European Commission

Natural Water Retention Measures

NWRM

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Individual NWRM

Land use conversion

ACTeon environment research & consultancy

Office International de l'Eau

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Environment

This report was prepared by the NWRM project, led by Office International de l'Eau (OIEau), in consortium with Actéon Environment (France), AMEC Foster Wheeler (United Kingdom), BEF (Baltic States), ENVECO (Sweden), IACO (Cyprus/Greece), IMDEA Water (Spain), REC (Hungary/Central & Eastern Europe), REKK inc. (Hungary), SLU (Sweden) and SRUC (UK) under contract 07.0330/2013/659147/SER/ENV.C1 for the Directorate-General for Environment of the European Commission. The information and views set out in this report represent NWRM project's views on the subject matter and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this report. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

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I. NWRM Description

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

II. Illustration

Afforestation of a hill

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Yes	Conversion of artificial impermeable land cover to treed, permeable land cover can have beneficial effects on hydrological functioning and deliver important amenity services such as urban forest parks (F11) or trees in urban areas (F12).
Agricultural Areas	Yes	Afforestation of former agricultural areas with either short-rotation or conventional forests may provide hydrological benefits but these need to be balanced carefully against negative

		impacts on food security and rural sustainability.
Forests and Semi-Natural Areas	Yes	Semi-natural areas other than forests may be afforested for improvements in water retention and hydrological cycling.
Wetlands	No	It is extremely unlikely that the benefits of converting wetlands to forests would exceed the costs related to loss of biodiversity and other ecosystem services.

Region	**Applicability**	**Evidence**
Western Europe	Yes	The potential for land use conversion depends on a number of factors including the current land use, societal demand and public opinion and the regulatory environment. European and national policies in many member states discourage the afforestation of agricultural land. In areas with low precipitation potential gains of afforestation should be weighed against potential adverse effects of reduced water supply on a local scale.
Mediterranean	Yes	The potential for land use conversion depends on a number of factors including the current land use, societal demand and public opinion and the regulatory environment. European and national policies in many member states discourage the afforestation of agricultural land. In areas with low precipitation potential gains of afforestation should be weighed against potential adverse effects of reduced water supply on a local scale.
Baltic Sea	Yes	The potential for land use conversion depends on a number of factors including the current land use, societal demand and public opinion and the regulatory environment. European and national policies in many member states discourage the afforestation of agricultural land. In areas with low precipitation potential gains of afforestation should be weighed against potential adverse effects of reduced water supply on a local scale.
Eastern Europe and Danube	Yes	The potential for land use conversion depends on a number of factors including the current land use, societal demand and public opinion and the regulatory environment. European and national policies in many member states discourage the afforestation of agricultural land. In areas with low precipitation potential gains of afforestation should be weighed against potential adverse effects of reduced water supply on a local scale.

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	Yes	Yes	Yes	Yes	Possible	Possible
Evidence	Land use conversion or afforestation is probably most effective in headwater areas where the benefits of increased infiltration and improvements to water quality are likely to be greatest. While the benefits of afforestation are seen locally, they will lead to downstream improvements in flow regime and water quality. At the same time potential adverse effects related to decrease of local water yield could be most pronounced in the headwaters in areas with low precipitation amounts. It should be stressed that indigenous species should be used for afforestation whenever possible.					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	High	Like other afforestation strategies, land use conversion has the potential to substantially increase landscape-scale runoff storage. Afforestation can increase runoff storage in several ways. The higher rates of evapotranspiration associated with growing forests can dry out soils, providing more infiltration and storage capacity for precipitation. Forests, with their relatively high rates of litter-fall, provide additional organic carbon to the soil, which can improve soil structure, leading to both higher water holding capacity and greater infiltration capacity.
	Slow Runoff	High	Afforested lands are better able to slow runoff than urban, pasture or arable land cover. Typically, forest soils are rougher, which physically slows the movement of water and have greater infiltration and water holding capacity than agricultural or urban soils. These three properties all contribute to slowing runoff. Snow often melts more slowly in forests than adjacent non-forest areas. Slower rates of snowmelt can contribute to a reduction in the height of peak spring flows in cooler regions.
	Store River Water	None	
	Slow River Water	None	

Reducing Runoff	Increase Evapotranspiration	High	Forests can have higher rates of evapotranspiration (ET) than other land cover types including urban and agricultural lands. Higher rates of ET can contribute to "keeping the rain where it falls" by returning a greater fraction of incoming precipitation to the atmosphere. In many regions of Europe, a significant fraction of forest ET will contribute to downwind precipitation.
	Increase Infiltration and/or groundwater recharge	High	Forest soils can have better water recharge properties when compared to similar soils with other types of land cover. This means that they will have improved infiltration, groundwater recharge and soil water retention capacities. Forest soils typically have a higher organic matter content than agricultural or urban soils. This contributes to a greater water retention capacity and helps improve the soil aggregate structure. The improved soil structure contributes to higher infiltration rates which in turn can aid in groundwater recharge. It is important to note that there is a balance between increased ET and greater water holding capacity. There has been a significant amount of scientific work done attempting to understand the forest hydrologic cycle (see Raftoyannis et al. 2011 for a recent review) and the actual hydrological effects of land use conversion to forests will vary.
	Increase soil water retention	Medium	
Reducing Pollution	Reduce pollutant sources	High	Forests and forest soils have a high ability to reduce pollutant sources and intercept pollution pathways. Thus, land use conversion through afforestation may play an important role in improving water quality. The organic matter in forest soils can retain metals, persistent organic pollutants and mercury. Forests also play an important role in intercepting and retaining atmospherically deposited nitrogen. Because of their longer water retention times, forests support biological and abiological processes which breakdown pathogens and pollutants. At the same time in high pollution (industrial) areas the deposition of atmospheric pollutants may lead to catchment acidification and nitrate concentrations in soil and groundwater. Also afforestation with conifers has in some cases reported to cause acidification of water bodies.
	Intercept pollution pathways	High	
Soil Conservation	Reduce erosion and/or sediment delivery	High	There are several ways in which forests reduce erosion and sediment delivery. The root networks and organic matter layer in forest soils can contribute to improving soil physical structure, making the soil more resistant to erosion. Organic matter also improves soil aggregation, further reducing potential for erosion. Forest cover intercepts precipitation, reducing the energy of rainfall which reaches the ground surface, thereby reducing erosion. Erosion rates will be lowest from natural or close-to-natural forests but may, on the other hand, substantially

			increase in poorly managed monoculture plantations with little understorey. Also poor planning of forest roads and drainage ditches in afforested areas may lead to increased sediment delivery.
	Improve soils	Medium	Forests have the potential to improve soils through greater accumulation of organic matter, improvement of soil aggregate structure, increased soil porosity and greater infiltration and water holding capacity. All of these functions contribute to an improvement in the natural water retention capacity of landscapes subject to afforestation.
Creating Habitat	Create aquatic habitat	Medium	If the afforestation extends to the edge of water bodies, forest will contribute to aquatic habitat by providing nutrients, organic matter and food sources.
	Create riparian habitat	Low	If afforestation is performed in areas adjacent to streams, creation of riparian habitats is possible.
	Create terrestrial habitat	High	Afforestation, or land cover conversion to forests, has a high potential to create ecologically valuable terrestrial habitat, especially if native or indigenous tree species are used. On the other hand, land cover conversion through abandonment of agricultural land may lead to loss of important cultural habitats in some cases.
Climate Alteration	Enhance precipitation	Low	Afforested areas will contribute to enhanced precipitation through higher rates of evapotranspiration (ET) from forests than from other land use types.
	Reduce peak temperature	High	Forest cover contributes to reducing peak temperature at the soil surface by intercepting radiation in the forest canopy. Shading and decreased wind speed can also moderate diurnal air temperature variations.
	Absorb and/or retain CO_2	High	Growing forests have the potential to absorb and/or retain CO_2 both in growing biomass and in organic matter accumulated in the soil.

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	High	For the reasons mentioned above, land use conversion through afforestation has a high potential to deliver ecosystem service benefits related to water storage. The greater infiltration and water holding capacity of forest soils can be a significant factor in maintaining base flows in many parts of the world.
	Fish stocks and recruiting	Medium	Through sediment retention, land conversion to forest may have certain impact on water quality in water bodies and thus also on the aquatic habitat, potentially affecting fish stocks. If afforestation extends to the edge of the water bodies, forest

			litter may have impact on aquatic ecosystem productivity.
	Natural biomass production	High	Land use conversion through afforestation has a high potential for natural biomass production. Depending on management goals, the forest biomass may be harvested or retained on the landscape. Biomass production goals need to be balanced against other desired ecosystem service benefits.
Regulatory and Maintenance	Biodiversity preservation	High	Under some circumstances, land use conversion through afforestation can offer significant ecosystem service benefits related to biodiversity preservation. Biodiversity benefits are most likely to be maximized if land use conversion relies on native or indigenous species. Using exotic species, such as short rotation willow, Sitka spruce or eucalyptus may in fact reduce biodiversity when compared to previous land cover.
	Climate change adaptation and mitigation	High	The carbon sequestration potential associated with land use conversion through afforestation has significant climate change mitigation potential. If the harvesting period of forest biomass is expanded, climate change mitigation benefits by substitution of fossil fuel energy sources may also be achieved. Forest cover maintains a high level of soil carbon.
	Groundwater / aquifer recharge	High	For reasons mentioned earlier, land use conversion through afforestation can contribute to improved groundwater and aquifer recharge. The greater infiltration and water holding capacity of forest soils, combined with their longer water transit times can all make a positive contribution to aquifer recharge. On the other hand, afforestation of agricultural land with fast-growing tree species may in some cases reduce groundwater recharge due to increased water use of the trees.
	Flood risk reduction	High	Land use conversion through afforestation plays in most cases an important role in flood risk reduction. Forests tend to reduce the height of the flood peak hydrograph by retaining water in the landscape, returning water to the atmosphere as evapotranspiration, and moderating rates of snowmelt. Mitigating effect will be most explicit at the small catchment scale and for small-scale flood events.
	Erosion / sediment control	High	In many parts of Europe, forests play an important role in slope stabilization and in controlling erosion, avalanches and sediment production and transport. Forest root systems can play a critical role in stabilizing soils, which can help to prevent hillslope erosion in mountainous areas. Erosion rates will be lowest in natural or close-to-natural forests but may, on the other hand, substantially increase in poorly managed monoculture plantations with little understorey. Also poor planning of forest roads and drainage ditches in afforested areas may lead to increased sediment delivery.
	Filtration of pollutants	High	Land use conversion through afforestation can increase landscape-scale filtration of pollutants. Forests are effective at retaining atmospherically deposited nitrogen and other

			pollutants including heavy metals and persistent organic pollutants. By retaining and filtering atmospherically deposited pollutants, forests can contribute to improved downstream water quality and reduced water treatment costs. At the same time in high pollution (industrial) areas the deposition of atmospheric pollutants may lead to catchment acidification and nitrate concentrations in soil and groundwater. Also afforestation with conifers may in some cases lead to acidification of water in the reservoir.
Cultural	Recreational opportunities	High	Forests created through land use conversion may offer important recreational opportunities, especially if such forests are located near urban areas. Forests can be important areas for walking and cycling trails, bird viewing, berry and mushroom picking and other outdoor activities.
	Aesthetic / cultural value	High	Natural and semi-natural forests can have high aesthetic value and potentially be important cultural resources. It should be stressed that the aesthetic and cultural value of forests created through land use conversion will be highest if based on afforestation with native or indigenous tree species.
Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good Surface Water Status	Improving status of biological quality elements	Low	Land use conversion through afforestation will not have direct Water Framework Directive benefits, but may have important indirect effects on water body ecological status and water quantity. Through maintenance of base flows, afforested lands can ensure the maintenance of headwater aquatic habitats during dry periods. The potential for forest land cover to control sediment mobilization and transport and to reduce the height of flood peaks can assist in maintaining hydromorphological quality elements
	Improving status of physico-chemical quality elements	Low	
	Improving status of hydromorphological quality elements	Low	
	Improving chemical status and priority substances	Medium	The pollutant filtering effect often associated with forests can under some circumstances improve chemical status related to priority substances. However, these improvements need to be evaluated on a case-by-case basis as there can be circumstances where forests will filter pollutants out of the atmosphere and then deliver them rapidly to surface waters. This has been observed with surface water acidification following afforestation of some UK upland catchments.

F5: Land use conversion

Achieve Good GW Status	Improved quantitative status	Medium	Land use conversion through afforestation can contribute to improvements in groundwater quantitative and chemical status. The improved infiltration and recharge capacities of forests compared to urban or agricultural lands can contribute to improved quantitative status, which will assist in maintaining base flows while the pollutant filtration and retention effects of forest soils can help to improve groundwater chemical status, especially with respect to nitrogen and organic pollutants.
	Improved chemical status	Medium	
Prevent Deterioration	Prevent surface water status deterioration	Medium	Land use conversion through afforestation can help to prevent deterioration of surface and groundwater status. When targeted areas of larger catchments are afforested, there will be a reduction in the total pollutant and sediment load to downstream water bodies. This can contribute to the maintenance of surface water body status and the filtering effect of forest cover can help to prevent deterioration of groundwater status.
	Prevent groundwater status deterioration	Medium	
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		High	Land use conversion through afforestation can be a key part of upstream measures designed to reduce flood risks. Afforestation, with its catchment-scale hydrologic benefits of greater evapotranspiration, enhanced infiltration, slower snowmelt and slower water transit times can contribute in a multi-functional manner to reducing the risks of downstream flooding.
Habitats and Birds Directives			
Protection of Important Habitats		Medium	Land use conversion through afforestation does not protect existing habitats but may create new habitats suitable for birds and potentially red list species. These effects are most likely to be achieved if afforestation is performed using native or indigenous tree species and by applying sustainable forest management.
2020 Biodiversity Strategy			
Better protection for ecosystems and more use of Green Infrastructure		Medium	Land use conversion through afforestation can be conceptualized as a spatially extensive form of green infrastructure offering flood management, carbon sequestration and biodiversity benefits in rural areas. Afforestation can help to increase the habitat available for many species, hereby contributing to ecosystem improvement, especially by connecting small forest patches
More sustainable agriculture and forestry		Medium	Land use conversion through afforestation may help to promote a more sustainable rural landscape. Afforestation of marginal agricultural land may contribute to carbon sequestration and hydrological benefits, and potentially provide new areas for bioenergy supply.
Better management of fish stocks		Low	Through sediment retention, afforestation of the reservoir catchment may have certain impact on water quality in the reservoir and thus also on the aquatic habitat, potentially affecting fish stocks.

Prevention of biodiversity loss	Medium	If land use conversion through afforestation is accomplished using native or indigenous tree species, there is a potential to prevent biodiversity loss, both of the trees themselves and of other species dependent on forest ecosystems. It should be noted, however, that abandonment of marginal agricultural land and subsequent afforestation can result in loss of potentially important culturally-maintained ecosystems associated with historical farming practices.

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	Land use conversion through afforestation will have benefits at all spatial scales. The smallest realistic conversion is probably the individual field, while the largest could be a whole watershed.
Space required	Land use conversion through afforestation is an extensive green infrastructure, the effects of which will be a function of spatial extent. Thus, the larger the area that can be afforested, the greater the likelihood that benefits related to landscape-scale water retention or biodiversity improvements will be observed.
Location	Land use conversion through afforestation is probably most beneficial in areas of marginal agricultural land, areas with steep slopes and significant erosion or landslide risk and near urban areas. Conversion of marginal agricultural land to forest, especially upstream of urban areas with significant flood risk, may achieve significant water quality benefits and improve the flood control capacity of the landscape. Afforestation of steeply sloping areas may have significant benefits for slope stabilization, reducing erosion and landslide risk. Afforestation of areas adjacent to cities can offer important recreational opportunities and potentially have important pollutant filtering benefits. Caution should be taken when planning afforestation in water-scarce areas. Experimental data suggest that afforestation of more than 15-20% of the catchment may lead to significant changes in stream flow.
Site and slope stability	Sites upstream of urban flood risk areas and sites with significant slope hazard should be targeted for land use conversion through afforestation.
Soils and groundwater	There are no immediate soil or groundwater related limitations to this measure.
Pre-treatment requirements	Some form of site preparation and planting may be necessary to ensure establishment of forests following land use conversion. Establishment and maintenance of access infrastructure to afforested areas should be planned so as to minimize possible negative impact.

Synergies with Other Measures	Land use conversion through afforestation is an extensive green infrastructure that can be part of a bundle of measures aimed at reducing urban flood risk through a process of keeping the rain where it falls in upstream areas. Afforestation activities most likely will have synergies with appropriate design of roads and stream crossings, as well as water sensitive driving.

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition		There is limited evidence for land acquisition costs. However, it is unlikely to be financially feasible to purchase high value agricultural or urban land for conversion.
Investigations & Studies		
Capital Costs		Costs associated with afforestation include the cost of tree planting and steps necessary to ensure seedling establishment.
Maintenance Costs		Depending on the manner in which the forest is used, there may be maintenance costs associated with i.e. trails and public access points, thinning and other management costs.
Additional Costs		The key additional costs relate to foregone income associated with land use prior to afforestation.

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
Thomas, Björn, et al. "Measures to sustain seasonal minimum runoff in small catchments in the mid-latitudes: A review." Journal of Hydrology 408.3 (2011): 296-307.	Review paper including discussion of land use change effects on maintaining low flows
Raftoyannis, Yannis, et al. "Afforestation Strategies with Respect to Forest–Water Interactions." Forest Management and the Water Cycle. Springer Netherlands, 2011. 225-245.	Review of benefits and consequences of afforestation on the hydrologic cycle
Hamilton, Lawrence S. Forests and water. FAO, 2008.	Summary of global forest water issues with a special focus on the developing world
David Ellison, Martyn N. Futter and Kevin Bishop. (2012) On the forest cover–water yield debate: from demand- to supply-side thinking. Global Change Biology 18: 806–820	Presents discussion on forest cover-water yield relations
Albert I.J.M. van Dijk, Rodney J. Keenan. (2007) Planted forests and water in perspective. Forest Ecology and Management 251(1-2): 1-9	Discusses effects of afforestation on water-related issues
D. Archer. (2003) Scale effects on the hydrological impact of upland afforestation and drainage using indices of flow variability: the River Irthing, England. Hydrology and Earth System Sciences Discussions, Copernicus Publications 7 (3): 325-338	Gives evidence on the importance of scale when assessing afforestation effects
I.R. Calder. 2007. Forests and water—Ensuring forest benefits outweigh water costs. Forest Ecology and Management 251: 110–120	Discusses gaps between science and policy issues related to forests and water.
Robert A. Vertessy, L. Zhang and W.R. Dawes. 2002. Plantations, river flows and river salinity. Australian Forestry 66 (1): 55–61	Discusses potential impacts of plantation establishment on water yield.
Kathleen A. Farley, Esteban G. Jobbágy and Robert B. Jackson. (2005) Effects of afforestation on water yield: a global synthesis with implications for policy. Global Change Biology 11 (10): 1565–1576	Discusses possible adverse effects of afforestation on water yield
Francesc Gallart, Pilar Llorens. (2004) Observations on land cover changes and water resources in the headwaters of the Ebro catchment, Iberian Peninsula. Physics and Chemistry of the Earth, Parts A/B/C 29 (11–12): 769–773	

Caroline Van der Salm, Hugo Denier van der Gon, Rick Wieggers, Albert Bleeker, Antonie van den Toorn. (2006) The effect of afforestation on water recharge and nitrogen leaching in The Netherlands. Forest Ecology and Management 221(1–3):170–182	