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'A decision support tool for a cost-effective mitigation of non-point source pollution'

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Non Point Source Pollution (NPS)

- Sediments
- Phosphorus (P)
- Nitrogen (nitrates nitrogen – N-NO3)

Their mitigation is linked to the EU legislation:

- River Basin Management Plans (RBMPs)
- Water Framework Directive (WFD)
- Nitrates Directive

BMPs to reduce NPS pollution

- Agricultural Best Management Practices (BMPs) – A viable solution to reduce NPS pollution
  - Nutrient application management (amounts and timing of chemical fertilizer and manure application)
  - Contour cropping
  - No-tillage
  - Buffer filter strips
  - Reduce the length of the grazing period
  - Manure storage
  - Reduction of livestock stocking rates

BMP selection problem

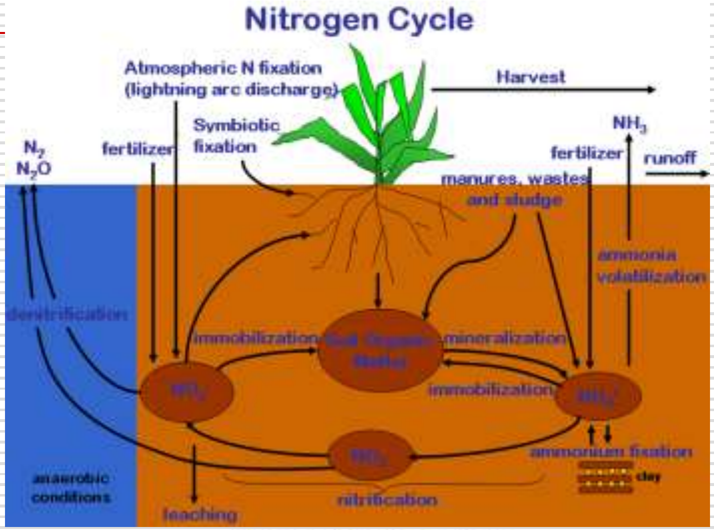
- BMP selection and placement is a complex task
  - Example: 5 BMPs to be selected in 100 farm fields will have 5^{100} combinations
  - Nutrient reduction effectiveness differs between fields due to differences in soil, climate and topography
  - NPS pollution reduction is in conflict with cost of BMPs implementation
  - The reduction of one pollutant (e.g. phosphorus) may be not the only environmental target in the catchment and may be disproportional to the reduction of another (e.g. nitrates)

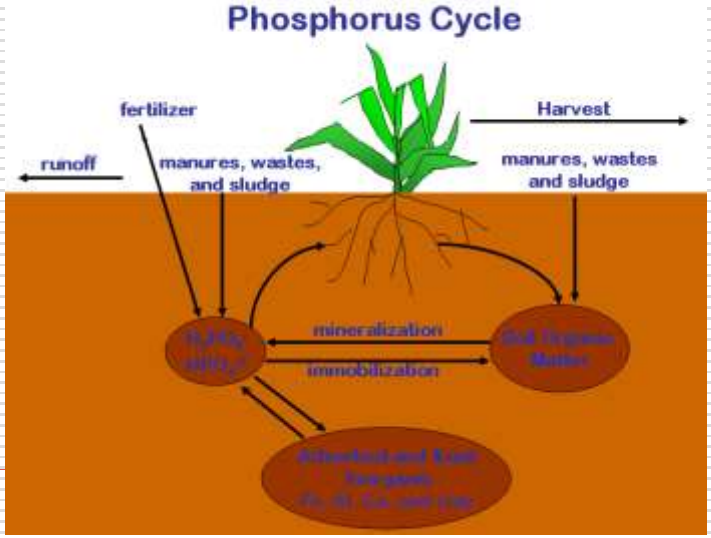
Facing the multiobjective problem

- Develop a Decision Support Tool to identify optimal BMP combinations including:
  - a robust NPS estimator, usually a process-based model, which can adequately represent the effect of several types of BMPs, at all locations within the catchment on the parameters of interest (usually TP and N-NO3)
  - an economic function that can adequately represent the cost of implementing different BMPs at various locations
  - an optimization algorithm, usually a Genetic Algorithm (GA), that can provide an efficient method of searching through an extensive, non-linear and non-continuous solution space

The NPS pollution estimator
(SWAT model – Soil Water Assessment Tool)

Why SWAT ?





Process-based (N, P cycle, management practices)

Distributed (Hydrologic Response Units – HRUs)

A wide variety of BMPs can be tested

Developed for use in agricultural catchments

Used for Policy Making in the USA (EPA, USDA)

The economic component

Calculate direct and indirect annual costs of BMP implementation

(additional annual cost or income compared to the baseline)

- chemical fertilizer prices
- crop yield reductions from the baseline (SWAT)
- crop yield prices
- livestock products prices
- labor and fuel costs

In the case of combined BMPs annual costs or incomes were calculated as the sum of the sole BMP values

The multiobjective spatial search optimization engine

A MATLAB-GA

Create an initial population of solutions
(unique combination of BMPs in all agricultural HRUs)

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Selection of the best solutions (individuals)

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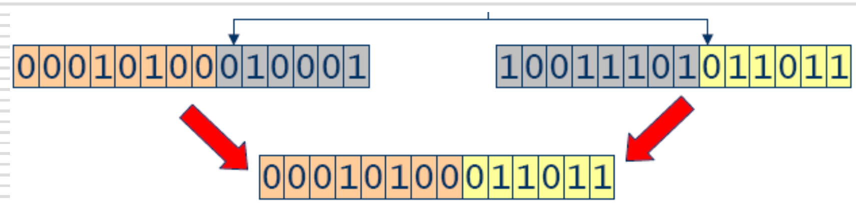
Crossover between individuals



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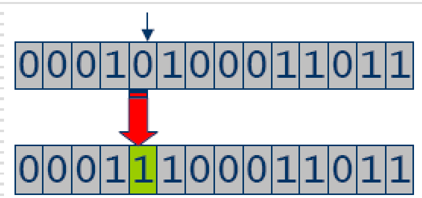
Mutation



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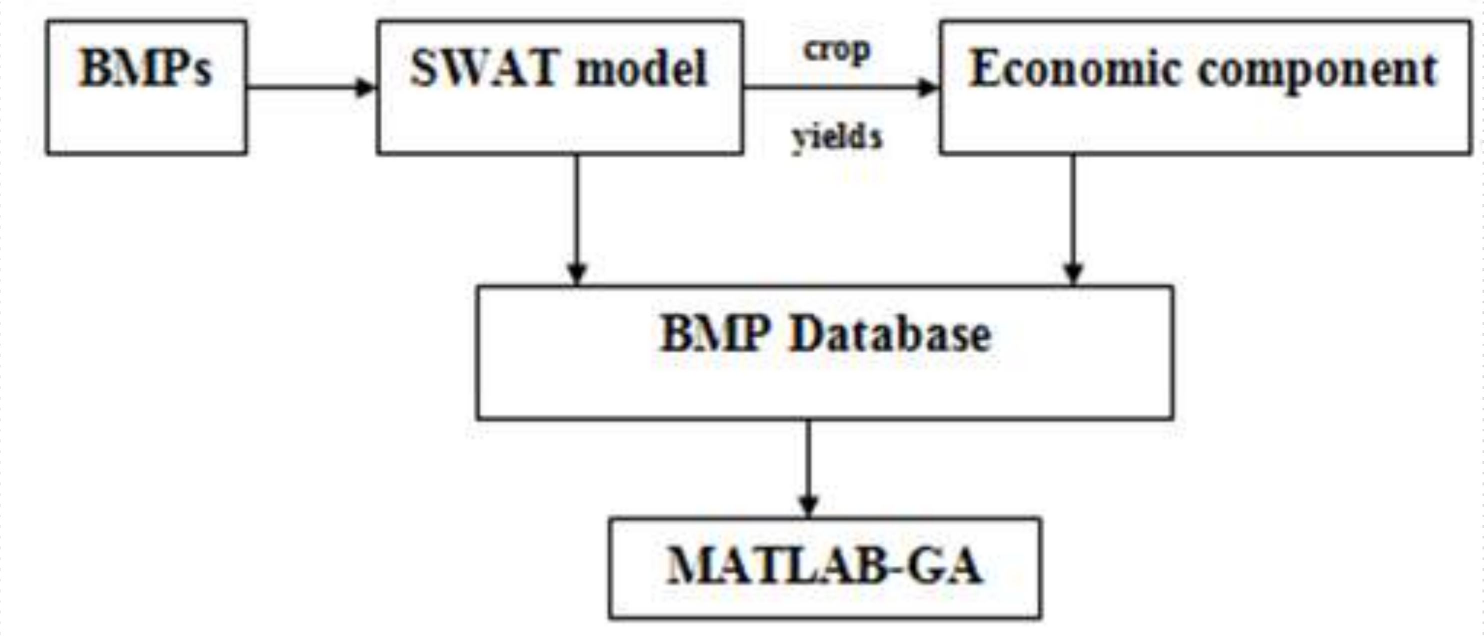
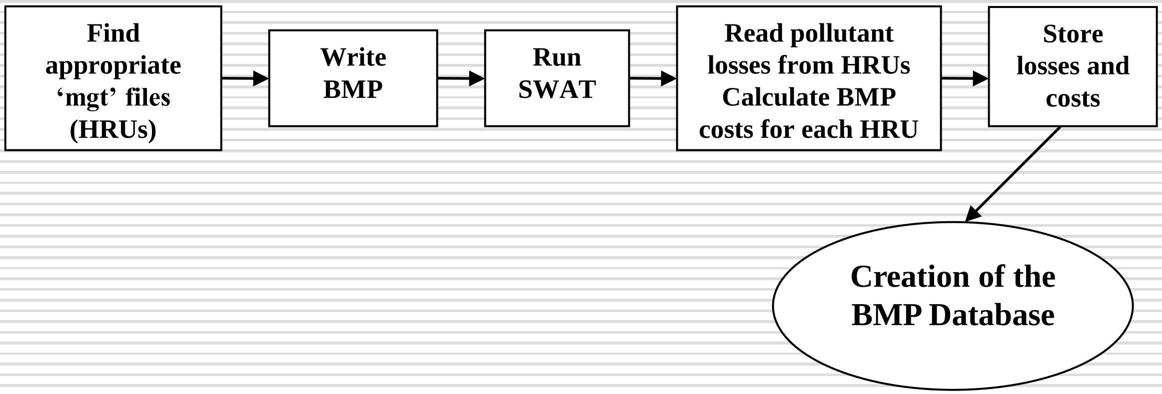
New individuals (population)

The structure of the Decision Support Tool



Substituting the time-consuming SWAT model in the optimization process

Development of a BMP Database (lookup-table)

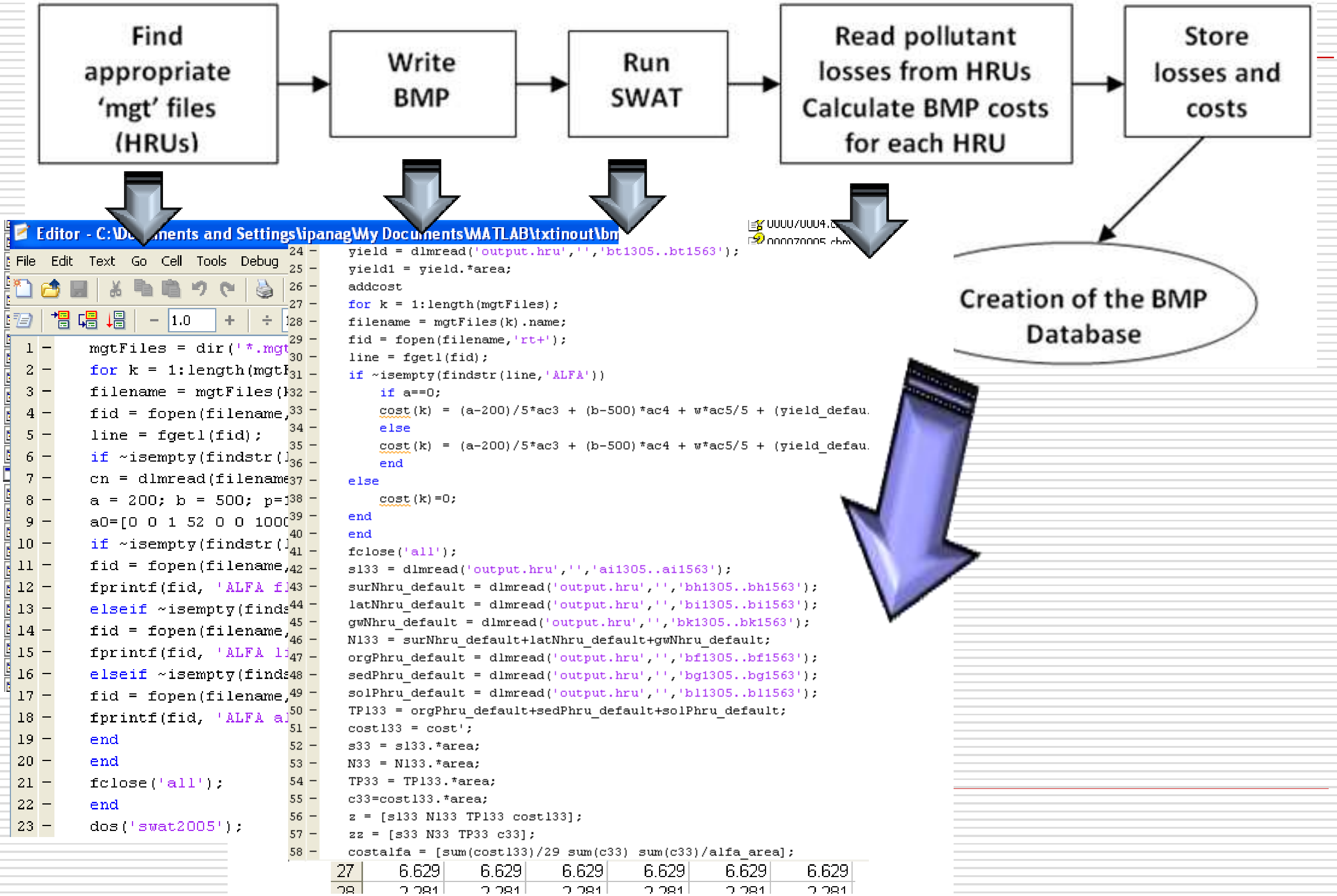


Find appropriate BMPs for each HRU (restrictions according to land use)

Evaluate the effectiveness of all possible BMPs in all HRUs as well as their cost of implementation

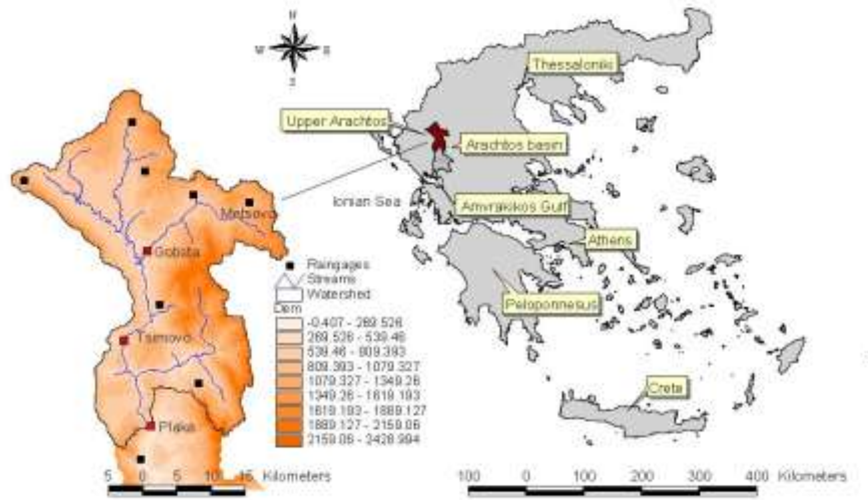
Store nutrient losses and costs in tabulated forms of *N* rows (HRUs) and *M* columns (BMPs)

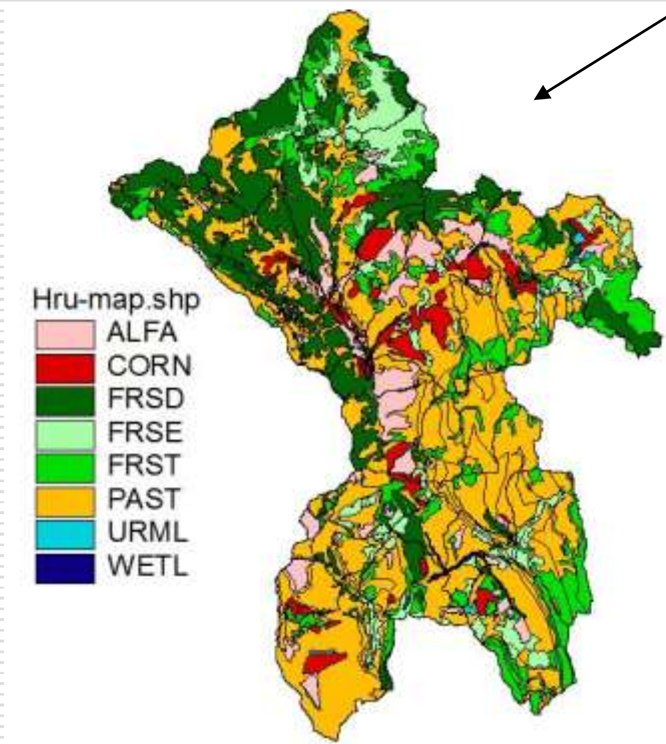
More details on the development of the BMP Database



Implementation in a medium-sized Greek catchment

Area: 940 km^2, Precipitation: 1550mm/y
Main crops: corn and alfalfa – 12%
Pastureland:40% -
Sheep grazing



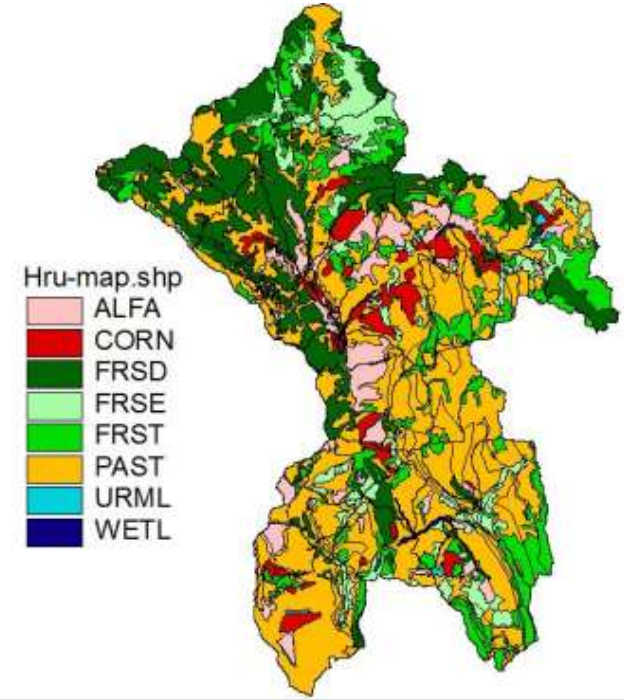


<u>BMPs in Corn</u> (fert. reduction, timing of appl. filter strip, no-till, contouring

<u>BMPs in Alfalfa</u>: fert. reduction, timing of appl. filter strip

<u>BMPs in Pastureland</u>: sheep reduction, grazing length reduction, poultry reduction, storage of manure, filter strip

Total number of BMPs tested



5 sole BMP types to CORN HRUs (23)

32 BMPs in total

$$CORN_{BMPs} = \binom{5}{1} + \binom{5}{2} + \binom{5}{3} + \binom{5}{4} + \binom{5}{5} + 1 = 32$$

Baseline

8 BMPs in Alfalfa HRUs (29)

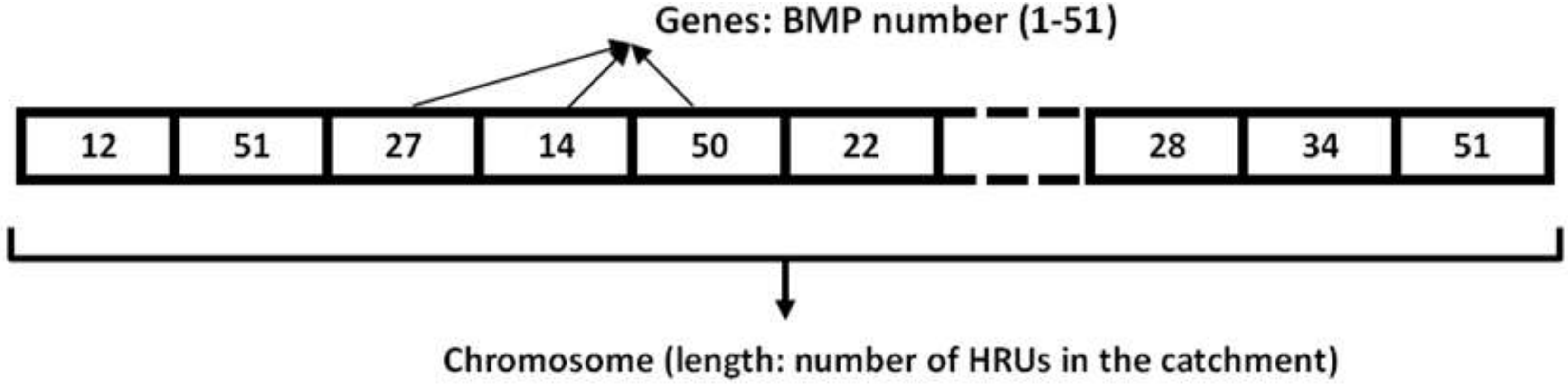
10 BMPs in pastureland HRUs (61)

1 BMP (no management) in other areas (146 HRUs)

51 BMPs in total - Possible solutions: $32^{23}\times8^{29}\times10^{61}\times1^{146} = 6.23\times10^{121}$

GA Coding

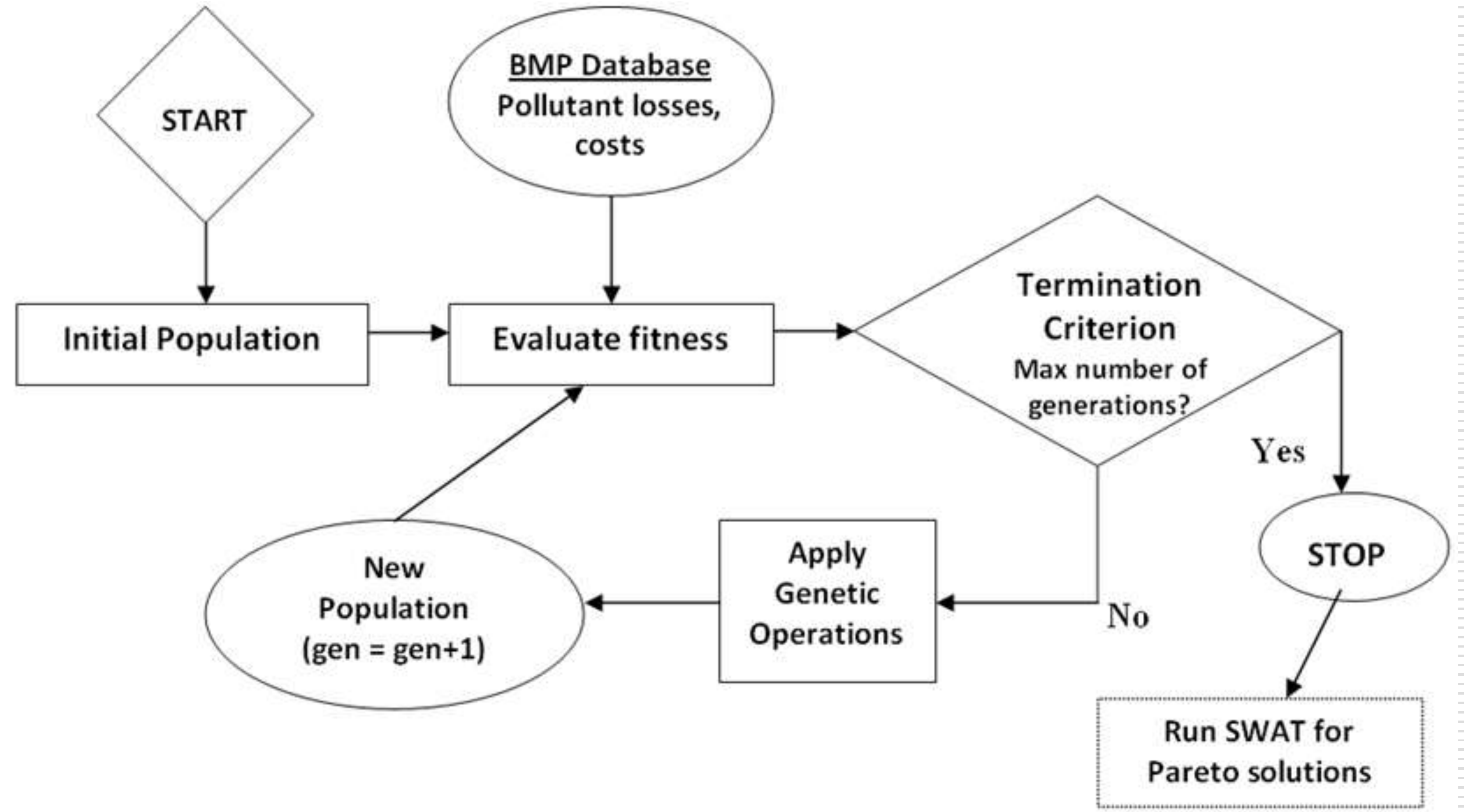
- 259 HRUs in the catchment or 259 chromosome genes
- Integer coding of genes (1-51) – BMPs



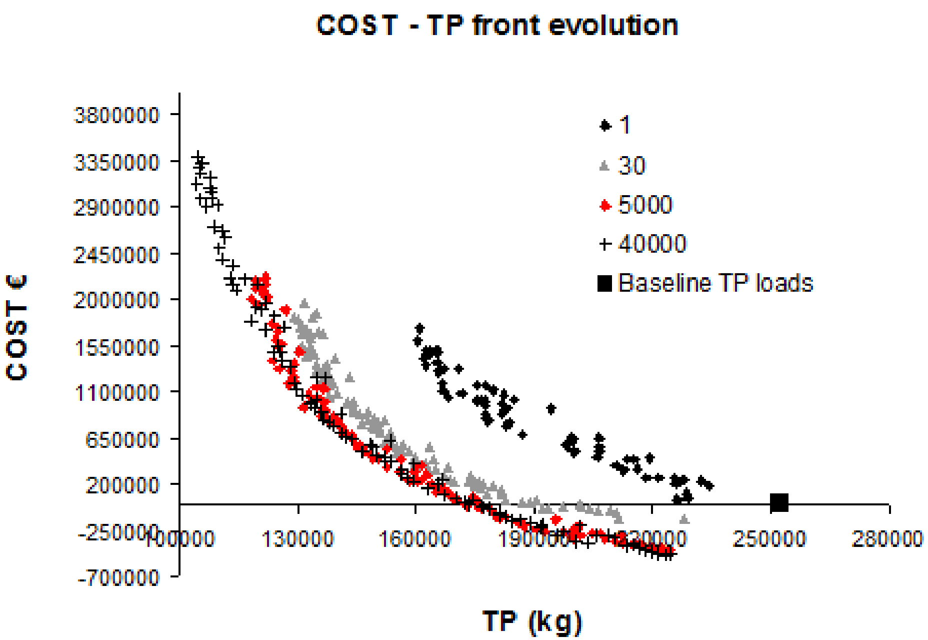
Constraints

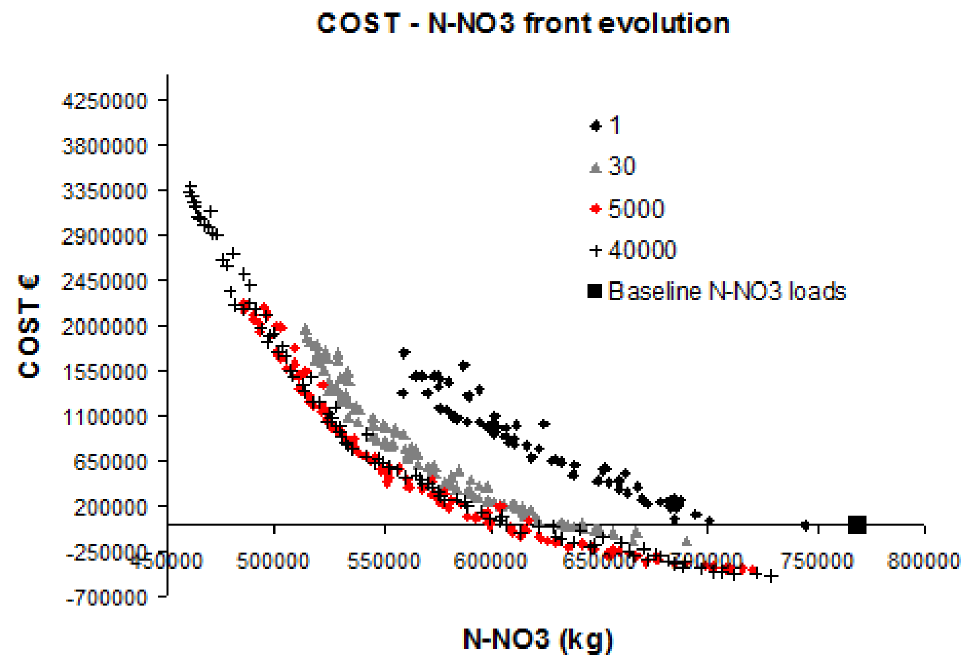
$$1 \le x_i^{CORN} \le 32 \;,\; 33 \le x_i^{ALFA} \le 40 \,,\; 41 \le x_i^{PAST} \le 50 \;,\; 51 \le x_i^{OTHER} \le 51$$

Multi-objective optimization



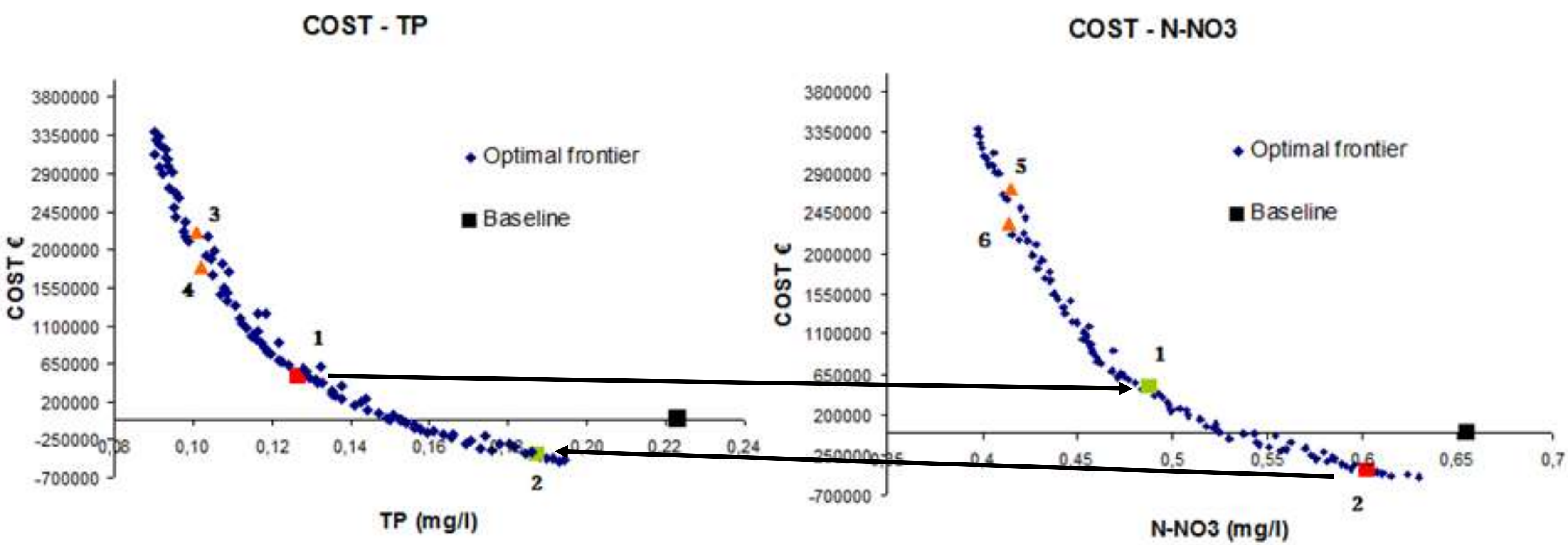
Termination of the multi-objective optimization (3 criteria)





- Termination after 40000 generations with a population of 250 individuals
- Identify the optimal non-dominated solutions (the optimal Pareto front)
- Preserve the diversity of the individuals (spread of solutions) on the front

Decision making from the optimal trade-off frontiers

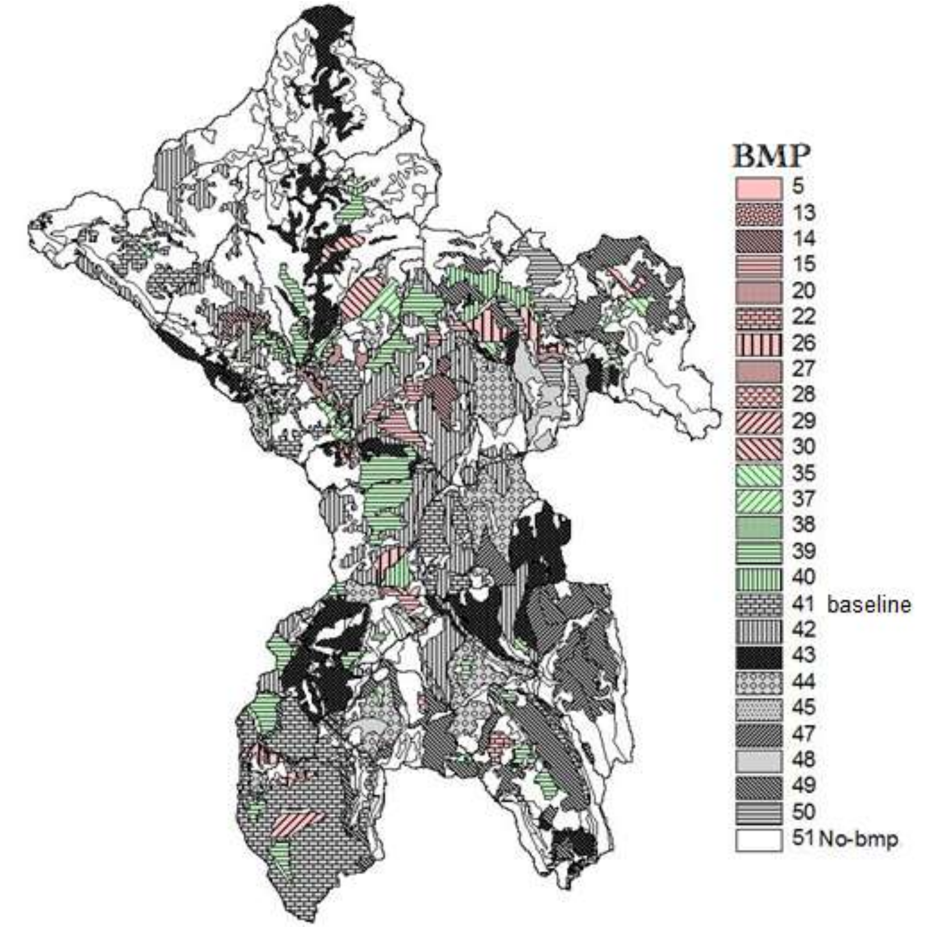


Run SWAT for the 100 Pareto solutions (BMP combinations)

Calculate mean annual loads and concentrations at the outlet

Select management schemes from the fronts between 'equal' best solutions

Solution Mapping



- A compromise between more and less expensive BMPs
- <u>Alfalfa fields (green background)</u>

  the solution suggests chemical fertilization reduction (BMP 35), combined with a delay in the timing of application in some fields (BMP 37) or more extensively with the establishment of filter strips (BMP39)
- <u>Corn fields (pink background)</u>

  the algorithm favors BMPs that mostly include the establishment of filter strips along with a series of alternative additional measures such as no-till, contour cropping, fertilizer reduction (BMP 13, 15, 22, 26, 28, 29, 30)
- <u>Pastureland (grey background)</u>

  A number of large pastureland HRUs, were not managed at all (BMP41)

BMP allocation of solution no.1 in the Arachtos catchment (TP: 0.125 mg/l, N-NO3: 0.49 mg/l, cost: 500000 €)

Conclusions – Future Research

- A multi-objective optimization offers the opportunity to explicitly see the trade-offs between cost and environmental objectives (more than one at the same time)
- The algorithm suggests management solutions that it would be impossible to plan otherwise e.g. management schemes with significant areas under no intervention
- The BMP Database accelerated drastically the optimization process

- Make the tool more user friendly (development of a Graphical User Interface) and increase its transferability to other catchments (more BMPs and environmental variables as well as programming improvements)

Issues for discussion

- Can such an optimization problem be finalized in reasonable time by executing SWAT? – Creating and using a BMP Database
- By optimizing pollutant losses at the edge of fields do we optimize at the same time pollutant loads at the catchment outlet? - Importance of in-stream processes
- Does SWAT simulate management practices accurately? – Further improvements are always needed
- Is the proposed BMP allocation across the catchment always acceptable? – Consider local socio-economic constraints

Thank you for your attention!