RUN-OFF

Best Management Practices

to reduce water pollution with plant protection products from run-off and erosion

TOPPS

PROWADIS

TOPPS projects started in 2005 with the 3-year funded project from Life and ECPA to reduce losses of Plant Protection Products (PPP) to water from point sources. TOPPS eos (2010) evaluated technologies on their contribution to optimise the environmental friendliness of sprayers.
The follow-up project, TOPPS Prowadis (2011 to 2014), is focussed on the reduction of diffuse sources. TOPPS Prowadis is funded by ECPA, involves 14 partners and is executed in 7 EU countries.

TOPPS projects develop and recommend Best Management Practices (BMP) with European experts and stakeholders. Intensive dissemination through information, training and demonstration is conducted in European countries to create awareness and help to implement better water protection.
TOPPS stands for: Train Operators to Promote Practices & Sustainability (www.TOPPS-life.org).

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FOREWORD

Protecting water is high on the list of public concerns about the environment, and it is recognised as one of the basic elements required for all life on the planet.

ECPA sees protection of water as a key pillar of its work and is strongly aware of the need to work continuously to support correct use of pesticides as part of sustainable and productive agriculture. We therefore set ourselves the task of working together with our own national associations and a broad group of international partners to develop and disseminate appropriate measures, recommendations and training materials to ensure that all relevant aspects of water protection are addressed, and that broad consensus is achieved on the recommended measures (referred to as Best Management Practices – BMPs).

This collaborative effort to build and improve available tools for water protection also fits very closely with the objectives contained in relevant EU legislation such as the Water Framework Directive (WFD) and the Sustainable use of Pesticides Directive (SUD). Our work has resulted in the multi-stakeholder TOPPS[1] projects which have been launched since 2005 in many EU countries, supported by ECPA and for the first three years also by the EU Commission (Life).

The TOPPS projects initially focused on the mitigation of point sources such as may occur when cleaning or emptying sprayers or as a result of spills, and now from 2011 we are seeking to concentrate on the more complex mitigation of diffuse source entries (primarily run-off and drift) so as to offer a broad set of recommended BMP to protect water. We refer to this new phase of the TOPPS projects as TOPPS Prowadis[2]. It is our hope that these resulting BMP will be used as a basis to inform, educate, and train operators, advisers and stakeholders in a range of different ways – in the classroom, in the field, and through demonstration. ECPA is committed to promoting the implementation of these BMP.

I would like to sincerely thank all the partners and experts for their great efforts and contributions to the TOPPS projects, both in terms of the technical know-how they have brought to the table, and their willingness to work together to achieve consensus on our common goals. I also truly hope that these BMP will help spark the enthusiasm that will be needed to implement these ideas "on the ground" and help create awareness and spread the knowledge which is necessary for sustainable use of pesticides and a high level of water protection.

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[1]www.TOPPS-life.org [2]TOPPS Prowadis – Protecting Water from Diffuse Sources

INTRODUCTION

Source of water pollution

Two main entry routes of plant protection products (PPP) into surface water need to be distinguished.

Point sources

Point sources are related to the handling of PPP mainly in the farmyard. Main risk areas are the cleaning; filling of sprayers and the management of contaminated diluted liquids resulting from cleaning and maintenance of sprayers on the farm.

Diffuse sources

Main diffuse source entry risks of PPP are related to field run-off and soil erosion due to adverse weather conditions (at or soon after the application), discharge from drainage systems (a specific form of run-off locally important) and from spray drift (off-target deposition of small droplets due to wind).
Most significant are entry risks from point sources followed by run-off/ erosion from fields.

Key differences in the mitigation of point and diffuse sources need to be considered. Point source mitigation is farm-specific as it addresses operators' behaviour directly and tries to optimise equipment and infrastructure to avoid mistakes. All relevant factors can be controlled.
Pollution from point sources therefore can be largely avoided.

Diffuse source mitigation is site-specific and depends also on uncontrollable factors like weather conditions and their interactions with soil and the shape of the landscape. It is linked to a water catchment area and individual fields. Mitigation measures often need to be implemented on an individual level (single farmer, field scale) and at a collective level (group of farmers, catchment scale).
Diffuse source entries can be largely reduced but extreme weather conditions can cause, at least sometimes, entry risks beyond our mitigation capabilities.

The challenge is to determine the need for mitigation, corresponding to a representative weather pattern. Extreme rain events (e.g. probability of occurrence 1 in 50 years) cannot be the basis for the recommendation and implementation of Best Management Practices (BMPs).

Types of run-off/erosion

1) Run-off by soil infiltration restrictions

The rain intensity is in excess of the water infiltration capacity of a soil. This is known as run-off due to infiltration restriction. A special case is the thawing of snow on frozen soil. Here, an impermeable layer is present and avoids infiltration. This can lead to both run-off and erosion.

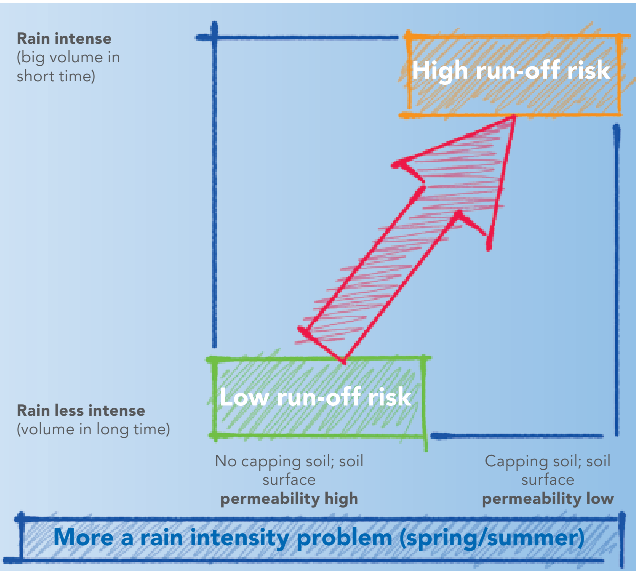


Fig. 1: link between infiltration and run-off risk

2) Run-off by soil water saturation

Run-off occurs when the soil is saturated with water and therefore no additional water can infiltrate into the soil, or excess water will exit the soil due to ponding in topsoil on an impermeable subsoil layer ("bucket is full").
Run-off by saturation is more a soil water capacity problem and occurs if total rainfall exceeds water-holding capacity.

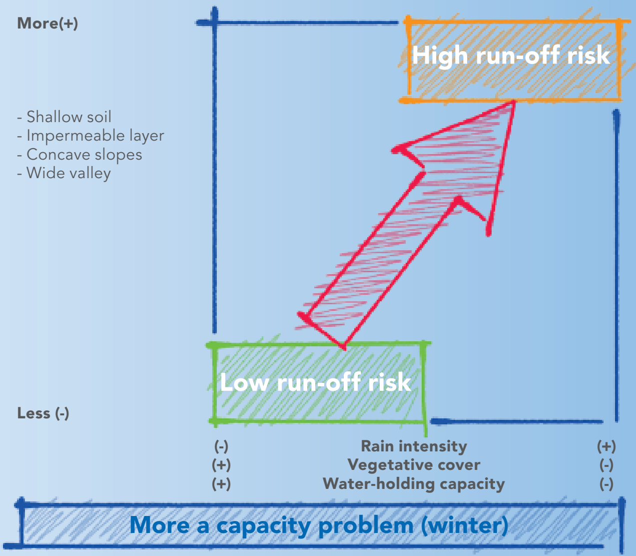


Fig. 2: link between capacity and run-off risk

a) Lateral seepage/interflow

If water infiltrates into the topsoil on a slope and reaches an impermeable layer (e.g. rock or clay), water will move/drain laterally within the soil downhill. Compared to surface run-off these situations represent a lower risk for PPP entries into surface water, due to relatively slow water movement through the soil and therefore the higher potential for degradation and adsorption. Lateral seepage can often be observed at riverbanks or directly in exposed places (terraces) in the catchment.

b) Drainage

A special case of subsurface run-off is artificial drainage. An artificial tile drain system removes excessive water in soil and transports it via the drain collectors to the next surface water body (therefore, surface run-off is generally low on drained fields). In drainage water from tile drains, also significant amounts of PPP can be found at times, especially if PPP are applied on drained soils, which are dry and cracked at the time of spraying or water-saturated.

3) Concentrated flow run-off

Concentrated flow occurs if water accumulates into small water streams due to structures related to the management of the fields (e.g. large fields, tramlines along slopes) or to the landscape (slope, talweg, soil characteristics). Concentrated flow is generally easily visible as it goes often along with erosion, a severe form of high-intensity surface run-off. Erosion favours the transfer of soil particles with the run-off water and primarily soil-bound substances like phosphates and some PPP.

Signs of concentrated flow can be sediments in lower corners in a field. Good early indicators are rills built by water in the field. Such rills generally accumulate water further in small valleys (talweg) and can then lead there to more severe run-off (talweg run-off, gully run-off). In the toolbox of mitigation measures respective measures can be selected according to the severity of the problem.

FACTORS INFLUENCING PPP TRANSFER WITH Run-off

The registration process for PPP in EU member states considers the potential for plant protection products to impact aquatic organisms and water quality. Risks associated with applications of the PPP product are evaluated and may result in denied registrations or regulatory use restrictions listed on the PPP label. The mandatory restrictions reported on the product labels must be considered as an essential part of a complex strategy to reduce surface water contamination, which also include the adoption of BMP based on an accurate catchment/field diagnosis. In highly vulnerable situations identified during a catchment/field diagnosis, it may be necessary to consider additional factors for product selection.

Intrinsic movement potential of PPP active substances

Not all products move in the same way with run-off water from fields. Weakly adsorbt substances are mainly transferred in dissolved state in the run-off water, while other strongly adsorbt substances are mainly tranferred with eroded soil particles. The properties of PPP influence the mode and extent of its transfer by water.
Two main types of properties characterise the behaviour of active substances in the soil:

a) Persistence in soil

Persistence depends on the dissipation rate in the field and it is usually expressed as the half-life (DT50). It provides the time period for 50% dissipation of the PPP active substance in soil. Dissipation rates are influenced by soil organic matter content, clay content, pH, and weather conditions (temperature, moisture). Substances with higher persistence in soil will remain for a longer period in relatively higher concentration in the topsoil, being to a higher extent available for transport to water bodies via surface run-off water.

b) Mobility in soil

The movement of pesticides with run-off depends on their fate and distribution in soil, particularly their adsorption and degradation in soil. Pesticides that are strongly adsorbed to soil can only enter surface water at significant levels if high levels of soil erosion accompany run-off. At the other extreme, pesticides that are weakly adsorbed to soil can only enter surface water at significant levels in run-off water, since they are mostly in the run-off water and not bound to any eroded soil particles. For all pesticides, however, the amount that can enter surface water is driven by how much run-off and/or soil erosion occurs, particularly when it occurs in close relation to the time of application. The longer the time between the application and the first significant rainfall event (a large run-off/soil erosion event) in a vulnerable location the less is the transfer risk of PPP in the run-off water.

Mitigation measures addressing the reduction of PPP losses to water are also relevant to mitigate entries of key nutrients like nitrogen (dissolved in water) and phosphates (mainly bound to soil).

GENERAL KEY FACTORS DETERMINING THE RISK OF PPP TRANSFER WITH WATER

A careful diagnosis at catchment and field level to determine the transfer risk is necessary in order to select the best-suited mitigation measures (BMP) for the situation. Factors listed below need to be evaluated.

Connection to surface water

The longer the distance of a sprayed field to surface water, the lower the risks of PPP transfer with run-off/erosion. It is not only the distance to surface waters (m) which needs to be considered, but also the speed of run-off water, which is leaving the fields towards watercourses, as well as potential concentrated flow pathways originating from this field (e.g. roads or talwegs, short cuts through pipes).

Soil characteristics

Soil properties influence infiltration of water and adsorption/dissipation of PPP. Infiltration of water into the soil reduces/eliminates the run-off water and erosion risk at the source. The presence of impermeable layers can reduce the capacity of the soil to infiltrate water and result in run-off. The longer the PPP is in direct contact with the soil/microorganisms the higher can be the potential degradation of the PPP and therefore reduces the risk of transfer. Water movement in the soil is generally much slower compared to that on the soil surface.

Weather pattern, climatic conditions

Representative weather patterns (rain events) need to be defined to propose and prepare for appropriate mitigation measures.

Shape and length of the slope: aggravating factors

Fields with steep and long slopes are more prone to run-off/erosion. Big fields may require a division of their size by in-field buffers or bunds to reduce the risk of water accumulations (concentrated flow), which favour erosion. Therefore mitigation measures to reduce water flow are necessary to increase infiltration of water in the soil. In the first instance, measures should focus on keeping the run-off water in the field (mitigation of run-off at source).

Soil cover

If soils are covered by vegetation the risk of run-off/erosion is low (grassland, meadows). Arable crops in their early development stage leave the soil highly exposed to the rain. Raindrops hit the soil with their full energy and therefore cause a higher risk of run-off and erosion. Two main effects need to be considered depending on the soil texture.

a. Especially in soils with higher silt content the raindrops have the effect of compacting the soil, which leads to the formation of a less permeable soil layer (capping soil). Such situations cause a high-risk scenario for run-off and erosion.

b. The energy of raindrops destroys soil aggregates and allows smaller particles to be washed away.

Covering the soil, especially at times, can mitigate such effects when the canopy of the crop cannot cover the soil completely. Mulch techniques leaving, e.g. organic remnants of an intermediate crop on the soil, have shown good mitigation effects. They protect the soil surface from being directly hit by the raindrops and slow down the water flow, which increases the infiltration capacity of the soils. A long-known technique in steep vineyards, where permanent vegetation cannot be tolerated due to crop competition, is to cover the soil between the vine rows with straw or other organic materials.

DIAGNOSIS/AUDIT APPROACH

A thorough diagnosis is the basis for proposing suitable and specific mitigation treatments. The aim is to understand the water pathways in the fields and catchment in order to determine run-off/erosion risk levels.

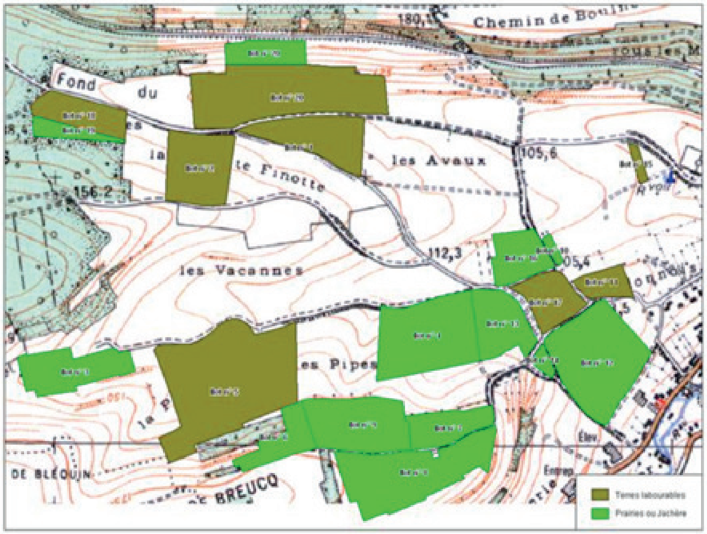
(Note: This diagnosis and audit methodology is based on work done by Arvalis Institut du végétal and IRSTEA in France and will be locally adapted by the TOPPS Prowadis partners to their situation. Specific aspects will be covered in the field manuals locally developed for agricultural advisers.)

Catchment diagnosis

The diagnosis starts on catchment level by collecting all available data (field maps, geology maps, soil maps, topography maps, maps on the hydraulic network, climatic information and information on the agricultural use and practices. The more data available, the less work is needed for the verification in the fields. If data are missing, necessary information needs to be collected in the fields.

Catchment map example: France

- Field map and size
- Hydraulic network
- Agricultural use (green permanent grass)
- Topography



Field diagnosis

Field diagnosis is necessary to verify available data, to close data gaps, determine especially the soil permeability in order to make proposals for Best Management Practices for a specific field. The field visit is necessary, as landscape and soil properties can change over a short distance, which is often not reflected in mapped information. A summary of key steps of the field diagnosis is shown in Fig. 3.

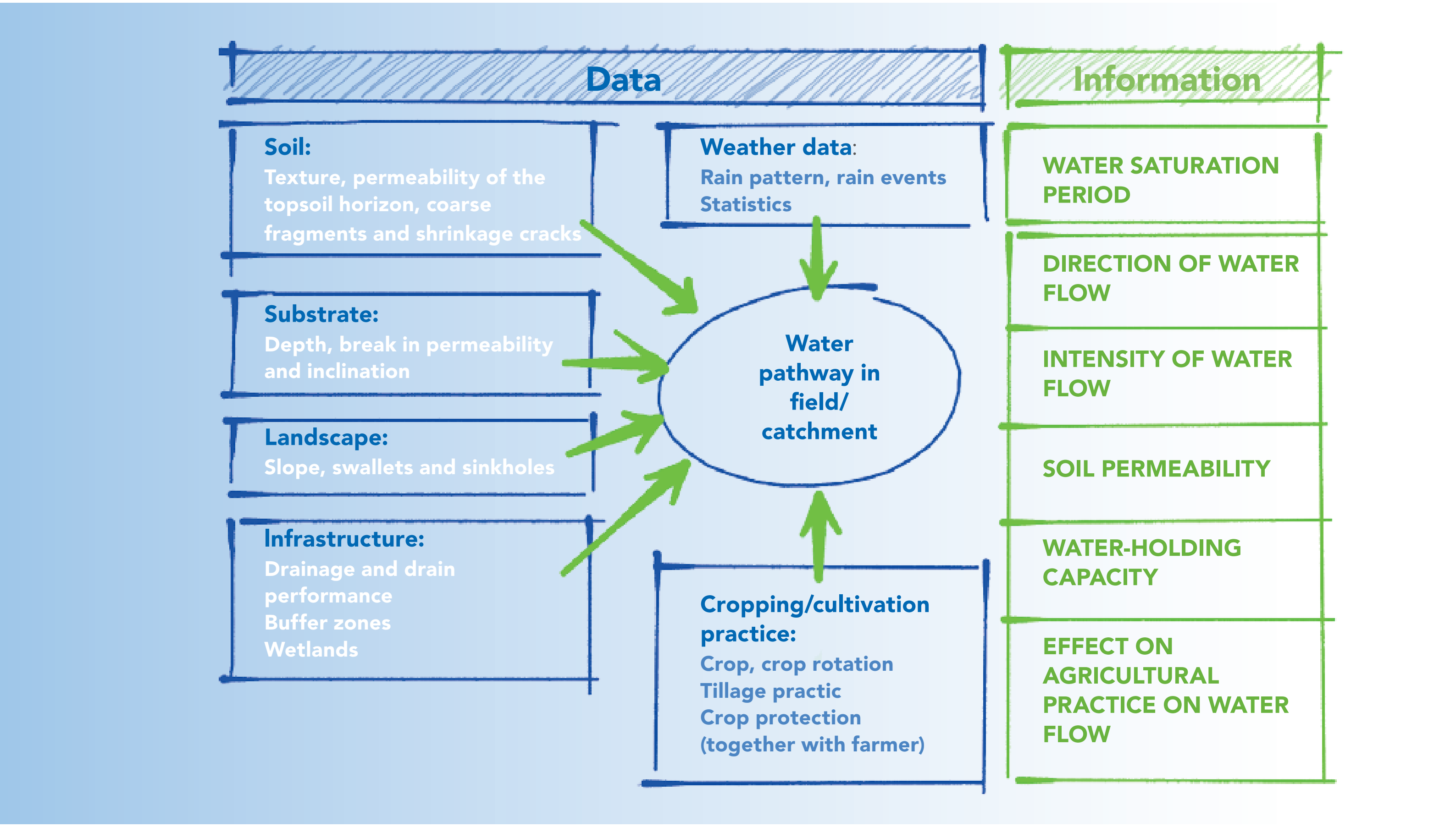


Fig. 3: Data needs from the field to develop the information needed to determine run-off risk level (Source: Arvalis Institut du Végétal)

Dashboard/Decision tree

Field methods and decision tree techniques have been developed to reduce complexity and to support correct decision-making. These tools should help to determine the risk level for run-off in a specific field. Two main dashboards have been developed to determine the risk level for run-off.

A dashboard for concentrated flow has been developed additionally, related to infiltration restrictions and to soil water saturation (Fig. 4, 5). If traces of concentrated flow are observed in the field, it is clear that mitigation measures need to be implemented as run-off risk is high. The dashboards are intended to support the diagnosis process in the field.

Three decision levels need to be addressed to define the run-off risk levels: very low risk (green), low risk (grey), medium risk (orange) and high risk (red).

Scenarios are described for the different situations that are linked to the determined risk levels. These scenarios are described in this document in general and may need to be adapted to the local situation (farming practices, climatic conditions and other factors). Depending on the local situation the farm adviser will propose mitigation measures listed in the TOOLBOX OF MITIGATION MEASURES (see page 30) addressing the different mitigation targets.

It is recommended to always use both dashboards in the field, because both run-off types can, in principle, be relevant. Run-off due to infiltration restrictions typically happens when high intensity rains occur in spring and early summer and vegetation cover is often still sparse. Run-off caused by soil saturation mainly occurs after long rain periods and when evapotranspiration is low typically in winter. In such situations soils become saturated with water, which occurs under European conditions mainly from late autumn to early spring.

FIG. 4: DIAGNOSIS OF RUN-OFF & EROSION FOR INFILTRATION RESTRICTION (D1)

The dashboard splits into two decision pathways depending on the decision in the first column. For the special case of run-off on frozen soil see the comments in the scenario description. (Reference: Dashboards are based on Arvalis decision trees, Syngenta advisory framework and TOPPS partners' contributions)

Proximity to Surface Water	Permeability of the Topsoil	Steepness of Slope	Risk Class & Scenario
Field Adjacent to Water Body	LOW	STEEP (>5%)	I 7
		MODERATE (2–5%)	I 6
		SHALLOW (<2%)	I 5
	MEDIUM	STEEP (>5%)	I 4
		MODERATE (2–5%)	I 3
		SHALLOW (<2%)	I 2
	HIGH	STEEP (>5%)	I 3
		MODERATE (2–5%)	I 2
		SHALLOW (<2%)	I 1

Proximity to Surface Water	Transfer of run-off downhill	Run-off reaches water body?		Risk Class & Scenario
Field not Adjacent to Water Body	YES		YES	T 3
			NO	T 2
	NO			T 1

HIGH RISK

MEDIUM RISK

LOW RISK

VERY LOW RISK

Example: For dashboard use D1 – infiltration restriction

The dashboard splits into two decision pathways depending on the decision in the first column

a) Field adjacent to water

b) Field not adjacent to water

Each column represent a decision level which needs to be taken step by step to reach the risk and scenario classification (from left to right). The last column to the right indicates a risk category (colour) and a scenario number, T stands for transfer, I stands for infiltration restriction. The numbered scenarios are described separately.

RUN-OFF FROM INFILTRATION RESTRICTION (D1) SCENARIOS

Field adjacent to water body

I 7	Minimise extreme risk for run-off and erosion with all suitable in-field measures, edge-of-field buffers, and landscape measures (buffers, retention structures). Combine all effective measures to achieve maximum effect. Frozen soil: if permeability of topsoil is medium and low the additional risk of frozen soil is relatively lower. Measures to increase the infiltration capacity of the topsoil are recommended.
I 4 / I 6	Minimise risk for run-off and erosion with all viable in-field measures, edge-of-field buffers, and landscape measures (buffers, retention structures). Combine effective measures to achieve maximum effect.
I 3 / I 5	Reduce run-off at source by using all suitable in-field measures. Furthermore, implement buffers (in-field, edge-of-field) or suitable measures at landscape level (e.g. talweg buffers, retention structure), especially for fields with spring crops, or when in-field measures are not viable. Frozen soil: all three situations (I1, I2, I3) need to be considered as high risk. The frozen soil needs to be seen as a major barrier for infiltration especially during snow-melting. Reduce slope length (e.g. strip cropping, in-field buffer/hedges). Basic recommendations to prevent run-off and implement buffer zones.
I 2	Reduce run-off at source using suitable in-field measures. If this is not possible, consider implementation of buffer zones (edge-of-field, in-field).
T 3	Stop run-off at source using in-field measures and/or edge-of-field buffers **OR** ensure water infiltration in downhill plot by suitable measures (buffers, retention structures), if acceptable for field owner. In case of large amounts of run-off, stop it at source to avoid transfer to downhill plot (groundwater protection). Frozen soil: implement buffer zones (hedges, woodlands) and/or wetlands across the slope or alongside water scourses.
T 2	Maintain good agricultural practices on field to minimise run-off and erosion. In case of large amount of run-off, stop it at source (in the field) to avoid transfer of water to downhill plot (groundwater protection). If run-off transfer to downhill plot is not acceptable, treat plot as if adjacent to water in dashboard analysis.
I 1 / T 1	Maintain good agricultural practices on field to minimise run-off and erosion.

FIG. 5: DASHBOARD TO ASSESS THE RISK FOR RUN-OFF DUE TO SATURATION EXCESS (D2)

Proximity to Surface Water	Drainage Status	Topographic Position	Subsoil Permeability	WHC*	Risk Class & Scenario
Field Adjacent to Water Body	Not Artificially Drained	Bottom of slope (concave)/Valley bottom (see scenario A)	Plough pan + Permeability disruption	ALL WHCS	S 4
			Plough pan OR Permeability disruption	<120 mm	S 4
				>120 mm	S 3
			No plough pan & Permeability disruption	<120 mm	S 3
				>120 mm	S 2
		Upslope/ Continuous slope	Plough pan + Permeability disruption	ALL WHCS	S 4
			Plough pan OR Permeability disruption	<120 mm	S 3
				>120 mm	S 2
			No plough pan & Permeability disruption	<120 mm	S 2
				>120 mm	S 1
	Artificially Drained	All Positions	Plough pan + Permeability disruption	ALL WHCS	SD 3
			Plough pan OR Permeability disruption	<120 mm	SD 3
				>120 mm	SD 2
			No plough pan & Permeability disruption	<120 mm	SD 2
				>120 mm	SD 1
Field not Adjacent to Water Body	All soils: If drained see also SD-Scenario advice	Transfer of run-off to downhill field?	YES – Run-off reaches water body?	YES	T 3
				NO	T 2
			NO		T 1

* WHC = Water-Holding Capacity

Example: for dashboard use D2 – saturation excess

The dashboard splits into two decision pathways depending on the decision in the first column.

a) Field adjacent to water
b) Field not adjacent to water

Each column represents a decision level which needs to be taken step by step to reach the risk and scenario classification (from left to right).

The last column to the right indicates a risk category (colour) and a scenario number.
T stands for transfer, S stands for saturation excess.
The numbered scenarios are described separately.

(Guidance on how to estimate soil texture in the field, water-holding capacity and symptoms for permeability disruptions are presented in the field diagnosis manual).

RUN-OFF FROM SATURATION EXCESS (D2) SCENARIOS

S 4	Minimise risk for run-off and erosion with all viable in-field measures, edge-of-field buffers, and landscape measures (buffers, retention structures). Combine effective measures to achieve maximum effect.
S 3 / SD 3*	Reduce run-off at source by using all suitable in-field measures. Furthermore, implement buffers (in-field, edge-of-field) or suitable measures at landscape level (e.g. talweg buffers, retention structure), when in-field measures not viable.
S 2 / SD 2*	Reduce run-off at source using suitable in-field measures. If this is not possible, consider implementation of buffer zones (edge-of-field, in-field).
S 1 / SD 1*	Maintain good agricultural practices on field to minimise run-off and erosion.

* For all SD – scenarios consider: if there is a risk of transfer via drainage water, avoid the application of mobile PPP during the drain flow period (late autumn to early spring) and on cracked soils (spring/summer). If possible, retain the drainage water through retention structures (wetlands, ponds).

Field not adjacent to water body

T 3	Stop run-off at source using in-field measures and/or edge-of-field buffers **OR** ensure water infiltration in downhill plot by suitable measures (buffers, retention structures), if acceptable for field owner. In case of large amounts of run-off, stop it at source to avoid transfer to downhill plot (groundwater protection). Frozen soil: implement buffer zones (hedges, woodlands) and/or wetlands across the slope or alongside water scourses.
T 2	Maintain good agricultural practices on field to minimise run-off and erosion. In case of large amount of run-off, stop it at source (in the field) to avoid transfer of water to downhill plot (groundwater protection). If run-off transfer to downhill plot is not acceptable, treat plot as if adjacent to water in dashboard analysis.
T 1	Maintain good agricultural practices on field to minimise run-off and erosion.

* Description for D1 + D2

FIG. 6: DIAGNOSIS OF CONCENTRATED RUN-OFF & EROSION (D3)

				Risk Class & Scenario
Run-off is not generated in the audited field	Run-off coming from uphill area in the catchment			C 1
Run-off is generated in the audited field	Run-off concentrating in wheel tracks			C 2
	Run-off concentrating in corner			C 3
	Run-off concentrating in field access area			C 4
	Run-off moderately concentrated in rills	No hydromorphic soil		C 5
		Hydromorphic soil		C 6
	Run-off moderately concentrated in talweg	No hydromorphic soil		C 7
		Hydromorphic soil		C 8
	Run-off strongly concentrated	Gully not in talweg		C 9
		Gully in talweg	High infiltration soil in buffer	C 10
			Low infiltration soil in buffer	C 11

If concentrated flow is visible in the field, the run-off risk is high and mitigation measures are needed.

The dashboard evaluation starts by deciding if the observed run-off is generated in the audited field or not, and by subsequent classification according to the form of concentrated run-off observed.

Observations on existing mitigation measures and their effectiveness lead to proposals on measures considered if they can help to avoid the run-off.

Concentrated run-off is often associated with erosion, which is one of the critical issues in global agriculture.

RUN-OFF FOR CONCENTRATED FLOW (D 3): BMP FOR RISK MITIGATION

Presence from concentrated flows within the field identify a high risk of transfer of pesticides, so application of suitable mitigation measures is needed. Examples given are: reducing soil tillage, applying contour tilling, doing strip cropping, establishing talweg buffers and hedges/woodland buffers, building fascines, establishing vegetated ditches and artificial wetlands/ponds.

In particular, it is necessary to put in place appropriate actions in relation to type of run-off.

C 1

Prevent concentrated run-off at source uphill in catchment. Make run-off risk audit of the field where run-off is generated. Implement buffers and retention structures to intercept any concentrated run-off downhill.

C 2

Manage tramlines across slope orientation. Practice double sowing on headlands. Enlarge headlands.

C 3

If soil is not hydromorphic: implement vegetative buffers in corner of field. If soil is hydromorphic: implement edge-of-field bunds and build retention ponds.

C 4

Reduce soil compaction and implement buffers in field access area to increase soil infiltration capacity.

C 5

Implement or enlarge edge-of-field buffer, build retention structure (fascines, hedges/hedgerows), divide field with in-field buffer upslope.

C 6

Implement wide edge-of-field buffer (wet meadow) and/or wetland. Divide field with in-field buffer upslope.

C 7

Practice double sowing and establish/enlarge vegetated talweg buffer (at the bottom of field) or vegetated ditch. Build retention structure (retention pond and wetland). Reduce slope length upslope where concentration of run-off starts by strip cropping and in-field buffer.

C 8

Increase infiltration capacity of the soil through reduced tillage and measures to reduce speed of water flow. Implement talweg buffers, retention structures and wet meadows.

C 9

Close rills, implement/enlarge vegetative buffers, do double sowing, build retention structure by fascines and hedge buffers. Reduce field length by in-field buffers. Audit upstream fields and eventually implement mitigation measures. Review current cropping practices and consider other land use.

C 10

Close gullies, implement or enlarge talweg buffer, implement vegetated ditch or infiltration retention ponds. Reduce length of field by in-field buffers. Audit uphill areas in which implement mitigation measures.

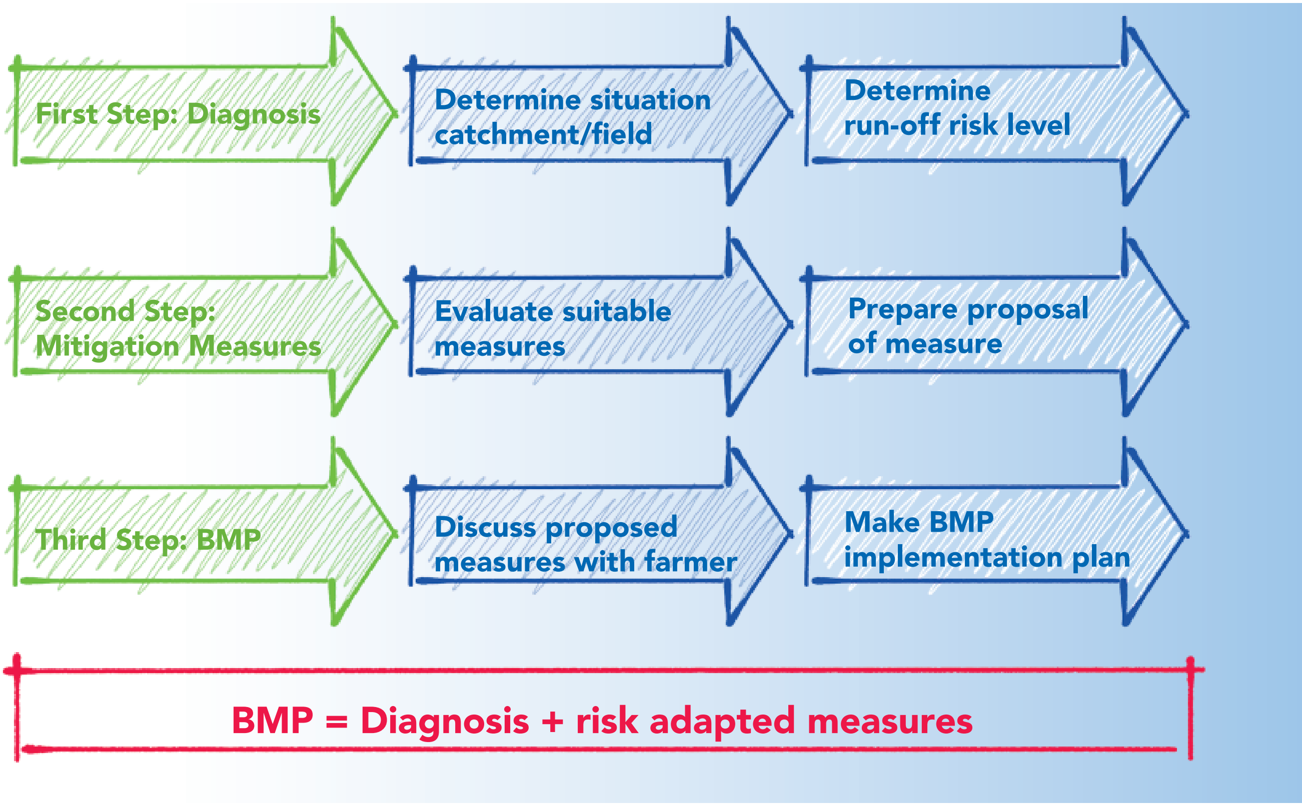
C 11

Close gully, implement or enlarge talweg buffer (e.g. wet meadows), build wetland or retention pond. Implement fascines to disperse the water and to reduce speed of water flow.

BEST MANAGEMENT PRACTICES (BMP)

Mitigation of run-off is complex and to generalise recommendations is difficult, as many influencing factors need to be considered. We therefore propose a concept, which actively involves the local adviser to optimise the set of different measures needed to mitigate run-off.

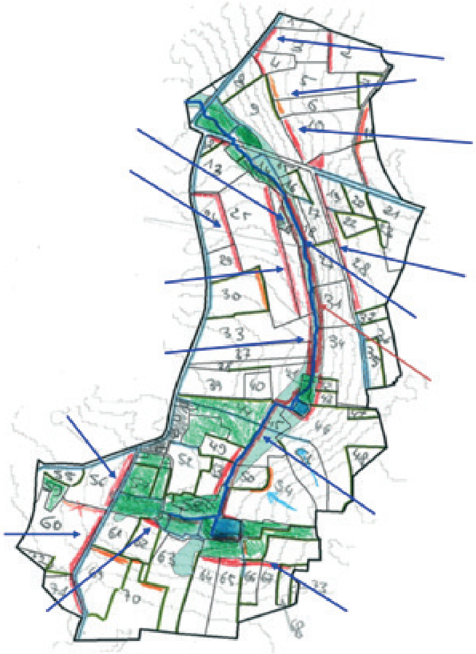
BMP Development Process



Implementation plan
Mitigation measures overview

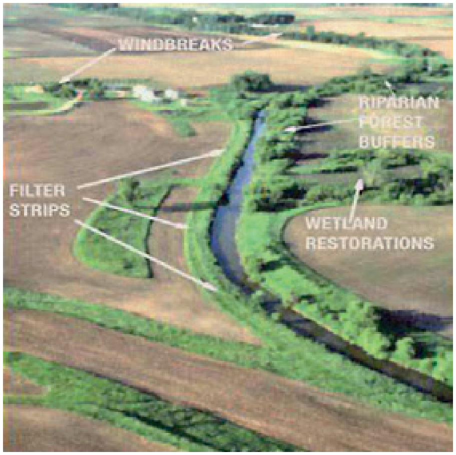
When the diagnosis/audit is completed the run-off risk in the catchment and in fields should be mapped. Mitigation measures need to be selected, which fit into the catchment-specific agricultural context (main production orientation, practices). The selected mitigation measures need to be discussed with farmers in the catchment and individually for specific fields. Funding options for measures requiring special infrastructural investments need to be investigated.

Communication on measures can be made more understandable and visible by showing them in maps (e.g. buffer strips, retention structure, already existing mitigation structures, water transfers in the catchments, etc.). At the end should be a concrete agreed plan between the farmer and the adviser, listing measures for implementation (Fig. 7 and 8).



Example: Catchment map for Fontaine du Theil, Bretagne, France (Source: IRSTEA)

- Blue arrows: water flow in catchment
- Blue: small water streams/water bodies
- Green: existing permanent grassland
- Field map, topography
- In red: proposed buffer structures for implementation



Example of various implemented mitigation measures

- Riparian buffer strip (Grass and woody structures)
- Wetlands to keep water in the catchment
- Filter strips in the field to prevent run-off at the source
- Windbreaks to mitigate wind erosion

OVERVIEW OF MITIGATION MEASURES AND EXAMPLE ON HOW TO DEVELOP BEST MANAGEMENT PRACTICES

Mitigation measures overview

Soil management	• Reduce tillage intensity • Manage tramlines • Prepare rough seedbed • Establish in-field bunds	• Manage surface soil compaction • Manage subsoil compaction • Do contour tilling/disking • Increase organic matter
Cropping practices	• Use crop rotation • Do strip cropping • Enlarge headlands	• Use annual cover crops • Use perennial cover crops • Double sowing
Vegetative buffers	• Use in-field buffers • Establish talweg buffers • Use riparian buffers • Use edge-of-field buffers	• Manage field access areas • Establish hedges • Establish/maintain woodlands
Retention structures	• Use edge-of-field bunds • Establish veget. ditches	• Establish artificial wetlands/ ponds • Build fascines
Adapted use of pesticides & fertiliser	• Adapt application timing • Optimise seasonal timing	• Adapt product and rate selection
Optimised irrigation	• Adapt irrigation technique	• Optimise irrigation timing and rate

Example: how to develop Best Management Practices

Efficacy of measures cannot be estimated generally and depends largely on the specific situations in a catchment and field. As a principle, water should be kept in the field where it is generated as much as possible and this principle determines the selection of the measures.
A consistent mitigation strategy needs to select the measures according to the risks identified during the diagnosis process. In low risk situations few measures may be needed, in high risk situations probably all available mitigation measures need to be applied. We also need to consider that combined measures have synergistic mitigation effects (e.g. soil coverage and tillage practice). These effects are not easy to estimate but local expertise can make judgements on the possible interactions.

BMP should be developed together with the farmer and adviser based on the field diagnosis and on the specific situation. Following Fig. (7, 8) show an example of how a set of measures can be selected in order to give a risk-adapted recommendation on Best Management Practices under a specific situation. As a result of the development of the BMP, the measures discussed and agreed should be documented in a report to enable a monitoring of the success of the measures.

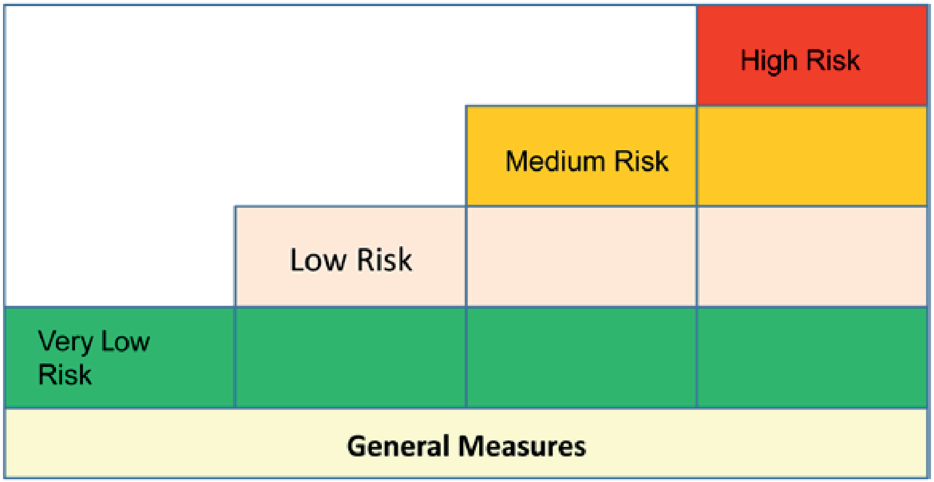


Fig. 7: Visual concept of how to build risk-adapted BMP by selecting appropriate mitigation measures

Fig. 8: Example to define BMP related to the estimated run-off risk and the efficiency of measures

Measures categories	General measures	Very low risk mitigation measures
Soil Management	Manage surface compaction Manage subsurface compaction Increase organic matter content	Prepare rough seedbed
Cropping practice	Use crop rotation (spring/winter crops)	Use cover crops Increase soil coverage with organic materials
Vegetative buffers		Manage field access areas Use riparian buffer
Retention structures		
Adapted use of PPP		
Optimised irrigation	Use modern technologies, adapt timing and rate of irrigation	

Low risk requires the implementation of few measures; high risk requires the implementation of most proposed measures

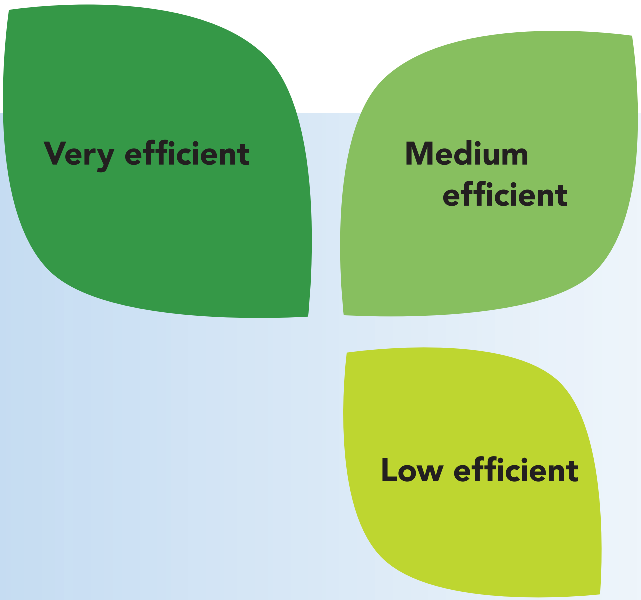
Low risk mitigation measures	Medium risk measures	High risk measures
Manage tramlines Apply contour tilling	Use in field bunds Reduce tillage intensity	Reduce tillage (no tillage)
Plant robust cover crop	Enlarge headlands Double sowing in more risky areas	Do strip cropping
	Use edge-of-field buffers Reduce length of field by in-field buffer	Establish talweg buffer Establish hedges/woodland buffers
	Use edge-of-field bunds	Build fascines Establish vegetated ditch Establish artificial wetlands/ponds
Adapt application timing	Adapt product and rate selection	

TOOLBOX OF MITIGATION MEASURES

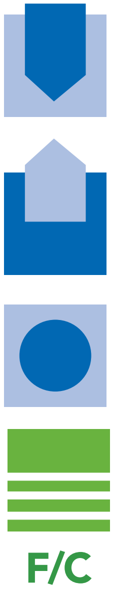
Mitigation measures are presented in this document by categories:

- Soil management
- Cropping practice
- Vegetative buffer strips
- Retention & dispersion structures
- Correct PPP use
- Irrigation

Before proposing/implementing mitigation measures always check that they are appropriate for the crop protection and tillage system of a farmer. Modifications of soil tillage or cropping practices should take into account all issues to be faced: soil, climate, materials, technology, weeds, pests, crop yields, crop quality and commercial factors.



To help selecting suitable measures, the efficiency of each measure has been evaluated regarding:



Infiltration restriction run-off

Run-off by saturation

Concentrated run-off

Implementation
Field scale (**F**)
Catchment scale (**C**)

Its efficiency has been defined by considering research available and "expert knowledge/assessment".
It has been defined with a colour code:

Soil management

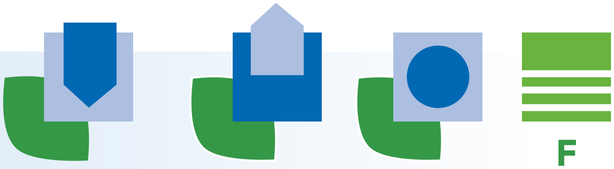
Soil management has an influence on the water infiltration capacity of the soil. Key elements to increase the infiltration capacity include:

- Breaking of soil compactions (soil surface and subsoil)
- Increasing the soil porosity (water-holding pores, aggregation)

The aim of these measures is to keep the water in the field and to avoid run-off at the source.

Reduced tillage, together with crop rotations and cover crops are the three core practices in conservation agriculture. In situations where reduced tillage may be difficult or not possible, all other measures, which help to reduce soil compaction, may become necessary. Traffic of machinery on the field needs to be reduced to an absolute minimum to avoid soil compaction as far as possible.
A diagnosis of the soil and catchment will help to target the soil management measures to the sensitive fields.

1. Reduce tillage intensity



What to do

Reducing soil tillage leads to an improved pore continuity in the topsoil and thus enhances infiltration of water. Reduced tillage also increases crop residues left on the soil surface slowing down water flow on the surface and reduces also the slaking effect of raindrops on uncovered soil surfaces (capping process). Reduced tillage also increases the biological activity in the topsoil layer. Especially the increase in the number of earthworms (soil macro pores) and microbial activity (stable aggregates) have a positive influence on water infiltration. Liming the soil has also a positive impact on soil structure as well as soil pH. Consequently less soil tillage needs to be done at the start of the next growing season.

How to do it

Reducing tillage intensity can be understood in three different ways:

- Changing the tillage system: change from ploughing to reduced tillage or no tillage
- Reduce energy of the machinery/tools working the soil
- Reduce number of passages
- Reduce driving velocity
- Replace power take-off (PTO) driven soil cultivation machines with non-PTO driven machines

Constraints

On clay soils a certain amount of light tilling may be necessary to reduce the amount of soil cracks formed during the summer and to avoid soil compaction. In the case of swelling clay soils, no tillage may result in even lower infiltration capacities. On fields with an artificial drainage network, some form of tillage is necessary to reduce the preferential water flow through the topsoil towards the tile drains via macropores and cracks formed during drying of the soil in summer. When implementing no tillage technical and economic issues (time and cost) need to be considered. Since soil cultivation modifies many parameters, any change made to the way crops are established must be accompanied by other modifications designed to optimise the cropping system.

Efficiency

Many studies show that it takes time for tillage modifications to have a significant impact on the movement and storage of water in soil. About 3 to 5 years of minimum tillage or no tillage management can be necessary for the system to reach the full positive effects on soil water. The effectiveness of adapted tillage to mitigate run-off/erosion is high, if the risks are mainly caused by poor soil management (e.g. capping). Better soil management can reduce run-off by about 50% and erosion by about 90%.

A reduced tillage practice tends to have lower rates of mineralisation of organic bound nitrogen, but more significant is the increased denitrification rate. Consequently, nitrogen transfer could be slightly reduced. Less disturbance of the soil increases soil biodiversity and needs less tractor power per area (energy-saving).

Clay soil with cracks

F

What to do

Studies have shown that rough seedbeds with clods can slow down the flow of run-off water and increases infiltration The soil clods work like little barriers and increase the infiltration of water into the soil. The soil clods also avoid the “splash-effect” of the rain droplets, which can break the silty fine aggregates and reduce the infiltration capacity of the soil surface (capping).

How to do it

Reduce tillage to a minimum when preparing the seedbed. Then coarse aggregates are preserved. Do not roll over after drilling.

When ploughing, keep as many clods as possible, particularly if PTO-driven machines for seedbed preparation are used.

If PTO-driven machines are used, speed of tool rotation should be as low as possible but travel speed of tractor should be as high as possible.

On silty soil, a cultivator to avoid a fine seedbed is ideal to use.

Efficiency

Roughness of the soil surface has a significant mitigation effect by slowing down water flow and increasing infiltration.

Soil clods slow down the flow of run off

3. Avoid surface soil compaction (capping, soil crusts)

F

What to do

Mainly soils with high silt content (>30%) are prone to capping (also termed crusting) after rains. Soil crusts reduce the infiltration capacity of the soil and therefore represent a high-risk situation for run-off and erosion.

Avoid surface soil compaction

How to do it

In general, maintenance of high organic matter content in topsoil improves aggregation and thus reduces the tendency of soils to crust. A high amount of plant residues on the soil surface reduces rain splash erosion of aggregates and thus also decreases formation of crusts. Reduced tillage and no tillage systems can be used to reduce these two processes in soil. If the formation of crusts or capping layers cannot be avoided, the crusts need to be destroyed mechanically.

To break the capping layer, hoes or harrows can be used. Measure should be implemented:

- When soil is not too moist
- Using low-pressure tyres or reducing tyre pressure
- On winter cereals, at early growth stage

- On maize (stage max. 8 and 10 leaves) or sugar beet

- Hoe as soon as the soil is capping (crack the crust)

Stubble ploughing should be done as soon as possible after harvest and if the inter-crop period is long, plant cover crops.

Efficiency

Avoiding surface compaction in fields is an efficient mitigation measure to reduce run-off and erosion due to better water infiltration. Studies made e.g. in France (Epreville-en-Roumois, 27, from 2000 to 2001, Chambre d'Agriculture de l'Eure) showed that run-off was 13 times lower on a field with stubble ploughing than without.

F

What to do

Subsoil compaction (e.g. plough pan) can be a barrier for water infiltration and a reason for subsurface run-off (lateral seepage or run-off by saturation). Soil compaction can best be observed in winter by monitoring the fields for areas with standing water. Also certain plants may indicate compacted areas (e.g. Plantago spp., Polygonum aviculare, Equisetum spp.). A thorough diagnosis is necessary to select the most effective mitigation measures.

How to do it

Avoid ploughing or harvesting when the soil is too moist, especially after late harvest of crops, e.g. sugar beet, maize or others.

Use low-pressure tyres or twin tyres to prevent soil compaction to a minimum level. Subsurface compaction can be broken mechanically (e.g. ripping) or by growing plants with taproots (e.g. oilseed rape, look for local recommendations).

Efficiency

Efficiency depends on how much the infiltration capacity of the soil could be increased.

Harvesting when the soil is too moist can generate soil compaction

5. Manage/orient tramlines

F

What to do

Tramlines are crop-free areas in the field, where the tractor drives to spray and to fertilise the crop. These tracks are adapted to the size of the machines to ensure precise application. During a season, machines will travel on the tramlines several times, which can result in soil compaction. If the tramlines are oriented in the direction of the slope they work like channels for run-off water and soil erosion.

If water is often observed in the tramlines (e.g. in winter), it indicates problems with compaction (reduced infiltration). Controlled traffic farming (CTF) intends to reduce random traffic on the fields by tramlines, which are used for several years. This may have advantages in the precision of the field work, but if the field is located in a risk area for run-off such compacted tracks can be just channels for water and erosion if not located correctly.

How to do it

- Avoid seedbed preparation when the soil is too moist. Avoid ploughing or harvesting when the soil is too moist, especially after late harvest of crops e.g. sugar beet, maize or others

- Reduce pressure in tyres or use low-pressure/twin tyres on machines

- Tramlines should run across the slope if possible (avoid channel effect). This can be difficult to achieve, if there is more than one slope direction in the field or slope creates risk for machinery overturns

- Compacted soil in tramlines can be broken mechanically by special implements attached to the machines, to have a plant cover or to create bunds slowing the water flow. This also roughens the tramline surface, slows down the flow and increases the infiltration rate of water

- Alternate the orientation of tramlines after each cropping season if possible (reduces hotspot compaction)

Efficiency

On sloping areas and fields located close to surface water correct tramline management is an effective mitigation measure to reduce run-off/erosion.

F

What to do

A bund is a barrier/small dam in the field which retains water in the field and slows down the water flow in order to allow more water infiltration.

How to do it

Bunds need to be designed to retain run-off water and give it more time to infiltrate. They mainly work in fields with slight slopes, because the water volume and pressure should not be too high in order not to break the bunds.

- In field bunds should be made across the field slope/ follow contour lines

- Inter-ridge bunds

In row crops like potatoes, bunds between the ridges have shown good effects to mitigate run-off. Special machines are available, which make such bunds when preparing/ maintaining the ridges. Bunds are especially important when the crop does not yet cover the soil surface completely.

Efficiency

Bunds are effective measures if the slope of the field is not too steep. The distance and height of bunds needs to be adapted to the expected water flow volume in the furrow.

Contour tilling is a practice that is still more common in North America than in Europe. The main reason why this practice is seldom used in Europe is probably the smaller size of the fields, which restricts the implementation of such a technique. Contour tilling means that soil cultivation follows the contour lines in a field to redirect water flowing downhill. This creates rough surfaces acting as small bunds to slow down water flow and increase water infiltration. Machines building ridges can increase the surface roughness. Contour tilling is efficient on slight to medium, rather uniform slope areas of 2 to 10%. The slope length should be longer than 35 m and not exceed 120 m.

(http://www.nrcs.usda.gov/Internet/FSE_Documents/nrs143_026017.pdf).

What to do/How to do

Special care or equipment is necessary to follow the contour lines during farming operations. Examine carefully the fields on their suitability for contour tilling (rather uniform slopes, not too steep) in the context of the available machinery (tractor with wheels vs. crawler, GPS systems).

Efficiency

Studies showed 10 to 50% reduction of rates of erosion compared with "downhill" tilling. Combined with other measures (e.g. conservation tillage) contour tilling showed a 95% reduction of erosion compared to traditional soil cultivation and downhill farming system.

An extreme but very efficient form of contour tilling is building terraces to reduce the slopes in the field/catchment, to reduce downhill water flow and to accumulate water in the soil of the terraces. Such measures require large investments to shape the catchment for cropping purposes.

Cropping practices

Cropping practices can strongly reduce the risk of run-off and erosion. Specific crops can improve the soil structure and stability. The goals are to balance physical-chemical soil properties via:

- Rotation of suitable crops
- Increase in water infiltration by planting crops with deep root systems (increasing soil porosity)
- Protection of the soil surface by plant cover/organic matter cover to reduce rain splash erosion
- Distribution of crops across large fields (reduce the field size). Crops may then serve as vegetative buffers to reduce the speed of surface run-off flow and to minimise run-off through infiltration (strip cropping)
- Distribution of crops in the catchment. A balanced crop distribution in the catchment also reduces the risk for a single PPP to enter into surface water due to less intensive use in a catchment (usually, different PPP will be used on different crops)

8. Optimise crop rotation

Crop rotation is the succession of crops on the same field with the main goal of maintaining soil fertility and crop productivity over the years. Long crop rotation (alternation of winter and spring crops) is a measure to reduce pest and disease pressure and is a major element for implementing Integrated Pest Management (IPM). Crop rotation should not only be seen at field scale but also on a catchment scale, especially in vulnerable areas.

The crop rotation influences largely the organic matter content in the soil. Crops like sugar beet, potato and silage corn are known as crops reducing the organic matter content, whereas, e.g. cereals with straw, oilseed rape, grain corn, intermediate crops and organic fertilisers increase organic matter. Organic matter supports soil structure, soil aggregates and has a high water-holding capacity. It also increases the microbiological activity and therefore the degradation and adsorption of PPP.

Optimised crop rotations have a direct and indirect mitigation effect on run-off and erosion.

What to do

Optimisation of crop rotations depends on weather, soil conditions and duration of the growing season. Commercial or work capacity aspects may interfere with the sustainable/agronomic optimum. The optimal management of the organic matter content in the soil should be a main consideration to define the crop rotation which at the same time mitigate run-off and erosion. In some countries regulations exist to support the management of organic matter contents. Additionally, crops differ in their ability to cover the soil during critical periods. Crops providing a dense plant cover for the soil in times when run-off risks are high should be preferred.

How to do it

Optimise crop rotation by thorough planning. Alternate between crops providing a dense soil cover, e.g. cereals, oilseed rape, on risky fields and periods and leave organic residues after harvest on the field surface. In vulnerable catchments crop rotations should be discussed among farmers in the same catchment. Respective structures/organisation should be implemented to support and plan a catchment-optimised crop rotation.

Efficiency

Crops which cover the soil during rain events may reduce run-off/erosion by 50 to 90% depending on the crop succession. Crop rotation is particularly effective if meadow crops are grown on the lower parts of slopes.

9. Implement strip cropping in field (across the slope)

Strip cropping in a large field can be seen as a measure to downsize the field by growing different crops on such a field. Strips of row crops e.g. potato, sugar beet, maize followed by a broadcast crop (e.g. winter cereals, oilseed rape or others) reduce water flow, increase infiltration and trap sediments. In semi-arid areas a strip of fallow land sometimes follows a strip of a crop. The main purpose of these fallow strips is to collect and store water in the soil. The crop strips follow as much as possible the contour lines in the field and function as annual in-field buffer strips.

In recent years also in Europe fields have increased in size and it seems therefore possible to apply such measures in areas where fields are large and run-off/erosion risks are high.

What to do/How to do

Divide large fields vulnerable to run-off/erosions by planting different crops in strips along the contour lines. Requirements and restrictions are widely comparable with those mentioned under contour tilling.

F

Sowing an intermediate crop after harvest and before sowing a new commercial crop to cover the bare soil, is a very effective mitigation measure. The cover crop selection depends on the available vegetation time, soil conditions, soil moisture and requirements of the next crop intended to be sown.

Cover crop systems reduce rainfall impact and increase soil organic matter that improves aggregate stability, splash resistance, and soil resistance to compaction. Due to improved water infiltration they can indirectly reduce the volume of run-off and/or drainage water. Cover crops are also beneficial; they reduce nutrient losses to water, because available nitrogen and phosphate will be utilised (trapped). Cover crops are easier to establish in humid and sub-humid regions, where precipitation is more reliable than for semi-arid regions, where precipitation is limited. Check with your adviser which cover crop would fit best into your crop rotation and to your (pedo-climatic) region.

Funding options and legal requirements should be considered if locally available. In France, for instance, cover crops are compulsory in vulnerable zones related to the nitrogen directive.

What to do

The duration of the growing season, requirements of the seedbed and sowing time of the following crop will determine the cover crop system.

a) The longer the cover crop (intermediate crop) is grown in the field between the main crops, the higher is the effect. Following crops are sown directly into the cover crop after desiccation or the cover crop is incorporated into the soil to allow sowing.
b) If seedbed requirements for the following crop are high (e.g. fine seedbed) a cover crop with shorter vegetation time can be selected, desiccated, e.g. by frost (e.g. Phacelia). In this case the mitigation effect in spring is mainly related to the organic material, which covers the soil surface.

How to do it

- Sowing conditions for cover crop should allow for fast and dense establishment
- If possible plant across the slope
- Different materials and techniques can be used for drilling: they need to be adapted to the local conditions and requirements of the seeds
- The establishment of cover crops can be done in different ways: e.g. sowing into a ripening crop or after harvest into the stubble. For instance, after harvest of silage maize, cover crops won't be well established. However, rye grass can be drilled before the harvest. This could be done with drilling machines at the 8 to 10 leaves stage of the maize
- When destroying cover crops, before the sowing of spring crop, vegetal residues should be left on the field to protect the soil

Efficiency

The efficiency of this measure depends on how well established the cover crop is at the time of the rain events. A well-established cover crop will almost totally eliminate run-off and erosion. For instance, a study from France (Fresquiennes 2004–2005 – Chambre d'Agriculture 76, France) showed that a mustard cover crop decreased erosion by a factor of 25 compared with a bare soil (from 1,000 kg soil loss to 40 kg soil loss).

Constraints

Cover crop can interfere with the following crop due to:

- Poor seed-soil contact of the following crop, if cover crop residues interfere with planting operations (slow and uneven emergence)
- Soil water depletion/scarcity: slower drying and warming up of soil in spring (delayed emergence)
- Allelopathic effects of cover crop residues
- Increased levels of soil-borne pathogens
- Increasing level of insects, snails, other pests and diseases

11. Implement double sowing

What to do

Usually the optimal density of crop is adapted to local conditions, but when diffuse run-off is observed on a field, a strip with a higher plant density of a crop can reduce the volume of surface run-off water, without implementing a non-crop buffer strip (works like an annual crop buffer strip).
Example: when sowing cereals in a talweg then double the sowing density to normal, which will reduce the flow of water strongly and will be less susceptible to erosion.

How to do it

The double sowing is done in a strip across the slope or in a talweg in addition to the first sowing process. The placement of the double-sowed strip follows in principle the same methodology as in-field vegetated buffer strips.

12. Establish perennial cover crops in plantations

Perennial cover crops offer the potential to protect and shade the soil and to increase the porosity of the soil. This slows down water flow, increases the infiltration of water, and traps sediment in run-off, thus effectively reducing run-off and erosion. Perennial cover crops are generally established with the plantation crop and are maintained throughout the existence of the plantation (vineyard, orchard, citrus groves, etc.). Establishment of perennial cover crops is recommended in areas where water availability is not a limiting factor. In dryer areas, perennial cover crops can compete for water with the plantation crop. In such situations cover crop species need to be selected carefully. It might be necessary to switch to annual cover crops, desiccate the cover crop at times, or to protect the soil with organic materials (e.g. straw, compost, others). However, plantations located in hilly areas without cover crops, often exhibit a very high risk for run-off and especially for erosion.

What to do

- Select the suitable cover crop for the plantation in your region, based on the risk category indicated in the field/catchment diagnosis. Examples of green covers are grasses, or a mixture of grass and clover. Maintain the cover crop in a way that it provides a rather complete soil cover and keeps the ability to mitigate run-off/erosion (resistance through strong stems). Establish a cover crop in every second row and investigate alternative/additional measures if soil and moisture conditions restrict the implementation of perennial cover crops
- Adapt recommendations to the local situations

How to do it

Establish perennial cover crops between the crop rows. Maintain the cover crop by mowing or other means to control the height of the cover crop (10 to 15 cm). If cover crops cannot fully cover the soil surface bring in additional organic materials to cover the soil. Consider also biodiversity aspects when selecting the cover crop (e.g. Lolium spp. showed lower biodiversity). Cover crops should not interfere with PPP applications needed through continuous flowering (reduce risks for bees).

Efficiency

In areas where plantations are grown on gentle slopes, the efficiency of cover crops to mitigate run-off can reach 100%. In steeper areas efficiency may only reach 50%. Such situations require additional measures to reduce the run-off/ erosion risk. It is important that the cover crop is not too high (<25 cm) and that the plant stems are strong enough to withstand the forces of the flowing run-off water.

13. Enlarge headlands

F

Often, the dominant cultivation direction of fields runs in the down slope direction and sometimes this cannot be changed due to various reasons. As the headland is usually cultivated in a perpendicular direction to the rest of the field, this area may serve as a cropped barrier for water running downslope.

What to do

Drill crops at the headlands across the slope. Enlarge the headland if field has been diagnosed as having a higher run-off risk. Double sowing of the headland might be an option to further increase the mitigation effect of the headland (buffer strip).

How to do it

Determine the size and the sowing density of the headland according to the run-off risk which has been determined by the field diagnosis. Headlands can be expanded until the land is getting too steep to work safely with the machines.

Vegetative buffers

General considerations

Vegetative buffers can be considered as infrastructure measures (established for several years) in a catchment. The functions of buffers are to:

- Provide infiltration areas for surface run-off water
- Slow down surface run-off water through appropriate vegetation and to catch sediments
- Provide habitats to increase biodiversity
- Provide areas where PPP are not applied, reducing applications close to surface water in vulnerable locations

Buffers are quite efficient at trapping eroded sediment and reducing the overall amount of water leaving the field. The main aim of vegetated buffer zones is to intercept run-off from cultivated plots upslope; therefore their positioning in the catchment is crucial. Due to the complexity and variability of factors controlling the effectiveness of a buffer zone, the recommendations for the location and sizing of buffer zones need to be **based on a thorough diagnosis**. General recommendations are given in this section. For more information, see CORPEN brochure: English reference (www.TOPPS-life.org).

Shortcuts, as seen often, should be avoided as they just transfer the problem out of one field to the next field or directly to a watercourse.

a) Buffer location and sizing

Buffers may vary in size, largely based on the buffering objectives, the soil and catchment characteristics, and their interaction with other mitigation measures. The positioning of buffer zones needs to consider the flow regime of surface water in a catchment: buffer zones should be preferentially located at sites near the origin of any diffuse run-off (ideally before any formation of concentrated run-off), in the upstream parts of the catchment. Surface run-off is initially diffuse at the level of the plot while it tends to become more concentrated as it flows downhill in the watershed (often accumulates in a valley/talweg).

The right positioning of the buffer in the catchment is usually more important for its efficiency to reduce run-off than its width. A buffer aiming to stop primarily eroded soil particles can be smaller than one with the aim of intercept run-off water and its dissolved pollutants. Other parameters such as soil permeability, soil saturation, slope length and the run-off area also have to be considered. In areas and at times when soils are waterlogged (or flooded) the efficiency of a grassed buffer zone is generally low, because buffers with saturated soil cannot capture run-off water by infiltration. This effect needs to be especially considered for riparian buffers, which are potentially more prone to waterlogging than upslope buffers.

Different buffer types are required to match these different run-off scenarios:

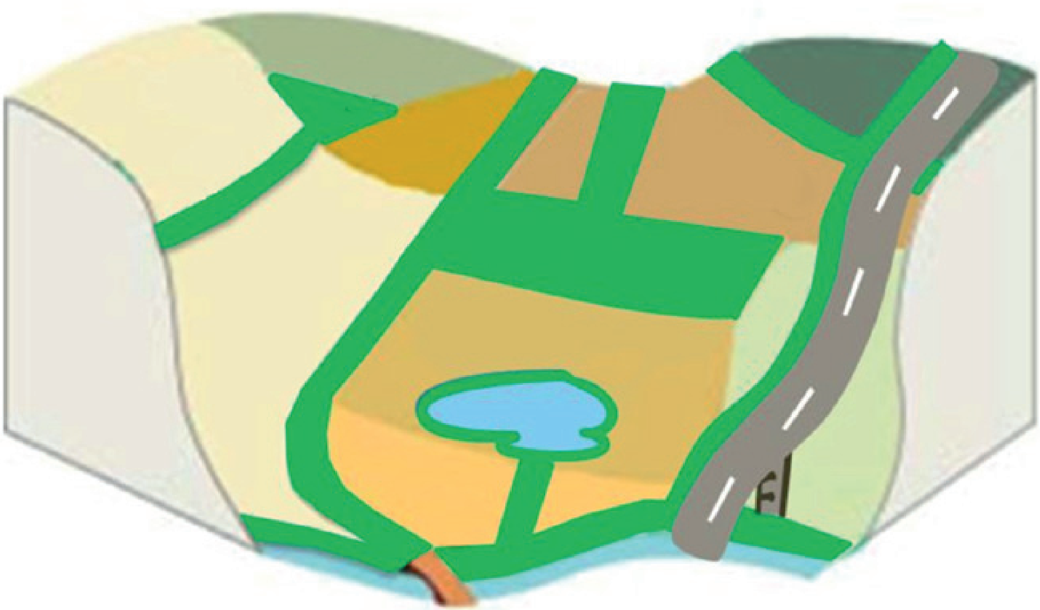
- In-field or edge-of-field grassed buffers are needed to intercept diffuse run-off on or near the plot

- Alongside riparian areas, grass filter strips are essential to prevent run-off water from fields from enter the surface water directly. Protection of surface water bodies by riparian buffers is especially important and effective in the upstream part of the catchment, as well as in the vicinity of water springs in chalk aquifer areas

- Establishment of grassed talweg buffers can be necessary to enhance infiltration of concentrated run-off water in natural water flow pathways/hollows on hillsides. Roads alongside fields often act as a concentrated flow pathway collecting run-off water: therefore establishing buffer zones alongside roads (edge of field buffers) protects these potential linear pathways from run-off water

- Natural water infiltration zones (e.g. dry valleys, sinkholes) in karstic areas should be protected from run-off in the same way as surface water bodies, as these areas provide a direct link from the soil surface to groundwater

1: In-field buffer, used to break up a long slope inside a cultivated field.
2: Edge-of-field buffer zone, protecting a road (potential water pathway).
3: Edge-of-field buffer zone in downslope corner of a field, where water is concentrating.
4: Grassed talweg, to reduce concentrated water flow.
5: Large grassed buffer zone (i.e. meadow), used to intercept, disperse and infiltrate concentrated water flow exiting from the upslope talweg.
6: Riparian buffer: grassed buffer strip between edge of field and a surface water body, to intercept diffuse run-off from the upslope field. (Source: CORPEN/IRSTERA Modified.)



Maintenance and care

Different types of vegetative buffers can be established:

- Grassed buffers
- Hedges
- Combination of hedges and grass
- Woodland
- Meadow

Water infiltration is better in buffer zones planted with woody and ligneous vegetation due to the more extensive root system. Dense grass vegetation is more efficient for slowing down surface water flow and thus enhances trapping of eroded soil particles. Combinations of both systems offer the advantages of both types of vegetation. As a side effect, dense vegetation on buffers also enhances the degradation of PPP in the soil due to the build-up of organic matter which stimulates microbial activity. Selection of plant species for vegetated buffer strips needs to consider local requirements and cannot be generalised. Species selection may also be influenced by other buffer functions, such as providing bee forage or habitats for selected plants or animals.

b) Buffers need to be maintained and managed to remain functional

Good surface roughness in the vegetated buffer zones is important to trap soil particles transported in run-off water. For grassed buffers a regular mowing of the grass is necessary. The average height of the grass should be around 10 cm and the maximum height should not exceed 25 cm to maintain erect grass leaves. If grass is allowed to grow higher, it will be pressed down by run-off water and the buffer will have a reduced efficiency for slowing down run-off water and trapping soil sediment. As a minimum, one mowing per year is necessary, respecting the breeding periods of birds as well as flowering/seeding periods of forage plants. Mowing machines should be equipped with warning systems to protect wildlife.

Essential for buffer zone functioning is also to avoid all processes that decrease water infiltration into the soil. Therefore soil compaction needs to be avoided by limiting the traffic of machinery to the minimum possible. Buffers should not be used as pathways for machines to fields. Use of buffer zones as animal pasture might be possible, but grazing with large animals can also cause soil compaction. In this respect also the contamination of surface water with additional nutrients and pathogenic microbes from animal faeces needs to be considered.

Buffer infiltration efficiency is also reduced by soil sediment accumulating on the buffer, causing a clogging of soil pores as well as leading to concentration of water flow in the buffer. Therefore a regular sediment removal or spreading out of sediment on vegetated buffers is needed. Soft tillage may be used to level the soil surface.

Buffer zones shouldn’t be fertilised or sprayed with PPP, unless it is essential for the establishment of desired plants: this is especially true for riparian buffers, where a quick transfer of run-off to adjacent surface water bodies is possible.

c) Efficiency and constraints

A review of scientific studies shows a large variability in the effectiveness of buffer zones, suggesting that a wide range of physical, chemical and biological factors are involved in the functioning of grassed buffer zones. Riparian buffers are effective mitigation measures reducing PPP entries into surface water. Yet, reduction efficiency varies between 50 and nearly 100% depending on infiltration capacity of the buffer (i.e. soil texture and structure), initial soil moisture content in the topsoil, the trapping capacity for soil particles, the characteristics of the rain events, and the width of the buffer strip.

However, three factors can be singled out that are usually responsible for low efficiency of buffer strips:

- **Waterlogging of soils:** if the soil in the buffer zone has become saturated, this will negatively impact the infiltration capabilities, despite the positive trapping effects of the vegetation. In this case, the efficiency of the buffer zone for retention of pesticides in run-off water is substantially reduced. This phenomenon is especially relevant for riparian buffers, which are close to surface water and typically show high groundwater levels

- **Soil compaction:** if the soil in the buffer zone is compacted by frequent passing of farming machinery or animal traffic, the water infiltration capacity of the soil will decrease, resulting in a reduced efficiency to intercept run-off

- Sediment deposits of eroded soil material in the grassed zone may lead to malfunctioning during successive rain events, due to the clogging of soil pores and development of concentrated flow pathways

d) Other positive effects

Vegetative buffers can serve various other functions in the catchment:

- Overall reduction of erosion in a catchment and thus reduction of siltation in streams. Reduction of nutrient (phosphorus, nitrogen) inputs to surface water, which lead to eutrophication of water bodies
- Providing habitats for key species and generally increasing biodiversity in agricultural catchments
- Increasing ecosystem connectivity in agricultural catchments by providing living and travelling corridors for species in catchments
- Contributing to catchment heterogeneity/diversity and attractiveness for tourism

The measures described in the following chapters discuss buffers, which differ in their location, size and composition; effects are similar for all kinds of buffers.

F/C

What to do

In-field buffers can be very efficient as they can infiltrate run-off water in the soil coming from uphill areas when the amount of run-off water is still relatively small. Compared to riparian buffers, which can be waterlogged at times and often face concentrated flow, in-field buffers potentially have higher infiltration capacities and can be more efficient to stop diffuse run-off at source. Typically such buffers are implemented as permanent grass buffers or hedges.

How to do it

Locate and size the buffers according to the diagnosis done for the specific field and related to the mitigation objective. In-field buffers should follow as much as possible the contour lines in the field and should be positioned in a way that no concentrated flow develops (rather uniform slope/no talweg). Shortcuts for water through buffers (e.g. via tramlines or tracks) should be avoided. In-field buffers can be set up as grassed buffers or hedges, depending on desired additional functions that hedges may provide (wind shield, biodiversity, etc.).

Species planted should:

- Be part of the natural vegetation; non-invasive)
- Be adapted to the local conditions (e.g. to regular drought or inundation)
- Have stiff leaves in order to resist the water flow, thus reducing the speed of the run-off water
- Provide a dense vegetation cover on the buffer

Efficiency and constraints

In-field buffers may increase the working time needed to produce a crop on a field if the general cropping direction is downhill. In-field buffers are effective for trapping diffuse run-off from fields. However, if concentrated run-off arrives at such buffers, it usually cuts quickly through the buffer. Therefore, the prevention of concentrated run-off in fields has highest priority (e.g. by managing tramlines, contour tilling, etc.). In case of unavoidable concentrated run-off at times, a deep furrow between the cropped area and the buffer may serve as a distribution structure for incoming run-off water.

15. Establish and maintain edge-of-field buffer

F/C

Edge-of-field buffers are located at the downslope end of a field, often separating a field from the next or from a road. The function of the buffer is to infiltrate run-off water in the soil and to trap sediments before run-off water reaches a road or enters into a downhill field.

What to do

Locate and size the buffers according to the diagnosis done for the specific field and related to the mitigation objective.

Edge-of-field buffers can be very efficient as they can infiltrate run-off water in the soil coming from uphill areas when the amount of run-off water is still relatively small. Compared to riparian buffers, which can be waterlogged at times and often face concentrated flow, edge-of-field buffers potentially have higher infiltration capacities and can be more efficient to reduce diffuse run-off. Typically, such buffers are implemented as permanent grass buffers or hedges.

How to do

Locate and size the grassed buffers according to the diagnosis done for the specific field and related to the mitigation objective. Shortcuts for water through buffers (e.g. via tramlines or tracks) should be avoided. Edge-of-field buffers can be set up as grassed buffers or hedges, depending on desired additional functions that hedges may provide (wind shield, biodiversity, etc.).

Species planted should:

- Be part of the natural vegetation; non-invasive)
- Be adapted to the local conditions (e.g. to regular drought or inundation)
- Have stiff leaves in order to resist the water flow, thus reducing the speed of the run-off water
- Provide a dense vegetation cover on the buffer
- If sediments accumulate on buffers: spread sediment across the buffer, or remove and spread on upslope field

Efficiency and constraints

Edge-of-field buffers are effective for trapping diffuse run-off from fields. However, if concentrated run-off arrives at such buffers, it usually cuts quickly through the buffer. Therefore, the prevention of concentrated run-off in fields has highest priority (e.g. by managing tramlines, contour tilling, etc.). In case of unavoidable concentrated run-off at times, dispersion measures or upslope measures need to be considered.

16. Establish and maintain riparian buffer

F/C

Riparian buffer strips are buffer zones of managed or unmanaged vegetation situated alongside watercourses or ditches. The functions of these buffers for run-off prevention are similar to the above-mentioned buffers: they reduce run-off by infiltrating water in the soil and trap sediment by reducing the water flow speed.

Additionally, riparian buffer strips are efficient mitigation measures to reduce entries of substances transferred by wind (e.g. spray drift of PPP or dust) to surface water. This effect can be even increased if hedges or woody structures (bushes, trees) are planted on the buffer.

Riparian buffer zones are regulated in some EU countries. Widths of required riparian buffers vary significantly from country to country as also do the basis for these regulations. Riparian buffers can support additional environmental targets: e.g. mitigation of pollutant nutrients, PPP, sediments, and pathogenic microbes.

a. Stabilising riverbanks
b. Improve ecological conditions in streams (providing forage, shading of water)
c. Increase biodiversity
d. Contribute to ecosystem connectivity (green corridors in catchments) and catchment diversity)

Studies show that most of the surface run-off water in a river comes from small streams in the upper catchment (level 1 or 2 streams, as defined by the Strahler method; see Fig. 12).

Therefore, high priority should be given to the protection of these categories of streams via riparian buffers. Protection of higher-level branches of the hydrographical network (level 3 and higher) by riparian buffers will only have a limited effect on the overall stream water quality, but may be quite important to achieve other protection goals (see above).

What to do

As a first step all protection goals of a riparian buffer need to be defined. A run-off risk diagnosis on catchment and field level should suggest the required buffer minimum width for mitigation of run-off input to surface water. If this analysis requires too large buffers, combination with further buffers/measures need to be considered to optimise buffer efficiency and area requirements for agricultural production. The vegetation on the buffer strip needs to be adapted to the intended protection goals: annual, perennial, or mixed vegetation (grass, bushes, hedges or trees).

How to do it

Smaller ditches/streams (permanent non-permanent) are often only protected by grassed buffer strips, while for larger streams and rivers woody vegetation becomes more important to achieve all protection goals.

Locate and size the grassed buffers according to the diagnosis done for the specific field and related to the mitigation objective. Shortcuts for water through buffers (e.g. via tramlines or tracks) should be avoided.

Species planted should:

- Be a natural vegetation; (non-invasive)
- Adapted to the local condition (e.g. to regular inundation),
- Have stiff leaves in order to resist the water flow, thus reducing the speed of the run-off water
- Provide a dense vegetation cover on the buffer

Riparian buffers should not be:

- Fertilised
- Sprayed with PPP
- Used as a pathway for machinery

If sediments accumulate on buffer strips: spread sediment across the buffer, or remove and spread sediments on up-slope field (e.g. harrow, other).

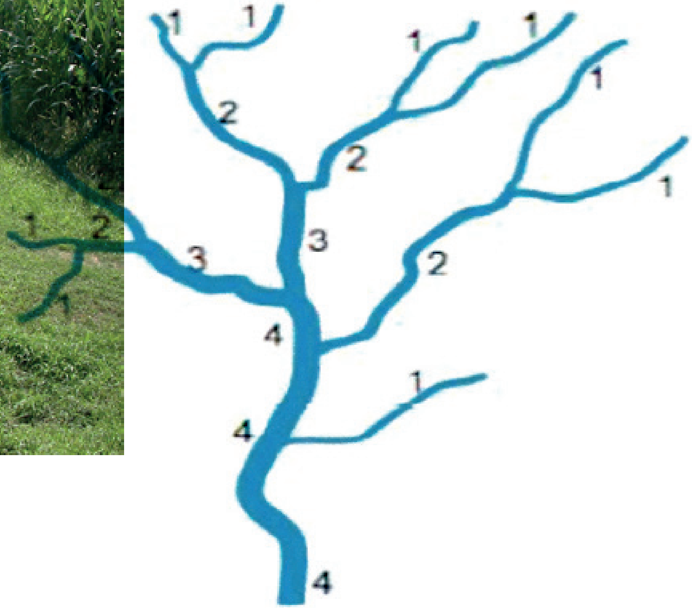
Efficiency and constraints

The soils of riparian buffers are often influenced by the water table in the adjacent ditch or stream. Soils in riparian buffers therefore are more frequently saturated with water. Under such conditions buffers are not efficient in mitigating run-off and the establishment of additional buffers in upslope fields should be considered.

A thorough diagnosis is therefore necessary to estimate the efficiency of a riparian buffer. Nevertheless, riparian buffers act as a line of "last defence" for run-off and wind-borne pollutants and therefore a minimum-width riparian buffer (e.g. 2 m) should be implemented wherever it is a priority for protection of surface water bodies.

Riparian grassed buffer strip

Strahler classification in a water catchment area (1 small stream, 2 next biggest, etc.)



17. Establish and maintain talweg buffer

F/C

What to do

Execute a diagnosis to determine the risk for your specific situation. A talweg describes a situation where two different slopes come together to define a linear indention structure in a catchment (dry valley, hollow). These talwegs may collect water from adjacent slopes during rain events which may lead to concentrated (linear) water flow in a catchment. Talweg situations are often the starting point of heavy rill/gully erosion. An efficient measure to reduce run-off/erosion is to plant a grass cover along the talweg; in high-risk situations hedges should be planted in addition to the grass across the talweg to increase buffer efficiency.

Talweg across a field

How to do it

Locate and size the buffer according to the diagnosis done for the specific field. Consider the selection of adapted buffer plants, density and maintenance requirements.

Large talweg buffers (i.e. meadows) are needed in situations where the risk of run-off/erosion is high and average weather patterns result in big amounts of run-off water entering the talweg buffers from upslope parts of the talweg. Such buffers or meadows across talwegs are useful for dispersing incoming concentrated run-off water, providing good conditions for infiltration of large amounts of water. Planting hedges in these talweg meadows will increase the efficiency for infiltrating run-off even further.

Constraints

Talweg buffers form new field boundaries, resulting in field shapes that are not ideally suitable for easy operations with machines. They may therefore increase working time for the cultivation of fields.

Hedges alongside water bodies or as upslope catchment elements can provide a lot of benefits to the environment. They serve as efficient windbreaks, improve the microclimate, stabilise riverbanks, and provide habitat for wildlife. Hedges also have important agronomic functions like the infiltration of run-off water from the fields, trapping of soil particles from erosion (reducing export of nutrients and PPP) and to intercept pollutants transferred by wind (e.g. spray drift, wind-eroded soil particles). Hedges are often compatible with regional/state environmental stewardship Fig. and thus may be subject to additional funding possibilities.

Buffers with perennial vegetation develop a deeper root system than buffers with grass vegetation only and thus often create better conditions to infiltrate water. Buffers with perennial vegetation are therefore generally quite efficient to mitigate run-off and erosion, being more efficient for diffuse run-off than concentrated run-off. Therefore, they are most effective when placed on upland slopes rather than further down in the catchment watershed. There is great potential for this measure in areas with complex soil or catchment patterns, particularly on erosion-susceptible sandy and silty soils.

What to do

The establishment of hedges needs to be based on a careful analysis of local conditions and on the main targets the buffer should achieve. This analysis determines the selection of bush and grass species and the area/width of buffer required, which in turn influences the necessary amount of maintenance work. The spray drift reduction efficiency of hedges varies strongly with plant species, vegetation density and leaf area /leaf wall and growing pattern.

Hedges should be planted along the catchments contour lines on narrow grassed zones (minimum of 2 m), increasing its efficiency to reduce run-off compared with a hedge alone. The hedge should be planted in the middle of the grassed zone, rather than on one side of it. Hedges must be planted dense enough to ensure water retention and to provide wind-shielding effects (0.5 to 1 m distance between woody plants).
Regarding plant species selection, the food supply for wildlife (arable fields do not provide food all year around) should be considered and the chosen species should not impact too much the growing conditions for arable crops (e.g. host plants for diseases/pests).

How to do it

The soil should be well prepared to allow root development of the selected bush/tree species. Different species should be selected so that they will enhance the overall robustness of a hedge and not lead to agronomic or interspecies competition. In order to achieve a vital and resilient hedge, regional and robust bush/tree species should be selected. Competition from weeds needs to be controlled during the establishment phase and the young plants may need to be protected against damage from wildlife/animals (e.g. protected by fence).

Sizing: hedges should be planted in two to three staggered rows, with a width of 50 cm to 1 m. Plants should be as dense as possible taking into account species and their ability to fill in open space. The objective would be to reach a density of 40 stalks/m² after 10 years.

For maintenance, the hedge should be trimmed regularly. Trees and shrubs have to be cut back severely in the first years. After a few years, routine maintenance consists of controlling the volume of wood stems and the width and form of the hedge. In general, a pyramid (A) form of the hedge is adequate for biodiversity conservation purposes.

Constraints

Planting hedges and making fields smaller will increase the time required for field operations and may encounter resistance by farmers of large-scale fields. On most farms, the establishment of hedges would have to be carried out over a number of years to fit in with current farming operations and work capacities. Hedges require significant efforts to maintain them.

19. Maintain woodlands

Woodlands can be efficient to achieve infiltration of run-off water from fields, trapping of soil particles from erosion (reducing export of nutrients and PPP) and to intercept pollutants transferred by wind (e.g. spray drift, wind-eroded soil particles). As hedges, woodlands provide additional benefits to the environment in agricultural catchments: they serve as efficient windbreaks, improve the microclimate, stabilise riverbanks, and provide habitat for wildlife.

Woodlands are usually quite effective to mitigate run-off due to their size (>10 m width) and their infiltration capacity of the soils which is higher than for cropped soils. Yet, establishment of woodlands requires a high initial investment and causes continuous management costs, which are partially recuperated when the wood can be harvested.

What to do
Woodlands are either residual natural woodlands and function as buffers in the catchment, or they are specifically planted on purpose as catchment elements for ecological or economic reasons. It is key to work with local advisors if woodlands are to serve multiple benefits in a catchment and will be eligible to funding according to the various agro-environmental programmes. Tree species selection depends on the main target the woodland should provide. (Focus on biodiversity? Production of high-quality wood? Production of low-quality wood with low investment?)

How to do it
Ideally, woodlands should be established on steep slopes or the downslope areas in catchments near streams. Shortcuts for water through woodlands via paths or roads in down-slope direction should be avoided, if possible.

Consult your local/regional forestry advisory service to learn about how to establish and maintain the woodlands to generate additional benefits besides reducing surface run-off in catchments.

20. Manage field access areas

What to do
Field access areas are potential water pathways in a catchment or are areas where concentrated water flow may start to form. Especially in the downslope position of a field, they need to be managed carefully to prevent formation of linear run-off. In the area of direct wheel traffic, soil compaction may be reduced by using a layer of coarse gravel on the top of the soil. The field access areas should be grassed using a robust grass species.

How to do
Use gravel or coarse stones to fortify the direct machinery travel tracks. Thereafter, sow a robust grass species, which is deep-rooting, sediment-tolerant and traffic-resistant. Smooth and recessed wheel tracks on the access area should be avoided, as these will serve as water channels for run-off from the field.

Retention and dispersion structures

Retention and dispersion structures are constructed in the catchment to mitigate concentrated flow run-off. If mitigation of run-off at source is unlikely to be achieved, the construction of retention structures may be an option to keep the water in the catchment.

The costs of constructing these "end-of-the-pipe" solutions should be weighed against the costs for changing existing land use practices in order to achieve run-off mitigation at source.

21. Establish or maintain vegetative ditches

Vegetated ditches are retention structures that are created in the catchment to protect downstream areas by retaining run-off water and sediments, as well as water discharged from artificially drained areas. Vegetated ditches do not usually contain water the whole year, but are only inundated when surface run-off (or drainage) occurs. Their primary function is to capture, evaporate and infiltrate run-off (or drainage) water and retain eroded sediment. Vegetated ditches are usually the best solution for water retention structures (e.g. alongside roads/between two field borders). As their main function is the retention of water in the catchment, the ditches should not be connected to surface water (ditch with dead ends).

What to do

The establishment of vegetated ditches is usually done after a thorough diagnosis of run-off risks and identification of a suitable location in the catchment. Regular removal of deposited soil sediments is sometimes necessary, as otherwise the accumulating deposits will reduce the water retention and infiltration capacity of the ditch. Ditches should be vegetated to ensure bank stability and to slow down water flow, thereby improving the retention of sediments in the ditch.

How to do it

Vegetated ditches should be sufficiently large to capture the run-off water and eroded sediment of at least the typical run-off event on site (e.g. first 2 to 3 mm of run-off). Vegetated ditches support the degradation of PPP, maximise the sedimentation of eroded soil particles, and capture nutrients. If a strong sedimentation occurs every year, sediments may need to be removed on a regular basis to maintain the water retention capacity at an adequate level.

General points to consider are:

- Locate vegetated ditch in the catchment at critical points, where run-off is difficult to prevent at the source, but needs to be retained before spilling over to next field, onto road, or to next surface water
- Limit or slow down exchange between vegetated ditches and groundwater by lining the banks and the bottom of the ditch with topsoil material (high organic carbon), if possible of loamy to clay texture
- Size ditches adapted to expected run-off:
  - Volume: should capture typical amount of run-off, or at least 2 to 3 mm of run-off from the contributing catchment
  - Depth: in the range of 0.5 to 1 m, with not too steep banks to ensure escape routes for small animals
  - Width/Length: design according to available space and volume requirements (see above)

- Vegetate by seeding local species (non-invasive), which are adapted to an irregular inundation
- If sediment accumulates and reduces the retention capacity by >20%, remove sediments

Efficiency

Vegetated ditches are a special form of artificial wetland (being of more transient nature). Studies have shown that vegetated wetland buffers can facilitate the degradation of PPP in run-off water. The retention performance is variable since it depends on the portion of run-off water per run-off event, which is completely retained.

The more hydrophobic pesticides are better retained in wetlands, as they enter aquatic ecosystems mainly bound to eroded soil particles, which are sedimented quite efficiently in wetland buffers. In addition, dissolved hydrophobic pesticides are adsorbed to a higher extent to plants and sediment during the wetland passage of water, than hydrophilic compounds.

Constraints

Vegetated ditches are anthropogenic, infrastructural installations, which are constructed to retain and clean run-off water from sediments, nutrients, and PPP. Therefore, any regulation regarding the protection of ecosystems/habitats, potentially interfering with the functionality of the retention structure, should be checked in advance with local environmental authorities.

It should be discussed before the establishment of such structures to ensure the original purpose of the structure can be maintained if endangered species enter the retention structure, since the purpose was to provide wider protection of water resources rather than special areas requiring protection.

22. Establish or maintain retention ponds/ artificial wetlands

Retention structures can be created in the catchment to protect downstream areas by retaining run-off water and transported sediments (concentrated flow), as well as water discharged from artificially drained areas. While passing through the retention structure the water is evaporated or infiltrated and any excess water is subsequently discharged into nearby surface water. Retention ponds or artificial wetland buffers do not usually contain water the whole year, but are only inundated when surface run-off (or drainage) occurs. Their primary function is to retain water and eroded sediment to be kept in the catchment.

Natural wetland areas (the term wetland is often used for protected areas) can also be suitable to collect run-off and drainage water and should therefore be maintained. Such natural wetlands can be riparian meadows or forests, which are regularly inundated.

What to do

The establishment of retention ponds/artificial wetlands is usually proposed by catchment managers or local authorities to improve or maintain good water quality in a catchment (e.g. reduce sediment and nutrient inputs to streams). A thorough diagnosis is necessary to identify a suitable location and to determine the necessary size of a wetland buffer. As such buffers usually retain run-off (or drainage) water from several fields belonging to various owners. A common management approach is often necessary to organise the construction and maintenance of the ponds/ artificial wetlands. A regular removal of deposited soil sediments and organic matter is normally necessary, as otherwise the accumulating deposits will reduce the buffer's water retention capacity and soil hydraulic permeability.

How to do it

Retention capacity of ponds/wetlands should be sufficient to capture the run-off water and eroded sediment of at least a typical run-off event. Residence time of the water detained in the retention structure should be optimised by using, e.g. weirs or barriers within the structure. Vegetation in retention structures support the degradation of PPP, maximises the sedimentation of eroded soil and captures nutrients. If strong sedimentation occurs every year, sediments need to be removed on a regular basis to maintain the water retention capacity at an adequate level.

While a retention pond is usually created with an impermeable layer at the bottom (e.g. concrete), artificial wetlands are usually constructed on soils/subsoil that have no or very little connection with underlying aquifers. Artificial wetlands thus develop some kind of natural vegetation, while retention ponds can be maintained in bare or vegetated conditions (i.e. including an artificial soil layer to enable plant growth).

General points to consider are:

- Define clear objectives:
  Either single-purpose to mitigate transfer of agricultural pollution, or multipurpose to also allow flood protection at the interface of agricultural and urban catchments
- Limit exchange between artificial wetlands and groundwater, by lining the bottom of the retention structure with topsoil material (high organic carbon), if possible of loamy to clayey texture
- Size wetlands adapted to expected run-off:
  - Volume: design to accept at least 2 to 5 mm of run-off from the contributing catchment, corresponding to an area ratio of 0.4 to 1% (this might need to be adapted, if flood prevention is the priority issue). In case of regular larger run-off events (>5 mm), the retention structure may need to be designed for a larger retention capacity
  - Water depth: in the range of 0.2 to 1 m with an average water depth of 0.5 m (adjust by weir at outlet of pond/wetland), when flooded
  - Length: if possible, maximise length of water pathway by constructing a meandering flow pathway using barriers/dams
- If vegetated, prefer the seeding of local species (non-invasive), which are adapted to an irregular inundation
- If sediment accumulates and reduces the retention capacity by >20%, remove sediments regularly

In general, expert knowledge is needed for establishment of efficient retention ponds/artificial wetlands. For more details, seek advice from local environmental advisors/authorities and also consult technical manuals, such as the technical guide "Mitigation of agricultural non-point-source pesticides pollution and bioremediation in artificial wetland ecosystems" from the EU Life Artwet project (LIFE 06 ENV/F/000133).

Efficiency

Studies have shown that vegetated wetland buffers can facilitate the degradation of PPP in run-off water. The retention performance is variable since it depends on the time that the run-off water is detained by the vegetated wetland buffer. The retention efficacy for weakly and moderately adsorbed compounds is estimated to be lower (approx. 50%), while for strongly adsorbed compounds efficacy can reach up to >90%. The more hydrophobic pesticides are, the better they are retained in ponds/wetlands, as they enter aquatic ecosystems bound to eroded soil particles, which are sedimented wetland buffers. Dissolved hydrophobic pesticides are adsorbed to a higher extent to plants and sediment during the wetland passage of water, than hydrophilic compounds.

Constraints

Constructed wetlands are anthropogenic, infrastructural installations such as dams, which are constructed to retain and clean run-off water from sediments, nutrients, and PPP. Therefore, any regulation regarding protection of wetlands or surface water bodies, potentially interfering with the functionality of the retention structure, should be checked in advance with local environmental authorities. It should be discussed before the establishment of the structures, what happens if endangered species occur in the retention structure and how the original purpose of the structure can be maintained. Especially for artificial constructions, it should be pointed out that the habitat only exists because of the original purpose of management of run-off or drainage discharge to surface water.

23. Establish or maintain edge-of-field bunding

F/C

Edge-of-field bunding is a small embankment or dam of soil at the lower edges of the field to keep run-off and erosion in the field. Essentially, bunding works by halting the movement of run-off and its sediment load, which enables run-off to infiltrate and eroded soil to deposit. Bunding is also used as a critical component in rice paddy systems for water and soil management.

What to do

Edge-of-field bunding is constructed by piling up soil in the form of a small embankment or dam. The bunding is established on the lower edges of fields to capture run-off and its sediment load.

Such bunding works best on heavier textured soils, i.e. more clayey soils that have higher run-off generation potential, unless they contain macropores that connect to the soil surface. How long this bunding remains functional depends on the strength of the soil, and whether the bunding is broken down by rainfall or breached by run-off, so it is important to inspect them regularly.

How to do it

Dig the soil up on the outer edge of the field and pile it up as bund with a breadth of 30–50 cm and to the required height and distance up the field edges. In order to estimate these heights and distances, some approximate guidelines are given here for two types of rectangular fields on uniformly sloping land.

For fields with the slope parallel to the edges of the fields, the height of the bund must be higher than the volume of run-off from the field.
For fields in which the slope is diagonal to the edges of the fields, the height of the bund must be also higher than the volume of run-off from the field. However, the required height is highest at the lowest corner of the field.

F/C

Dispersive constructions include fascines and mini-dams. They are artificial structures of logs/branches/stones that are erected in catchments to disperse concentrated surface run-off in catchments. Fascines limit erosion and capture sand and silt transported in run-off water. Mini-dams are mainly aimed at dispersing and slowing down the water flow.

What to do

Fascines are constructed from bundles of branches between wooden logs (resembling a low wall), and are established across the slope to cut off pathways of concentrated run-off water. The structure is permeable to water, but slows down its flow considerably; dispersing the water and thereby leading to sedimentation of eroded soil.

Fascines

The wood used to make fascines can be either dead or alive (e.g. bushes). If it is dead, the construction may remain functional during 2 to 4 years. If it is alive, the construction can be permanent, but the bundles of branches will need to be replaced every 2 to 4 years.

Mini-dams consist of stones and wooden logs, and are established at the mouth of the streamlets. Like fascines, the mini-dams have to be permeable to water, slow down the water flow and retain eroded sediment. Mini-dams are constructed on the entire section of the streamlet by connecting the wooden logs with the riverbed and the banks.

The mini-dam structures can be permanent, and may require maintenance every 2–3 years.

How to do it

Dig the soil up to 30 cm depth and 50 cm width.
Push in two rows of logs (about 1.0 to 1.5 m long) on the verges of the ditch: logs should be spaced approx. 1 to 1.5 m apart. Logs should be pushed in until 50 cm deep in soil. Subsequently the ditch is filled in with bundles up to the top of the logs and soil dug out is used to fill in the ditch and create smooth boundaries towards the surrounding soil surface.

Fascines can be combined with vegetative buffers, by constructing them in the middle of a grassed buffer strip. Mini-dams can be combined with vegetative ditches.

Constraints

Dispersive constructions are labour-intensive and need considerable investment to build and to maintain.

Correct PPP use

General
PPP registration addresses risks associated with applications of the PPP in relation to environmental and human safety aspects. Related to water protection, these PPP evaluations may result in regulatory requirements listed on product labels to mitigate predicted exposure concentrations in surface water following drift, run-off and/or drainage events. The mandatory requirements reported on the product labels must be considered as an integral part of the complex strategy to reduce surface water contamination, which include the adoption of other Best Management Practices (BMP). The following measures are specifically related to mitigation of run-off/erosion.

Correct use of PPP starts with regular checks and the precise calibration of the spray equipment. (In some countries regular sprayer testing is obligatory/other EU member states still need to implement audit systems as required in the machinery directive.)

25. Optimise PPP application timing

What to do
In general the following points need to be considered to reduce the risk for water pollution:

- Do not apply products when significant rainfall is forecasted for your region within the next 48 h
- Do not apply PPP on saturated soils or fields where the water is flowing from drains
- Reduce the number of applications and the amount of applied PPP to the necessary minimum; check alternative PPP strategies in case of run-off risks

How to do it
- Indicate or mark field areas where application restrictions need to be respected according to your PPP selections
- Study PPP label carefully if application timing requirements in relation to rainfall exist
- Check weather forecast for rain in your area (the first significant rain event after application is the most critical one)
- Check the soil water saturation levels in the field you intend to spray and avoid spraying on saturated soils
- If the field is artificially drained, check if water is flowing from drains and avoid spraying at these times

26. Optimise seasonal PPP application timing

F/C

A key factor is to check PPP applications if during times when the groundwater recharge takes place and drains are flowing.

What to do

- Select appropriate PPP, according to the time window for application
- Apply pesticides outside of main groundwater recharge/ drain flow season
- Study PPP label carefully if seasonal application timing requirements exist

How to do it

- Indicate or mark field areas, where application restrictions need to be respected according to your PPP selections
- Avoid spraying as far as possible late in autumn or early in spring when soils are typically (almost) saturated with water or water flows from artificial drains. Check for product-specific requirements and product stewardship recommendation

27. Select appropriate crop protection products

F

What to do

- Select appropriate PPP, which can solve your crop protection problem
- Read PPP label carefully and respect required risk reduction measures
- If PPP selected requires specific mitigation measures, which are difficult to realise, check alternative solutions or consult your adviser, if a modification of the use is possible (e.g. dose reduction in combination with other PPP (mixture); reduction of dose rate on the area treated (e.g. band spraying, or alternative PPP)
- Take measures to eliminate any point pollution sources and apply viable measures to reduce the diffuse pollution risk (run-off, spray drift) of PPP used
- If the pollution problems with specific PPP persist, discuss with advisor alternative crop protection strategies

How to do it

- Follow PPP advice given for your area
- Make a list of fields where specific crop protection restrictions for PPP apply and document your PPP practices. Check if the handling of PPP is correctly on the farmyard to avoid point source pollution (use a checklist). Focus especially on the following aspects
- Are precautionary measures applied when filling or cleaning the sprayer on the farmyard?
- Is the sprayer equipped with a rinse tank, internal cleaning/ rinsing system? (Ref.: TOPPS – BMP to reduce point source pollution)
- All farmers in a catchment area should be informed/trained on the BMP to avoid point sources
- Audit the catchment and fields and implement mitigation measures to reduce run-off/erosion and spray drift from fields in the catchment (BMP)
- Optimise timing of application to reduce the risk for PPP transfers with water
- Reduce application rates (e.g. by using low-rate combi-products). Use application techniques to reduce PPP treated area if possible (band spraying, directed spray, sensor spraying)
- Consult with advisor about other options to ensure crop protection
  - By, e.g. alternative, non-chemical crop protection practices
  - Choose alternative PPP, which have different substance properties (soil degradation half-life, mobility in soil, aquatic toxicity = different Environmental Quality Standards)

If no solution can be found, consider other crops to be planted.

Constraints

After a thorough check, a point-source reduction plan needs to be discussed with the advisor and farmer. Measures focus on correct PPP handling and awareness for water protection and on improvements of equipment and infrastructure (storage, washing place, biobed). Ideally, such action plans should also be discussed with all farmers in the catchment.

Implementation of mitigation measures to reduce run-off/ erosion is an individual and a collective task. All persons involved should work out an implementation plan with defined targets. Public funding options are often available for technical and infrastructural measures and should be explored.

In areas with water pollution problems, authorities controlling the water quality should interact with farmers in an open and constructive way to find commonly agreed solutions (examples of such cooperation exist in some countries). Most encouraging is, if actions taken can be linked to subsequent improvements of water quality.

Irrigation

Irrigation is an artificial application of water to soil where natural water availability for a crop is not sufficient at certain times. The main challenge in protecting water quality from excess irrigation water is to control the amount of water and to manage drainage water in situations where drainage systems are established to prevent salinisation. Run-off risks are directly associated with the irrigation systems implemented and the management of the irrigation.

28. Select irrigation technology

The different systems are characterised by variations in water volumes used and by distinct differences of application. Flood irrigation requires the highest amount of water; 800–1,200 m³/ha, sprinkler irrigation uses about 300–500 m³/ha. The sprinkler application can cause surface compaction/crusting through splashing drops onto the soil surface. Drip irrigation works with a low amounts of water, and it is mostly used in high-value crops due to high investment needs for its establishment.

The key to reduce the risk of run-off is the correct irrigation management considering soil water content, soil water-holding capacity and crop requirements in relation to evapo-transpiration.

Still most common in Southern Europe is flood irrigation. It delivers large amounts of water and does not allow easy control of the volumes to prevent over-application.

What to do/how to do

The most efficient mitigation measure is investment in less water-consuming and better manageable irrigation technologies (sprinkler, micro-sprinkler, drip irrigation).

29. Optimise irrigation timing and rate

What to do

The key to reduce the risk of run-off is the correct irrigation management considering soil water content, soil water-holding capacity and crop requirements in relation to evapo-transpiration.

How to do

Most important is to monitor, estimate and manage the correct amount of water needed by the crop. Key indicators are soil moisture content, soil moisture tension and consideration of possible rainfalls forecast. There are IT-based decision support systems available for planning of irrigation.

If less controllable systems (flood irrigation) are used, furrow irrigation may help to save water and to reduce run-off. Such practice may also be helpful to infiltrate more water in case of rainfalls.

Constraints

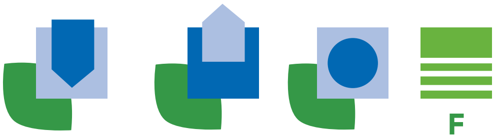
In most irrigated areas the amount of water and the availability is regulated. Detailed advice therefore needs to refer especially to the local situations.

Evaluation on mitigation measures' efficacy

In the following Fig. measures are evaluated on their efficacy concerning different run-off types: infiltration restriction, saturation excess and concentrated flow (see legend on pp. 30).

The scale category defines where the measures can be basically applied: in the field (F) or in the catchment (C).

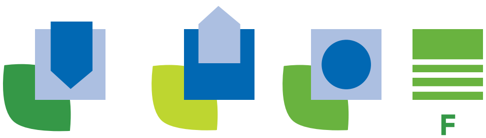
1 Reduce tillage intensity



2 Prepare rough seedbed

3 Avoid surface soil compaction

4 Avoid subsoil compaction



5 Manage/Orient tramlines

6 Create bunds in the field (contour bunding)

7 Implement contour tilling

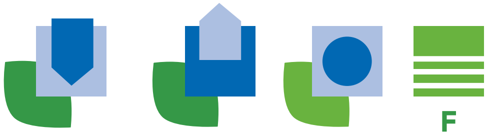
8 Optimise crop rotation

9 Implement strip cropping in field (across the slope)

10 Plant annual cover crops

11 Implement double sowing

12 Establish perennial cover crops in plantations



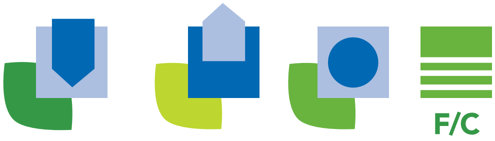
13 Enlarge headlands

14 Establish and maintain in-field buffer

15 Establish and maintain edge-of-field buffer

16 Establish and maintain riparian buffers

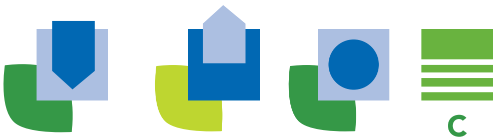
17 Establish and maintain talweg buffer



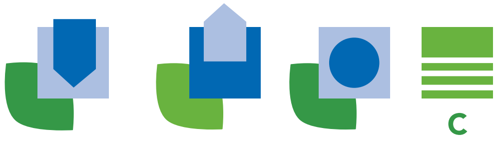
18 Establish and maintain hedges

19 Maintain woodlands

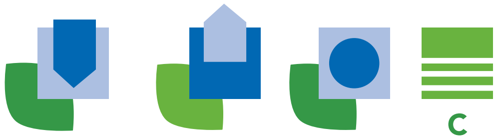
20 Manage field access areas



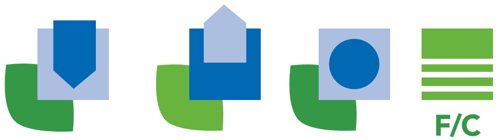
21 Establish or maintain vegetative ditches



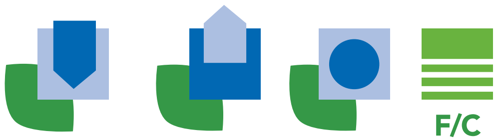
22 Establish or maintain retention ponds/artificial wetlands



23 Establish or maintain edge-of-field bounding



24 Implement dispersive constructions



25 Optimise PPP application timing

26 Optimise seasonal PPP application timing

27 Select appropriate crop protection products

28 Select irrigation technology

29 Optimise irrigation timing and rate

B

BMP
Best Management Practices: in the context of the document, recommendations and tool to prevent losses of PPP to water/sensitive areas.

Buffer strip
Buffer strip is a vegetated non-cropped strip between a crop and a water body in order to prevent run-off/erosion.

Buffer zone
Buffer zone is an untreated cropped or non-cropped area designed and dedicated to prevent adjacent sensitive areas being contaminated by pesticides through spray drift.

Bund
A bund is a small dam to reduce water flow and to keep as much water as possible in the field to prevent run-off and to increase soil infiltration.

C

Capping soil
Soil compaction on the soil surface, especially on soils with higher silt content (>25%). Capping soils tend to be vulnerable to run-off and erosion.

Catchment
An area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes to a particular point in a water course (normally a lake or a river confluence).

Cover crops
A crop grown between two main crops, e.g. after harvest until new seeding. Purpose of the cover crop is to protect the soil structure (reduce splash effect from rain, shading effect) and to utilise water. Cover crops are efficient mitigation measures to reduce transfer of water-soluble nutrients/pollutants to surface and groundwater.

Crop rotation
Sequence of crops on a field or in a landscape. A wide crop rotation has many positive agronomic effects, such as buffering the flow of water, reducing pest and weed pressure.

Cropping practice
General practice to grow crops in an area. Often a result of the main agricultural production in an area (mainly determined by commercial, climatic, soil and other agronomic conditions)

D

Dashboard
Dashboard/decision tree provide aggregated key data, which allow the user to make fast and structured decisions without the need to know all details (e.g. dashboard in a car). (See decision tree)

Decision tree
Decision tree/dashboard support fast decision-making in complex situations in a structured way. It combines implicit and tacit knowledge and generally provides a high degree of correct decisions. (See dashboard)

Diffuse sources
Diffuse sources in the context of agricultural pollution can be defined as pollution source originating directly out of a field. Often all agricultural pollution is reported as diffuse-source pollution in general, which in our opinion does not capture important differences (e.g. pollution originating from activities on farm or farmyard) and therefore may lead to inconsistent recommendations for mitigation measures.

Ditch artificial drainage channel.

Drainage
Drainage systems are installed to make land which stays wet for a long time suitable for agriculture production. Drain water will flow into a ditch or wetland.

E

Erosion Erosion is the transfer of soil by water or wind.

Gully erosion
Extreme sign of erosion in a landscape. It is a steep and deep drainage channel built by surface water which is not flowing permanently.

Rill erosion
Rill erosion is the intermediate process between sheet and gully erosion. It results from concentration of sheet erosion into small, ephemeral concentrated flow paths that produces channels up to 30 cm deep.

Sheet erosion
Sheet erosion is a removal of soil particles in thin layers from an area of gently sloping land. Sheet erosion is commonly unnoticed by many, but can be responsible for extensive soil loss in both cultivated and non-cultivated environments.

H

I

L

M

P

Headland
Headland is an area of land at the edge of a field. Tillage or seeding direction is often across the main cropping direction in such a field.

Infiltration
Downward entry of water into the soil. Soil characteristics determine the amount of water, which can be kept in the field. Key criterion is the soil infiltration ability/ capacity

Lateral seepage
lateral subsurface transfer of water e.g. forced by a layer of reduced permeability or impermeability

Mulch
Materials from crop residues or cover crops on the soil surface reduce water flow on the surface and have a positive effect on water infiltration into soil.

Pesticide
According to EU legislation (Directive 2009/128/EC), "pesticides" include Plant Protection Products (as defined in Regulation (EC) 1107/2009) and biocidal products (as defined in Directive 98/8/EC). In this document the term refers to Plant Protection Products only.

Point source
The term point-source pollution is used in different ways. In the context of these BMP point sources are entries of PPP to water originating directly from activities or installations on the farm or farmyard. Relevant factors can be widely controlled by the operator through correct behaviour, appropriate equipment and infrastructure.

PPP
Plant Protection Products: according to EU legislation (Regulation (EC) 1107/2009), PPP are products consisting of or containing active substances, safeners or synergists, and intended for: (a) protecting plants or plant products against all harmful organisms or preventing the action of such organisms; (b) influencing the life processes of plants (as substances influencing their growth), other than as a nutrient; (c) preserving plant products; (d) destroying undesired plants or parts of plants; (e) checking or preventing undesired growth of plants.

R

Rain event
Rainfall from start to end. In the context of the BMP the intensity (time and volume) of the rain event is important to generate run-off or erosion.

Retention structure
Retention structures are natural or artificial structures able to capture run-off water and sediments in the catchment

Run-off
Surface water run-off is the water that flows over the land when some or all of the water from rain, irrigation or melt water cannot infiltrate the soil: (1) as fast as it arrives at the soil surface (soil infiltration restrictions); or (2) if the capacity to infiltrate water is exceeded (soil water saturation). Soil management often influences both types of run-off, e.g. by capping the soil surface, or by plough pans restricting the vertical drainage of soils.

Concentrated run-off
Concentrated run-off is when surface water accumulates in rills or gullies in the field (e.g. in a talweg). Depending on the soil conditions concentration of run-off is the start for serious erosion problems

S

Sheet run-off/sheet flow
Sheet run-off is water flowing downhill in thin sheets without concentration (e.g. rills).

Soil permeability
Soil permeability describes how much water can percolate on a certain area/time through the soil layer (see Darcy equation)

Soil texture
Soil texture describes the content of different particle sizes in a soil (sand, loam, clay)

Substrate
In the context with soil science the substrate is the bedrock, which produces the soil by alteration

T

Talweg
A talweg is an abstract line that connects the lowest points in a river channel, or, in general, the lowest points where different slopes come together to build a valley. The term derives from the German word elements Tal (= valley), and Weg (= way)

Tillage
Tillage is a general term for soil cultivation. Traditionally tillage is linked to ploughing of the soil. Reduced or no tillage are cultivation techniques which do not disturb the soil structure as much as ploughing, which has a positive effect on the water infiltration capacity.

Tramlines
Tramlines are crop-free areas used for driving the tractor/machines in a field. Tramlines can be areas to concentrate water and additionally soil compaction may increase the risk of run-off/erosion.

W

Water body
In this document refers to "Body of surface water": a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal (Directive 2000/60/EC).

Wetland see retention structure

This BMP brochure is based on personal experiences of our partners and experts, who contributed to this project, but also on a variety of research which has been conducted over the years at various places. The reference list refers to publications, which might be useful for further in-depth studies on the subject of run-off and erosion.

We acknowledge the work provided by our technical support partners

Arvalis Institute du vegetal (Boigneville, France) to share experiences based on their advice tools Aqua-vallee and Aqua-plaine and specific expertise from Irstea Lyon France on evaluating vegetative buffers, their location and sizing.

We acknowledge all contributions from our run-off partners and experts who adapted the BMP to their specific situations and helped to translate research into practical applications.

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