European Commission

NWRM

Natural Water Retention Measures

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Individual NWRM

Maintenance of forest cover in headwater areas

Environment

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I. NWRM Description

Headwaters are the source areas for rivers and streams, crucial for sustaining the structure, function, productivity and complexity of downstream ecosystems. They are vital to hydrologic cycling as they are one of the main areas where precipitation contributes to surface and groundwater. Headwaters are typically less intensively used than downstream areas. In many headwater areas, extensive agriculture, forests or other semi-natural land cover types predominate. Forests in headwater areas have a beneficial role for water quantity and quality. Creating or maintaining forest cover in headwater catchments is a widely used practice in many major cities including New York, Istanbul and Singapore, as these cities are reliant on headwater forests for drinking water provisioning. Forest soils generally have better infiltration capacity than other land cover types and may act as a "sponge", slowly releasing rainfall. In areas of high relief, afforestation of headwater catchments can contribute to slope stabilization and may reduce the risks associated with landslides. On the other hand, afforestation of headwaters in dry areas may lead to reduction of water yield.

II. Illustration

Before and after afforestation in a headwater area

Source: http://www.intechopen.com/books/advances-in-landscape-architecture/reclamation-of-degraded-landscapes-due-to-opencast-mining

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Possible	Targeted land use conversion through afforestation (measure F5) could transform artificial surface in headwater areas to headwater forest catchments.
Agricultural Areas	Possible	Targeted land use conversion through afforestation (measure F5) could transform agriculture in headwater areas to headwater forest catchments.
Forests and Semi-Natural Areas	Yes	Forests and semi-natural land cover in headwater catchments can play a role in controlling the hydrology and water quality of downstream areas. Both traditional semi-natural forests and short rotation or plantation forestry may have beneficial effects on the

		hydrological cycle, primarily through increased evapotranspiration. Semi-natural or lightly managed forests may have greater benefits for infiltration of precipitation than are seen with plantation forests. Afforestation of headwaters in semi-arid areas, on the other hand, may cause a decrease in downstream water resources.
Wetlands	Yes	Inland wetlands in headwater areas can have beneficial effects on hydrology and water quality in downstream areas.

Region	**Applicability**	**Evidence**
Western Europe	Yes	This measure is applicable throughout the montane areas of Europe. Afforestation of headwater catchments in montane areas may be an effective tool for controlling landslides. Ideally, afforestation will be conducted using native species which are known to be robust to the potential effects of a changing climate. Afforestation of headwaters can have beneficial effects on water quality and quantity and flood control in downstream locations. Afforestation of headwater areas for water retention should be performed in light of local conditions and local hydrological issues, as decrease of water yield after afforestation due to increased evapotranspiration (ET) has been reported in dry mountain areas.
Mediterranean	Yes	This measure is applicable throughout the montane areas of Europe. Afforestation of headwater catchments in montane areas may be an effective tool for controlling landslides. Ideally, afforestation will be conducted using native species which are known to be robust to the potential effects of a changing climate. Afforestation of headwaters can have beneficial effects on water quality and flood control in downstream locations. Afforestation of headwater areas for water retention should be performed in light of local conditions and local hydrological issues, as decrease of water yield after afforestation due to increased evapotranspiration (ET) has been reported in dry mountain areas.
Baltic Sea	Yes	This measure is applicable throughout the montane areas of Europe. Afforestation of headwater catchments in montane or high-relief areas may be an effective tool for controlling landslides. Ideally, afforestation will be conducted using native species which are known to be robust to the potential effects of a changing climate. Afforestation of headwaters can have beneficial effects on water quality and flood control in downstream locations. Afforestation of headwater areas for water retention should be performed in light of local conditions and local hydrological issues.
Eastern Europe and Danube	Yes	This measure is applicable throughout the montane areas of Europe. Afforestation of headwater catchments in montane areas may be an effective tool for controlling landslides. Ideally, afforestation will be conducted using native species which are known to be robust to the potential effects of a changing climate. Afforestation of headwaters can have beneficial effects on water quality and flood control in

		downstream locations. Afforestation of headwater areas for water retention should be performed in light of local conditions and local hydrological issues, as decrease of water yield after afforestation due to increased evapotranspiration (ET) has been reported in dry mountain areas.

IV. Scale

	0-0.1km^2	0.1-1.0km^2	1-10km^2	10-100km^2	100-1000km^2	>1000km^2
Upstream Drainage Area/Catchment Area	Possible	Possible	Yes	Yes	Yes	Yes
Evidence	Because of the fractal nature of rivers, headwater forests can have a beneficial effect at almost all spatial scales. Typically, any catchment smaller than 1km^2 is a headwater catchment. It is only as one moves to larger spatial scales that a meaningful separation develops between headwater and downstream catchments. While the effect of individual headwater catchments decline as the size of the total catchment increases, the beneficial effects can be maintained so long as the percent area of headwater catchments subject to afforestation is maintained.					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	High	Because of their greater infiltration capacity when compared to many arable, pasture or urban soils, forest soils can have a significant capacity to store excess precipitation and limit or prevent runoff. Furthermore, because of their greater surface roughness, and high water holding capacity, forest soils can act to slow runoff in much the same way as a sponge can store water and slow the rate at which water travels.
	Slow Runoff	High	
	Store River Water	None	
	Slow River Water	None	
Reducing Runoff	Increase Evapotranspiration	High	When compared to non-forest land cover types, forests often have higher rates of evapotranspiration (ET) and canopy interception. Thus, headwater forest areas are able to reduce the absolute volume of water which may eventually contribute to runoff by returning a greater fraction of precipitation to the atmosphere, thereby increasing precipitation recycling.
	Increase Infiltration and/or groundwater recharge	High	Forest soils are characterized by high porosity, good infiltration capacity and high water holding ability. Therefore, headwater forest catchments are able to increase infiltration and

			groundwater recharge rates above those common to agricultural or urban areas. While headwater forests can increase infiltration and groundwater recharge, the actual change in groundwater levels will be driven by both rates of ET (which return precipitation to the atmosphere) and infiltration (which facilitate recharge).
	Increase soil water retention	High	For much the same reasons as headwater forests are able to increase infiltration and groundwater recharge, they can also contribute to soil water retention. Forest soils often have a higher organic matter content than agricultural or urban soils. The organic matter can act as a sponge, holding or slowing precipitation on its way to generating runoff.
Reducing Pollution	Reduce pollutant sources	High	Headwater forest catchments can reduce pollutant delivery to receiving waters. Forests are able to effectively retain atmospherically deposited pollutants such as nitrogen. Metals and organic pollutants may be tightly bound to the organic matter in forest soils, and the longer water transit times of forest soils are conducive to increased degradation of pollutants.
	Intercept pollution pathways	High	Headwater forest catchments can intercept and retain atmospherically deposited pollutants such as nitrogen and persistent organic pollutants, thereby improving groundwater and surface water quality.
Soil Conservation	Reduce erosion and/or sediment delivery	High	Compared to bare soils, forest cover can significantly reduce erosion and sediment delivery. The energy of rainfall reaching the soil surface is moderated by forest cover, reducing the potential for erosion. The dense organic mat characteristic to many forest soil surfaces is also more erosion resistant than bare soils or soils low in organic matter.
	Improve soils	Medium	For the reasons mentioned above (higher organic matter content, greater water holding capacity, higher porosity, higher infiltration rates) forests are able to improve soils. Thus land conversion where headwater catchments are afforested will, over time, contribute to an improvement in soil quality.
Creating Habitat	Create aquatic habitat	Medium	While headwater forest catchments do not directly create aquatic or riparian habitat, they contribute to these habitats by providing nutrients, organic matter and food sources. Streams in forest covered landscapes have the potential to support a more diverse biological community than streams in agricultural or urban areas.
	Create riparian habitat	Medium	
	Create terrestrial habitat	High	Forested headwater catchments are terrestrial habitats by their very nature. Afforestation of headwater catchments creates terrestrial forest habitats that may have considerable biodiversity or recreational values. It should be noted that terrestrial habitat can be both created and preserved by this measure.

Climate Alteration	Enhance precipitation	Low	Because forests often have higher rates of evapotranspiration than other land cover types, they can contribute to precipitation recycling. Some fraction of water returned to the atmosphere by forests will fall as precipitation in downwind areas.
	Reduce peak temperature	Moderate	Compared to agricultural, bare or urban soils, forest soils have a lower peak temperature as much of the radiant energy of the sun is absorbed by forest vegetation before it reaches the soil surface. Through providing shade, forests will also reduce water temperature in headwater streams and moderate diurnal air temperature variations.
	Absorb and/or retain CO_2	High	Depending on the rates of tree growth, headwater forest catchments can have a moderate to high ability to absorb or retain CO_2. Growing forests are often a strong carbon sink and thus, under some circumstances, headwater forest catchments can contribute positively to the greenhouse gas balance of a region.

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	High	For the reasons mentioned above (increased infiltration, high porosity, and greater recharge capacity) the soils in forest headwater catchments have a high water storage capacity. It should be noted that planting forests in headwater areas is not a guarantee of increased downstream water supply as the greater rates of evapotranspiration typical of forests will return more precipitation to the atmosphere than other land cover types.
	Fish stocks and recruiting	Low	Even though the direct impact on fish stocks is limited, forest headwater catchments may indirectly contribute to sustaining productivity of downstream ecosystems, including food for some fish species. Sediment retention may also positively influence spawning habitat for some fish species.
	Natural biomass production	High	Growing forests are a significant source of natural biomass production. However, demands for biomass production must be balanced against other ecosystem service benefits. Typically, an exclusive focus on biomass production as has been seen in some upland afforestation projects will limit biodiversity preservation or recreational opportunities and may conflict with water retention goals.
Regulatory and Maintenance	Biodiversity preservation	Medium	Preservation of existing headwater forest catchments has a direct positive impact on biodiversity preservation, as these areas are often biodiversity hotspots. When afforestation of headwater catchments uses indigenous or local species, there is a considerable potential for biodiversity preservation. Indigenous or local forests can be important habitats for many species including

			plants, animals and insects.
	Climate change adaptation and mitigation	High	The carbon sequestration potential of growing forests can offer significant climate change mitigation possibilities. Biomass harvesting from forest catchments may also contribute to climate change mitigation by substitution of fossil fuel energy sources. Biomass harvesting has, however, to be balanced against other ecosystem services.
	Groundwater / aquifer recharge	High	For the reasons mentioned above, headwater forest catchments can play a significant role in groundwater / aquifer recharge. It must be stressed that the greater infiltration, water holding and recharge capacity of forest soils needs to be balanced against higher rates of forest evapotranspiration when evaluating the net hydrologic benefit of headwater forest catchments.
	Flood risk reduction	High	Headwater forest catchments have a high potential for flood risk reduction. They are able to reduce the absolute volume of water contributing to runoff through higher rates of evapotranspiration. Furthermore, forest soils slow the transit of water through a catchment, reducing the height of the flood peak and contributing to maintenance of base flows.
	Erosion / sediment control	High	Headwater forest catchments have a high potential for ecosystem service delivery related to erosion and sediment control. Compared to bare soils, forest cover can significantly reduce erosion and sediment delivery, thereby improving downstream water quality and potentially reducing water treatment costs or extending the operational life of reservoirs. The energy of rainfall reaching the soil surface is moderated by forest cover, reducing the potential for erosion. The dense organic surface layer characteristic to many forest soil surfaces is also more erosion resistant than bare soils or soils low in organic matter.
	Filtration of pollutants	High	Headwater forest catchments can be important filters of atmospherically deposited pollutants, thereby reducing pollutant delivery to receiving waters. Forests are able to effectively retain atmospherically deposited pollutants such as nitrogen. Metals and organic pollutants may be tightly bound to the organic matter in forest soils and the longer water transit times of forest soils are conducive to increased degradation of pollutants. These processes can reduce downstream drinking water treatment costs.
Cultural	Recreational opportunities	High	Semi-natural forests with a significant amount of indigenous vegetation can offer significant recreational opportunities and have high aesthetic and cultural values. The semi-natural forests which can be produced through afforestation of headwater catchments can mimic the structure and composition of natural forests. Two of the most archetypal forest recreational areas in North America: Algonquin Park and the Adirondacks, were originally established as headwater forest catchments for water supply management.
	Aesthetic / cultural value	High	

Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	Managed forests in headwater catchments can contribute biomass for energy production but they do not have any clear abiotic potential for energy production.

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good Surface Water Status	Improving status of biology quality elements	Low	Afforestation of headwater catchments will have limited direct effects on the achievement of WFD objectives. However, the moderation of peak flows and maintenance of base flows as well as pollutant filtering and sediment retention can contribute to improved water and habitat quality in downstream water bodies.
	Improving status of physico-chemical quality elements	Low	
	Improving status of hydromorphological quality elements	Low	
	Improving chemical status and priority substances	Low	
Achieve Good GW Status	Improved quantitative status	Medium	Afforestation of headwater areas can have direct benefits for groundwater quantitative and chemical status. Improved infiltration associated with more permeable forest soils can facilitate higher rates of groundwater recharge, which results in improved quantitative status while the pollutant filtering and retention abilities of forests can lead to improved groundwater chemical status.
	Improved chemical status	Medium	
Prevent Deterioration	Prevent surface water status deterioration	Medium	Afforestation of headwater can have an indirect effect on deterioration of surface water body status and a direct effect on preventing deterioration of groundwater status. Because surface water WFD water bodies are often downstream of headwater forests, there will be an indirect beneficial effect of afforestation on preventing surface water deterioration. Since groundwater water bodies are directly below headwater ad downstream areas, the hydrologic and water quality benefits of headwater forest catchments can have a direct effect on preventing deterioration of groundwater status.
	Prevent groundwater status deterioration	High	
Floods Directive			

Take adequate and co-ordinated measures to reduce flood risks	High	Headwater forest catchments can play an important role in flood risk reduction as they are able to reduce the total volume of precipitation contributing to runoff as well as to lower the height of the flood peak as they are able to retain and slow water more effectively than other land cover types.
Habitats and Birds Directives		
Protection of Important Habitats	High	As headwater streams differ widely in physical, chemical and biotic attributes, they provide habitats for a range of unique species, both permanent residents and migrants traveling to headwaters at particular seasons and life stages. This is true also for headwater forest catchments. When a headwater forest contains a site relevant for the Habitats or Birds Directive, protection of important habitats can have a dual benefit of biodiversity preservation and enhanced water retention.
2020 Biodiversity Strategy		
Better protection for ecosystems and more use of Green Infrastructure	High	By their very nature, headwater forests are a green infrastructure. Protection of headwater forests for water management purposes will ensure that the ecosystems they contain are protected also.
More sustainable agriculture and forestry	Medium	Forestry practiced in headwater forest catchments has the potential to be performed in a biodiversity-aware and sustainable manner. Use of native or indigenous tree species will contribute to biodiversity goals.
Better management of fish stocks	Medium	Even though the direct impact on fish stocks is limited, forest headwater catchments may indirectly contribute to sustaining productivity of downstream ecosystems, including food for some fish species. Sediment retention may also positively influence spawning habitat for some fish species.
Prevention of biodiversity loss	High	If headwater forest catchments are managed to promote native or indigenous tree species, there is a potential to prevent biodiversity loss and potentially to restore species and biological communities that had previously been extirpated from a region. Clear-cuts above a certain size can have detrimental effects on green infrastructure, soil retention and evapotranspiration.

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	The creation or maintenance of headwater forest catchments is dependent on large scale land conversion or preservation. Typically, an area of several hectares to tens of square kilometres must be afforested for there to be significant downstream benefits.

Space required	Headwater forest catchments are extensive measures requiring an area of several hectares to tens of square kilometres.
Location	The most suitable headwater catchments for afforestation are located upstream of urban or peri-urban areas where flood risk reduction or improvements in water quality are desired.
Site and slope stability	There are no limitations to site and slope stability. Afforestation of headwater catchments is most likely to be effective in regions with sufficient precipitation to support tree growth.
Soils and groundwater	There are no restrictions on soils or groundwater.
Pre-treatment requirements	None
Synergies with Other Measures	Afforestation of headwater catchments can be part of a larger flood risk management strategy designed to "keep the rain where it falls".

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition		Land acquisition costs can range from nil to extremely high depending on whether the land is already owned by the state, and if it is not, what compensation is needed for expropriation.
Investigations & Studies		
Capital Costs		Costs associated with afforestation of headwater catchments include the cost of tree planting and steps necessary to ensure seedling establishment, costs for thinning and sustainable forest management.
Maintenance Costs		Limited to none
Additional Costs		Limited to none

X. Governance and Implementation

Requirement	Evidence
n/a	

XI. Incentives supporting the financing of the NWRM

Type	Evidence
n/a	

XII. References

Reference	Comments
Neary, Daniel G., George G. Ice, and C. Rhett Jackson. "Linkages between forest soils and water quality and quantity." Forest Ecology and Management258.10 (2009): 2269-2281.	Good general reference on forest water issues
Dudley, Nigel; Stolton, Sue. 2003. Running Pure : The Importance of Forest Protected Areas to Drinking Water. World Bank/WWF Alliance for Forest Conservation and Sustainable Use. © World Bank.	https://openknowledge.worldbank.org/handle/10986/15006 License: CC BY 3.0 IGO."
Hamilton, L. S. (2008). Forests and water. FAO.	Excellent review of forest and water issues in a global perspective http://www.fao.org/docrep/011/i0410e/i0410e00.htm
Wipfli, Mark S., Richardson, John S., and Naiman, Robert J. 2007. Ecological Linkages Between Headwaters and Downstream Ecosystems: Transport of Organic Matter, Invertebrates, and Wood Down Headwater Channels. Journal of the American Water Resources Association (JAWRA) 43(1):72-85.	Highlights linkage of headwaters to downstream ecosystems
Takashi Gomi, Sidle, Roy C. and Richardson, John S. 2002. Understanding Processes and Downstream Linkages of Headwater Systems. Bioscience 52(10): 905-916	Highlights importance of headwater systems to downstream ecosystems
Freeman, Mary C., Pringle, Catherine M. and Jackson, C. Rhett. 2007. Hydrologic Connectivity and the Contribution of Stream Headwaters to Ecological Integrity at Regional Scales. Journal of the American Water Resources Association (JAWRA) 43(1):5-14.	Explains large-scale effects of altering headwater catchments on downstream ecosystems
K. Bishop, I. Buffam, M. Erlandsson, J. Folster, H. Laudon, J. Seibert and J. Temnerud. 2008. Aqua Incognita: the unknown headwaters. Hydrological Processes 22: 1239–1242	Highlights importance of headwaters and knowledge gaps in relation to them
Lee H. MacDonald and Drew Coe. 2007. Influence of Headwater Streams on Downstream Reaches in Forested Areas. Forest Science 53(2): 148-168	Explains interactions between headwaters and downstream reaches, discusses implications for adaptive management of headwater areas.
John S. Richardson and Robert J. Danehy. 2007. A Synthesis of the Ecology of Headwater Streams and their Riparian Zones in Temperate Forests. Forest Science 53(2): 131-147	Gives overview of structures and processes, occurring in headwater streams.
Meyer, Judy L., David L. Strayer, J. Bruce Wallace, Sue L. Eggert, Gene S. Helfman, and Norman E. Leonard, 2007. The Contribution of Headwater Streams to Biodiversity in River Networks. Journal of the American Water Resources Association (JAWRA) 43(1):86-103.	Highlights the importance of headwaters to the biological integrity of the whole river network.