

Formulation and solution technique for agricultural waste collection and transport network design

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Agricultural waste mis-
management

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Location-Assignment-
Routing-Problem

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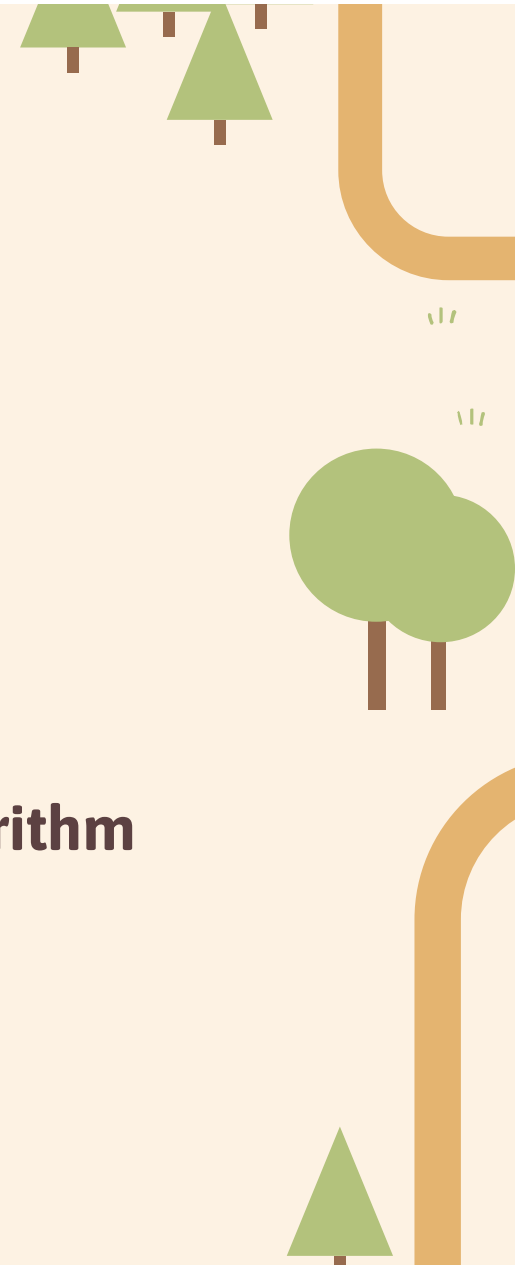
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A meta-heuristic
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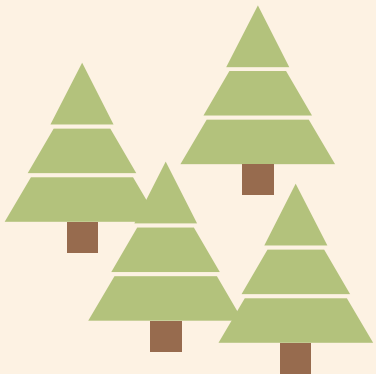



01

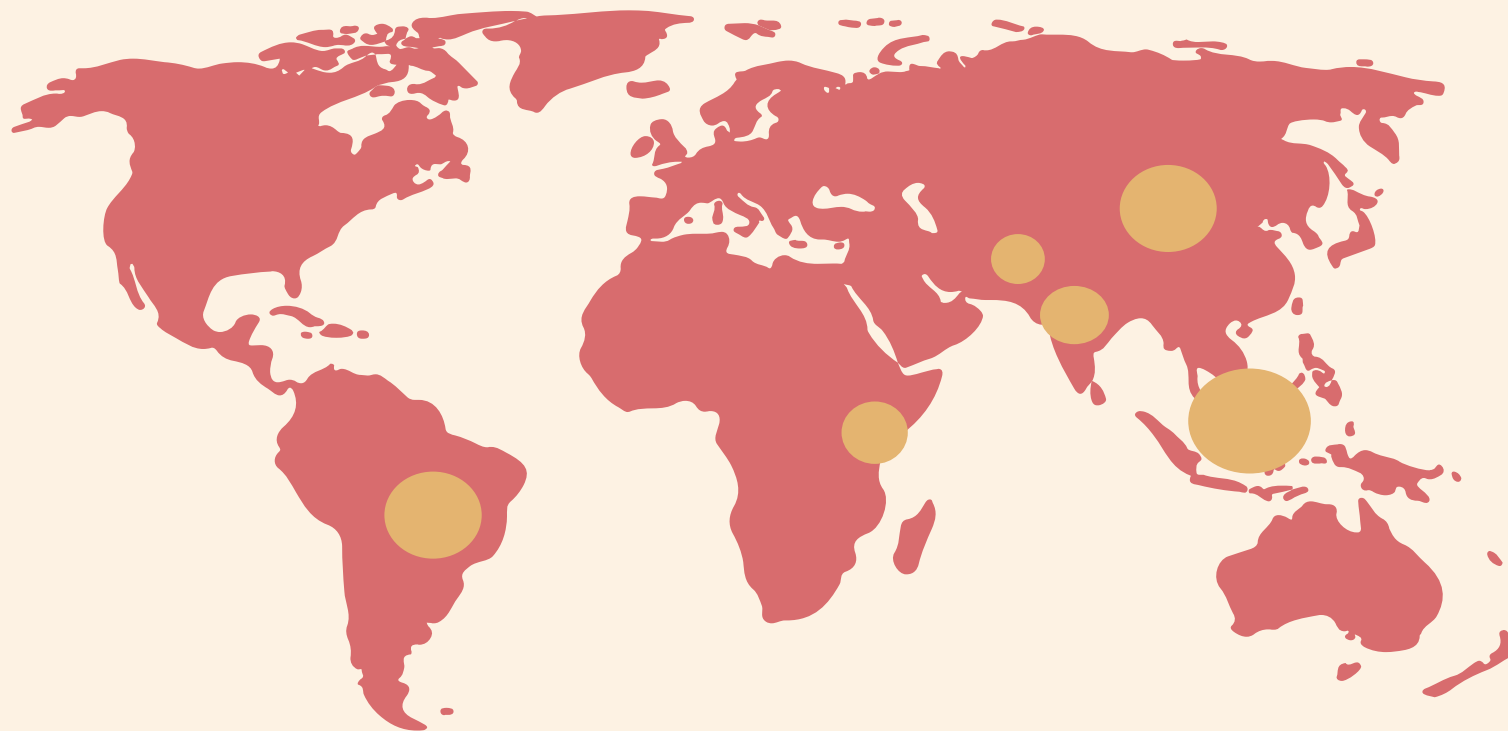
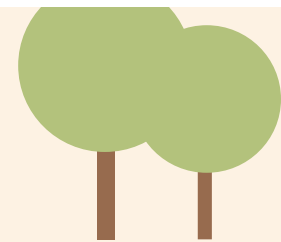
Problem Introduction

Agricultural waste management

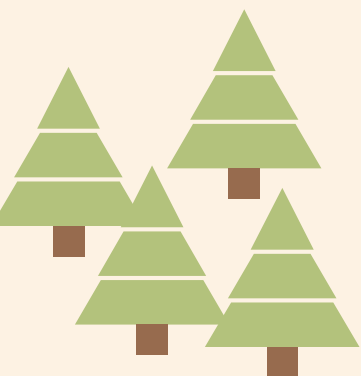


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- In developing countries, agricultural sectors have rapidly developed into become major contributions in the economy.
 - Agricultural waste management has posed a challenge for rural planner due to lack of efficient planning tool.
 - Burning the agricultural waste at fields after each harvesting season is the present solution, this caused air and water pollution in rural areas.
- 

Agricultural waste around the world for developing countries



source: International Journal of Environmental Research and Public Health



45,22 million tons

Rice straw

10 millions tons

Vegetable by-products

6,33 millions tons

Maize by-products



source: Ministry of Agriculture and Rural Development of Vietnam

An efficient way to collect agricultural waste



02

Modelling

Location-Assignment-Routing-Problem





Logistic problem

Which and how many places should be chosen where storages should be built to ensure coverage over all cultivation fields?

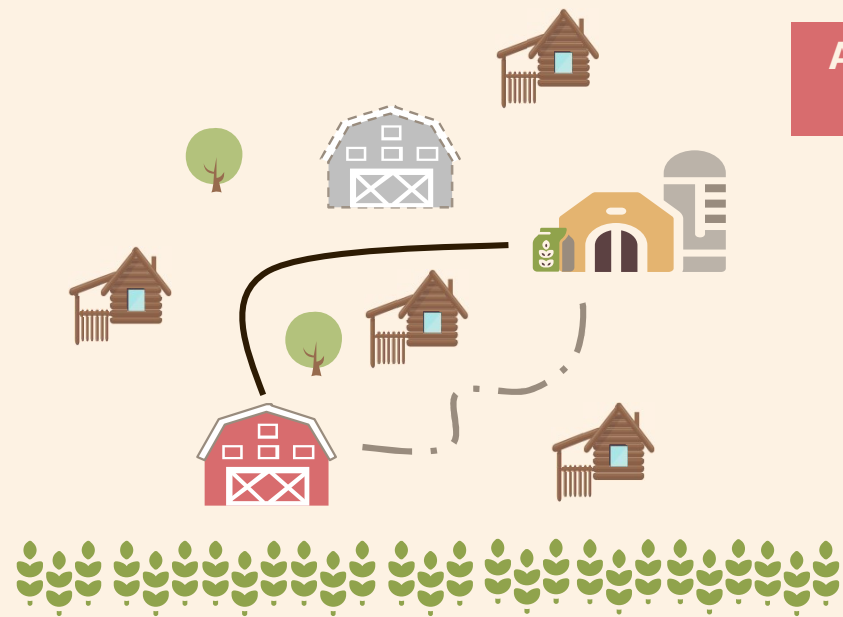


Location Assignment Problem

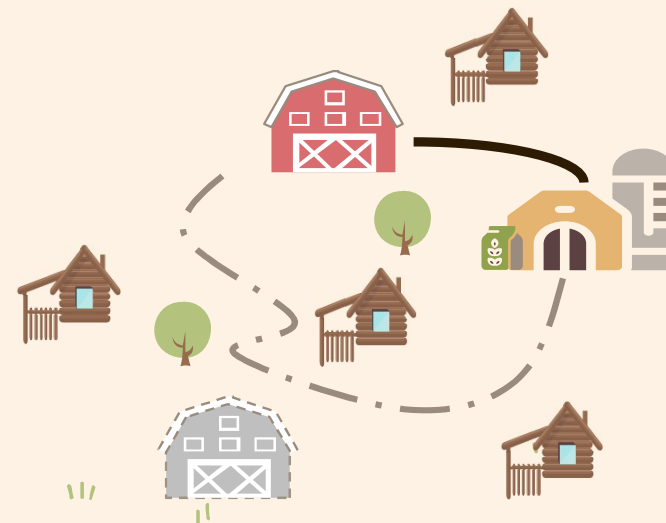
Which roads should trucks take to visit all the storages and bring agricultural waste to the fertiliser factory?



Routing Problem



A possible scenario



Another possible scenario



Model Formulation (1/3)



Sets and indexes

I Set of agricultural waste fields (indexed by) i

J Set of storages (indexed by) j

J_0 Set of storages and the facility, i.e., $J_0 = J \cup 0$ indexed by u, v

Parameters

n Number of agricultural waste fields

m Number of storages

f_j Fixed cost to open a storage j

$c_{i,j}, c_{u,v}$ Distance between nodes i, j or u, v

d_i Amount of agricultural waste to be collected at field i

q_j Capacity of storage j

k Number of vehicles

Q Capacity of vehicle

Decision variables

$X_j = \begin{cases} 1 & \text{if storage is located at site } j \\ 0 & \text{otherwise} \end{cases}$

$Y_{ij} = \begin{cases} 1 & \text{if field } i \text{ is served by storage } j \\ 0 & \text{otherwise} \end{cases}$

$Z_{uv} = \begin{cases} 1 & \text{if a vehicle travels from node } u \text{ to node } v \\ 0 & \text{otherwise} \end{cases}$

T_u, T_v Auxiliary variables

Model Formulation (2/3)

location cost assignment cost transportation cost

$$\min \sum_{j \in J} f_j \cdot X_j + \sum_{i \in I} \sum_{j \in J} c_{ij} \cdot d_i \cdot Y_{ij} + \sum_{u \in J_0} \sum_{v \in J_0: u \neq v} c_{uv} \cdot Z_{uv}$$

$$(C1) \sum_{j \in J} Y_{ij} = 1 \quad \text{for each } i \in I$$

$$(C2) \sum_{i \in I} d_i \cdot Y_{ij} \leq q_j \cdot X_j \quad \text{for each } j \in J$$

$$(C3) \sum_{u \in J} Z_{u0} = k$$

$$(C4) \sum_{v \in J} Z_{0v} = k$$

Legenda

Capacitated facility location

TSP adjusted for CVRP

Assignment

$$(C5) \sum_{u \in J_0: u \neq v} X_u \cdot Z_{uv} = X_v \quad \text{for each } v \in J$$

$$(C6) \sum_{v \in J_0: v \neq u} X_v \cdot Z_{uv} = X_u \quad \text{for each } u \in J$$

$$(C7) T_u - T_v + Q \cdot Z_{uv} \leq Q - \frac{1}{k} \cdot \sum_{i \in I} d_i \cdot Y_{iv} \quad \text{for each } u, v \in J : u \neq v$$

$$(C8) \frac{1}{k} \cdot \sum_{i \in I} d_i \cdot Y_{iv} \leq T_u \leq Q \quad \text{for each } u \in J$$

$$(C9) X_j \in \{0, 1\} \quad \text{for each } j \in J$$

$$(C10) Y_{ij} \geq 0 \quad \text{for each } i \in I, \text{ for each } j \in J$$

$$(C11) Z_{uv} \in \{0, 1\} \quad \text{for each } u, v \text{ in } J_0 : u \neq v$$

$$(C12) T_u \geq 0 \quad \text{for each } u \in J$$

Not required
to empty the
storages



Model Formulation (3/3)

Product of decision variables

$$(C5) \sum_{u \in J_0: u \neq v} X_u \cdot Z_{uv} = X_v \quad \text{for each } v \in J$$

$$(C6) \sum_{v \in J_0: v \neq u} X_v \cdot Z_{uv} = X_u \quad \text{for each } u \in J$$

$$u \in J_0 : u \neq v$$

$$v \in J_0 : v \neq u$$

$$W_{uv} = X_u \cdot Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

Linearization of non-linear constraints

$$W'_{uv} = X_v \cdot Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C13) \sum_{v \in J_0: u \neq v} W_{uv} \leq X_u \quad \text{for each } u \in J$$

$$(C14) W_{uv} \leq X_u \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C15) W_{uv} \leq Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C16) W_{uv} \geq X_u + Z_{uv} - 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C17) W_{uv} \in 0, 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C18) \sum_{v \in J_0: u \neq v} W'_{uv} \leq X_u \quad \text{for each } u \in J$$

$$(C19) W'_{uv} \leq X_v \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C20) W'_{uv} \leq Z_{uv} \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C21) W'_{uv} \geq X_v + Z_{uv} - 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C22) W'_{uv} \in 0, 1 \quad \text{for each } u, v \in J_0 : u \neq v$$

$$(C5) \sum_{u \in J: u \neq v} X_u \cdot Z_{uv} = X_v \quad \text{for each } v \in J$$

$$(C6) \sum_{v \in J: u \neq v} X_v \cdot Z_{uv} = X_u \quad \text{for each } u \in J$$

$$D_0 = 1 \quad \text{location of facility}$$

$$D_0 \cdot Z_{0v} = 1 \quad \text{for each } v \in J$$

$$D_0 \cdot Z_{u0} = 1 \quad \text{for each } u \in J$$

03

Case studies & Scalability analysis

LARP optimal solution



Three scenarios for a proof-of-concept



X 3

Main facilities where bio-fertilizer is produced from the agricultural wastes (only one per scenario)



X 6

Storages with a certain capacity and fix opening cost



X 7

Cluster of agricultural fields with a certain amount of agricultural waste



X 3

Truks with a certain capacity and capable to move agricultural wastes from storages to the main facility

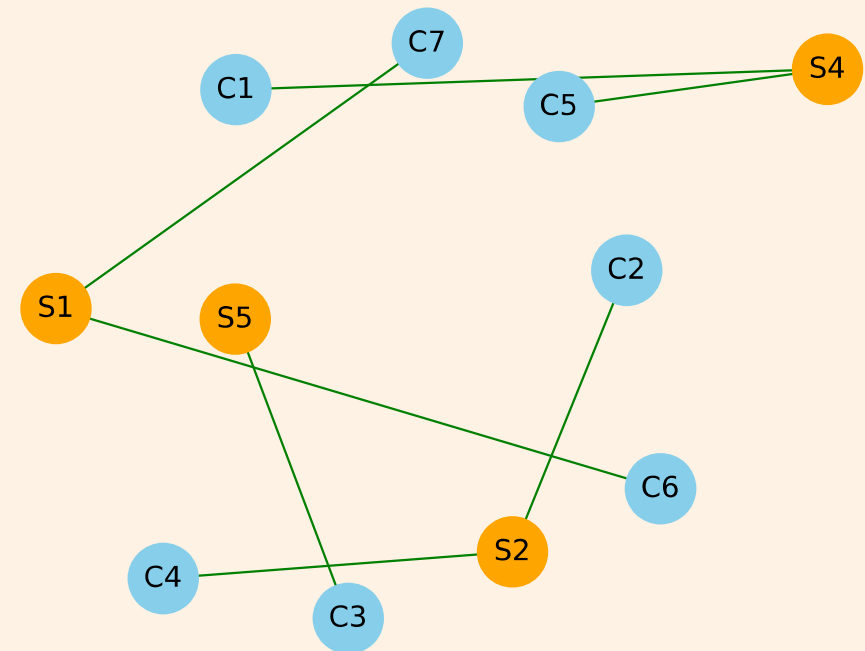


Graphical representations (1/2)

- All the scenarios share the same assignments among storages and agricultural fields
- Storages «S3» and «S6» are not considered in the result, it means that opening a storage to these locations is not suggested

Location cost = 400
Assignment cost = 80,2

Same result
as the **paper**!

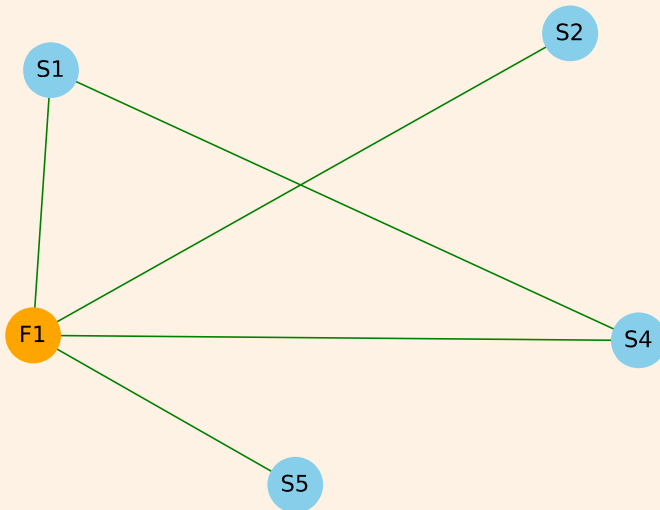


Graphical representations (2/2)

Same results
as the **paper**!

scenario 1

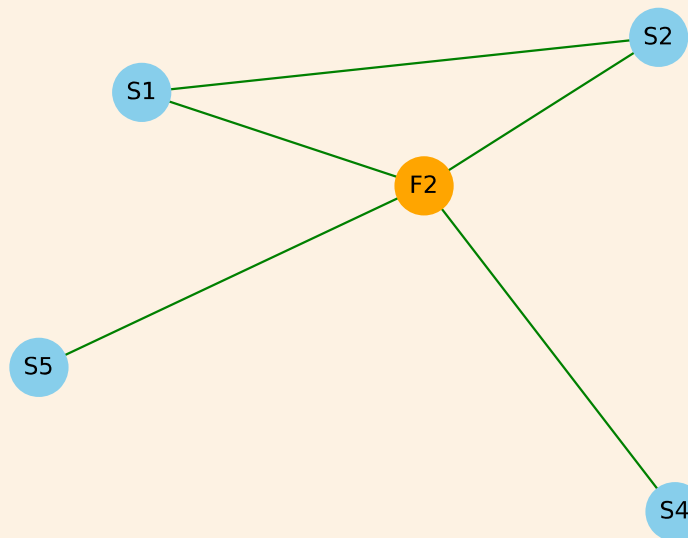
Transportation cost = 57,0
Total cost = 537,2



R1 composed by: F1, S1, S4, F1
R2 composed by: F1, S2, F1
R3 composed by: F1, S5, F1

scenario 2

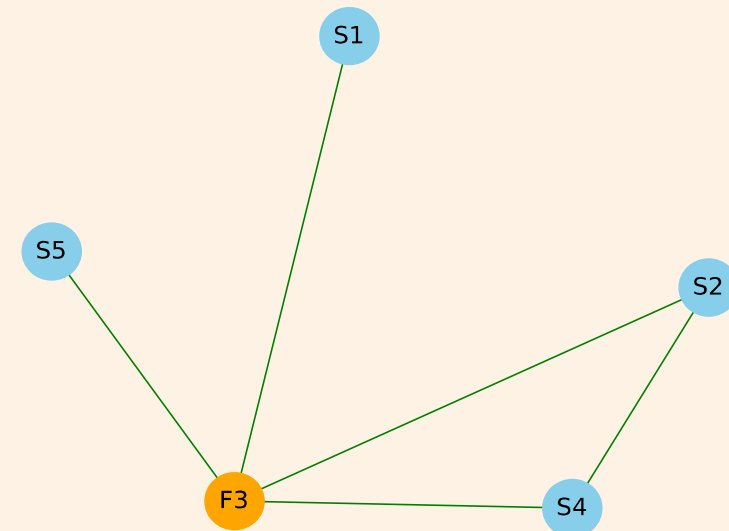
Transportation cost = 119,2
Total cost = 599,4



R1 composed by: F2, S1, S2, F2
R2 composed by: F2, S4, F2
R3 composed by: F2, S5, F2

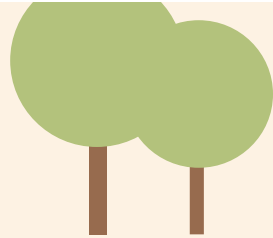
scenario 3

Transportation cost = 55,0
Total cost = 535,2



R1 composed by: F3, S1, F3
R2 composed by: F3, S4, S2, F3
R3 composed by: F3, S5, F3

Scalability analysis



Parameters used for the experiment:

Facility = 'F'

Num iterations = 10

Num fields = 100

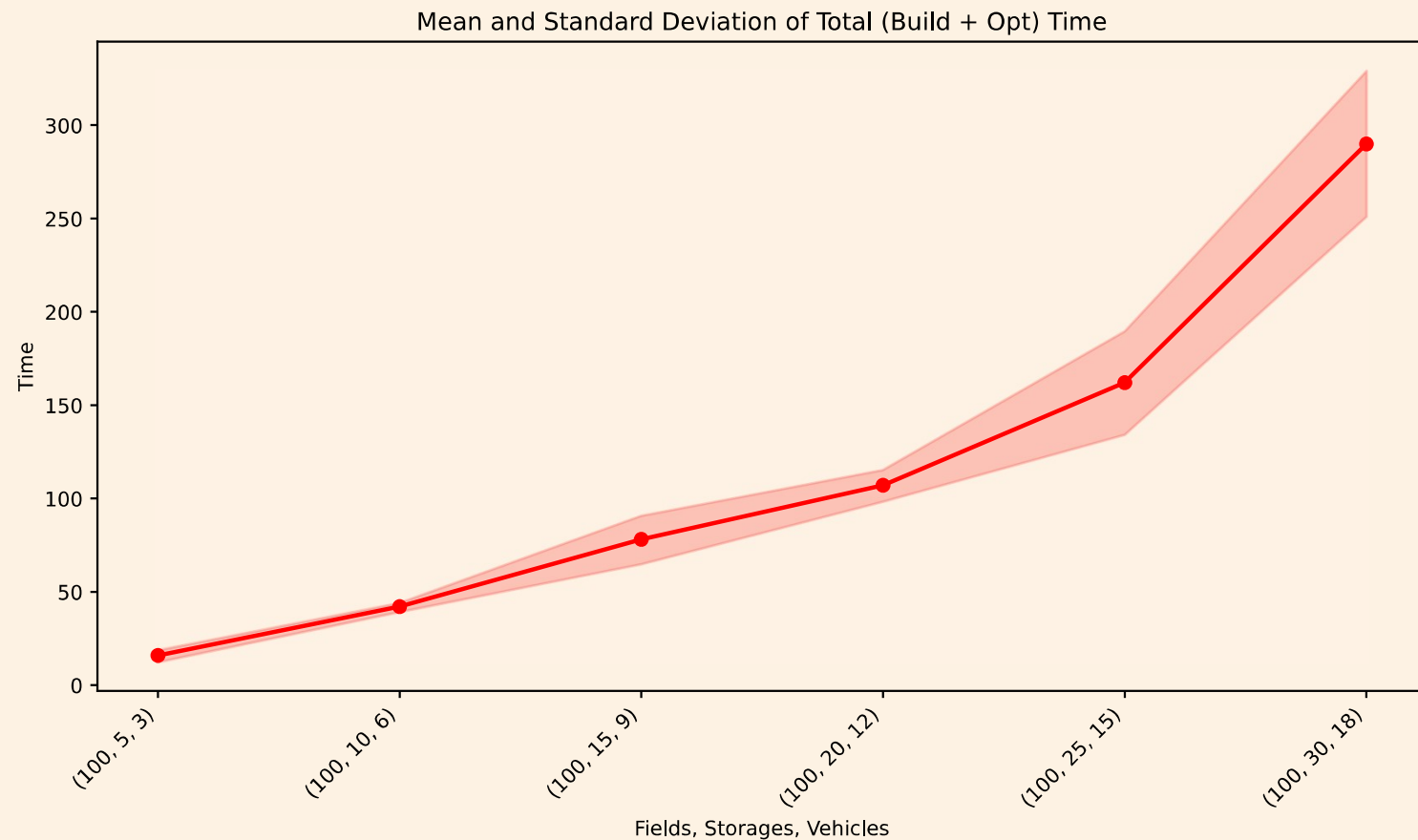
Num storages = [5, 10, 15, 20, 25, 30]

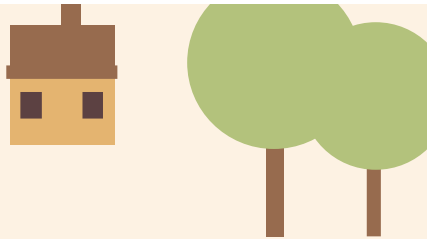
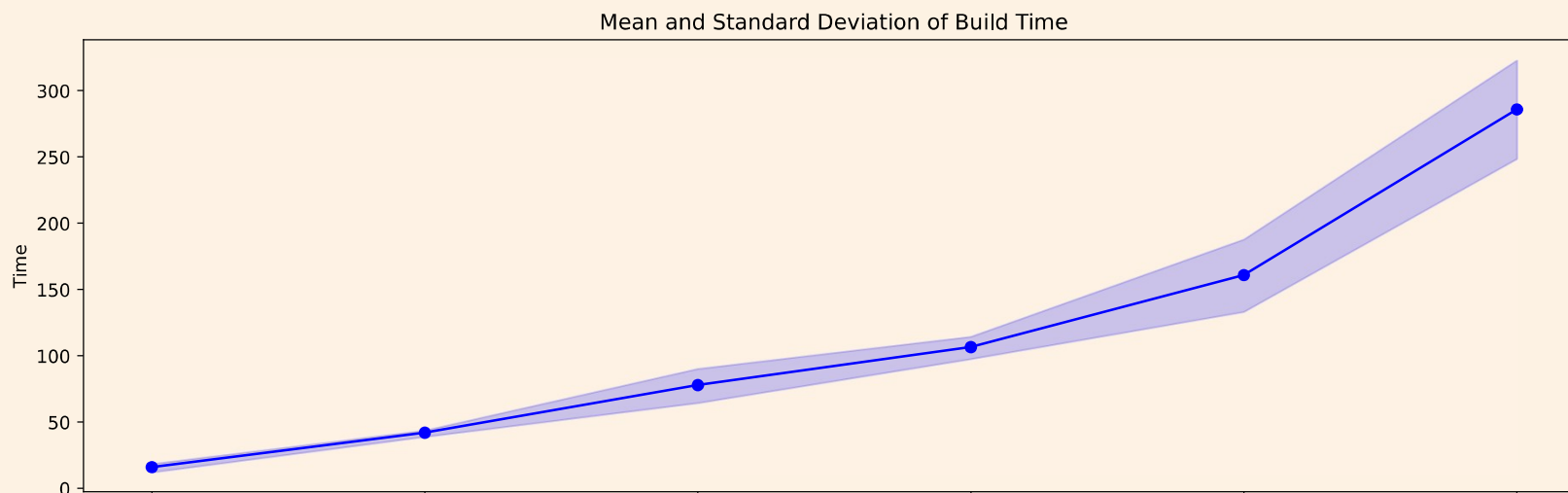
Num vehicles = [3, 6, 9, 12, 15, 18]

Vehicle capacity = 2000 (tons)

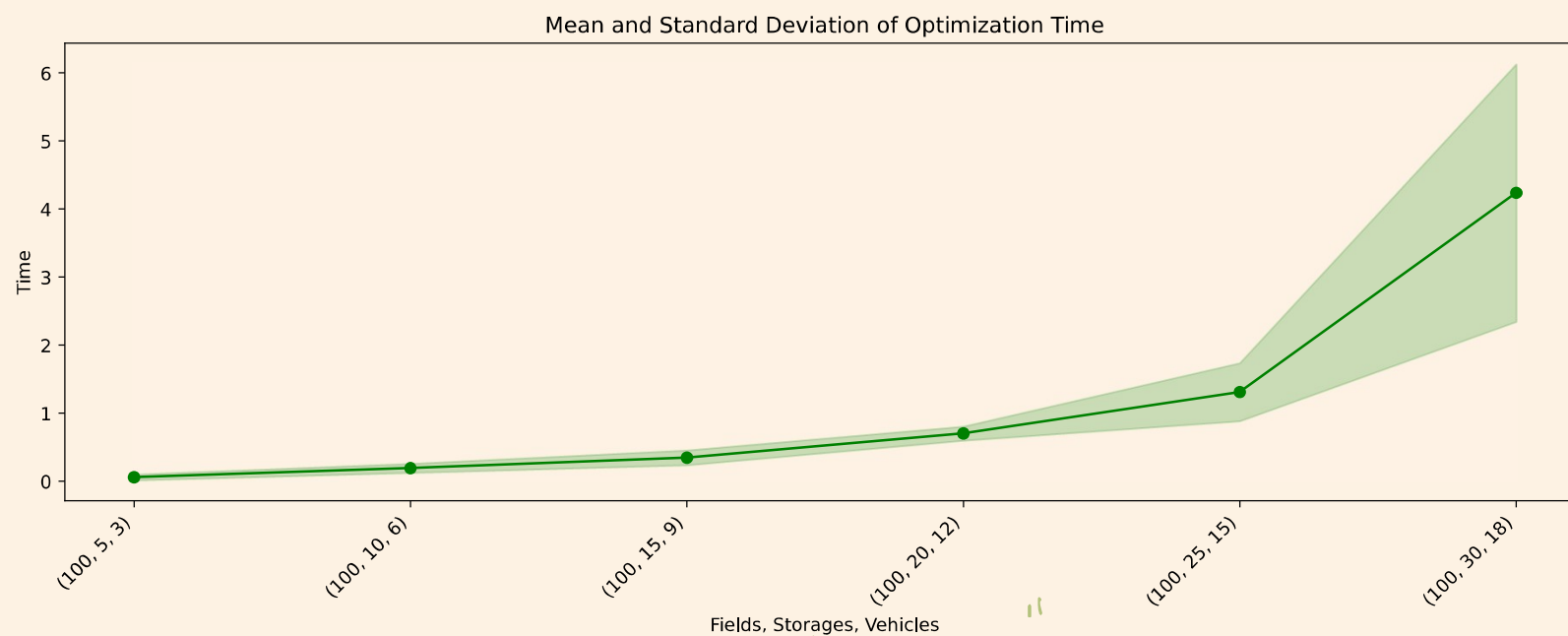
Proposed model formulation is clearly not able to provide an optimal solution for different sizes of the problem, in «acceptable» timeframe.

Scalability plot match the optimization model **complexity** of $O(m^2 + nm)$.

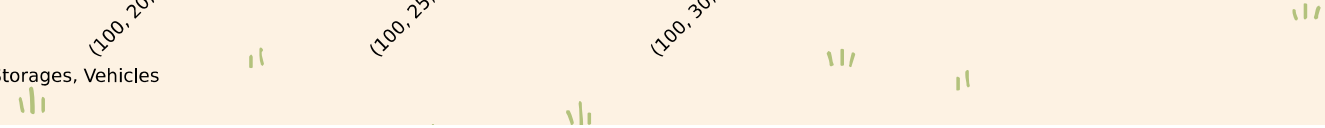




Major contribution to the Scalability Analysis comes from the **Build** phase



Optimization phase starts to relatively impact later



04

Water Flow Algorithm

A meta-heuristic improvement



Water Flow Algorithm

A couple of disclaimers

Proposed description of the WFA is short, poor in detail and, at times, confusing



A «personal» interpretation is implemented for this project



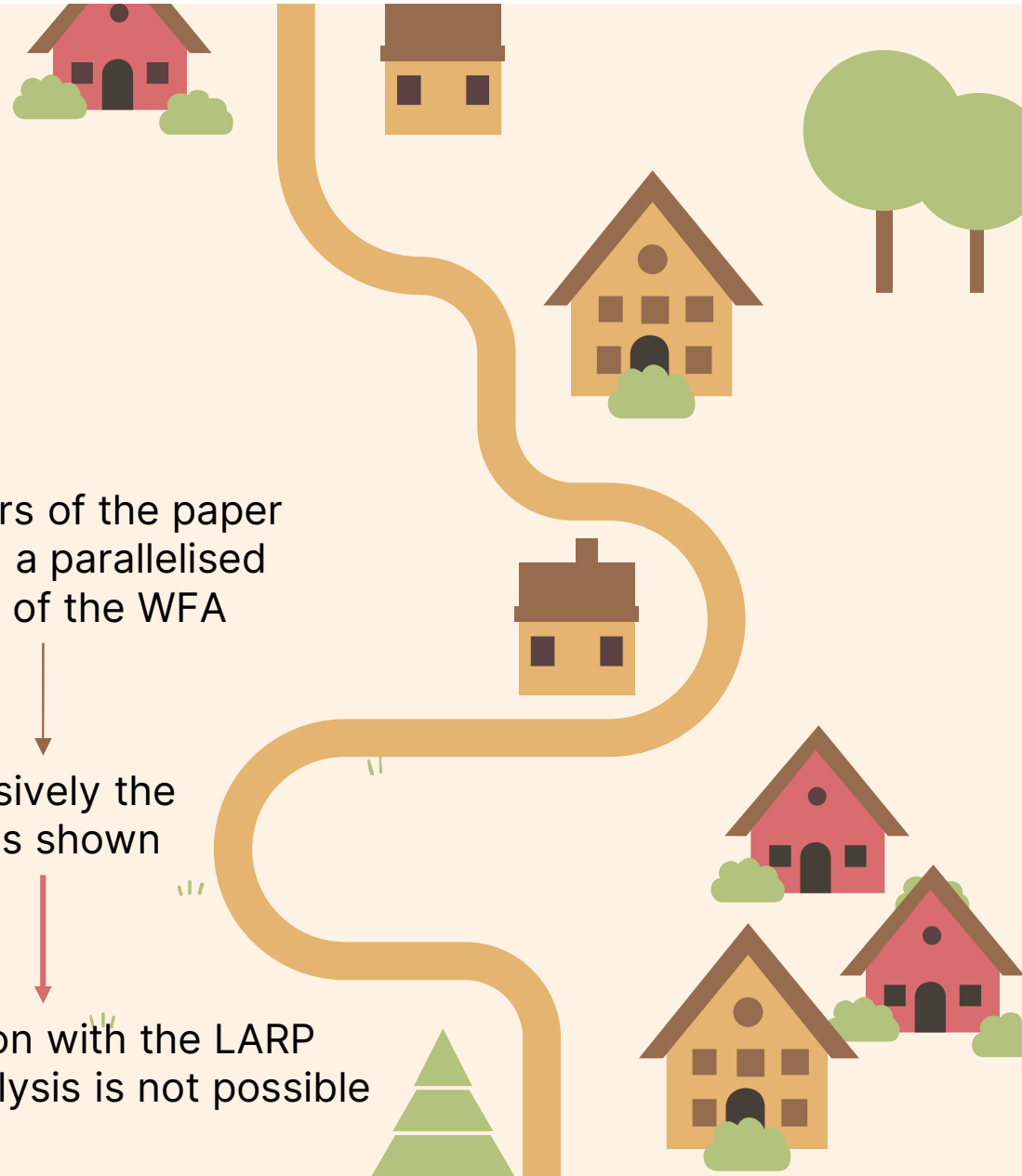
The authors of the paper proposed a parallelised version of the WFA



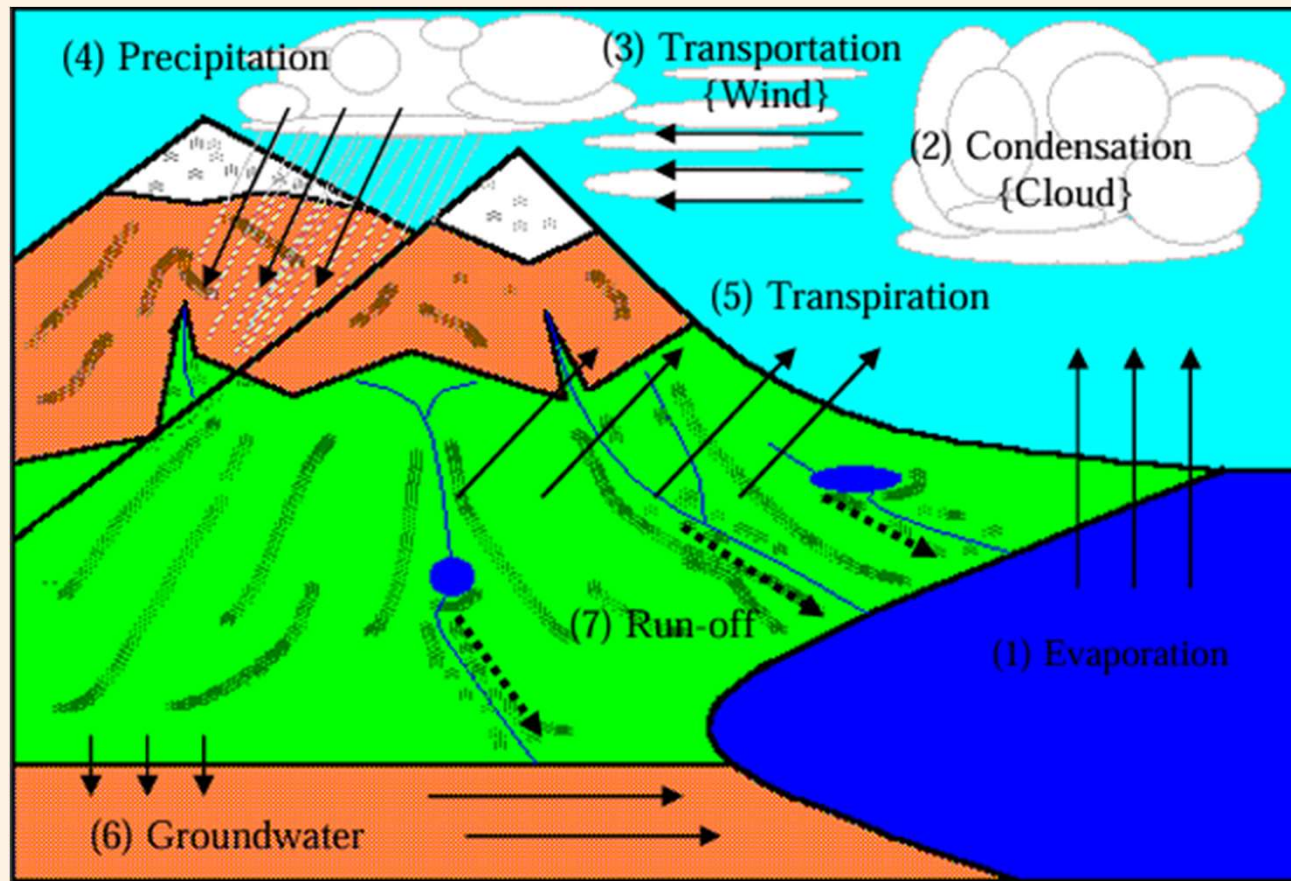
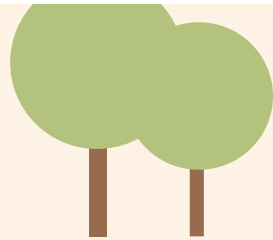
Exclusively the WFA is shown



A comparison with the LARP Scalability Analysis is not possible



Basic Components of the Hydrological Cycle



We focus just on the following stages:

- **(2) Condensation**
- **(4) Precipitation**
- **(6) Groundwater**

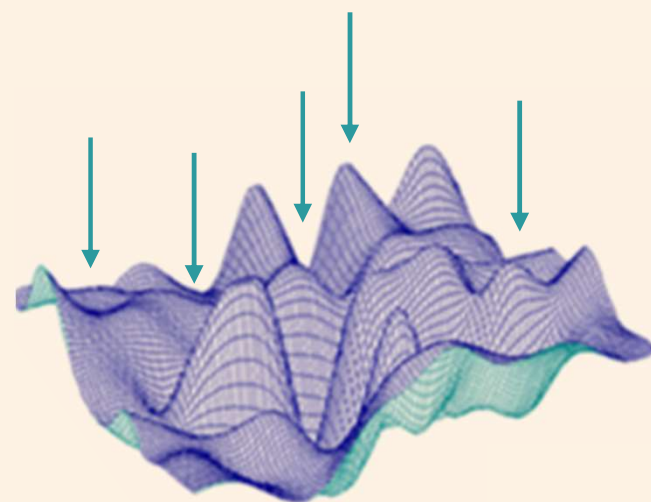


From Water Cycle to Water Flow Formulation (1/3)

Condensation

Precipitation

How is a DOW
concretely
defined?



Drop-of-Waters (DOWs) are generated from a cloud and they falls on the earth

A «DOW» identify a location (point) in the solution space for the LARP model, and a set of DOWs is randomly generated





From Water Cycle to Water Flow Formulation (2/3)



Storage (m)				Field (n)				Vehicle (k)					
1	2	...	m	1	2	...	n	1	2	...	k		
$\{0,1\}$	$\{0,1\}$...	$\{0,1\}$	y_1	y_2	...	y_n	0	z_1	0	...	0	z_k
$X_j \forall j \in J$				$Y_{ij} \forall i \in I, j \in J$				$Z_{uv} \forall u, v \in J_0$					

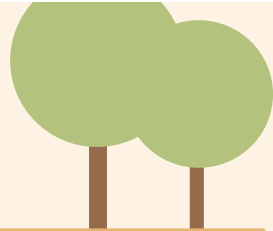
A «DOW» represents a solution for LARP model

Storage ($m = 4$)				Field ($n = 8$)								Vehicle ($k = 2$)				
1	2	3	4	1	2	3	4	5	6	7	8	1	2			
1	1	1	0	2	1	3	2	1	2	3	1	0	1	3	0	2
$X_j \forall j \in J$				$Y_{ij} \forall i \in I, j \in J$								$Z_{uv} \forall u, v \in J_0$				

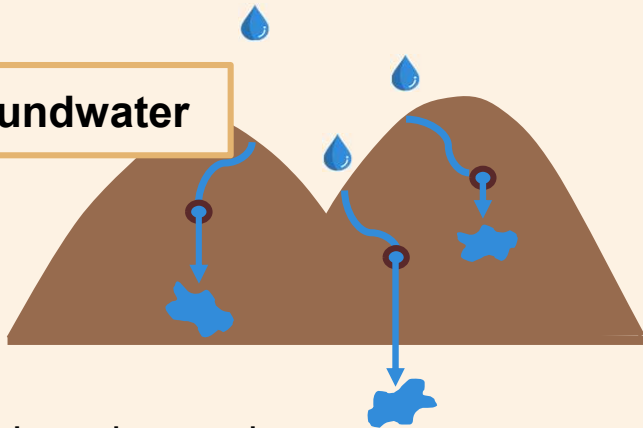
An example of DOW/Solution formulation



From Water Cycle to Water Flow Formulation (3/3)



Groundwater



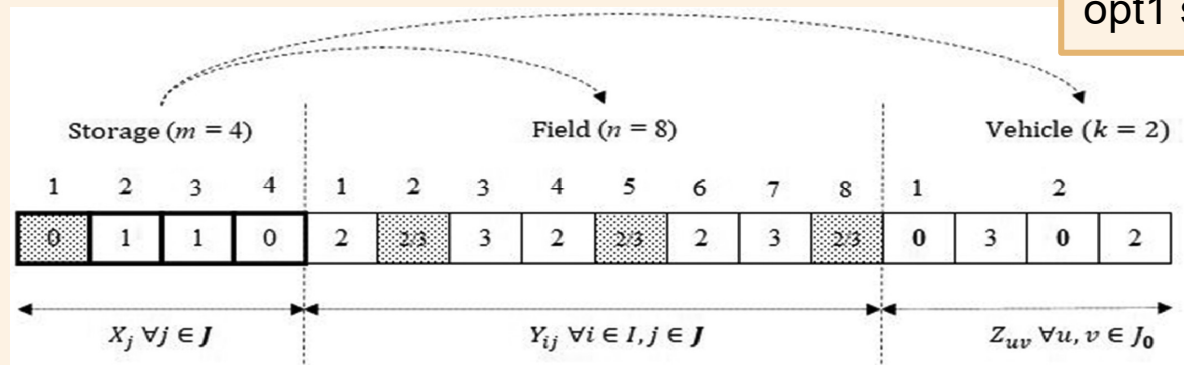
Local search

«DOWs» on the ground start to move down due to the Gravity force until they stop somewhere

Erosion process

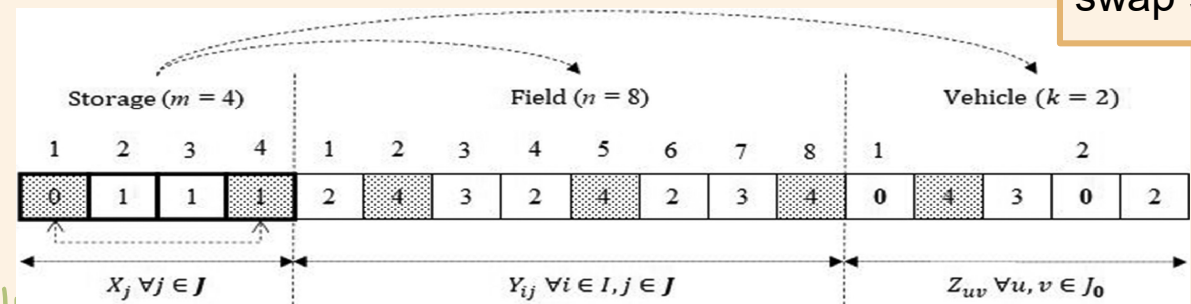
«DOWs», gathered in puddle, begin to seepage the ground

opt1 strategy



1	2	3	4	1	2	3	4	5	6	7	8	1	2			
1	1	1	0	2	1	3	2	1	2	3	1	0	1	3	0	2

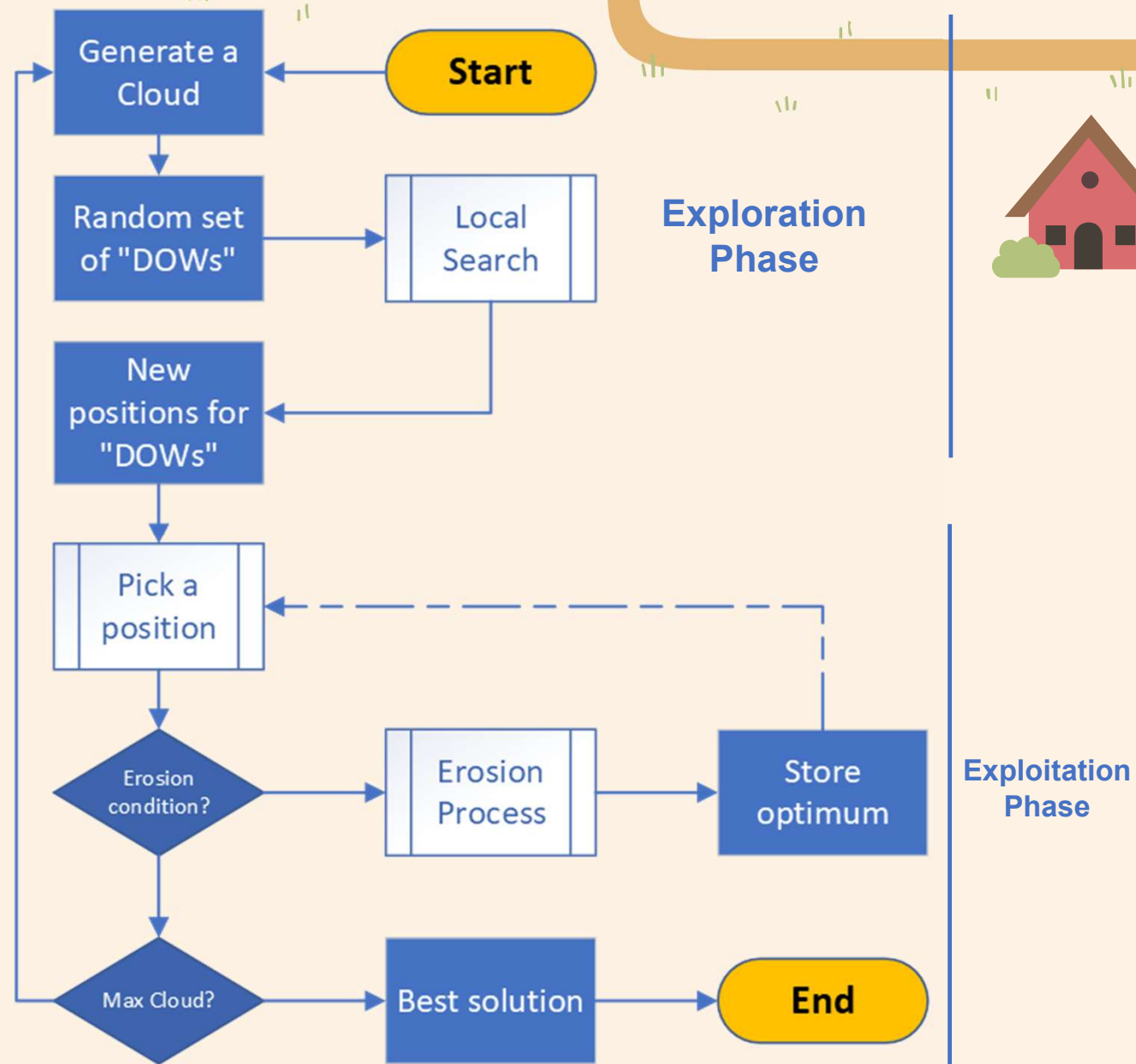
swap strategy



Simplified flow-chart for the Water Flow Algorithm

During the **Exploration phase** a Cloud is generated, the cloud rains a fixed number of water drops randomly which fall on the earth at some position and start to move somewhere down

During the **Exploitation phase** those water drops which are gathered in a single point start to erode the ground and infiltrate through the ground until they stop somewhere in a groundwater



Condensation →

Precipitation →

Gravity force →

New positions →

Erosion condition →

Erosion process →

New local optimum →

```
clouds = clouds_generator(max_cloud, larp, max_pop)

for cloud in clouds:
    print('start to rain...')
    rainfall, discarded_dows = cloud.make_rain(E_list, discarded_list)
    print('stopped to rain.')
    discarded_list.extend(discarded_dows)

    print('gravity force push down dows...')
    for dow in rainfall:
        local_optimum, neighbours, excluded_dows, discarded_dows = local_search(larp, dow)
        excluded_list.extend(excluded_dows)
        discarded_list.extend(discarded_dows)
        UE_list.append(local_optimum) # for erosion process

        if local_optimum not in optimal_dows.keys():
            optimal_dows[local_optimum] = neighbours
    print('dows sink in some local positions.')

    for dow, neighbours in optimal_dows.items():
        print('dow:\n', dow)
        print('n. neighbours:', len(neighbours))

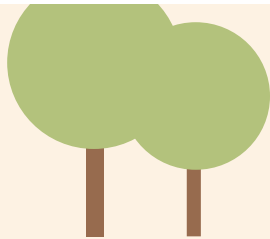
    dow_occurances = Counter(UE_list)
    dow_occurances = [dow for dow, occurs in dow_occurances.items() if occurs >= min_ero]
    print(f'{len(dow_occurances)} optimal(s) satisfy the erosion condition.')
    for dow in dow_occurances:

        neighbours = optimal_dows[dow]
        print('following dow can start the erosion process:\n', dow)
        print(f'dow has {len(neighbours)} neighbours that might be considered...')

        tmp = erosion(larp, dow, neighbours, max_UIE,
                      excluded_list, discarded_list, optimal_dows,
                      PO_list, UE_list, E_list)

        dow_optimum, _, excluded_list, discarded_list, \
            optimal_dows, UE_list, E_list = tmp
        PO_list.append(dow_optimum)

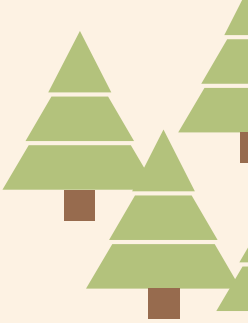
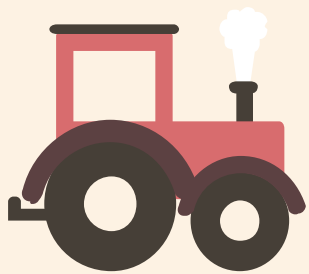
    print('dow optimum:', dow_optimum)
```



Exploration

Exploitation

**Thank you
for the
attention!**



References

- Formulation and solution technique for agricultural waste collection and transport network design, European Journal of Operational Research
- Waste Mismanagement in Developing Countries: A Review of Global Issues, International Journal of Environmental Research and Public Health
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- A Waterflow Algorithm for Optimization Problems (2011), Tran Trung Hieu

