreement about regular groundwater chemical analysis results exchange between national GW monitoring (ARSO), local monitoring (MOL) and VO-KA water supply should be prepared.

The groundwater monitoring networks of different institutions should be coordinated in order to get maximum results by the use of financial resources available.

The responsible institution for joined groundwater chemical data base should be identified, which would provide also regular interpretation of the Ljubljansko polje and Ljubljansko barje aquifers chemical status by the use of the results of INCOME project.

2.4 Recommendations for the Brest water pumping station

Any pumping of the well VD Brest-1a should be stopped, including also the long time pumping for the groundwater water sampling, in order to prevent leakage of desetilatrazine from the upper to the lower aquifer. For the sampling very short pumping times should be used.

The gravel fill of the pumping well VD Brest-1a should be packed to prevent possible contact between upper desetilatrazine heavy contaminated aquifer and lower aquifer.

Any future drilling on the heavy contaminated area NE of the Brest pumping station should be avoided.

Regular observations of desetilatrazine on the pumping well VD Brest 3a should be continued together with the observations of main chemical and isotope parameters (Oxygen-18, tritium) in order to acquire time series data, which will able to identify concentration trends.

New exploitation wells in the Brest water pumping area should be located in SW part of Brest pumping station in order to minimize the possibility of contamination with desetilatrazine.

Improved Management of Contaminated Aquifers by Integration of Source Tracking, Monitoring Tools and Decision Strategies

DSS for improvement of chemical status of the aquifers (DSS-2)

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TABLE

1 Introduction

The report presents part of results of the action A.5.1. Establishment of programme of activities based on Decision Support System (DSS), performed by Geological Survey of Slovenia within the project INCOME (LIFE07 ENV/SLO/000725). The main objective of the project is long-term effective management of aquifers and preservation of the quality of these water resources for future generations. The project is co-financed by European Commission, Municipality of Ljubljana and Ministry of the Environment and Spatial Planning of Republic of Slovenia.

The decision support system for improvement of chemical status of the aquifer is built in order to assist at the decisions which measures should be implemented in order to improve the quality of groundwater. It is built for the stakeholders in the field of water management and improvement of groundwater quality.

The developed DSS was customized to the project requirements by programming which was provided by Logon d.o.o.

2 Basic principles of the functioning of the DSS for improvement of chemical status of the aquifer

DSS for improvement of chemical status of the aquifer uses several assumptions and simplifications in order to have short response time. The aquifer is simulated as closed system, with its inputs and output. This is valid for the groundwater, as well as for the pollution. System assumes that water input into the aquifer is clean, without pollution. The pollution is added as input of the substance in the aquifer, as a consequence of agriculture, sewer system leakage, traffic, industry or similar. The consequence of the pollution is change of the concentration of the pollutant in the groundwater. Figure 1 represents the model.

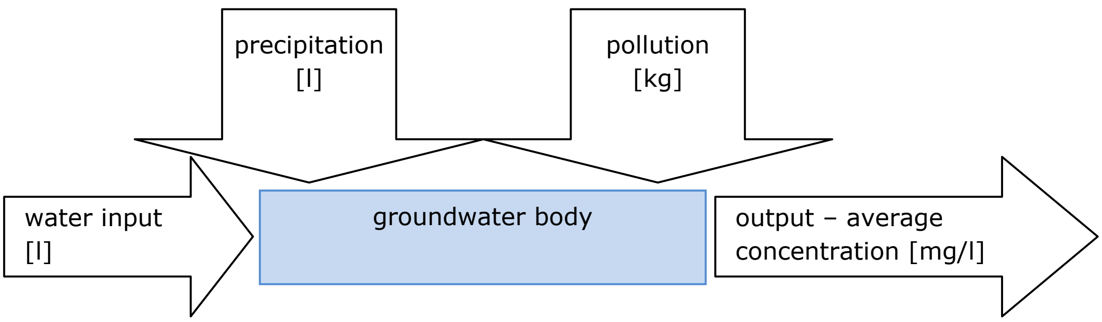

Figure 1: Schematic model of the interaction between input of pollutant and concentrations of the pollutant in the groundwater.

Such model does not take into account the time and space dimension, because this tool is not meant to simulate dispersion of pollution plumes in time or space. It is meant to suggest possible measures, which can be implemented on a recharge area of specific aquifer in order to improve the quality of groundwater, taking into account the needed costs and effects, which will be detected on the longer period of time - in the period of several months or years. Model uses linear interconnectivity between free parameters in the model, between input of the pollutant in the aquifer and its average concentration in the groundwater. Two points are needed in order to draw a straight line, which determines the model itself. First assumption is, which represents the first point on the regression line, that if there is zero input, there is zero concentration. Second point on the regression line is current (known) state of aquifer, named as "zero-state" which means the conditions prior to any measures undertaken, which is: at certain input of the pollutant, there is certain concentration. The last value must be properly put into the model in order for it to be able to correctly calculate the pollutant concentration after steady state is achieved after measures are implemented. All values in-between aforementioned points are calculated according to linear regression. Figure 2 represents the used model for the prediction of new steady-state concentrations.

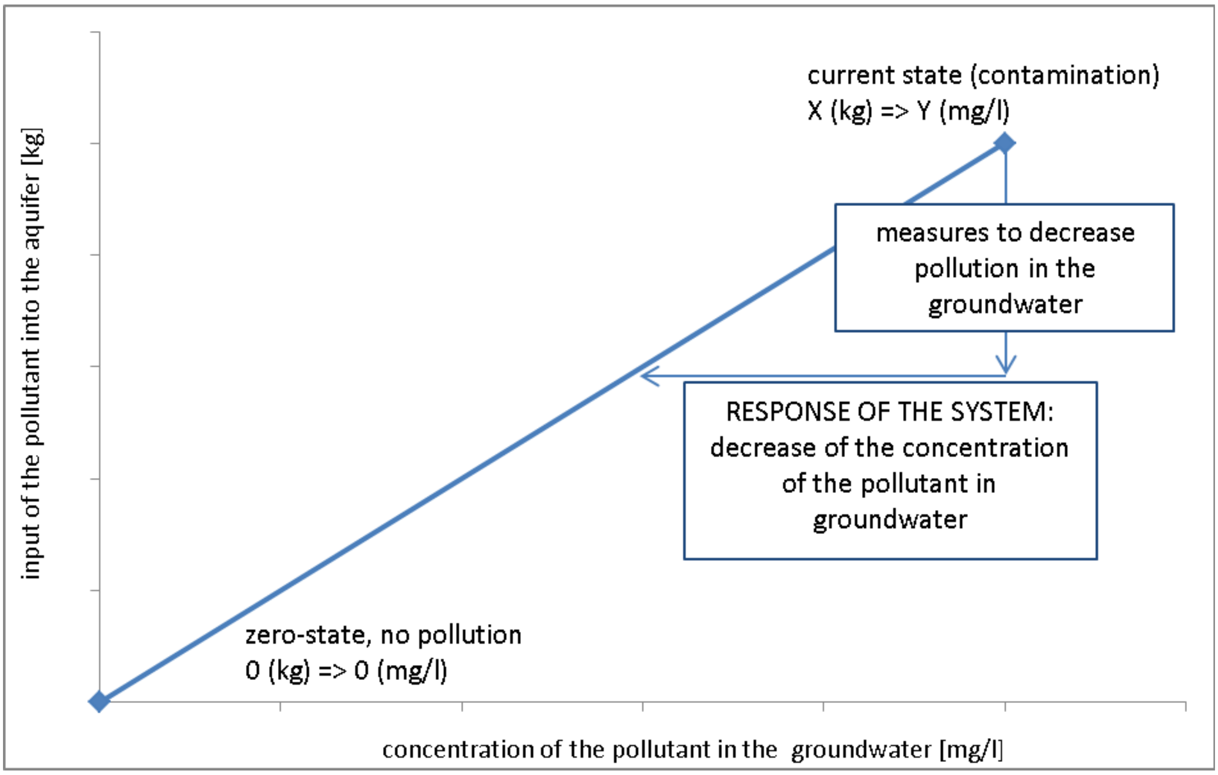

Figure 2: Linear model of the decision support system for the assessment of new steady-state concentrations after measures for the improvement of groundwater were implemented.

Properly identified zero-state is vital for the model to work properly. This means that current input of the pollutant must be properly estimated/calculated. In a case of pollution with nitrogen, input to the groundwater is calculated as nitrogen surplus ("presežek") from agriculture, industrial waste waters, settlements, landfills and traffic. The impact to the groundwater of the pollution with nitrogen is average concentration of nitrate in the aquifer.

3 Functions of the DSS application

The application is made of three main modules. First one is measures editor, second one the module for the optimization of measures, and third one the generator of the report. Other functions are support functions, such as load/save, groundwater body selector, export module etc. Figure 3 shows main interdependence of the modules. The source code of the application is made in a way that it allows to upgrade this application with the interaction with GIS environments in the future. Main building blocks of the application which must be provided by the user and which will be described in next sections are: (I) measures, (II) parameters of the aquifers and (III) available funds for measures.

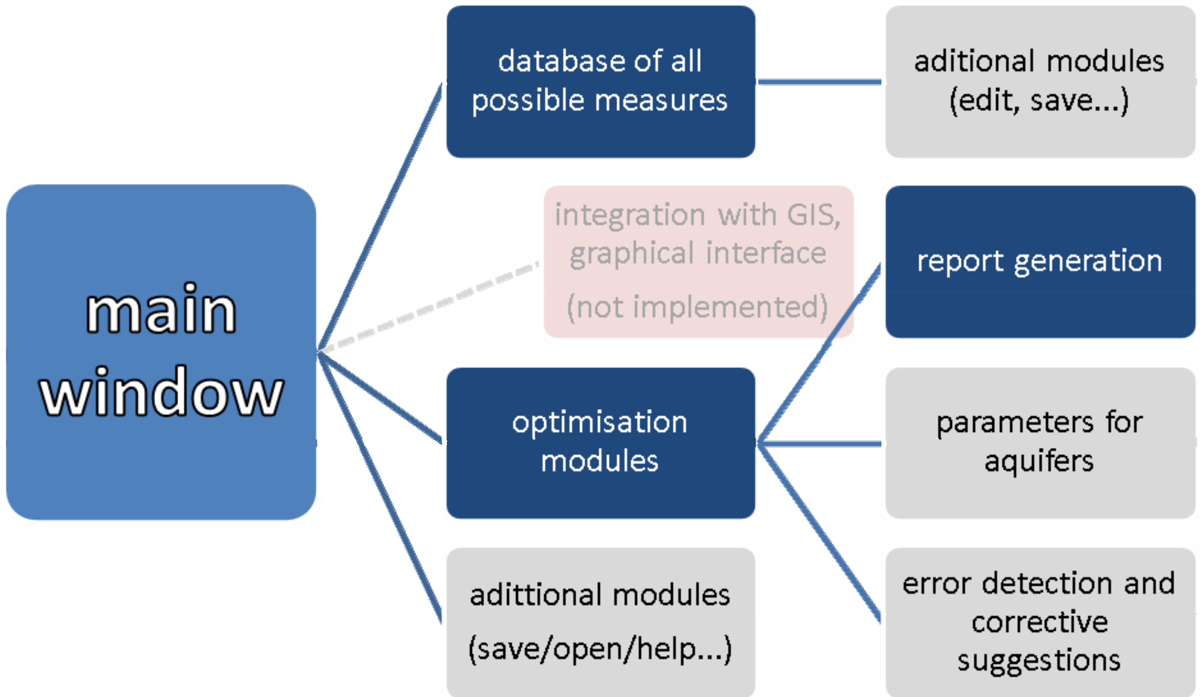

Figure 3: Main parts of the application – decision support system for improvement of chemical status of the aquifer.

3.1 Measures

Measures for the improvement of the groundwater quality can be divided into two parts. Basic measures are defined in current legislation and are already implemented. Supplementary measures are measures, which must be implemented in order to achieve good chemical status of groundwater (Ur.l.RS, št. 100/2005). Application is built in order for the decision makers support decisions for the selection and implementation of supplementary measures when basic measures do not function sufficiently, due to the natural constraints or due to the ineffectiveness.

Measures in the application must contain following information:

- price of the measure per unit, usually of ha, but the programme can work also with other units, such as m (meters of sewer pipe, road...) or year (for inspection for example);
- effect of the measure on the corresponding unit; measure must be numerically determined as reduction of the pollutant in kg on the corresponding unit (ha, m, year...);
- maximum area, where measure can be implemented; for example, measure "catch crops with late ploughing" cannot be done on roads, or the measure "extensive use of pasture land" cannot be implemented on corn field; this is why expert judgement is needed for the appropriate selection of the set of measures, which will be optimised in the next stage;
- interdependence between different measures; some measures cannot be implemented simultaneously on a designated area;
- measure can have the effect of reducing several pollutants simultaneously.

The application contains set of possible measures, which are appropriate for the aquifers Ljubljana Polje and Ljubljana Barje. These measures (but not all of them) are primarily focused on the reduction of the nitrogen surplus. But the application allows inclusion of new measures and pollutants, when required.

It is needed to be stated out that application can operate also with measures, which does not have a direct measurable impact to the quality of groundwater. One example is funding of the inspection services (control). In such case, we can add zero impact value into the measures editor, but in order for such measures to be included in the optimization, we must specify an exact amount of funds we want to invest in funding of such measures.

3.2 Determination of the optimal set of measures

The basic criteria for the selection of the in-build supplementary measures were determination of chemical status of the groundwater (concentrations of the pollutants, and determined temporal trends), assessment of the pressures and impacts on the groundwater and efficiency of the basic measures, already implemented according to the existent regulations in legislation. Parameters, which exceed the quality standard for the groundwater (Ur.l.RS, št.100/2005) and quality standard for drinking water (Ur.l.RS, št.19/2004) on different pumping stations or monitoring sites, are recognised as critical parameters. In case that groundwater quality exceeds the quality standard the effectiveness of basic measures must be checked first. If basic measures are not efficient enough, supplementary measures should be implemented. Measures in the DSS application represent the preliminary list of supplementary measures.

Estimation of pressures and impacts on the groundwater, trends of the pollutant concentrations on monitoring stations, and evaluation of the effectiveness of basic measures were evaluated by Prestor and Pestotnik (2011). Critical parameters have been identified: nitrates, atrazine, desetylatrazine, Cr6+, PCE and TCE.

Table 1 shows the preliminary list of supplementary measures which are implemented in the application at its initial stage, and which are suitable for the aquifers of Ljubljana polje and Barje. It contains agricultural measures, which reduce the surplus of the nitrogen in soil, thus reducing the concentrations of nitrates in the groundwater. Source of measures are national legislation, FAL catalogue (FAL Bundesforschungsanstalt für Landwirtschaft, 2007) and River basin management plan of the Danube and Adriatic see River Basin 2009-2015 (MOP, 2011).

Table 1: Agricultural measures, implemented in the application which reduce the surplus of the nitrogen in soil, thus reducing the concentrations of nitrates in the groundwater (unit = ha).

MEASURE	Price (€/unit)	Reduction (kg/unit)
Catch crops after field vegetables and successive summer-crops (no vegetables!) (1)	200	60
Reduction of drainage area (1)	400	50
Two-year fallow, greening without legumes, no ploughing in autumn (1)	120	50
Catch crops after rape and successive summer-crops (1)	150	50
Winter hardy catch crops, late ploughing (1)	100	40
One-year fallow, greening without legumes, no ploughing in autumn (1)	110	40
Catch crops after potatoes and successive summer-crops (1)	150	40
Catch crops, late ploughing (1)	90	35
Ecological farming (3)	727	20
Winter-turnip rape as catch crops before winter grain (1)	60	20
Catch crops with normal ploughing (standard) (1)	70	20
Fertilising plans for all farming areas (1)	16	20
Annual alternation of winter/summer crops (4 years) (1)	200	20
Undersawn crops (1)	80	10
Extensification of grassland (annual average cattle/ha 1.4; no artificial fertilisers)	100	10

(1)		
Extensive use of pasture land (no pasture after 15th of October; max. 2 cattle/ha; no additional hay) (1)	77	10
Moment of N-fertilisation on arable farm land (no fertilising at late summer/autumn; no organic nitrogen) (1)	20	10
Using slurry application with improved technique to preserve groundwater (residue from biodiesel production for example) (1)	25	10
No organic fertiliser after harvest (1)	20	10
Longer blocking period for organic fertiliser (1)	25	10
Scaling down N-fertil. on arable farm land incl. no late fertilising to cereals (1)	80	5
Using improved technique in distribution manure to preserve groundwater (1)	35	5
Water control, inspection (2)	1000	0

(1) FAL Bundesforschungsanstalt für Landwirtschaft, 2007.
(2) MKO, 2011.
(3) Programme of farmland development in Slovenia 2007-2013.

Important criterion for the selection of the measures was also the availability of the data (price, efficiency, technical setup, time...) in the literature. All possible measures are not suitable for the aforementioned aquifers, because on Ljubljana polje aquifer is densely urbanised, and on Barje aquifer farmlands dominate.

3.3 Parameters of the aquifer

Parameters of the aquifer define the response of the aquifer to the reduced input of the pollutant, after steady-state has been achieved. Two critical parts are important for correct functioning of the system. These two parameters are input of the pollutant into the aquifer, and current (average) concentration in groundwater. As already mentioned in the chapter 1, model assumes zero-input-zero-concentration state, and current state pollution-concentration response, and all values in-between according to linear regression equation.

This is why it is of vital importance in order that the application can assess the reduction of the concentration of the pollutant in the groundwater after measures were implemented, that proper value of average surplus of the pollutant or average input of pollutant into the groundwater on the whole surface of the aquifer is put in equations (in kg/ha). For making such estimation, all possible inputs of pollutant needs to be taken into account.

Resistant pollutant, which are stored in the pores of aquifer and have long retention times are special cases. Such example is atrazine and its degradation products. As the application operates with the steady states in aquifer, and for such pollutants it takes very long time for the aquifer in order to reach it, the application is not a suitable tool for such cases.

3.4 Funds in DSS application

Because decision support system for improvement of chemical status of the aquifer is primarily meant to optimise measures for the reduction of the pollutants in the groundwater according to the available funds, funds are third important part of it (beside measures and aquifer parameters). Basic assumption of the module for the optimisation of measures is that funds are spent in the way that the largest reduction of the concentration in groundwater is achieved by spending the minimum amount of funds. Because application operates also with measures, such as inspection control, which does not have a direct impact on the quality of groundwater, available funds needed to be split apart to the fixed amount and variable amount.

For the user it is important to properly distribute funds in two phases. In the first phase, user inserts the total available amount of funds, which are available for the implementation of measures. In the second stage, user sets the measures, which should be fixed, such as inspection, and sets to them appropriate amount of funds. Also, if user wants a certain measure to be applied to a certain area, he also has an option for such measure to be locked and a specific amount of funds to be assigned to it. In such way, user creates a "fixed load" of funds, which does not enter into a second optimisation phase.

In the next phase optimisation algorithm uses variable part of the funds and makes suggestion which measures and in which extents should be implemented and costs of implementation of the measures. After the optimisation, application presents the results in table which contains several information:

- the amount of funds, used in the optimisation algorithm and the amount of fixed funds;
- the amount of funds which would be needed to finance all possible measures over complete territory;
- expected concentration after measures would be implemented (the programme also checks whether the target concentration is reached or is not);
- application also suggested the amount of funds which needed to be invested in order to reach the target concentration or the amount of funds which can be reduced from the total amount of funds, because target was already reached.

The methodology of the calculation is linear regression, taking into account: zero funds – zero reduction and a specific amount of funds for a case – specific reduction. All intermediate values are calculated according to the linear regression between these two points. Such way of the calculation of surplus/deficit might yield for different sets of measures, depending on the effectiveness of the measures which ware suggested by the application. All aforementioned issues are graphically presented in a DSS application screenshot in Figure 4.

3.5 Optimisation of the measures

Optimisation of the measures, according to the available funds and available set of possible measures, is done only for one specific pollutant at the time. But nevertheless, the application calculates the effect also to other pollutants, in case some measures influence more pollutants simultaneously.

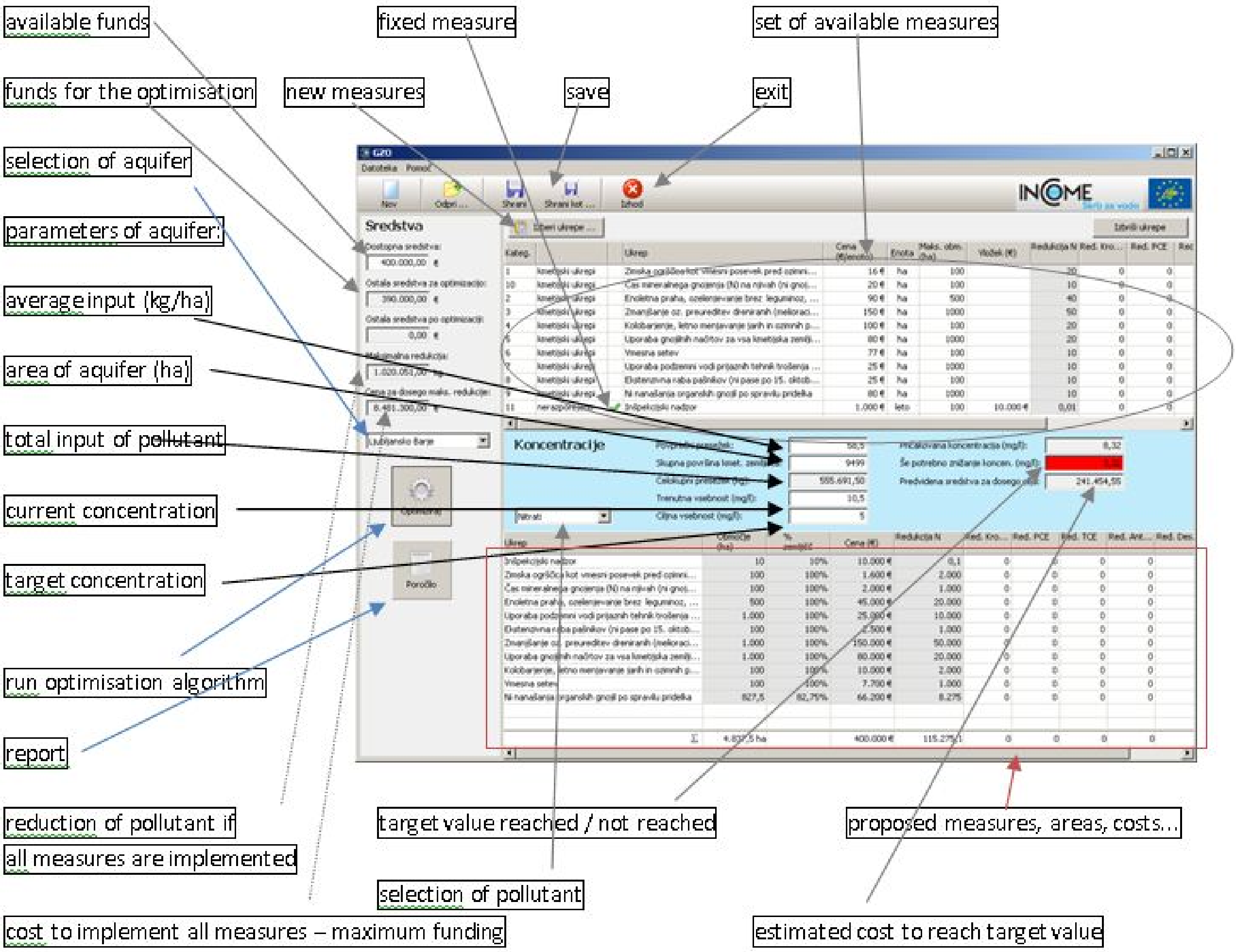

Figure 4: Optimisation window in the application.

Basic principle for the algorithm is that maximum effect is achieved by spending minimum funds. In order to find such solution, programme introduces a new variable, which measures effectiveness of a specific measure, which tells how much a reduction of 1 kg of the pollutant costs. Algorithm finds most effective measure, and suggests it first. After that, it calculates the amount of funds, needed to use this measure over total available territory, and after that compares this cost with the total amount of funds. It does the surplus of the pollutant by analogy – it calculates the amount of the reduction (in kg) and compares it with total amount of the pollution in the area. Reduced amount of the pollutant is then subtracted from a total amount of the pollution. This operation is needed for the calculation of the expected concentration in the groundwater. After that, programme continues with next most effective measure and repeats the procedure. It has two stopping criteria. First one is when available funds are exhausted, and second one is when all of the pollution (for an example – surplus of the nitrogen) is eliminated. When finished, a programme presents the information in a table, and in a form of the report (html document).

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