European Commission

NWRM

Natural Water Retention Measures

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Service contract n°07.0330/2013/659147/SER/ENV.C1

Individual NWRM

Afforestation of reservoir catchments

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

Planting trees in reservoir catchments can have both negative and positive effects. . Afforestation of previously bare or heavily eroded areas can control soil erosion, thereby extending the life of the reservoir and improving water quality. Water quality can also be improved if precipitation is able to infiltrate into forest soils before flowing to the reservoir. These potential improvements in water quality need to be balanced against the possibility that less precipitation will be available for reservoir recharge due to the potentially greater interception and evapotranspiration associated with forests. Studies have indicated decrease of water yield after afforestation of the catchment and with the increase of forest age. Forests in reservoir catchments should typically not be managed for timber production, but maintained in as close to a natural state as possible as the fertilization and ground disturbance associated with intensive forest management can have negative impacts on reservoir water quality. Increased acidification and eutrophication after afforestation with conifer species have also been reported. Use of long-lived native deciduous tree species for afforestation instead of fast growing conifers or eucalypts is likely to bring enhanced biodiversity benefits while minimizing water loss.

II. Illustration

Example of reservoir catchment with forest

Source: http://www.surfat10.com/climate_care/Success%20Story%20of%20Afforestation/

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Possible	Afforestation of artificial surfaces in reservoir catchments is a form of land use conversion (F5) which have beneficial effects on water quality and quantity in reservoirs. Some "artificial non-agricultural vegetated areas" may serve this function if they are parks created for recreation (see measure F11)
Agricultural Areas	Possible	Afforestation of agricultural areas in reservoir catchments is a form of land use conversion (F5) which have beneficial effects on water quality and quantity in reservoirs. Some forms of extensive agriculture with limited stocking density and intact vegetation cover may also have beneficial effects.
Forests and Semi-Natural Areas	Yes	Creation or preservation of forests in reservoir catchments have beneficial effects on water quality and quantity in reservoirs. Semi-natural areas with intact vegetation cover (i.e. extensive pasture or grassland) may have a similar benefit.
Wetlands	Possible	Inland wetlands in reservoir catchments are not likely to have any clear net benefits on reservoir water quality. While wetlands may retain sediments and other pollutants, they typically sequester higher concentrations of organic carbon than other land cover types.

Region	Applicability	Evidence
Western Europe	Yes	Afforestation of reservoir catchments will be of greater benefit in parts of Europe where rainfall is abundant and the population are reliant on drinking water from surface water sources. Afforestation stabilizes land surfaces and improve infiltration but it will often lead to lower water yields because of greater interception and evapotranspiration. Afforestation using native deciduous species is likely to be more beneficial than conifers and the balance of evidence suggests that intensive forestry should be avoided.
Mediterranean	Yes	Afforestation of reservoir catchments will be of greater benefit in parts of Europe where rainfall is abundant and the population are reliant on drinking water from surface water sources. Afforestation stabilizes land surfaces and improve infiltration but it will often lead to lower water yields because of greater interception and evapotranspiration. Afforestation using native deciduous species is likely to be more beneficial than conifers and the balance of evidence suggests that intensive forestry should be avoided.
Baltic Sea	Yes	Afforestation of reservoir catchments will be of greater benefit in parts of Europe where rainfall is abundant and the population are reliant on drinking water from surface water sources. Afforestation stabilizes land surfaces and improve infiltration but

		it will often lead to lower water yields because of greater interception and evapotranspiration. Afforestation using native deciduous species is likely to be more beneficial than conifers and the balance of evidence suggests that intensive forestry should be avoided.
Eastern Europe and Danube	Yes	Afforestation of reservoir catchments will be of greater benefit in parts of Europe where rainfall is abundant and the population are reliant on drinking water from surface water sources. Afforestation stabilizes land surfaces and improve infiltration but it will often lead to lower water yields because of greater interception and evapotranspiration. Afforestation using native deciduous species is likely to be more beneficial than conifers and the balance of evidence suggests that intensive forestry should be avoided.

IV. Scale

	0-0.1km²	**0.1-1.0km²**	**1-10km²**	**10-100km²**	**100-1000km²**	**>1000km²**
Upstream Drainage Area/Catchment Area	Yes	Yes	Yes	Yes	Yes	Possible
Evidence	Reservoirs are typically located in mesoscale catchments so as to have sufficient contributing area for precipitation capture. However, the benefits associated with reservoir afforestation are largely scale independent and may become apparent across a range of spatial scales. Local scale processes related to sediment mobilization and infiltration will improve reservoir water quality. It should be noted that there are both benefits and potential adverse consequences associated with reservoir afforestation. Afforestation, if carried out together with soil preparation, may lead to high sediment run-off in short-term. In water scarce areas, it may not be desirable to reduce the water yield of reservoir catchments by planting trees.					

V. Biophysical Impacts

Biophysical Impacts		**Rating**	**Evidence**
Slowing & Storing Runoff	Store Runoff	High	Reservoir catchments have a high potential to store and / or slow runoff. The ability of a reservoir to store or slow runoff from a precipitation or snowmelt event is dependent on the antecedent wetness of the surrounding soils and the depth of water in the reservoir. So long as there is capacity, either in the reservoir or surrounding soil, runoff can be slowed and stored. Once the soils are saturated and the reservoir is full, there is no longer any potential for storing or slowing runoff.
	Slow Runoff	High	

F3: Afforestation of reservoir catchments

	Store River Water	None	
	Slow River Water	None	
Reducing Runoff	Increase Evapotranspiration	High	Forest covered catchments and associated reservoirs can increase evapotranspiration (ET) rates above background levels. Forests often have higher ET rates than pasture or arable agriculture. Evaporation from reservoir surfaces can be considerable, especially in drier regions.
	Increase Infiltration and/or groundwater recharge	High	Afforested catchments have the potential to soil water retention, increase infiltration and / or groundwater recharge (see F2, Headwater Areas).
	Increase soil water retention	High	
Reducing Pollution	Reduce pollutant sources	High	Afforested reservoir catchments can reduce pollutant sources and intercept pollution pathways both in the reservoir and surrounding catchment. Forests can intercept many atmospheric pollutants, preventing them from reaching receiving waters (see F2, Headwater Areas). Pollutant retention in catchment soils and reservoir sediments also has the potential to reduce downstream concentrations of heavy metals, organic pollutants and nutrients. Because they are open water systems, reservoirs provide a location for photodegradation (breakdown by light) of some classes of organic 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 may in some cases lead to acidification of water in the reservoir.
	Intercept pollution pathways	High	
Soil Conservation	Reduce erosion and/or sediment delivery	High	Afforested reservoir catchments can reduce erosion and / or sediment delivery in two ways. Forests are efficient at retaining sediment (see F2 Headwater Areas). Reservoirs can function as settling ponds. Suspended sediment entering the reservoir will often settle out due to slower water transit times. Erosion rates will be lowest from natural or close-to-natural forests but may, on the other hand, substantially increase in poorly managed plantations.
	Improve soils	Medium	The forests in afforested reservoir catchments will improve soil quality (see F2 Headwater Areas) through increased accumulation of organic carbon and the development of greater porosity and water holding capacity.
Creating Habitat	Create aquatic habitat	Low	If the afforestation of the reservoir catchment extends to the edge of the reservoir, forest will contribute to aquatic habitat by providing nutrients, organic matter and food sources.
	Create riparian habitat	Medium	If the afforestation of the reservoir catchment extends to the edge of the reservoir, potentially valuable riparian forest

			habitat will be created.
	Create terrestrial habitat	High	Afforestation of reservoir catchments using endemic or indigenous tree species will create terrestrial habitats (this is also possible with non-endemic species). Afforestation for intensive biomass production is not recommended as UK experiences have shown that this can result in excessive sediment and nutrient leakage to the reservoir.
Climate Alteration	Enhance precipitation	Low	Afforestation has the potential to increase downwind precipitation by increasing rates of evapotranspiration (see F2 Headwater Areas). However, this effect is likely to be so small as to be difficult to detect in practice.
	Reduce peak temperature	Medium	Forest cover will reduce peak soil temperatures (see F2 Headwater Areas) and the reservoirs themselves will have a moderating influence on peak temperatures due to energy consumed by evaporation.
	Absorb and/or retain CO_2	High	Afforestation of reservoir catchments will increase carbon sequestration as a result of increased vegetation growth (see F2 Headwater Areas) Reservoirs themselves can contribute to carbon sequestration through sedimentation of dissolved organic carbon which enters in runoff from the surrounding catchment.

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	Medium	Afforested reservoir catchments provide moderate ecosystem service benefits related to water storage. Forest soils in the surrounding catchment will often have better water holding and infiltration capacity than soils under arable or pasture agriculture (see F2 Headwater Areas) while the reservoir itself will also provide water storage.
	Fish stocks and recruiting	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. If afforestation extends to the edge of the reservoir, forest litter may have impact on aquatic ecosystem productivity.
	Natural biomass production	High	With afforestation of a reservoir catchment , there is significant potential for natural biomass production. It should be noted that afforestation with exotic fast growing conifers or eucalypts will lead to higher rates of biomass production but this is less natural than the use of native of local species for afforestation. Furthermore, biomass harvest can cause water quality problems in the reservoir. Afforestation with conifer species may cause acidification of water and biomass harvesting can cause water quality problems in the

			reservoir associated with excess inputs of nutrients and sediments.
Regulatory and Maintenance	Biodiversity preservation	High	Afforestation of reservoir catchments with local or endemic species can make a significant contribution to biodiversity preservation. Forests consisting of local or endemic species provide habitat for all kinds of indigenous plants and animals. It should be noted that afforestation with exotic species or primarily for fibre production will almost certainly have negative consequences for biodiversity and reservoir water quality.
	Climate change adaptation and mitigation	High	Carbon sequestration associated with forests growing in reservoir catchments can contribute to climate change adaptation. There are limited possibilities for climate change mitigation by substitution of fossil fuel energy sources as the standing biomass in reservoir catchment forests should probably not be harvested so as to avoid negative impacts on reservoir water quality.
	Groundwater / aquifer recharge	High	Forest soils have high infiltration and water storage capacity which, when combined with their ability to slow water flow through the landscape, leads to afforested reservoir catchments having a high potential for groundwater / aquifer recharge.
	Flood risk reduction	Medium	Both the surrounding afforested catchment and the reservoir can contribute to flood risk reduction. Afforested catchments may have higher rates of evapotranspiration than other land cover types, resulting in a smaller fraction of precipitation contributing to runoff. Furthermore, forest soils with their greater surface roughness, higher infiltration capacity and greater water holding capacity have the potential to slow flows through a catchment, moderating peak flows and maintaining base flows. Mitigating effect will be most explicit at the small catchment scale and for small-scale flood events.
	Erosion / sediment control	High	Any sediment inputs shorten the operational life of reservoirs by reducing their water storage volume. Intact natural or semi-natural forests in reservoir catchments have a high potential to contribute to erosion and sediment control. Afforestation of non-forested catchments is being explored in the UK and elsewhere as a means of controlling sediment inputs to reservoirs. However, managing forests for biomass production can result in excessive sediment delivery due to poorly planned or implemented forest harvest roads and stream crossings.
	Filtration of pollutants	High	Forests and forest soils have a high capacity to filter pollutants, especially atmospherically deposited nitrogen, heavy metals and persistent organic pollutants. This filtering function can contribute to improved water quality in the reservoir when the surrounding catchments are afforested, thereby reducing 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 are widely prized for their amenity and recreational value. Afforestation of reservoir catchments can offer both recreational and aesthetic services. The value of these services will be leveraged by proximity to open water reservoirs which offer aesthetic and sometimes recreational benefits.
	Aesthetic / cultural value	High	
Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	Forests in reservoir catchments should probably not be intensively managed for energy production as this may have deleterious effects on water quality and quantity.

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good Surface Water Status	Improving status of biological quality elements	Low	Most reservoirs are classified as heavily modified water bodies for the purposes of the Water Framework Directive. As such, they are managed with a goal of achieving good ecological potential (GEP) instead of good ecological status (GES). Afforestation of catchments can have indirect effects on the water quality of downstream water bodies, primarily by reducing the inputs of atmospherically deposited pollutants. Any reduction in pollutant loading to a receiving water body has (in principle) the ability to contribute to an improvement in status of both biological and physico-chemical quality elements. By reducing inputs of atmospherically deposited pollutants, afforestation of reservoir catchments can contribute to improvements in chemical status with respect to some priority substances. Afforestation of reservoir catchments has no clear impact on hydromorphological quality elements but may contribute to a reduction in sediment loading.
	Improving status of physico-chemical quality elements	Low	
	Improving status of hydromorphological quality elements	Medium	
	Improving chemical status and priority substances	Low	
Achieve Good GW Status	Improved quantitative status	Medium	Afforestation of reservoir catchments can contribute to improvements in groundwater quantitative and chemical status in much the same way as F2 (Headwater areas). Because forests act as pollutant filters and improve infiltration rates, they can both reduce the pollutant load to groundwater and increase rates of groundwater recharge.
	Improved chemical status	Medium	
Prevent Deterioration	Prevent surface water status deterioration	Low	Afforestation of reservoir catchments can help to prevent deterioration of surface water and groundwater status in much the same way as headwater afforestation (F2 headwater areas). The increased infiltration and greater water holding capacity of forest soils combined with the forest pollutant filtering effect means that afforestation of reservoir catchments can contribute to prevention or status deterioration under many circumstances. However, in areas of high sulphate deposition, afforestation of reservoir catchments may actually cause
	Prevent groundwater status deterioration	Medium	

			surface water acidification and cause deterioration of surface water status. Furthermore, groundwater status deterioration in afforested catchments located in industrial areas has been reports as a very real outcome.
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		High	Afforestation of reservoir catchments can be an important part of an adequate and coordinated program to reduce flood risks. Forests are able to return a significant fraction of precipitation to the atmosphere through evapotranspiration and forest soils have the ability to slow the transit of water through the catchment, reducing the height of the flood peak and maintaining base flows.
Habitats and Birds Directives			
Protection of Important Habitats		Medium	Afforestation of reservoir catchments with indigenous or native species can provide and protect important habitat needed for meeting the requirements of the Birds and Habitats Directives.
2020 Biodiversity Strategy			
Better protection for ecosystems and more use of Green Infrastructure		High	Afforestation of reservoir catchments using indigenous or native tree species is an aerial green infrastructure strategy that will contribute to better protection of ecosystems.
More sustainable agriculture and forestry		None	
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		High	Afforestation of reservoir catchments using indigenous or native tree species can help to prevent biodiversity loss by maintaining or creating new terrestrial habitat suitable for use by biota from the region. It also helps improving green infrastructures by avoiding fragmentation of habitats.

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	Generally as much of the reservoir catchment as possible should be afforested and tree coverage maintained, so that protection can be maximized without undue reduction in reservoir inputs due to higher evapotranspiration from forest cover.
Space required	

Location	In regions of sufficient precipitation the riparian areas of the reservoir catchment should be prioritized for afforestation, followed by riparian areas of inflowing streams and then the remainder of the catchment. Some modelling results suggest that in water-limited environments planting trees on upper slopes potentially has a much lesser impact on streamflow. It should be noted that the evidence base for this is based on studies from Australia, but the argument behind this, that soils near streams tend to get deeper and accumulate more surface runoff, is most likely applicable also in Europe.
Site and slope stability	Afforestation of more steeply sloping areas is likely to result in greater benefits related to sediment retention and prevention of erosion.
Soils and groundwater	
Pre-treatment requirements	
Synergies with Other Measures	Afforestation of reservoir catchments may have synergies with other measures implemented on the same area, e.g., riparian buffers, and also measures related to appropriate design of reads and stream crossings.

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition		Typically, as the responsible authority operating the reservoir owns much of the surrounding catchment, the land acquisition costs may be relatively minor. If the responsible authority does not own the land, acquisition costs may be prohibitive and other mechanisms such as easements or landowner agreements should be considered.
Investigations & Studies		
Capital Costs		The capital costs of afforestation are low compared to other costs associated with reservoir operation and provision of drinking water
Maintenance Costs		e.g. thinning
Additional Costs		The construction of roads can be taken into account under certain aspects.

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 Management*258.10 (2009): 2269-2281.	Good general reference on forest water issues
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	Overview of the impact of afforestation on water resources, quality, precipitation floods and landslides
Johnson, R.C. 1995. Effects of upland afforestation on water resources The Balquhidder Experiment 1981-1991. Institute of Hydrology Report No. 116, 51 pages	Presents results from catchment afforestation experiments.
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.
Greene, L.A. 1987. The effect of catchment afforestation on public water supplies in Strathclyde Region, Scotland. Transactions Transactions of the Royal Society of Edinburgh: Earth Sciences, Volume 78(04): 335-340	Highlights possible adverse effects of afforestation on water quality