Water and Environment Support
in the ENI Southern Neighbourhood region

Explore the Potential of Natural Water Retention Measures (NWRM) at the catchment scale
Activity No. : N-W-JO-2

Analysis of Natural Water Retention Measures in Natural Areas – Application in Azraq City Lowland Area

Stakeholders' Consultation Workshop

15 May 2024

Kempinski Hotel, Amman, Jordan

Presented by: Dr. D. ZARRIS, WES Non-Key Expert

S. Vavoulogiannis, M.Sc. Hydrologist

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Review of Natural Water Retention Measures in River Systems and Floodplains

Water and Environment Support
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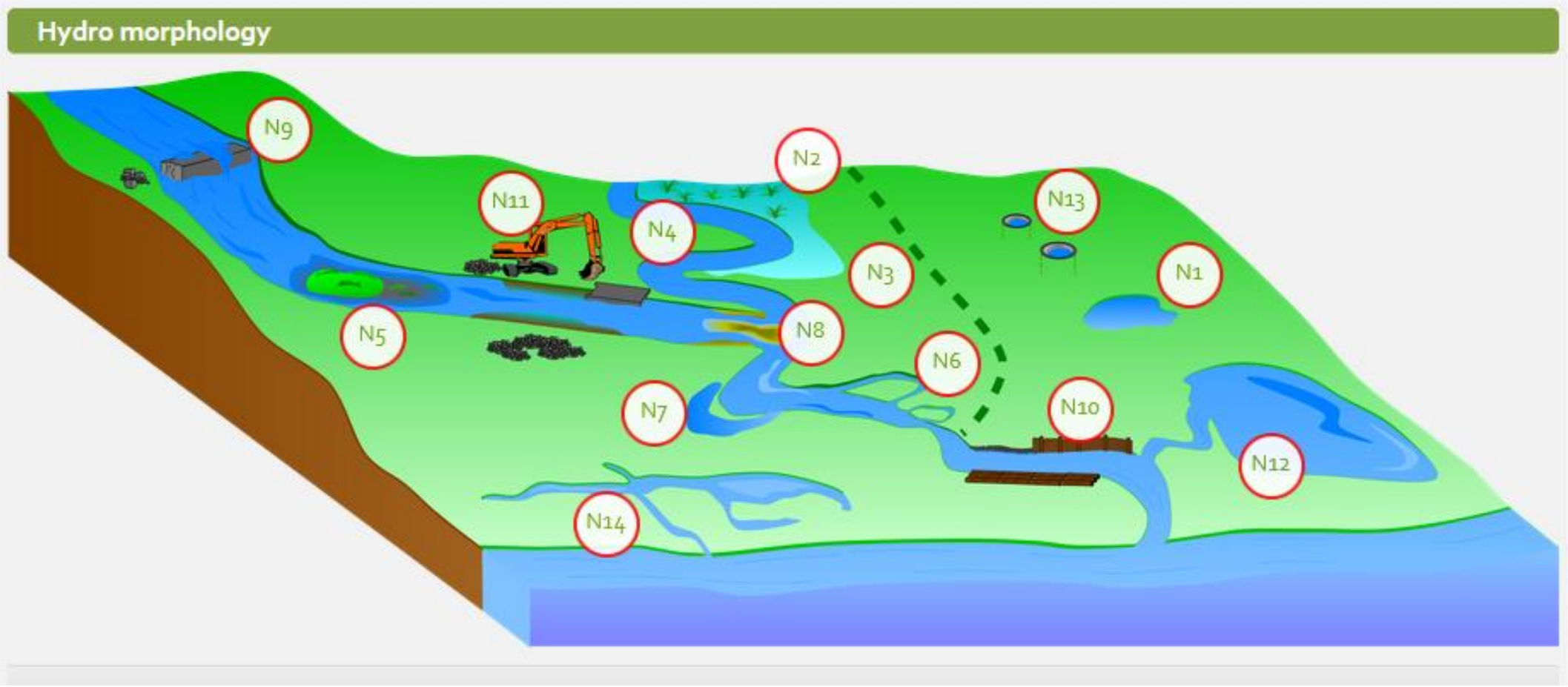

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Review of Natural Water Retention Measures in River Systems and Floodplains

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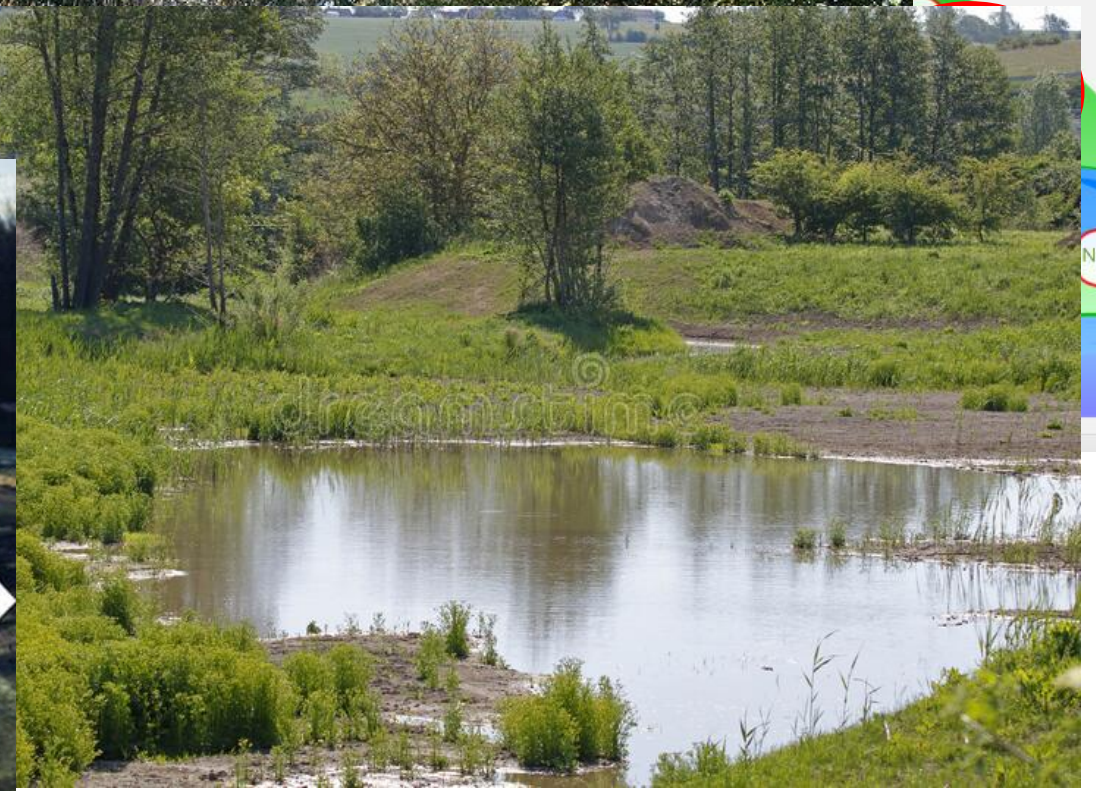
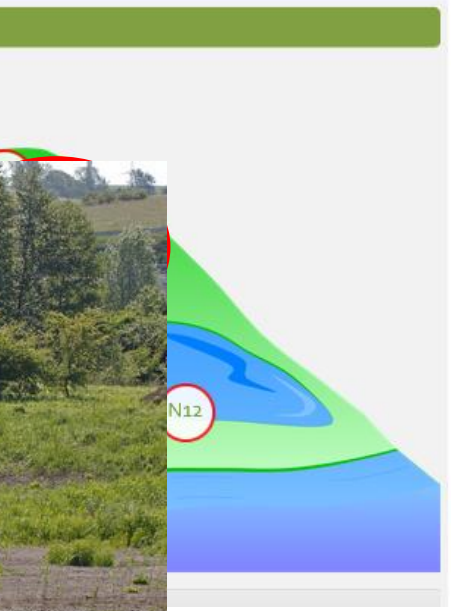
1. Basins and Ponds

Definition: Both retention and detention basins





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2. Wetland Restoration and Managemer

Definition:
A wetland is an area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

Wetland restoration and management can involve: technical, spatially large-scale measures (including the installation of ditches for rewetting or the cutback of dykes to enable flooding); technical small-scale measures such as clearing trees; changes in land-use and agricultural measures, such as adapting cultivation practices in wetland areas. They can improve the hydrological regime of degraded wetlands and generally enhance habitat quality. Creating artificial or constructed wetlands in urban areas can also contribute to flood attenuation, water quality improvement and habitat and landscape enhancement.

Wetlands are mo
former agricultura
drained to increas

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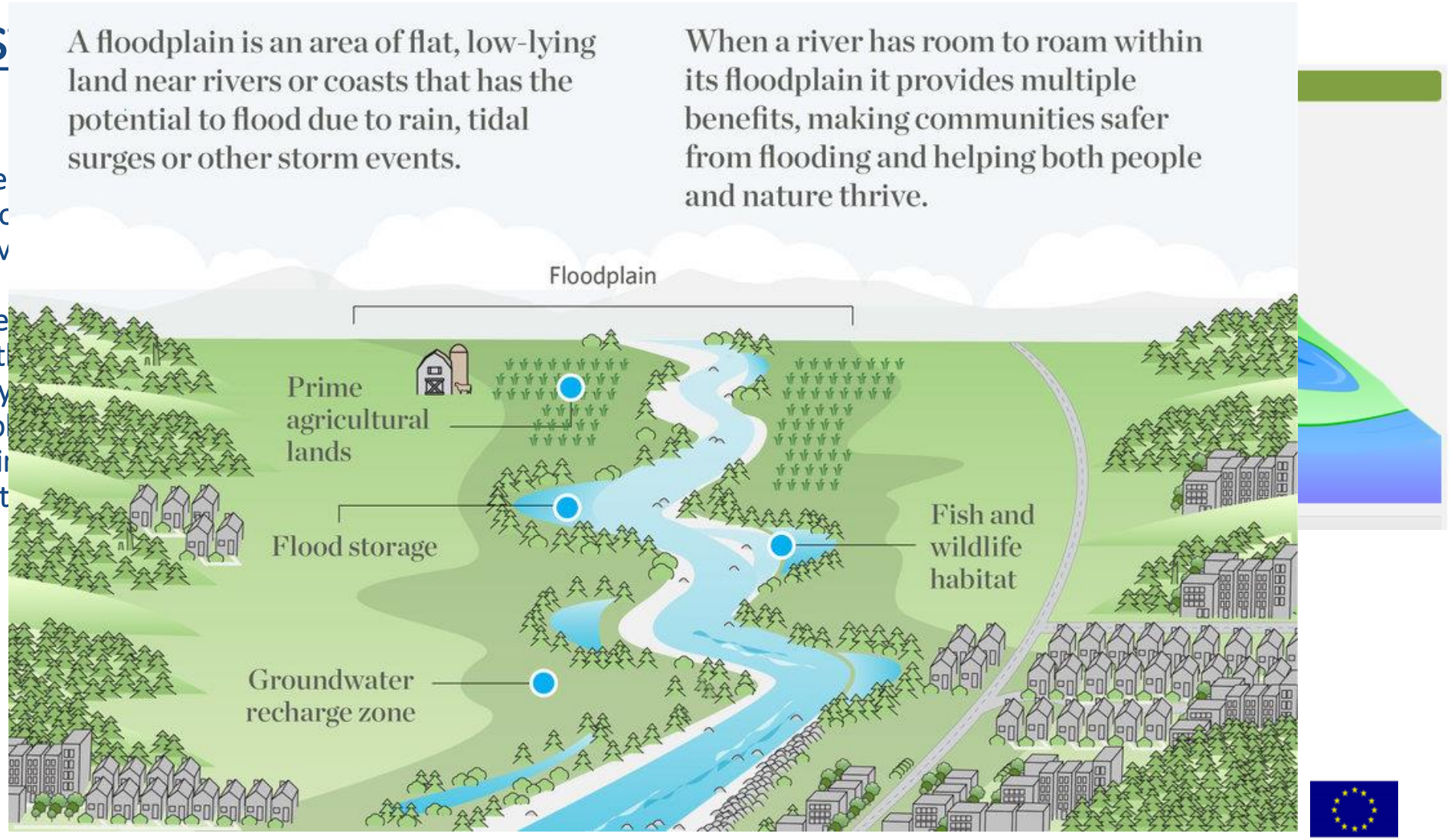
3. Floodplain Res

Definition:
A floodplain is the area borde
provides space for the retentic
Floodplain soils are generally v
often been dried-out to be
Floodplains in many places have
the river by dikes, berms or ot
control the flow of the river. They
legacy sediments. Major flood p
lost, due to land drainage, i
river channelization. The object
their retention capacity and
reconnecting them to the river.



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4. Re-meandering

Definition:
A river meander is a U-form taken by the river, allowing it to decrease water velocity. In the past, rivers have been straightened by cutting off meanders. Many rivers in norther
channe
speed
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newly
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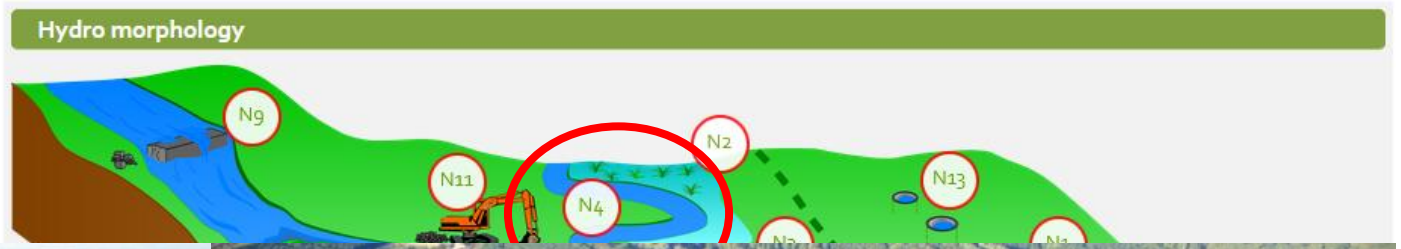

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Review of Natural Water Retention Measures in River Systems and Floodplains (also in Urban Areas)

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5. Stream bed re-naturalization

Definition:
Streambed (or riverbed) represents the floor of the river, including each riverbank. In the past, riverbeds were artificially reconstructed with concrete or big stones, therefore modifying flows and decreasing fauna habitat and vegetation diversity. T
flood prevention or
practices for example.
rivers and often having
the river. Streambed r
some concrete or inert
riverbanks, then replaci
order to avoid these da

Kallang river , Singapore

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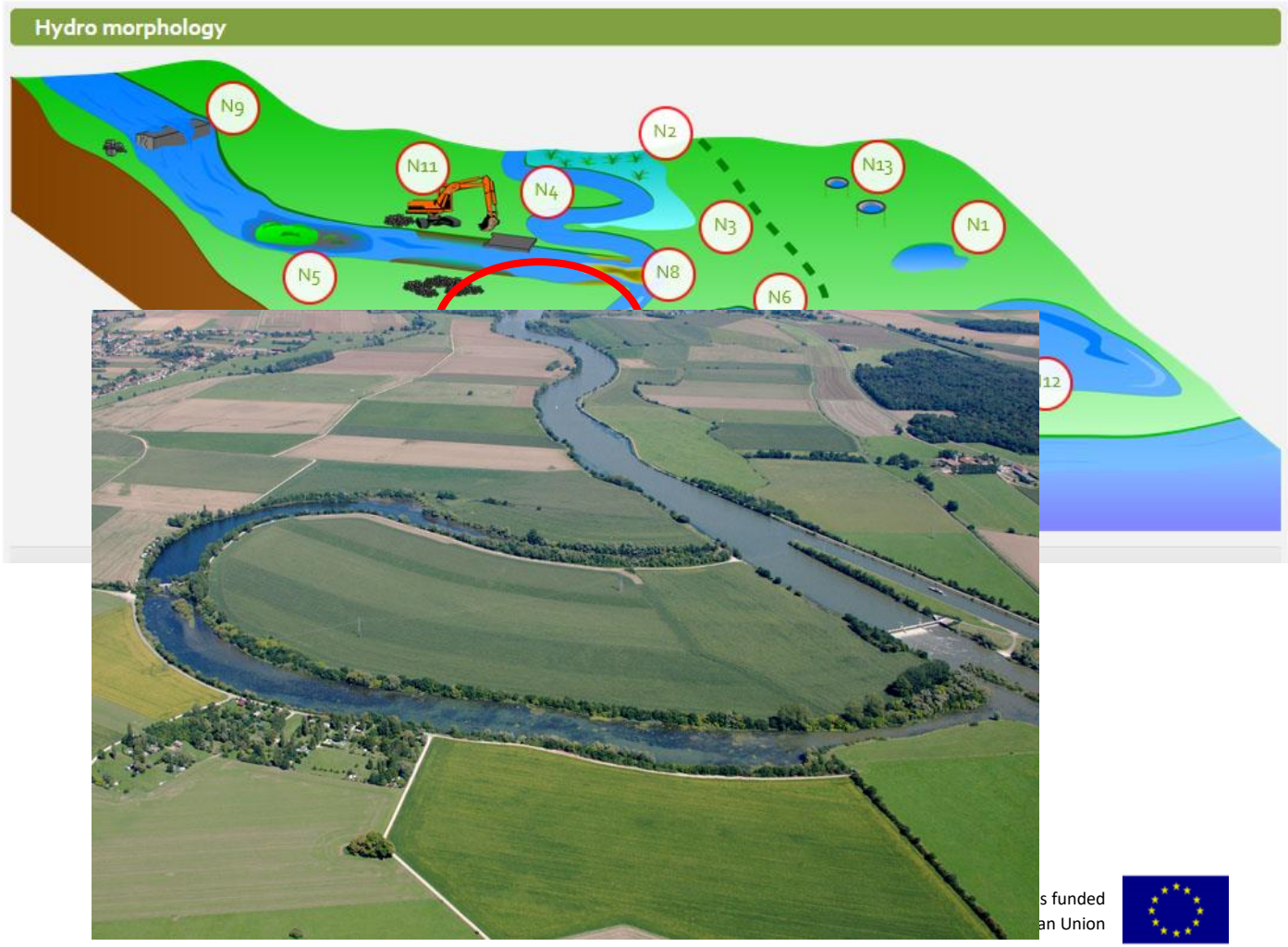
6. Reconnection of oxbow lakes and similar features

Definition:
An oxbow lake is an ancient meander that was cut off from the river, thus creating a small lake with a U form. Reconnecting it with the river consists in removing terrestrial lands between both water bodies, therefore favouring the overall functioning of the river by restoring lateral connectivity, diversifying flows and cleaning the river section of the present oxbow for a better water retention during floods.

In some cases old oxbow lakes are dried and transformed into forest plantations, pastures, meadows or other semi-natural areas. Reconnection could be challenged by the need for land use change. An ox-bow lake, even if disconnected, can accumulate surface runoff from adjacent lands. However, its reconnection to riverbed, therefore increasing the river length, can largely increase its capacity in this aspect.



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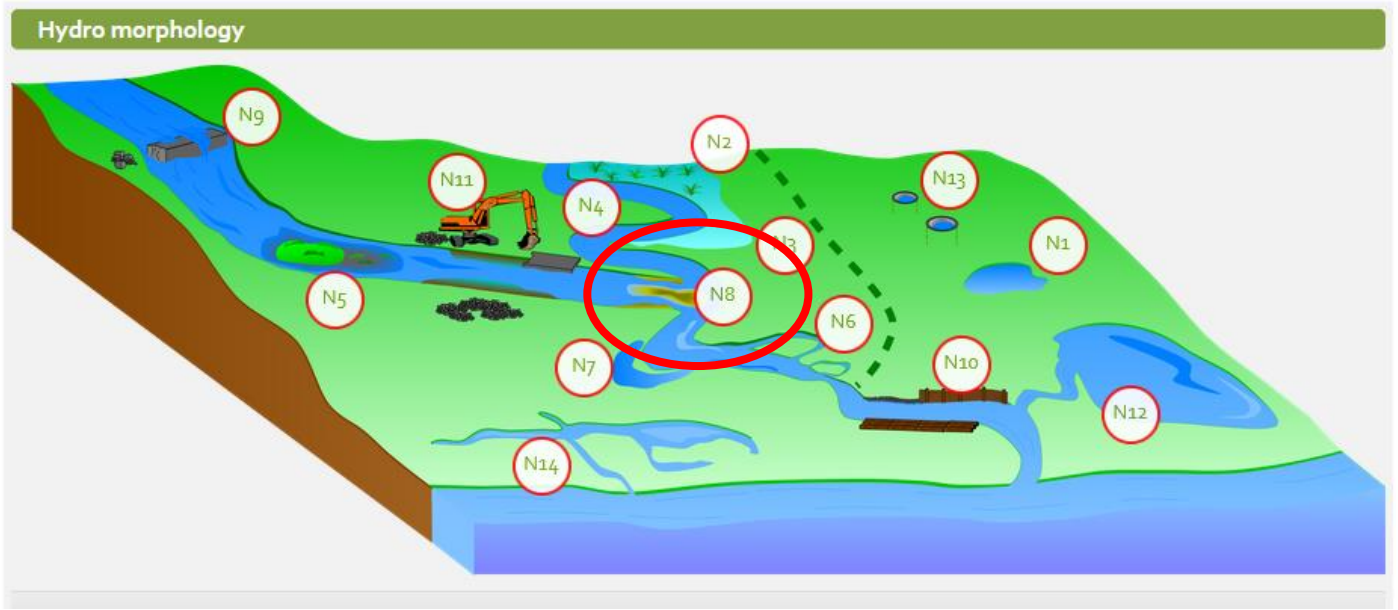
8. Riverbed material renaturalization

Definition:
Riverbed material represents the sediment eroded upstream, transported by the river and deposited on the river floor. It can be composed of coarse and/or fine material. Its re-naturalization consists in recovering the nature-like structure and composition of the bed load, in particular the equilibrium between coarse and fine sediment.



In case of a dam upstream, gravel transport diminishes and river incision commences. Spawning fields for fish is also diminishing.

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10. Natural bank stabilization

Definition:
Riverbank represents both natural and artificial terrain following the river flow. In the past, lots of artificial banks were built with concrete or other types of retention walls, therefore limiting rivers' natural movements, leading to degradation of the river, increased water flow velocity, increased erosion and decreased biodiversity. River bank renaturalisation consis
components, thus reve
allowing bank to be stab
freely. Nature-based so
preferable, but civil eng
strong hydrological const

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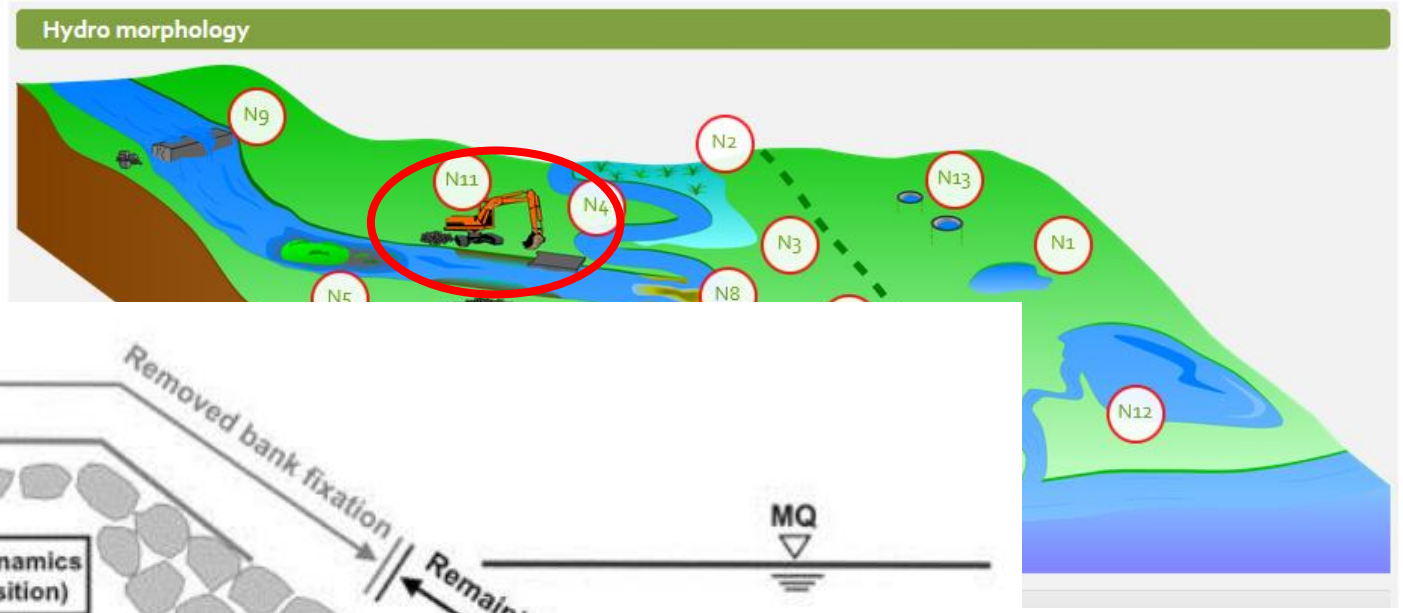
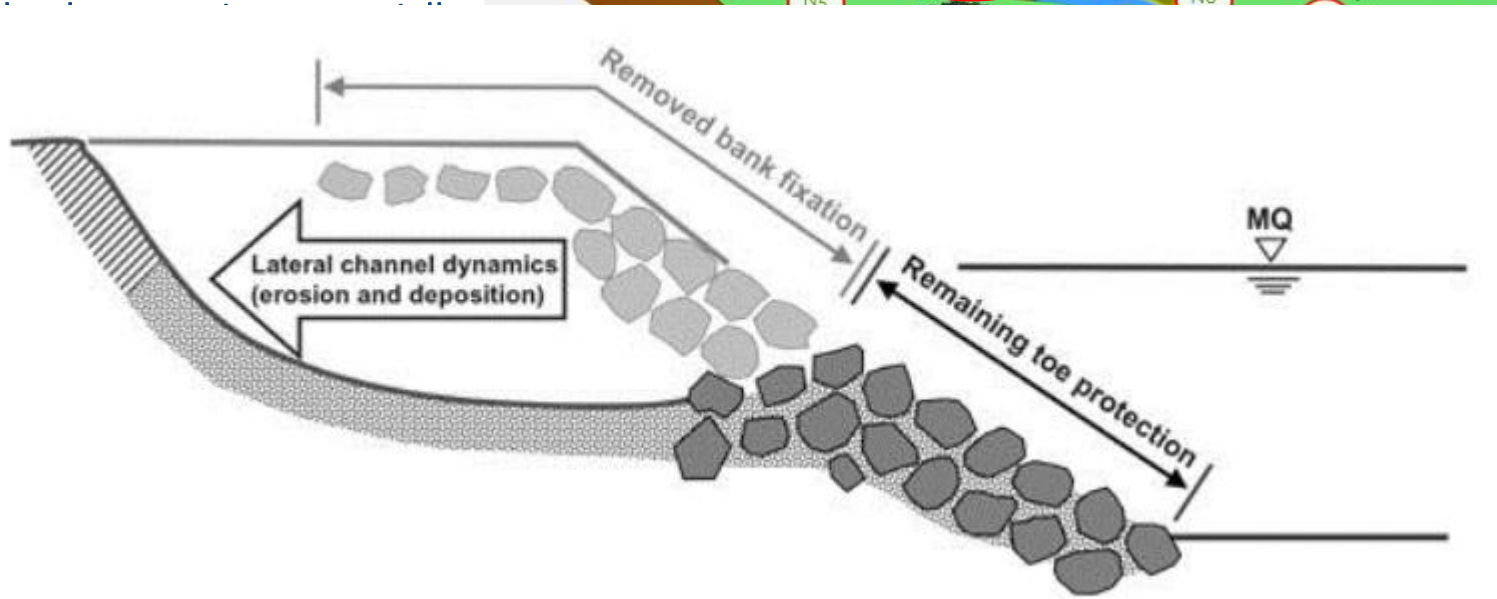
11. Elimination of riverbank protection

Definition:
A riverbank protection is an “hard” or “soft” construction providing bank fixation but also an obstacle for the lateral connection of the river. Eliminating it consists in removing some parts of th
the inert ones, in order to enh
river, diversify flows (depth,
habitats, but also cap floods
prerequisite for many other
or widening, as well as initi
and dynamics.





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Water and Environment Support
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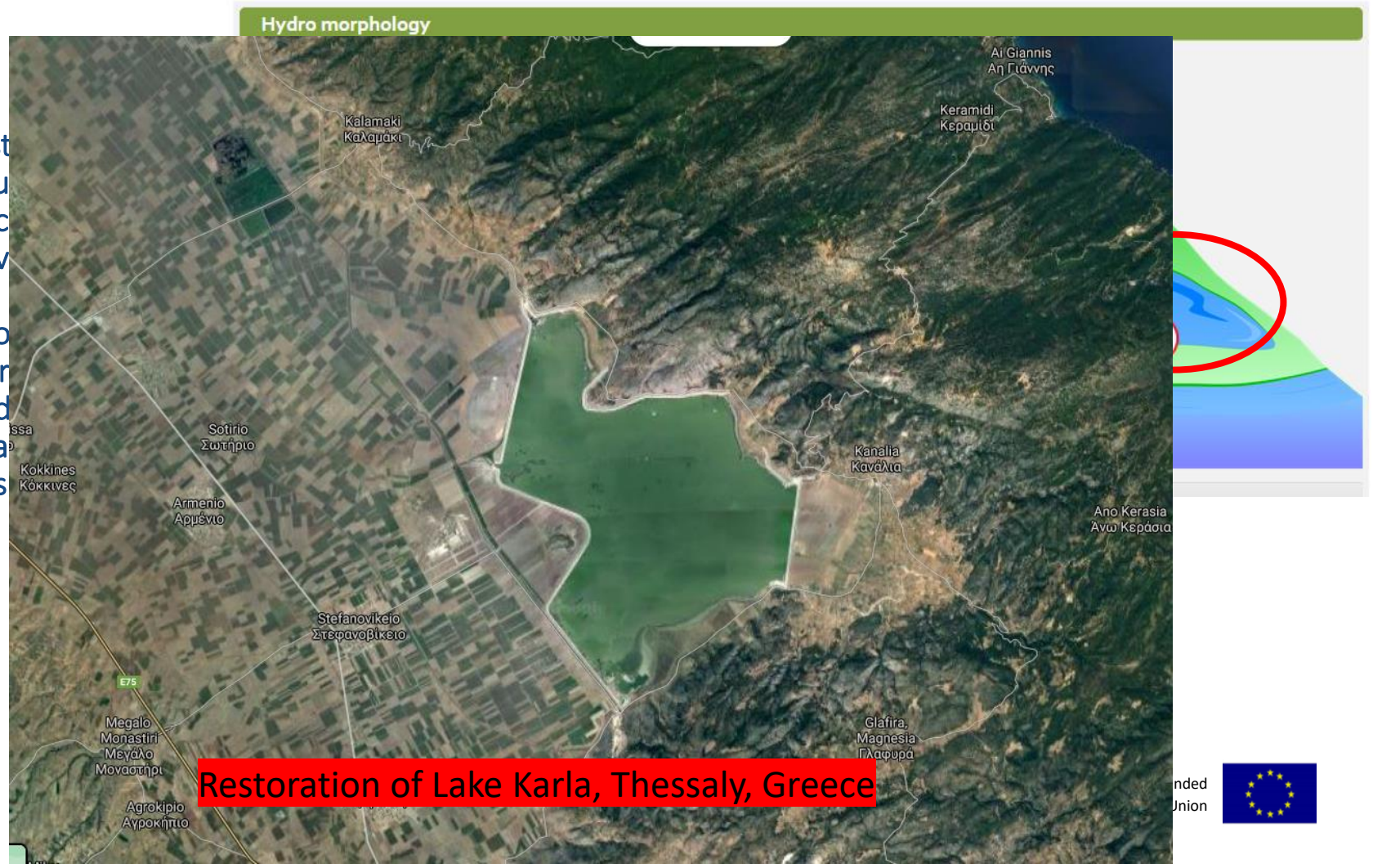
12. Lake Restoration

Definition:
A Lake is a water retention facility. It can st
flood control) and provide water for many pu
water supply, irrigation, fisheries, tourism, etc
serves as a sink for carbon storage and prov
habitats for numerous species of plants
including waders. In the past, lakes have so
drained to free the land for agriculture pur
simply not been maintained and have silted
lakes consists in enhancing their structure a
where they have been drained in former times



Restoration of Lake Karla, Thessaly, Greece

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Union

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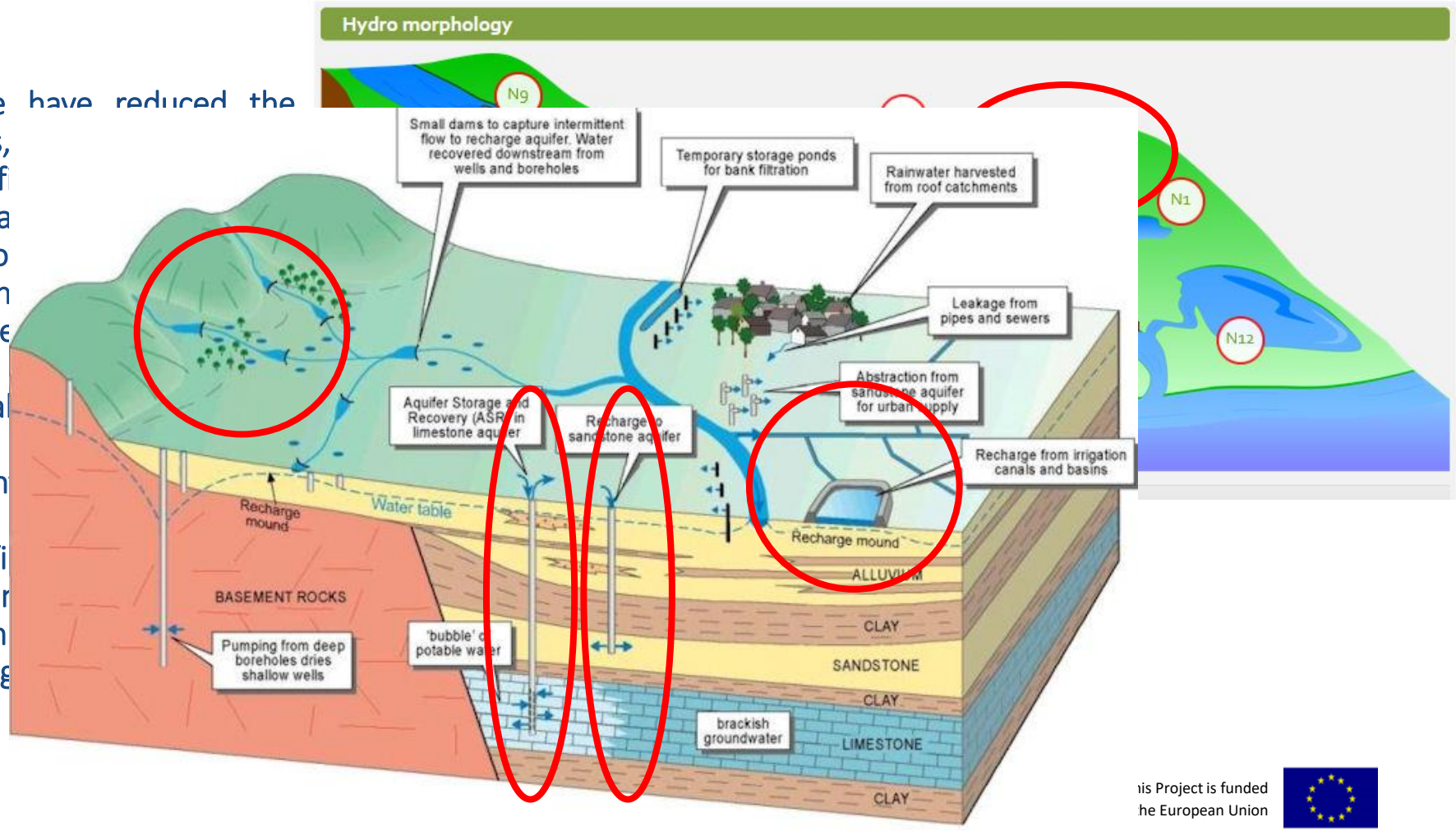
in the ENI Southern Neighbourhood region

14. Artificial Groundwater Recharge

Definition:
Previous modifications of the landscape have reduced the infiltration capacity of many European soils, rate at which precipitation is able to inf groundwater aquifers. Restoration of na groundwater enables a lowering of run-o land, and enhances the condition of groun water availability. The natural cleaning proce infiltration can improve water quality.
Mechanisms to restore or enhance natural include:
(i) surface structures to facilitate/augmen soakaways and infiltration basins);
(ii) subsurface indirect recharge – infi enhanced through wells drilled within the ur
(iii) subsurface direct recharge – infiltration groundwater aquifer is accomplished throug saturated zone.



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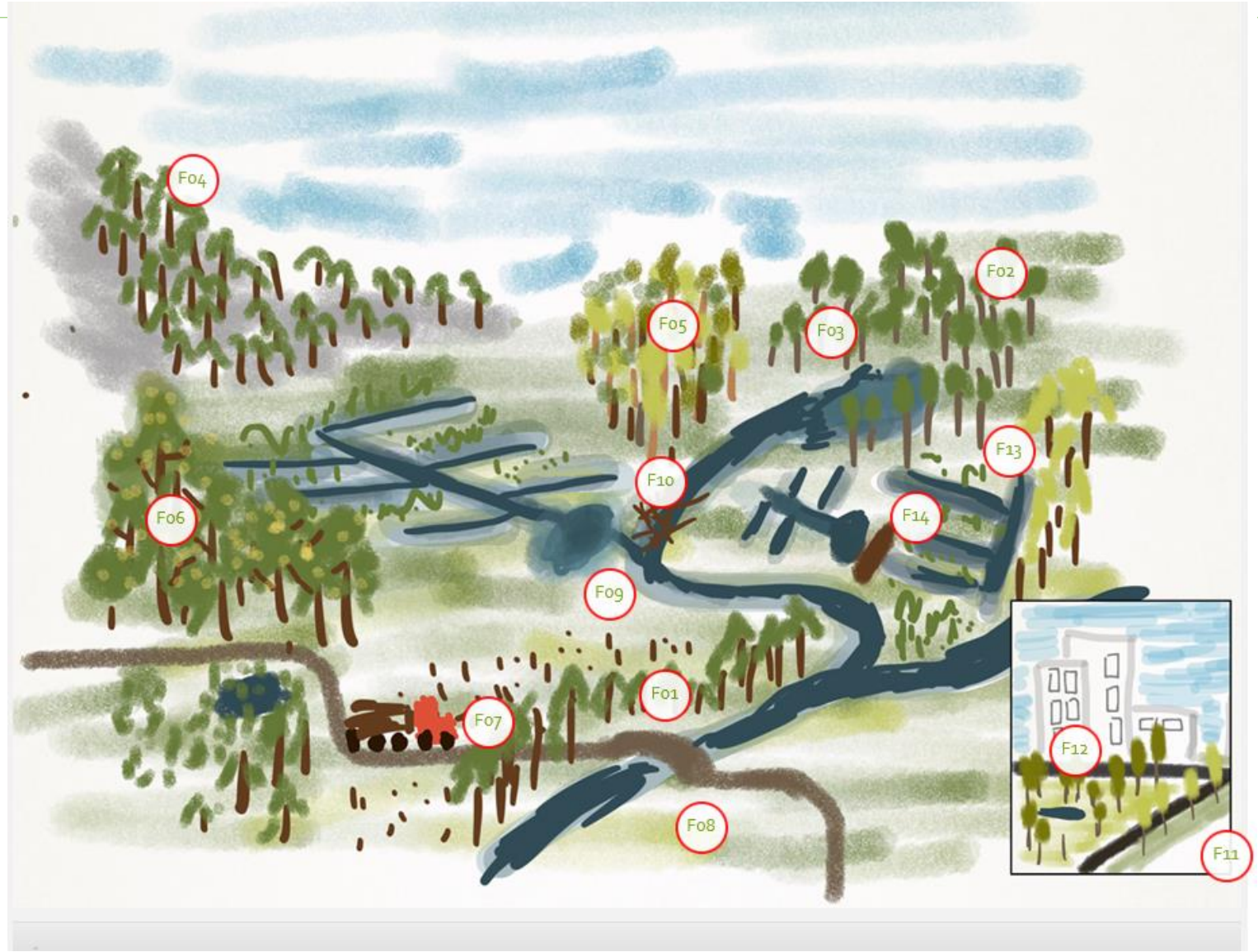
Review of Natural Water Retention Measures in Forests

Water and Environment Support
in the ENI Southern Neighbourhood region



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Review of Natural Water Retention Measures in Forest Lands

Water and Environment Support
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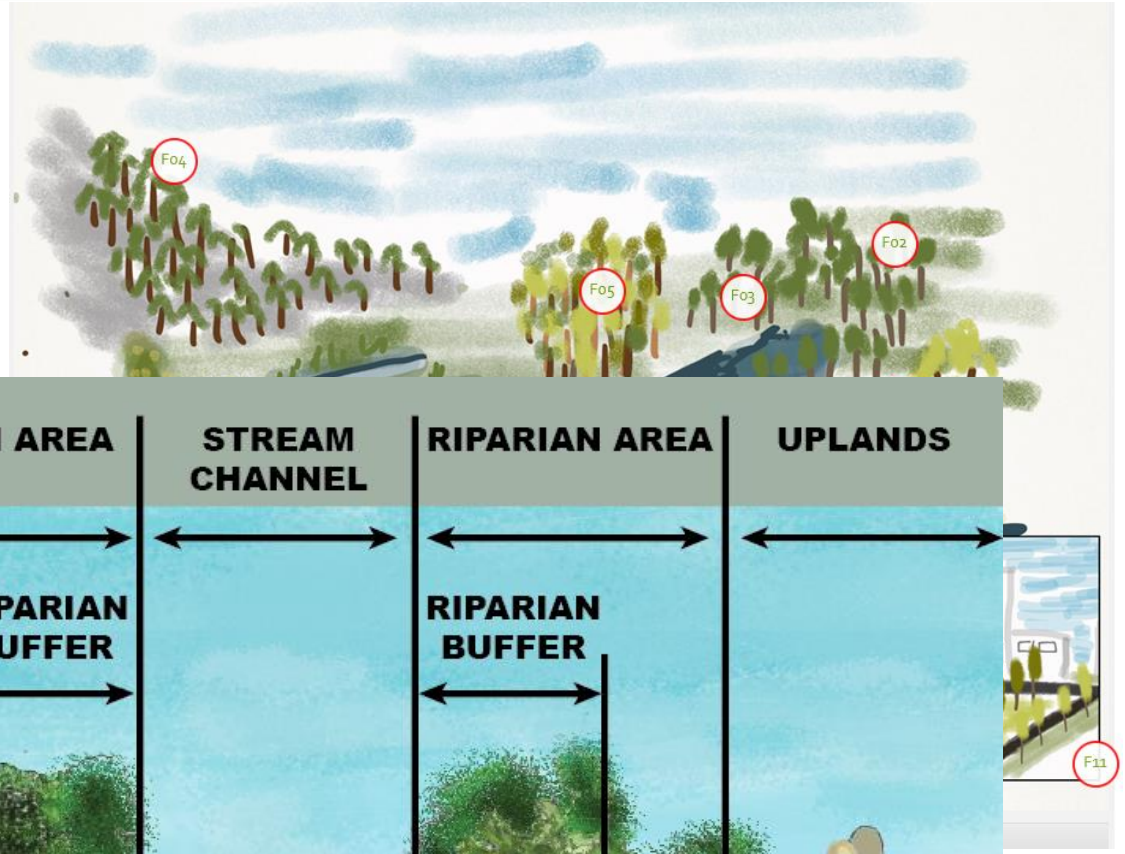

Review of Natural Water Retention Measures in Forest Lands

Water and Environment Support
in the ENI Southern Neighbourhood region

3. Maintenance of forest cover in headwater areas

Definition:
Headwaters are the source areas for rivers and streams, crucial for sustaining the structure, function, productivity and complexity of downstream ecosystems. They are vital to hydrologic cycling as they are one of the main areas where precipitation contributes to surface and groundwater. Headwaters are typically less intensively used than downstream areas. In many headwater areas, extensive agriculture, forests or other semi-natural land cover types predominate. Forests in headwater areas have a beneficial role for water quantity and quality. Creating or maintaining forest cover in headwater catchments is
New York, Istanbul and S
forests for drinking wate
infiltration capacity than
slowly releasing rainfall.
catchments can contribut
associated with landslides
dry areas may lead to redu

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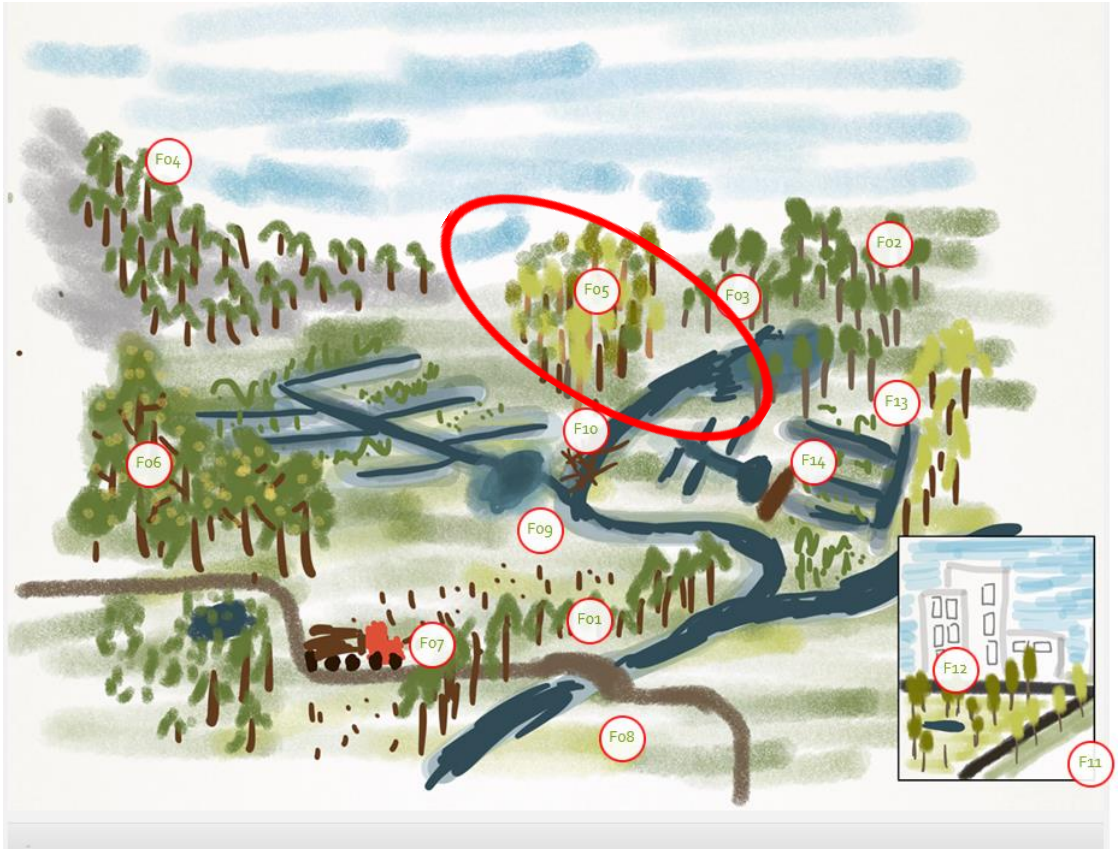
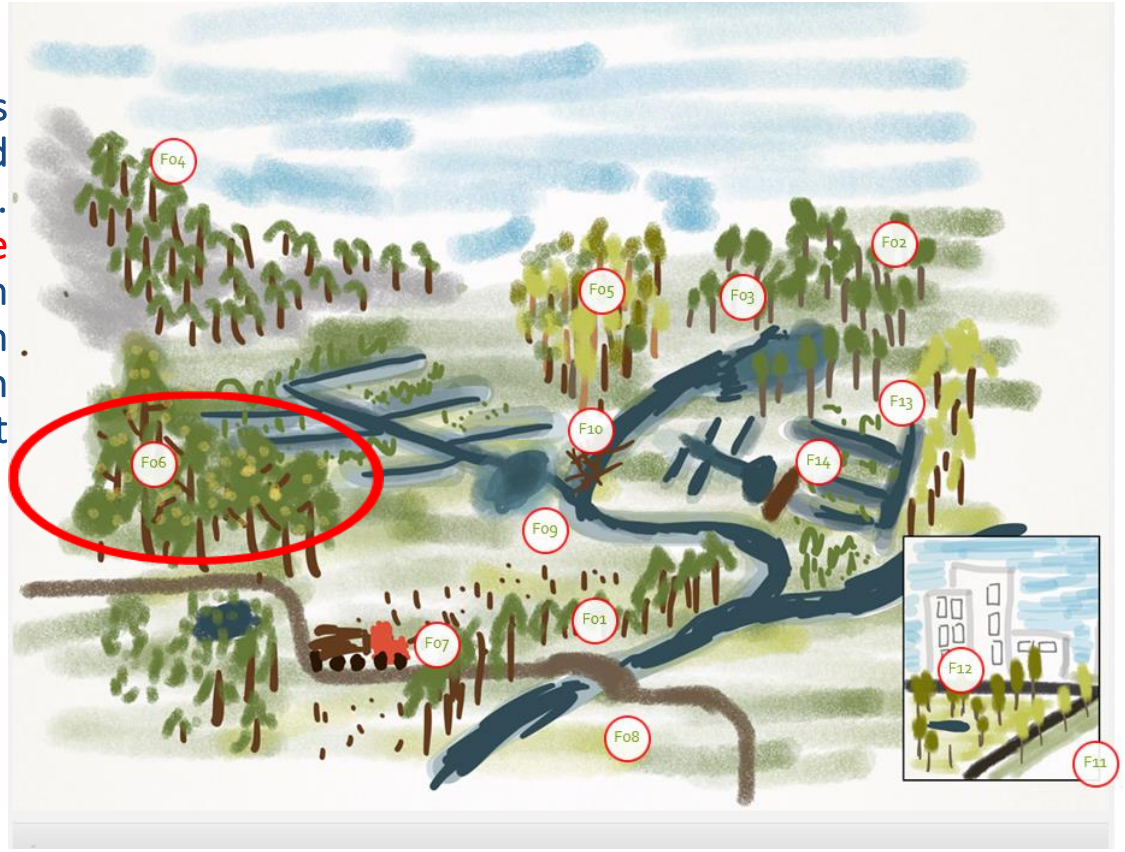
5. Land use conversion

Definition:
Land use conversion is a general term for large scale geographic change. Afforestation is one such land conversion in which trees are planted on previously non forested areas. Afforestation may occur deliberately or through the abandonment of marginal agricultural land. Depending on the tree species planted and the intensity of forest management, afforestation may have more or less environmental benefits. The NWRM related benefits include potentially enhanced evapotranspiration associated with growing forests and better water holding capacity associated with forest soils. The greatest environmental benefits are probably associated with planting of indigenous broadleaves and low intensity forestry. Plantation forestry with exotic species is likely to be less beneficial to the environment. It should be mentioned that afforestation in dry areas can cause or intensify water shortage. Even though afforestation may reduce available water supply at local scale, forest cover increases water supply regionally and globally, in particular through the intensification of the water cycle.



6. Continuous cover forestry

Definition:
Continuous cover forestry is a broad range of forest management practices which may have some beneficial hydrological effects. The main idea behind continuous cover forestry is a reduction in the number or size of clear-cuts. Some definitions of continuous cover forestry state that no clear-cuts shall be larger than 0.25 ha. Continuous cover forestry ensures that there is an uninterrupted tree canopy and that the soil surface in never exposed. An uninterrupted tree canopy will have higher interception than a site with discontinuous tree cover. Ensuring that soils are never exposed will limit sediment production.



Review of Natural Water Retention Measures in Forest Lands

Water and Environment Support
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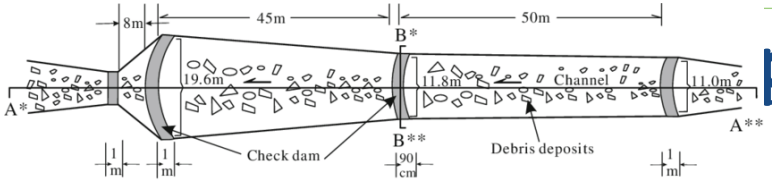
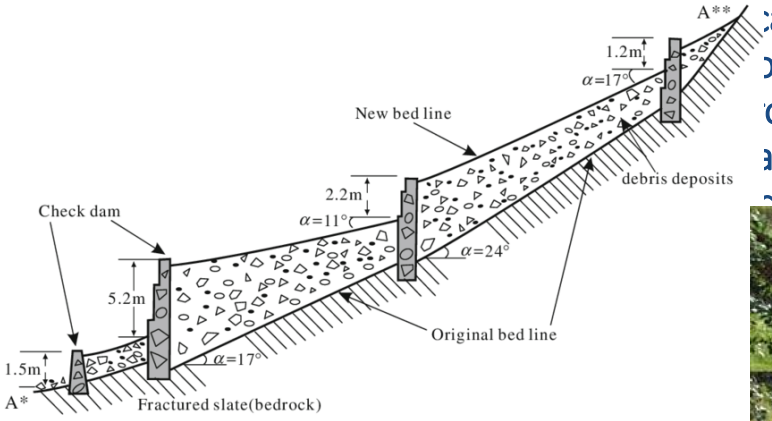
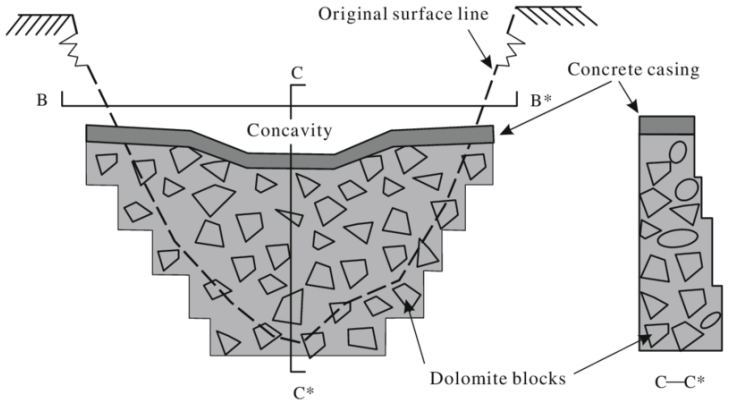
ponds (check dams)



a Plane view of the four check-dams in sequence



b Longitudinal profile of the four check-dams in sequence



c Cross and longitudinal profiles of a check-dam

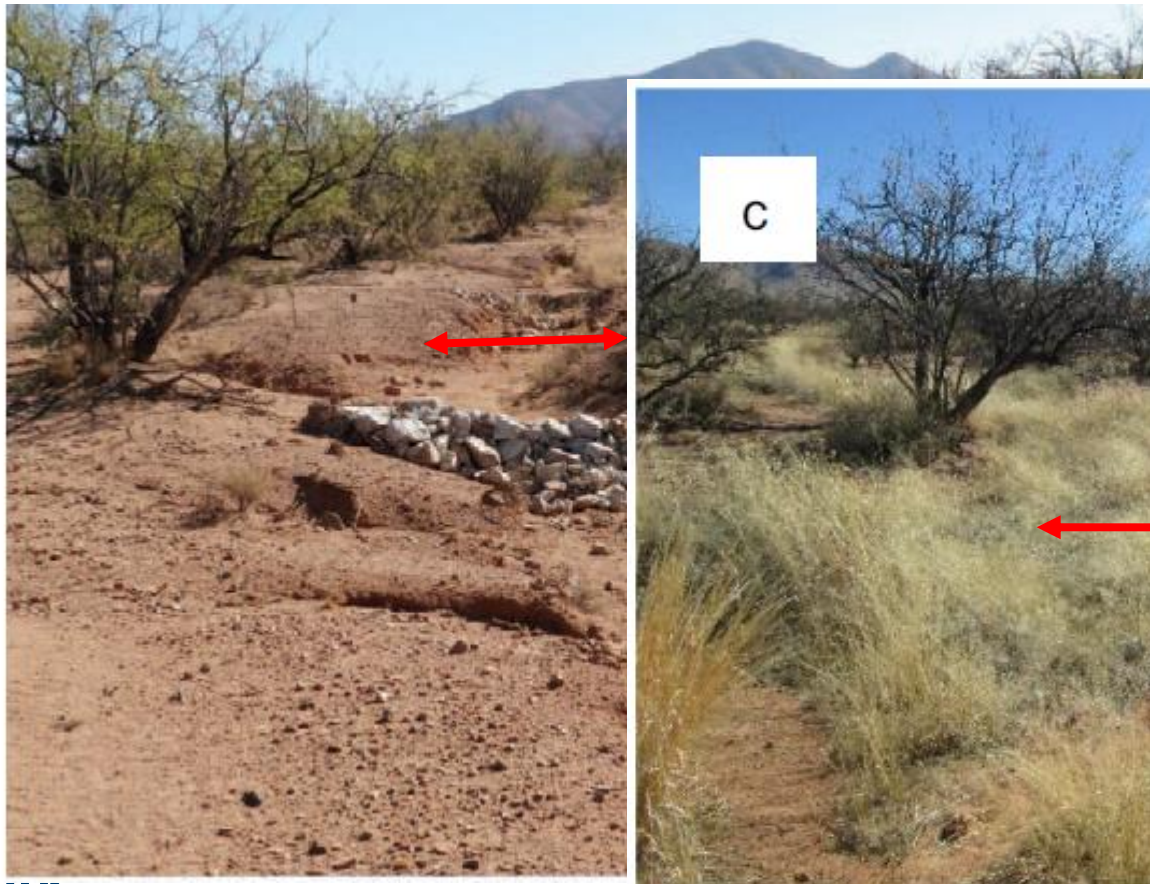
onds placed in networks of forest
ause the deposition of suspended
st useful for managing the effects
oad work and final feeling. While
apture ponds may be a useful
uality in and around construction

Review of Natural Water Retention Measures in Forest Lands

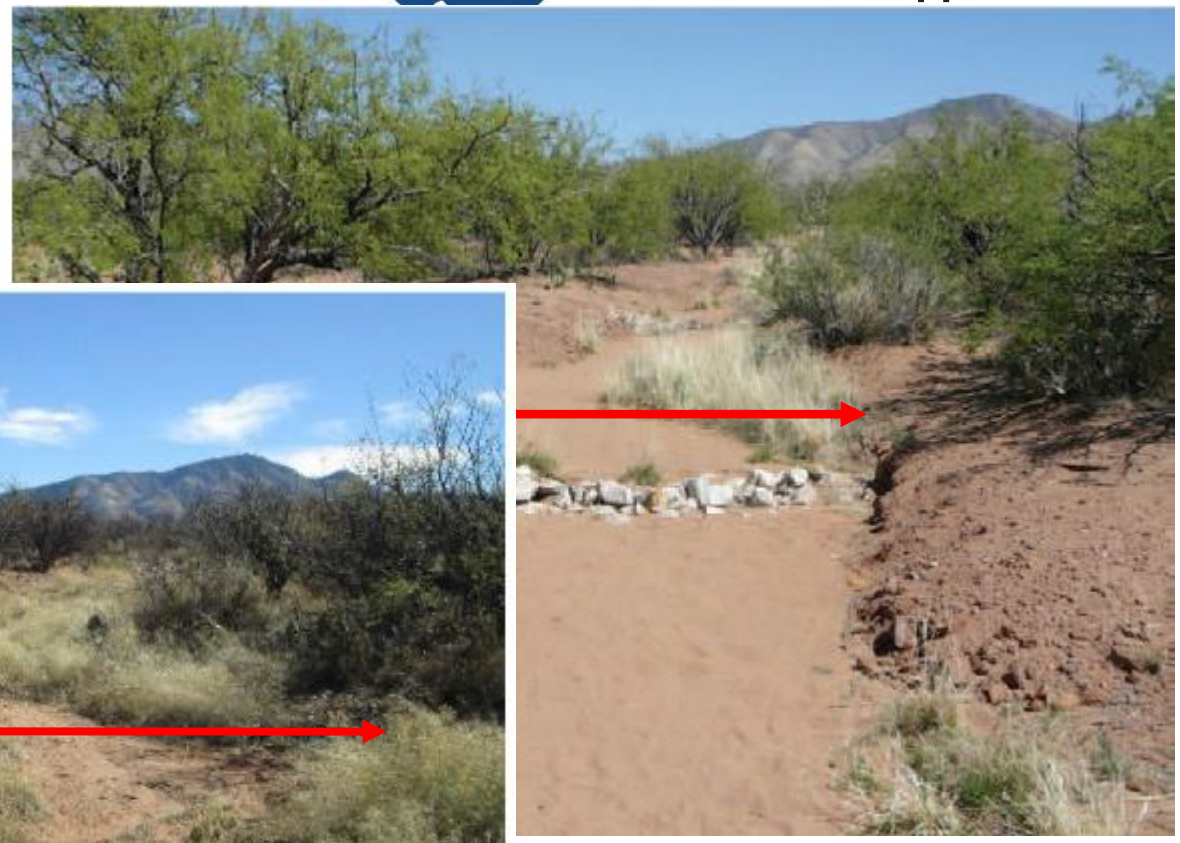
Water and Environment Support

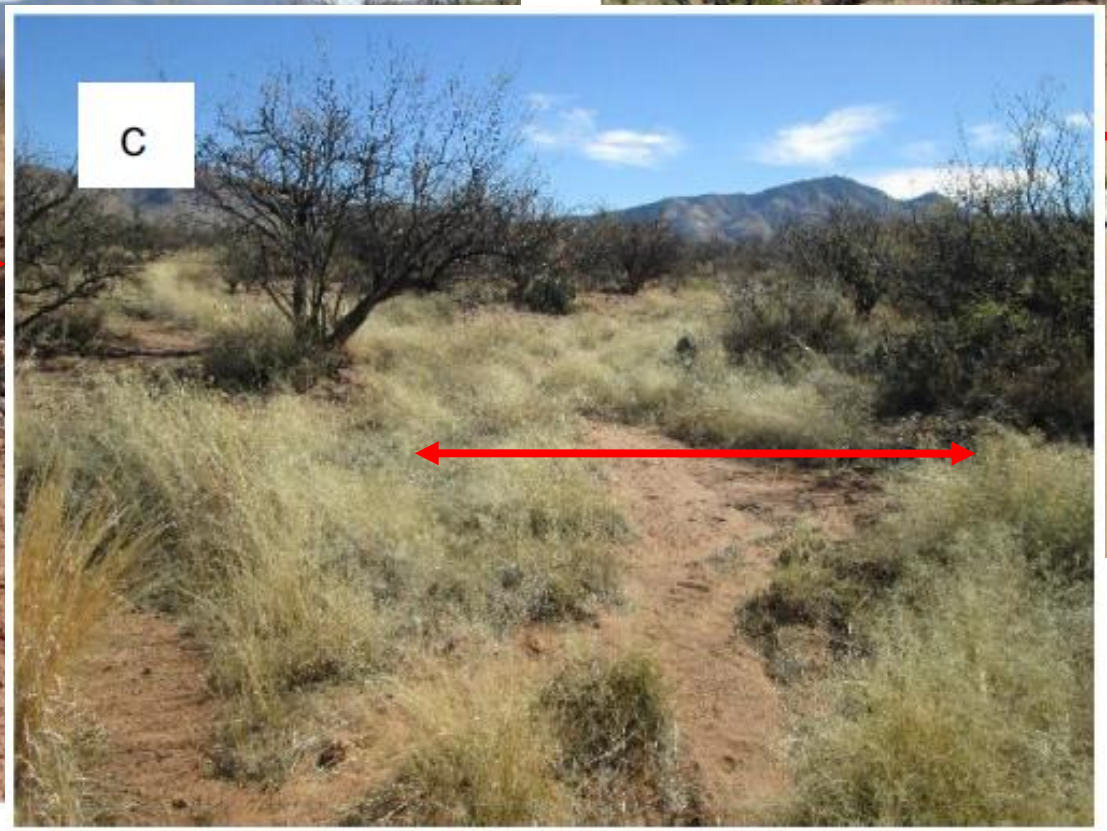
9. Sediment capture ponds (check da

(a)



(b)





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9. Sediment captu

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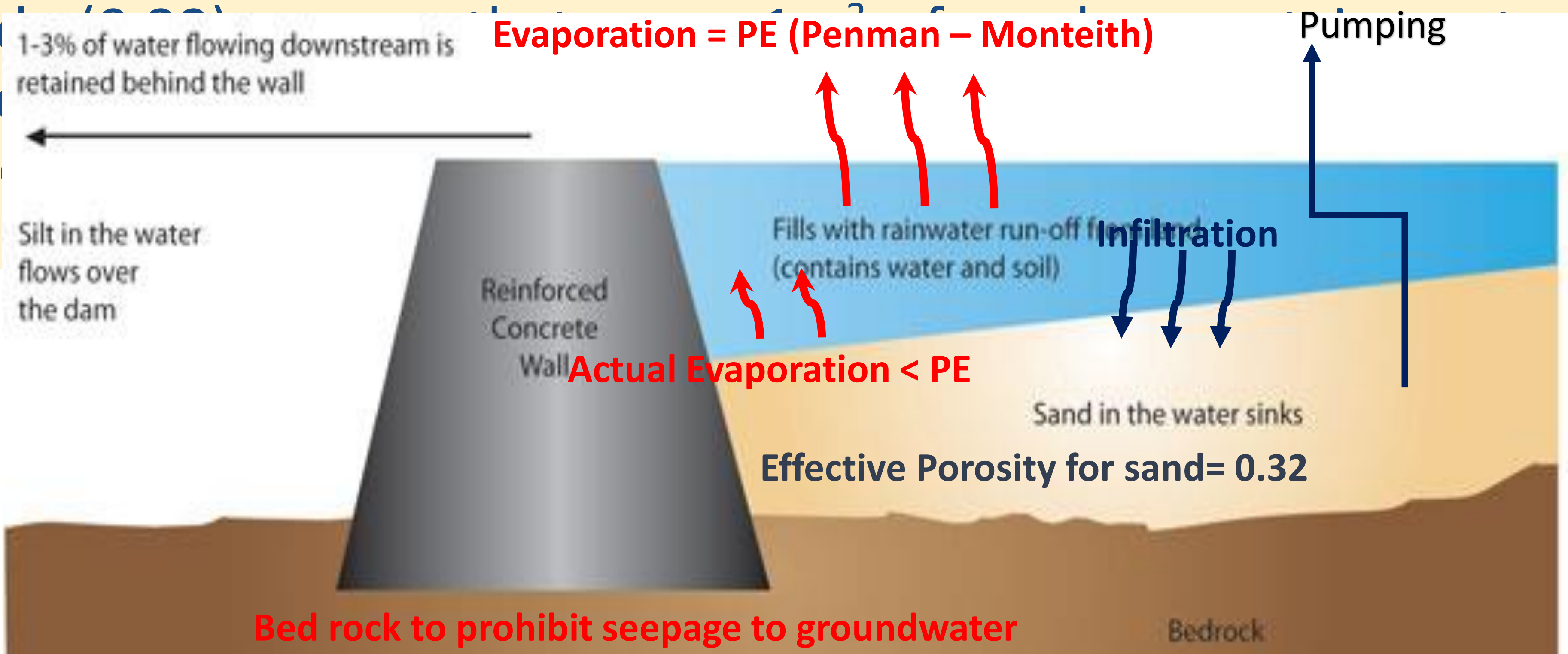
Sand Dams

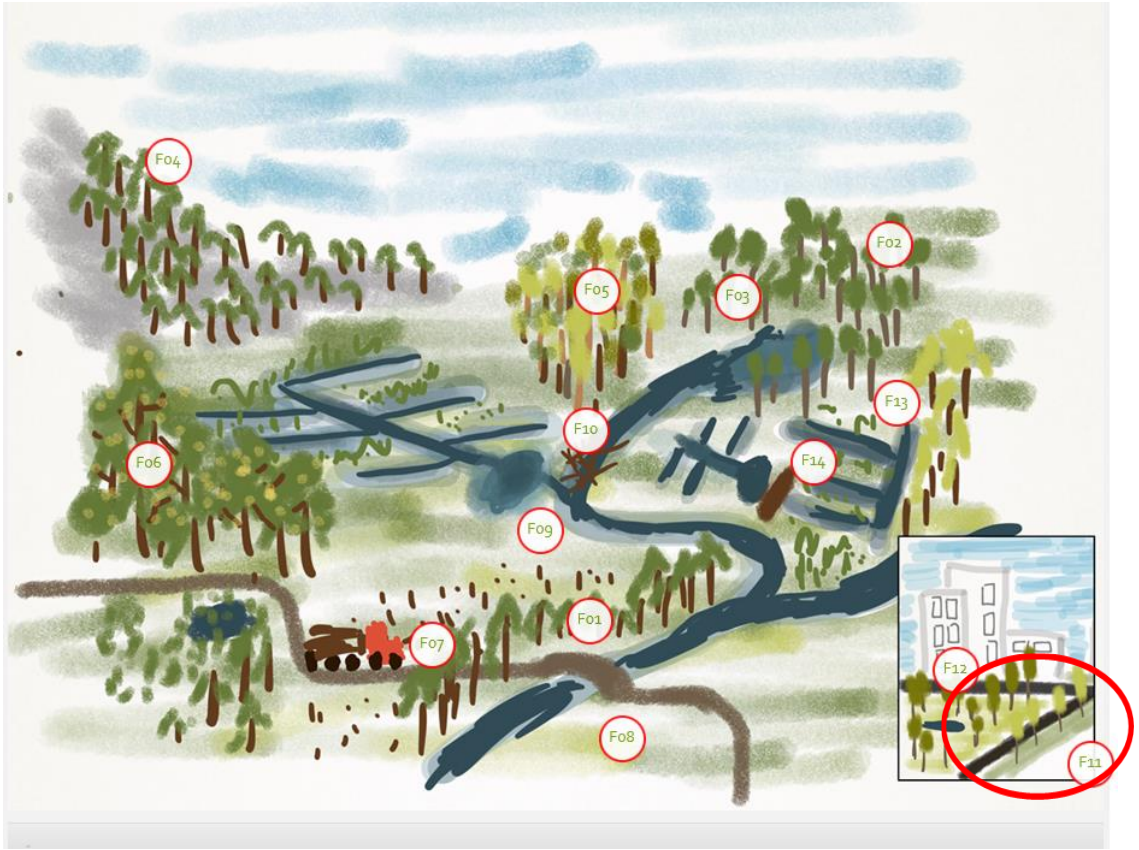
- **Sand Dams** are exploiting the effective porosity of the underlying sand to provide storage and to minimize evaporation losses. In fact, below 60 cm depth, evaporation from sand is negligible. For effective porosity for medium sized san … 320L of water. Th … e lost to evaporati…



Sand dams: a sustainable solution for water scarce regions - International Water Power

11. Urban Forest Parks

Definition:
Urban forest parks can deliver a broad range of hydrology-related and other ecosystem services. Forests in urban areas have great amenity value, can improve air quality, moderate local microclimates, improve urban biodiversity and contribute to climate change mitigation as well as having ancillary hydrological benefits. Forest soils often have greater infiltration capacity than other urban land cover and can be an important location for aquifer recharge.



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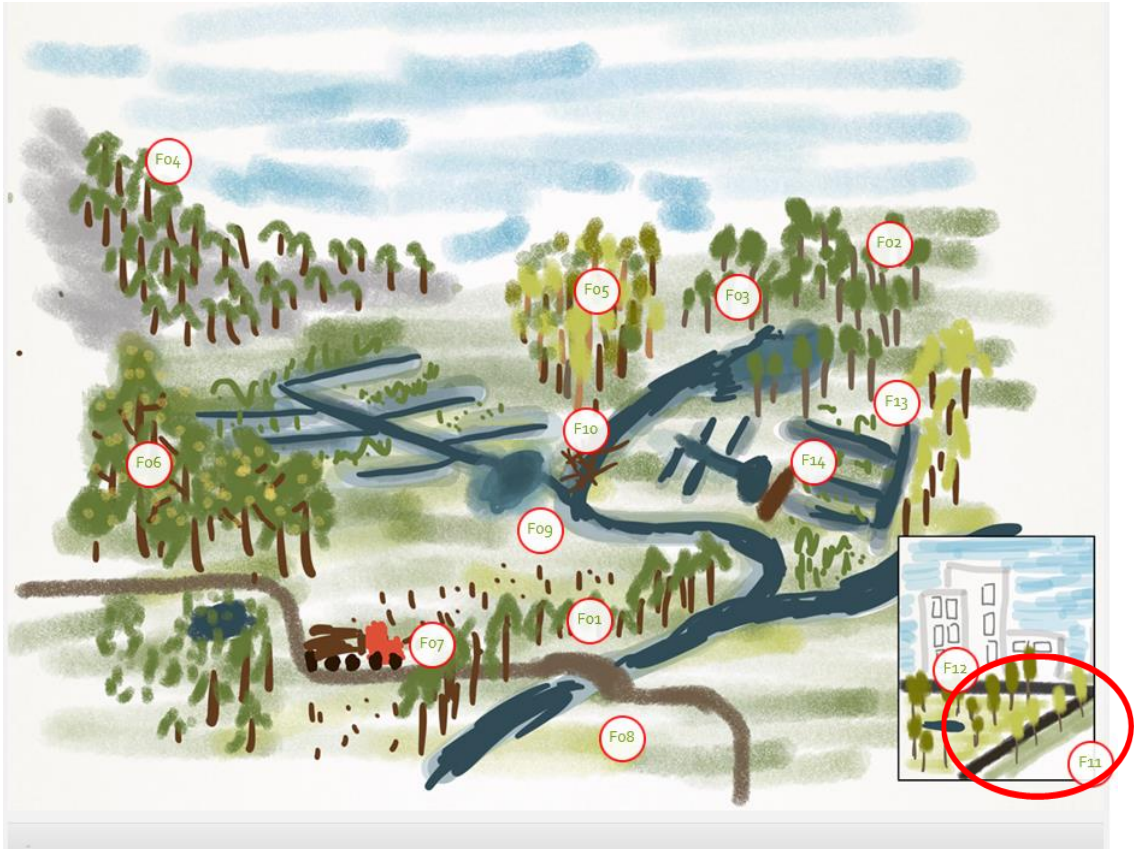
12. Trees in Urban Areas

Definition:
Trees in urban areas can have multiple benefits related to aesthetics, microclimate regulation and urban hydrology. Trees in urban areas can also be important biodiversity refuges and can contribute to reducing particulate air pollution. Trees intercept precipitation, reducing the amount of rainfall which must be processed by sewers and other water transporting infrastructure. The area around urban trees may also have greater infiltration capacity than the impermeable surfaces often found in urban areas. Trees also transpire, which dries the soil and gives greater capacity for rainfall storage.



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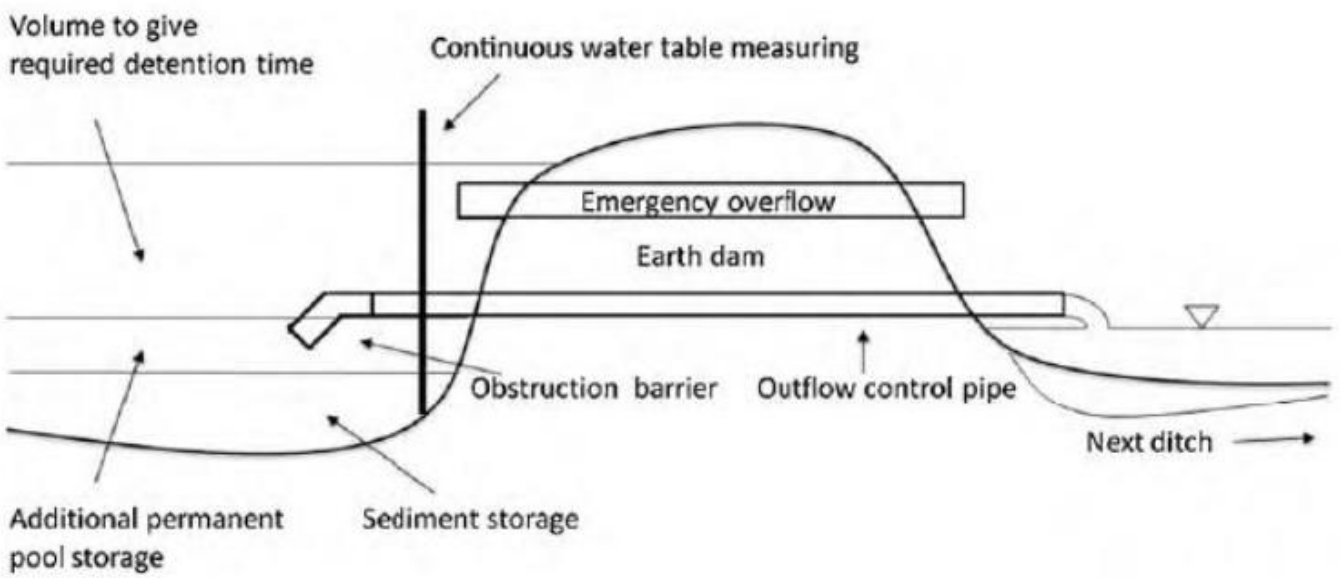
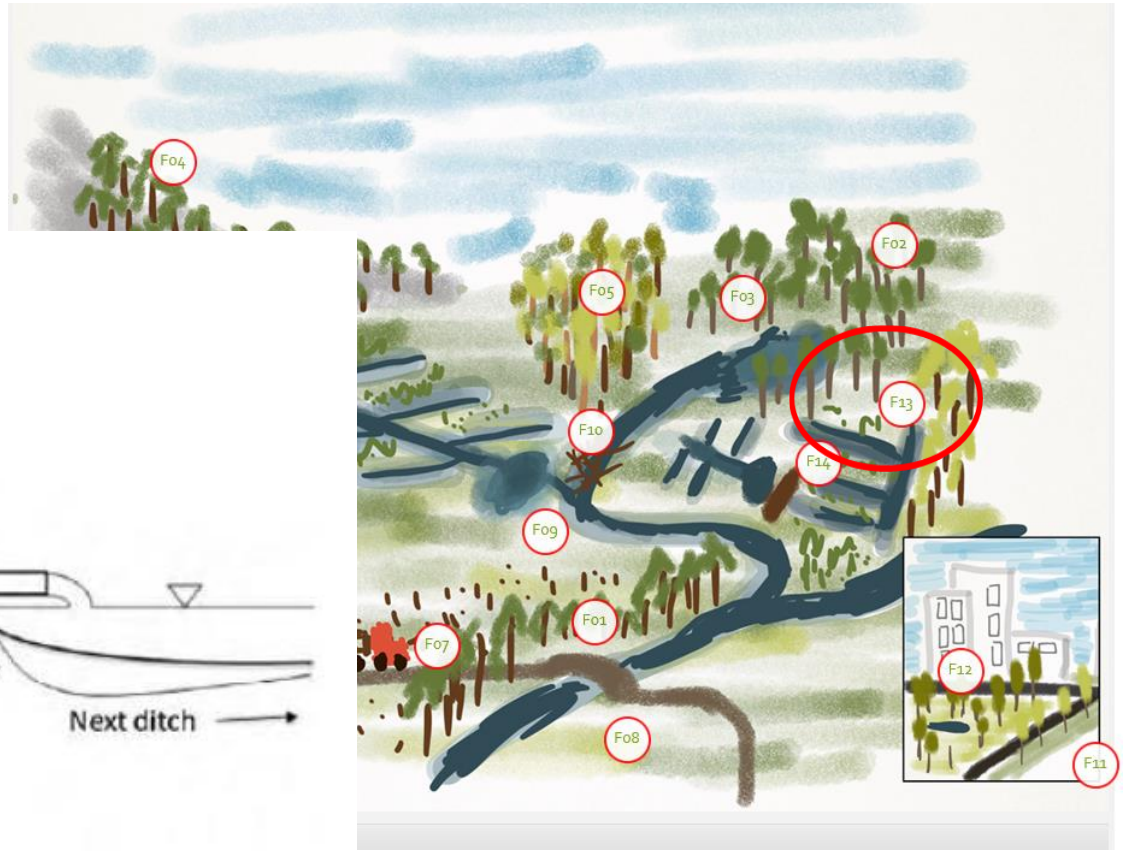
Review of Natural Water Retention Measures in Forest Lands

Water and Environment Support
in the ENI Southern Neighbourhood region

13. Peak flow Control Structures

Definition:
Peak flow control structures are designed to reduce flow velocities in networks of forest ditches. Peak flow control structures are engineered ponds designed to limit the rate at which water flows out of a ditch network. Because the structures slow water flow, they will contribute to sediment control and
will have a li
detention p
accumulated





Schematic of peak flow control structure from Martilla et al. (2010)

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Review of Natural Water Retention Measures in Agriculture

Water and Environment Support
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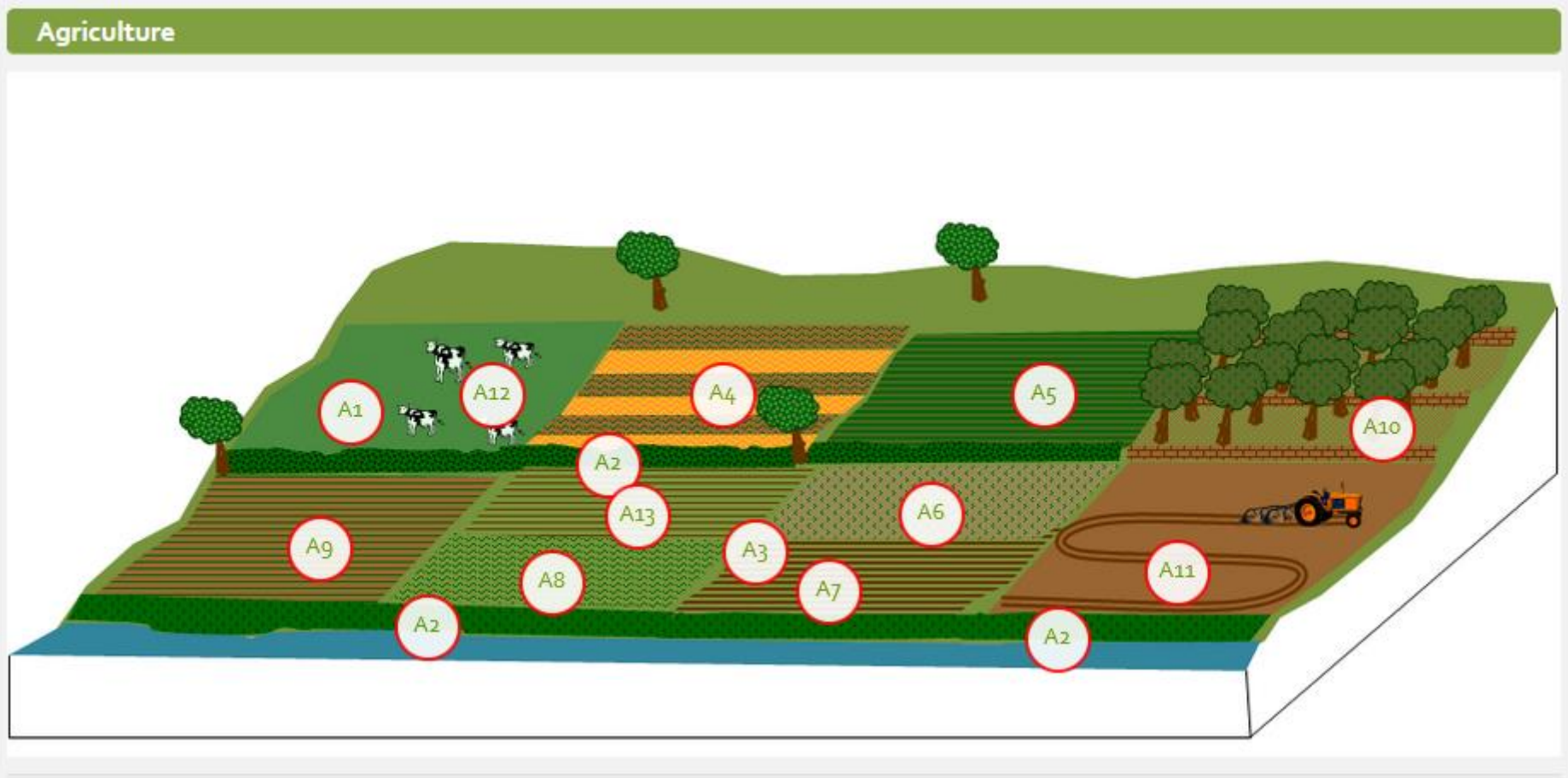

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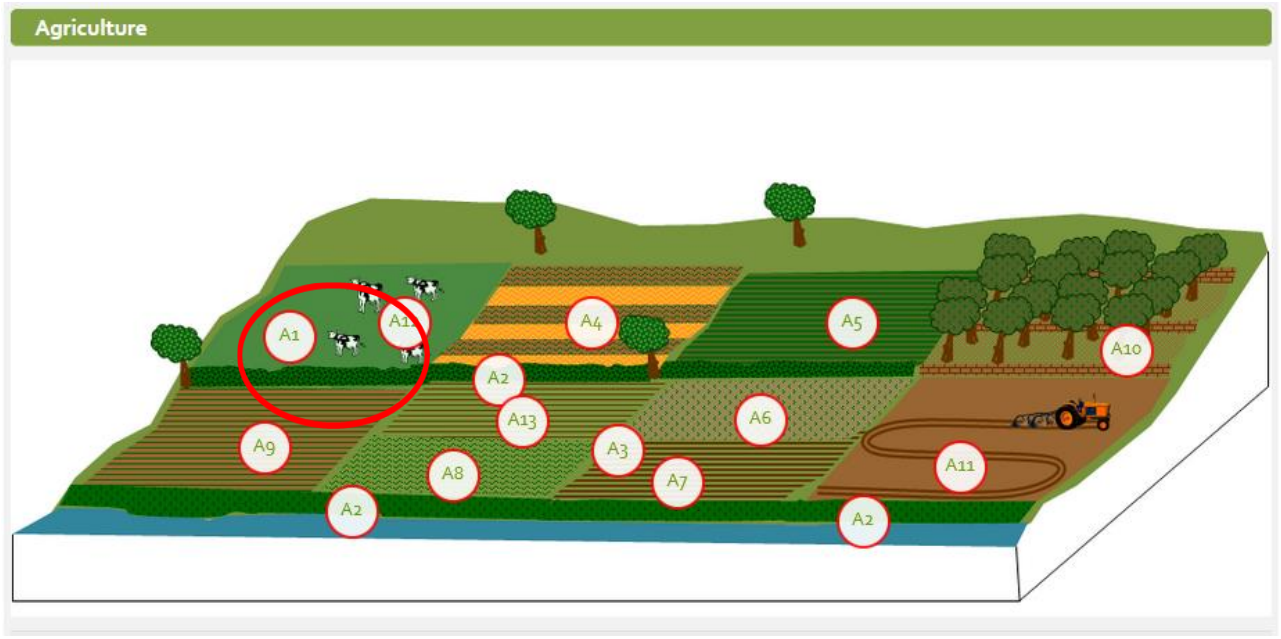
Review of Natural Water Retention Measures in Agriculture

Water and Environment Support
in the ENI Southern Neighbourhood region

1. Meadows and pastures

Definition:
Meadows are areas or fields whose main vegetation is grass, or other non-woody plants, used for mowing and haying. Pastures are grassed or wooded areas, moorland or heathland, generally used for grazing. Due to their rooted soils and their permanent cover, meadows and pastures provide good conditions for the uptake and storage of water during temporary floods. They also protect water quality by trapping sediments and assimilating nutrients.

The measure offers the potential for temporary flood storage, increased water retention in the landscape and runoff attenuation. Soil cover is maintained at all times with rooted vegetation, this reduces the surface flow of water and allows greater infiltration to the soil. Rates of soil erosion are considerably lower than arable land with potential benefits for water quality.



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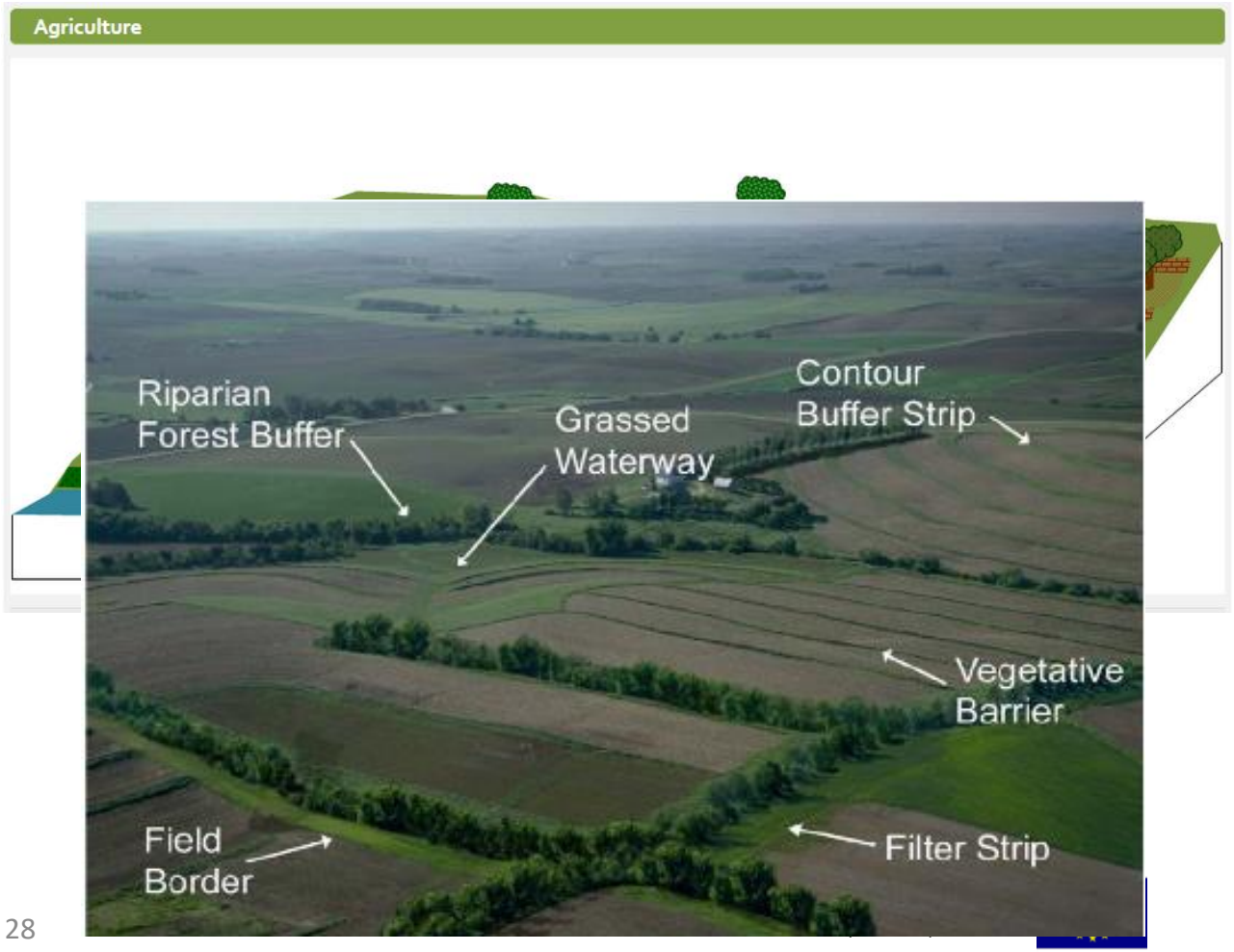
2. Buffer strips and hedges

Definition:

Buffer strips are areas of natural vegetation cover (grass, bushes or trees) at the margin of fields, arable land, transport infrastructures and water courses. They can have several different configurations of vegetation found on them varying from simply grass to combinations of grass, trees, and shrubs. Due to their permanent vegetation, buffer strips offer good conditions for effective water infiltration and slowing surface flow; they therefore promote the natural retention of water. They can also significantly reduce the amount of suspended solids, nitrates and phosphates originating from agricultural run-off. Buffer strips can be sited in riparian zones, or away from water bodies as field margins, headlands or within fields (e.g. beetle banks). Hedges across long, steep slopes may reduce soil erosion as they intercept and slow surface run-off water before it builds into damaging flow, particularly where there is a margin or buffer strip alongside.

Borin et al (2010) report on a study in Padova, Italy, in which a 6m wider buffer strip of trees and shrubs reduced runoff by 78% compared to no buffer strip, this was equivalent to a runoff depth of 231mm over 5 years.



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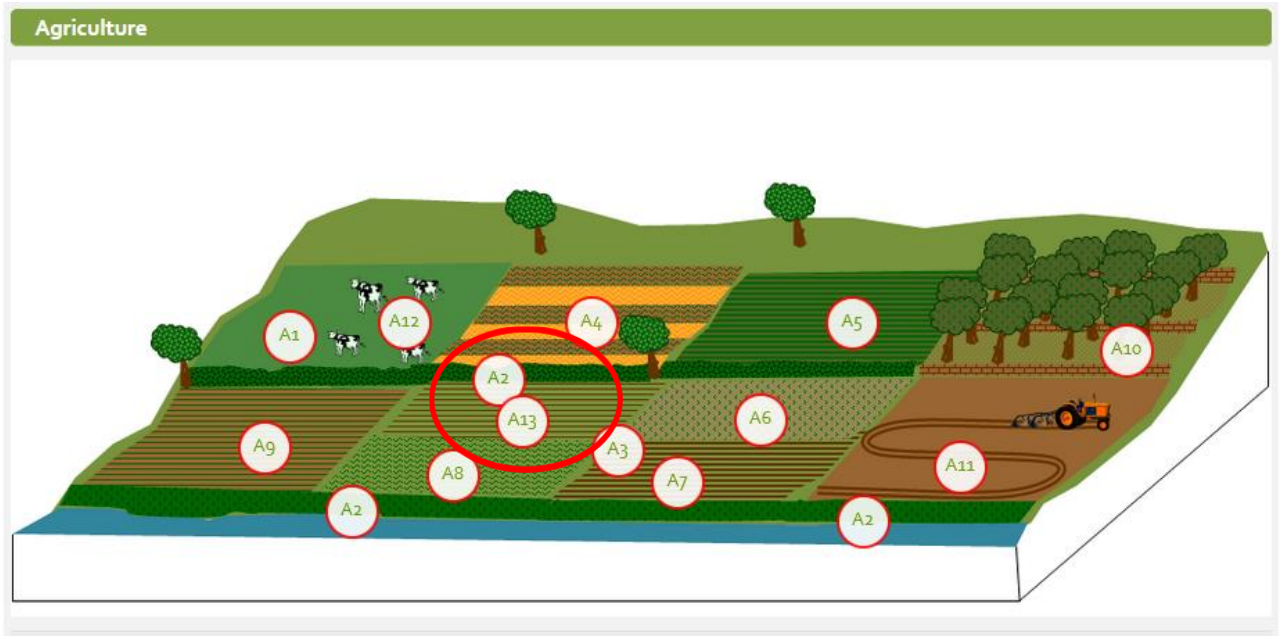
3. Crop Rotation

Definition:

Crop rotation is the practice of growing a series of dissimilar/different types of crops in the same area in sequential seasons. Judiciously applied (i.e. selecting a suitable crop) crop rotation can improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. In turn this can reduce erosion and increase infiltration capacity, thereby reducing downstream flood risk. It gives various benefits to the soil. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. Crop rotation also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped.

Carefully designed crop rotations can reduce the period of time that soil is left bare or fallow. This may lead to increased infiltration and runoff reduction.



Review of Natural Water Retention Measures in Agriculture

Water and Environment Support
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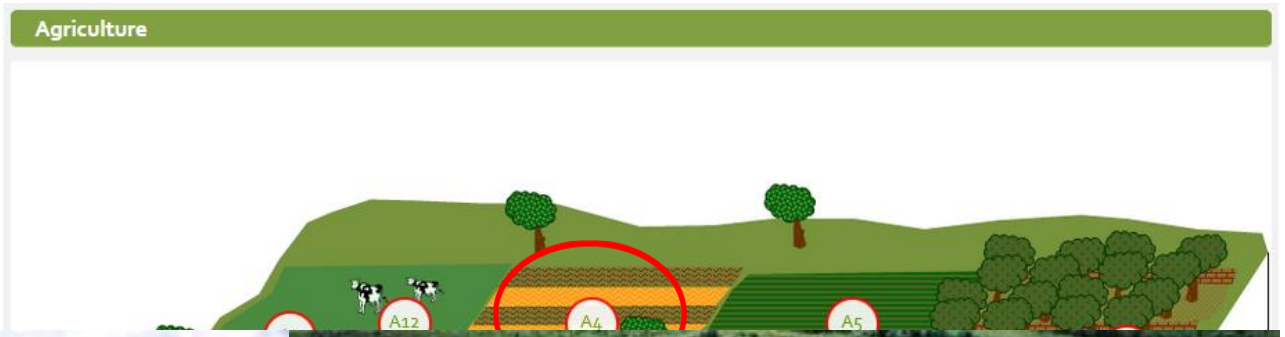
4. Strip cropping along contours

Definition:
Strip cropping is a method of farming used when a slope is too steep or too long, or otherwise, when one does not have an alternative method of preventing soil erosion. It alternates strips of closely sown crops such as hay, wheat, or other small grains with strips of row crops, such as corn, soybeans, cotton, or sugar beets. Strip cropping helps to stop
for water, helping to preserve
of plants will absorb mine
effectively than others. Whe
lacks the minerals needed to
away. When strips of soil ar
from moving through them,
normally would. Because of t
There is no available informa
Europe.



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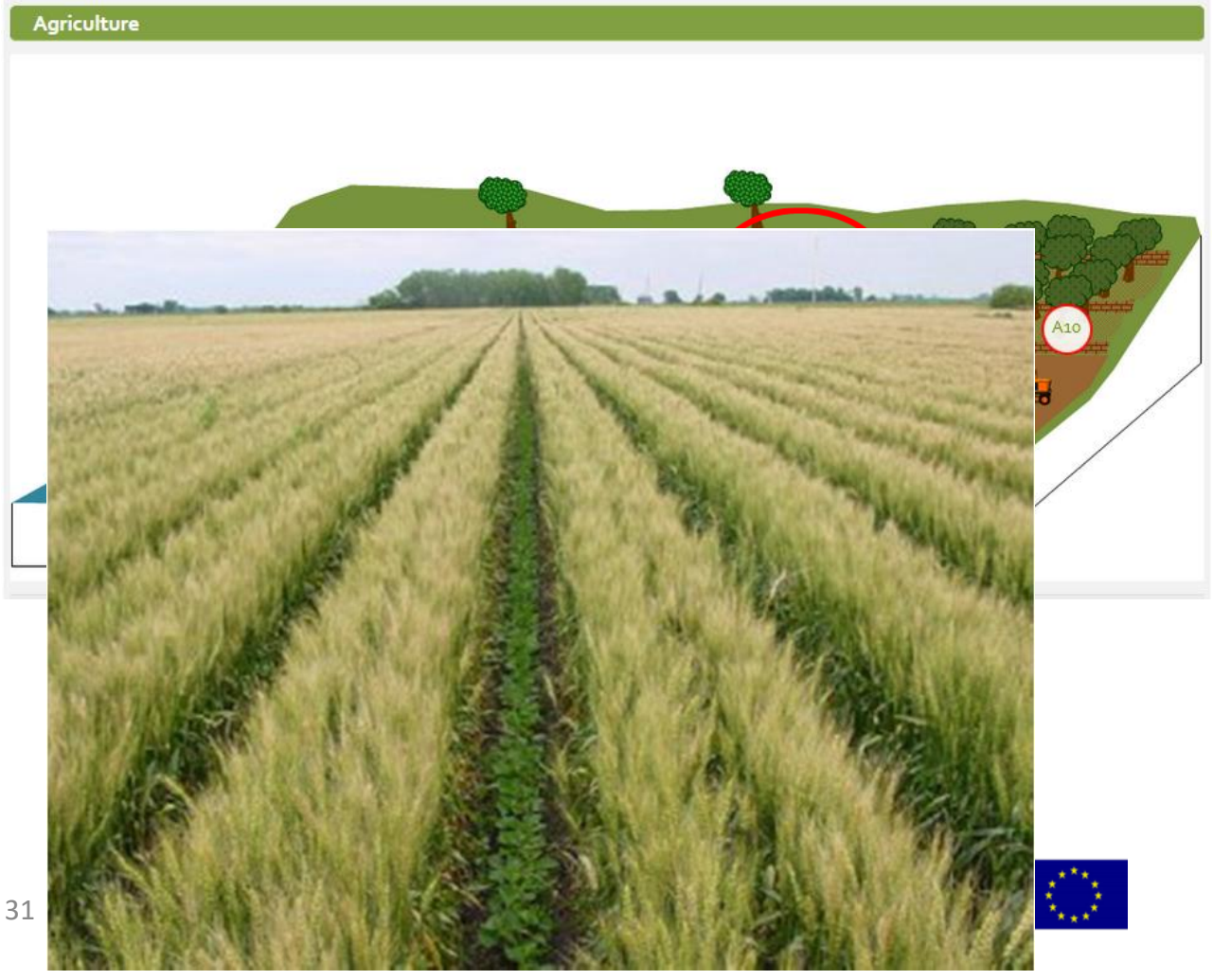
Review of Natural Water Retention Measures in Agriculture

Water and Environment Support
in the ENI Southern Neighbourhood region

5. Intercropping

Definition:
Intercropping is the practice of growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop or planting a tall crop with a shorter crop that requires partial shade. Numerous types of intercropping, all of which vary the temporal and spatial mixture to some degree, have been identified: mixed intercropping, row cropping, relay cropping, etc.

By implementing cover crops where the soil is otherwise left bare (under other crops, between rows...) intercropping contributes to reduce runoff and increase water infiltration (Battany, 2000). For instance, experiments in the Sahel region showed that runoff decreased by 20-30% with sorghum-cowpea intercropping compared to sorghum sole crop and by 45-55% compared to cowpea monoculture (Zougmore, 2000).



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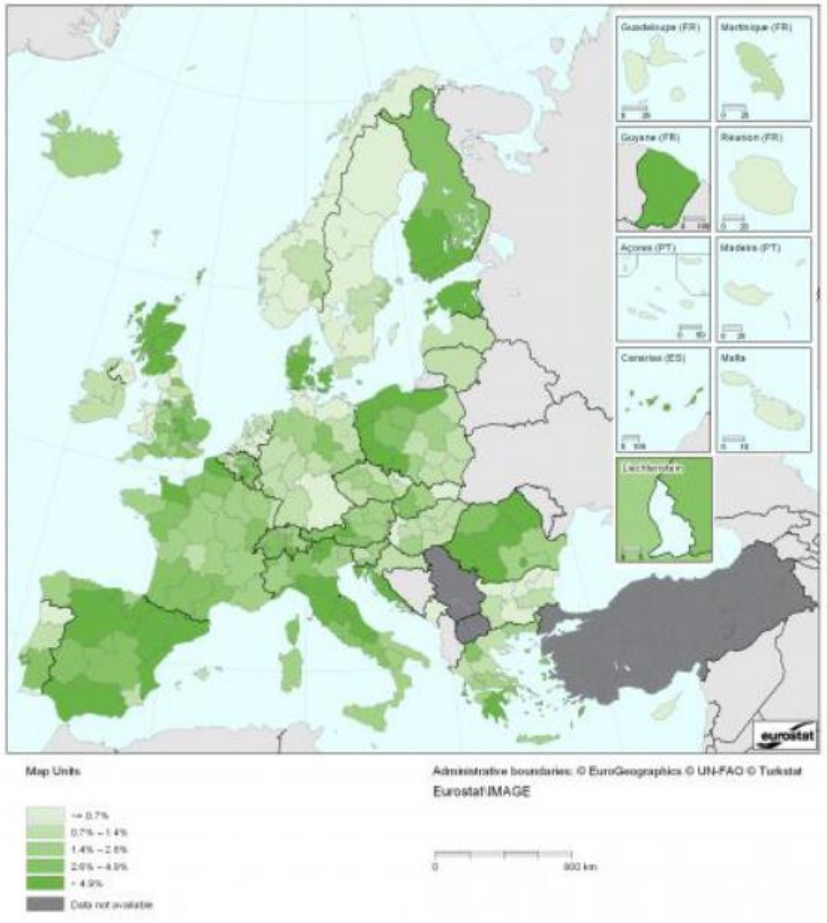
6. No-Till Agriculture

Definition:
Tillage is a mechanical modification of the soil. Intensive tillage can disturb the soil structur
retention capacity, re
compaction and trans
called zero tillage or d
pasture from year to
tillage. No-till is an a
amount of water that i
matter retention and
agricultural regions it ca
benefit of no-tillage i
making soils more resili

By implementing cover
(under other crops, bet
reduce runoff and incr
instance, experiments
decreased by 20-30
compared to sorghum
cowpea monoculture (Z



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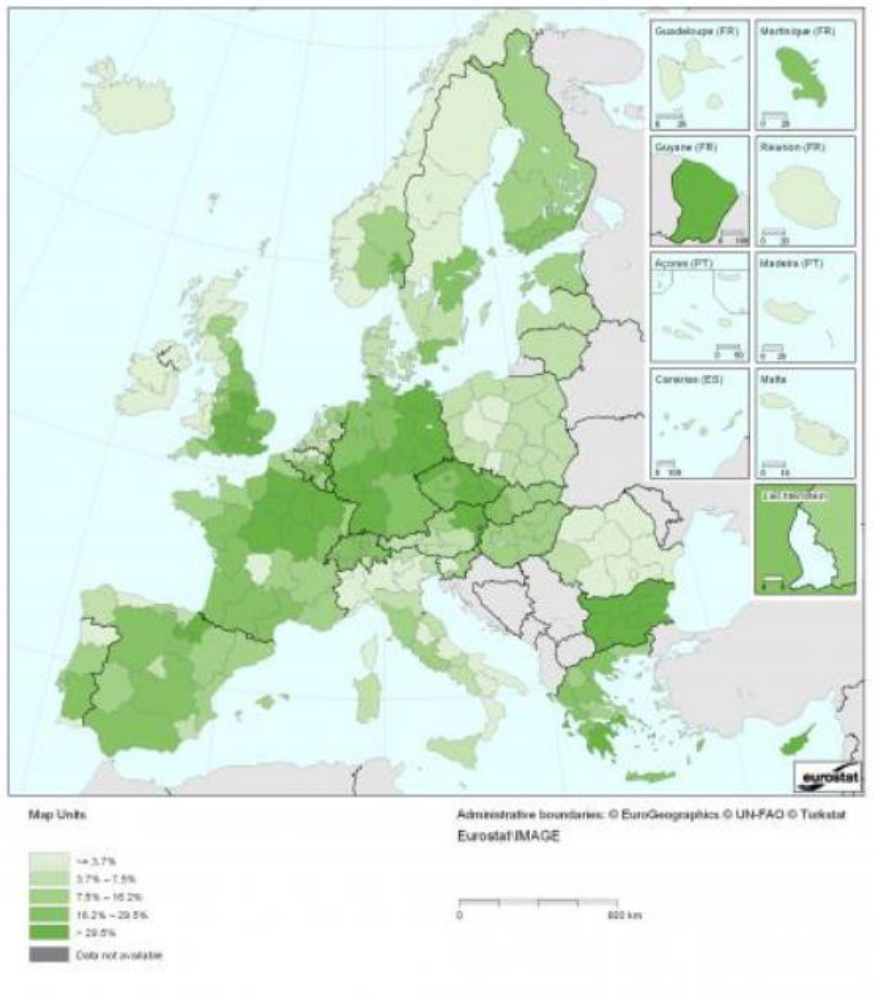
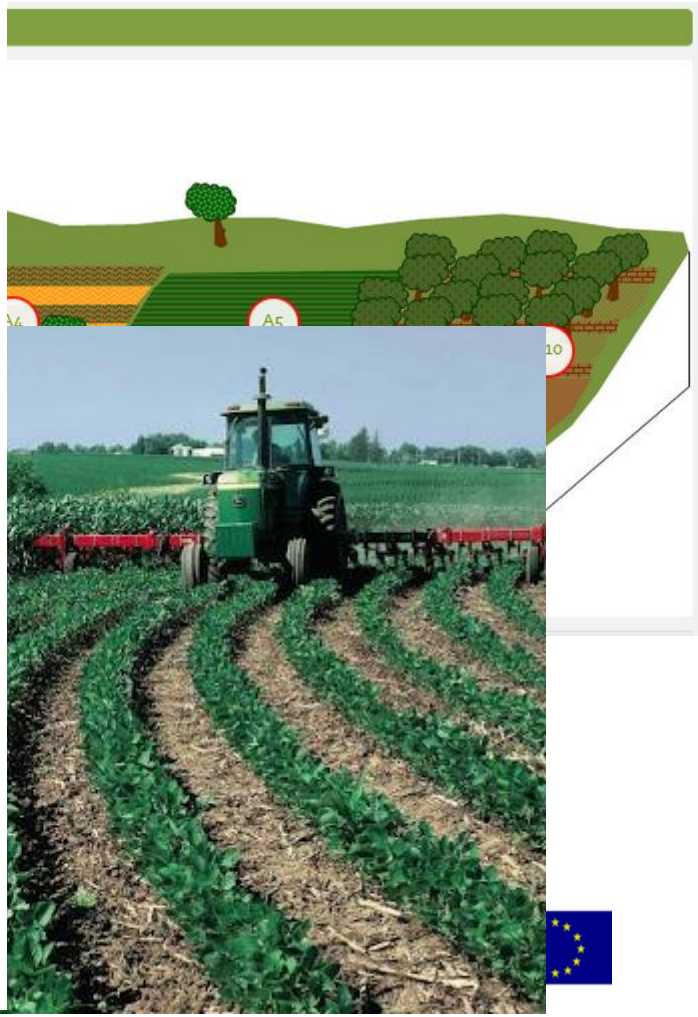
7. Low-Till Agriculture

Definition:
Low till agriculture, also known as conserv
applies to arable land. It consists of a combin
which leaves at least 30% of crop residue on
the critical soil erosion period and some surfa
slows water movement, which reduces the a
and potentially leads to greater infiltration.





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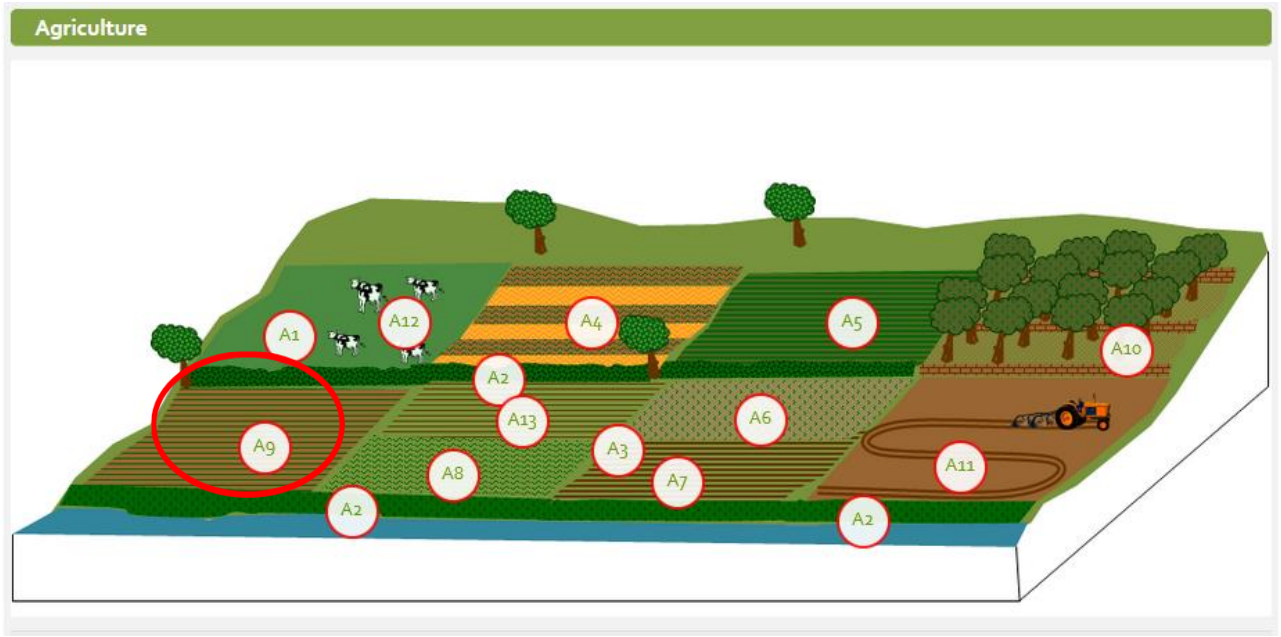
8. Green cover

Definition:
Green cover (including cover crops or catch crops) refers to crops planted in late summer or autumn, usually on arable land, to protect the soil, which would otherwise lie bare during the winter, against wind and water erosion. Green cover crops also improve the structure of the soil, diversify the cropping system, and mitigate the loss of soluble nutrients.

9. Early Sowing

Definition:
Early sowing refers to sowing up to six weeks before the normal sowing season. This allows for an earlier and quicker establishment of winter crops that can provide cover over winter and of a root network that leads to soil protection. The period in which the soil lies bare is shorter and, therefore, erosion and run-off are less significant and water infiltration is improved. Early sowing can also help to mitigate summer drought impacts on spring sown crops, in particular the extreme evapotranspiration rates of Mediterranean regions. However, early sown plants are frost sensitive; therefore farmers run the risk of losing the crops because of the low temperatures, not applicable in Israel. For both spring and winter crops, early sowing involves a number of trade-offs. For example, different pest and disease risks arise that might require changes in management.



Review of Natural Water Retention Measures in Agriculture

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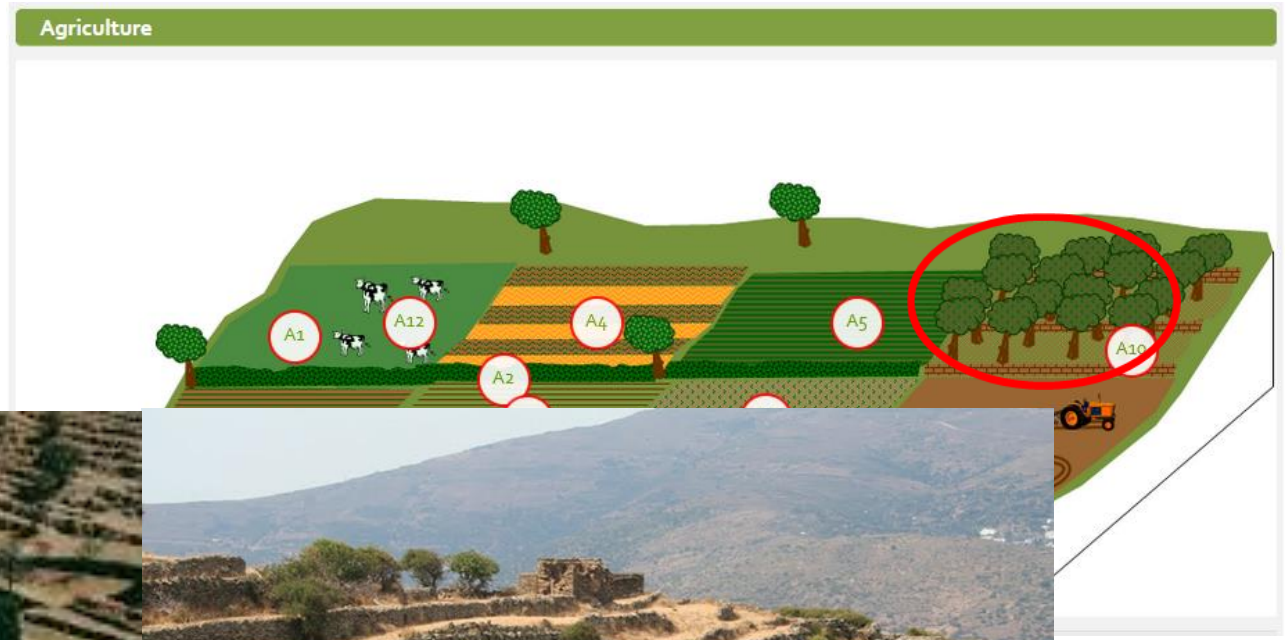
10. Traditional Terracing

Definition:
Traditional terraces consist of nearly level platforms built along contour lines of slopes, mostly sustained by stone walls, used for farming on hilly terrain. By reducing the effective slope of land, terracing can reduce erosion and surface run-off by slowing rainwater to a non-erosive velocity. This also increases the degree if infiltration and improves soil moisture. However, abandonment of traditional terracing can result in high levels of erosion and run-off due to the lack of maintenance of stone walls. Abandonment can also change the nature beneficial, for example can present a risk of wil This measure focuses involves less disturbanc as significant levelling measure is highly labo focus of the measure rather than expansion.



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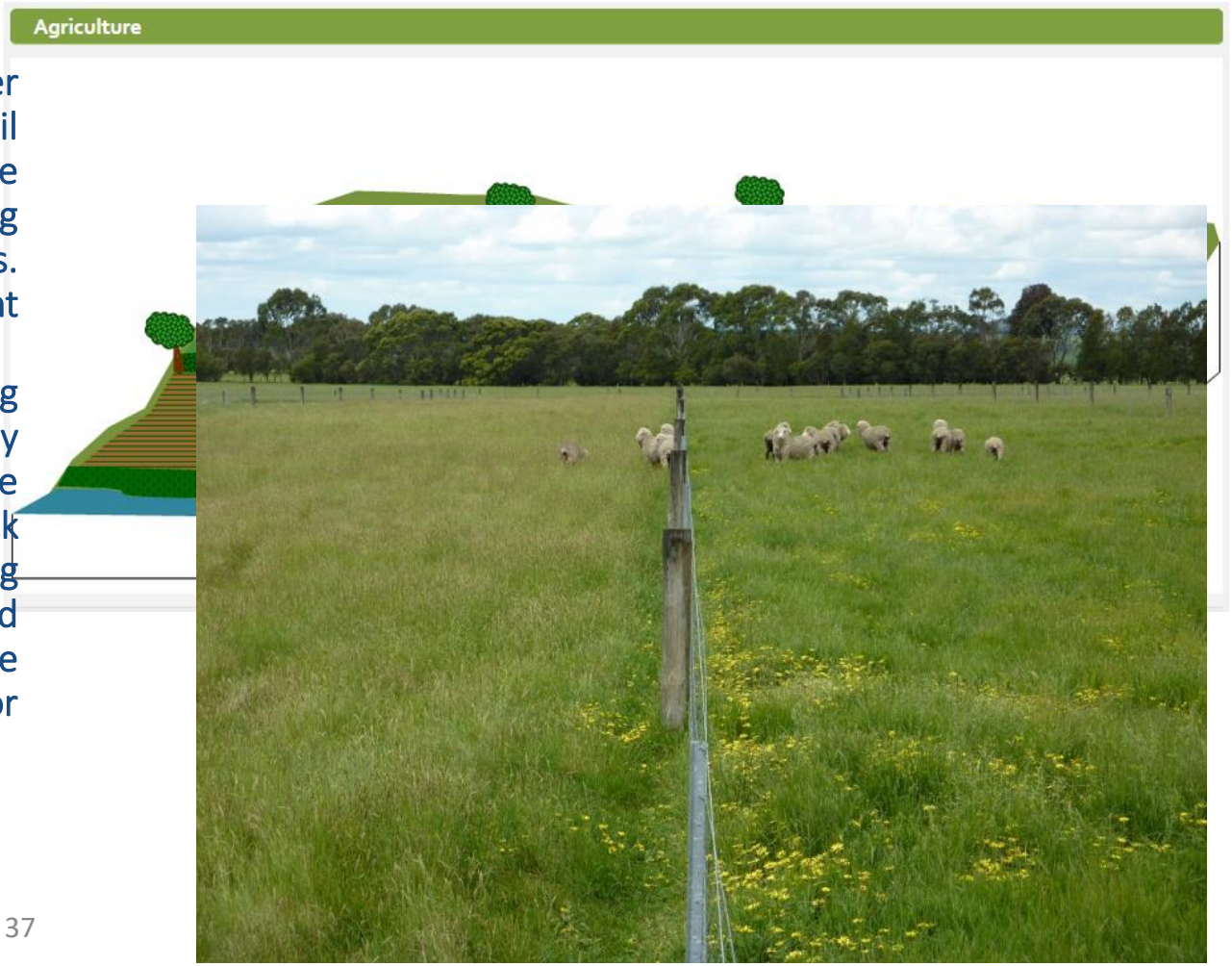
12. Reduced Stocking Density

Definition:
Livestock, particularly heavy species such as cattle, can have a number of damaging impacts on soil including compaction, destruction of soil structure (poaching) and loss of vegetation. These impacts can reduce infiltration of water into the soil, resulting in pooling and water logging with consequent impacts of denitrification and nitrous oxide emissions. Soil compaction will also increase the risk of run-off with consequent impacts on water quality and flood risks.
Reduced stocking density will limit soil compaction, thereby facilitating more rapid infiltration during precipitation events and potentially reducing peak flows and sediment runoff. There may also be issues due to management decisions which can increase risks due to livestock without changing stocking levels. For example increased out-wintering of cattle to avoid housing costs will exacerbate risks due to the increased vulnerability of soils during the winter months. The measure may be effectively achieved by moving grazing livestock from high risk areas or by increasing the use of housing.



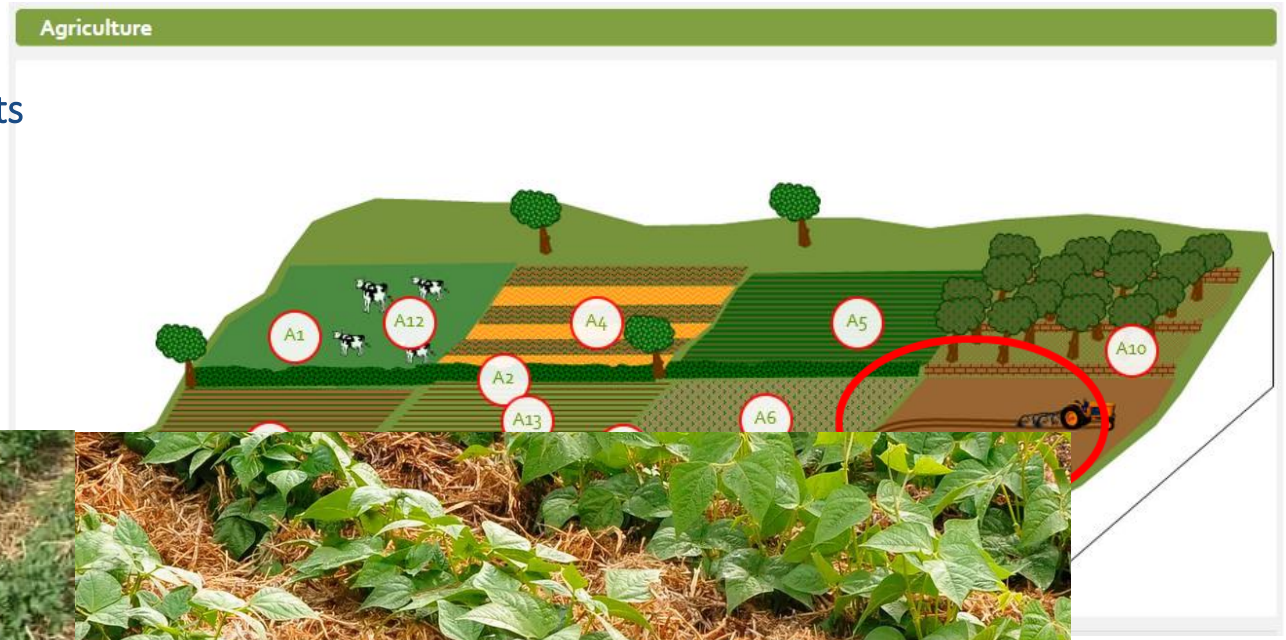
Review of Natural Water Retention Measures in Agriculture

Water and Environment Support
in the ENI Southern Neighbourhood region

13. Mulching

Definition:
A mulch is a layer of material applied to the surface of an area of soil. Its purpose is any or all of the following:

- to conserve moisture reducing evapotranspiration
- to improve the fertility and health of the soil
- to reduce weed growth
- to enhance the visual appeal of the area



Mulching as NWRM is u
grape pulp, shell nuts, gr
straw, dry grass, leaves et
applied to bare soil, or a
compost will be incorpor
worms and other organis
crop production and in
dramatically improve the

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Landscape Architectural Elements

1. Natural Building Materials (Stone / Wood Masonry, Traditional Terracing in Jordan etc.)
2. Planting Vegetation in catchments (Natural Species adjusted to dry local conditions, etc.).
3. Effects on Biodiversity in Natural Areas(e.g. increase of vegetated area with shrubs, etc.).
4. Effects of Vegetation and Natural Building Materials on Water and Soil Retention

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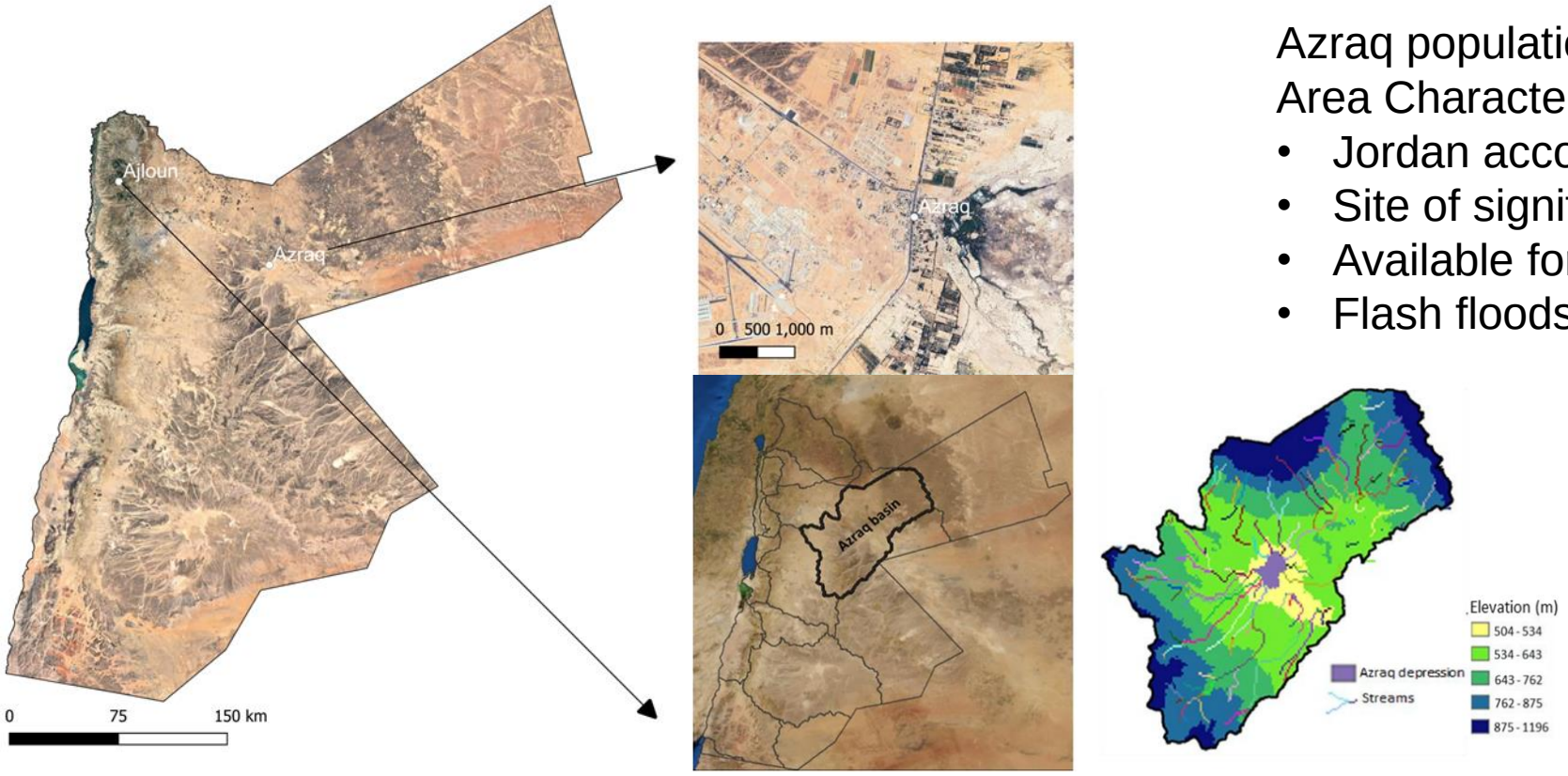
Azraq Case – Study Area



Azraq population: 15,000

Area Characteristics:

- Jordan accounts for 94% of the catchment
- Site of significant importance under threat
- Available for aquifer recharge
- Flash floods

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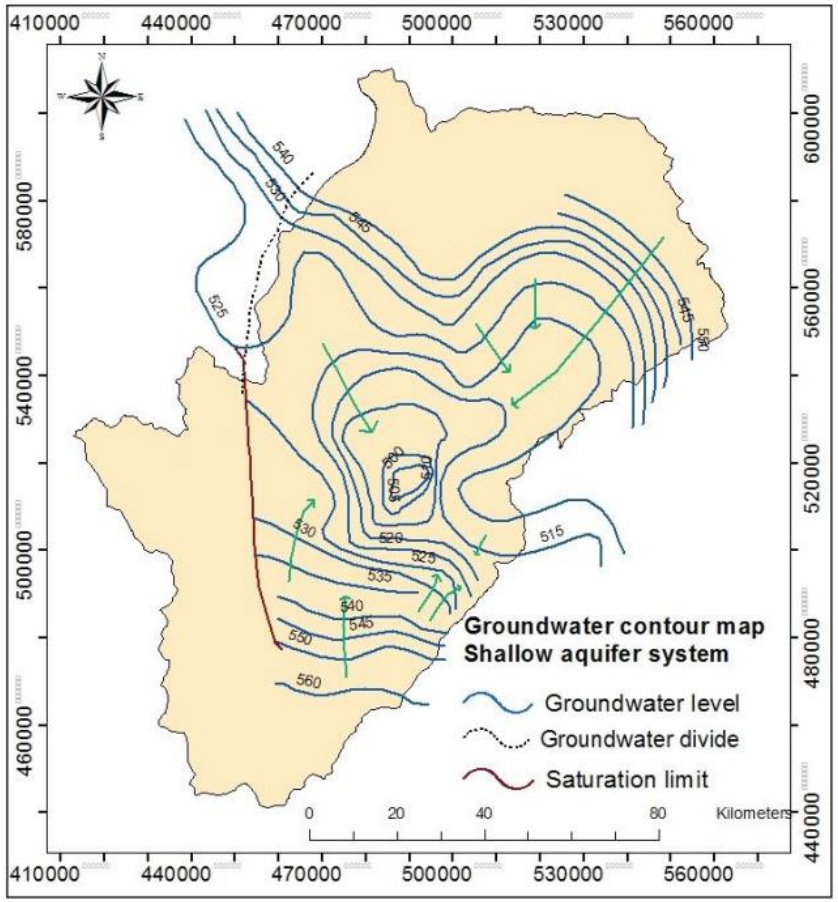
Azraq Case – Study Area



Catchment of study area

Area Characteristics:

- Soils: chalky limestone (downstream) and basalts (upstream)
- Land use: Basalt plain
- Geology: Abed Olivin Basalt and Mudflat

Source: Hobler, M., Margane, A., Almomani, M., Subah, A. (2001). Groundwater resources of northern Jordan Volume-4 contribution to the hydrogeology of Northern Jordan. BGRWAJ technical cooperation project.

Pilot Area: Wadis draining to Azraq Mudflat

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Locations of Proposed MAR sites

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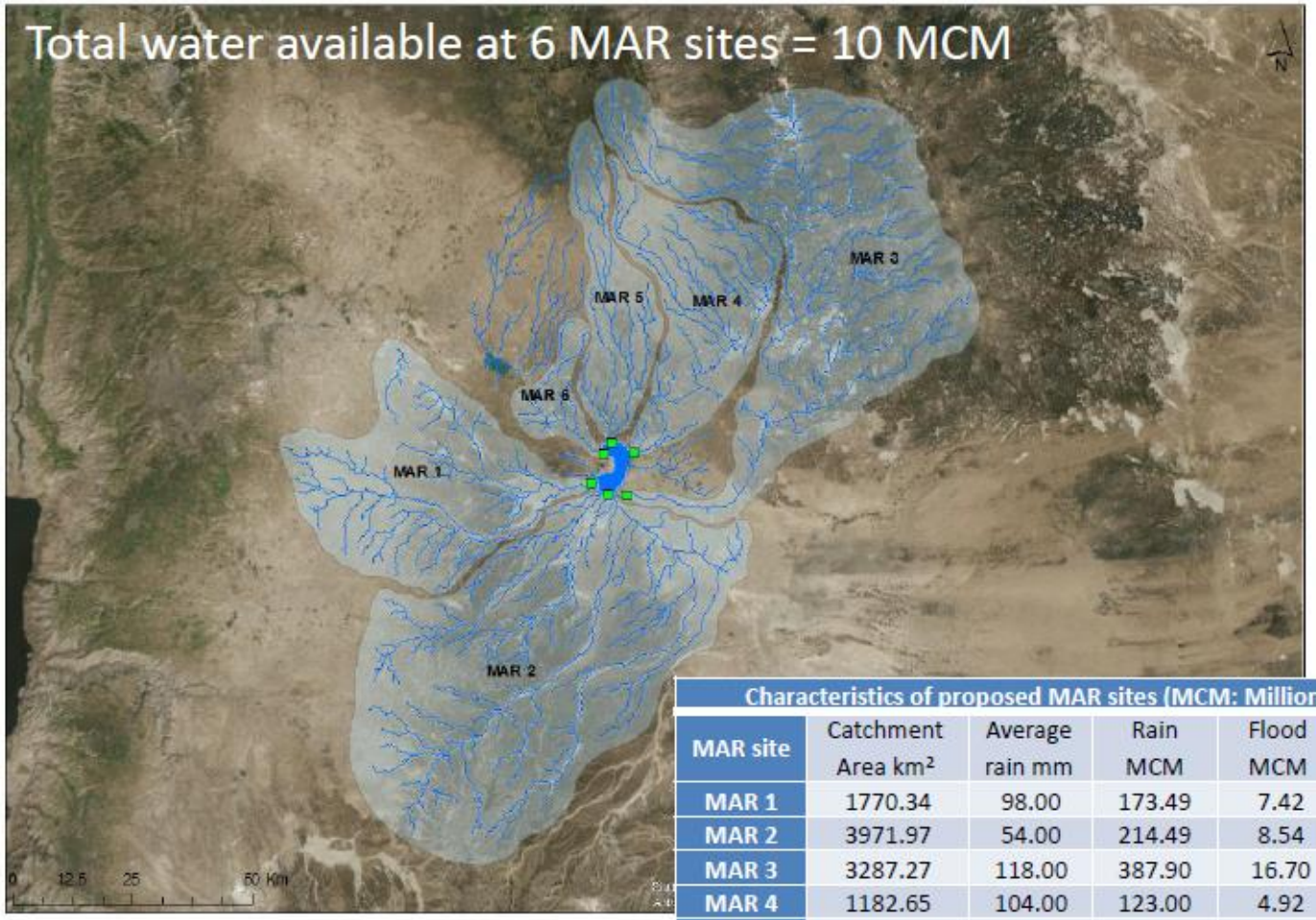
Pilot Area: Wadis draining to Azraq Mudflat

INWRDAM
Water diplomacy



Characteristics of proposed MAR sites (MCM: Million Cubic Meters)

MAR site	Catchment Area km²	Average rain mm	Rain MCM	Flood MCM	Flood reachi MAR site MC
MAR 1	1770.34	98.00	173.49	7.42	3.37
MAR 2	3971.97	54.00	214.49	8.54	1.10
MAR 3	3287.27	118.00	387.90	16.70	3.50
MAR 4	1182.65	104.00	123.00	4.92	1.62
MAR 5	681.58	118.00	80.43	3.22	2.54

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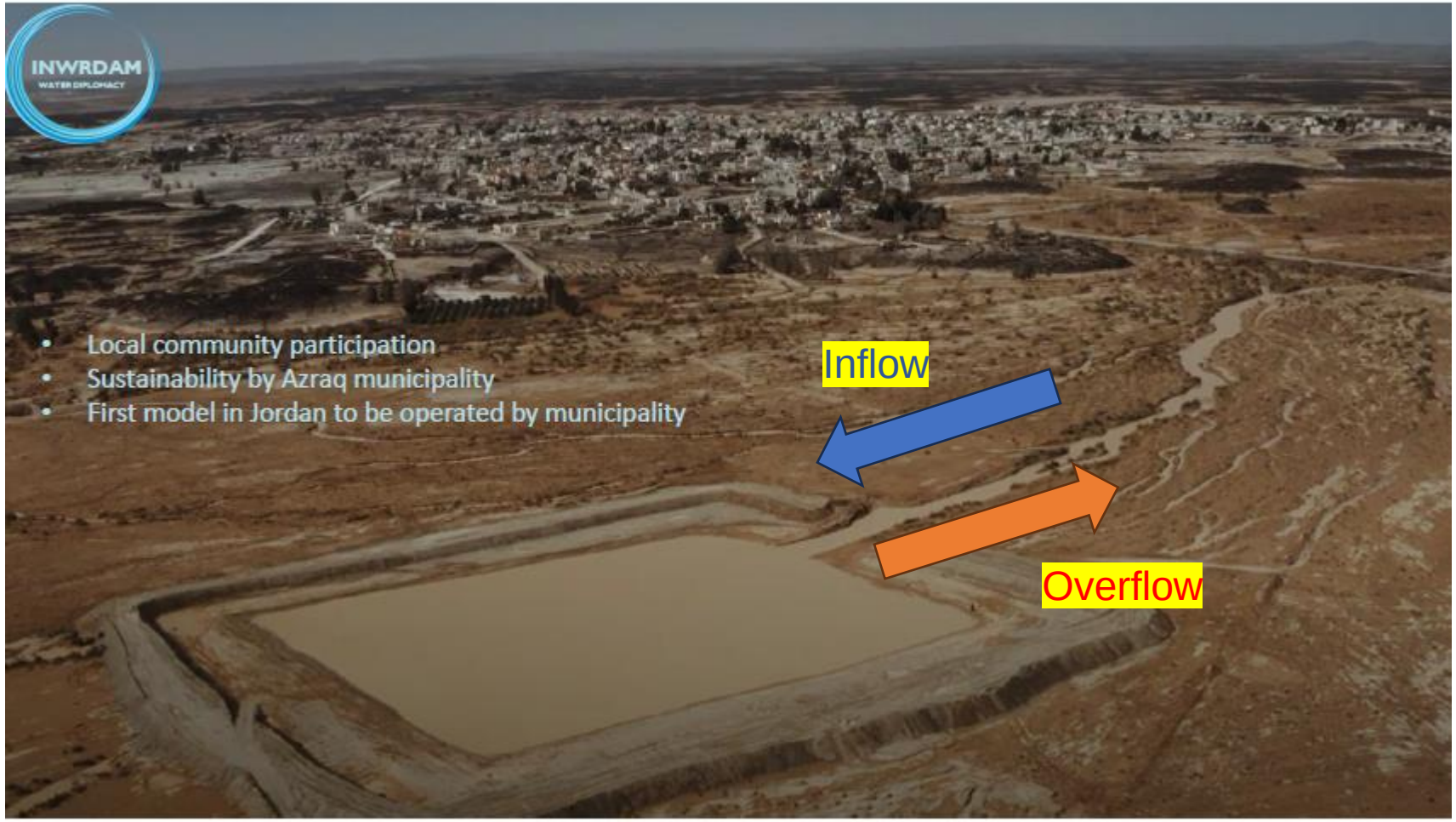
Pilot Area: Wadis draining to Azraq Mudflat

Drone photography of water harvesting structure implemented in Azraq by INWRDAM/UNDP 2021

60000 m3



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Pilot Area: Objectives of NWRMs Design

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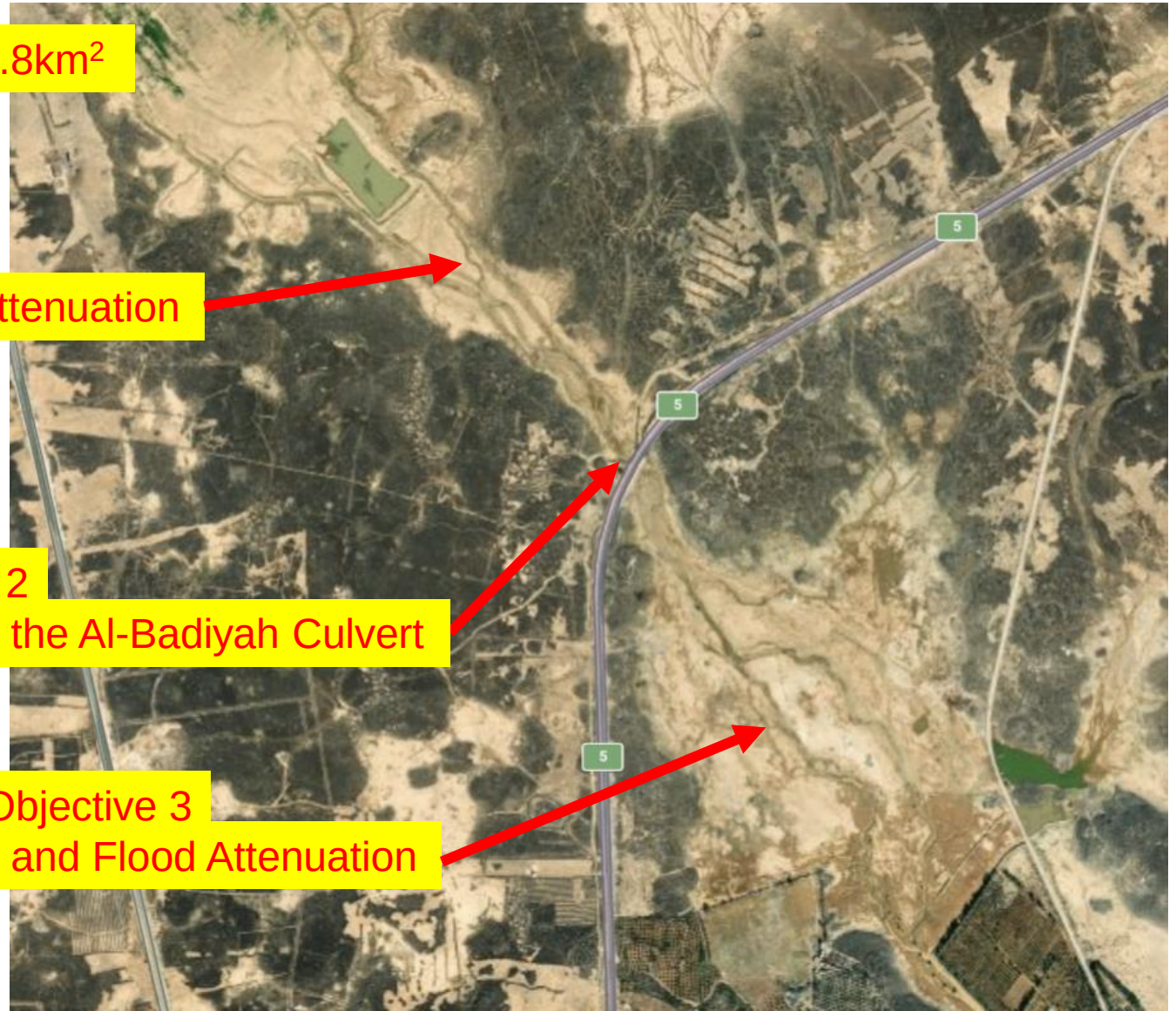
Catchment Area: 145.8km^2



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Pilot Area: Wadis draining to Azraq Mudflat

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Azraq Case – Schematization of the NWRMs

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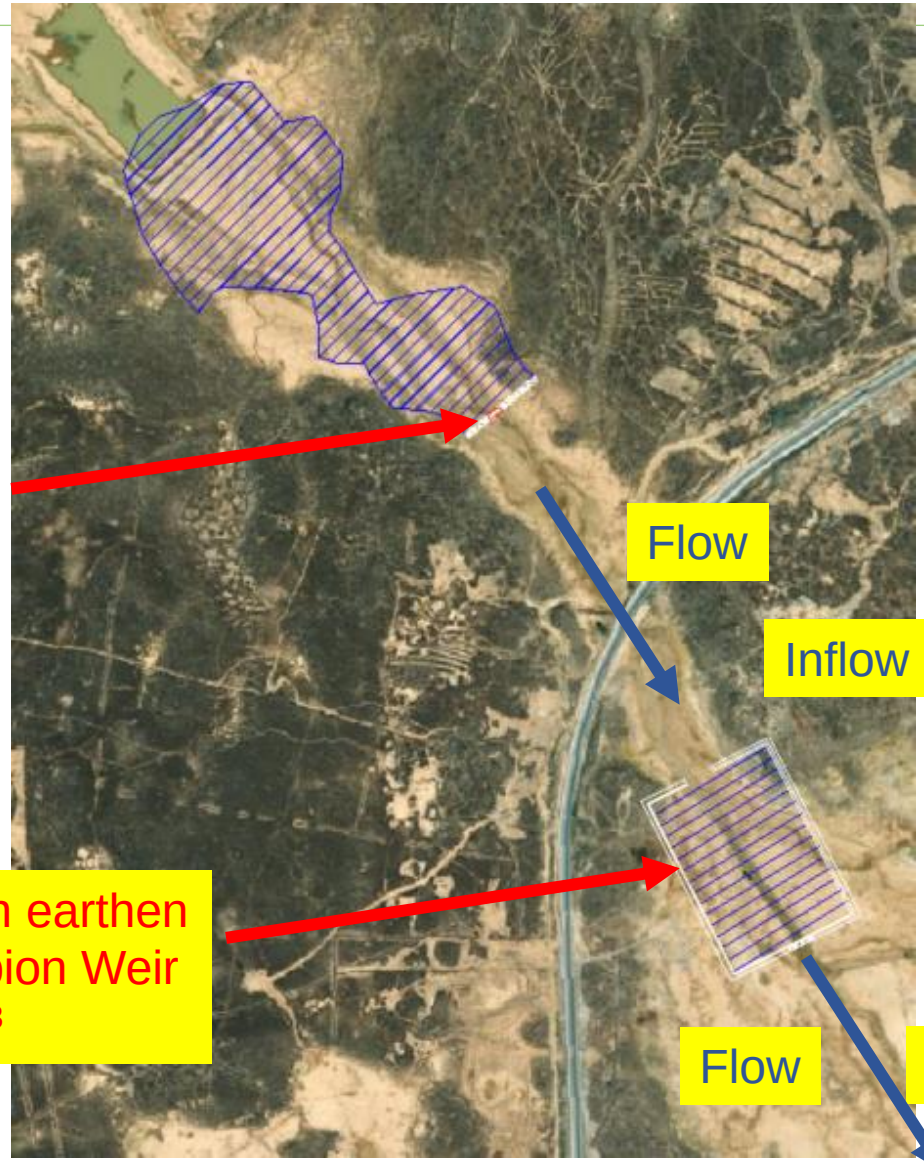
in the ENI Southern Neighbourhood region

Project 1

Gabion Weir with Retention Storage V=200,000m^3



Project 2

Detention Storage with earthen levees and outlet Gabion Weir V=125,000m^3

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Pilot Area Site 4: Wadis draining to Azraq Mudma

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Pilot Area: Site 4 – Detention Storage with Embankments

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Pilot Area Site 5: Wadis draining to Azraq Mudma

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Pilot Area: Site 5 – Gabion Overflow Weir

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Environment Support
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Pilot Area: Site 5 – Afforestation of the Riparian Zone

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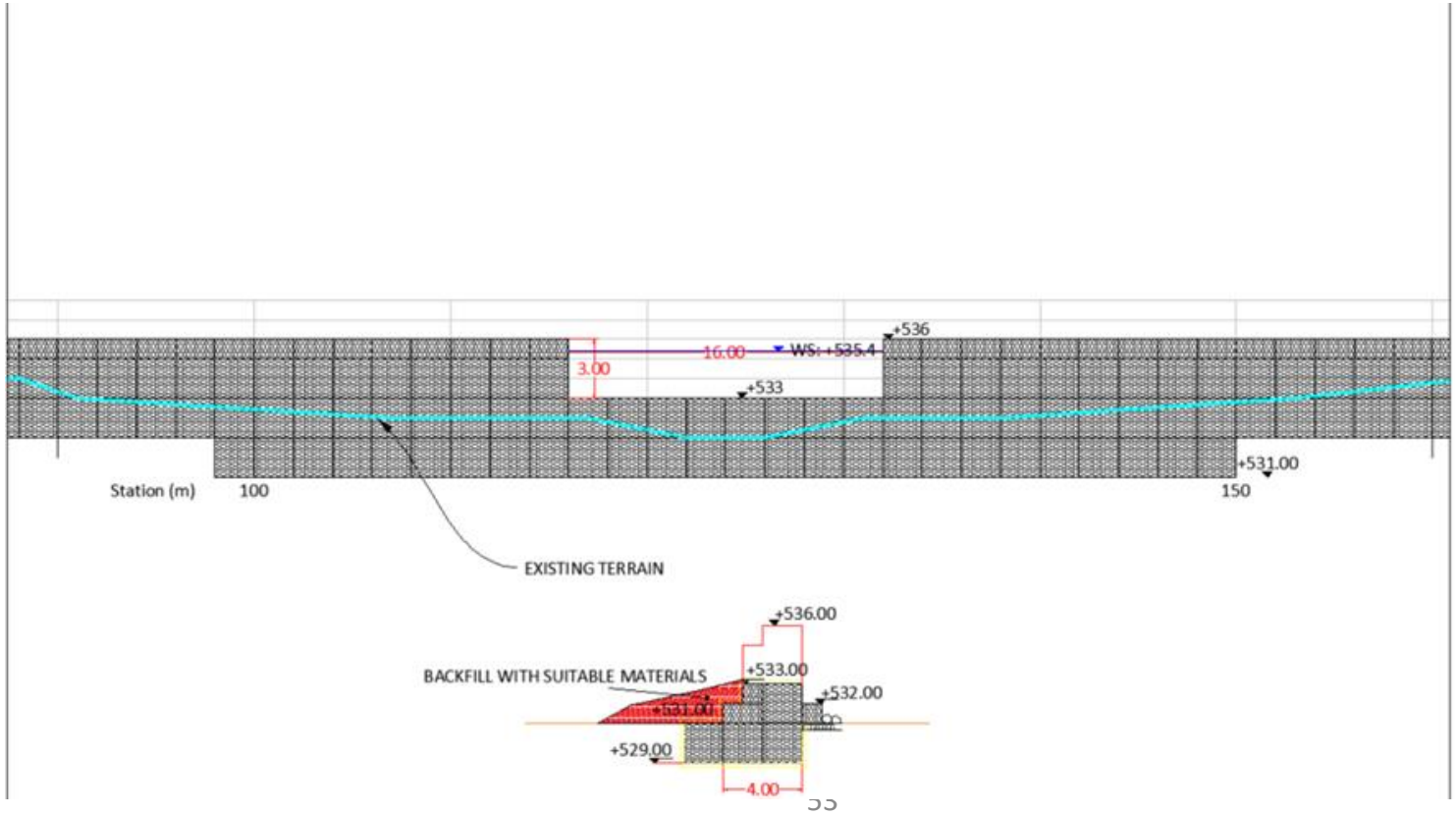
Azraq Case – Schematization of the NWRMs

Water and Environment Support
in the ENI Southern Neighbourhood region

NWRM	*Spillway elevation (m)*	Spillway length (m)	Peak Water Level Elevation (m)	Freeboard (m)	Total Volume (1000m^3)
Dam	+533	16	535.4	0.6	200
Pond	+536	30	537.5	1.0	125.75



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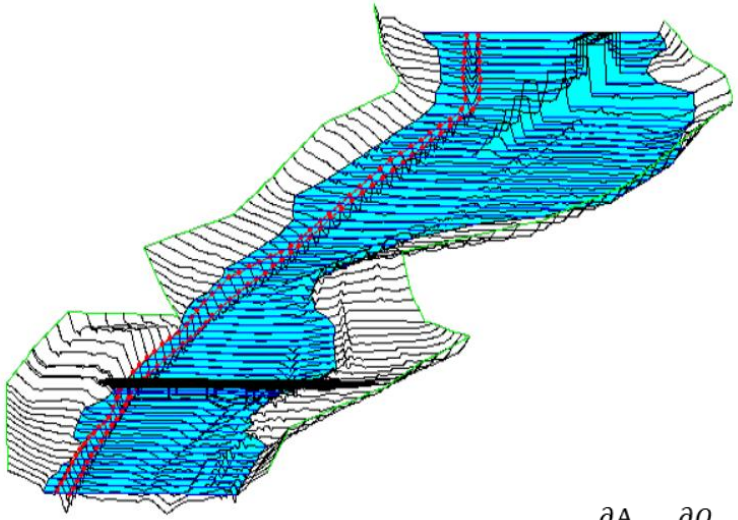
Azraq Case – HEC-RAS Model



$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_t$$

Where:

t = time (s)

Q is the flow (m^3/s)

A is the cross-sectional area (m^2)

q_t is the lateral inflow per unit length. (m^2/s)

- HEC-RAS is one of the most suitable numerical modelling software for hydraulic simulation and one of the most widely used and accepted modelling software worldwide.
- Currently, HEC-RAS can calculate the 1D and 2D water surface profile for a steady, gradually varied flow in channels that are either natural or constructed.

$$\frac{\partial A}{\partial t} + \frac{\partial (\overline{v} A)}{\partial x} gA \frac{\partial H}{\partial x} + gAS_f$$

x = distance (m)

t = time (s)

A = flow cross-sectional area (m^2)

H= hydraulic head of water in the conduit (Z + Y) (m)

Z = conduit invert elevation (m)

Y = conduit water depth (m)

Sf = friction slope (head loss per unit length)

g = acceleration of gravity (m/s^2).

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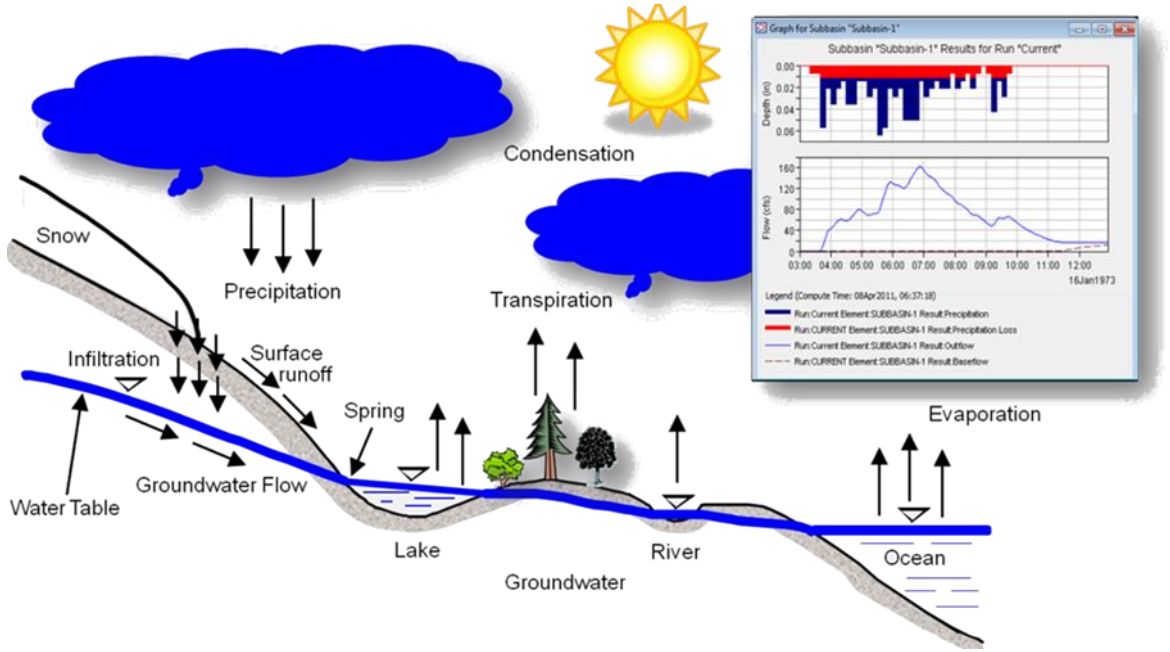
Azraq Case – HMS Model



Source: https://www.hec.usace.army.mil/factsheets/Software/HEC_FactSheet_HEC-HMS.pdf

The Hydrologic Modeling System (HEC- HMS) is designed to simulate the rainfall-runoff processes of den-dritic watershed systems

The software's design allows applicability in a wide range of geographic areas for solving diverse problems including large river basin flood hydrology. It can simulate:

- Surface Runoff
- Infiltration
- Evapotranspiration
- Engineered Structures (Dams, Reservoirs, Spillways)
- Routing
- Baseflow

And has Tools including:

- Uncertainty analysis
- Optimization

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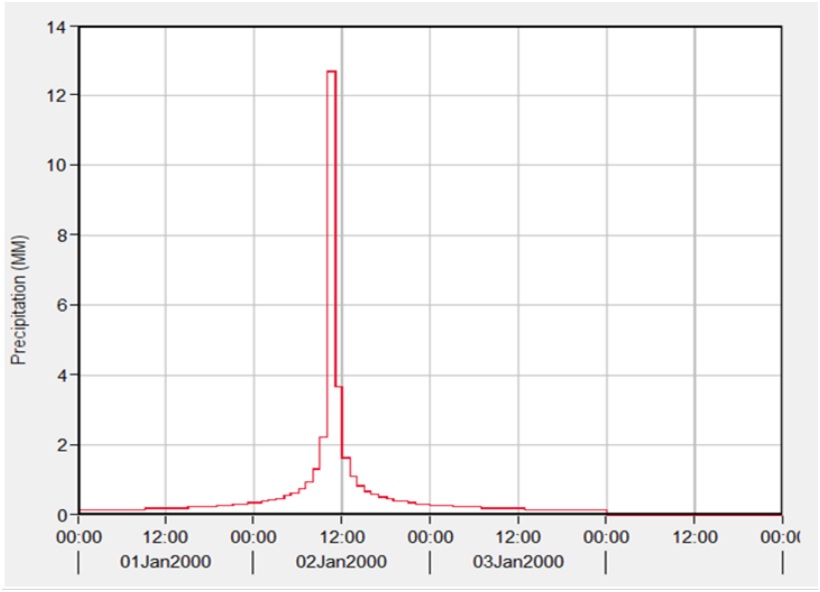
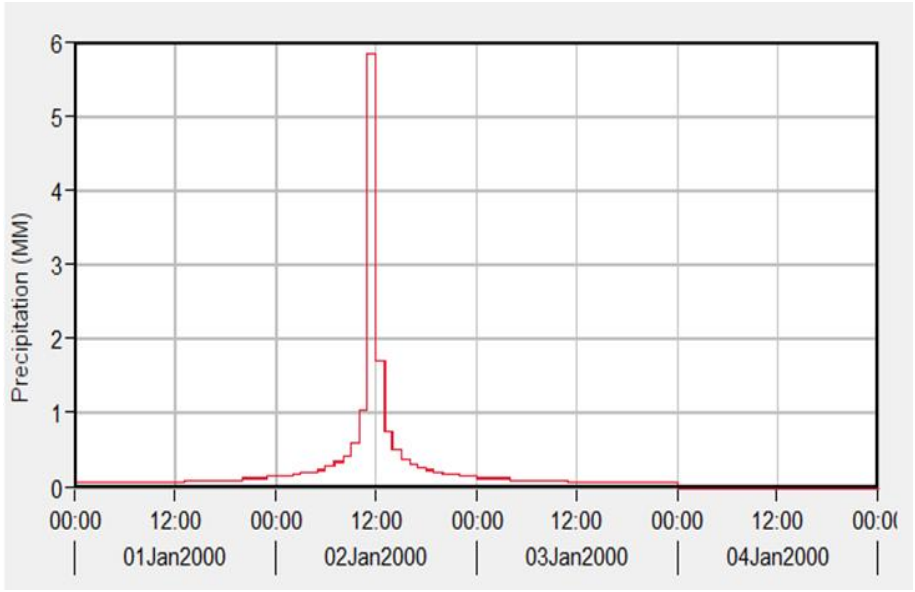
Azraq Case – Climate and precipitation data



T=5 years



T=50 years

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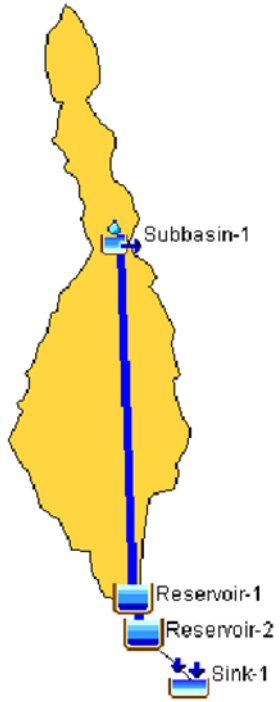
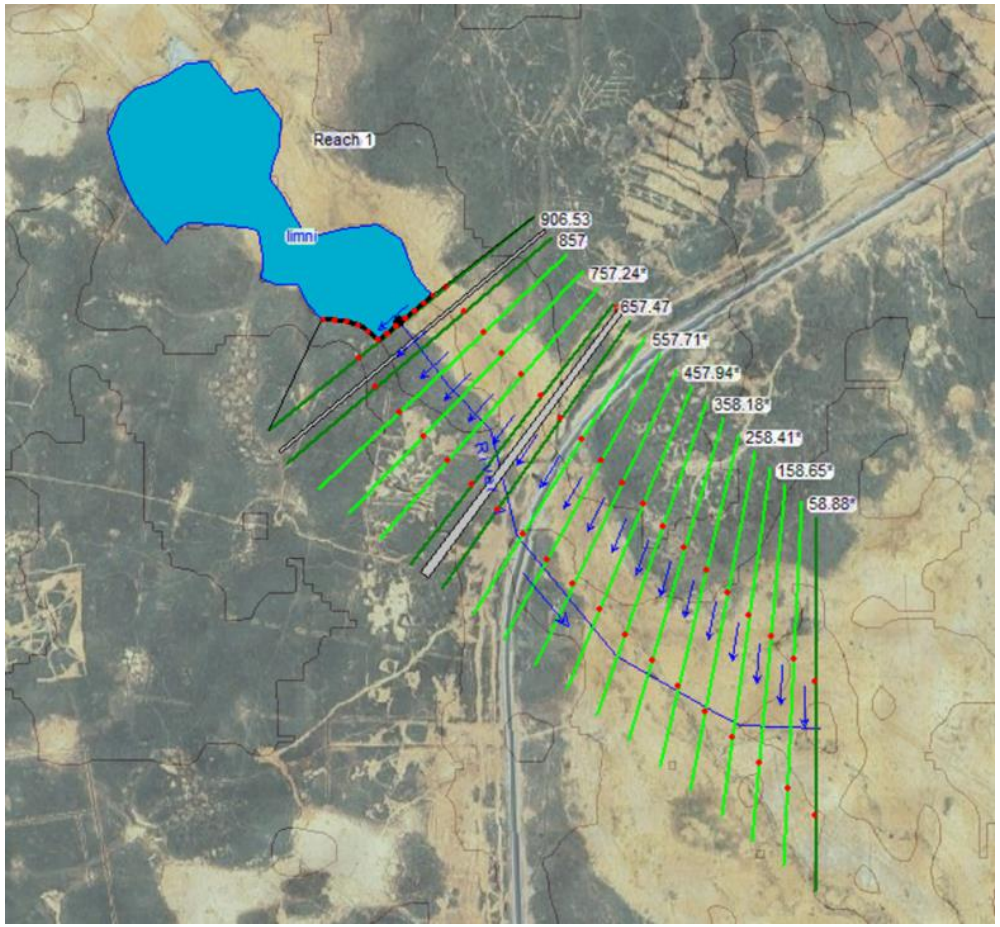
Azraq Case – Hydrologic Model Parameters

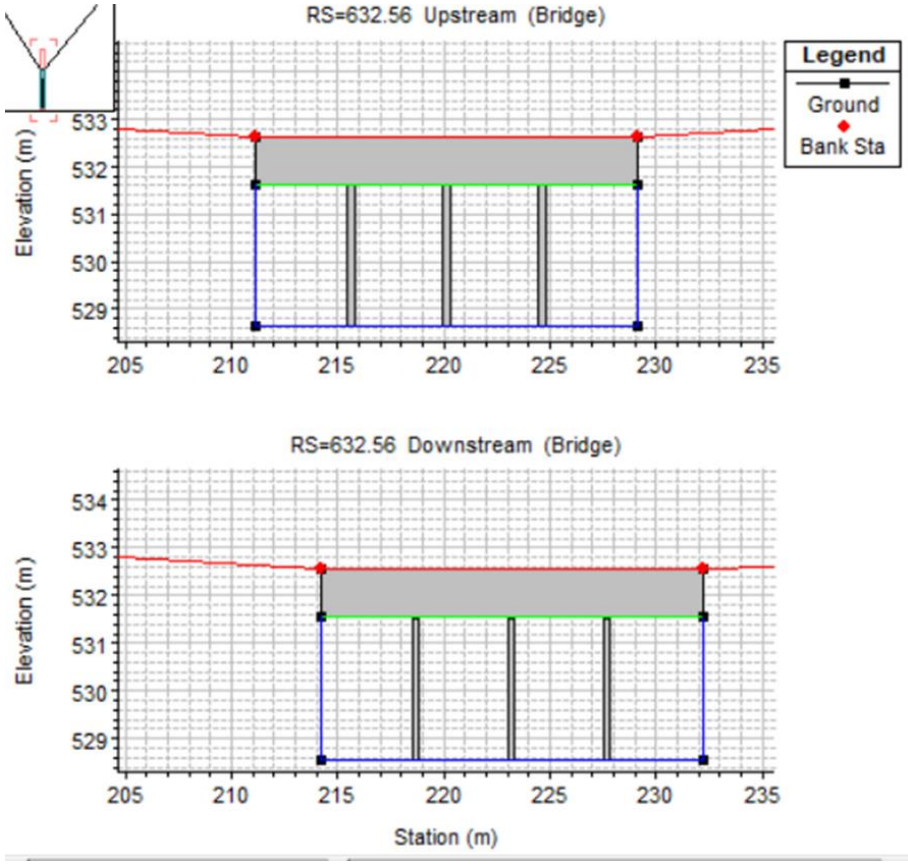


Basin Characteristics	
Average elevation (m)	680.4
Minimum elevation (m)	527.0
Maximum elevation (m)	947.0
Length of main reach	43.6
Slope (%)	0.00963

NWRM	*Spillway elevation (m)*	Spillway length (m)	Peak Water Level Elevation (m)	Freeboard (m)	Total Volume (1000m^3)
Dam	+533	16	535.4	0.6	200
Pond	+536	30	537.5	1.0	125.75

Azraq Case – Hydraulic Model Parameters





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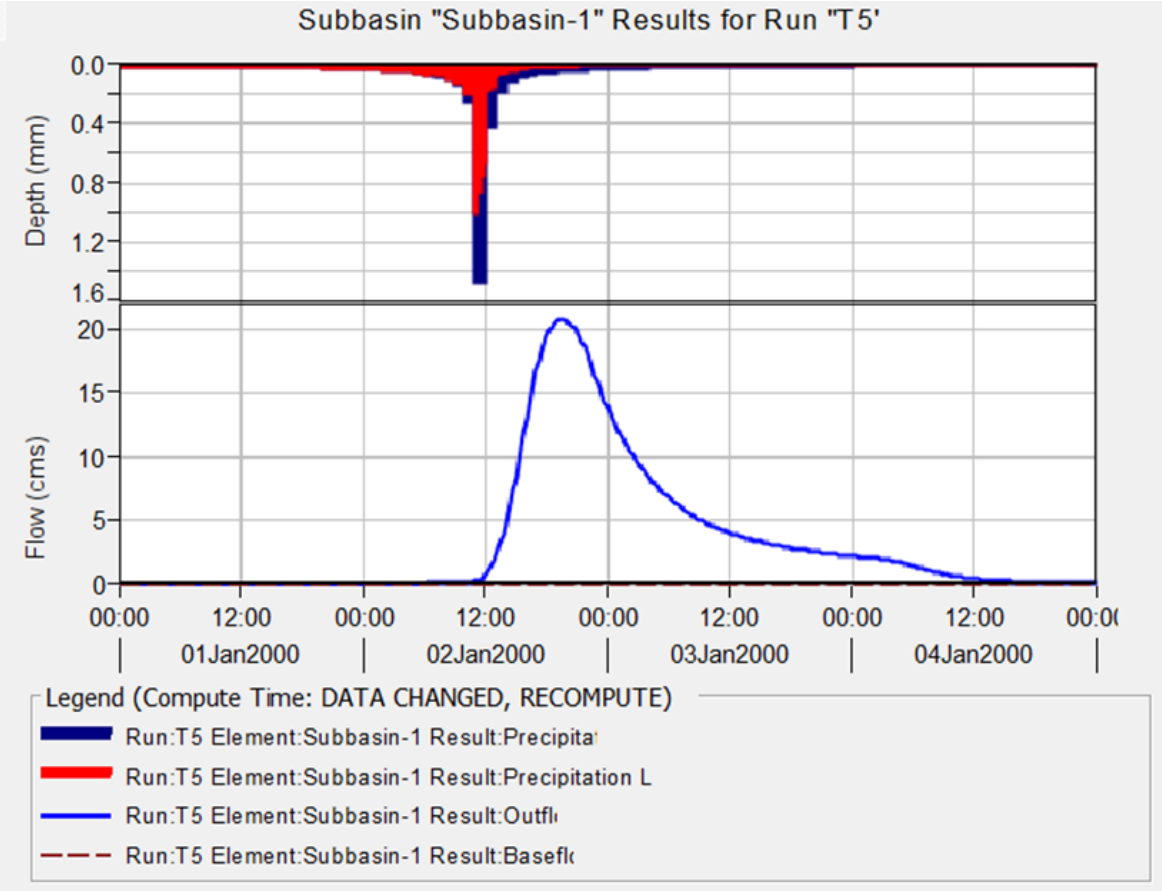
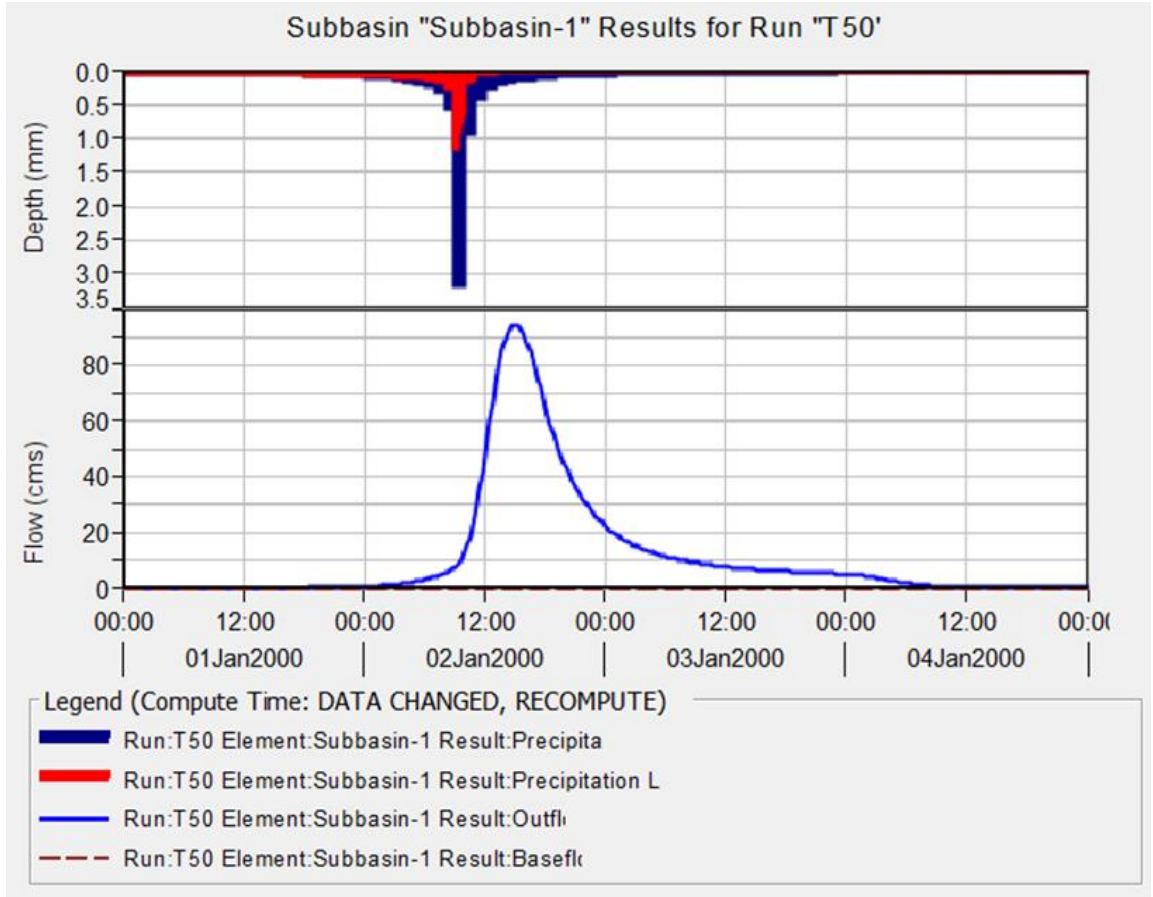
Azraq Catchment – Hydrologic Simulation Results

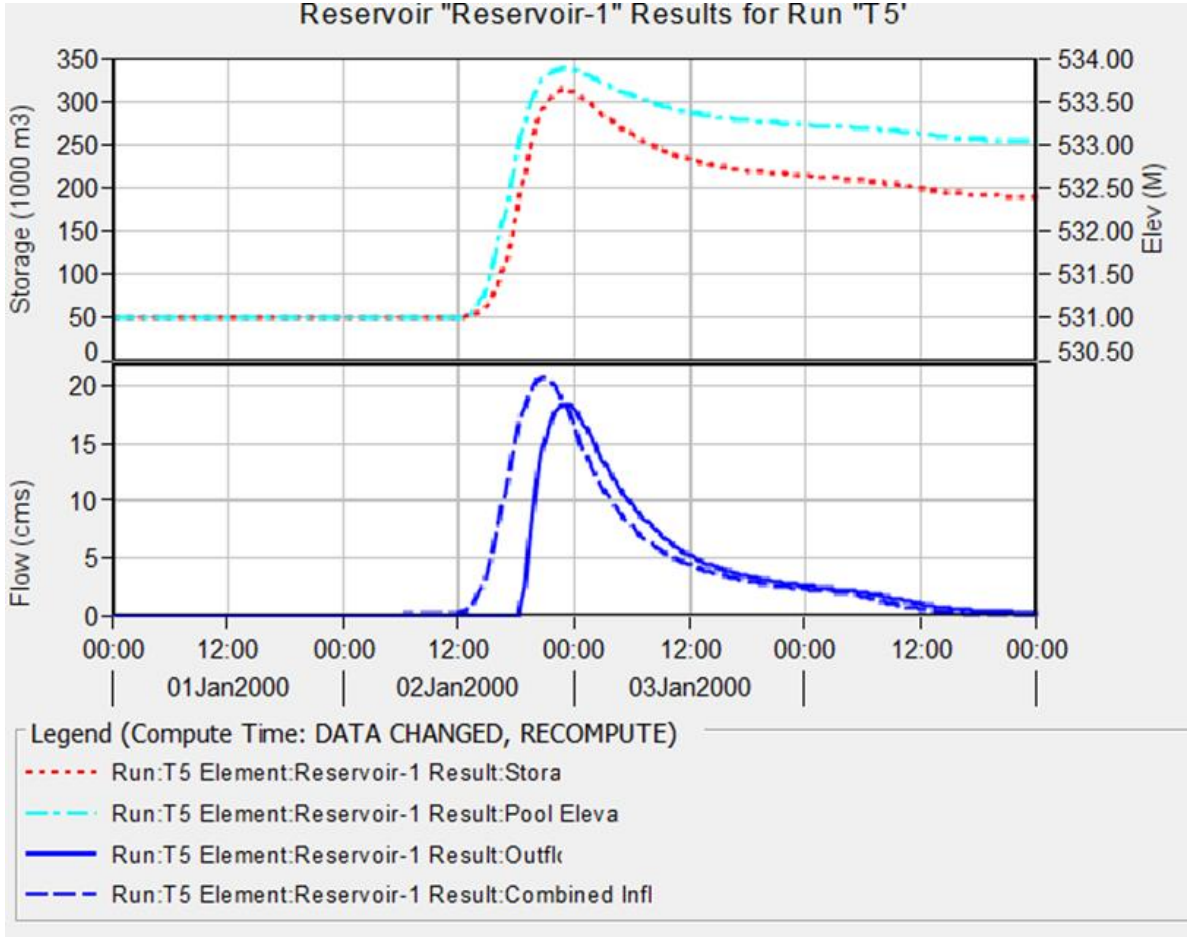


T=5 years



T=50 years

Project 1 – Gabion Weir / Results



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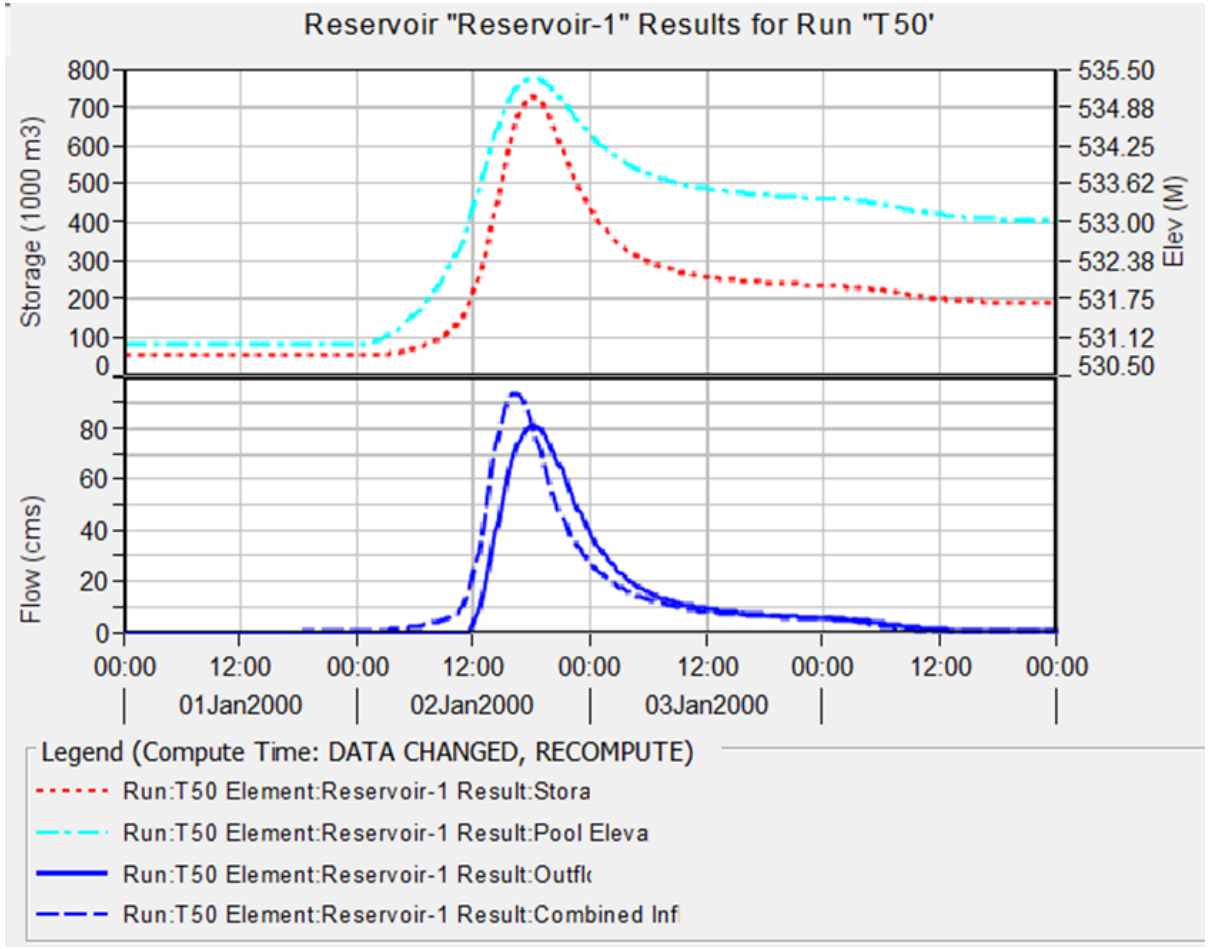

T=50 years

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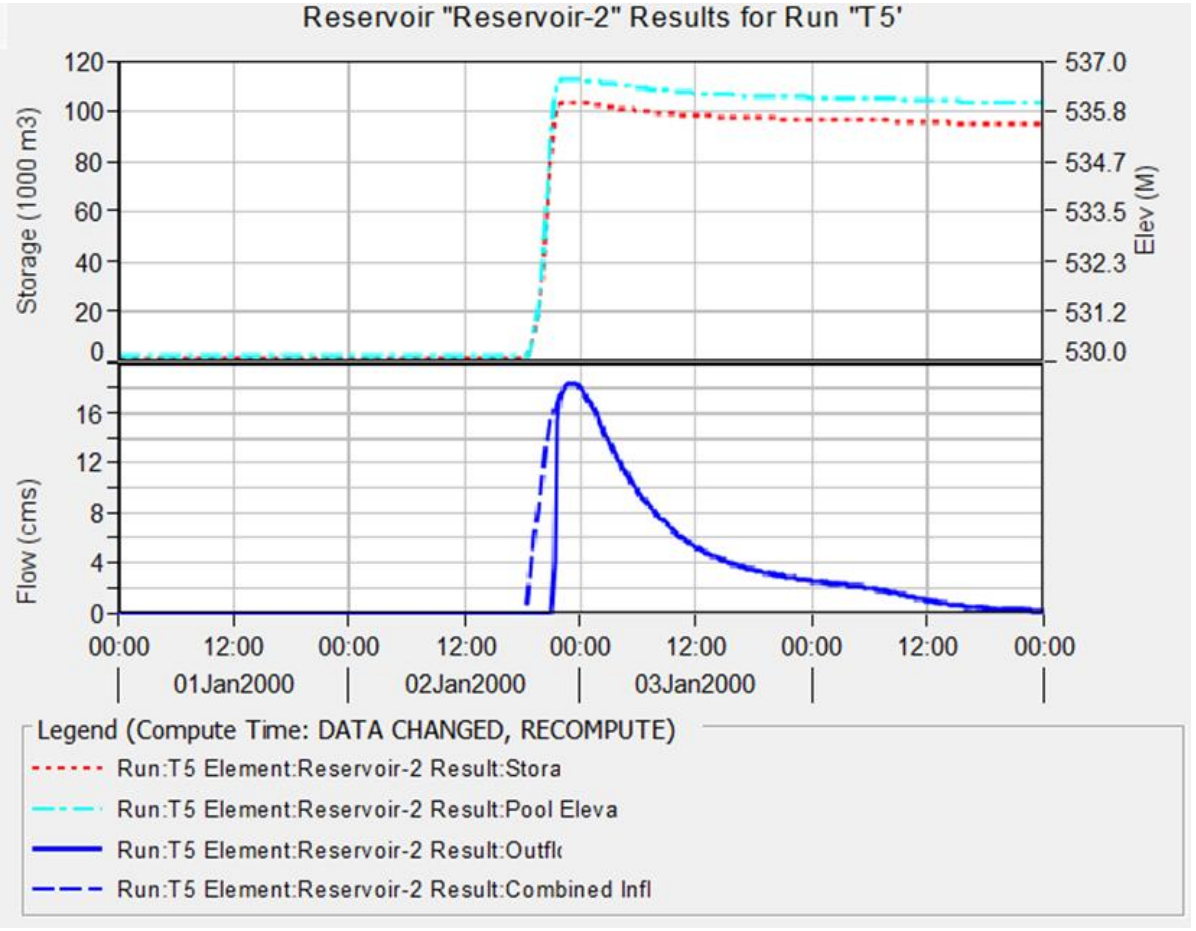
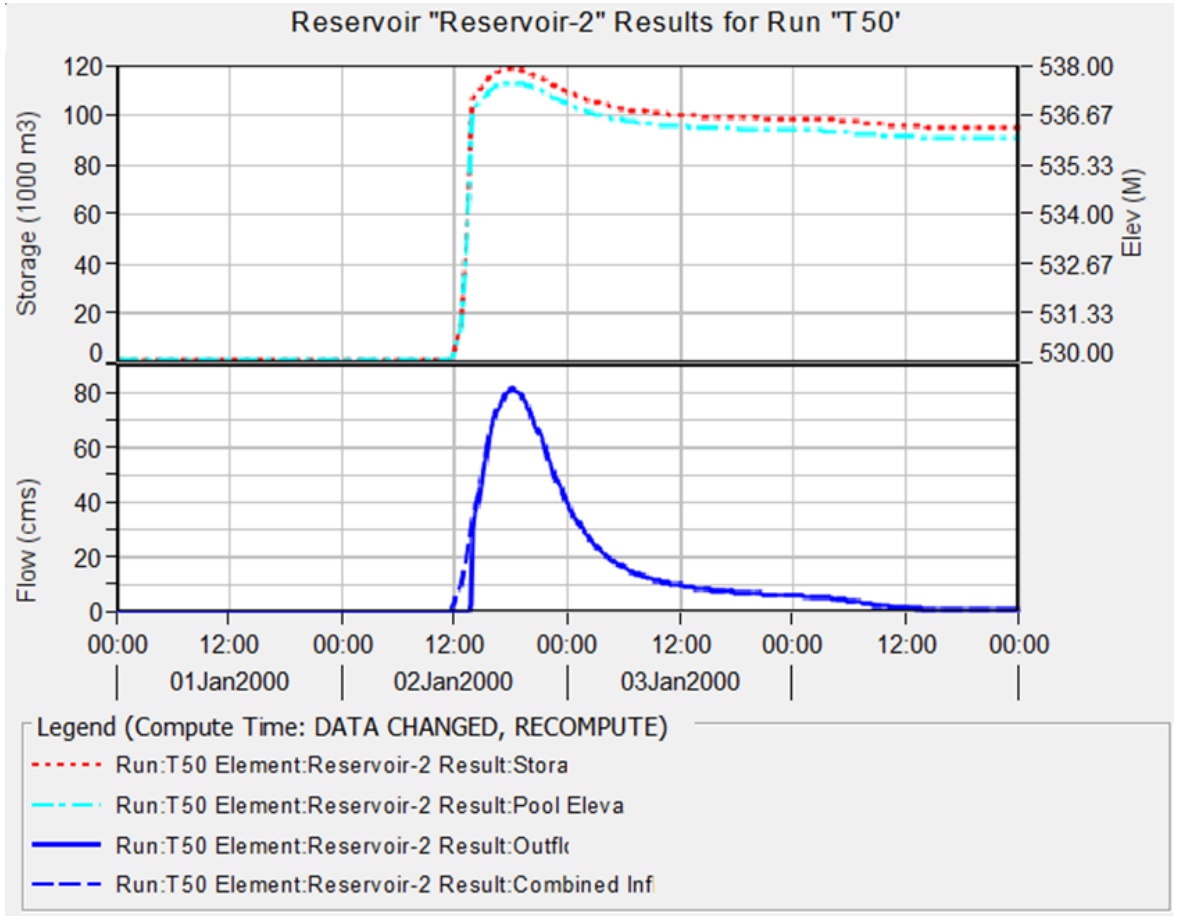
Project 2 – Detention Storage / Results

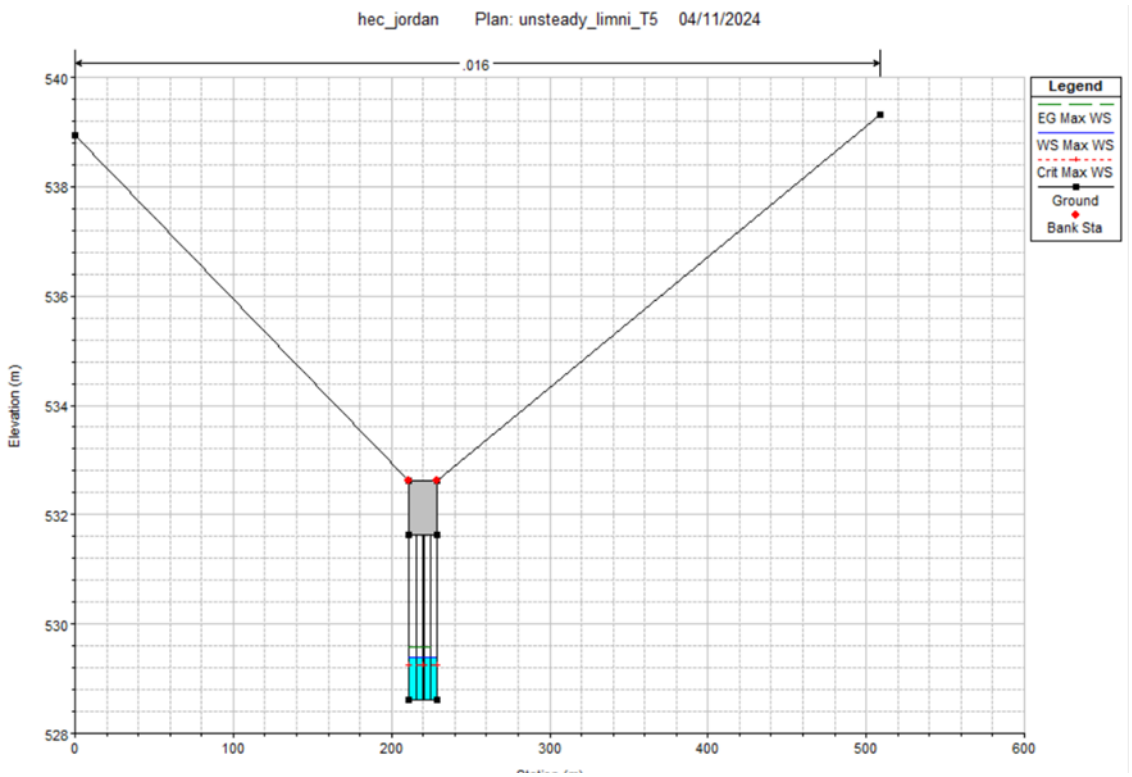


T=5 years

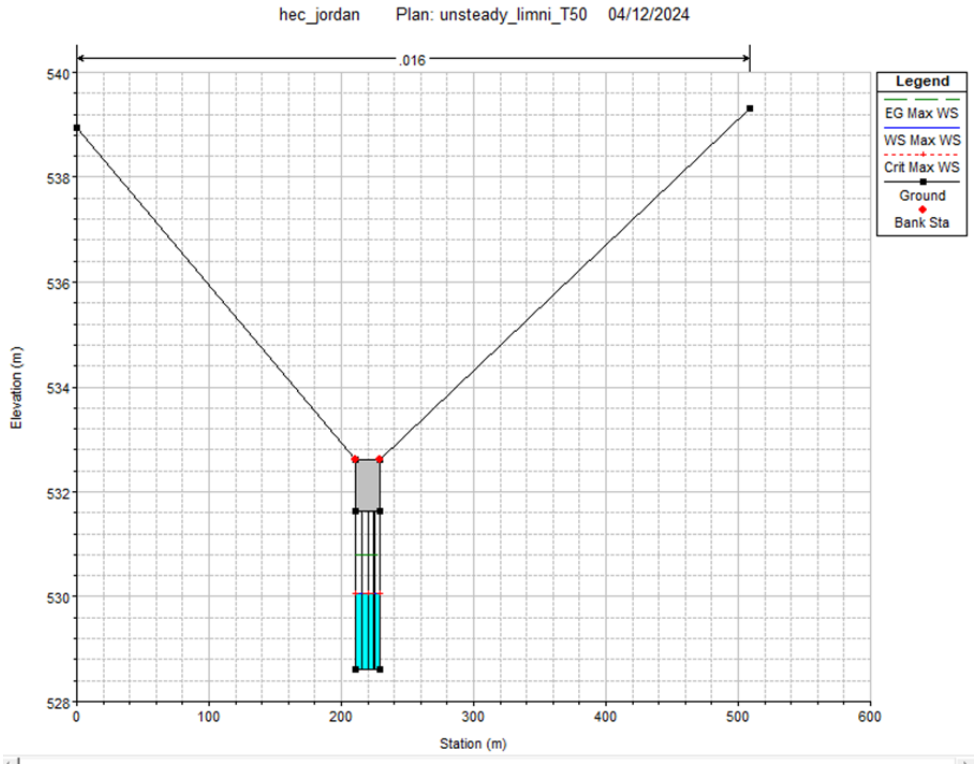


T=50 years

Azraq Case – Results



T=5 years



T=50 years

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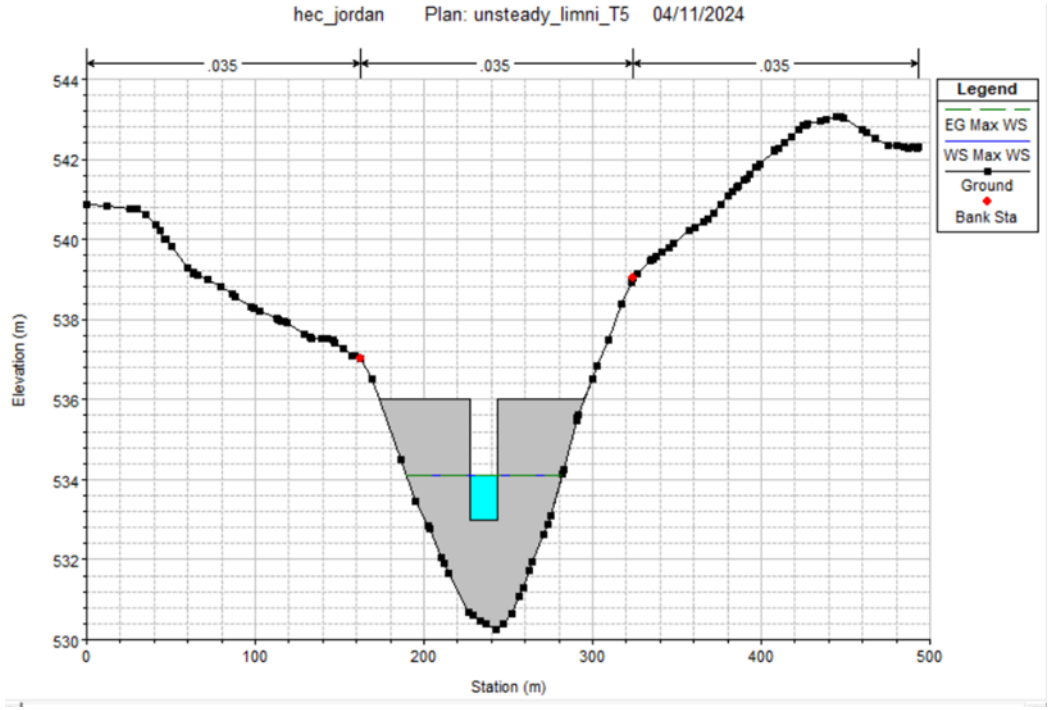
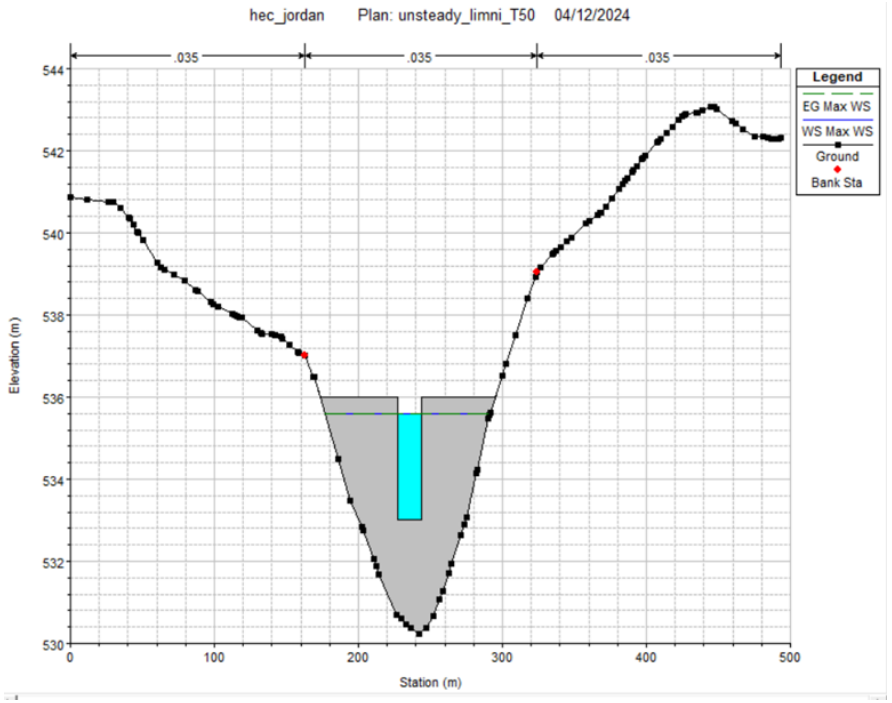
Azraq Case – Results



T=5 years



T=50 years

WH & NWRMs applied in natural areas

- Detention / Infiltration Storage.
- Overflow weirs with Storage for infiltration.
- Afforestation of the Riparian Zone.
- Small check dams in narrow streams in the upstream catchment.
- Plantation with shrubs and drought resistant vegetation in the upstream catchment

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Catchment plantation with shrubs / bushes

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- **Catchment Roughness**: Roughness induced by short and thick vegetation (brushes, sclerophyllous vegetation) impose obs slower. For instance, the kinematic wave equati proportional to catchment roughness

$$t_c = \frac{5.48 n^{0.8} L^{0.8}}{P_2^{0.5} S^{1.3}}$$

Table 15–1 Manning's roughness coefficients for sheet flow (flow depth generally ≤ 0.1 ft)

Surface description	n [1]
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short-grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The Manning's n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Thank you for your attention