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REFORM

REstoring rivers FOR effective catchment Management

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1. Aims of this Policy Paper

This policy paper aims are to identify specific issues and raise awareness of the issues related to groundwater-river interactions by improving knowledge transfers to policy makers and water managers. Groundwater is a key factor in supporting ecological flows (Eflows), both concerning quantity and quality of surface water required for Good Status of aquatic ecosystems. We want to draw attention to the recommendations concerning groundwater and associated aquatic ecosystems made by the EU CIS working groups on groundwater and Eflows in the respective WFD documents (to be) published in 2015. In addition, this policy paper aims to emphasize the need for close cooperation between these fields of expertise (groundwater and Eflows) to develop a mutually practical approach to the issues related to groundwater-river interaction as a driver of ecological condition. Moreover, this policy paper aims to stress that successful restoration of groundwater-river connectivity and groundwater-dependent ecosystems requires strategies for solutions at catchment scale.

This policy paper is the result of discussions that took place at a 3-day expert workshop (Biebrza Valley, Poland, 15–17 September 2014) organized by the REFORM[1] project on the relevance of groundwater-surface water interactions in European actions oriented at sustainable water management. REFORM made a first step in combining groundwater characteristics and pressures with stresses on rivers, floodplains and wetland ecosystems. This work is currently being continued in the project FP7 projects MARS[2] and GlobAqua[3].

Five key messages to support water policies and management

1. Groundwater is the main factor supporting Eflows in streams during low flow conditions in dry seasons.
2. Groundwater will play a crucial role in maintaining the resilience of the water system and aquatic environment during projected increasingly dry periods in the future and more ecosystems will become groundwater-dependent (Nature Based Solutions).
3. Groundwater is the main provider of high quality water that supports groundwater-dependent ecosystems (Ecosystem Service).
4. Cooperation between groundwater and environmental flows experts at all levels is indispensable for tackling issues related to groundwater-dependent ecosystems.
5. Successful mitigation and adaptation of groundwater-river connectivity to restore groundwater-dependent ecosystems requires strategies for solutions at catchment scale.

[1] Restoring river ecosystems in Europe: REFORM will provide tools to support cost-effective implementation of restoration measures and monitoring. REFORM (FP7 GA 282656) is a 4-yr large integrated research project, grouping 26 partners from 15 countries, that addresses the challenges to reach the ecological objectives for rivers as required by the EU Water Framework Directive. More information: www.reformrivers.eu

[2] Managing Aquatic ecosystems and water Resources under Multiple Stress: MARS (FP7 GA 603378) addresses the assessment and management of waters bodies in Europe. The consortium combines the European expertise in biological assessment, inter-calibration, uncertainty estimation, modelling and restoration of freshwater ecosystems. More information: www.mars-project.eu

[3] Managing the effects of multiple stressors on aquatic ecosystems under water scarcity: GLOBAQUA aims to achieve a better understanding on how current water management practices and policies could be improved by identifying their main drawbacks and alternatives. GLOBAQUA (FP7 GA 603629) is a 4-year project that assembles a multidisciplinary consortium in order to study the interaction of multiple stressors within the frame of strong pressure on water resources.

2. Groundwater is central to the Good Status of rivers

Water is essential for all life. Much of it is visible in the sea, rivers, lakes and wetlands. However, a substantial proportion (about 30% of all freshwater) is stored underground in aquifers in sediments and permeable rocks. Groundwater is normally not static but flows slowly through aquifers and out of springs and seepages and discharges into rivers, lakes, wetlands, estuaries and the sea. The high water storage capacity and slow velocity mean that receiving waters often remain well-supplied during droughts (i.e. there is a high base-flow). Aquifers are replenished by rain water percolating down through the soils and rocks, this changes the water chemistry by dissolving chemical components and removes contaminants, thus making groundwater of higher quality. The recharging water may come directly from rainfall or indirectly through groundwater discharge to the beds of rivers and wetlands, thus emphasizing the close inter-relationship between surface and sub-surface waters. Groundwater is a major contributor to the natural water balance in most catchments and river basins throughout Europe and worldwide. It is part of the hydrological cycle and performs important ecological functions. Groundwater tends to remain at a constant temperature (around 10^{o}C in northern Europe) and thus has a major role in controlling temperature in receiving water bodies by providing cooler water in summer and warmer water in winter. Overall, the quality and quantity of the groundwater influences the condition of surface waters (Henriksen et al., 2008). Thus any deterioration in quantity or quality may result in failure to meet the requirements of the Water Framework Directive (WFD) in any surface water body.

3. Challenges of managing groundwater-associated surface water

Many aquifers in Europe are intensively exploited for a variety of uses, including irrigation (particularly in southern Europe), public water supply and thermal power plants. Increased abstraction often coincides with periods of low rainfall resulting in falling groundwater levels, dried-up rivers and degraded wetlands (Acreman, 2001). Over past few decades considerable effort has been made to restore the ecological and chemical condition of European streams and rivers. The initial focus was to improve the chemical condition of surface waters, are more recently on hydromorphological and ecological restoration measures in rivers and adjacent floodplains, such as re-meandering of streams, building fish passages or replanting vegetation along streams and within floodplains. However, such measures may not be successful if streams run dry or water quality is poor due to decreased connectivity with the groundwater. Thus, stream restoration investments by the EU and national and local water managers may be thwarted in catchments in which groundwater-river interactions have deteriorated by poor groundwater quality or disputed connectivity. Moreover, climate change is expected to pose challenges to the resilience of the hydrological cycle and ecology of catchments (Karlsson et al., 2015). Rivers, lakes and wetlands that depend on groundwater can be very vulnerable to climatic changes if the supply from the aquifer reduces following, for example, longer or more frequent drought periods.

In many European catchments, a significant parts of groundwater bodies is in a less than optimal condition due to poor quantitative or chemical status and the supply of groundwater to surface waters is disturbed. This causes various types of stress to surface water bodies, as the interactions between groundwater and surface water are vitally important for sustaining the discharge of good quality water to streams and rivers (Text box 1, Figure 1, and Figure 2). Groundwater supply is particularly crucial for meeting WFD requirements in stream with limited surface water, such as headwater rivers. In addition, groundwater is especially important during climatic dry conditions for sustaining minimum low-flows in streams and rivers and preventing water scarcity during drought conditions.

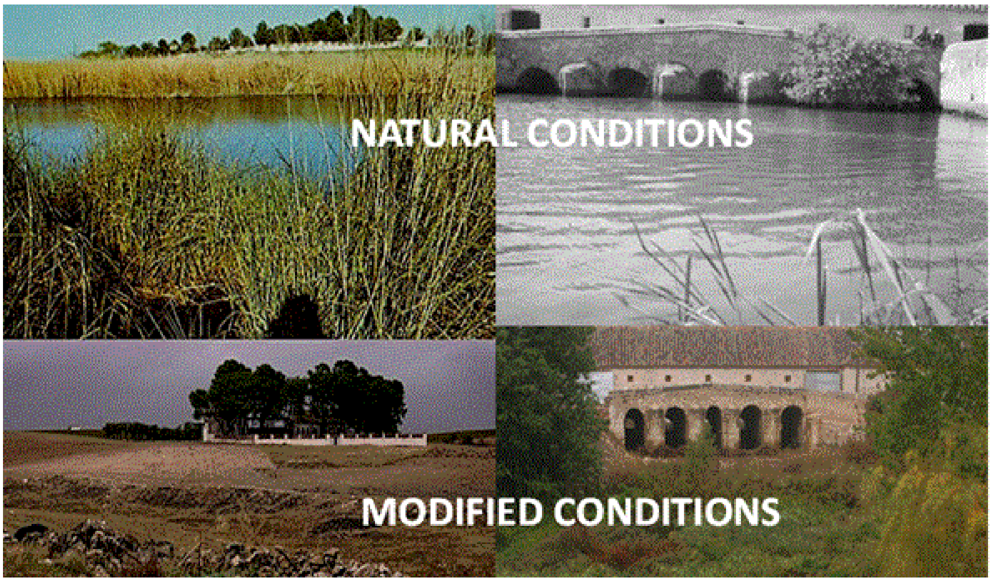

Figure 1: Surface water draw-down due to unsustainable groundwater abstraction in Daimiel National Park (Spain)

Figure 2: Rivers run dry due to extensive tile drainage and over dimensioned ditches.

Text box 1: Examples of poor groundwater management leading to stresses in rivers ecosystems

Anthropogenic pressures in Iłzanka catchment (Poland)
Groundwater abstraction and mining activities are major issues in the Iłzanka catchment. Groundwater abstraction at Trębowice for the city of Starachowice is circa 17,000 m^3/d, while the city's waste water is discharged outside the Iłzanka catchment, thus there is a net export of water. Drainage connected with the mining activities has a discharge of circa 5,000 m^3/d and the water is transfer to an adjacent catchment. These pressures resulted in significant depression of groundwater levels, which has led to the drying-out of the Pakoslaw peat-bog (NATURA 2000), while the river itself dries-out during drought periods (Dr. P. Herbich, Polish Geological Institute NRI).

Undesired effects of river flow augmentation in Yorkshire (UK)
Many schemes in the UK, both existing and proposed, attempt to mitigate the loss of flow due to abstraction by augmentation from upstream reservoirs or pumping of groundwater into adjacent rivers. The impact of flow regulation by reservoirs is well documented, but little attention has focused on the effect of groundwater augmentation (which may be chemically very different) on the biota, particularly fisheries, in the receiving river. Concerns were raised when groundwater was pumped into minor tributaries of the Yorkshire Ouse in England with respect to poor water quality and reduced water temperature. Small reductions in river water temperature brought about by discharge of cold (≤ 10 °C) groundwater could have serious detrimental effects on cyprinid fish recruitment and juvenile growth in the receiving river, leading to a decline in stocks (Cowx, I., 2000).

Low flow reduction due to agricultural activities in Twente and Brabant (Netherlands)
In many sandy catchments in the Netherlands, intensive agricultural activities have been developed since 1900. This has included installation of extensive drainage systems (ditches and tile drainage; Figure 2) and significant amounts of groundwater are being abstracted for irrigation during the crop growing season. Analyses of the Twente area and catchments in the province of Brabant, based on monitoring data and geohydrological models, indicated that these agricultural activities have led to 25 to over 50 % reduction in base-flow and lowering of flows during the growing season (Hendriks et al., 2014).

Abstraction and lack of data led to degradation of Las Tablas de Damiel wetlands (Spain)
Some 66% of the upper Guadiana basin in central Spain is underlain by porous water-bearing rocks. These are connected with the rivers and wetlands in a complex way, so that some rivers and wetlands are fed-by the aquifers whilst others recharge the aquifers. Development of the region since 1972 has been achieved through expanding irrigated agriculture. Intensive use of groundwater, especially during long periods of low rainfall led to a fall in water level of 20 m in 15 year and caused the degradation of important wetlands, such as Las Tablas de Damiel (a Ramar site, Biosphere Reserve and Special Protection area for Birds). In 1994, the La Mancha Occidental aquifer was declared "overexploited". However, lack of data meant uncertainty in the hydrological processes and mis-trust between farmers and the catchment authority have hampered attempts to agree reasonable abstraction rates.

4. Policy background

The WFD explicitly states the relationship between the chemical and ecological status of surface water bodies and the chemical and quantitative status of groundwater bodies (WFD Annex V.2). In addition, the EU CIS working group C (groundwater) confirmed that the Environmental Flow Needs (EFN) of the related surface water bodies must be determined as part of quantitative status assessments of groundwater bodies (Guidance doc.18: Blum *et al*., 2009).

The Blueprint (European Commission, 2012) highlights that data assessments show increasing trends in river flow droughts in Europe over the last few decades, which underlines the need to improve the resilience of aquatic ecosystems. In addition, the Blueprint Impact Assessment (European Commission, 2012) reported that the status of groundwater bodies affects the state of aquatic ecosystems, which greatly impacts their functions and their capacity to provide ecosystem services. A coherent set of actions at the river basin scale, including nature-based water retention measures, is required within the planning process of the WFD to reduce the number and duration of river flow droughts. However, the technical report on methodologies used for assessing groundwater-dependent terrestrial ecosystems (European Commission, 2014) explicitly highlights that a consideration of associated groundwater-dependent ecosystems is lacking, but is encouraged in the explanatory text to the Groundwater Directive (EU, 2006).

In its communication to the European Parliament and the Council (European Commission, 2015), the Commission expresses the need to address better the link between quality and quantity in assessing pressures on the aquatic ecosystems and to put in place measures that target abstractions and flow regulations. Member States need to take preventive measures to avoid moving into unsustainable levels of abstraction, which are particularly important for groundwater bodies connected to important water-dependent ecosystems. Water abstraction pressures can lead to changes in the natural volume and flow regimes of affected water bodies and thereby adversely altering aquatic and terrestrial groundwater-dependent habitats. Up to now, six out of 22 Member States (27%) reported that altered habitats were a significant impact resulting from pressures on groundwater. Furthermore, overexploitation and groundwater drawdown in the aquifer can have adverse impacts on the aquifer sustainability (Henriksen and Refsgaard, 2013), with deteriorated water quality of natural constituents (Cl, Ni, Su etc.), which again can negatively affect surface water quality.

The WFD guidance document on Eflows (European Commission, 2015), which aims to support a shared understanding of Eflows and ways to use Eflows in the River Basin Management Plans, recommends that hydrological monitoring should cover locations where groundwater is exploited and that controls on groundwater abstractions form a strong basis to protect and restore Eflows. In addition, the EU CIS working group Groundwater is currently preparing a technical report on groundwater-associated aquatic ecosystems, which includes recommendations for the consideration of groundwater-associated aquatic ecosystems within the WFD river basin management planning (European Commission, in preparation).

5. Combine groundwater and Eflow expertise at all levels

Successful management of groundwater-associated surface waters starts with thorough understanding of groundwater-surface water interactions in relation to sustainable water resources management and protection of aquatic ecosystems (Figure 3). Currently, policy-makers and water managers are insufficiently familiar with the knowledge that is available and how to apply this knowledge in policy documents, RBMPs and the practice of local water management. Different fields of expertise have extensive knowledge of the various relevant aspects: hydrology, hydrogeology, ecology, hydrochemistry and hydromorphology. Experts from these knowledge-fields should combine their efforts and work closely together to improve local and regional water management and groundwater-dependent ecosystems. The actions listed below could be undertaken by such experts to improve the understanding of groundwater–river interactions and their importance for groundwater-dependent ecosystems:

Figure 3: Wetlands and floodplains in the valley of the Biebrza River

- Assemble and evaluate existing knowledge on groundwater-river interaction processes and their ecological implications, both at large and small scales;
- Assemble and evaluate existing knowledge on pressures that cause ecological deterioration resulting from altered groundwater-river interaction or contaminated groundwater;
- Assemble of knowledge of groundwater-related stressors in streams, rivers and floodplains and analyse their impact groundwater-river connectivity, both for water quantity and quality. This will establish the degree of ecological stress the various types of pressures may exert;
- Align definitions of appropriate and unequivocal indicators for each type of stressor. Existing indicators can be assessed and adapted, however some new indicators may be required that show a higher sensitivity to changes in groundwater-river connectivity;
- Explore the possibility and feasibility of using integrated indicators that simultaneously evaluate and weight various types of stressors that may occur in a catchment;
- Align methodologies for threshold values, or threshold ranges, for each indicator to meet WFD requirements. Thresholds may differ between river type, river segment, and between upstream and downstream parts of the catchment.
- Evaluate measurements and monitoring results that could be used to quantify existing metrics and to determine relevant indicators and threshold ranges. This may require combined use of time series and spatially distributed data, if available;
- Produce case studies that demonstrate how knowledge has been successfully or unsuccessfully applied to managing groundwater and its groundwater-dependent ecosystems, including costs and timescales.
- Develop new guidelines for effective monitoring and integration with modelling that can be applied by water managers to assess groundwater-river connectivity. Such

guidelines must be adaptable to local conditions, e.g. river type, relevant stressors, pressures and availability of data.

For successful execution and implementation of the actions listed above, policy makers, water managers and experts at the European and national level, as well as at the regional to local level, should be involved. At the European and national level, a generic knowledge base, guidelines, and tools could be developed. On the other hand, all generic knowledge and products need interpretation by local experts to be practical and applicable to local situations. Also, information and knowledge gathered at the local and regional level is indispensable input for the generic products and tools developed at the European level.

6. Strategies for solutions at catchment scale

The processes underlying the ecological significance of groundwater-river interactions occur at a range of spatial and temporal scales. Large scale processes include catchment hydrological mechanisms such as groundwater recharge, geohydrological structure, subsurface flow patterns, catchment morphology, land use and the distribution of infiltration and seepage zones. Small-scale processes are mainly related to local geohydrological structures, stream morphology and micro-habitats. The small scale processes are particularly important at the interface between the river-bed and underlying groundwater, called the hyporheic zone, which marks the hotspots of connectivity, exchange and interactions between subterranean and surface flow on an ecosystem level. The hyporheic zone performs a range of important ecological as well as hydrological functions and supports specific elements of biodiversity. For example, it is considered that the hyporheic zone is responsible for the effective self-purification capacity of streams. This is complementary to broader scales processes across the catchment where lateral (between river and floodplain – Junk et al., 1989), longitudinal (between upstream and downstream - Vannote et al. 1980) and vertical (between surface and subsurface - Brunke and Gonser, 1997) connectivity are all crucial (Ward, 1989). Conceptual model (taking the form of flow charts) are often employed to clarify the presence and importance of the above-mentioned processes and the interaction between them. The conceptual models can be revisited and updated when data become available.

Hence, strategies for solutions to mitigate pressures on groundwater-river connectivity will be required at a range of spatial and temporal scales, from hydromorphological restoration of stream channels and floodplains to large scale changes in the catchment (Text box 2). For example, pressures that affect upstream infiltration and groundwater recharge (e.g. groundwater abstraction, soil compaction, intensive drainage and changes in vegetation; Figure 4) can have major impacts on groundwater conditions across the whole catchment (Eflows guidance document, 2015). Such catchment-wide measures may require land use changes and/or reduction of groundwater abstraction in upstream parts of the catchment. Successfully implementing such mitigation or adaptation measures at catchment scale can be difficult, as they require long-term cooperation with stakeholders such as farmers, industries and municipalities and adequate/adaptive integrated water resource management, modelling and monitoring approaches for the different scales in time and space. Because of the lack of direct involvement and identification with the problem, these stakeholders may show a reduced willingness to cooperate with restoration schemes. This is compounded by the limited control of water managers over land use and activities in all parts of the catchment as well as by historical ties with farmer organizations or municipalities that may have other interests (EC, 2008). Stakeholder participation needs to be facilitated by provision of public access to data and information so that all potential actors are well-informed. Some of these actions have been set out in the outputs of past European Commission research studies (e.g. GRAPES; Acreman, 2000; Mysiak et al., 2009; Aguilera et al., 2013).

Text box 2: Examples of sustainable groundwater management that reduce stresses in rivers

Mitigation and adaptation of pressures from mining in River Uherka (Poland)
Open-cast mining from chalk rocks is undertaken in the River Uherka catchment. The mine has a drainage system with a discharge of circa 24,000 m^3/d. To prevent any negative effects on the nearby wetland area of the Chelm Marshes (NATURA 2000), the drainage system is controlled and modified. In addition, the water that comes from the mine's drainage system is used by the city communal water supply. City sewage water is purified by modern wastewater treatment and then transferred and discharged into River Uherka to guarantee maintenance of the environmental flow in the river.

Recovery of aquatic ecology by reduced groundwater abstractions in River Pang, Berkshire (UK)
River flows in the River Pang (Berkshire) were depleted due to abstraction from a local groundwater borehole. This led to stakeholder complaints about loss of species, recreation and cultural amenity value of the river. The situation was evaluated by hydrological modelling of various scenarios. Based on the results, groundwater abstraction was reduced and switched to another less ecologically sensitive site, leading to recovery of biodiversity and other ecosystem services in the Pang.

Hydrological and ecological recovery in River Misbourne due to halving groundwater abstractions (UK)
Historically, significant quantities of groundwater have been abstracted from the catchment of the River Misbourne, a Chalk stream in the Chilterns Hills, in southern England. Abstraction started in 1901, peaking at 30 Ml/d by the late 1980s. An Alleviation of Low Flow (ALF) scheme in 1998 reduced the average abstraction by around a half. Post project appraisal of the hydrology (flow recovery) and ecology (habitat and aquatic biota recovery) demonstrated an improvement in flows and biota. In particular, the presence of notable species in the upper reaches highlighted the importance of groundwater-river interaction in the periodic drying to winterbourne sections.

Restoration land use and hydromorphology causes improved flow dynamics in River Regge (Netherlands)
The River Regge in the eastern part of the Netherlands is a heavily modified water body due to various pressures, e.g. straightening of water courses, large areas with intensive drainage, groundwater abstractions, and other land use changes. Among others, this has caused a change in flow dynamics (increased peak flows, reduced base flow) and degradation of the ecological conditions. However, since the 1990s areas in the catchment have been restored to more natural conditions, drainage was removed in several areas, and streams were re-naturalized by hydromorphological measures. Recent research pointed out that this has led to improvement of groundwater conditions and flow dynamics in the River Regge.

Farmers improve the (ground)water system with innovative drainage in Limburg (Netherlands)
In the Province of Limburg (The Netherlands), approximately 65% of the land is being used for agriculture. For this purpose intensive drainage systems have been built over the past century, which cause peak runoff events as well as a reduction of the groundwater recharge. As a result, terrestrial ecosystems suffered from low groundwater levels and ecology in and around streams suffers from drought in water courses. Through close cooperation with farmers, part of the existing drainage system was removed and an innovative system of tile drainage was implemented that enables steering of (ground)water levels. As a result groundwater levels were significantly increased and peak discharges were reduced both in frequency and magnitude. Moreover, increased seepage of groundwater towards streams has improved base flow conditions and surface water quality. Simultaneously, farmers' profit increased due to reduced drought damage to their crops, increased nutrient uptake from the soil and an increase in agricultural surface area because of ditch removal.

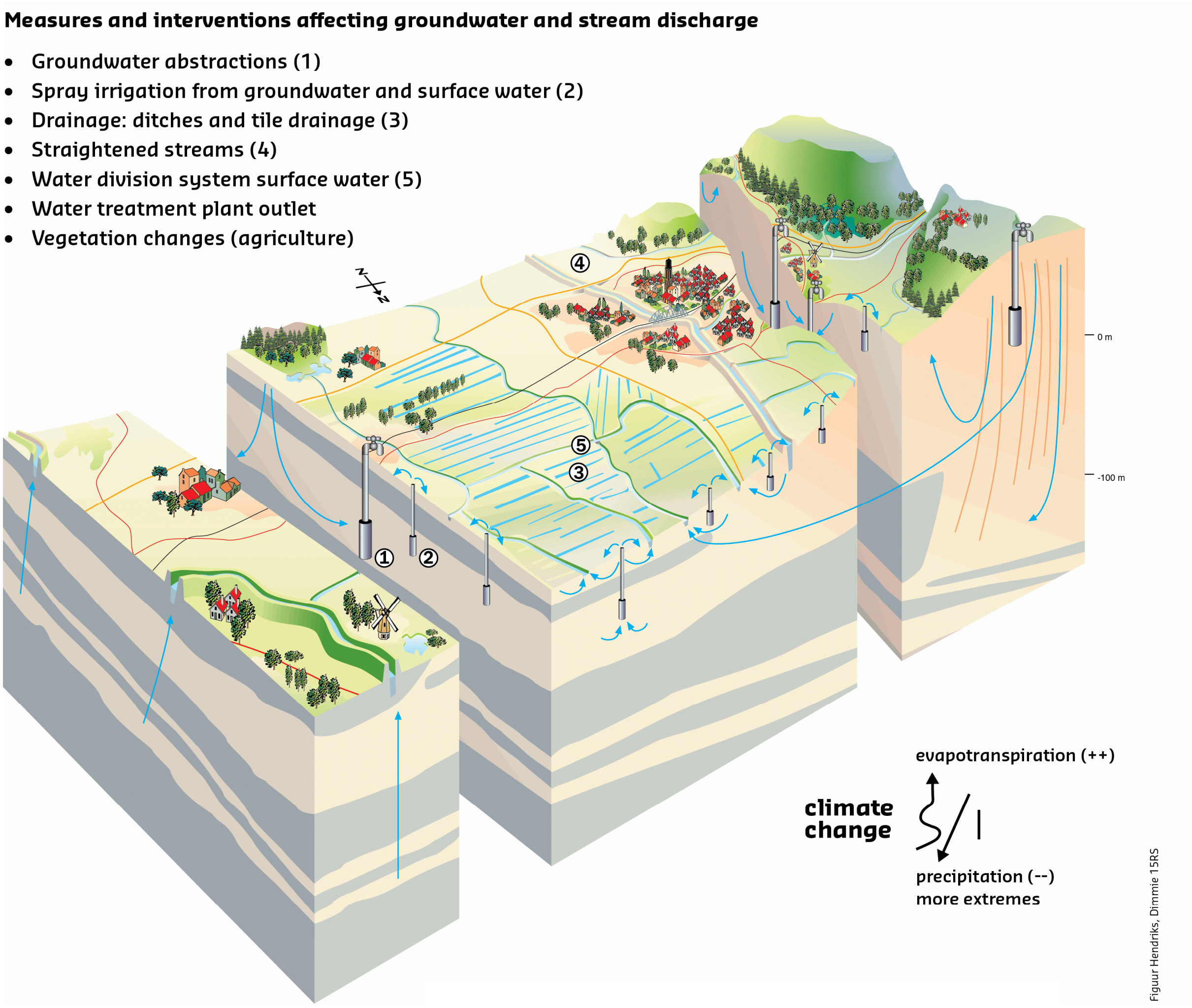

Figure 4: Schematic of pressures on groundwater-river interaction in catchments.

7. Policy and management recommendations

Based on the outcomes of the REFORM workshop on *Groundwater – River interactions as driver for ecology*, the following recommendations are made. These recommendations are relevant for both policy makers and water managers.

Firstly, we recommend that policy-makers and water managers enhanced their knowledge of issues related to groundwater-river interactions and ecosystems response. Groundwater is not only a key factor in supporting ecological flows (Eflows), determining both the quantity and quality of surface waters, it is also a very important aspect in enhancing the resilience of water systems necessary to prepare for future climate conditions.

Secondly, we recommend promoting close cooperation between the relevant fields of expertise (groundwater and Eflows). Available knowledge needs to be combined and it should be made clear how this knowledge can be applied in policy documents, RBMPs and the practice of local water management. Indispensable cooperation is required between policy-makers, national and local experts and water managers who develop mitigation and adaptation measures at the local catchment level.

Finally, we recommend developing river basin-wide strategies for solutions rather than isolated mitigation and adaptation measures because groundwater bodies extend mostly beyond the scale of individual water bodies or beyond surface catchment boundaries. Since such an approach requires long-term planning and involvement and cooperation of all stakeholders in the catchment, local water managers may require substantial support from policy makers and water managers at the national and European level.

These basin wide solution strategies to improve the conditions that support Eflows in streams consist mainly of Nature Based Solutions, measures based on applying or stimulating ecosystem processes and structures to create climate robust solutions. Such Nature Based Solutions consist of water retention measures that increase the catchment resilience to climatic extremes directly and benefit both Eflows and aquatic ecosystems. Such solution strategies reflect the actions proposed by the Blueprint, e.g. combining solutions for floods and droughts with measures to improve and protect ecosystems, environmental flows, and ecosystem services.

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