Management of mountain forests in the hydrology of a landscape, the Czech Republic – Review

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ABSTRACT: Forests important from a water-management perspective cover 723,000 ha of the Czech Republic (CR), i.e. 27.6% of the forest area. These forests play an important role especially in a mountain landscape. Forests decrease peak flood flows, compensate water discharge and represent a source of high-quality fresh water. The optimum hydrological function is provided by forests that are healthy, ecologically stable, diversified, proper to site, growing on a good forest soil, managed by small-area felling and emulating natural processes. For mountain sites of the CR, the optimum proportion of Norway spruce (+ Silver fir) ranges from 70 to 80% and of European beech from 20 to 30%. Clear-cuts due to air pollution disasters led to replacement of the forest stand by perennial grassland increasing stormflows and decreasing the soil water supply to groundwater resources and the quality of water discharged from the forest. Skidding and hauling operations and an improperly constructed and maintained road network increased the surface runoff from a forest. Intraskeletal erosion occurs on pollution-disaster stone fields and in dying forest stands on stony sites. Reforestation of stone fields is necessary for the preservation of forests on stony and bouldery localities and their services for the cultural landscape situated below. In mountain headwaters, torrent control and forest amelioration are of great importance. These decrease peak flood flows, compensate water discharge and reduce bed-load and sediment transport. Forest amelioration enables the reforestation of waterlogged pollution-disaster areas.

Keywords: silvicultural measure; clear-cut; forest soil; water regime; logging operations; intraskeletal erosion; torrent control; forest amelioration

Forests important from a water management viewpoint make up 27.6% (726,000 ha) of those in the Czech Republic. These are primarily forests of headwater areas having a water management function for boosting the yield of water resources (16%, 420,000 ha) and forests in water protected zones having a complex water management function, i.e. boosting the yield of fresh water resources and quality of such water (11.7%, 306,000 ha). Forests important from a water management viewpoint occupy an especially important place in a mountain landscape.

Silvicultural measures (management) in forests. These include modification of a forest's species and spatial composition, regeneration and felling technologies, whose goal in support of forests' hydrologic functions is the "supply of springs", i.e. care of the water regime, mitigation of floods and care of the quality of waters draining from the forest. In forestry, we are able to influence these hydrologic functions by the species and spatial composition of stands, cultivation of stands, regeneration, logging (including maintenance of the transportation network), and protection of the water component of forests by means of forestry amelioration and torrent control.

Tree species composition. Tree species composition influences the depth of effective rainfall onto the forest soil, water consumption by the forest stand, and water infiltration into forest soil.

The main commercial tree species in Czech mountain forests are currently – and in future

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shall remain – Norway spruce and European beech. This and the often complicated air pollution situation must be borne in mind when proposing target tree compositions. Naturally, silver fir will also be presented. An increase in the proportion of silver fir (realistic estimate up to 10 to 20%) as a replacement of spruce probably does not appreciably change the hydrologic efficiency of forest stands. On the contrary, it is most likely to be reflected favourably in the sustainability and safety of forest ecosystems.

In evaluating the species composition of forest stands (coniferous species – spruce and fir; broadleaved species – beech) from the viewpoint of efficiently fulfilling the hydrologic efficiency of forests, it is necessary to distinguish between concerns as to the qualitative side of the hydrologic function (reducing streamflow fluctuation, preventing surface runoff, minimizing the potential risk of flash floods, and the like) and concerns as to more efficiently fulfilling the quantitative side of the hydrologic function (increasing the supply of water available to discharge out of the forest).

Based on 32 years of experimental investigations in the Orlické hory Mts. (Kantor et al. 2008), it has been proved that from a qualitative hydrologic perspective properly managed, fully closed coniferous (spruce) and broadleaved (beech) stands perform their function very well even in slope sites. Especially considering the greater discharge compensation in winter periods and the lower rate of snowmelt in spring, spruce stands function more favourably in this regard. For these reasons, in areas where so far it has not appeared necessary to increase the amount of water available for drainage generally it is possible to suggest the proportion of spruce (+ fir) for acidic and fertile sites of spruce-beech and beech-spruce forest vegetation (altitudinal) zones in the range of 70 to 80% and of beech at 20 to 30%.

The situation will be different in areas where an increase in the parameters of the quantitative water management function and an increase of water yield from the forest are concerned. The results of the experimental investigations evidence that pure beech stands increase the flow of precipitation water through the soil profile with subsequent subsurface drainage in mountain sites due to significantly lower interception as compared with pure spruce stands by 150 mm (i.e. 1,500 $m^3 \cdot ha^{-1}$) per year. On this basis, a gain of water available to discharge can be modelled at 150 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for every 10% of the portion of beech in spruce stands. In territories in which the quantitative water management function will be of priority importance, it will be necessary to increase the proportion of beech to a range exceeding 30 to 40% (Kantor 1995; Kantor et al. 2006, 2007).

Choice of regeneration method. From a survey of foreign findings collectively analysed in the study "Forests and Floods" (Krečmer et al. 2004) it is evident that due to the operation and synergies of an entire complex of factors – in particular geographic, climatic, soil-related and stand-related – no generally valid data and values on the impact of clear-felling treatments on water discharge from forest catchments can be established. However, it can be stated that:

- clear-felling of forest stands always involves an increase in annual streamflow as an immediate consequence, because reducing the canopy interception and withdrawal of soil water for the purpose of forest stand transpiration makes more water available to drainage,
- the increase in streamflow is generally most significant immediately after logging,
- due to weed infestation and development of new forests after regular regeneration of forest stands, the hydrologic effect of a water yield increase sooner or later wanes, as does the possibility of increased runoff owing to soils becoming more saturated with water.

Škopek and Stránský (1985) arrived at similar conclusions in local conditions from the region of the Jizerské hory Mts., where the clear-cutting of an entire partial catchment increased runoff only insignificantly. Similarly, Urban (1984) also characterized mean annual discharge in catchments disturbed by an air pollution disaster especially as heightening the variability.

Based on evaluation of a 30-year series of observations in the experimental catchments Malá Ráztoka and Červík in the Beskids Mountains, Jařabáč (1980, 1984) and Jařabáč and Chlebek (1983) came to the conclusion that even with an 84% harvest cutting of forest stands in a small mountain catchment the hydrologic effects of the treatment on total runoff were only slightly pronounced and could therefore be partly or entirely concealed by the fluctuation of climatic elements. These findings were confirmed also in the course of subsequent years. Bíba et al. (2001) stated that the results of measurements to date in the Beskids Mts. did not confirm the opinion with regard to management that harvesting in forests is a cause of flooding. Nor is the clear-cutting system a treatment that would negatively affect the water regime of forest streams by the merely temporary clearing of the aboveground biomass of forest stands.

Experimental fellings in a natural forest region in the foothills of the Orlické hory Mts. in a size at the upper limit under the valid forestry law (40 × 175 m each) can be regarded as representing runoff plots that approach by their area of 0.7 ha each the category of larger elementary runoff plots.

The clear-felling method followed by artificial regeneration with spruce on a steep southerly slope (5K1, 5N1) during 27 years in total provided the lowest total hill-slope runoff (water available to drainage) in the growing season. At the same time the clear-felling method provided the highest total lateral runoff, especially surface runoff but also shallow subsurface runoff. However, the lateral component of runoff (both surface and shallow subsurface one) constitutes only a fraction of a percentage point of the water available to discharge in a forest slope with well-drained soil.

The largest amount of water available to discharge was provided in the same proportions as in the regeneration method by two-phase shelterwood felling with combined natural and artificial regeneration, as stocking reduced to 0.5 and shelterwood hindered total evaporation on a steep southern slope. The young mixed coniferous stand (Norway spruce, European larch, Scots pine) produced a loose mixed litter and soil profile (root zone) with the highest infiltration rate and the lowest lateral shallow subsurface runoff and surface runoff.

Vertical flow (infiltration, seepage) permits the evaluation of soil-water regime at individual fellings in relation to the groundwater recharge (percolative, semi-percolative, and non-percolative regimes; see Drbal 1986) of the soil profile during the growing season (May to October). During the growing season, a (semi)-percolative regime also predominated on the steep southerly slope. However, during dry and warm summer it resembled a non-percolative regime.

Lateral movement of water through the soil (surface and shallow subsurface flow measured from the boundary of the LFH/A and A/B horizons) by laterally oriented macropores and seepage occurred during intensive precipitation and in a dry (arid) organic (LFH) stratum or stratum enriched with humus (Ah).

No surface runoff with an on-site erosive impact occurred on an undisturbed soil surface. On the other hand, an increase in the frequency of surface flow in the last decade in a section with clear-felling and artificial regeneration by spruce monoculture could create a potential risk of off-site soil erosion.

In contrast to foreign data, in many cases no substantial increase in water yields of watercourses was confirmed under the conditions of the Czech Republic even after large-area salvage fellings in response to pollution disasters. The explanation is that these fellings are carried out in the course of several years and are generally a consequence of the gradual dieback of forest ecosystems over several years, during which stands are opening up and the soil becomes completely infested with weeds. The markedly high evapotranspiration from forest weeds then correspondingly reduces total runoff from such salvage-operation clearcuts.

This follows from the assumption of 100% coverage based on measurements in the Orlické hory Mts. in a range of 300–350 mm·yr^{-1} and represents by far the most significant outflow item in the water balance. Even in the case of a one-time harvest cutting of the entire partial catchment, an increase of total water yield in mountain catchments can be expected immediately after the treatment, generally by a maximum of 100 mm·yr^{-1}. This effect of greater flow can be expected only during several initial years immediately after harvesting, before the transpiration and interception of subsequent stands begin to participate in the water regime. During this time, the high soil water retention by the structural forest soil fully persists (high retention dwindles in deforested soil after several decades).

The increase of the water yield in catchments after regeneration fellings, represented by increased streamflows that comprise an indicator of increased water saturation of the catchment, codetermines for individual instances of flooding the levels of peak flows and volumes of stormflows. At non-reforested salvage-operation clearcuts, stormflows gradually increase by 5–20%, and on average by 10–13% (Šišák et al. 2007). Thus, the importance of reforestation is evident.

A large forest complex reduces the peak stormflow in comparison with an agricultural catchment. The main cause is the interception of precipitation water through the retention capacity of forest soils. Considering the high infiltration capacity of forest soils (1–10 mm·min^{-1}), forest soil absorbs the major portion of precipitation water and retains part of it permanently while converting the rest into subsurface runoff and baseflow.

The rainfall-runoff process on Velká hora Mount in the Karlštejn National Nature Reserve recorded 119.4 mm of atmospheric precipitation (AP) (higher than 100-year periodicity), surface runoff of 11.5 mm (9.6% of AP), subsurface runoff of 14.4 mm (12.1% of AP) and 93.5 mm of retention in forest soil (78.3% of AP). The Velká hora soil profile of 1 m in thickness reduced the peak flow of flash flooding by 52%. In mountain forest soils, total retention capacity ranges between 50 and 130 mm (Beskids Mts., Orlické hory Mts.), while the capacity used during flooding episodes tends to be 27–45%. Forests in the Elbe River basin reduce the peak flow of flash flooding in Děčín by 16%, i.e. by 981 $m^3 \cdot s^{-1}$ (581 $l \cdot s \cdot km^{-2}$). Water reservoirs of storage capacity of 356 million m^3 and costing approximately 125 billion CZK would have the same function (Švihla in Krečmer et al. 2004).

A reduction of the peak flow of flash floods by forest complexes depends mainly on the quality of forest soil. Stable forest soils with optimum hydrophysical properties have a maximum effect on the water component forests and are a condition for the optimum retention function of forests. Such forest soils require forest stands with tree species compositions corresponding to natural conditions and small-scale management by low-impact harvesting technology. Their importance in terms of water management is regional.

Forest road network and logging practices. The transport network influences runoff generation especially by producing surface runoff on roads due to their decreased infiltration rate, seepage of subsurface runoff from cut slopes and conversion of such water into concentrated surface runoff. From the aspect of maximum discharges, Krešl (1976) calculated for model territories that increasing the density of the road network above 40 $m \cdot ha^{-1}$ and decreasing the slope road spacing below 200 m would cause that a maximum would occur during torrential rainstorms. Thereafter, hillslope runoff is significantly converted into concentrated surface runoff along the transport network.

No increase in total annual discharge from catchments was essentially recorded during the experimental investigations. This result corresponds to the fact that surface coverage by roads in catchments does not exceed 20–30%, in which case the difference could be conclusively reflected in total evaporation due to the reduction of evapotranspiration (Bosch, Hewlett 1982).

The impact of the road network may, however, be reflected in the volumes of individual stormflows, but especially in the amounts of peak flows. The area of roads plays an extraordinarily significant role here, where a 12% proportion of roads in catchments including cut and fill slopes is a marginal value. Given such a road area, peak flows rise by as much as 25%.

The development of findings as to the impact of roads on flood discharges points to the conclusion that only synergy of the road network and harvesting with skidding encroaching on ca one-third of a small catchment generally results in an influence on the characteristics describing maximum streamflows. An increase in maximum streamflows depends not only on a reduction of evapotranspiration and interception due to timber harvesting and slash burning but also on the modification of snow accumulation and melting on cutovers.

Using findings from the literature and based on personal experimental investigations in the catchment of the Klínový stream (850 ha) in the Krkonoše Mountains (Šach 1990), we endeavoured to create a visual conception of the impact of the transportation network on the runoff conditions from a model hectare of a clear-felling in a mountain area of the Czech Republic. The surface runoff from the 1 ha clear-felling in relative values was established using the method of a rainfall simulation model on elementary runoff plots and is presented in Table 1.

Given a density of the constructed road network of essentially 30 $m \cdot ha^{-1}$ and a surface share of 1.5%, the presumed surface runoff from the 1 ha model clear-felling with a complete transportation network (logging roads and skidding trails) as well as

Table 1. Expected surface runoff (% of precipitation) on skidding roads per 1-ha clear-cut calculated for different skidding operations (slopes 27–41%)

Logging-skidding technique	Skidding road		Time after logging	Surface runoff per 1-ha clear-cut (%)
	area (%)	density ($m \cdot ha^{-1}$)		
Tractors	8.2	274	< 1 year	6.6
			3 years	5.0
Tractors on less favourable soils	13.0	405	< 1 year	11.3
			3 years	8.3
Half-hanging uphill cable logging system	1.7	110	< 1 year	1.2
			3 years	1.0
Horses	6.6	471	< 1 year	2.2
			3 years	1.4
Paved roads	1.5	30		1.4

the presumed direct (quick) runoff can be deduced from Table 1 by completing a qualified estimate of the second component of quick runoff, subsurface runoff, caught during outflow (seepage) from road cuts having a permanent character and transformed into surface runoff. An example of surface runoff and quick runoff for the model 1 ha clearfelling in relative figures is presented in Table 2.

Analyses of the impact of a forest transportation network on the runoff regime demonstrate that the production of surface runoff on roads plays an especially important role, followed in particular by surface runoff with the participation of subsurface runoff seeping from road cuts, together forming the so-called quick, or direct, runoff. The quick runoff may subsequently become evident in earlier and higher peak flow and increased volume of stormflows. At the same time, it is an important fact that surface runoff shows only a slight drop with the age and overgrowth of trails. This is also confirmed by the experimental findings from a study of quick (direct) runoff (Jones, Grant 1996), as the impacts of building a transportation network and a clearfelling approach to tree harvesting persist for up to 25 years in small experimental catchments.

Table 2. Expected surface runoff and expected accelerated (direct) runoff from 1-ha clear-cut with completed skidding network expressed as % of precipitation

Logging-skidding technique	Time after logging (year)	Runoff (%)	
		surface	accelerated
Tractors	< 1	8.0	17.2
	3	6.4	15.5
Tractors on less favourable soils	< 1	12.7	21.8
	3	9.7	18.8

In order to exclude the indicated longer-term impacts on maximum streamflows, it is essential to prevent the concentration of surface runoff already in logged areas. It is advisable to continue in restricting the concentration of surface runoff also on skidding, forwarding and hauling roads. Therefore, measures should be implemented that support the dissipation of water flow with the goal of its infiltration into the stand soil. Such measures include using broad-based dip with a gravel surface, selecting the appropriate distance between water-bars, and possibly road drainage by means of a cross slope leading to a fill slope.

The above-mentioned measures not only prevent the increase and acceleration of peak flows but also they may even lead to their reduction and delay. By diverting surface runoff into the soil matrix of the fill slope or cleared trails, slower forms of runoff in the soil can thus be achieved. Subsequent prolonging of the stormflow period may then result in the reduction and delay of peak flows.

In terms of reducing maximum streamflows, the conception of the forest transportation network within the catchment is itself of course particularly significant (Beneš 1986). From the perspective of road placement, surface and subsurface water is minimally concentrated on ridgeway roads. Valley roads do not have any greater importance with regard to influencing maximum streamflows. However, they clearly tend to be destroyed during floods. Slope roads and contour roads prove the most unfavourable. Their construction requires the greatest displacement of soil, and their particular road structure then collects water flowing on the surface and in the subsurface and accelerates its runoff.

In addition to influencing maximum streamflows, the acceleration of runoff from rainfall or snow melt due to the draining impact of skidding trails and cut slopes can cause a reduction in groundwater reserves and thereby also of the water levels in watercourses during a period with no precipitation.

Intraskeletal erosion (ISE). The dynamics of intraskeletal erosion can be presented on an example from the Krkonoše Mts. in the form of thinning the soil stratum covering debris, enlarging the area of surface stoniness, and accentuating the vertical segmentation of the microrelief of the terrain.

An evaluation of the dynamics of ISE in the model area of the Krkonoše Mts. in an 18-year time series demonstrated the reduction of the (soil) stratum covering stony debris in boulder stands. *Under fragmenting spruce trunks*, the reduction of the soil stratum (by ca 7 cm with an initial average stratum thickness of 18.7 cm) constitutes a slow but enduring process decelerating until 2003 with a subsequent estimation of improvement in 2007, the actual year of the survey. *At salvage-operation clearcuts* where the stratum was already reduced by felling and skidding (initial stratum thickness of 14 cm on average), the stratum was further reduced until 2003 (again by ca 7 cm). *At stony skidding corridors for a cable system* where the initial stratum thickness after timber transport was mere 7.5 cm on average, a further average reduction by 6.5 cm took place until 2003 with only slightly perceptible indications of revitalisation until 2007.

The results of the investigations in Table 3 document the expanding dimensions of the territory in the Krkonoše Mts. affected by intraskeletal erosion from 20% up to 30% of the area and the shift of surfaces to levels with higher impacts in the last decade of the 20th century.

Table 3. Forest soils affected by intraskeletal erosion in the Krkonoše Mts.

Intraskeletal erosion threat by site by Šach and Pašek (1996)	Area of affected soils	
	ha	%
Extreme: steep and avalanche slopes, stony slopes above tree line, rocks, kettles, detritus	1,744	5.4
Higher: larger detritus areas (categories Y, Z9, N, N4) surrounded by N0 sites, granite and/or gneiss bedrock prevails	399	1.2
Moderate: frequently occurring patches of detritus (categories N, N4), various bedrocks, mostly granite and/or gneiss, it is allowed to include them to N0 sites	2,394	7.4
Low: categories N, A, M, K – isolated patches of detritus on stony slopes, gneiss bedrock prevails	1,664	5.2
Total area 32,251 ha	6,201	19.2
Intraskeletal erosion threat by site by Šach and Jurásek (2002, 2003)		
Extreme: detritus (9Y site)	316	0.9
Very high: detritus areas above tree line (9Z, 9K sites)	3,201	9.4
High: large detritus areas (8Y, 8Z9, 8N0, 7Y sites)	912	2.7
Moderate: frequent detritus on stony slopes (6Y, 6N0, 7N0, 6N4, 7N4, 8N1, 8N3 sites)	1,971	5.8
Low: isolated patches of detritus on stony slopes (6M9, 6N1, 6N3, 7M9, 7N1, 7N3, 8Z2, 8M, 8K9, 8N5 sites)	3,988	11.7
Total area 33,965 ha	10,388	30.5

Site-classification system, Forest Management Institute, Brandýs n. L., for the site explanation see Viewegh et al. (2003)

The process of intraskeletal erosion in debris stands invariably occurs primarily at locations where the soil-protecting function of forest stands is reduced. Storm rainfall, long periods of drought, movement of snow cover over slopes, and frost phenomena especially accelerate the destruction of the upper soil stratum and its loss to subterranean spaces between rocks. Among anthropogenic impacts, especially overland skidding accelerates the destruction of the upper soil stratum. Numerous woodless islands strongly damaged by intraskeletal erosion are often found on debris slopes with regenerated forest. At present, in cases of serious disturbance by harmful agents, spruce monocultures that are not ecologically very stable do not protect lands against the ongoing process of intraskeletal erosion. Debris islands are interconnected into debris fields. Extensive debris fields on mountain peaks and slopes will not fulfil the environmental-protection function of the forest, at least to the former extent, and especially not the water-management function (protection from flooding and erosion), and not even for a lower situated region.

Locations at which the soil is completely lost and where detritus appears lose their production capacity. For reforestation with spruce, special technologies must be used. The costs as compared to using a standard planting technology increase 4–6 fold, i.e. from ca 50,000 CZK·ha^{-1} to 200,000 to 300,000 CZK·ha^{-1} with an average of 250,000 CZK·ha^{-1}.

Among proposed corrective measures, the provision of mineral subsoil and addition of rock powder admixtures to the seedling hole showed positive effects during regeneration, while at the locations most characterized by boulders the insertion of a textile lining into the space between rocks was helpful. Underplantings of group-fragmenting adult spruce stands also proved justified (in addition to spruce, also beech, sycamore and Carpathian birch, as well as dwarf pine, in groups located in gaps). The experimental planting of a small group of green alders also shows promise for successfully protecting against erosion prior to the creation of stone seas.

Discharge regime of watercourses in agroforest catchments. For the Svratka catchment at the Dalešín profile (43% forested), Švihla and Šimunek (2000) established through their investigation the following:

– forest runoff is lower than the runoff from fields for m-day discharge of up to 180 days and lower than the runoff from perennial grasslands (PGL) for m-day discharge up to 220 days.
– forest runoff is higher than the runoff from fields for m-day discharge upwards of 180 days and higher than the runoff from PGL for m-day discharge upwards of 220 days, with a maximum at a 355-day discharge, i.e. certainly of runoff from groundwater by springs from hydrological structures that are naturally better endowed by forest than by PGL and fields.

– in the driest August, 1.3 times more water drained from forests than from fields and 1.4 times more than from PGL.
– in the driest month of a drought year (August 1990), the runoff from forests was 1.4 times greater than the runoff from fields and 1.6 times greater than that from PGL.

The analysis shows that the replacement of forest at clearings created in response to pollution disasters with PGL results in a reduction in the yield of groundwater resources and an increase in maximum runoffs in that area and is in conflict with the protection of water resources.

Quality of waters draining from forests. Not least of all, forests influence *water quality*. High-quality water drains from forests. In the Krkonoše Mts., for example, the water has 3.8 $N\text{-}NO_3$ $mg \cdot l^{-1}$, which is 38% of the nationwide average. The forests of the Krkonoše Mts. are a true water resource not only in quantity but also in quality. Preserving the quality of water involves the care of humus in forest soils. Sudden disintegration of spruce raw humus upon clearcutting causes an increase in the concentration of fulvic acids in draining waters, like, for example, after logging and broadcast site preparation due to air pollution disaster in the Krušné hory Mountains.

The function of torrent control and forestry amelioration. Torrent control and forestry amelioration aim in particular to provide the following forestry services:
– protect and maintain the productivity of forest soils and increase the soil profile retention
– protect valley lands, roads and real estate threatened by torrents from the effects of floods and sediment and bed-load transport
– support the management of watercourses in order to ensure the lasting impact of control structures and to achieve the better use of water power
– support land improvement, which is connected with the management of watercourses.

The modernization of torrent control brings an increased use of riparian stands for protecting embankments against erosion by torrents, adjustments in the role of inundation areas in absorbing flood waters, and artificial roughening of streambeds and bottoms of chutes. More natural routing of torrent channels is maintained. Fish passes are constructed, or sturdy structures of sills and dams are appropriately modified so that the passability of the watercourse for fauna is enhanced. Polders and retention reservoirs are used more frequently.

Partial torrent modifications have a local significance. They mostly shift the destructive power of the water element to unregulated parts of the watercourse and only partially hold back bed loads. The 1997 flood demonstrates that comprehensive modifications in the Krkonoše Mts. in the second flooding incident in July 1997, when the streamflow in the mountain section of the catchment practically reached a 100-year level, reduced progressive stormflow by transforming it into a harmless streamflow with a 10 to 20-year periodicity, i.e. by some 30%. The damage caused by flood was negligible in that catchment compared to others. Retention areas (for example, the Les Království reservoir) were put to good use. This demonstrates the important role of the state authorities in managing torrents (Hladný et al 1998).

Forestry amelioration is neglected in the Czech Republic. Correctly designed amelioration afforestation for erosive areas and temporary sporadic draining of waterlogged areas after fellings for current forest regeneration are in place. There are no catastrophic scenarios in existence, as shown by the sporadic ditch draining network in the U dvou louček catchment in the Orlické hory Mts. (Černohous 2007). This enabled the reforestation of a section of a clearing created due to catastrophic pollution damage, and its impact was temporary. After integrating the forest stand into the water regime, it returned to its condition prior to the clearing of the pollution damage. Afforestation of erosive areas not only stabilizes the soil on the slopes but also contributes positively to reducing flood peak flows and balancing the water regime of forest streams.

Lastly, we remark that flood runoff from pollution-damage clearings in the Krkonoše Mts. has increased by 10–13%, according to our estimate, following the destruction of the forest soil structure, and this may last for several decades. The importance of reforestation is also evident here from a water-management perspective.

CONCLUSIONS

The species composition of mountain forests influences the water component of draining waters. Considering the greater discharge compensation (especially in winter periods) and the lower rate of snowmelt in spring, spruce stands function more favourably in terms of ensuring the qualitative water-management function. On the other hand, with regard to more efficiently fulfilling the quantitative side of the hydrologic function (increasing the supply of water available to discharge out of the forest), beech stands are more effective given their lower interception. The method of mixing stands anticipates the beneficial influence of annual and episodic hydrograms by the extension of their continuation and the reduction of peak flows.

Statutory clearcuts that are subsequently forested influence the water regime of a forest stand only slightly. Small-area undergrowth management methods are the most sensitive to the water component.

At clearings resulting from pollution disasters with longer lasting replacement of forests with PGL, stormflows increase and the contribution to groundwater reserves decreases.

The felling technologies used in forest stand regenerations crucially impact the volume of surface runoff from forest stands. Tractor technologies increase surface runoff fivefold and animal technologies twofold in comparison with cableway technologies. The density of the forest network increases surface runoff starting from 40 $m \cdot ha^{-1}$. Its layout fundamentally impacts upon the generation of surface runoff.

Intraskeletal erosion occurs in the Krkonoše Mts. on 20–30% of the forest area. It especially increases the creation of debris fields in deforested areas. Their reforestation is a condition for conserving the forests in these localities and the services they provide for the cultural landscape situated below.

Forests regulate the water component of the agroforest landscape, decrease floods and increase minimum runoffs. Deforestation by the preservation of clearings due to pollution disaster thus impacts negatively upon the water regime of a deforested area and the adjacent landscape.

High-quality waters drain from forests. The replacement of a forest with perennial grasslands leads to a worsening of the quality of those waters.

Torrent control and forestry amelioration are of great importance for sections of mountain headwater areas. They reduce peak flood flows, balance the water regime and restrict sediment and bed-load transport. Forestry amelioration enables reforestation of waterlogged pollution-disaster clearings.

Forests that are healthy, ecologically stable and diversified have an optimal influence on the quality of the water component.

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